ELECTRICIAN (POWER DISTRIBUTION)

NSQF LEVEL - 4

1st Year

TRADE THEORY

SECTOR: POWER

(As per revised syllabus July 2022 - 1200 Hrs)

Directorate General of Training

DIRECTORATE GENERAL OF TRAINING
MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP
GOVERNMENT OF INDIA

NATIONAL INSTRUCTIONAL MEDIA INSTITUTE, CHENNAI

Post Box No. 3142, CTI Campus, Guindy, Chennai - 600 032

Sector : Power

Duration : 2 Years

Trades : Electrician (Power Distribution) - Trade Theory - 1st Year - NSQF Level - 4 (Revised 2022)

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FOREWORD

The Government of India has set an ambitious target of imparting skills to 30 crores people, one out of every four Indians, to help them secure jobs as part of the National Skills Development Policy. Industrial Training Institutes (ITIs) play a vital role in this process especially in terms of providing skilled manpower. Keeping this in mind, and for providing the current industry relevant skill training to Trainees, ITI syllabus has been recently updated with the help of Media Development Committee members of various stakeholders viz. Industries, Entrepreneurs, Academicians and representatives from ITIs.

The National Instructional Media Institute (NIMI), Chennai, has now come up with instructional material to suit the revised curriculum for **Electrician (Power Distribution) - Trade Theory - 1st Year - NSQF Level - 4 (Revised 2022) - in Power Sector** in **Annual Pattern.** The NSQF Level - 4 (Revised 2022) Trade Practical will help the trainees to get an international equivalency standard where their skill proficiency and competency will be duly recognized across the globe and this will also increase the scope of recognition of prior learning. NSQF Level - 4 (Revised 2022) trainees will also get the opportunities to promote life long learning and skill development. I have no doubt that with NSQF Level - 4 (Revised 2022) the trainers and trainees of ITIs, and all stakeholders will derive maximum benefits from these Instructional Media Packages IMPs and that NIMI's effort will go a long way in improving the quality of Vocational training in the country.

The Executive Director & Staff of NIMI and members of Media Development Committee deserve appreciation for their contribution in bringing out this publication.

Jai Hind

Atul Kumar Tiwari, *I.A.S*
Secretary
Ministry of Skill Development & Entrepreneurship,
Government of India.

December 2023
New Delhi - 110 001

PREFACE

The National Instructional Media Institute (NIMI) was established in 1986 at Chennai by then Directorate General of Employment and Training (D.G.E & T), Ministry of Labour and Employment, (now under Directorate General of Training, Ministry of Skill Development and Entrepreneurship) Government of India, with technical assistance from the Govt. of Federal Republic of Germany. The prime objective of this Institute is to develop and provide instructional materials for various trades as per the prescribed syllabus under the Craftsman and Apprenticeship Training Schemes.

The instructional materials are created keeping in mind, the main objective of Vocational Training under NCVT/NAC in India, which is to help an individual to master skills to do a job. The instructional materials are generated in the form of Instructional Media Packages (IMPs). An IMP consists of Theory book, Practical book, Test and Assignment book, Instructor Guide, Audio Visual Aid (Wall charts and Transparencies) and other support materials.

The trade practical book consists of series of exercises to be completed by the trainees in the workshop. These exercises are designed to ensure that all the skills in the prescribed syllabus are covered. The trade theory book provides related theoretical knowledge required to enable the trainee to do a job. The test and assignments will enable the instructor to give assignments for the evaluation of the performance of a trainee. The wall charts and transparencies are unique, as they not only help the instructor to effectively present a topic but also help him to assess the trainee's understanding. The instructor guide enables the instructor to plan his schedule of instruction, plan the raw material requirements, day to day lessons and demonstrations.

IMPs also deals with the complex skills required to be developed for effective team work. Necessary care has also been taken to include important skill areas of allied trades as prescribed in the syllabus.

The availability of a complete Instructional Media Package in an institute helps both the trainer and management to impart effective training.

The IMPs are the outcome of collective efforts of the staff members of NIMI and the members of the Media Development Committees specially drawn from Public and Private sector industries, various training institutes under the Directorate General of Training (DGT), Government and Private ITIs.

NIMI would like to take this opportunity to convey sincere thanks to the Directors of Employment & Training of various State Governments, Training Departments of Industries both in the Public and Private sectors, Officers of DGT and DGT field institutes, proof readers, individual media developers and coordinators, but for whose active support NIMI would not have been able to bring out this materials.

Chennai - 600 032 **EXECUTIVE DIRECTOR**

ACKNOWLEDGEMENT

National Instructional Media Institute (NIMI) sincerely acknowledges with thanks for the co-operation and contribution extended by the following Media Developers and their sponsoring organisation to bring out this IMP for the trade of **Electrician (Power Distribution) - 1st Year - Trade Practical - NSQF Level - 4 (Revised 2022)** under the **Power** Sector for ITIs.

MEDIA DEVELOPMENT COMMITTEE MEMBERS

Smt. V.K. Sunija	_	Principal (Retd.) Govt. I.T.I. Thiruvambadi. Kozhikode, Kerala.
Smt. P.J. Philomina Jeffy Jennifar	_	Principal (Retd.) Govt. I.T.I. Kuttaikol. Kasaragod, Kerala.

NIMI - COORDINATORS

Shri. Nirmalya Nath	_	Deputy Director, NIMI, Chennai - 32.
Shri. G. Michael Johny	_	Manager NIMI, Chennai - 32.

NIMI records its appreciation of the Data Entry, CAD, DTP Operators for their excellent and devoted services in the process of development of this Instructional Material.

NIMI also acknowledges with thanks, the invaluable efforts rendered by all other staff who have contributed for the development of this Instructional Material.

NIMI is grateful to all others who have directly or indirectly helped in developing this IMP.

INTRODUCTION

TRADE PRACTICAL

The trade practical manual is intented to be used in workshop . It consists of a series of practical exercises to be completed by the trainees during the 1nd year course of the **Electrician (Power Distribution)** under **Power Sector.** Trade supplemented and supported by instructions/ informations to assist in performing the exercises. These exercises are designed to ensure that all the skills in compliance with NSQF Level - 4 (Revised 2022) syllabus are covered.

This manual is divided into Eleven modules. The Eleven modules are given as below

Module 1	-	**Safety Precautions**
Module 2	-	**Electrical Wire Joints & Solderings**
Module 3	-	**Measurements Using Instruments**
Module 4	-	**Electronics Circuits**
Module 5	-	**Cells and Batteries in Substation**
Module 6	-	**Wiring Installation and Testing**
Module 7	-	**Illumination**
Module 8	-	**AC Motor & Starters**
Module 9	-	**Alternator and Synchronous Motors**
Module 10	-	**Speed Control of AC Motors**
Module 11	-	**Inverter, Stabilizer, Battery Charger and UPS**

The skill training in the shop floor is planned through a series of practical exercises centered around some practical project. However, there are few instances where the individual exercise does not form a part of project.

While developing the practical manual a sincere effort was made to prepare each exercise which will be easy to understand and carry out even by below average trainee. However the development team accept that there is a scope for further improvement. NIMI, looks forward to the suggestions from the experienced training faculty for improving the manual.

TRADE THEORY

The manual of trade theory consists of theoretical information for the two years course of the **Electrician (Power Distribution)** Trade Theory NSQF Level - 4 (Revised 2022) under **Power Sector**. The contents are sequenced according to the practical exercise contained in NSQF Level - 4 (Revised 2022) syllabus on Trade Theory attempt has been made to relate the theoretical aspects with the skill covered in each exercise to the extent possible. This correlation is maintained to help the trainees to develop the perceptional capabilities for performing the skills.

The Trade theory has to be taught and learnt along with the corresponding exercise contained in the manual on trade practical. The indicating about the corresponding practical exercise are given in every sheet of this manual.

It will be preferable to teach/learn the trade theory connected to each exercise atleast one class before performing the related skills in the shop floor. The trade theory is to be treated as an integrated part of each exercise.

The material is not the purpose of self learning and should be considered as supplementary to class room instruction.

CONTENTS

LEARNING / ASSESSABLE OUTCOME

On completion of this book you shall be able to

S.No.	Learning Outcome	Ref. Ex.No.
1	Prepare profile with an appropriate accuracy as per drawing following safety precautions. (Mapped NOS: PSS/N2001)	1.1.01 - 1.1.19
2	Prepare electrical wire joints, carry out soldering and crimping. (Mapped NOS: PSS/N0108)	1.2.20 - 1.2.25
3	Verify basic characteristics of electrical and magnetic circuits and perform measurements using analog / digital instruments. (Mapped NOS: PSS/N1707)	1.3.26 - 1.3.57
4	Assemble simple electronic circuits and test for functioning. (Mapped NOS: PSS/N2504)	1.4.58 - 1.4.72
5	Carry out installation, testing and maintenance of batteries and battery room in distribution substation. (Mapped NOS: PSS/N2504)	1.5.73 - 1.5.85
6	Estimate, Assemble, install and test wiring system. (Mapped NOS: PSS/N1707)	1.6.86 - 1.6.97
7	Plan and install electrical illumination system and test. (Mapped NOS: PSS/N1707)	1.7.98 - 1.7.103
8	Plan, Execute commissioning, testing of AC motors& Starters and carry out their maintenance. (Mapped NOS: PSS/N1709)	1.8.104 - 1.8.116
9	Perform testing and carry out maintenance of Alternator and Synchronous motor. (Mapped NOS: PSS/N1711)	1.9.117 - 1.9.124
10	Perform speed control of AC motors by using solid state devices/ AC drives. (Mapped NOS: PSS/N1709)	1.10.125 - 1.10.127
11	Detect the faults and troubleshoot inverter, stabilizer, battery charger and UPS etc. (Mapped NOS: PSS/N6002)	1.11.128 - 1.11.132

SYLLABUS

1st Year **Duration: Two years**

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
Professional Skill 95 Hrs; Professional Knowledge 21 Hrs	Prepare profile with an appropriate accuracy as per drawing following safety precautions. **(Mapped NOS: PSS/ N2001)**	1 Visit various sections of the institutes and location of electrical installations. (05 hrs) 2 Identify safety symbols and hazards. (05 Hrs) 3 Preventive measures for electrical accidents and practice steps to be taken in such accidents. (05 hrs) 4 Practice safe methods of fire fighting in case of electrical fire. (05 hrs) 5 Use of fire extinguishers. (05 Hrs) 6 Practice elementary first aid. (05 hrs) 7 Rescue a person and practice artificial respiration. (05 Hrs) 8 Disposal procedure of waste materials. (05 Hrs) 9 Use of personal protective equipments. (05 hrs) 10 Practice on cleanliness and procedure to maintain it. (05 hrs)	Scope of the “Electrician – Power Distribution” Trade. Power sector scenario in India. Safety rules and safety signs. Introduction to Electricity Act2003, CERC, SERC. First aid safety practice. Hazard identification and prevention. Personal safety and factory safety. Response to emergencies e.g. power failure, system failure and fire etc. Types and working of fire extinguishers. Standard distance for safe working zone, clearance from live HV electrical system. (09 hrs.)
		11 Identify trade tools andmachineries. (10 Hrs) 12 Practice safe methods of lifting and handling of tools & equipment. (10 Hrs) 13 Select proper tools for operation and precautions in operation. (05 Hrs) 14 Care & maintenance of trade tools. (05 Hrs)	Concept of Standards and advantages of BIS/ISI. Trade tools specifications. Introduction to National Electrical Code-2011. Store keeping of equipments for Repair works. (05 hrs.)
		15 Workshop practice on filing and hacksawing. (15 Hrs)	Description of files, hammers, chisels, hacksaw frames, blades, their specification and grades. (07 hrs.)
Professional Skill 40 Hrs; Professional Knowledge 07Hrs	Prepare profile with an appropriate accuracy as per drawing following safety precautions. **(Mapped NOS: PSS/ N2001)**	16 Practice in marking and cutting of straight and curved pieces in metal sheets. (10 Hrs) 17 Workshop practice on drilling, chipping, internal and external threading of different sizes. (15Hrs) 18 Practice of making square and round holes, securing by screw and riveting. (06Hrs) 19. Prepare an open box from metal sheet. (09 Hrs)	Marking tools; Introduction to fitting tools, calipers, Dividers, Surface plates, Angle plates, Scribers, punches, surface gauges Types, Uses, Care and maintenance. Sheet metal tools: Description of marking & cutting tools. Types of rivets and riveted joints. Use of thread gauge. Care and maintenance of tools. (07 hrs.)

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
Professional Skill 56Hrs; Professional Knowledge 10Hrs	Prepare electrical wire joints, carry out soldering and crimping. **(Mapped NOS: PSS/ N0108)**	20 Prepare terminations of cable ends (02 hrs) 21 Practice on skinning, twisting and crimping. (10 Hrs) 22 Identify various types of cables and measure conductor size using SWG and micrometre. (8 Hrs) 23 Make simple twist, married, Tee and western union joints. (13 Hrs) 24 Make Britannia straight, Britannia Tee and rat tail joints. (13 Hrs) 25 Practice in Soldering of joints / lugs. (10 Hrs)	Fundamentals of electricity, definitions, units & effects of electric current. Conductors and insulators. Conducting materials and their comparison. Joints in electrical conductors, contact resistance measurement and required pressure. Techniques of soldering. Types of solders and flux. (10 hrs.)
Professional Skill 60Hrs; Professional Knowledge 10Hrs	Verify basic characteristics of electrical and magnetic circuits and perform measurements using analog / digital instruments. **(Mapped NOS: PSS/ N1707)**	26 Practice on measurement of parameters in combinational electrical circuit by applying Ohm's Law for different resistor values and voltage sources. (04 Hrs) 27 Measure current and voltage in electrical circuits to verify Kirchhoff's Law (03 Hrs) 28 Verify laws of series and parallel circuits with voltage source in different combinations. (03 Hrs) 29 Measure voltage and current against individual resistance in electrical circuit (04 hrs) 30 Measure current & voltage and analyse the effects of shorts and opens in series and parallel circuits. (04 Hrs) 31 Measure resistance using voltage drop method. (04 Hrs) 32 Measure resistance using Wheatstone bridge. (03 Hrs) 33 Determine the change in resistance due to temperature. (03 Hrs) 34 Verify the characteristics of series parallel combination of resistors. (03 Hrs) 35 Determine the poles and plot the field of a magnet bar. (03 Hrs) 36 Wind a solenoid and determine the magnetic effect of electric current. (04 Hrs) 37 Measure induced emf due to change in magnetic field. (04hrs) 38 Determine direction of induced emf and current. 1(04hrs) 39 Practice on generation of mutually induced emf. (04 hrs)	Ohm's Law; Simple electrical circuits and problems. Kirchhoff's Laws and applications. Series and parallel circuits. Open and short circuits in series and parallel networks. Laws of Resistance and various types of resistors. Wheatstone bridge; principle and its applications. Effect of variation of temperature on resistance. Different methods of measuring the values of resistance. Series and parallel combinations of resistors. Magnetic terms, magnetic materials and properties of magnet. Principles and laws of electro magnetism. Self and mutually induced EMFs. **Electrostatics:** Capacitor Different types, functions, grouping and uses. Inductive and capacitive reactance, their effect on AC circuit and related vector concepts. Handling of charging and discharging of static capacitors and other static charged equipment. (10 hrs.)

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
		40 Measure the resistance, impedance and determine inductance of choke coils in different combinations. (04 Hrs) 41 Identify various types of capacitors, charging / discharging and testing. (03Hrs) 42 Group the given capacitors to get the required capacity and voltage rating. (03Hrs)	
Professional Skill 60Hrs; Professional Knowledge 10Hrs	Verify basic characteristics of electrical and magnetic circuits and perform measurements using analog / digital instruments. **(Mapped NOS: PSS/ N1707)**	43 Measure current, voltage and PF and determine the characteristics of RL, RC and RLC in AC series circuits. (08Hrs) 44 Measure the resonance frequency in AC series circuit and determine its effect on the circuit. (06hrs) 45 Measure current, voltage and PF and determine the characteristics of RL, RC and RLC in AC parallel circuits. (08Hrs) 46 Measure the resonance frequency in AC parallel circuit and determine its effects on the circuit. (06hrs) 47 Measure power, energy for lagging and leading power factors in single phase circuits and compare characteristic graphically. (08Hrs) 48 Measure Current, voltage, power, energy and power factor in three phase circuits. (06hrs) 49 Practice improvement of PF by use of capacitor in three phase circuit. (06Hrs) 50 Measure power factor in three phase circuit by using power factor meter and verify the same with voltmeter, ammeter and wattmeter readings. (10Hrs)	Comparison and Advantages of DC and AC systems. Related terms frequency, Instantaneous value, R.M.S. value Average value, Peak factor, form factor, power factor and Impedance etc. Sine wave, phase and phase difference. Active and Reactive power. Single Phase and three-phase system. Problems on A.C. circuits. Classification of electrical instruments and essential forces required in indicating instruments. PMMC and Moving iron instruments. Measurement of various electrical parameters using different analog and digital instruments. Measurement of energy in three phase circuit. (10 hrs.)
Professional Skill 60Hrs; Professional Knowledge 08Hrs	Verify basic characteristics of electrical and magnetic circuits and perform measurements using analog / digital instruments. **(Mapped NOS: PSS/ N1707)**	51 Ascertain use of neutral by identifying wires of a 3- phase 4 wire system and find the phase sequence using phase sequence meter. (08Hrs) 52 Determine effect of broken neutral wire in three phase four wire system. (06hrs) 53 Determine the relationship between Line and Phase values for star and delta connections. (08Hrs) 54 Measure the Power of three phase circuit for balanced and unbalanced loads. (08Hrs)	Advantages of AC poly-phase system. Concept of three-phase Star and Delta connection. Line and phase voltage, current and power in a 3 phase circuits with balanced and unbalanced load. Phase sequence meter. Basic concept of Digital MultiFunction Meter.

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
		55 Measure current and voltage of two phases in case of one phase is shortcircuited in three phase four wire system and compare with healthy system.(10 hrs) 56 Measure electrical parameters using tong tester in three phase circuits. (10 Hrs) 57 Measure various electrical parameters using digital multifunction meter.(10hrs)	Basic concept of Accuracy class of meters. Communication from MFM to SCADA system. Improvement of power factor using Capacitor Bank. (08 hrs.)
Professional Skill 50Hrs; Professional Knowledge 10Hrs	Assemble simple electronic circuits and test for functioning. **(Mapped NOS: PSS/ N2504)**	58 Determine the value of resistance by colour code and identify types. (06Hrs) 59 Test active and passive electronic components and its applications. (10Hrs) 60 Determine V-I characteristics of semiconductor diode. (06Hrs) 61 Construct half wave, full wave and bridge rectifiers using semiconductor diode. (14Hrs) 62 Check transistors for their functioning by identifying its type and terminals. (06Hrs) 63 Use transistor as an electronic switch and series voltage regulator. (08Hrs)	Resistors – colour code, types and characteristics. Active and passive components. Atomic structure and semiconductor theory. P-N junction, classification, specifications, biasing and characteristics of diodes. Rectifier circuit - half wave, full wave, bridge rectifiers and filters. Transistors; Principle of operation, types, characteristics various configuration and biasing of transistor. Application of transistor as a switch, voltage regulator and amplifier. (10 hrs.)
Professional Skill 50Hrs; Professional Knowledge 10Hrs	Assemble simple electronic circuits and test for functioning. **(Mapped NOS: PSS N2504)**	64 Operate and set the required frequency using function generator. (05Hrs) 65 Make a printed circuit board for power supply. (05Hrs) 66 Construct simple circuits containing UJT for triggering and FET as an amplifier. (05Hrs) 67 Troubleshoot defects in simple power supplies. (05Hrs) 68 Construct power control circuit by SCR, Diac, Triac and IGBT. (05Hrs) 69 Construct variable DC stabilized power supply using IC. (05Hrs) 70 Practice on various logics by use of logic gates and circuits. (06Hrs) 71 Generate and demonstrate wave shapes for voltage/ current of rectifier and single stage amplifier using CRO. (08Hrs) 72 Construct 1ϕ or 3ϕ bridge rectifier/ inverter/ logic gate, measure input and output voltage and analyze waveforms by using oscilloscope (06Hrs)	Basic concept of power electronics devices. IC voltage regulators Digital Electronics - Binary numbers, logic gates and combinational circuits. Functions & settings of oscilloscope and waveform analysis. Construction and working of SCR, DIAC, TRIAC and IGBT. Types and applications of various multivibrators. (10 hrs.)

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
Professional Skill 50Hrs; Professional Knowledge 10Hrs	Carry out installation, testing and maintenance of batteries and battery room in distribution substation. **(Mapped NOS: PSS/ N2504)**	73 Identify and use of various types of cells. (02Hrs) 74 Measure voltage of different cells and Batteries. (03Hrs) 75 Practice on grouping of cells for specified voltage and current under different conditions with due care. (02Hrs) 76 Measure specific gravity of electrolyte and determine correction factor. (03Hrs) 77 Identify various components of battery charger used in sub station. (02Hrs) 78 Perform proper setting of voltage according to mode of charging and practice on Battery charging. (03Hrs) 79 Perform setting and carry out Trickle charging of Battery. (05Hrs) 80 Practice charging and discharging of Ni-Cd battery. (05Hrs) 81 Charge batteries by using float and boost charger. (05Hrs) 82 Check DC leakage and practice for its protection. (05Hrs) 83 Carry out testing of batteries. (05Hrs) 84 Practice on routine, care/ maintenance of batteries. (05Hrs) 85 Determine the number of solar cells in series / parallel for given power requirement. (05Hrs)	Chemical effect of electric current and Laws of electrolysis. Explanation of Anodes and cathodes. Types of cells, advantages/ disadvantages and their applications. Lead acid cell; Principle of operation and components. Types of battery charging, Load test of Ni-Cd and Lead Acid batteries, Safety precautions, test equipment and maintenance. Grouping of cells for specified voltage and current. Alkaline batteries Types of Battery operation: - Floating operation - Change over operation Boost charging Two Battery two charger system End cell cutting. C5 and C10 charging methods Factors affecting Battery life: - Over charging - Under charging - Leakage Correction factor, Calculation of Battery capacity Inspection of Battery Principle and operation of solar cell. Awareness of maintenance free battery concept. Safety compliance of battery room. (10 hrs.)
Professional Skill 60Hrs; Professional Knowledge 12Hrs	Estimate, Assemble, install and test wiring system. **(Mapped NOS: PSS/ N1707)**	86 Identify various conduits and different electrical accessories. (03Hrs) 87 Practice cutting, threading of different sizes & laying Installations. (03Hrs) 88 Prepare test boards / extension boards and mount accessories like lamp holders, various switches, sockets, fuses, relays, MCB, RCCB, RCBO, MPCB, MCCB etc. (06Hrs) 89 Draw layouts and practice in PVC Casing-capping, Conduit wiring with minimum to a greater number of points of minimum 15 metres. length. (06Hrs)	I.E. rules on electrical wiring. Types of domestic and industrial wirings. Study of wiring accessories e.g. switches, fuses, relays, MCB, RCCB, RCBO, MCCB etc. MPCB and its accessories. Under voltage, over voltage, shunt modules. Grading of cables and current ratings. Principle of laying out of domestic wiring.

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
		90 Wire up PVC conduit wiring to control one lamp from two or three different places. (06 Hrs) 91 Wire up PVC conduit wiring and practice control of sockets and lamps in different combinations using switching concepts. (06Hrs) 92 Wire up the consumer's main board with ICDP switch MCB and distribution fuse box. (05Hrs) 93 Prepare and mount the energy meter board. (03Hrs) 94 Estimate the cost/bill of material for wiring of hostel/ residential building and workshop. (04Hrs) 95 Practice wiring of hostel and residential building as per IE rules. (06Hrs) 96 Practice wiring of institute and workshop as per IE rules. (06Hrs) 97 Practice testing / fault detection of domestic and industrial wiring installation and repair. (06Hrs)	Voltage drop concept. PVC conduit and Casingcapping wiring system. Different types of wiring - Power, control, Communication and entertainment wiring. Wiring circuits planning, permissible load in sub-circuit and main circuit. Estimation of load, cable size, bill of material and cost. Inspection and testing of wiring installations. Special wiring circuit e.g. godown, tunnel and workshop etc. (12 hrs.)
Professional Skill 40Hrs; Professional Knowledge 12Hrs	Plan and install electrical illumination system and test. **(Mapped NOS: PSS/ N1707)**	98 Group different wattage of lamps in series for specified voltage. (04 Hrs) 99 Practice installation of various lamps e.g. fluorescent tube, HP sodium vapour, metal halide etc. (14Hrs) 100 Prepare decorative lamp circuit. (05 Hrs) 101 Prepare decorative lamp circuit to produce rotating light effect/running light effect. (05 Hrs) 102 Install light fitting for show case lighting. (06Hrs) 103 Install light fittings with various types of LEDs and fixture. (06Hrs)	Laws of Illuminations. Types of illumination system. Illumination factors, intensity of light. Type of lamps, advantages/ disadvantages and their applications. Calculations of lumens and efficiency. Different types of LEDs and fixtures. Luminous efficiency of LED Various color temperatures – Cool Day light - 5700K/ 6500K, Warm white - 2700K/ 300K False Recess type / Surface type. (08 hrs.)
Professional Skill 90Hrs; Professional Knowledge 16 Hrs	Plan, Execute commissioning, testing of AC motors& Starters and carry out their maintenance. **(Mapped NOS: PSS/ N1709)**	104 Identify parts and terminals of three phase AC motors. (05 Hrs) 105 Practice reading of power and control schematic drawings of motors. (05 Hrs) 106 Connect, start and run three phase induction motors by using DOL, star-delta starters. (05 Hrs) 107 Connect, start, run and reverse the direction of rotation of slip-ring motor through rotor resistance starter. (08 Hrs)	Introduction of DC motors and their applications. Working principle of three phase induction motor. Squirrel Cage Induction motor, Slip-ring induction motor; construction, characteristics, Slip and Torque. Different types of starters for three phase induction motors, its necessity, basic contactor circuit, parts and their functions.

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
		108 Practice on connection and settings of Soft starters. (06 Hrs) 109 Determine the efficiency of three phase squirrel cage induction motor by no load test and blocked rotor test. (06 Hrs) 110 Test for continuity and insulation resistance of three phase induction motor. (06 Hrs) 111 Perform speed control of three phase induction motor by various methods like rheostatic control, autotransformer etc. (12 Hrs) 112 Identify parts and terminals of different types of singlephase AC motors. (05 Hrs) 113 Install, connect and determine performance of single-phase AC motors. (08Hrs) 114 Start, run and reverse the direction of rotation of single-phase AC motors. (08 Hrs) 115 Practice on speed control of single phase AC motors. (08 Hrs) 116 Practice repair and maintenance of AC motors. (08 Hrs)	Basic knowledge of soft starter Single phasing prevention. No load test and blocked rotor test of induction motor. Losses & efficiency. Various methods of speed control. Braking system of motor. Maintenance and repair. Working principle, different method of starting and running of various single-phase AC motors. Domestic and industrial applications of different AC motors. Characteristics, losses and efficiency. (16 hrs.)
Professional Skill 65Hrs; Prof essional Knowledge 15Hrs	Perform testing and carry out maintenance of Alternator and Synchronous motor. **(Mapped NOS: PSS/ N1711)**	117 Identify parts and terminals of alternator. (07 Hrs) 118 Test for continuity and insulation resistance of alternator. (08 Hrs) 119 Connect, start and run an alternator and build up the voltage. (08 Hrs) 120 Determine the load performance and voltage regulation of three phase alternator. (08 Hrs) 121 Parallel operation and synchronization of three phase alternators. (08 Hrs) 122 Identify parts and terminals of a synchronous motor. (06 Hrs) 123 Connect, start and plot Vcurves for synchronous motor under different excitation and load conditions. (10 Hrs) 124 Carry out maintenance of Alternator and synchronous motor. (10 Hrs)	Principle of alternator, e.m.f. equation, relation between poles, speed and frequency. Types and construction. Efficiency, characteristics, regulation, phase sequence and parallel operation. Effect of changing the field excitation and power factor correction. Working principle of synchronous motor. Effect of change of excitation and load. V and anti V curve. Power factor improvement. Rotary Converter, MG Set description and Maintenance. (15 hrs.)

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
Professional Skill 20Hrs; Professional Knowledge 05Hrs	Perform speed control of ACmotors by using solid state devices/ AC drives. **(Mapped NOS: PSS/ N1709)**	125 Enter motor data and perform auto tuning on thyristors/ AC drive. (06 Hrs) 126 Perform reversing the direction of rotation of AC motors by using thyristors / AC drive. (08 Hrs) 127 Perform connections and identify parameters of AC drives. (06 Hrs)	Working, parameters and applications of AC drive. Speed control of 3 phase induction motor by using VVVF/AC Drive. (05 hrs.)
Professional Skill 44Hrs; Professional Knowledge 08 Hrs	Detect the faults and troubleshoot inverter, stabilizer, battery charger and UPS etc. **(Mapped NOS: PSS/ N6002)**	128 Identify and assemble circuits of voltage stabilizer and UPS. (08 Hrs) 129 Assemble circuits of battery charger and inverter. (08 Hrs) 130 Test, analyze defects and repair voltage stabilizer, emergency light and UPS. (09 Hrs) 131 Maintain, service and troubleshoot battery charger and inverter. (09 Hrs) 132 Install an Inverter with battery and connect it in domestic wiring for operation. (09 Hrs)	Basic concept, block diagram and working of voltage stabilizer, battery charger, emergency light, inverter and UPS. Preventive and breakdown maintenance. (08 hrs.)

Organisation of ITI's and scope of Electrician Power Distribution Trade

Objectives: At the end of this lesson you shall be able to
- **explain the duties of electrician general lineman, light and power, electrical line installers, repairers and cable jointers electrical fitter and their NCO**
- **explain power sector scenario in India**
- **list out the job opportunities and self employment opportunities.**

Brief Introduction of Industrial Training Institute (ITIs)

Industrial Training Institute plays a vital role in economy of the country, especially interms of providing skilled manpower.

The Directorate General of Training (DGT) comes under Ministry of Skill Development and Entrepreneurship (MSDE) offers a range of vocational training trades in different sectors based on economy /labour market. The vocational training programs are delivered under the aegis of National Council of Vocational Training (NCVT). Craftsman Training scheme (CTS) and Apprenticeship Training Scheme (ATS) and two pioneer programs of NCVT for Propagatory Vocational Training.

Total number of ITIs in India as on April 2016 is about 13105 (Govt. 2293 + 10812 Private ITIs). They are giving training about 132 trades including Engineering and Non-engineering with the duration of 1 or 2 years. The minimum eligibility for admission in ITIs 8th, 10th and 12th pass with respect to the trades and admission process will be held in every year in July.

From 2013, semester pattern was introduced with 6 months/Semester and revised the syllabus for each semester. Then in 2014, they introduced and implemented "Sector Mentor council (SMC)" re-revised syllabus under 11 sectors of about 80 trades.

At the end of each semester, All India Trade Test (AITT) will be conducted in every July and January, with OMR answer sheet pattern and multiple choice type questions. After passing, National trade certificates (NTC), will be issued by DGT which is authorized and recognized internationally. In 2017, for some trades they have introduced and implemented National Skill Qualification Frame work (NSQF) with Level 4 and Level 5.

After finishing instructional training with 'NTC' certificate, they have to undergo Apprenticeship training (ATS) for one or two year in respective trades under the Apprentice ACT 1961, in various government and private establishments with stipend. At the end of the Apprenticeship training, All India Apprentice Test will be conducted and apprentice certificate will be issued. They can get job opportunities in private or government establishment in India/Abroad or they can start small scale industries in manufacturing or in service sector with subsidiary government loan.

Organizational Structure of ITIs

In most of the ITIs, the head of the institute is the principal under him one vice-principal (VP). then Training Officers (TO)/Group Instructors (GI) who are the management and supervisory staff. Then Assistant Training Officers(ATO), Junior Training Officer (JTO), and Vocational Instructors (VI) are under Training officers for each trade and for Workshop calculations, Engineering Drawing, Employability skills etc. Administrative staff, Hostel Superintendent (H.S.) physical Education Trainer (PET), Library incharge, Pharmacist, etc. will be under the head of the Institution.

The typical organizational of ITI chart is shown in Fig 1

Welcome to the electrician power distribution trade

Electrician power distribution trade under craftsman training scheme (CTS) is one of the most popular trade delivered nationwide through the network of ITIs. This trade is of two year (4 semester) duration.

It mainly consists of domain area and core areas. In domain area trade practical and trade theory and core area workshop calculation and science, Engineering drawing and employability skills which imparts soft and life skills. There are two professional classification in electrician trade based on National Code of Occupation (NCO) as

(i) Electrician general (NCO - 2015 reference is 7411.0100)

(ii) Electrical fitter (NCO - 2015 reference is 7412.0200)

(iii) Lineman, Light and Power (NCO - 2015 reference is 7412.0200)

(iv) Electrical line installers, Repairers and cable Jointers (NCO - 2015 reference is 7412.0200)

Scope of the "Electrician Power Distribution"

Duties of Electrician - General and Electrical - Fitter

Electrician - General installs, maintains and repairs electrical machinery, equipment and fittings in factories, workshops, power houses, business and residential premises, etc. Studies drawings and other specifications to determine electrical circuit, installation etc. Positions and installs electrical motors, transformers, switchboards, microphones, loud-speakers and other electrical equipment, fittings and lighting fixtures. Makes connections and solder terminals. Tests electrical installations and equipment and locates faults using megger, test lamp etc.

Repairs or replaces defective wiring , burnt out fuses and defective parts and keeps fittings and fixtures in working order. may do armature winding, draw wires and cables and do simple cable joining. May operate, attend and maintain electrical motors, pumps etc. NCO - 2015 reference is 7411.0100

Record class of work in which experienced such as factory, power-house, ship etc., whether experienced in electrical repairs or detecting faults, details of experience in electrical equipment such as sound recording apparatus, air purification plant, heating apparatus etc. whether used to working do drawing, whether accustomed to high tension or low tension supply system and if in possession of competency certificate issued under electricity act.

Lineman, Light and Power: Erects and maintains overhead electric power lines to conduct electricity from power plant to place of use. Erects poles and small towers at specified distances with assistance of other workers. Climbs pole s and towers and fixes insulators, lightning arresters, cross-brass etc. and other auxiliary equipment at proper heights. Strings and draws cables (wires) through insulators fixed on cross bars, exercising great care to leave proper sag in wires to avoid breakage under changing atmospheric conditions. Joins cable by various methods, fixes joint-boxes at specified places, replaces fuses and faulty components as necessary and tests for electrical continuity. Checks overhead lines in allotted section as necessary and maintains them in order for carrying electricity by effecting repairs of defective lines, poles, towers and auxiliary equipment as directed. May install and repair overhead power lines for electric trains, trams or trolley buses. May work on high tension or low-tension power lines.

Electrical Line Installers, Repairers and Cable Jointers, Other: Perform number of routine and low skilled tasks in erecting and maintaining overhead lines, joining cables, etc., and are designated as Lineman's Mate; Cable Jointer Helper; etc., according to work performed.

Electrical Fitter: Fits and assembles electrical machinery and equipment such as motors, transformers, generators, switchgears, fans etc., Studies drawings and wiring diagrams of fittings, wiring and assemblies to be made. Collects prefabricated electrical and mechanical components according to drawing and wiring diagrams and checks them with gauges, megger etc. to ensure proper function and accuracy.

Fits mechanical components, resistance, insulators, etc., as per specifications, doing supplementary tooling where necessary. Follows wiring diagrams, makes electrical connections and solders points as specified. Checks for continuity, resistance, circuit shorting, leakage, earthing, etc. at each stage of assembly using megger, ammeter, voltmeter and other appliances and ensures stipulated performance of both mechanical and electrical components filled in assembly.

Erects various equipment such as bus bars, panel boards, electrical posts, fuse boxes switch gears, meters, relays etc. using non-conductors, insulation hoisting equipment as necessary for receipt and distribution of electrical current to feeder lines.

Installs motors, generators, transformer etc. as per drawings using lifting and hoisting equipment as necessary, does prescribed electrical wiring, and connects to supply line. Locates faults in case of breakdown and replaces blown out fuse, burnt coils, switches, conductors etc. as required. Checks, dismantles, repairs and overhauls electrical units periodically or as required according to scheduled procedure.

May test coils. May specialize in repairs of particular equipment manufacturing, installation or power house work and be designated accordingly.

Test electrical equipment and rewind blown out coils. May specialize in repairs of particular type of electrical appliances and machinery, equipment manufacturing, installation or power house work and be designated accordingly NCO - 2015 reference is 7412.0200

Record nature of work done; if specialized in repairing or assembling any particular item such as generator, motor, transformer, relays switchgear, domestic appliance etc. , experience of working in power-house and distribution centre and if in possession of electrician's competency certificate.

Power sector scenario in India

India is a nation in trsnsition. Considered an "emergency economy". Increasing GDP is driving the demand for additional electrical energy, as well as transportation fuels. The electricity sector in india supplies the world's 5th largest energy consumer, accounting for 4% of global energy consumption by more than 17% of global population. Rapid economic growth has created a growing need for dependable and reliable supplies of elctricity, gas and petroleum products. Due to the fast-paced growth of India's economy, the countrys energy demand has grown an average of 3.6% per annum over the past 3 years. In August 2011, the installed power generation capacity of India stood at 181.558 GW and per capital enery consumption stood at 787 kwh. The countrys Annual energy production increased from about 190 billion kwh in 1986 to more than 837 billion kwh in 2010.

During the year 2010-11 the energy requirement registered a growth of 3.7% during the year against the projected growth 5.6% and peak demand registered a growth of 2.6% against the projected growth of 6.5% thorough the total ex-bus energy availability increased by 5.6% over the previous year and the peak met increased by 6% the shortage conditions prevailed in the countryboth in term of energy and peaking availability. Base load requirement was 861,591 (MW) against availbility of 788,355 mu which is a shortage of 73,236 mu is 8.5% deficit. During peak load the demand was for 122,287 MW against availability of 110,256 MW which is a shortage of 12,031 MW is 9.8%. Electricity losses in india during transmission and distribution are high. Due to shortage of electricity power cuts are common through out india and this has power plants and 10.42% by renewable energy stotes.

Key Skills

Objectives: At the end of this lesson you shall be able to
- **state the key skills and carrier pathway for electrician power distribution**

Key Skills of Electrician power distribution

After passing the electrician power distribution trade, they are able to

- Read and interpret technical parameter documents, plan and organic work process, identify necessary materials and tools.
- Perform tasks with due consideration to safety rules, accident prevention regulation and environment protection.
- Apply professional skill knowledge and employability skills while performing jobs.
- Checking job/assembly as per drawing for functioning, identifying and rectifying errors in job/assembly.
- Document the technical parameters related to the tasks undertaken.
- Replace and maintenance of control elements for protection.

Carrier Progress Pathways

After passing the electrician power distribution trade the trainee can appear in 10+2 examination through National Institute of Open Schooling (NIOS) for acquiring higher secondary certificate and can go further for general Technical education.

- Take admission in diploma course in notified branches of engineering by lateral entry.
- Can join the apprenticeship training in different types of industries and obtain National Apprenticeship Certificate (NAC).
- Can join Craftsman Instructor Training Scheme (CITS) in the trade to become instructor in ITIs.
- Eligible to obtain directly wireman 'B' license, which is issued by the Electrical Licensing Board Authorities .

Job Opportunities: There are good numbers of job opportunities for an electrician.

- Electrician in local electricity boards, railways, Telephone department, airport and other government and semi-government establishments.
- Electrician in factories (Public/Private) Install, test and maintain electrical equipment in auditorium and cinema halls.
- Assembler of electrical control gears and switches on panel boards at switch gear factories.
- Technician in battery rooms in s/s, industries etc.
- Electrical appliances repairer in electrical shops.
- Electrician to Install, service and maintain electrical equipment and circuits in hotels, resorts hospitals and flats.
- Assembler in the domestic appliances manufacturing factories.
- Service technician for domestic appliances in reputed companies.
- Technician in fire fighting equipment section.

Self-employment opportunities

- Service centre for repairing electrical switch gear and motors in rural and urban areas.
- Maintenance contractor of wiring installation in hotels/ resorts/hospitals/banks etc.
- Manufacturer of sub-assembly for electrical panels.
- Contractor for domestic wiring and industrial wiring.
- Armature winder of electrical motors.
- Repairer of simple electronic of gadgets.
- Service, maintain and repair of domestic appliances.
- Dealership/agency for electrical hardware.
- With an added training in the specified field can become Audio/Radio/ TV Mechanic.
- Contractor for cable layouts in s/s.

Safety rules - Safety signs

Objectives: At the end of this lesson you shall be able to
- **First aid safety pratise**
- **explain the necessity of adopting the safety rules**
- **list the safety rules to be followed by the electrician**
- **explain how to treat a person for electric shock/injury**

Necessity of safety rules: Safety consciousness is one of the essential attitudes required for any job. A skilled electrician always should strive to form safe working habits. Safe working habits always save men, money and material. Unsafeworking habits always end up in loss of production and profits, personal injury and even death. The safety hints given below should be followed by Electrician to avoid accidents and electrical shocks as his job involves a lot of occupational hazards.

The listed safety rules should be learnt, remembered and practised by every electrician. Here a electrician should remember the famous proverb, **"Electricity is a good servant but a bad master".**

Safety rules

- Only qualified persons should do electrical work.
- Keep the workshop floor clean, and tools in good condition, and keep proper places.
- Do not work on live circuits; if unavoidable, use rubber gloves rubber mats, etc.
- Use wooden or PVC insulated handle screwdrivers when working on electrical circuits.
- Do not touch bare conductors
- When soldering, place the hot soldering irons in their stand. Never lay switched 'ON' or heated soldering iron on a bench or table as it may cause a fire to break out.
- Use only correct capacity fuses in the circuit. If the capacity is less it will blow out when the load is connected. If the capacity is large, it gives no protection and allows excess current to flow and endangers men and machines, resulting in loss of money.
- Replace or remove fuses only after switching off the circuit switches.
- Use extension cords with lamp guards to protect lamps against breakage and to avoid combustible material coming in contact with hot bulbs.
- Use accessories like sockets, plugs, switches and appliances only when they are in good condition and be sure they have the mark of BIS (ISI). Necessity of using BIS(ISI) marked accessories is explained under standardisation.
- Never extend electrical circuits by using temporary wiring.
- Stand on a wooden stool, or an insulated ladder while repairing live electrical circuits/ appliances or replacing fused bulbs. In all the cases, it is always good to open the main switch and make the circuit dead.
- Stand on rubber mats while working/operating switch panels, control gears etc.
- Position the ladder, on firm ground.
- While using a ladder, ask the helper to hold the ladder against any possible slipping.
- Always use safety belts while working on poles or high rise points.
- Never place your hands on any moving part of rotating machine and never work around moving shafts or pulleys of motor or generator with loose shirt sleeves or dangling neck ties.
- Only after identifying the procedure of operation, operate any machine or apparatus.
- Run cables or cords through wooden partitions or floor after inserting insulating porcelain tubes.
- Connections in the electrical apparatus should be tight. Loosely connected cables will heat up and end in fire hazards.
- Use always earth connection for all electrical appliances along with 3-pin sockets and plugs.
- While working on dead circuits remove the fuse grips; keep them under safe custody and also display 'Men on line' board on the switchboard.
- Do not meddle with interlocks of machines/switch gears.
- Do not connect earthing to the water pipe lines.
- Do not use water on electrical equipment.
- Discharge static voltage in HV lines/equipment and capacitors before working on them.

Safety practice - first aid:

Electric shock

We are aware that the prime reasons for severity of shock are the magnitude of current and duration of contact. In addition, the other factors contribute to the severity of shock are:

- age of person
- body resistance

- not wearing insulating footwear or wearing wet footwear
- Weather condition
- Wet or dry floor
- Mains voltage etc.

If assistance is close at hand, send for medical aid, then carry on with emergency treatment.

If you are alone, proceed with the treatment immediately.

Make sure the victim is not in contact with the supply.

Effects of electric shock

The effect of current at very low levels may only be an unpleasant tingling sensation, but this itself may be sufficient to cause some persons to lose their balance and fall.

At higher levels of current the person receiving a shock may be thrown off his feet and will experience severe pain and possibly minor burns at the point of contact.

At an excessive shock can also cause burning of the skin at the point of contact.

Treatment of electric shock

Prompt treatment is essential.

Check for the victim's natural breathing and consciousness. Take steps to apply respiratory resuscitation if the victim is unconscious and not breathing.

Check the victim for injury and burns. Decide on the suitable method of artificial resuscitation.

In the case of injury/burns to chest and or belly, follow the mouth-to-mouth method.

In the case of burns/injury in the back, follow Nelson's method

In case the mouth is closed tightly, use Schafer's or Holgen-Nelson method.

These methods should be practiced. (Refer Exercise 1.1.06)

Treatment for electrical burns

A person receiving an electric shock may also sustain burns when the current passes through the body.

Do not waste time by rendering first aid to the victim until breathing has been restored and the patient can breathe normally unaided.

Burns are very painful. If a large area of the body is burnt, do not give treatment, except to exclude the air, eg. by covering with clean paper or a clean cloth, soaked in clean water. this relieves the pain.

Severe bleeding

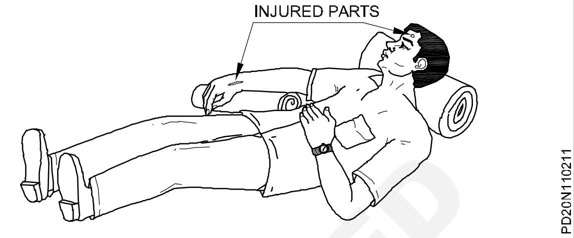
Any wound which is bleeding profusely, especially in the wrist, hand or fingers must be considered serious and must receive professional attention. As an immediate first aid measure, pressure on the wound itself is the best means of stopping the bleeding and avoiding infection.

Immediate action

Always in cases of severe bleeding

- make the patient to lie down and rest
- if possible, raise the injured part above the level of the body (Fig 1)

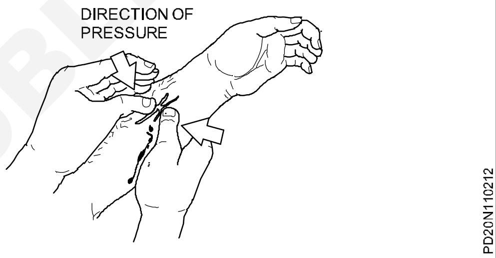
Fig 1



- apply pressure to the wound
- call for medical assistance

To control severe bleeding

Fig 2



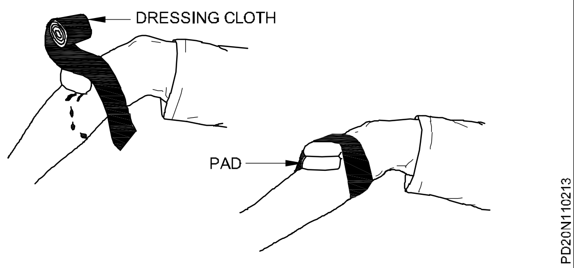
Squeeze together the sides of the wound. Apply pressure as long as it is necessary to stop the bleeding. When the bleeding has stopped, put a dressing over the wound and cover it with a pad of soft material. (Fig 2)

For an abdominal wound which may be caused by falling on a sharp tool, keep the patient bending over the wound to stop internal bleeding.

Large wound

Apply a clean pad and bandage firmly in place. If bleeding is very severe apply more than one dressing. (Fig 3)

Fig 3



Safety signs (Road signals)

Objectives: At the end of this lesson you shall be able to
- **Hazard identification and prevention**
- **Personal of feeling safety.**

In olden days road locomotive carrying a red flag by day and red lantern by night. Safety is the prime motive of every traffic.

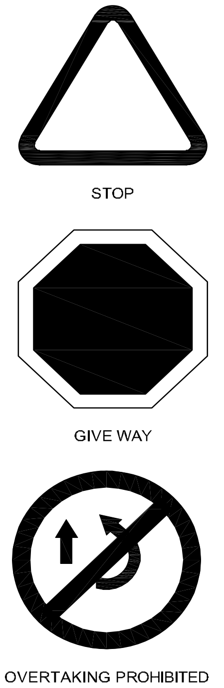
Kinds of road signs

- Mandatory
- Cautionary and
- Informatory

Mandatory signs (Fig 1)

Violation of mandatory sign can lead to penalties.

Fig 1



Eg. Stop, give way, limits, prohibited, no parking and compulsory sign.

Cautionary signs (Fig 2)

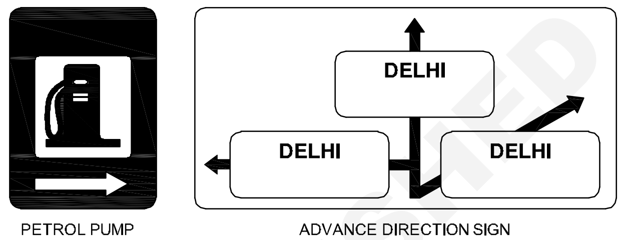
Fig 2

Cautionary/ warning signs are especially safe. Do's and don'ts for pedestrians, cyclists, bus passengers and motorists.

Information signs (Fig 3)

Information signs as especially benefit to the passengers and two wheelers.

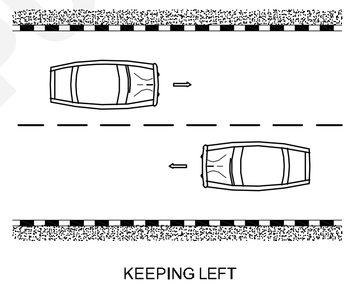
Fig 3



Marking lines on road (Fig 4)

- Marking lines are directing or warning to the moving vehicles, cyclist and pedestrians to follow the law.

Fig 4



- Single and short broken lines in the middle of the road allow the vehicle to cross the dotted lines safely overtake whenever required.
- When moving vehicle approaching pedestrian crossing, be ready to slow down or stop to let people cross.
- Do not overtake in the vicinity of pedestrian crossing.

Police signals (Fig 5)

To stop a vehicle approaching from behind. (Fig 5/1)

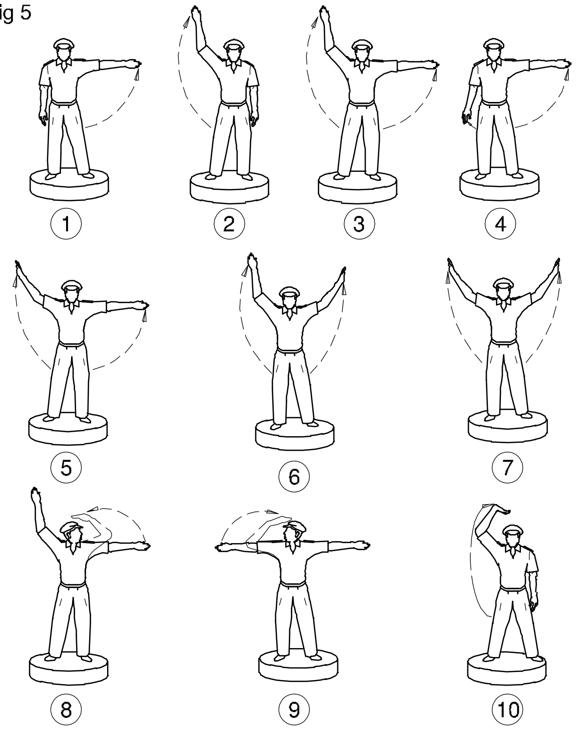
To stop a vehicle coming from front. (Fig 5/2)

To stop vehicles approaching simultaneously from front and behind. (Fig 5/3)

To stop traffic approaching from left and wanting to turn right. (Fig 5/4)

To stop traffic approaching from the right to allow traffic from left to turn right. (Fig 5/5)

Fig 5



POLICE SIGNALS

PD20N110225

To allow traffic coming from the right and turning right by stopping traffic approaching from the left. (Fig 5/6)

Warning signal closing all traffic. (Fig 5/7)

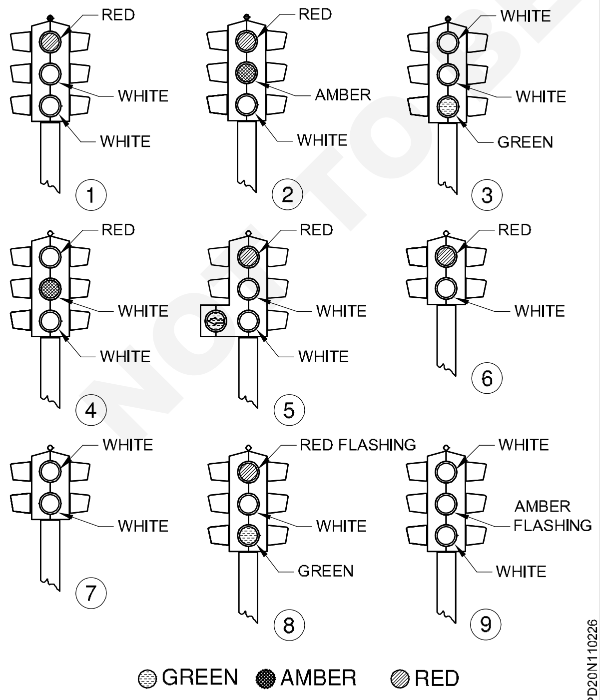
Beckoning on vehicles approaching from left. (Fig 5/8)

Beckoning on vehicles approaching from right. (Fig 5/9)

Beckoning on vehicles from front. (Fig 5/10)

Traffic light signals (Fig 6)

Fig 6



PD20N110226

Red means stop. Wait behind the stop line on the carriage way. (Fig 6/1)

Red and amber also means stop. Do not pass through or start until green shows. (Fig 6/2)

Green means you may go on if the way is clear. Take special care if you mean to turn left or right and give way to pedestrians who are crossing. (Fig 6/3)

Amber means stop at the stop line. you may only go on if the amber appears after you have crossed the stop line or so close to it that to pull up may not be possible. (Fig 6/4)

Green arrow means that you may go in the direction shown by the arrow. You may do this whatever other lights may be showing. (Fig 6/5)

Pedestrians - do not cross. (Fig 6/6)

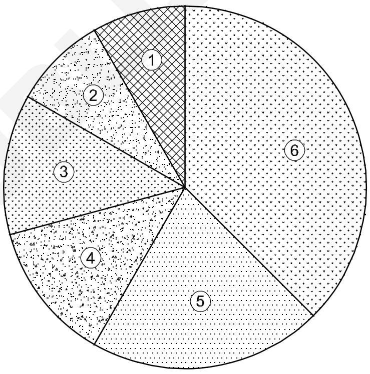
Pedestrians - cross now. (Fig 6/7)

Flashing red means stop at the stop line and if the way is clear proceed with caution. (Fig 6/8)

Flashing amber means proceed with caution. (Fig 6/9)

Collision causes (Fig 7)

Fig 7



1. VEHICLE DEFECTS
2. ROAD DEFECTS
3. PHYSICAL DEFECTS OF DRIVER
4. LACK OF SKILL OF DRIVER
5. LACK OF KNOWLEDGE
6. WRONG ATTITUDES

COLLISION CAUSES

PD20N110227

Three factors are responsible for collision

- Roads
- Vehicles and
- Drivers

The Fig 8 shows approximately proportionate causes of collision. In wrong attitudes such that avoid foolish acts at the wheel (Fig 8). Driving time is not play time.

Fig 8

PD20N110228

Safety practice - Safety signs

Responsibilities

Safety doesn't just happen - it has to be organised and achieved like the work-process of which it forms a part. The law states that both an employer and his employees have a responsibility in this behalf.

Employer's responsibilities

The effort a firm puts into planning and organising work, training people, engaging skilled and competent workers, maintaining plant and equipment, and checking, inspecting and keeping records - all of this contributes to the safety in the workplace.

The employer will be responsible for the equipment provided, the working conditions, what the employees are asked to do, and the training given.

Employee's responsibilities

You will be responsible for the way you use the equipment, how you do your job, the use you make of your training, and your general attitude to safety.

A great deal is done by employers and other people to make your working life safer; but always remember you are responsible for your own actions and the effect they have on others. You must not take that responsibility lightly.

Rules and procedure at work

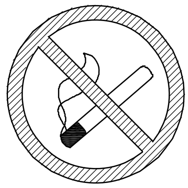
What you must do, by law, is often included in the various rules and procedures laid down by your employer. They may be written down, but more often than not, are just the way a firm does things - you will learn these from other workers as you do your job.

They may govern the issue and use of tools, protective clothing and equipment, reporting procedures, emergency drills, access to restricted areas, and many other matters. Such rules are essential; they contribute to the efficiency and safety of the job.

Safety signs

As you go about your work on a construction site you will see a variety of signs and notices. Some of these will be familiar to you - a 'no smoking' sign for example; others you may not have seen before. It is up to you to learn what they mean - and to take notice of them. They warn of the possible danger, and must not be ignored.

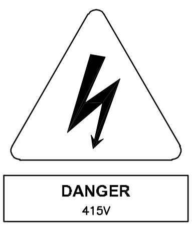
Safety signs fall into four separate categories. These can be recognised by their shape and colour. Sometimes they may be just a symbol; other signs may include letters or figures and provide extra information such as the clearance height of an obstacle or the safe working load of a crane.

Fig 1 	SHAPE	Circular.
	COLOUR	Red border and cross bar. Black symbol on white background.
	MEANING	Shows it must not be done.
	Example	No smoking.

Mandatory signs

Fig 2 	SHAPE	Circular.
	COLOUR	White symbol on blue background
	MEANING	Shows what must be done.
	Example	Wear hand protection.

Warning signs

Fig 3 	SHAPE	Triangular.
	COLOUR	Yellow background with black border and symbol.
	MEANING	Warns of hazard or danger.
	Example	Caution, risk of electric shock.

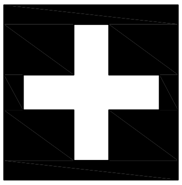
The four basic categories of signs are as follows:

- prohibition signs (Fig 1 & Fig 5)
- mandatory signs (Fig 2 & Fig 6)
- warning signs (Fig 3 & Fig 7)
- information signs (Fig 4)

Prohibition signs

Information signs

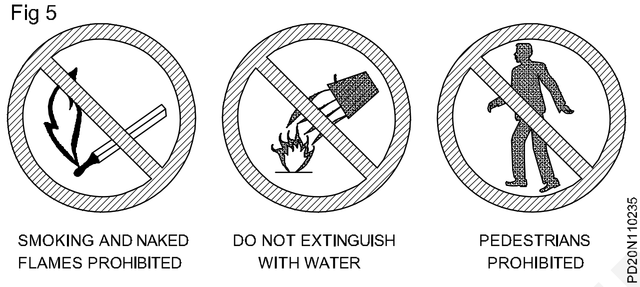
Fig 4



SHAPE	Square or oblong.
COLOUR	White symbols on green background.
MEANING	Indicates or gives information of safety provision.
Example	First aid point.

Prohibition signs

Fig 5



Mandatory signs

Fig 6

Introduction to electricity Act 2003, CERC, SERC

An Act to consolidate the laws relating to generation, transmission, distribution, trading and use of electricity and generally for taking measures conducive to development of electricity industry, promoting competition therein, protecting interest of consumers and supply of electricity to all areas, rationalization of electricity tariff, ensuring

Warning signs

Fig 7

transparent policies regarding subsidies, promotion of efficient and environmentally benign policies, constitution of Central Electricity Authority, Regulatory Commissions and establishment of Appellate Tribunal and for matters connected therewith or incidental thereto.

CERC Central Electricity Regulatory Commission (CERC), a key regulator of power sector in India, is a statutory body functioning with quasi-judicial status under sec – 76 of the Electricity Act 2003.

It is to regulate the inter-State transmission of electricity; to determine tariff for inter-State transmission of electricity; to issue licenses to persons to function as transmission licensee and electricity trader with respect to their inter-State operations; Improve access to information for all stakeholders.

State Electricity Regulatory Commission (India) is an autonomous, statutory and Regulatory body constituted for ensuring generation and distribution of Electricity in States and Union Territories of India.

Acts as a regulator for distribution licensees during the purchase and procurement of electricity by them.

Facilitates during transmission of electricity between different states.

Facilitates issuing of licenses to transmission and distribution licensees applicants and electricity traders within the state.

Resolve conflicts between the licensees and/or the generating companies.

Standard distance for safe working zone

Clearances as per Indian Standard Code shall be provided for electrical apparatus so that sufficient space is available for easy operation and maintenance without any hazard to the operating and maintenance personnel working near the equipment and for ensuring adequate ventilation. (ii) The following minimum clearances shall be maintained for bare conductors or live parts of any apparatus in out-door substations, excluding overhead

Voltage Class		Ground clearance (Metres)	Sectional clearance (Metres)
Not exceeding	11KV	2.75	2.6
-do-	33KV	3.7	2.8
-do-	66KV	4.0	3.0
-do-	132KV	4.6	3.5
-do-	22OKV	5.5	4.3
-do-	40OKV	8.0	6.5

lines, of HV and EHV installations.

Clearances from buildings of high and extra-high voltage lines

1 Where a high or extra-high voltage overhead line passes above or adjacent to any building or part of a building it shall have on the basis of maximum sag a vertical clearance above the highest part of the building immediately under such line, of not less than.

(a) For high voltage lines upto and including 33,000 volts	3.7 metres
(b) For extra-high voltage lines	3.7 metres plus 0.30 metre for every additional 33,000 volts or part thereof.

2 The horizontal clearance between the nearest conductor and any part of such building shall, on the basis of maximum deflection due to wind pressure, be not less than.

(a) For high voltage lines upto and including 11,000 volts.	1.2 metres
(b) For high voltage lines above 11,000 volts and up to and including 33,000 volts	2.0 metres
(c) For extra-high voltage lines	2.0 metres plus 0.3 metre for every additional 33,000 volts for part thereof.

Fire - Types - Extinguishers

Objectives: At the end of this lesson you shall be able to
- **state the effects of a fire break out and causes of fire in a workshop**
- **distinguish the different types of fire extinguishers**
- **state the classification of fires and basic ways for extingushing the fire**
- **determine the correct type of fire extinguisher to be used based on the class of fire**
- **describe the general procedure to be adopted in the event of fire**
- **state the method of operation of fire extinguisher and extinguishing of fire.**

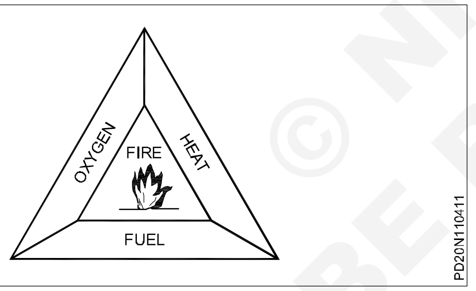
Fire

Fire is the burning of combustible material. A fire in an unwanted place and on an unwanted occasion and in an uncontrollable quantity can cause damage or destroy property and materials. It might injure people, and sometimes cause loss of life as well. Hence, every effort must be made to prevent fire. When a fire outbreak is discovered, it must be controlled and extinguished by immediate corrective action.

Is it possible to prevent fire? Yes, fire can be prevented by eliminating anyone of the three factors that causes fire.

The following are the three factors that must be present in combination for a fire to continue to burn. (Fig 1)

Fig 1



Fuel: Any substance, liquid, solid or gas will burn, if there is oxygen and high enough temperatures.

Heat: Every fuel will begin to burn at a certain temperature. It varies and depends on the fuel. Solids and liquids give off vapour when heated, and it is this vapour which ignites. Some liquids do not have to be heated as they give off vapour at normal room temperature say 15^0C, *eg.* petrol.

Oxygen: Usually exists in sufficient quantity in air to keep a fire burning.

Extinguishing of fire: Isolating or removing any of these factors from the combination will extinguish the fire. There are three basic ways of achieving this.

- **Starving** the fire of fuel removes this element.
- **Smothering** - ie. isolate the fire from the supply of oxygen by blanketing it with foam, sand etc.
- **Cooling** - use water to lower the temperature.

Removing any one of these factors will extinguish the fire.

Preventing fires: The majority of fires begin with small outbreaks which burn unnoticed until they have a secure hold. Most fires could be prevented with more care and by following some simple common sense rules.

Accumulation of combustible refuse (cotton waste soaked with oil, scrap wood, paper, etc.) in odd corners are a fire risk. Refuse should be removed to collection points.

The cause of fire in electrical equipment is misuse or neglect. Loose connections, wrongly rated fuses, overloaded circuits cause overheating which may in turn lead to a fire. Damage to insulation between conductors in cables causes fire.

Clothing and anything else which might catch fire should be kept well away from heaters. Make sure that the heater is shut off at the end of the working day.

Highly flammable liquids and petroleum mixtures (thinner, adhesive solutions, solvents, kerosene, spirit, LPG gas etc.) should be stored in the flammable material storage area.

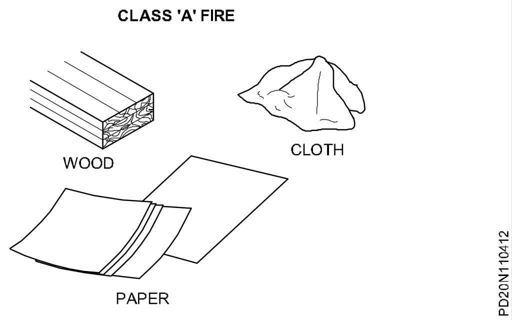
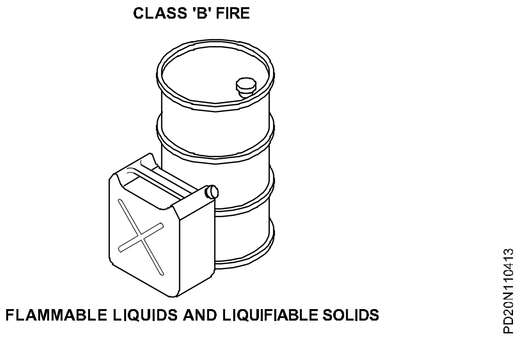
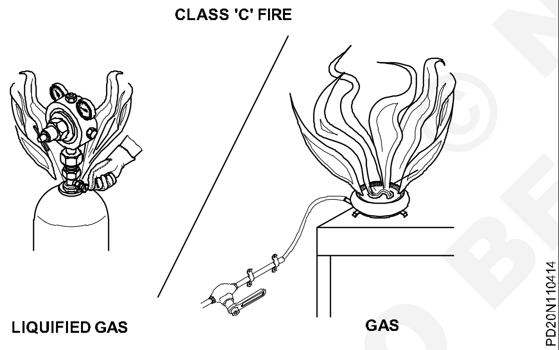
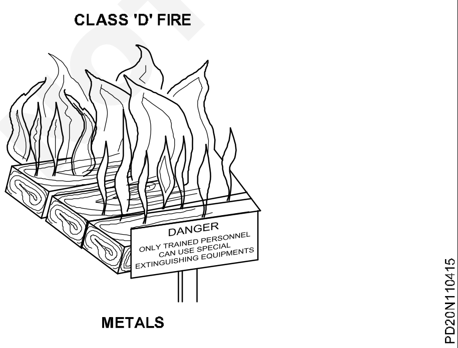
Blowlamps and torches must not be left burning when they are not in use.

Classification of fires: Fires are classified into four types in terms of the nature of fuel.

Different types of fires (Fig 2, Fig 3 Fig 4 & Fig 5) have to be dealt with in different ways and with different extinguishing agents.

An extinguishing agent is the material or substance used to put out the fire, and is usually (but not always) contained in a fire extinguisher with a release mechanism for spraying into the fire.

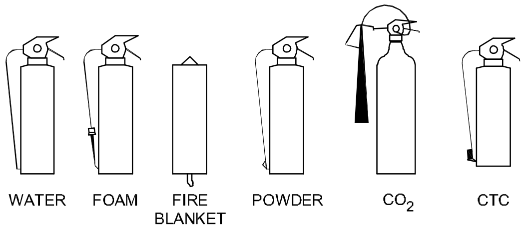
It is important to know the right type of agent for extinguishing a particular type of fire; using a wrong agent can make things worse.There is no classification for 'electrical fires' as such, since these are only fires in materials where electricity is present.

Fire Classification and Fuel	Extinguishing Method
Fig 2  	Most effective ie., cooling with water. Jets of water should be sprayed on the base of the fire and then gradually upwards.
Fig 3  	**Should be smothered** :- The aim is to cover the entire surface of the burning liquid. This has the effect of cutting off the supply of oxygen to the fire. Water should never be used on burning liquids. Foam, dry powder or CO_2 may be used on this type of fire.
Fig 4  	Extreme caution is necessary in dealing with liquefied gases. There is a risk of explosion and sudden outbreak of fire in the entire vicinity. If an appliance fed from a cylinder catches fire - shut off the supply of gas. The safest course is to raise an alarm and leave the fire to be dealt with by trained personnel.
Fig 5  	Dry powder extinguishers are used on this type of fire. Special powders have now been developed which are capable of controlling and/or extinguishing this type of fire. The standard range of fire extinguishing agents is inadequate or dangerous when dealing with metal fires. Fire on electrical equipment. Halon, Carbon dioxide, dry powder and vapourising liquid (CTC) extinguishers can be used to deal with fires in electrical equipment. Foam or liquid (eg. water) extinguishers must not be used on electrical equipment under any circumstances.

Types of Fire Extinguisher

Many types of fire extinguishers are available with different extinguishing 'agents' to deal with different classes of fires. (Fig 1)

Fig 1

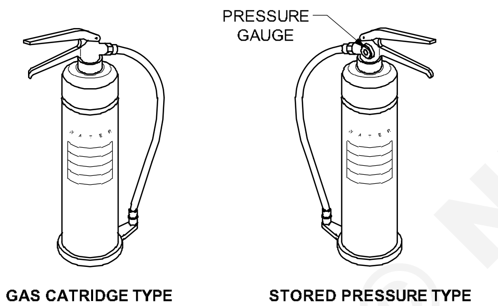


Water-filled extinguishers: There are two methods of operation. (Fig 2)

- Gas cartridge type
- Stored pressure type

With both methods of operation the discharge can be interruted as required, conserving the contents and preventing unnecessary water damage.

Fig 2



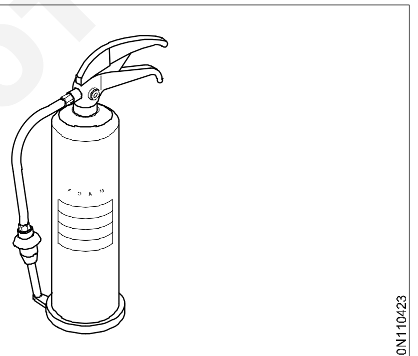
Foam extinguishers (Fig 3):These may be of stored pressure or gas cartridge types. Always check the operating instructions on the extinguisher before use.

Most suitable for

- flammable liquid fires
- running liquid fires

Must not be used on fires where electrical equipment is involved.

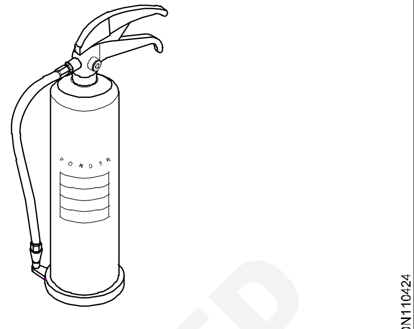
Fig 3



FOAM EXTINGUISHERES

Dry powder extinguishers (Fig 4): Extinguishers fitted with dry powder may be of the gas cartridge or stored pressure type. Appearance and method of operation is the same as that of the water-filled one. The main distinguishing feature is the fork shaped nozzle. Powders have been developed to deal with class D fires.

Fig 4



DRY POWDEER EXTINGUSHERS

Carbon dioxide (CO_2): This type is easily distinguished by the distinctively shaped discharge horn. (Fig 5).

Fig 5

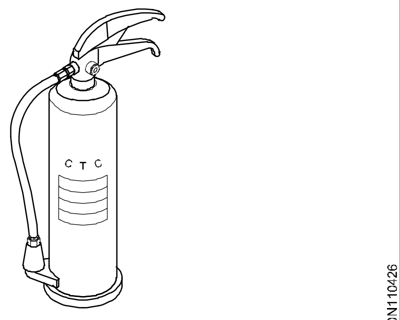
CARBAN DIOXIDE(CO_2)

Suitable for Class B fires. Best suited where contamination by deposits must be avoided. Not generally effective in open air.

Always check the operating instructions on the container before use. Available with different gadgets of operation such as - plunger, lever, trigger etc.

Halon extinguishers (Fig 6)**:** These extinguishers may be filled with carbon-tetrachloride and Bromochlorodifluoro methene (BCF). They may be either gas cartridge or stored pressure type.

Fig 6



HALON EXTINGUISHERS

They are more effective in extinguishing small fires involving pouring liquids. These extinguishers are particularly suitable and safe to use on electrical equipment as the chemicals are electrically non-conductive.

The fumes given off by these extinguishers are dangerous, especially in confined space.

The general procedure in the event of a fire:

- Raise an alarm.
- Turn off all machinery and power (gas and electricity).
- Close the doors and windows, but do not lock or bolt them. This will limit the oxygen fed to the fire and prevent its spreading.
- Try to deal with the fire if you can do so safely. Do not risk getting trapped.
- Anybody not involved in fighting the fire should leave calmly using the emergency exits and go to the designated assembly point.

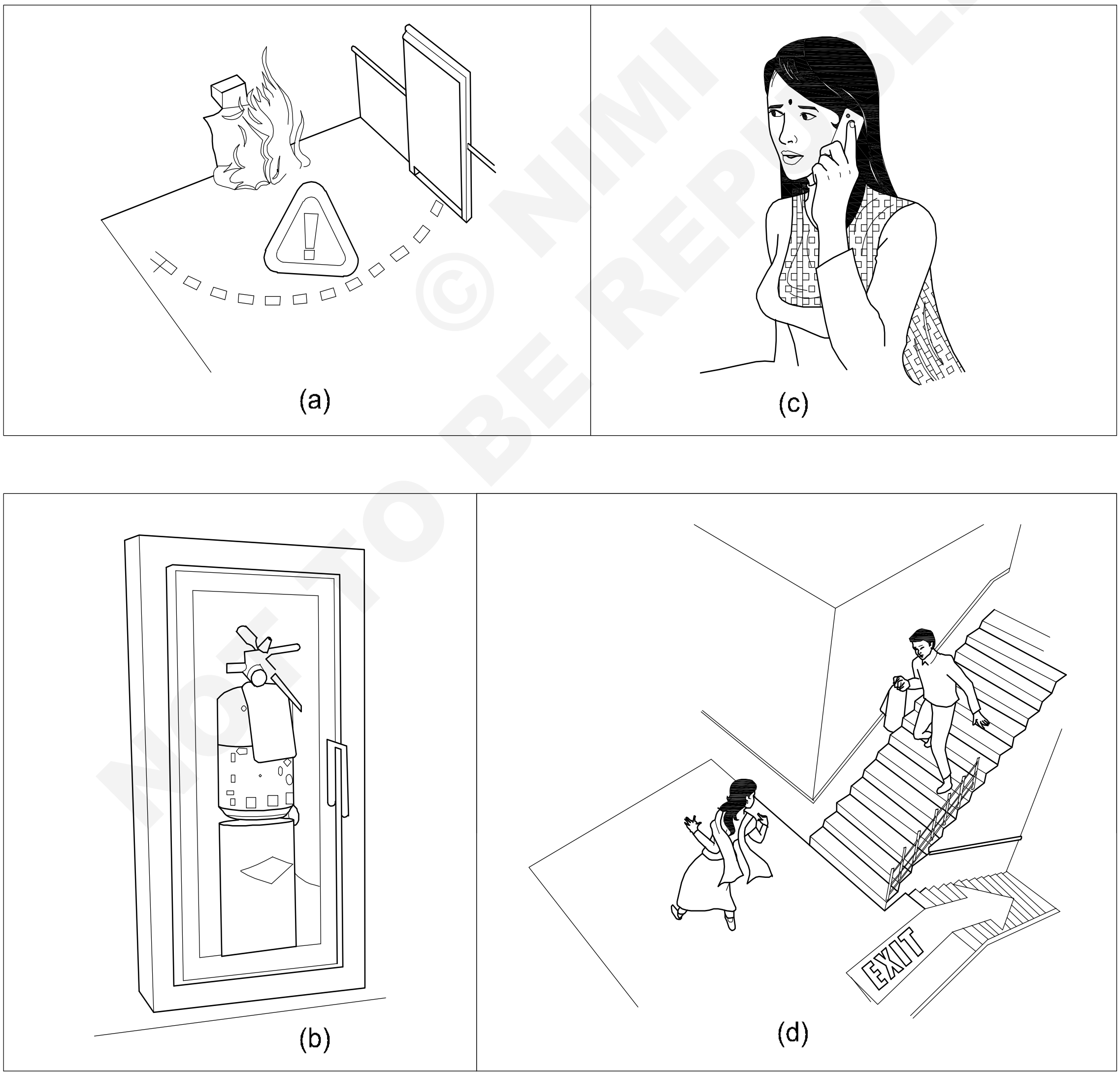
Failure to do this may mean that some person being unaccounted for and others may have to put themselves to the trouble of searching for him or her at risk to themselves.

Working on fire extinguishers:-

- Alert people sorrounding by shouting fire, fire, fire when observe the fire. (Fig 1a & b)
- Inform fire service or arrange to inform immediately. (Fig 1c)
- Open emergency exist and ask them to go away. (Fig 1d)
- Put “OFF” electrical power supply.

Don’t allow people to go nearer to the fire

Fig 1



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- Analyze and identify the type of fire. Refer Table1.

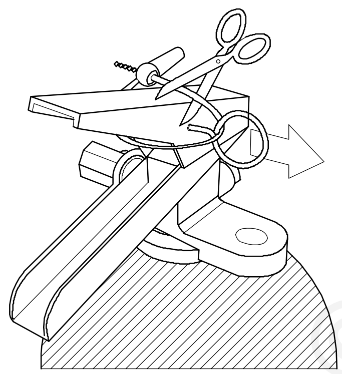
Table 1

Class 'A'	Wood, paper, cloth, solid material
Class 'B'	Oil based fire (grease, gasoline, oil) liquifiable gases
Class 'C'	Gas and liquifiable gases
Class 'D'	Metals and electrical equipment

Assume the fire is 'B; type (flammable liquifiable solids)

- Slect CO_2 (Carbon di oxide) fire extinguisher.
- Locate and pickup, CO_2 fire extinguisher. Click for its expiry date.
- Break the seal (Fig 2)

Fig 2



BREAK THE SEAL

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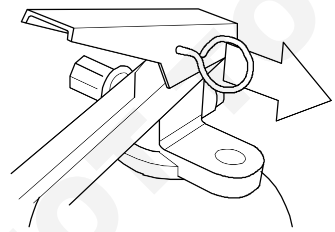
- Pull the safety pin from the handle (Pin located at the top of the fire extinguisher) (Fig 3)

Fig 3



PULL THE SAFTY PIN

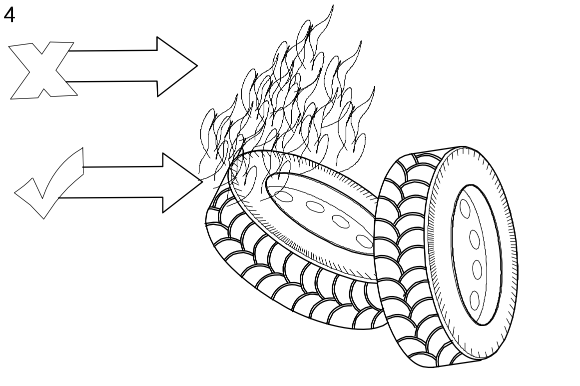
PD20N110433

- Aim the extinguisher nozzle or hose at the base of the fire (this will remove the source of fuel fire) (Fig 4)

Keep your self low and safe distance

- Squeeze the handle lever slowly to discharge the agent (Fig 5)
- Sweep side to side approximately 15 cm over the fuel fire until the fire is put off (Fig 5)

Fig 4



AIM THE EXTINGUISHER

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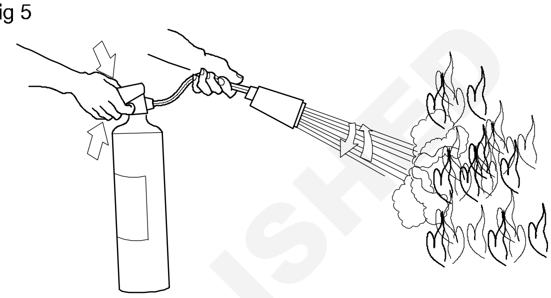
Fig 5



SQUEEZE THE HANDLE LEVER

ELN110435

Fire extinguishers are manufactured for use from the distance.

Caution

- **While putting off fire, the fire may flare up**
- **Do not be panick belong as it put off promptly.**
- **If the fire doesn't respond well after you have used up the fire extinguisher move away yourself away from the fire point.**
- **Do not attempt to put out a fire where it is emitting toxic smoke leave it for the professionals.**
- **Remember that your life is more important than property. So don't place yourself or others at risk.**

In order to remember the simple operation of the extinguisher. Remember P.A.S.S. This will help you to use the fire extinguisher.

P for Pull

A for Aim

S for Squeeze

S for Sweep

Rescue operation - First aid treatment - Artificial respiration

Objectives: At the end of this lesson you shall be able to
- **explain how to rescue a person who is in contact with a live wire**
- **state the first aid and its key aims**
- **explain ABC of the first aid**
- **brief how to give first aid treatment for a victim**
- **explain how to treat a person affected due to electric shock/injury.**

The severity of an electric shock will depend on the level of current which passes through the body and the length of time of contact. Do not delay, act at once. Make sure that the electric current has been disconnected. If the victim is still in contact with the supply - break the contact either by switching off or by removing the plug or pulling the cable free.

If not, stand on some insulating material such as dry wood, rubber or plastic or newspaper and then pull his shirt sleeves. However, you have to insulate yourself and break the contact by pushing or pulling the person free. (Figs1 & 2)

Fig 1

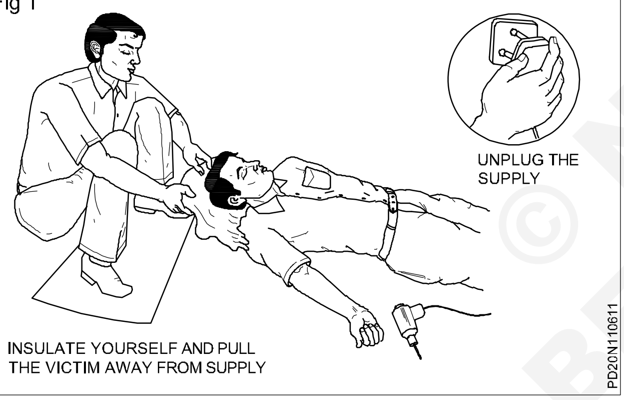
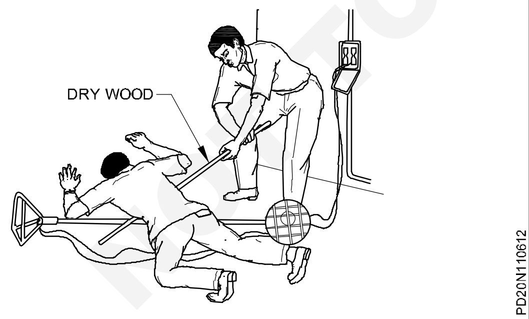


Fig 2



In any case avoid direct contact with the victim. Wrap your hands in dry material if rubber gloves are not available.

If you remain un-insulated, do not touch the victim with your bare hands until the circuit is made dead or he is moved away from the equipment.

If the victim is at a height, efforts must be taken to prevent him from falling or to make him fall safe.

Electric burns on the victim may not cover a big area but may be deep seated. All you can do is to cover the area with a clean, sterile dressing and treat for shock. Get expert help as quickly as possible.

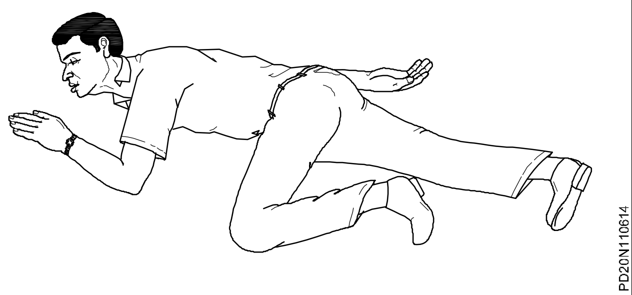
If the casualty is unconscious but is breathing, loosen the clothing about the neck, chest and waist (Fig 3) and place the casualty in the recovery position.

Fig 3

Keep a constant check on the breathing and pulse rate.

Keep the casualty warm and comfortable in the recover position. Send for help.(Fig 4)

Fig 4



Do not give an unconscious person anything to eat or drink.

Do not leave an unconscious person unattended.

If the casualty is not breathing - **Act at once to resuscitate the victim** - do not waste time.

There are four methods of artificial resuscitation is illustrated in Exercise 1.1.07 follow them.

Basic first-aid treatment

First aid is defined as the immediate care and support given to an acutely injured or ill person, primarily to save life, prevent further deterioration or injury, plan to shift the victim to safer place, provide best possible comfort and finally help them to reach the medical centre/ hospital through all available means. It is an immediate life-saving procedure using all resources available within reach.

Imparting knowledge and skill through institutional teaching at younger age group in schools, colleges, entry point at industry level is now given much importance. Inculcating such habits at early age, helps to build good healthcare habits among people.

First aid procedure often consists of simple and basic life saving techniques that an individual performs with proper training and knowledge.

The key aims of first aid can be summarized in three key points:

- **Preserve life:** If the patient was breathing, a first aider would normally then place them in the recovery position, with the patient leant over on their side, which also has the effect of clearing the tongue from the pharynx. It also avoids a common cause of death in unconscious patients, which is choking on regurgitated stomach contents.

  The airway can also become blocked through a foreign object becoming lodged in the pharynx or larynx, commonly called choking. The first aider will be taught to deal with this through a combination of 'back slaps' and 'abdominal thrusts'. Once the airway has been opened, the first aider would assess to see if the patient is breathing.

- **Prevent further harm:** Also sometimes called prevent the condition from worsening, or danger of further injury, this covers both external factors, such as moving a patient away from any cause of harm, and applying first aid techniques to prevent worsening of the condition, such as applying pressure to stop a bleed becoming dangerous.

- **Promote recovery:** First aid also involves trying to start the recovery process from the illness or injury, and in some cases might involve completing a treatment, such as in the case of applying a plaster to a small wound.

Training

Basic principles, such as knowing to use an adhesive bandage or applying direct pressure on a bleed, are often acquired passively through life experiences. However, to provide effective, life-saving first aid interventions requires instruction and practical training.

This is especially true where it relates to potentially fatal illnesses and injuries, such as those that require **Cardio Pulmonary Resuscitation (CPR)**; these procedures may be invasive, and carry a risk of further injury to the patient and the provider. As with any training, it is more useful if it occurs before an actual emergency, and in many countries, emergency ambulance dispatchers may give basic first aid instructions over the phone while the ambulance is on the way.

Training is generally provided by attending a course, typically leading to certification. Due to regular changes in procedures and protocols, based on updated clinical knowledge, and to maintain skill, attendance at regular refresher courses or re-certification is often necessary. First aid training is often available through community organization such as the Red cross and St. John ambulance.

ABC of first aid

ABC stands for **A**irway, **B**reathing and **C**irculation.

- **Airway:** Attention must first be brought to the airway to ensure it is clear. Obstruction (choking) is a life-threatening emergency.
- **Breathing:** Breathing if stops, the victim may die soon. Hence means of providing support for breathing is an important next steps. There are several methods practiced in first aid.
- **Circulation:** Blood circulation is vital to keep person alive. The first aiders now trained to go straight to chest compressions through CPR methods.

When providing first aid one needs to follow some rule. There are certain basic norms in teaching and training students in the approach and administration of first aid to sick and injured.

Not to get panic

Panic is one emotion that can make the situation more worse. People often make mistake because they get panic. Panic clouds thinking may cause mistakes. First aider need calm and collective approach. If the first aider himself is in a state of fear and panic gross mistakes may result. It's far easier to help the suffering,

When they know what they are doing, even if unprepared to encounter a situation. Emotional approach and response always lead to wrong doing and may lead one to do wrong procedures. Hence be calm and focus on the given institution. Quick and confident approach can lessen the effect of injury.

Call medical emergencies

If the situation demands, quickly call for medical assistance. Prompt approach may save the life.

Surroundings play vital role

Different surroundings require different approach. Hence first aider should study the surrounding carefully. In other words, one need to make sure that they are safe and are not in any danger as it would be of no help that the first aider himself get injured.

Do no harm

Most often over enthusiastically practiced first aid viz. administering water when the victim is unconscious, wiping clotted blood (which acts as plug to reduce bleeding), correcting fractures, mishandling injured parts etc., would leads to more complication.

Patients often die due to wrong FIRST AID methods, who may otherwise easily survive. Do not move the injured person unless the situation demands. It is best to make him lie wherever he is because if the patient has back, head or neck injury, moving him would causes more harm.

Reassurance

Reassure the victim by speaking encouragingly with him.

Stop the bleeding

If the victim is bleeding, try to stop the bleeding by applying pressure over the injured part.

Golden hours

India have best of technology made available in hospitals to treat devastating medical problem viz. head injury, multiple trauma, heart attack, strokes etc, but patients often do poorly because they don't gain access to that technology in time.

The risk of dying from these conditions, is greatest in the first 30 minutes, often instantly. This period is referred to as **Golden period**. By the time the patient reach the hospital, they would have passed that critical period. First aid care come handy to save lives.

It helps to get to the nearest emergency room as quickly as possible through safe handling and transportation. The shorter that time, the more likely the best treatment applied.

Maintain the hygiene

Most important, the first aider need to wash hands and dry before giving any first aid treatment to the patient or wear gloves in order to prevent infection.

Cleaning and dressing

Always clean the wound thoroughly before applying the bandage gently wash the wound with clean water.

Not to use local medications on cuts or open wounds

They are more irritating to tissue than it is helpful. Simple dry cleaning or with water and some kind of bandage are best.

CPR (Cardio-Pulmonary Resuscitation) can be life-sustaining

CPR can be life sustaining. If one is trained in PR and the person is suffering from choking or finds difficulty in breathing, immediately begin CPR. However, if one is not trained in CPR, do not attempt as you can cause further injury. But some people do it wrong.

This is a difficult procedure to do in a crowded area. Also there are many studies to suggest that no survival advantage when bystanders deliver breaths to victims compared to when they only do chest compressions. Second, it is very difficult to carry right maneuver in wrong places. But CPR, if carefully done by highly skilled first aiders is a bridge that keeps vital organs oxygenated until medical team arrives.

Declaring death

It is not correct to declare the victim's death at the accident site. It has to be done by qualified medical doctors.

How to report an emergency?

Reporting an emergency is one of those things that seems simple enough, until actually when put to use in emergency situations. A sense of shock prevail at the accident sites. Large crowd gather around only with inquisitive nature, but not to extend helping hands to the victims. This is common in road side injuries.

The first aiders need to adapt multi-task strategy to control the crowd around, communicate to the rescue team, call ambulance etc., all to be done simultaneously. The mobile phones helps to a greater extent for such emergencies.

Assess the urgency of the situation. Before you report an emergency, make sure the situation is genuinely urgent. Call for emergency services if you believe that a situation is life-threatening or otherwise extremely critical.

- A crime, especially one that is currently in progress. If you're reporting a crime, give a physical description of the person committing the crime.
- A fire - If you're reporting a fire, describe how the fire started and where exactly it is located. If someone has already been injured or is missing, report that as well.
- A life-threatening medical emergency, explain how the incident occurred and what symptoms the person currently displays.
- A car crash - Location, serious nature of injures, vehicle's details and registration, number of people involved etc.

Call emergency service

The emergency number varies - 100 for Police & Fire, 108 for Ambulance.

Report your location

The first thing the emergency dispatcher will ask is where you are located, so the emergency services can get there as quickly as possible. Give the exact street address, if you're not sure of the exact address, give approximate information.

Give the dispatcher your phone number

This information is also imperative for the dispatcher to have, so that he or she is able to call back if necessary.

Describe the nature of the emergency

Speak in a calm, clear voice and tell the dispatcher why you are calling. Give the most important details first, then answer the dispatcher's follow-up question as best as you can.

Do not hang up the phone until you are instructed to do so. Then follow the instructions you were given.

How to do basic first aid?

Basic first aid refers to the initial process of assessing and addressing the needs of someone who has been injured or is in physiological distress due to choking, a heart attack, allergic reactions, drugs or other medical emergencies. Basic first aid allows one to quickly determine a person's physical condition and the correct course of treatment.

Important guideline for first aiders

Evaluate the situation

Are there things that might put the first aider at risk. When faced with accidents like fire, toxic smoke, gasses, an unstable building, live electrical wires or other dangerous scenario, the first aider should be very careful not to rush into a situation, which may prove to be fatal.

Remember A-B-Cs

The ABCs of first aid refer to the three critical things the first aiders need to look for.

- **A**irway - Does the person have an unobstructed airway?
- **B**reathing - **I**s the person breathing?
- **C**irculation - Does the person show a pulse at major pulse points (wrist, carotid artery, groin)

Avoid moving the victim

Avoid moving the victim unless they are immediate danger. Moving a victim will often make injuries worse, especially in the case of spinal cord injuries.

Call emergency services

Call for help or tell someone else to call for help as soon as possible. If alone at the accident scene, try to establish breathing before calling for help, and do not leave the victim alone unattended.

Determine responsiveness

If a person is unconscious, try to rouse them by gently shaking and speaking to them.

If the person remains unresponsive, carefully roll them on the side (recovery position) and open his airway.

- Keep head and neck aligned.
- Carefully roll them onto their back while holding his head.

Fig 1

- Open the airway by lifting the chin (Fig 1).

Look, listen and feel for signs of breathing

Look for the victim's chest to raise and fall, listen for sounds of breathing.

If the victim is not breathing, see the section below

- If the victim is breathing, but unconscious, roll them onto their side, keeping the head and neck aligned with the body. This will help drain the mouth and prevent the tongue or vomit from blocking the airway.

Check the victim's circulation

Look at the victim's colour and check their pulse (the carotid artery is a good option; it is located on either side of the neck, below the jaw bone). If the victim does not have a pulse, start CPR.

Treat bleeding, shock and other problems as needed

After establishing that the victim is breathing and has a pulse, next priority should be to control any bleeding. Particularly in the case of trauma, preventing shock is the priority.

- **Stop bleeding:** Control of bleeding is one of the most important things to save a trauma victim. Use direct pressure on a wound before trying any other method of managing bleeding.
- **Treat shock:** Shock may causes loss of blood flow from the body, frequently follows physical and occasionally psychological trauma. A person in shock will frequently have ice cold skin, be agitated or have an altered mental status, and have pale colour to the skin around the face and lips. Untreated, shock can be fatal. Anyone who has suffered a severe injury or life-threatening situation is at risk for shock.
- **Choking victim:** Choking can cause death or permanent brain damage within minutes.
- **Treat a burn:** Treat first and second degree burns by immersing or flushing with cool water. Don't use creams, butter or other ointments, and do not pop blisters. Third degree burns should be covered with a damp cloth. Remove clothing and jewellery from the burn, but do not try to remove charred clothing that is stuck to burns.
- **Treat a concussion:** If the victim has suffered a blow to the head, look for signs of concussion. Common symptoms are: loss of consciousness following the injury, disorientation or memory impairment, vertigo, nausea, and lethargy.
- **Treat a spinal injury victim:** If a spinal injury is suspected, it is especially critical, not move the victim's head, neck or back unless they are in immediate danger.

Stay with the victim until help arrives

Try to be a calming presence for the victim until assistance can arrive.

Unconsciousness (COMA)

Unconscious also referred as Coma, is a serious life threatening condition, when a person lie totally senseless and do not respond to calls, external stimulus. But the basic heart, breathing, blood circulation may be still intact, or they may also be failing. If unattended it may lead to death.

The condition arises due to interruption of normal brain activity. The causes are too many.

Causes for COMA Stage

- Shock (Cardiogenic, Neurogenic)
- Head injury (Concussion, Compression)
- Asphyxia (obstruction to air passage)
- Extreme of body temperature (Heat, Cold)
- Cardiac arrest (Heart attack)
- Stroke (Cerbro-vascular accident)
- Blood loss (Haemorrhage)
- Dehydration (Diarrohea & vomiting)
- Diabetes (Low or high sugar)
- Blood pressure (Very low or very high)
- Over dose of alcohol, drugs
- Poisoning (Gas, Pesticides, Bites)
- Epileptic fits (Fits)
- Hysteria (Emotional, Psychological)

The following symptoms may occur after a person has been unconscious:

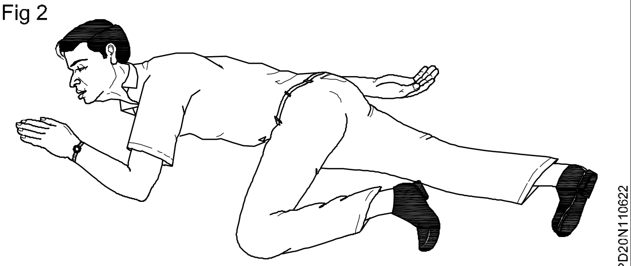
- Confusion
- Drowsiness
- Headache
- Inability to speak or move parts of his or her body (see stroke symptoms)
- Light headedness
- Loss of bowel or bladder control (incontinence)
- Rapid heartbeat (palpitation)
- Stupor

First aid

- Call EMERGENCY number.
- Check the person's airway, breathing, and pulse frequently. If necessary, begin rescue breathing and CPR.
- If the person is breathing and lying on the back and after ruling out spinal injury, carefully roll the person onto the side, preferably left side.

  Bend the top leg so both hip and knee are at right angles. Gently tilt the head back to keep the airway open (Fig 2). If breathing or pulse stops at any time, roll the person on to his back and begin CPR.

Fig 2



- If there is a spinal injury, the victims position may have to be carefully assessed. If the person vomits, roll the entire body at one time to the side. Support the neck and back to keep the head and body in the same position while you roll.
- Keep the person warm until medical help arrives.
- If you see a person fainting, try to prevent a fall. Lay the person flat on the floor and raise the level of feet above and support.
- If fainting is likely due to low blood sugar, give the person something sweet to eat or drink when they become concious**.**

DO NOT

- Do not give an unconscious person any food or drink.
- Do not leave the person alone.
- Do not place a pillow under the head of an unconscious person.
- Do not slap an unconscious person's face or splash water on the face and try to revive him.

Loss of consciousness may threaten life if the person is on his back and the tounge has dropped to the back of the throat, blocking the airway. Make certain that the person is breathing before looking for the cause of unconsciousness. If the injuries permit, place the casualty in the recovery position (Fig 2) with the neck extended. Never give any thing by mouth to an unconscious casualty.

How to diagnose an unconscious injured person

- **Consider alcohol:** look for signs of drinking, like empty bottles or the smell of alcohol.
- **Consider epilepsy:** are there signs of a violent seizure, such as saliva around the mouth or a generally dishevelled scene?
- **Think insulin:** might the person be suffering from insulin shock.
- **Think about drugs:** was there an overdose? Or might the person have under dosed - that is not taken enough of a prescribed medication?
- **Consider trauma:** is the person physically injured?
- **Look for signs of infection:** redness and/ or red streaks around a wound.
- **Look around for signs of Poison:** an empty bottle of pills or a snakebite wound.

- **Consider the possibility of psychological trauma:** might the person have a psychological disorder of some sort?
- Consider stroke, particularly for elderly people.
- Treat according to what you diagnose.

Electric Shock (Fig 3)

A severe loss of body fluid will lead to a drop in blood pressure. Eventually the blood's circulation will deteriorate and the remaining blood flow will be directed to the vital organs such as the brain. Blood will therefore be directed away from the outer area of the body, so the victim will appear pale and the skin will feel ice cold.

As blood flow slows, so does the amount of oxygen reaching the brain. The victim may appear to be confused, weak, and dizzy and may eventually deteriorate into unconsciousness. Try to compensate for this lack of oxygen, the heart and breathing rates both speed up, gradually becoming weaker, and may eventually cease.

Potential causes of shock include: sever internal or

Fig 3

external bleeding; burns; severe vomiting and diarrohea, especially in children and the elderly; problems with the heart.

Symptoms of shock

Victims appear pale, ice cold, pulse appear initially faster and gets slower, breathing becomes shallow. Weakness, dizziness, confusion continue. If unattended the patient may become unconscious and die.

First aid

Keep the patient warm and at mental rest. Assure of good air circulation and comfort. Call for help to shift the patient to safer place/ hospital.

- **Warmth:** Keep the victim warm but do not allow them to get overheated. If you are outside, try to get something underneath her if you can do easily. Wrap blankets and coats around her, paying particular attention to the head, through which much body heat is lost.
- **Air:** Maintain careful eye on the victim's airway and be prepared to turn them into the recovery position if necessary, or even to resuscitate if breathing stops. Try to keep back bystanders and loosen tight clothing to allow maximum air to victim.
- **Rest:** Keep the victim still and preferably sitting or lying down. If the victim is very giddy, lay them down with there legs raised to ensure that maximum blood and therefore maximum oxygen is sent to the brain.

Treatment of electric shock

Prompt treatment is essential.

If assistance is close at hand, send for medical aid, then carry on with emergency treatment.

If you are alone, proceed with treatment at once.

Switch off the supply, if this can be done without undue delay. Otherwise, remove the victim from contact with the live conductor, using dry non-conducting materials such as a wooden bar, rope, a scarf, the victim's coat-tails, any dry article of clothing, a belt, rolled-up newspaper, non-metallic hose, PVC tubing, bakelised paper, tube

Fig 1

etc. (Fig 4)

Avoid direct contact with the victim. Wrap your hands in dry material if rubber gloves are not available.

Electrical burns: A person receiving an electric shock may also sustain burns when the current passes through his body. Do not waste time by applying first aid to the burns until breathing has been restored and the patient can breathe normally - unaided.

Burns and scalds: Burns are very painful. If a large area of the body is burnt, give no treatment, except to exclude the air, eg.by covering with water, clean paper, or a clean shirt. This relieves the pain.

Artificial respiration methods to the electric shock victim

Artificical respiration methods already dealt in practical exercise 1.1.07 in detail. Refer practical book.

Personal Protective Equipment (PPE)

Objectives: At the end of this lesson you shall be able to
- **state about Personal Protective Equipment (PPE) and its purpose**
- **explain the occupational health safety, hygien**
- **explain occupational hazards**
- **list the most common type of personal protective equipment for hazards**

Personal Protective Equipment (PPE)

The Devices, equipment, or clothing used or worn by the employees, as a last resort, to protect against hazards in the workplace. The primary approach in any safety effort is that the hazard to the workmen should be eliminated or controlled by engineering methods rather than protecting the workmen through the use of personal protective equipment (PPE).

Engineering methods could include design change, substitution, ventilation, mechanical handling, automation, etc. In situations where it is not possible to introduce any effective engineering methods for controlling hazards, the workman shall use appropriate types of PPE.

The Factories Act, 1948 and several other labour legislations 1996 have provisions for effective use of appropriate types of PPE. Use of PPE is an important.

Ways to ensure workplace safety and use personal protective equipment (PPE) effectively.

- Workers to get up-to-date safety information from the regulatory agencies that oversees workplace safety in their specific area.
- To use all available text resources that may be in work area and for applicable safety information on how to use PPE best.
- When it comes to the most common types of personal protective equipment, like goggles, gloves or bodysuits, these items are much less effective if they are not worn at all times, or whenever a specific danger exists in a work process. Using PPE consistently will help to avoid some common kinds of industrial accidents.
- Personal protective equipment is not always enough to protect workers against workplace dangers. Knowing more about the overall context of your work activity can help to fully protect from anything that might threaten health and safety on the job.
- Inspection of gear thoroughly to make sure that it has the standard of quality and adequately protect the user should be continuously carried out.

Categories of PPEs

Depending upon the nature of hazard, the PPE is broadly divided into the following two categories:

1 **Non-respiratory:** Those used for protection against injury from outside the body, i.e. for protecting the head, eye, face, hand, arm, foot, leg and other body parts

2 **Respiratory:** Those used for protection from harm due to inhalation of contaminated air.

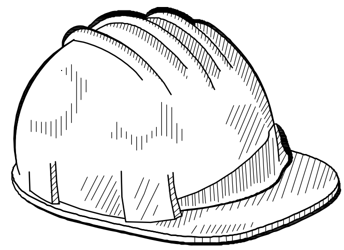
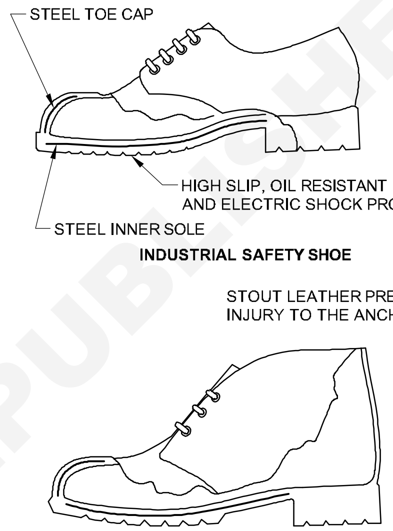
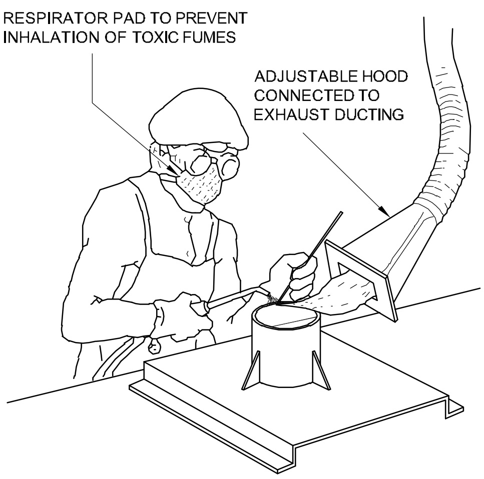
The guidelines on 'Personal Protective Equipment' is issued to facilitate the plant management in maintaining an effective programme with respect to protection of persons against hazards, which cannot be eliminated or controlled by engineering methods listed in table1.

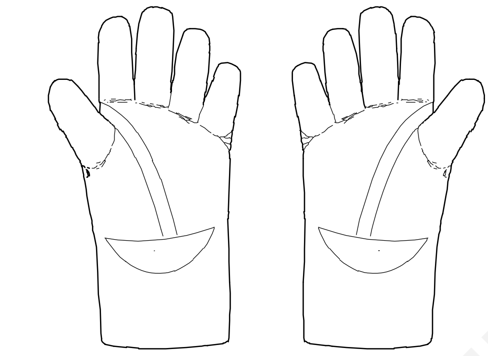
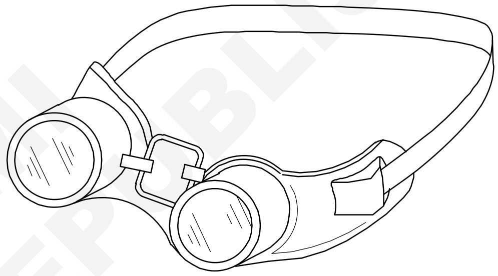
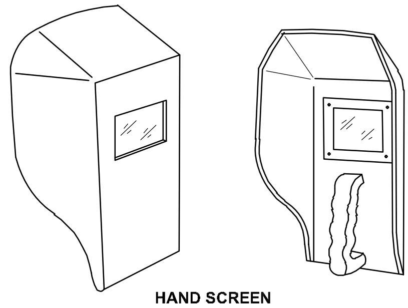
Table1

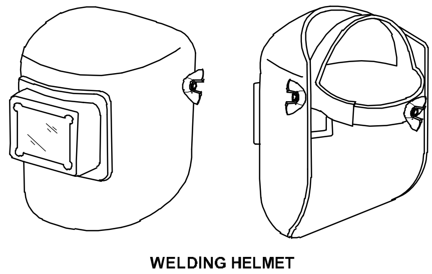
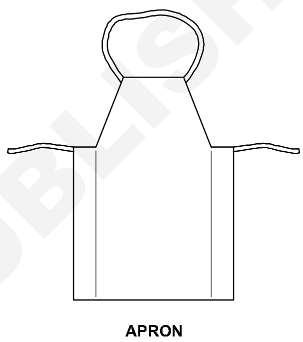
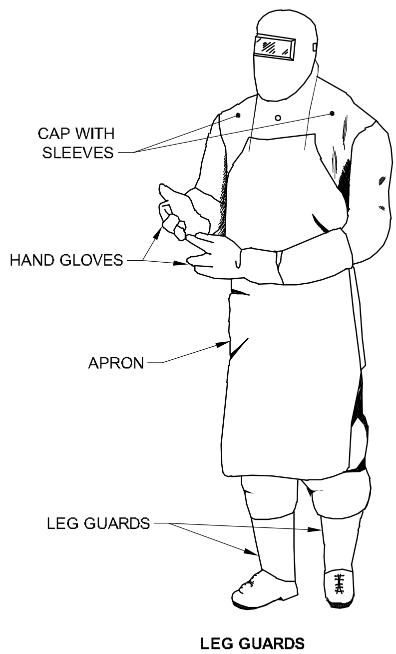
No.	Title
PPE1	Helmet
PPE2	Safety footwear
PPE3	Respiratory protective equipment
PPE4	Arms and hands protection
PPE5	Eyes and face protection
PPE6	Protective clothing and coverall
PPE7	Ears protection
PPE8	Safety belt and harnesses

Quality of PPE's

Personal protective equipments and their uses and hazards are as follows

Types of protection	Hazards	PPE to be used
Head Protection (Fig 1)	1. Falling objects 2. Striking against objects 3. Spatter	Fig 1  HELMET PD20N110911
Foot protection (Fig 2)	1. Hot spatter 2. Falling objects 3. Working wet area	Fig 2  PD20N110912 **and leather leg guards**
Nose	1. Dust particles	**Nose Mask**
(Fig 3)	2. Fumes/ gases/ vapours	Fig 3  PD20N110913
Hand protecion	1. Heat burn due to direct	

Types of protection	Hazards	PPE to be used
(Fig 4)	contact 2. Blows sparks moderate heat 3. Electric shock	**Hand Gloves** Fig 4 
Eye protection (Fig 5, Fig 6)	1. Flying dust particles 2. UV rays, IR rays heat and High amount of visible radiation	**Googgles** Fig 5  **and** **Face Shield** **Head Shield** **Hand Shield**
Face Protection (Fig 6, Fig 7) Ear protection	1. Spark generated during Welding, grinding 2. Welding spatter striking 3. Face protection from UV rays 1. High noise level	Fig 6  **and** **Face Shield** **Head Shield with or without Ear Muff** **Helmets with screen for welders**

Types of protection	Hazards	PPE to be used
(Fig 7)		Fig 7  **Head shield with Ear muff** **and** **Ear plug** **Ear Muff**
Body protection (Fig 8, Fig 9)	1. Hot particles	Fig 8  Fig 9  **Body Guard**

PPE must meet the following criteria with regard to its quality-provide absolute and full protection against possible hazard and PPE's be so designed and manufactured out of materials that it can withstand the hazards against which it is intended to be used.

Selection of PPE's requires certain conditions

- Nature and severity of the hazard
- Type of contaminant, its concentration and location of contaminated area with respect to the source of respirable air
- Expected activity of workman and duration of work, comfort of workman when using PPE
- Operating characteristics and limitations of PPE
- Easy of maintenance and cleaning
- Conformity to Indian/ International standards and availability of test certificate.

Proper use of PPEs

Having selected the proper type of PPE, it is essential that the workman wears it. Often the workman avoids using PPE. The following factors influence the solution to this problem.

- The extent to which the workman understands the necessity of using PPE
- The ease and comfort with which PPE can be worn with least interference in normal work procedures
- The available economic, social and disciplinary sanctions which can be used to influence the attitude of the workman
- The best solution to this problem is to make 'wearing of PPE' mandatory for every employee.
- In other places, education and supervision need to be intensified. When a group of workmen are issued PPE for the first time.

Occupational health hazard and safety

Safety

Safety means freedom or protection from harm, danger, hazard, risk, accident, injury or damage.

Occupational health and safety

- Occupational health and safety is concerned with protecting the safety, health and welfare of people engaged in work or employment.
- The goal is to provide a safe work environment and to prevent hazards.
- It may also protect co-workers, family members, employers, customers, suppliers, nearby communities, and other members of the public who are affected by the workplace environment.
- It involves interactions among many related areas, including occupational medicine, occupational (or industrial) hygiene, public health, and safety engineering, chemistry, and health physics.

Need of occupational health and safety

- Health and safety of the employees is an important aspect of a company's smooth and successful functioning.
- It is a decisive factor in organizational effectiveness. It ensures an accident-free industrial environment.
- Proper attention to the safety and welfare of the employees can yield valuable returns.
- Improving employee morale
- Reducing absenteeism
- Enhancing productivity
- Minimizing potential of work-related injuries and illnesses
- Increasing the quality of manufactured products and/ or rendered services.

Occupational (Industrial) hygiene

- Occupational hygiene is anticipation, recognition, evaluation and control of work place hazards (or) environmental factors (or) stresses
- This is arising in (or) from the workplace.
- Which may cause sickness, impaired health and well being (or) significant discomfort and inefficiency among workers.

Anticipation (Identification): Methods of identification of possible hazards and their effects on health

Recognition (Acceptance): Acceptance of ill-effects of the identified hazards

Evaluation (Measurement & Assessment): Measuring or calculating the hazard by Instruments, Air sampling and Analysis, comparison with standards and taking judgement whether measured or calculated hazard is more or less than the permissible standard.

Control of workplace hazards: Measures like Engineering and Administrative controls, medical examination, use of Personal Protective Equipment (PPE), education, training and supervision

Occupational hazards

"Source or situation with a potential for harm in terms of injury or ill health, damage to property, damage to the workplace environment, or a combination of these".

Types of occupational health hazards

- Physical Hazards
- Chemical Hazards
- Biological Hazards
- Physiological Hazards
- Mechanical Hazards
- Electrical Hazards

- Ergonomic Hazards.

1 **Physical hazards**
- Noise
- Heat and cold stress
- Vibration
- Radiation (ionising & Non-ionising)
- Illumination etc.,

2 **Chemical hazards**
- Inflammable
- Explosive
- Toxic
- Corrosive
- Radioactive

3 **Biological hazards**
- Bacteria
- Virus
- Fungi
- Plant pest
- Infection.

4 **Physiological**
- Old age
- Sex
- Ill health
- Sickness
- Fatigue.

5 **Psychological**
- Wrong attitude
- Smoking
- Alcoholism
- Unskilled
- Poor discipline
  - absentism
  - disobedience
  - aggressive behaviours
- Accident proneness etc,
- Emotional disturbances
  - voilence
  - bullying
  - sexual harassment

6 **Mechanical**
- Unguarded machinery
- No fencing
- No safety device
- No control device etc.,

7 **Electrical**
- No earthing
- Short circuit
- Current leakage
- Open wire
- No fuse or cut off device etc,

8 **Ergonomic**
- Poor manual handling technique
- Wrong layout of machinery
- Wrong design
- Poor housekeeping
- Wrong tools etc,

Safety Slogan
A Safety rule breaker, is an accident maker

Trade hand tools - specification - standards - NEC code 2011

Objectives: At the end of this lesson you shall be able to
- **list the tools necessary for an electrician**
- **specify the tools and state the use of each tool**
- **explain the care and maintenance of electrician hand tools.**

It is important that the electrician uses proper tools for his work. The accuracy of workmanship and speed of work depend upon the use of correct tools. If the tools are properly used, and maintained, the electrician will find the working efficiency increases and the skills becomes a work habit.

Listed below are the most commonly used tools by electrician.

Their specifications and BIS number are given for your reference. Proper method of care and maintenance will result in prolonged tool life and improved working efficiency.

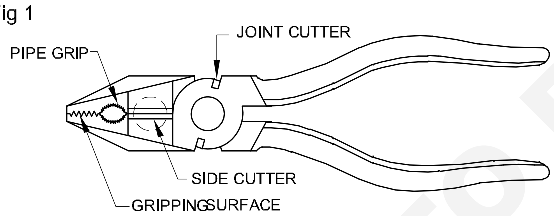
Pliers

They are specified with their overall dimensions of length in mm. The pliers used for electrical work will be of insulated grip.

1 **Combination pliers with pipe grip, side cutter and insulated handle**. BIS 3650 (Fig 1)

Size 150 mm, 200 mm etc.

Fig 1



COMBINATION SIDE CUTTING PLIERS
(ENGINEER'S PLIERS, COMBINATION PLIERS)

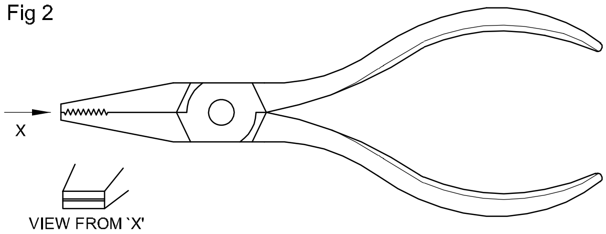
PD20N111111

It is made of forged steel. It is used for cutting, twisting, pulling, holding and gripping small jobs in wiring assembly and repairing work. A non-insulated type is also available. Insulated pliers are used for work on live lines.

2 **Flat nose pliers** BIS 3552 (Fig 2)

Size 100 mm, 150 mm, 200 mm etc.

Fig 2



FLAT NOSE PLIERS

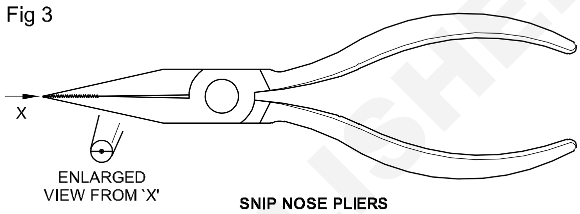
PD20N111112

Flat nose pliers are used for holding flat objects like thin plates etc.

3 **Long nose pliers** or (snip nose pliers) with side cutter. BIS 5658 (Fig 3)

Size 100 mm, 150 mm etc.

Fig 3



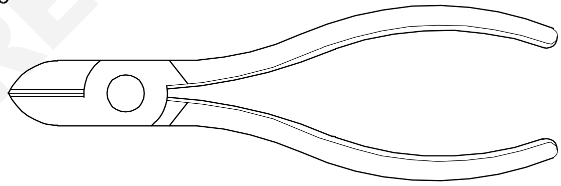
SNIP NOSE PLIERS

PD20N111113

Long nose pliers are used for holding small objects in places where fingers cannot reach.

4 **Side cutting pliers** (Diagonal cutting pliers) BIS 4378 (Fig 4) Size 100 mm, 150 mm etc.

Fig 4



DIAGONAL CUTTING PLIERS/NIPPER

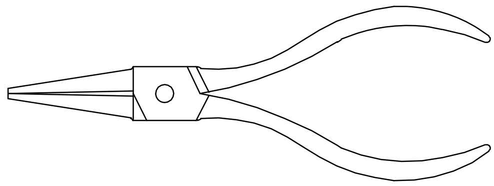
PD20N111114

It is used for cutting copper and aluminium wires of smaller diameter (less than 4mm dia).

5 **Round nose pliers** BIS 3568 (Fig 5)

Size 100 mm, 150 mm etc.

Fig 5



ROUND NOSE PLIERS

PD20N111115

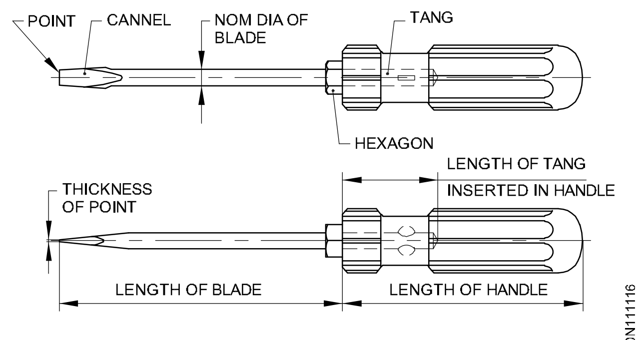
Wire hooks and loops could be made using the round nose pliers.

Care and maintenance of pliers

- Do not use pliers as hammers.
- Do not use pliers to cut large sized copper or aluminium wires and hard steel wires of any size.
- While using the pliers avoid damages to the insulation of hand grips.
- Lubricate hinged portions.

6 **Screwdriver BIS 844** (Fig 6)

Fig 6



NOMENCLATURE FOR SCREWDRIVERS

The screwdrivers used for electrical works generally have plastic handles and the stem is covered with insulating sleeves. The size of the screw driver is specified by its blade length in mm and nominal screwdriver's point size (thickness of tip of blade) and by the diameter of the stem.

eg. 75 mm x 0.4 mm x 2.5 mm

150 mm x 0.6 mm x 4 mm

200 mm x 0.8 mm x 5.5 mm etc.

The handle of screwdrivers is either made of wood or cellulose acetate.

Screwdrivers are used for tightening or loosening screws. The screwdriver tip should correctly fit the grooves of the screw to have maximum efficiency and to avoid damage to the screw heads.

As the length of the screw driver is proportional to the turning force, for small work choose a suitable small sized screwdriver and vice versa.

Star-head Screwdriver

It is used for driving star headed screws.

Care and maintenance

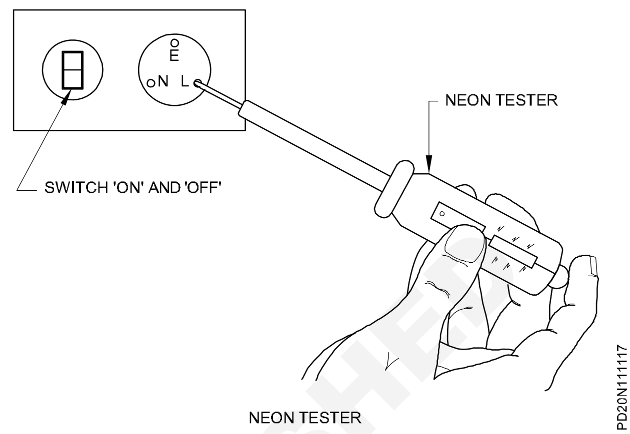
- Never use a screwdriver as a lever to apply force as this action will make the stem to bend and the use of the screw driver will be lost.
- Keep the tip in correct shape and in rare cases it could be grinded to shape.

7 **Neon tester** BIS 5579 - 1985 (Fig 7)

It is specified with its working voltage range 100 to 250 volts but rated to 500 V.

It consists of a glass tube filled with neon gas, and electrodes at the ends. To limit the current within 300 micro-amps at the maximum voltage, a high value resistance is connected in series with one of the electrodes. It may have a tip like a probe or screwdriver at one end. The presence of supply is indicated by the glow of the lamp when the tip is touched on the live supply and the brass contact in the other end of neon tester is touched by hand.

Fig 7



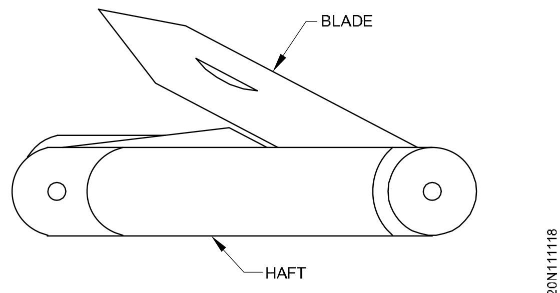
NEON TESTER

Care and maintenance

- Never use the neon tester for voltage higher than the specified range.
- While testing see the circuit is completed through the body. In case if you are using rubber soled shoes, the earthing of the body could be provided by touching the wall by one hand.
- Use the screwdriver tipped neon tester for light duty work only.

8 **Electrician's knife** (Double blade) (Fig 8)

Fig 8



ELECTRICIAN'S KNIFE

The size of the knife is specified by its largest blade length eg. 50 mm, 75 mm.

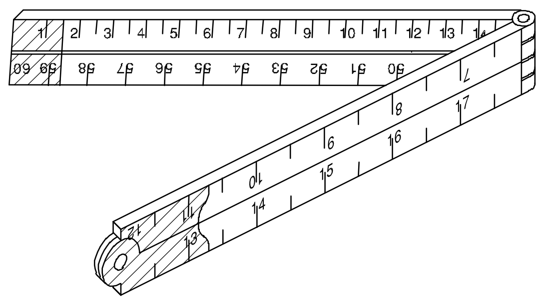
It is used for skinning the insulation of cables and cleaning the wire surface. One of the blades which is sharp is used for skinning the cable and the rough edged blade is used for cleaning the surface of the wires.

Care and maintenance

- Do not use the knife for cutting wires.
- Keep it free from rust.
- Keep one of the blades in a sharp condition.
- Fold the knife blade when not in use.

9 **Four-fold box wood rule 600mm** (Fig 9)

Fig 9

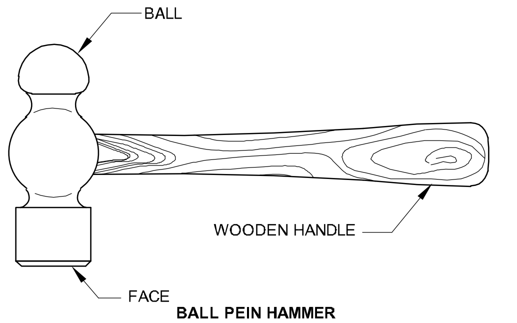


FOUR-FOLD BOX WOOD RULE

Used for measuring short lengths. To be kept in folded condition when not in use.

10 **Hammer ball pein** (Fig 10)

Fig 10



BALL PEIN HAMMER

The size of the hammer is expressed in weight of the metal head. Eg.125 gms, 250 gms etc.

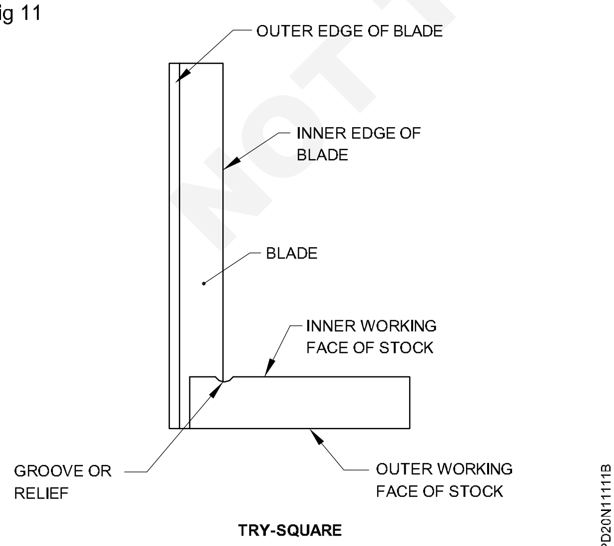
The hammer is made out of special steel and the striking face is tempered. Used for nailing, straightening, and bending work. The handle is made of hard wood.

Care and maintenance

- Do not use a hammer with a loose handle.
- The face of the hammer must be free from oil, grease and mushrooms.

11 **Try-square** (Engineer's square) (Fig 11) BIS 2103

Fig 11



TRY-SQUARE

This is specified by its blade length.

Eg. 50 mm x 35 mm

100 mm x 70 mm

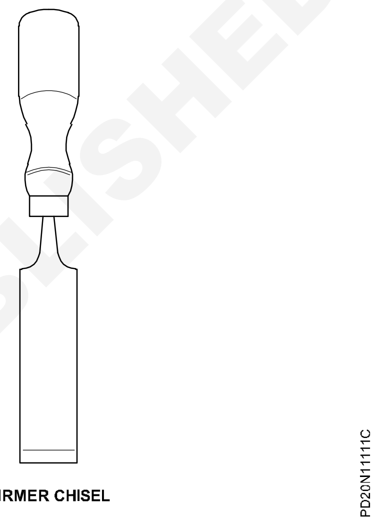
150 mm x 100 mm etc.

There are two types; one is the bevelled edge with stock and the other is the flat edge without stock. It is used to check whether the object is plane, perpendicular and at right angle. Two straight blades set at right angles to each other constitute the try-square. The steel blade is riveted to the stock. The stock is made of cast iron. The stock should be set against the edge of the job.

Do not use it as a hammer.

12 **Firmer chisel** (Fig 12)

Fig 12



FIRMER CHISEL

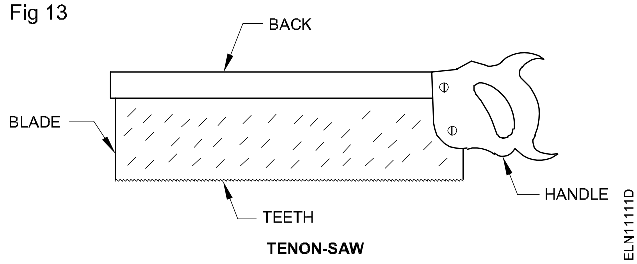
It has a wooden handle and a cast steel blade of 150 mm length. Its size is measured according to the width of the blade eg. 6 mm, 12 mm, 18 mm, 25 mm. It is used for chipping, scraping and grooving in wood.

Care and maintenance

- Do not use it for driving screws.
- Use mallet for chiseling.
- Grind on a water stone and sharpen on an oilstone.
- Do not use it in places where nails are driven.

13 **Tenon-saw** (Fig 13) BIS 5123, BIS 5130, BIS 5031

Fig 13



TENON-SAW

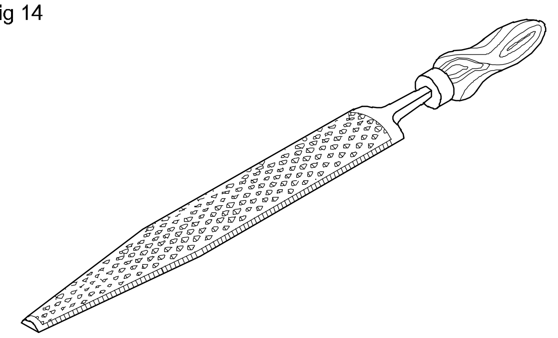
Generally the length of a tenon-saw will be 250 or 300 mm. and has 8 to 12 teeth per 25.4 mm and the blade width is 10 cm. It is used for cutting thin, wooden accessories like wooden batten, casing capping, boards and round blocks.

Care and maintenance

- Keep free from rust.
- Apply grease when not in use.

14 **Wood rasp file** (Fig 14) BIS 1931

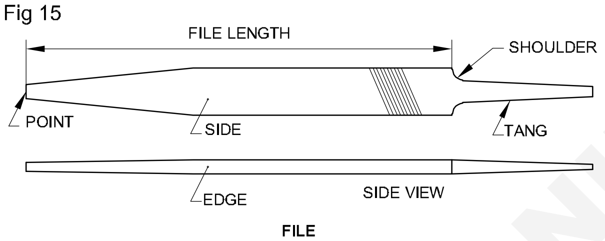
Fig 14



It is used for filing wooden articles where finish is not important. Wood rasp files are of half round shape. They have sharp coarse single cut teeth.

15 **Files** (Fig 15) BIS 1931

Fig 15



These are specified by their nominal length.

Eg.150 mm, 200 mm, 250 mm 300 mm etc.

These files have different numbers of teeth designed to cut only in the forward stroke. They are available in different lengths and sections (Eg.flat, half round, round, square, triangular), grades like rough, bastard second cut and smooth and cuts like single and double cut.

These files are used to remove fine chips of material from metals. The body of the file is made of cast steel and hardened except the tang.

Care and maintenance

- Never use the file as a hammer.
- Do not use the file without the handle.
- Do not throw a file since the teeth get damaged.

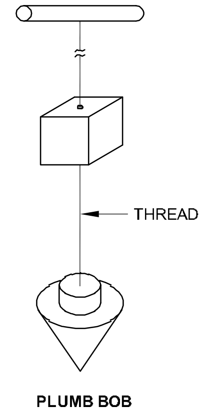
16 **Plumb bob** (Fig 16)

It has a pointed tip with a centre hole at the top for attaching a string as shown in Fig 16. It is used for marking vertical lines on the wall.

Care and maintenance

Do not drop to the ground.

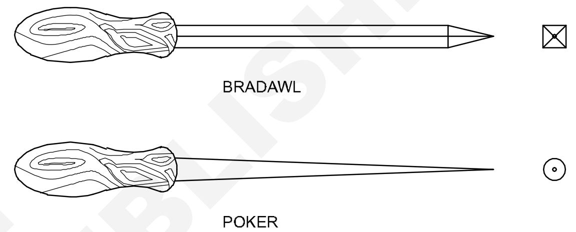
Fig 16



17 **Bradawl square pointed (or poker) (**Fig 17)

BIS 10375 - 1982

Fig 17



It is specified by its length and diameter eg. 150 mm x 6 mm.

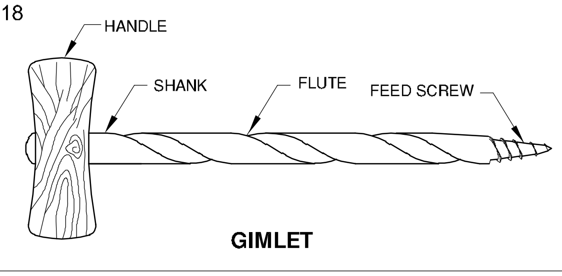
It is a long sharp tool used for making pilot holes on wooden articles to fix screws.

Care and maintenance

- Do not use it on metals for making holes.
- Keep it in good sharpened condition.

18 **Gimlet** (Fig 18)

Fig 18



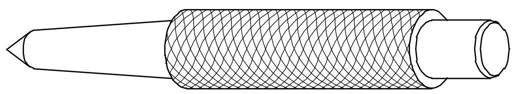
It is used for boring small holes on wooden articles. It has a wooden handle and a boring screwed edge. The size of it depends upon its diameter. Eg. 3 mm, 4 mm, 5 mm, 6 mm.

Care and maintenance

- Do not use it without the handle.
- Do not use it on nails.
- Keep it straight while making holes, otherwise the screwed portion can get damaged.

19 **Centre punch** (Fig 19) BIS 7177

Fig 19



CENTRE PUNCH

PD20N1111J

The size is given by its length and diameter of the body.

Eg. 100 mm x 8 mm. The angle of the tip of the centre punch is 90°.

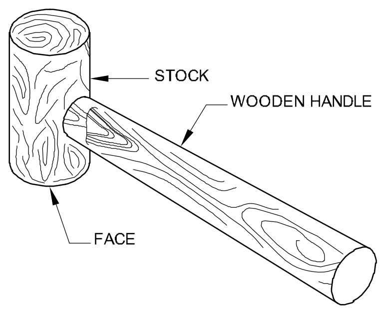
It is used for marking and punching pilot holes on metals. It is made of tool steel and the ends are hardened and tempered.

Care and maintenance

- Keep the tip sharp and at a proper angle.
- Avoid mushroom heads.

20 **Mallet** (Fig 20)

Fig 20



MALLET

PD20N1111K

The mallet is specified by the diameter of the head or by the weight.

eg. 50 mm x 150 mm

75 mm x 150 mm or 500gms, 1 Kg.

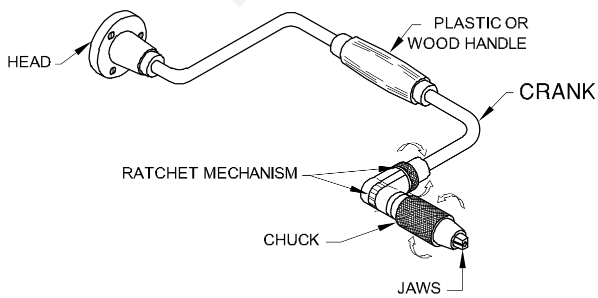
It is made out of hard wood or nylon. It is used for driving the firmer chisel, and for straightening and bending of thin metallic sheets. Also it is used in motor assembly work.

Care and maintenance

- Do not use it for fixing nails.
- Never use it on hard metal like steel and iron.

21 **Ratchet brace** (Fig 21) BIS 7042

Fig 21



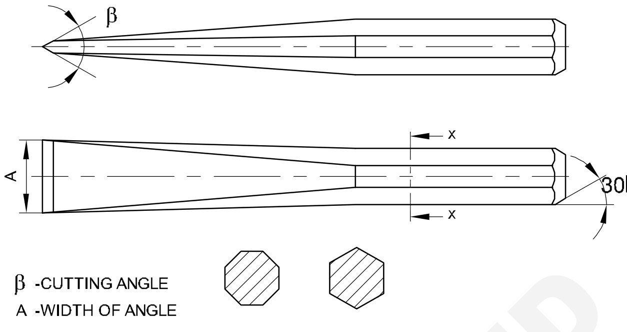
RATCHET BRACE

PD20N1111L

The size of a ratchet brace is given by the size of drill bit it can accommodate ie. 0 - 6 mm, 0 - 12 mm. It is used to drill holes on wooden blocks.

22 **Flat cold chisel** (Fig 22) BIS 402

Fig 22



COLD CHISEL

PD20N1111M

Its size is given by the nominal width and length.

ie. 14 mm x 100 mm

15 mm x 150 mm

20 mm x 150 mm

The body shape of a cold chisel may be round or hexagon.

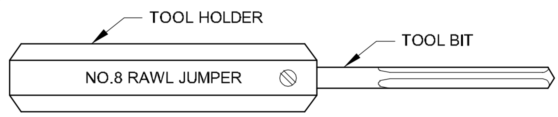
The cold chisel is made out of high carbon steel. Its cutting edge angle varies from 35° to 45°. The cutting edge of the chisel is hardened and tempered. This chisel is used for making holes on wall etc.

Care and maintenance

- The edge of a chisel must be maintained as per the required angle.
- While grinding a chisel apply a coolant frequently so that its temper may not be lost.

23 **Rawl plug tool and bit** (Fig 23)

Fig 23



RAWL PLUG TOOL

PD20N1111M

Its size depends upon the number. As the number increases, the thickness of the bit as well as the plug also increases. Eg. Nos.8, 10, 12, 14 etc.

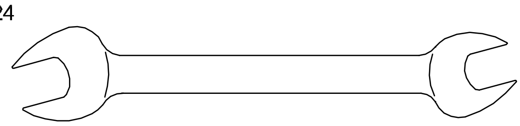
A rawl plug tool has two parts, namely the tool bit and tool holder. The tool bit is made of tool steel and the holder is made of mild steel. It is used for making holes in bricks, concrete wall and ceiling. Rawl plugs are inserted in them to fix accessories.

Care and maintenance

- Slightly rotate the holder after each hammering stroke.
- Hold the tool straight.
- Do not throw it on the ground.
- Keep its head free from mushrooms.

24 **Spanner: double ended** (Fig 24) BIS 2028

Fig 24



DOUBLE ENDED OPEN JAW SPANNER

The size of a spanner is indicated so as to fit on the nuts. They are available in many sizes and shapes.

The sizes, indicated in double-ended spanners are

10-11 mm

12-13 mm

14-15 mm

16-17 mm

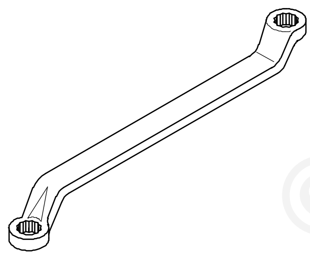
18-19 mm

20-22 mm.

For loosening and tightening of nuts and bolts, spanner sets are used. It is made out of cast steel. They are available in many sizes and may have single or double ends.

25 **Ring spanner set** (Fig 25) BIS 2029

Fig 25

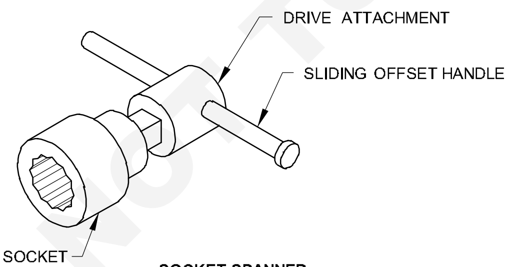


RING SPANNER

The ring spanner is used in places where the space is restricted and where high leverage is required.

26 **Socket (box) spanner** (Fig 26) BIS 7993, 7991, 6129

Fig 26



SOCKET SPANNER

These spanners are useful at places where the nut or bolt is located in narrow space or at depth.

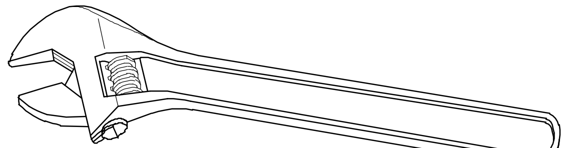
27 **Single ended open jaw adjustable spanner** (Fig 27) BIS 6149

It saves time and working. The movable jaw is made adjustable by operating a screw. It is known as a monkey wrench also. Available in 150,200,250mm etc.

Care and maintenance

- Use correct size spanner suitable to the size of nut and bolt.
- Do not use a spanner as a hammer.
- While using a spanner do not strike it with a hammer.
- Prevent the grease and oil traces on its jaws.

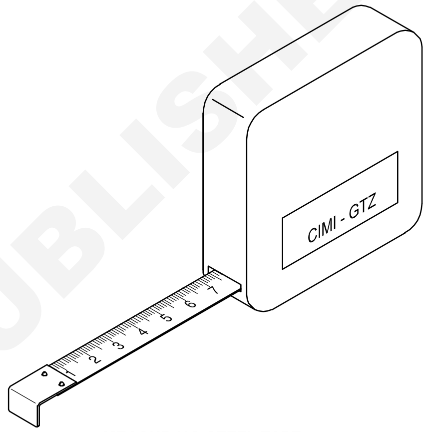
Fig 27



ADJUSTABLE SPANNER

28 **Measuring steel tape** (Fig 28)

Fig 28



MEASURING STEEL TAPE

The size will be the maximum length it can measure. Eg.Blade 12 mm wide 2 metres long.

The measuring tape is made of thin steel blade, bearing dimensions on it.

It is used for measuring the dimension of the wiring installation and general measurements.

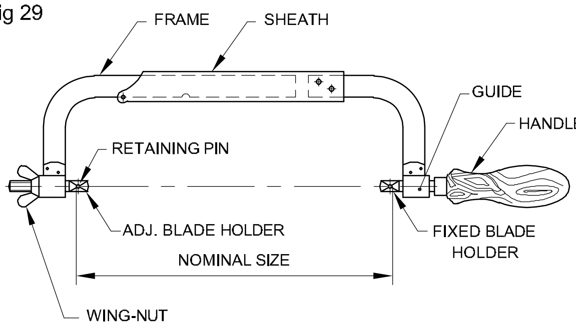
Care and maintenance

Handle with great care as carelessness may spoil the graduation.

29 **Hacksaw** (Fig 29) BIS 5169-1986 for frames

BIS 2594 - 1977 for blades

Fig 29



NOMENCLATURE FOR HACKSAW FRAME

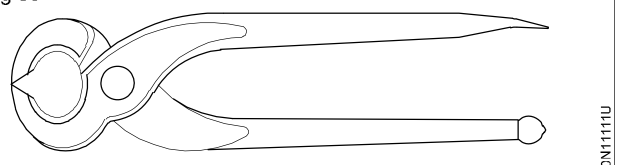
It is made out of sturdy nickel plated steel frame. The frame can be adjusted for 250 mm to 300 mm blades. It should be fixed on the frame with its teeth pointing away from the handle in order to do the cutting in forward stroke. It is mainly used for cutting metals.

Care and maintenance

- The blade should be properly tightened.
- Use a coolant while cutting.
- It should be straight during cutting.
- Lift the saw slightly on the return stroke.
- Do not attempt to saw too fast.

30 **Pincers** (Fig 30) BIS 4195

Fig 30

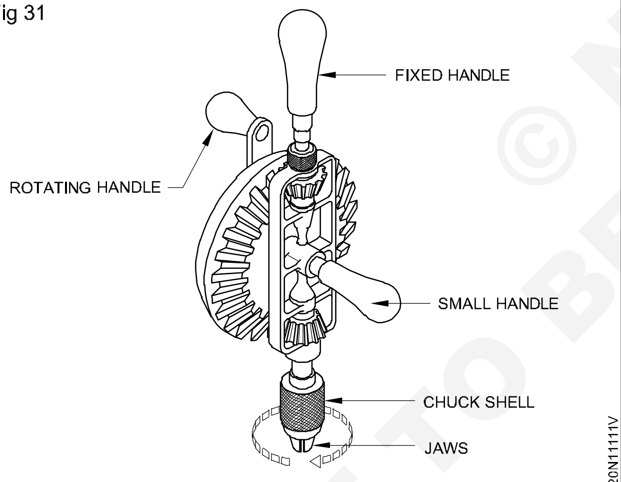


PINCERS

The size is given by its length. Eg. 100 mm, 150 mm, 200 mm.

It is used for extracting nails from the wood.

Fig 31



HAND DRILL

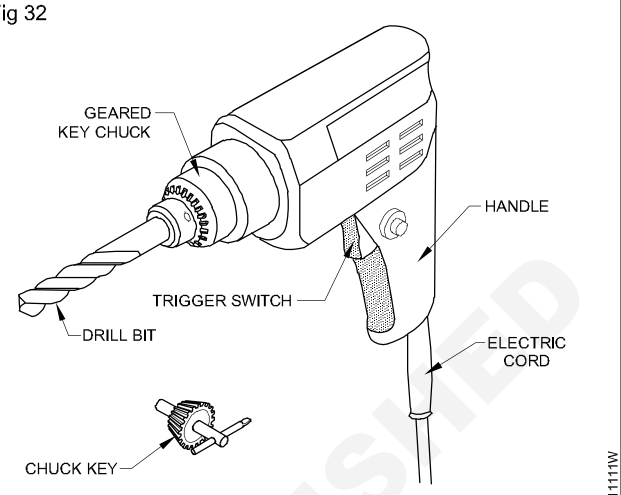
Care and maintenance

- Do not use it as a hammer.

31 **Hand drill** (Fig 31)

The size is given by the twist drill bits which can be fitted in. Eg. 6 mm, 0-12 mm capacity.

Fig 32



ELECTRIC DRILLING MACHINE

A hand drill machine is used for making holes in thin metal sheets or wooden articles.

32 **Portable Electric drilling machine** (Fig 32)

When power is available, a power drilling machine is a more convenient and accurate tool for drilling holes on wooden and metal articles.

Care and maintenance

- Lubricate all the moving parts of the machine.
- Fix the drill bit firmly in the jaws.
- Before drilling, mark the job with a centre punch.
- For taking out the drill bit move the chuck in the reverse direction.
- Do not apply excess pressure on small bits.
- In the case of an electric drilling machine it must be properly earthed and the insulation should be sound.

Standard and standardisation

Objectives: At the end of this lesson you shall be able to
- **state what is meant by standardisation and standard**
- **state the names of various standard organisetion**
- **read and interpret the basic concept of electrical code 2011**
- **state the types of injury caused by the improper lifting method**
- **describe the procedure to be followed for moving heavy equipments**

Standardization can be defined as the process of formulating and applying rules for an orderly approach to specific activity for the benefit of the user and the manufacturer, and in particular for the promotion of optimum overall economy taking due account of functional conditions and safety requirement.

It is based on the consolidated results of science, technique and experience. It determines not only the basis for the present but also for future development, and to keep pace with progress.

The materials/tools/equipment produced in any country should be of certain standard. To meet this requirement, the international organisation for standarization(ISO) is started and specifies the units of measurement, technology and symbols, products and processes, safety of persons and goods through a number of booklets coded with ISO number.

Standard can be defined as a formulation established verbally, in writing or by any other graphical method or by means of a model, sample or other physical means of representation to serve during a certain period of time for defining designating or specifying certain features of a unit or basis of measurement, physical object, an action, process, method, practice, capacity, function, duty, right of responsibility, a behaviour, an attitude a concept or a conception.

To sell Indian goods in the local and international market certain standardization methods are essential. The standard is specified by the **B**ureau of **I**ndian **S**tandard **BIS**(ISI) for various goods through their booklets. The BIS only certifies a good often the product meets the specification and passes necessary tests. The manufacturer allows to use the BIS(ISI) mark on the product only after BIS certification.

These are a number of organisation for standardisation throughout the world in different countries.

The standard organisation and the respective countries are given below:

BIS - Bureau of Indian Standard (ISI) - India

ISO - International standard Organisation

JIS - Japanese Industrial Standard - Japan

BSI - British Standards Institution BS(S) - Britain

DIN - Deutche Industrie Normen - Germany

GOST - Russian

ASA - American standards association - America

Advantages of BIS(ISI) certification marks scheme:

A number of advantages accrue to different sectors of economy from the BIS(ISI) certification marks scheme.

To manufacturers

- Streamlining of production processes and introduction of quality control system.
- Independent audit of quality control system by BIS
- Reaping of production economics accruing from standardization
- Better image of products in the market, both internal and overseas
- Winning for whole-salers, retailers and stockists consumer confidence and goodwill
- Preference for ISI-marked products by organised purchasers, agencies of Central and State Governments, local bodies, public and private sector undertakings etc. Some organised purchasers offer even higher price for ISI-marked goods.
- Financial incentives offered by the Industrial Development Bank of India (IDBI) and nationalised banks.

To consumers

- Conformity with Indian Standards by an independent technical, National Organisation
- Help in choosing a standard product
- Free replacement of ISI-marked products in case of their being found to be of substandard quality
- Protection from exploitation and deception
- Assurance of safety against hazards to life and property

To organised purchasers

- Convenient basis for concluding contracts
- Elimination of the need for inspection and testing of goods purchased, saving time, labour and money
- Free replacement of products with ISI-mark, found to be sub-standard

To exporters

- Exemption from pre-shipment inspection, wherever admissible
- Convenient basis for concluding export contracts

To export inspection authorities

- Elimination of the need for exhaustive inspection of consignments exported from the country, saving expenditure, time and labour.

Introduction to National Electrical Code - 2011

National Electrical Code - 2011

National electrical code describes several indian standards deciding with the various aspects relating to electrical installation practice. It is there fore recommended that individual parts/ sections of the code should be read in conjunction with the relevant indian standards.

There are 8 parts and each part contains number of sections. Each section refers the description of the electrical item/ devices, equipment etc.

Here, 20 sections of the part - 1 are described which aspect it covers

In part 1, 20 sections are there. Each sections reference is given below.

Section 1 part 1/ section 1 of the code describes the scope of the NEC.

Section 2 covers definition of items with references.

Section 3 covers graphical symbols for diagrams, letter symbols and signs which may be referred for further details.

Section 4 covers of guidelines for preparation of diagrams, chart and tables in electro technology and for marking of conductors.

Section 5 covers units and systems of measurement in electro technology.

Section 6 covers standard values of AC and DC distribution voltage preferres values of current ratings and standard systems frequency.

Section 7 enumerates the fundamental principles of design and execution of electrical installation.

Section 8 covers guidelines for assesing the characteristics of buildings and the electrical installation there in.

Section 9 Covers the essential design and constructional requirement for electrical wiring installation.

Section 10 covers guidelines and general requirements associated with circuit calculators.

Section 11 covers requirements of installation work relating to building services that use electrical power.

Section 12 covers general criteria for selection of equipment.

Section 13 covers general principles of installation and guide lines on initial testing before commissioning.

Section 14 covers general requirements associated with earthing in electrical installations. Specific requirements for earthing in individual installations are covered in respective parts of the code.

Section 15 covers guidelines on the basic electrical aspects of lightning protective systems for buildings and the electrical installation forming part of the system.

Section 16 covers the protection requirements in low voltage electrical installation of buildings.

Section 17 covers causes for low power factor and guidelines for use of capacitors to improve the same in consumer installations.

Section 18 covers the aspects to be considered for selection of equipment from energy conservation point of view and guidence on energy audit.

Section 19 covers guidelines on safety procedures and practices in electrical work.

Section 20 gives frequently referred tables in electrical engineering work.

The above description is part 1 only you can refer remaining parts and section for other electrical installation, items devices and equipments.

1 **Store Keeping:** Store keeping refers to the safe custody of materials, stocked in the store room, for which the store-keeper acts as a trustee. It means that the materials received are checked and carried into the store room, and stored in a systematic manner and protected/ guarded against all kinds of damages and spoilages until they are issued.

The important functions of store-keeping are

a) Receipt of Materials

(b) Storage

(c) Preservation

(d) Issue of materials and

(e) Accounting and maintenance of records.

2 **Layout for stores:** The internal arrangement of a store house is known as 'LAYOUT'. A proper layout, which should be clean with clear and defined lanes for each item of a stock, having respective BINS, SHELVES, RACKS, etc., will ensure free movement of materials, timely inspection, and day-to-day verification of Receipts and Issues.

3 **Storage:** Storage means custody of materials in a systematic manner, so as to help, easy movement of materials into and out of stores, and physical verification.

4 **Preservation:** Preservation means protection of materials from 'FIRE, RUST, CORROSION, DUST, THEFT, WEATHER, HEAT, COLD, MOIS TURE, etc., with the aim of maintaining their value and quality.

5 **Receipt of materials:** Materials, as and when received, are to be verified/checked inspected and moved into the appropriate area of the store room. A proper record shall be kept in respect of all receipts.

6 **Accounting and maintenance of records:** Maintenance of Records in respect of materials received and issued, is one of the important functions in store keeping. Proper, upto date and complete records result in reduction or elimination of wastage and misappropriation.

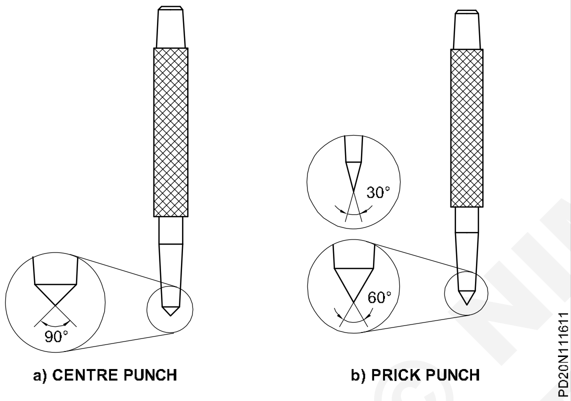
Marking tools - punches - calipers - scriber, divider

Objectives: At the end of this lesson you shall be able to
- **state different punches used in marking**
- **name commonly used calipers**
- **explain outside and inside calipers**
- **state the features of scriber & divider.**

Types of marking punches: In order to make certain dimensional features of the layout permanent, punches are used. There are two types of punches.

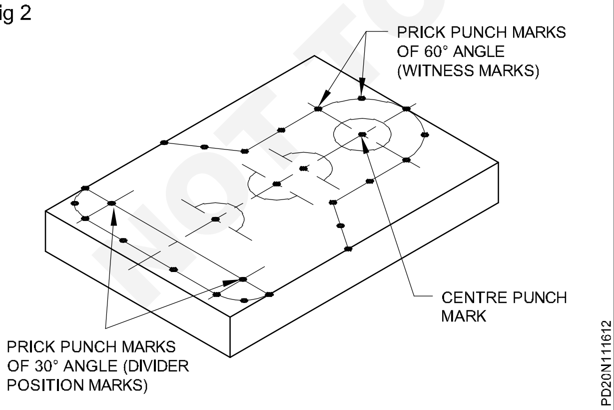
Centre punch: The angle of the point is 90°. The punch mark made by this is wide and not very deep. This punch is used for locating holes. The wide punch mark gives a good seating for starting the drill. (Figs 1a)

Fig 1



Prick punch: The angle of the prick punch is 30° or 60° (Fig 1b). The 30° point punch is used for making light punch marks needed to position dividers. The divider leg will get proper seating in this punch mark. The 60° punch is used for Witness Marks. Witness marks should not be too close. (Fig 2)

Fig 2



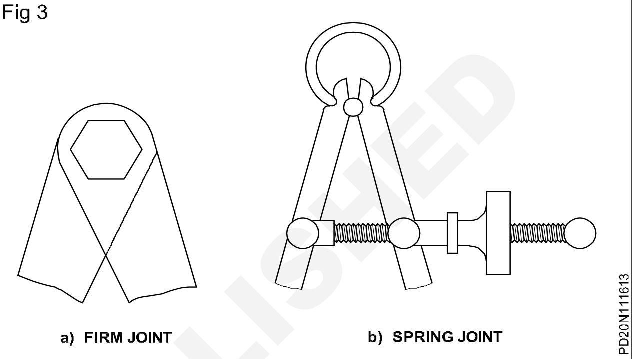
Types of calipers

Calipers (firm and spring joints) : Calipers are simple measuring instruments used to transfer measurements from the steel rule to objects and vice versa.

The commonly used calipers are:

- firm joint calipers (Fig 3a)
- spring joint calipers. (Fig 3b)

Fig 3



Firm joint calipers : In the case of firm joint calipers both legs are pivoted on one end. To take measurement of the workpiece, it is opened roughly to the size. Fine setting is done by lightly tapping it on a wooden surface. (Figs 4 & 5)

Fig 4

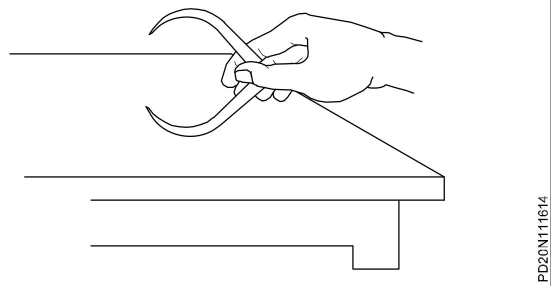
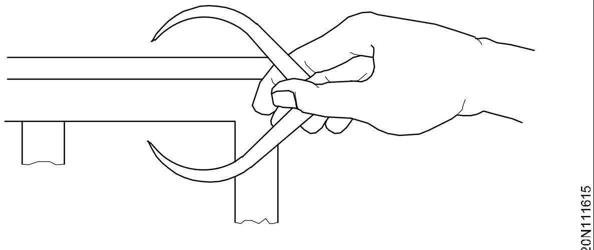


Fig 5



FIRM JOINT CALIPER

Spring joint calipers: For these type of calipers, the legs are assembled by means of a pivot loaded with a spring. For opening and closing of the caliper legs a screw and nut are provided.

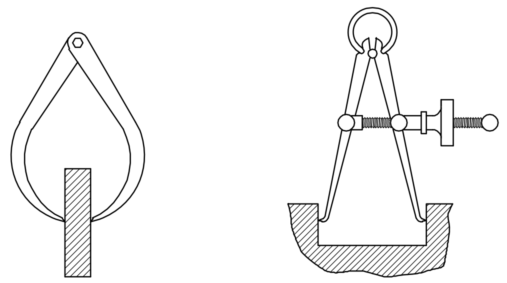
Spring calipers have the advantage of quick setting. The setting made will not change unless the nut is turned. Caliper sizes are specified by the length which is the distance between the pivot centre and the tip of the leg.

Accuracy of the measurement taken depends very much on the sense of `FEEL' or `TOUCH' while measuring the job. You should get the feel when the legs are just touching the surface.

Outside and inside measurements: Calipers used for outside measurements are known as outside calipers while calipers used for internal measurements are the inside calipers. (Figs 6a & 6b)

Calipers are used with steel rules whose accuracy is limited to 0.5 mm; parallelism can be checked with a higher degree of accuracy.

Fig 6

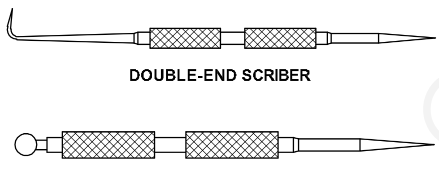


Scriber, divider

Scriber: A scriber is a sharp, pointed, steel tool made from carbon tool steel. There are two types of scribers.

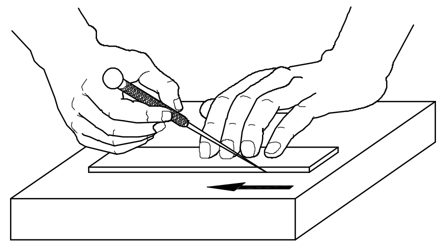
- Double end and plain scribers (Fig 7)

Fig 7



Uses: Used for scribing lines on the metal being laid out. (Fig 8)

Fig 8

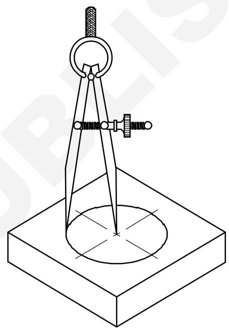


Divider: A divider consists of a pair of steel legs adjusted by a screw and nut, and held together by a circular spring at one end. A handle is inserted on the spring.

Uses: A divider is used for

- measuring distances between points
- transferring measurements directly from a rule
- scribing circles and arcs on metals. (Fig 9)

Fig 9



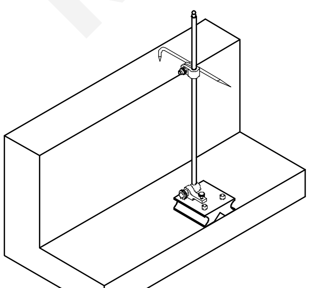
Universal surface gauge

Objectives: At the end of this lesson you shall be able to
- **state the constructional features of surface gauges**
- **name the different types of surface gauges**
- **state the uses of surface gauges**
- **state the advantages of universal surface gauges.**

Universal surface gauge : A surface gauge is one of the most common marking tools used for:

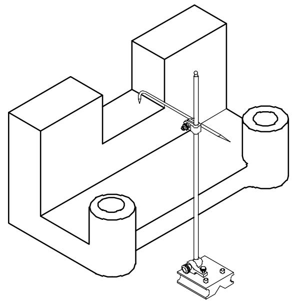
- scribing lines parallel to a datum surface (Fig 1)

Fig 1



- setting jobs on machines parallel to a datum surface (Fig 2)
- checking the height and parallelism of jobs
- setting jobs concentric to the machine spindle.

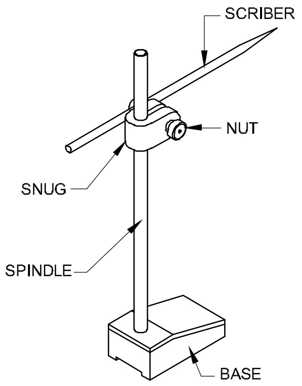
Fig 2



Types of surface gauges: A surface gauge/scribing block is of two types.

- Fixed Surface gauge (Fig 3)

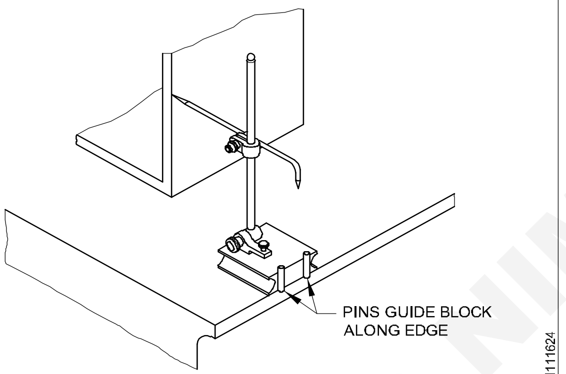
Fig 3



FIXED SURFACE GAUGE

- Universal Surface gauge (Fig 4)

Fig 4



PIN GUIDE BLOCK UNIVERSAL SURFACE GUAGE

Surface gauge (fixed type)**:** This consists of a heavy flat base and a spindle, fixed upright to which a scriber is attached with a snug and a clamp nut.

Universal surface gauge: This has the following additional features.

- The spindle can be set to any position.
- Fine adjustments can be made quickly.
- Can also be used on cylindrical surfaces.
- Parallel lines can be scribed from any datum edge with the help of guide pins.(Fig 4)

Parts and functions of a universal surface gauge (Fig 5)

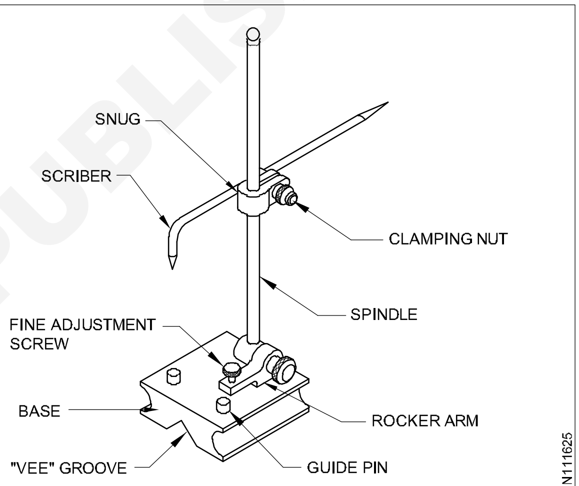
Base: The base is made of steel or cast iron with a `Vee' groove at the bottom. The `Vee' helps to seat on the circular work. The guide pins fitted in the base are helpful for scribing lines from any datum edge.

Rocker arm: A rocker arm is attached to the base along with a spring and a fine adjustment screw. This is used for fine adjustments.

Spindle: The spindle is attached to the rocker arm.

Scriber: The scriber can be clamped in any position on the spindle with the help of a snug and clamp nut.

Fig 5



UNIVERSAL SURFACE GAUGE

Sheet metal - marking and cutting tools - rivet joints

Objectives : At the end of this lesson you shall be able to
- **state the six types of metal sheets used in sheet metal work**
- **state the different types of snips and their uses**
- **state the uses of solid cold punches.**

A large quantity of sheet metal used in the sheet metal industry is steel, rolled into sheets of various thicknesses and coated with zinc, tin or other metals. Other than steel, the worker uses sheets made out of zinc, copper, aluminium, stainless steel etc.

Types of sheets

Sheet steel

Galvanised iron sheet:

Copper sheets

Aluminium sheets

Tin plates

Brass sheet

Snips: A snip is a cutting tool and is used for cutting thin sheets of metal.

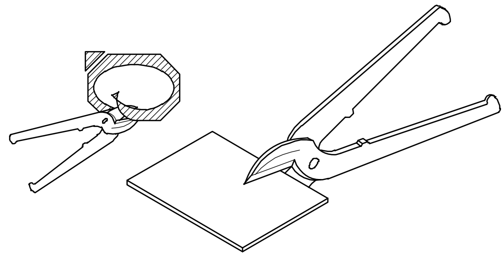
There are two types of snips.

- Straight snips
- Bent snips

Straight snips: A straight snip has straight blades for straight line cutting. It can also be used for external curved cuts. (Fig 1)

Bent snip: Bent snips have curved blades used for cutting internal curves. For trimming a cylinder keep the lower blade on the outside of cut. (Fig 2)

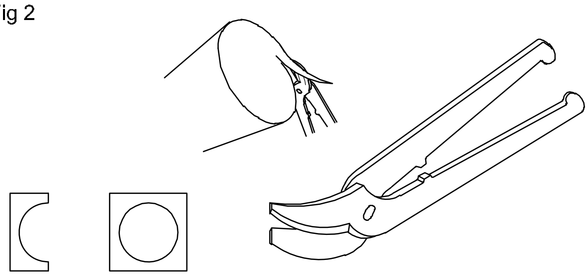
Fig 1



STRAIGHT SNIP

PD20N111631

Fig 2



BENT SNIP

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Solid cold punches

Objectives: At the end of this lesson you shall able to
- **state the solid cold punches.**

For making holes in sheet metal, cold punches can be utilized.

There are two types of cold punches used on sheet metal.

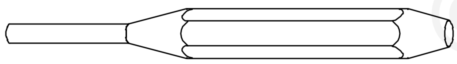
- Solid cold punch
- Hollow cold punch

In this lesson you will know about solid cold punches.

Solid cold punch: It is used to punch small holes in sheet metal (thin gauge).

Generally small holes can be made by this punch. (Fig 1)

Fig 1



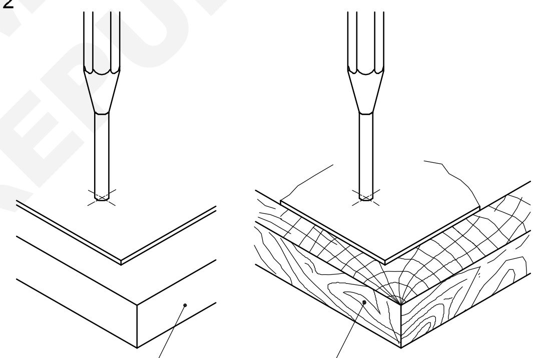
COLD PUNCH

PD20N111641

Precautions to be observed while using a solid cold punch: The sheet should be kept on lead cake or on a hardwood block while punching (Fig 2).

While striking, watch the cutting point, not the head of the punch.Hold the punch in a vertical positon on the correct locations.

Fig 2



METHOD OF PUNCHING SMALL HOLES

PD20N111642

Folding tools

Objectives: At the end of this lesson you shall able to
- **list out the different folding tools**
- **state the uses of folding tools.**
- **state the types of notches and their uses**
- **state the types of hem and their application**

The common tools used in the folding of sheet metal are:

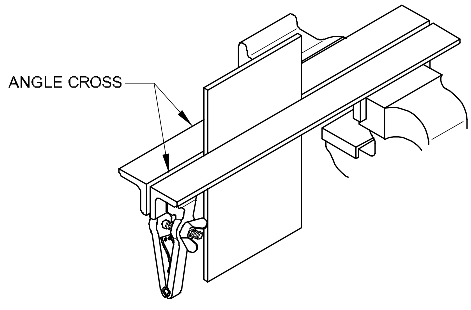
- angle steel and folding bar
- C clamp
- stakes
- mallet.

Angle steel: Two pieces of angles are used for folding at 90°. For longer sheets lengthy angles will be used along clamp (or) hand vice. (Fig 1)

Folding bar: The sheet metal to be bent is clamped in the folding bars. The folding bars are clamped in the vice as shown in the figure. (Fig 2)

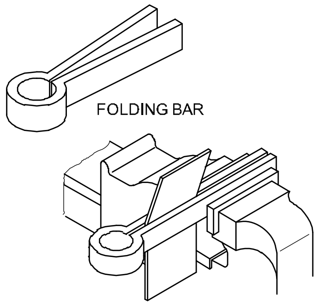
**`C' clamp:** The shape of the clamp is in the form of the letter `C'. `C' clamp is a holding device. This clamp is used when the piece has to be securely fixed to another piece. It is available in different sizes according to the opening of jaws. (Fig 3)

Fig 1



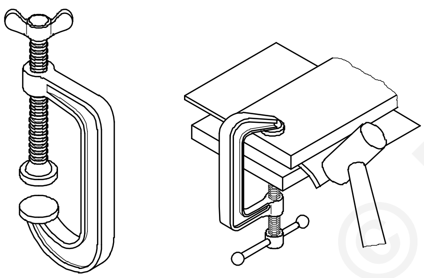
ANGLE STEEL

Fig 2



FOLDING BAR

Fig 3



`C' CLAMP / `G' CRAMP

Stakes: Stakes are used for bending, seaming and forming of sheet metal that cannot be done on any regular machine. For the above purposes, different stakes are used. Stakes are made of forged steel or cast steel.

Types of stakes

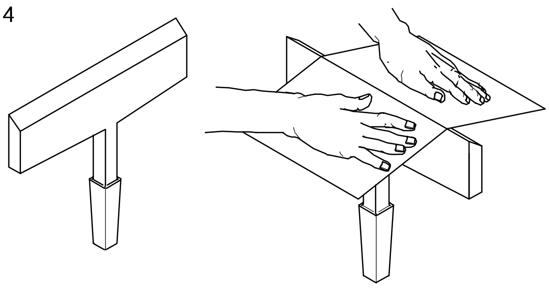
- Hatchet stake
- Square stake
- Blow-horn square stake
- Bevel-edge square stake.

Hatchet stake: A hatchet stake has a sharp straight edge bevelled on one side. It is used for making sharp bends, for bending edges and for folding sheet metal. (Fig 4)

Square stake: A square stake has a flat and square-shaped head with a long shank. It is used for general purposes. (Fig 5)

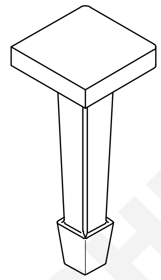
Blow-horn stake: It has a short tapered horn at one end, and a long tapered one at the other end. It is used in forming, riveting or seaming tapered, cone-shaped articles, such as funnels etc. (Fig 6)

Fig 4



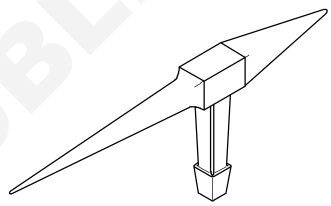
HATCHET STAKE

Fig 5



SQUARE STAKE

Fig 6

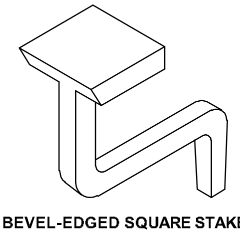


BLOW HORN STAKE

Bevel-edged square stake: A bevel-edged square stake is used to form corners and edges.(Fig 7)

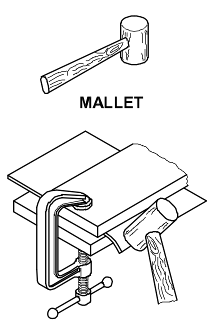
Mallet: A mallet is used for working on sheet metal. It will not damage the sheet surface while working. Mallets are made of wood, rubber, copper etc.(Fig 8)

Fig 7



BEVEL-EDGED SQUARE STAKE

Fig 8



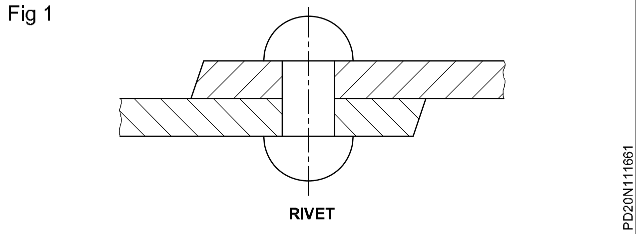
USE OF MALLET

Rivets

Objectives : At the end of this lesson you shall be able to
- **define riveting and state their uses**
- **list out the different types of rivets and which materials the rivets are made.**

Riveting: Riveting is one of the satisfactory methods of making permanent joints of two pieces - metal snips. (Fig 1)

Fig 1



It is customary to use rivets of the same metal as that of the parts that are being joined.

Uses: Rivets are used for joining metal sheets and plates in fabrication work, such as bridges, ships, cranes, structural steel work, boilers, aircraft and in various other works.

Material: In riveting, the rivets are secured by deforming the shank to form the head. These are made of ductile materials like low carbon steel, brass, copper and aluminium.

Types of rivets (Fig 2)

The four most common types of rivets are:

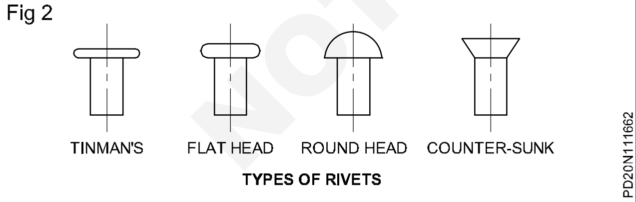
- tinmen's rivet
- flat head rivet
- round head rivet
- countersunk head rivet.

Each rivet consists of a head and a cylindrical body called as shank.

Sizes of rivets: Sizes of rivets are determined by the diameter and length of the shank.

Method of riveting: Riveting may be done by hand or by machine.

Fig 2

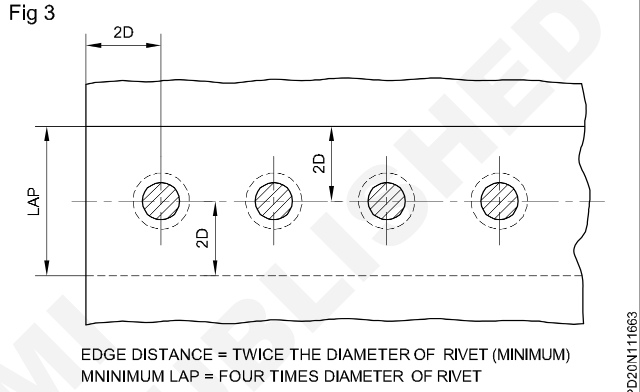


While riveting by hand, it can be done with a hammer and a rivet set.

Spacing of rivets: The space or distance from the edge of the metal to the centre of any rivet should be atleast twice the diameter of the rivet to avoid tearing. The `Lap' distance (4D) is shown in Fig 3.

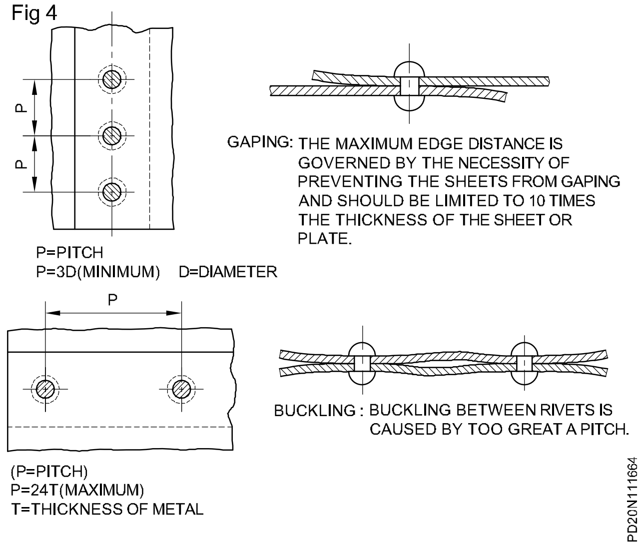
The minimum distance between the rivets (pitch) should be sufficient to allow the rivets to be driven without interference. The distance should be atleast three times the thickness of the sheet or above.

Fig 3



The maximum distance should never exceed 24 times the thickness of the sheet. Otherwise buckling will take place as shown in Fig 4.

Fig 4



Fundamental of electricity - conductors - insulators - wire size measurement - crimping

Objectives: At the end of this lesson you shall be able to
- **define electricity and atom**
- **explain about the atomic structure**
- **define the fundamental terms and definition of electricity**
- **state the type of supply, polarity and the effects of electric current**
- **state the conductors, insulators, wires - size measurement methods**

Introduction

Electricity is one of the today's most useful sources of energy. Electricity is of utmost necessity in the modern world of sophisticated equipment and machinery.

Electricity in motion is called electric current. Whereas the electricity that does not move is called static electricity.

Examples of static electricity

- Shock received from door knobs of a carpeted room.
- Attraction of tiny paper bits to the comb.

Structure of matter

Electricity is related to some of the most basic building blocks of matter that are atoms (electrons and protons). All matter is made of these electrical building blocks, and, therefore, all matter is said to be 'electrical'.

Atom

Matter is defined as anything that has mass and occupies space. A matter is made of tiny, invisible particles called molecules. A molecule is the smallest particle of a substance that has the properties of the substance. Each molecule can be divided into simpler parts by chemical means. The simplest parts of a molecule are called atoms.

Basically, an atom contains three types of sub-atomic particles that are of relevance to electricity. They are the electrons, protons and neutrons. The protons and neutrons are located in the centre, or nucleus, of the atom, and the electrons travel around the nucleus in orbits.

Atomic structure

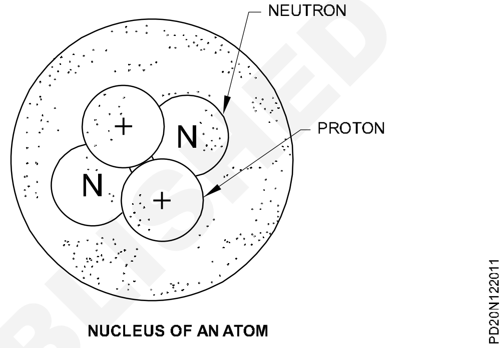
The Nucleus

The nucleus is the central part of the atom. It contains the protons and neutrons in equlal numbrs shown in Fig 1.

Protons

The proton has a positive electrical charge. (Fig 1) It is almost 1840 times heavier than the electron and it is the permanent part of the nucleus; protons do not take an active part in the flow or transfer of electrical energy.

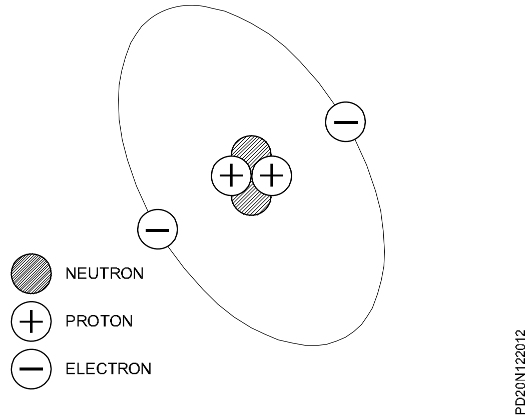
Fig 1



Electron

It is a small particle revolving round the nucleus of an atom (as shown in Fig 2). It has a negative electric charge. The electron is three times larger in diameter than the proton. In an atom the number of protons is equal to the number of electrons.

Fig 2



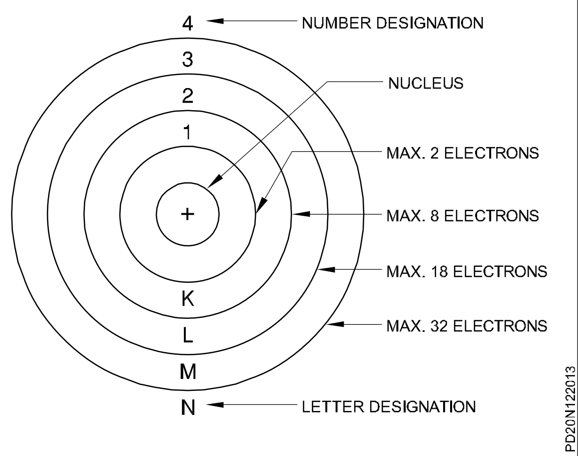
Neutron

A neutron is actually a particle by itself, and is electrically neutral. Since neutrons are electrically neutral, they are not too important to the electrical nature of atoms.

Energy shells

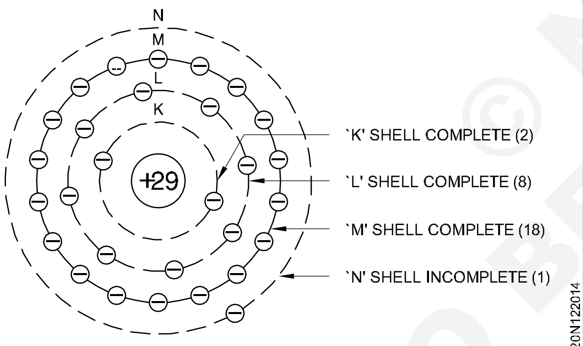
In an atom, electrons are arranged in shells around the nucleus. A shell is an orbiting layer or energy level of one or more electrons. The major shell layers are identified by numbers or by letters starting with 'K' nearest the nucleus and continuing alphabetically outwards. There is a maximum number of electrons that can be contained in each shell. Fig 3 illustrates the relationship between the energy shell level and the maximum number of electrons it can contain.

Fig 3



If the total number of electrons for a given atom is known, the placement of electrons in each shell can be easily determined. Each shell layer, beginning with the first, is filled with the maximum number of electrons in sequence. For example, a copper atom which has 29 electrons would have four shells with a number of electrons in each shell as shown in Fig 4.

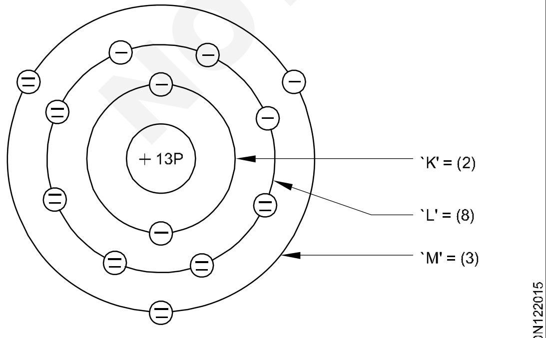
Fig 4



COPPER ATOM

Similarly an aluminium atom which has 13 electrons has 3 shells as shown in Fig 5.

Fig 5



ALUMINIUM ATOM

Electron distribution

The chemical and electrical behaviour of atoms depends on how completely the various shells and sub-shells are filled.

Atoms that are chemically active have one electron more or one less than a completely filled shell. Atoms that have the outer shell exactly filled are chemically inactive. They are called inert elements. All inert elements are gases and do not combine chemically with other elements.

Metals possess the following characteristics.

- They are good electric conductors.
- Electrons in the outer shell and sub-shells can move more easily from one atom to another.
- They carry charge through the material.

The outer shell of the atom is called the valence shell and its electrons are called valence electrons. Because of their greater distance from the nucleus, and because of the partial blocking of the electric field by electrons in the inner shells, the attracting force exerted by nucleus on the valence electrons is less. Therefore, valence electrons can be set free most easily. Whenever a valence electron is removed from its orbit it becomes a free electron. Electricity is commonly defined as the flow of these free electrons through a conductor. Though electrons flow from negative terminal to positive terminal, the conventional current flow is assumed as from positive to negative.

Conductors, insulators and semiconductors

Conductors

A conductor is a material that has many valance electrons permitting electrons to move through it easily. Generally, conductors have many valence shells of one, two or three electrons. Most metals are conductors.

Some common good conductors are Copper, Aluminium, Zinc, Lead, Tin, Eureka, Nichrome, are conductors, where as silver and gold are very good conductors

Insulators

An insulator is a material that has few, if any, free electrons and resists the flow of electrons. Generally, insulators have full valence shells of five, six or seven electrons. Some common insulators are air, glass, rubber, plastic, paper, porcelain, PVC, fibre, mica etc.

Semiconductors

A semiconductor is a material that has some of the characteristics of both the conductor and insulator. Semiconductors have valence shells containing four electrons.

Common examples of pure semiconductor materials are silicon and germanium. Specially treated semiconductors are used to produce modern electronic components such as diodes, transistors and integrated circuit chips.

Simple electrical circuit and its elements

Objectives: At the end of this lesson you shall be able to
- **describe a simple electric circuit**
- **explain the current, its units and method of measurement (ammeter)**
- **explain the emf, potential difference, their units and method of measurement (voltmeter)**
- **explain resistance and its unit, and quantity of electricity.**

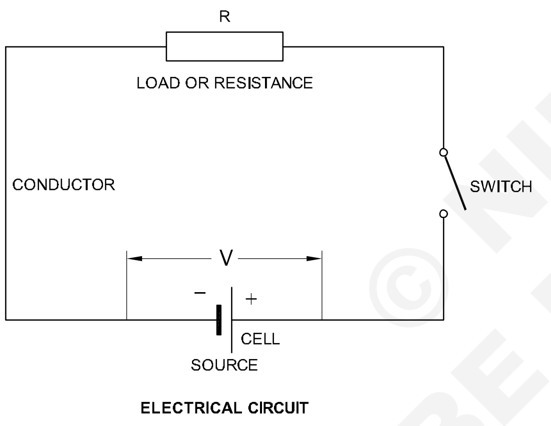
Simple electric circuit

A simple electrical circuit is one in which the current flows from the source to a load and reaches back the source to complete the path.

As shown in Fig 1, the electrical circuit should consist of the following.

- An energy source (cell) to provide the voltage needed to force the current through the circuit.
- Conductors through which the current can flow.
- A load (resistor 'R') to control the amount of current and to convert the electrical energy to other forms.
- A control device (switch 'S') to start or stop the flow of current.

Fig 1

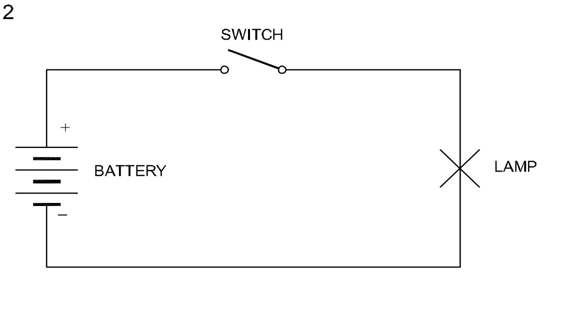


In addition to the above, the circuit may have insulators (PVC or rubber) to confine the current to the desired path, and a protection device (fuse 'F') to interrupt the circuit in case of malfunction of the circuit (excess current).

Electric current

Fig 2 shows a simple circuit which consists of a battery as the energy source and a lamp as the resistance. In this circuit, when the switch is closed, the lamp glows because of the electric current flows from the +ve terminal of the source (battery) via the lamp and reaches back the –ve terminal of the source.

Fig 2



Flow of electric current is nothing but the flow of free electrons. Actually the electrons flow is from the negative terminal of the battery to the lamp and reaches back to the positive terminal of the battery.

However direction of current flow is taken conventionally from the +ve terminal of the battery to the lamp and back to the –ve terminal of the battery. Hence, we can conclude that conventional flow of current is opposite to the direction of the flow of electrons. Throughout the Trade Theory book, the current flow is taken from the +ve terminal of source to the load and then back to the –ve terminal of the source.

Ampere

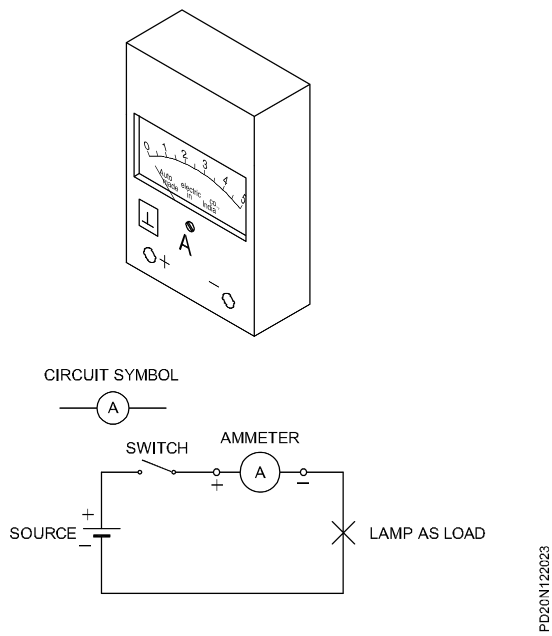
The unit of current (abbreviated as I) is an ampere (symbol A). If 6.24 x 10^{18} electrons pass through a conductor per second having one ohm resistance with a potential difference of one volt causes one ampere current has passed through the conductor.

Ammeter

We know the electrons cannot be seen and no human being can count the electrons. As such an instrument called ammeter is used to measure the current in a circuit.

As an ammeter measures the flow of current in amperes it should be connected in series with the resistance (Load).

Fig 3



as shown in Fig 3. For the decimal and decimal sub-multiples of the ampere we use the following expressions.

1 kilo-ampere = 1 kA = 1000 A = 1 x 10^3A

1 milli-ampere = 1 mA = 1/1000 A = 1 x 10^{-3}A

1 micro-ampere = 1 μA = 1/1000000 A = 1 x 10^{-6}A

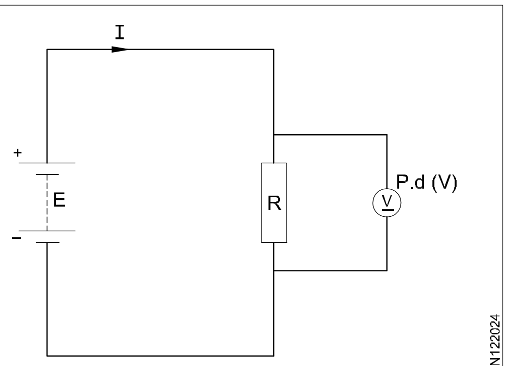
Electro Motive Force (EMF)

In order to move the electrons in a circuit- that is to make the current to flow, a source of electrical energy is required. In a torch light, the battery is the source of electrical energy.

The terminals of the battery are indicated in the circuit symbol by two lines, the longer line for the positive and the shorter for the negative terminal.

Within the battery the negative terminal contains an excess of electrons whereas the positive terminal has a deficit of electrons. The battery is said to have an electromotive force (emf) which is available to drive the free electrons in the closed path of the electrical circuit. The difference in the distribution of electrons between the two terminals of the battery produces this emf.

Fig 4



ELECTROMOTIVE FORCE

In Simple,

Electromotive force (EMF) is the electrical force, which is initially available in elecrical source, cause to move the free electrons in a conductor

Its unit is ‘Volt’

It is denoted by letter ‘E’

It cannot be measured by any meter. It can be only calculated by using the formula

E = Potential Difference (P.D) + V. drop

= p.d + V.drop

E = V + IR

Electromotive force is essential to drive the electrons in circuit

This force is obtained from the source of supply i.e. Torch lights, dynamo

System International (SI) unit of electromotive force is Volts (symbol ‘E’)

Potential Difference (PD)

The difference of volatge and pressure across two points in a circuit is called a potential difference (p.d) and is measured in volts.

In a circuit, when a current flows, there will be a potential difference across the terminals of the resistor/load. In the circuit shown in Fig 4, when the switch is in open conidition, the voltage across the terminals of the cell is called electromotive force (E) whereas when the switch is in the closed position, the voltage across the cell is called potential difference (p.d) which wil be lesser in value than the electromotive force earlier measured. This is due to the fact that the internal resistance of the cell drops a fer volts when the cell supplies current to the load.

The force which causes current to flow in the circuit is called emf. Its symbol is E and its unit is Volts (V). It can be calculated as

EMF = voltage at the terminal of source of supply + voltage drop in the source of supply

or emf = V_T + IR

Terminal voltage (p.d)

It is the voltage available at the terminal of the source of supply. Its symbol is V_T. Its unit is also the volt and is also measured by a voltmeter. It is given by the emf minus the voltage drop in the source of supply, i.e.

V_T = EMF - IR

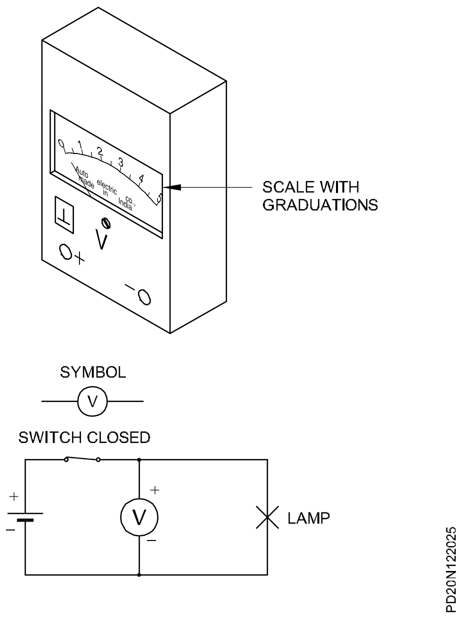
where I is the current and R is the resistance.

Hence EMF is always greater than p.d [E.M.F>p.d]

Voltmeter

Electrical voltage is measured with a voltmeter. In order to measure the voltage of a source, the terminals of the voltmeter must be connected to the terminals of the source. Positive to the positive terminal and negative to the negative terminal, as shown in Fig 5. The voltmeter connection is across or it is a parallel connection.

Fig 5



For the decimal or decimal sub-multiples of the volt, we use the following expressions.

1 kilo-volt = 1 KV = 1000 V

= 1 x 10^3V

1 milli-volt = 1 mV = 1/1000 V

= 1 x 10^{-3}V

1 micro-volt = 1 μV = 1/1000000

V = 1 x 10^{-6}V

Resistance (R)

In addition to the current and voltage there is a third quantity which plays a role in a circuit, called the electrical resistance. Resistance is the property of a material by which it opposes the flow of electric current.

The resistance is the property of opposition to the flow of the current offered by the circuit elements like resistance of the conductor or load is limit the flow of current

In absence of resistance in a circuit, the current will reach an abnormal high value endangering the circuit itself

Ohm

The unit of electrical resistance (abbreviated as R) is ohm (symbol Ω).

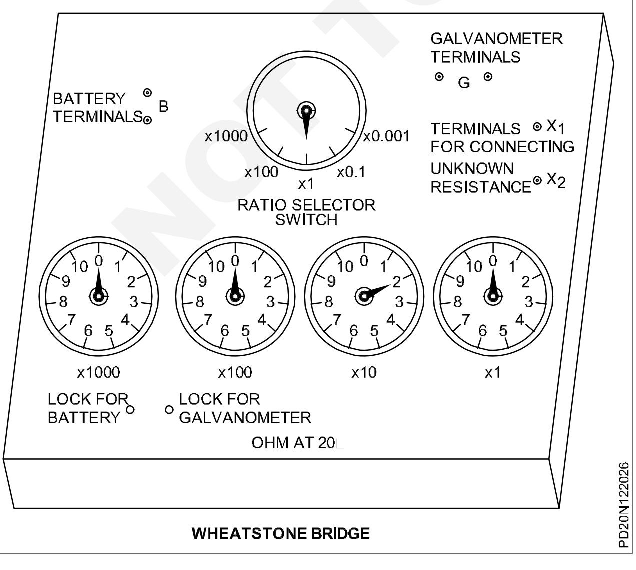
For the decimal multiples or decimal sub-multiples of the ohm we use the following expressions

1 megohm	= 1 MΩ = 1000000Ω	= 1 x 10^6Ω
1 kilo-ohm	= 1 kΩ = 1000Ω	= 1 x 10^3Ω
1 milli-ohm	= 1 mΩ = 1/1000Ω	= 1 x 10^{-3}Ω
1 micro-ohm	= 1 μΩ = 1/1000000Ω	= 1 x 10^{-6}Ω

Meter to measure resistance

Ohmic value of a medium resistance is measured by an ohmmeter or a Wheatstone bridge. (Fig 6) There is a provision to measure the ohmic value of a resistance in a multimeter. There are various methods to determine the ohmic value of resistance. Some of these methods will be explained later in this book.

Fig 6



WHEATSTONE BRIDGE

International Ohm

It is defined as that resistance offered to an unvarying current (DC) by a column of mercury at the temperature of melting ice (i.e. 0°C), 14.4521 g in mass, of constant cross-sectional area (1 sq. mm) and 106.3 cm in length.

International ampere

One international ampere may be defined as that unvarying current (DC) which when passed through a solution of silver nitrate in water, deposits silver at the rate of 1.118 mg per second at the cathode.

Internation volt

It is defined as that potential difference which when applied to a conductor whose resistance is one international ohm produces a current of one international ampere. Its value is equal to 1.00049V.

Conductance

The property of a conductor which conducts the flow of current through it is called conductance. In other words, conductance is the reciprocal of resistance. Its symbol is G (G = 1/R) and its unit is mho represented by ℧. Good conductors have large conductances and insulators have small conductances. Thus if a wire has a resistance of R Ω, its conductance will be 1/R

Quantity of electricity

As the current is measured in terms of the rate of flow of electricity, another unit is necessary to denote the quantity of electricity (Q) passing through any part of the circuit in a certain time. This unit is called the coulomb (C). It is denoted by the letter Q. Thus

Quantity of electricity = current in amperes (I) x time in seconds (t)

or $Q = I \times t$

Coulomb

It is the quantity of electricity transferred by a current of one ampere in one second. Another name for the above unit is the ampere-second. A larger unit of the quantity of electricity is the ampere-hour (A.h) and is obtained when the time unit is in hours

1 A.h = 3600 Asec or 3600 C

For or a DC source it is advisable to use a moving coil type voltmeter with a suitable range, of say 0-300 volts (Fig 6). To protect the meters, always use higher range meters above the rated voltage of the generator or DC source supply.

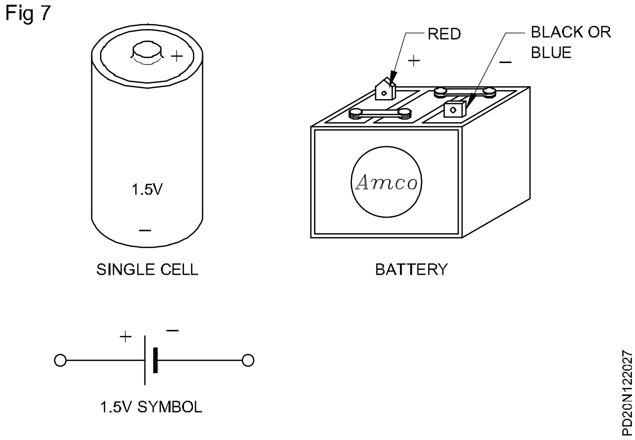
Marking made in practice

Generally in DC source the +ve terminal of the supply lead is Red in colour and –ve terminal of the supply lead is Blue or Black in colour. Battery terminals are marked as +ve and –ve on the body or on the terminal post.

- For cells on top of the cell is marked as +ve and the bottom is marked as –ve

- The battery terminal is marked as + and is Red in colour, and the other terminal is marked as – and Black or Blue in colour. (Fig 7)

Fig 7

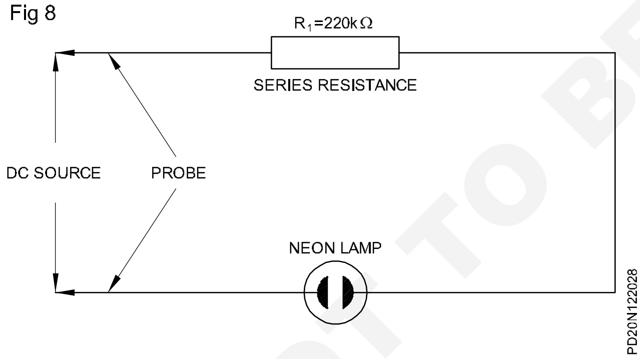


Neon polarity indicator

To check the polarity, a neon lamp in series with a 220k ohms resistor could be used (as shown in Fig 8). Touch the probes of the neon lamp circuit across the circuit to be tested. The lamp will light when voltage is present. If both electrodes in the lamp glow, you have an AC power source. If only one electrode glows, the voltage is DC and the lighted electrode will be on the side of the negative polarity of the source.

Therefore, you also have a polarity check on DC circuits. (Fig 8) A commercial neon polarity indicator is shown in Fig 9. It has an indicating glass window in which the polarity touched by the pointed end of the indicator will be displayed as +ve or –ve through neon signs.

Fig 8



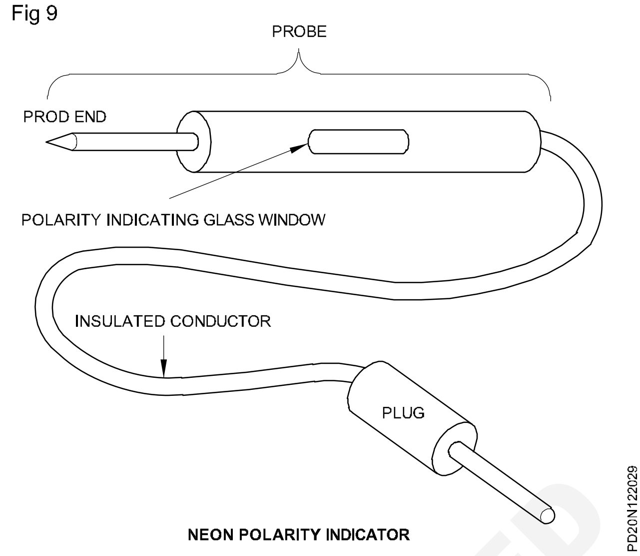
Effects of electric current

When an electric current flows through a circuit, is judged by its effects, which are given below.

1 Chemical effect

When an electric current is passed through a conducting liquid (i.e. acidulated water) called an electrolyte, it is decomposed into its constituents due to chemical action. The practical application of this effect is utilized in electroplating, block making, battery charging, metal refinery, etc.

Fig 9



2 Heating effect

When an electric potential is applied to a conductor, the flow of electrons is opposed by the resistance of the conductor and thus some heat is produced. The heat produced may be greater or lesser according to the circumstances, but some heat is always produced. The application of this effect is in the use of electric presses, heaters, electric lamps, etc.

3 Magnetic effect

When a magnetic compass is placed under a current carrying wire, it is deflected. It shows that there is some relation between the current and magnetism. The wire carrying current does not become magnet but produces a magnetic field in the space. If this wire is wound on an iron core (i.e. bar), it becomes an electro-magnet. This effect of electric current is applied in electric bills, motors, fans, electric instruments, etc.

4 Gas ionization effect

When electrons pass through a certain gase sealed in a glass tube, it becomes ionised and starts emitting light rays, such as in fluorescent tubes, mercury vapour lamps, sodium vapour lamps, neon lamps, etc.

5 Special rays effect

Special rays like X-rays and laser rays can also be developed by means of an electric current.

6 Shock effect

The flow of current through the human body may cause a severe shock or even death in many cases. If this current is controlled to a specific value, this effect of current can be used to give light shocks to the brain for the treatment of mental patients.

Conductors - insulators - wires - types

Objectives: At the end of this lesson you shall be able to
- **differentiate between conducting and insulating materials**
- **state the electrical properties of conducting materials**
- **state the terms used in electrical cables**
- **state the characteristics of copper and aluminium conductors**
- **state the types and propertites of insulating materials.**
- **describe the method of measurement of wire size using SWG**
- **explain the method of measure wire size by outside micrometer.**

Conductors and insulators

Material with high electron mobility (many free electrons) are called conductor.

Materials that contain many free electrons and are capable of carrying an electric current are known as conductors.

Examples - silver, copper, aluminium and most other metals.

Materials with low electron mobility (few (or) no free electron) are called insulators

Materials that have only a few electrons and are incapable of allowing the current to pass through them are known as insulators.

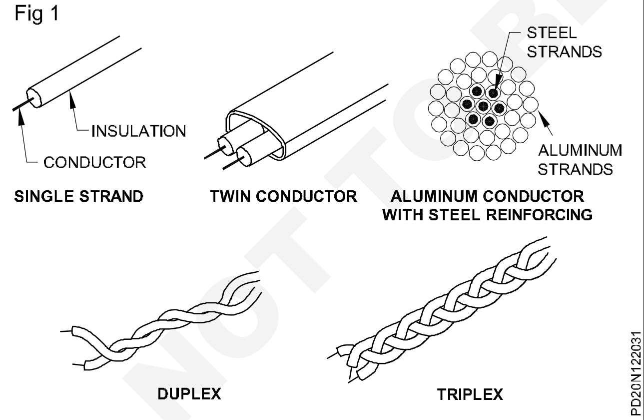
Examples - wood, rubber, PVC, porcelain, mica, dry paper and fibreglass.

Conductors

The use of conductors and their insulation is regulated by I E regulations and BIS (ISI) code of practice.

The I E regulations and I S cover all electrical conductors listing the minimum safety precautions needed to safeguard people, buildings and materials from the hazards of using electricity.

Fig 1



Wires and cables are the most common forms of conductors. They are made in a wide variety of forms to suit many different applications. (Fig 1)

Conductors form an unbroken line carrying electricity from the generating plant to the point where it is used. Conductors are usually made of copper or aluminium.

Current passing through a conductor generates heat. The amount of heat generated depends on the square of the current that passes through the conductor and the resistance of the conductor.

As the heat developed in the conductor depends upon the resistance of the conductor the cross-sectional area of the conductor must have a large enough area to give it a low resistance. But the cross- sectional area must also be small enough to keep the cost and weight as low as possible.

The best cross-sectional area depends upon how much current the conductor can carry without much voltage drop in the line and heat generation in the conductor.

There is a limit to the temperature each kind of insulation can safely withstand and also the type of insulation which can withstand the physical chemical and temperature zones of the surroundings.

BIS (ISI) code specifies the maximum current considered safe for conductors of different sizes, having different insulation and installed in different surroundings.

Size of conductors

The size is specified by the diameter in mm or the cross-sectional area. Typical sizes are 1.5 sq.mm, 2.5 sq.mm, 6 sq.mm etc.

Still in India the old method of specifying the diameter by the standard wire gauge number is in use.

Classfication of conductors

Wires and cables can be classified by the type of covering they have.

Bare conductors

They have no covering. The most common use of bare conductors is in overhead electrical transmission and distribution lines. For earthing also bare conductors are used.

Insulated conductors

They have a coating of insulation. The insulation separates the conductor electrically from other conductors and from the surroundings. It allows conductors to be grouped without danger. Additional covering over the insulation adds mechanical strength and protection against weather, moisture and abrasion.

Solid and stranded conductors

A solid conductor is one in which there will be only one conductor in the core as shown in Fig 2. A stranded conductor is one in which there will be a number of smaller sized conductors twisted to form the core as shown in Fig 3.

The number of conductors ranges from 3 to 162 and the conductor size varies from 0.193 mm to 3.75 mm diameter depending upon the current carrying capacity and also upon whether these conductors are used in cables or overhead lines.

Fig 2

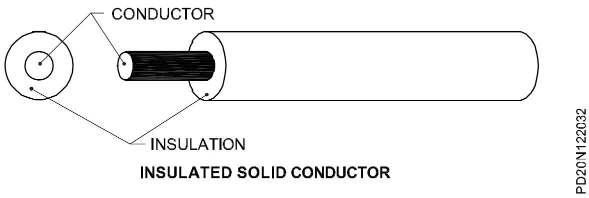
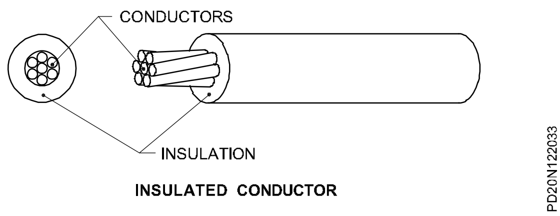


Fig 3



Normally stranded conductors are designated as 10 sq. mm cable of size 7/1.40 where 10 sq.mm gives the area of the cross-section, in the size, numerator (7) gives the number of conductors and the denominator 1.40 gives the diameter of the conductor in mm. Alternatively 7/1.40 cable is the same as 7/17 whereas in the latter case the denominator is expressed in Standard Wire Gauge (SWG) number.

Stranded conductors are more flexible and have better mechanical strength. According to recent stipulation, the cable size should be expressed in sq. millimetres or they can be expressed in terms of the number of conductors in the cable and the diameter of the conductor in mm.

Cable

A cable is a length of single, insulated conductor (single or stranded), or two or more such conductors - each provided with its own insulation, and are laid up together. The insulated conductor or conductors may or may not be provided with an overall mechanical protective covering.

Cable (armoured)

An armoured cable is provided with a wrapping of metal (usually in the form of tape or wire), serving as a mechanical protection.

Cable (flexible)

A flexible cable contains one or more cores, each formed of a group of wires, the diameters of the cores and of the wires being sufficiently small to afford flexibility.

Core

All cables have one central core or a number of cores of stranded conductors farming high conductivity; generally there are one, two, three, three and half and four cores. Each core is insulated separately and there is overall insulation around the cores.

Wire

A solid substance (conductor) or an insulated conductor (solid or stranded) subjected to tensile stress with or without screen is called a wire.

Copper and aluminium

In electrical work, mostly copper and aluminium are used for conductors. Though silver is a better conductor than copper, it is not used for general work due to higher cost.

Copper used in electrical work is made with a very high degree of purity, say 99.9 percent.

Characteristics of copper

1 It has the best conductivity next to silver.

2 It has the largest current density per unit area compared to other metals. Hence the volume required to carry a given current is less for a given length.

3 It can be drawn into thin wires and sheets.

4 It has a high resistance to atmospheric corrosion: hence, it can serve for a long time.

5 It can be joined without any special provision to prevent electrolytic action.

6 It is durable and has a high scrap value.

Next to copper, aluminium is the metal used for electrical conductors.

Characteristics of aluminium

1 It has good conductivity, next to copper. When compared to copper, it has 60.6 percent conductivity. Hence, for the same current capacity, the cross-section for the aluminium wire should be larger than that for the copper wire.

2 It is lighter in weight.

3 It can be drawn into thin wires and sheets. But loses its tensile strength on reduction of the cross-sectional area.

4 A lot of precautions needs to be followed while joining aluminium conductors.

5 The melting point of aluminium is low, hence it may get damaged at points of loose connection due to heat developed.

6 It is cheaper than copper.

Table 1 shows the properties of copper compared with those of aluminium.

Table 1

Chararacteristics of conductor materials

Sl. No.	Properties	Copper (Cu)	Aluminium (Al)
1	Colour	Reddish	White brown
2	Electrical conductivity in MHO/metre	56	35
3	Resistivity at 20°C in ohm/metre (Cross-sectional area in 1 mm^2)	0.01786	0.0287
4	Melting point	1083°C	660°C
5	Density in kg/cm^3	8.93	2.7
6	Temperature coefficient of resistance at 20°C per °C	0.00393	0.00403
7	Coefficient of linear expansion at 20°C per °C	17×10^{-6}	23×10^{-6}
8	Tensile strength in Nw/mm^2	220	70

Properties of insulating materials

Two fundamental properties of insulation materials are insulation resistance and dielectric strength. They are entirely different from each other and measured in different ways.

Insulation resistance

It is the electrical resistance of the insulation against the flow of current. Megohmmeter (Megger) is the instrument used to measure insulation resistance. It measures high resistance values in megohms without causing damage to the insulation. The measurement serves as a guide to evaluate the condition of the insulation.

Dielectric strength

It is the measure of how much potential difference the insulation layer can withstand without breaking down. The potential difference that causes a breakdown is called the breakdown voltage of the insulation.

Every electrical device is protected by some kind of insulation. The desirable characteristics of insulation materials are:

- high dielectric strength
- resistance to temperature
- flexibility
- mechanical strength.

No single material has all the characteristics required for every application. Therefore, many kinds of insulating materials have been developed.

Insulating tapes

Various tapes are used for insulating electrical equipments, conductors and components. Some of these are adhesive. The tapes commonly used include friction, rubber, plastic and varnished cambric tapes.

Rubber tape

Rubber tapes are used for insulating joints. The tape is applied under slight tension. Pressure causes the layers to bend together. Application of this restores insulation but will not be mechanically strong.

Friction tape

This is used over rubber tape insulation. This is made up of cotton cloth impregnated with an adhesive. It does not stretch like the rubber tape. The friction tape does not have insulating qualities of the rubber tape, hence should not be used by itself for insulation.

Plastic tape (PVC tape)

This is used more than the other tapes. PVC tapes have the following advantages.

- High dielectric strength
- Very thin
- Stretches to conform to contours of joints

Varnished cambric tapes

These tapes are made of cloth impregnated with varnish. It usually has no adhesive coating. Available in sheets and rolls and are ideal for insulating motor connecting leads.

Measurement of wire sizes - standard wire gauge - outside micrometer

Necessity of measuring the wire sizes

To execute a wiring job proper planning is necessary. After considering the requirements of the house owner, the electrician prepares a layout plan of the wiring and an estimate of the cost of the wiring materials and labour. A proper estimate involves determination of current in different loads, correct selection of the type of cable, size of the cable and the required quantity. Any error will result in defective wiring, fire accidents and bring unhappiness to both the house owner and the electrician.

Wire joints - Types - Soldering methods

Objective: At the end of this lesson you shall be able to
- **state the different types of wire joints and their uses**
- **state the necessity of soldering and types of soldering**
- **state the purpose and types of fluxes**
- **explain the different method of soldering and techniques of soldering**
- **explain the type of solder and flux used for soldering aluminium conductor**

Joints in electrical conductors are necessary to extend the cables, overhead lines, and also to tap the electricity to other branch loads wherever required.

Definition of joint: A joint in an electrical conductor means connecting/tying or interlaying together of two or more conductors such that the union/junction becomes secured both electrically and mechanically.

Types of joints: In electrical work, different types of joints are used, based on the requirement. The service to be performed by a joint determines the type to be used.

Some joints may require to have good electrical conductivity. They need not necessarily be mechanically strong.

Example : The joints made in junction boxes and conduit accessories.

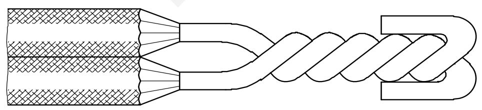
On the other hand, the joints made in overhead conductors, need to be not only electrically conductive but also mechanically strong to withstand the tensile stress due to the weight of the suspended conductor and wind pressure.

Some of the commonly used joints are listed below.

- Pig-tail or rat-tail
- twisted joints
- Married joint
- Tee joint
- Britannia straight joint
- Britannia tee joint
- Western union joint
- Scarfed joint
- Tap joint in single stranded conductor

Pig-tail/Rat-tail/Twisted joint: (Fig 1) This joint is suitable for pieces where there is no mechanical stress on the conductors, as found in the junction box or conduit accessories box. However, the joint should maintain good electrical conductivity.

Fig 1



RAT TAIL JOINT

PD20N122041

Married joint: (Fig 2) A married joint is used in places where appreciable electrical conductivity is required, along with compactness.

As the mechanical strength is less, this joint could be used at places where the tensile stress is not too great.

Fig 2

MARRIED JOINT

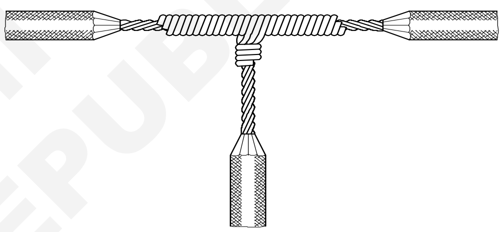
PD20N122042

Tee joint (Fig 3)**:** This joint could be used in overhead distribution lines where the electrical energy is to be tapped for service connections.

Britannia joint: (Fig 4) This joint is used in overhead lines where considerable tensile strength is required.

It is also used both for inside and outside wiring where single conductors of diameter 4 mm or more are used.

Fig 3



TEE JOINT

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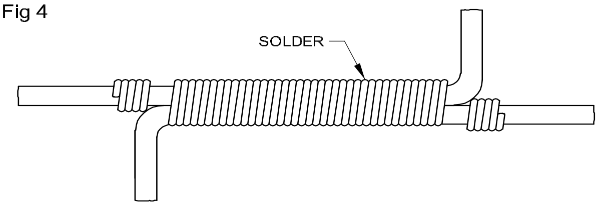
Britannia tee joint: This joint (shown in Fig 5) is used for overhead lines for tapping the electrical energy perpendicular to the service lines.

Fig 4



BRITANNIA JOINT

PD20N122044

Western union joint (Fig 6)**:** This joint is used in overhead lines for extending the length of wire where the joint is subjected to considerable tensile stress.

Scarfed joint (Fig 7)**:** This joint is used in large single conductors where good appearance and compactness are the main considerations, and where the joint is not subjected to appreciable tensile stress as in earth conductors used in indoor wiring.

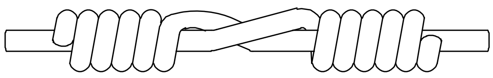
Fig 5

BRITANNIA TEE JOINT

PD20N122045

Tap joints in single stranded conductors of diameter 2 mm or less

Fig 6



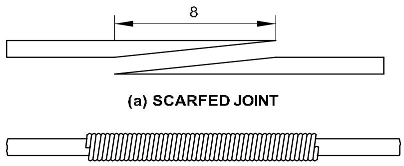
WESTERN UNION JOINT

By definition, a tap is the connection of the end of one wire to some point along the run of another wire.

The following types of taps are commonly used.

– Plain
– Aerial
– Knotted
– Cross - Double - Duplex

Fig 7



(a) SCARFED JOINT

(b) SCARFED JOINT

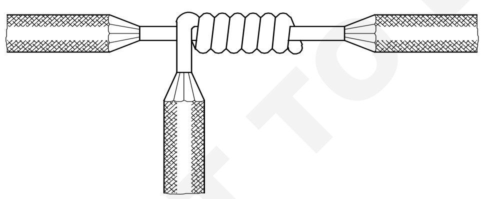
Plain tap joint: (Fig 8) This joint is the most frequently used, and is quickly made. Soldering makes the joint more reliable.

Aerial tap joint : (Fig 9) This joint is intended for wires subjected to considerable movement, and it is left without soldering for this purpose. This joint is suitable for low current circuits only. It is similar to the plain tap joint except that it has a long or easy twist to permit the movement of the tap wire over the main wire.

Knotted tap joint : (Fig 10) A knotted tap joint is designed to take considerable tensile stress.

Duplex cross-tap joint: (Fig 11) This joint is used where two wires are to be tapped at the same time. This joint could be made quickly.

Fig 8



PLAIN TAP JOINT

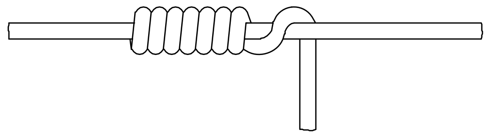
Double-cross tap joint: (Fig 12) This joint (shown in Fig 12) is simply a combination of two plain taps.

Contact resistance measurements

Contact resistance measurements are used to assess the risks of using various contacts and connectors. The Automated Contact Resistance Probe (ACRP) at the CALCE was developed, with assistance from AMD and Bell core, for this purpose.

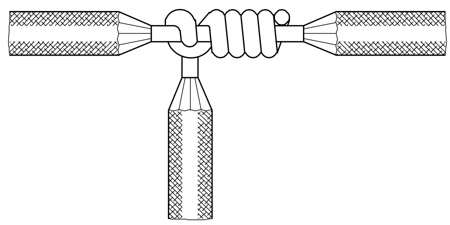
The standard method for measuring contact resistance is the 6Volt 1Amp method, sometimes referred to as four wire measurement. It is a simple method that can be easily implemented with two power supplies, and a digital voltage meter (DVM).

Fig 9



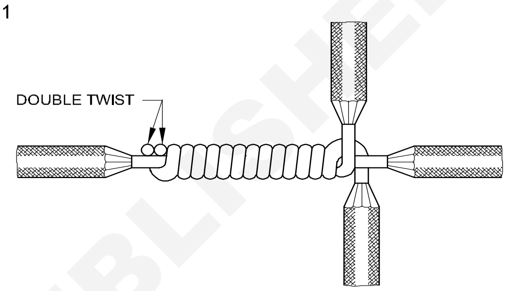
AERIAL TAP JOINT

Fig 10



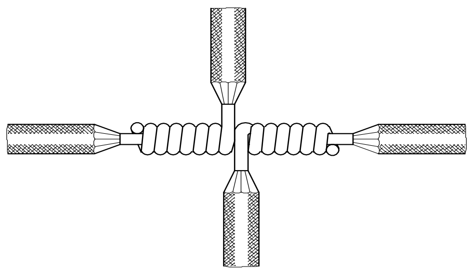
KNOTTED TAP JOINT

Fig 11



DUPLEX-CROSS TAP JOINT

Fig 12



DOUBLE-CROSS TAP JOINT

The term contact resistance refers to the contribution to the total resistance of a system which can be attributed to the contacting interfaces of electrical leads and connections as opposed to the intrinsic resistance. This effect is described by the term electrical contact resistance (ECR) and arises as the result of the limited areas of true contact at an interface and the presence of resistive surface films or oxide layers. ECR may vary with time, most often decreasing, in a process known as resistance creep.

The contact resistance is in the order of μΩ and it is approximately 20 μΩ. Important Point: In a circuit breaker, the main contacts are usually made up of copper and conduct current in closed positions.

The electrical contact resistance is the resistance at the electrical connection point that oppose the flow of electric current. The high electrical contact resistance leads more opposition to current flow. The contact resistance of the different contacting surfaces may vary. But, for a reliable electrical system, the contact resistance must be as minimum as possible.

Electrical devices, such as breakers, contactors, relays, switches, and other switching devices, are used for closing and opening the electrical circuit. Thus, all these devices have the contact resistance when in operation. The resistance between the contact points depends on the tightness of the connections and the metallurgy of contacts.

The cables have contact resistance when we join two cables through straight-through joints. Also, the cable conductor has contact resistance at the cable termination point at the connector in the feeder. The cable jointing and the termination point must have minimum contact resistance.

The increase in contact resistance causes serious problems in the electrical circuit.

Soldering - types of solders, flux and methods of soldering

Soldering: Soldering is the process of joining two metal plates or conductors without melting them, with an alloy called solder whose melting point is lower than that of the metals to be soldered. The molten solder is added to the two surfaces to be joined so that they are linked by a thin film of the solder which has penetrated into the surfaces.

Necessity of soldering: Wire and cable joints should have the same electrical conductivity and mechanical strength as that of the parent conductor. This cannot be achieved by a mere mechanical joint. As such cable joints are soldered to have good mechanical strength, electrical conductivity and also to avoid corrosion.

Solders

The following are the general proportions of tin and lead used in the solders.

Designation Uses		Compo-	Working sitiontemp.
Plumbing/ Tinman's solder	Tin-50% Lead-50%	212°C.or 413.6°F.	Heavy duty soldering
Electrician's solder	Tin-60% Lead-40%	185°C. or 365°F.	Tinning and soldering electrical joints etc.
Fine solder	Tin-63% Lead-37%	183°C.or 361°F.	Tinning/ Electrical/ Electronic Compound

Solder used for copper: The metal alloy used as a bonding agent in soldering is called a solder. The solders used for soft soldering consist of an alloy (mixture) of mostly tin and lead.

Factors influencing the choice of a solder

The factors that influence the choice of a solder are:

- place of use
- melting point
- solidification range
- strength
- hardness
- sealability
- price.

Flux: Flux is a substance used to dissolve oxides on the surface of conductors and to protect against de-oxidisation during the soldering process.

General properties of flux

The purpose of the flux is to

- dissolve oxides, sulphides etc. thereby making the soldering surface free of oxides and dirt
- prevent re-oxidation during the soldering operation thereby making the solder adhere to the surface to be soldered.
- facilitate the flow of the solder through surface tension so as to make the solder flow into the surface to be soldered.

The state of the flux can be solid or liquid.

The activity of the flux can be weak or strong, and is classified with regard to the corrosive properties, as slightly corrosive or highly corrosive.

The type of solder often determines the flux to be used for soldering.

The following table lists the fluxes used for soldering.

Table

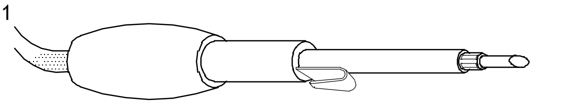
Sl. No.	Suitable flux	Metals/job - used for	Type of solder
1	Zinc chloride (acidic)	Cast iron, wrought iron, mild steel,cast steel, brass, bronze, copper etc. for soldering at low temperature	Tinman's solder Fine solder
2	Hydrochloric acid 10% diluted with water 90%	Zinc Galvanised iron	Coarse solder
3	Sal ammonia rosin (Not fully acid-free)	Copper, brass, tin plate, gun-metal: for clean and finer soldering work.	Coarse solder
4	Rosin	Joining electrical conductors	Electrician's solder
5	Tallow - (turpentine, acid free)	For joining electrical conductors, for soldering.	Electrician's fine solder

Fluxes shown under 1, 2 and 3 are not recommended for electrical purposes as they are highly corrosive, hygroscopic (absorb moisture), and the residues are electricity conductive.

Soldering methods

Soldering with a soldering iron: The most common method of soldering is with a soldering iron as shown in Fig 1. This is widely used for most kinds of soft soldering work.

Fig 1

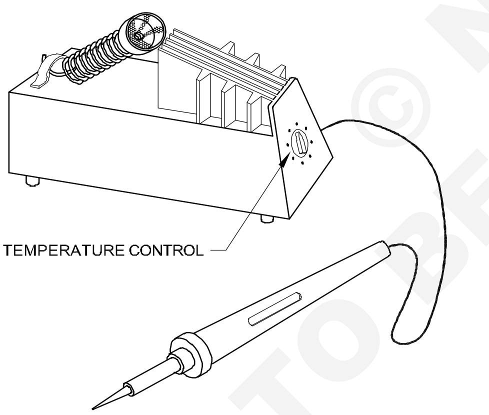


This tool is simple and inexpensive. Soldering irons are available in a wide range of sizes and models. Heating is generally by electrical means, though non-electrical irons are also used.

Temperature controlled soldering

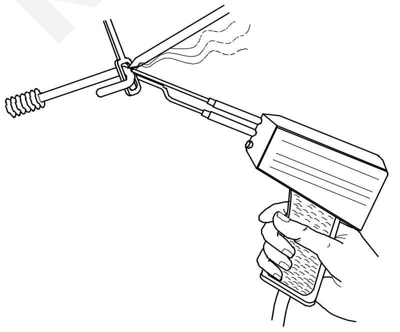
For soldering miniature components on printed circuit boards, a temperature-controlled soldering iron is used as shown in Fig 2. The electrical supply given to the soldering iron is of low voltage, and is completely isolated from the main supply. Low voltage does not endanger the life of the user and will also not spoil the sensitive electronic components. Controlled temperature makes the job easy for the user.

Fig 2



Soldering with a soldering gun: This method, shown in Fig 3, is used for individual soldering, e.g. for servicing and repair work.

Fig 3



SOLDERING WITH A SOLDERING GUN

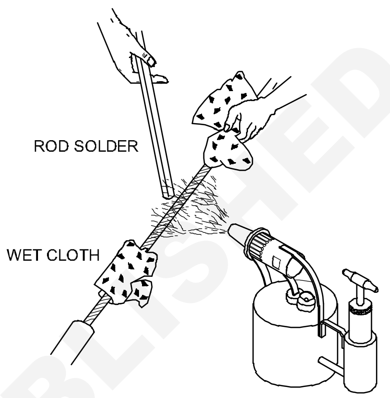
The principle of this method is that an electric current flows through a wire coil heating it. The temperature is difficult to check, and overheating can easily occur. This is the disadvantage.

Soldering with a flame: Soldering with a flame is used when the heat capacity of a soldering iron is insufficient.

This method, shown in Fig 4, permits rapid heating and is used primarily for larger jobs, such as piping and cable work, vehicle body repairs and some applications in the building trade.

This method requires skilful management of the flame.

Fig 4



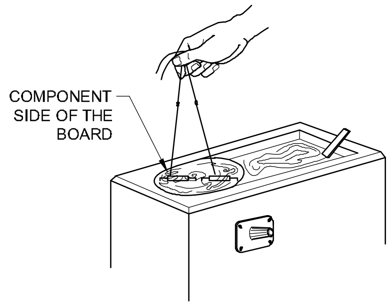
SOLDERING WITH BLOWLAMP

Dip soldering: This method, shown in Fig 5, is used for quantity production and for tinning work similar to component soldering on Printed Circuit Boards (P.C.B.). Components to be soldered or tinned are dipped into a bath of molten solder, which is heated electrically.

The solder is kept in motion by an agitator in order to obtain an even temperature and to keep the surface free from oxides. If no agitator is provided, the surface must be protected or skimmed at regular intervals to remove the oxides.

The temperature can be controlled very accurately.

Fig 5



DIP SOLDERING

Machine soldering: This method, shown in Fig 6, is used for quantity production, and is based on the principle that molten solder or a mixture of oil and molten solder is set in rapid motion, thus breaking up the oxide film. The solder comes into direct contact with the component ends to be soldered.

Soldering machines of different designs are used for wave soldering, cascade soldering and jet soldering.

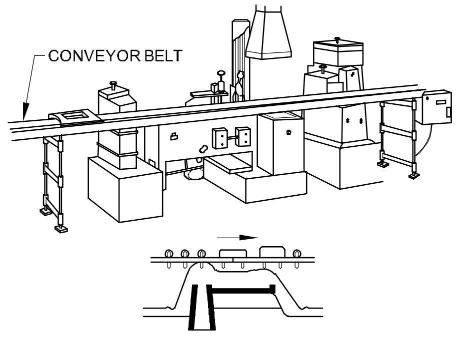
Equipment for machine soldering is expensive and the cost of production is high.

Accurate temperature control can be arranged.

Apart from these, any one of the following methods can also be used for soldering.

- Resistance soldering
- Induction soldering
- Oven soldering
- Soldering in vegetable oil
- Soldering by hot gas

Fig 6



MACHINE SOLDERING

Soldering - Techniques - pot and ladle

Soldering with electric soldering iron: In this method, the joining surface is first cleaned and then the flux is applied over the surface. The joint is then heated, and the solder is kept over the surface to be soldered, and heat is applied by keeping the soldering iron tip over it. The solder melts and spreads on the surface evenly.

The electric soldering iron: The heating element in the iron is heated by an electric current passing through it.

The bit is heated by the heating element.

The face of the bit is the part of the iron, used to make contact with the surfaces to be soldered.

Soldering irons of the following voltages and input power (wattage) are available (I.S.950-1980).

Ratings

Voltage	6	12	24	50		110230 or 240
Wattage	25	25	25	25	25,75, 250	5,10,25,75, 125,250,500

Select an iron with adequate power to suit the size of the work.

The bit: Most bits are made of copper because it is a good conductor of heat. The face of the bit may be either:

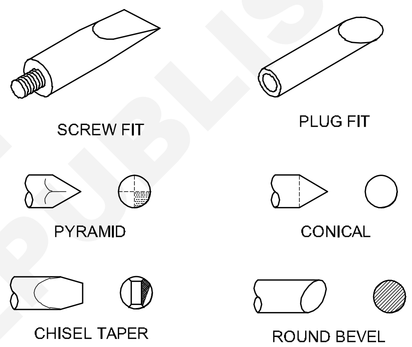
- un-plated or
- iron-plated.

Iron-plated faces do not wear out as rapidly as un-plated faces.

Most irons are so constructed that the bit can be changed.

Different shapes of bits are available as shown in Fig 1.

Fig 1

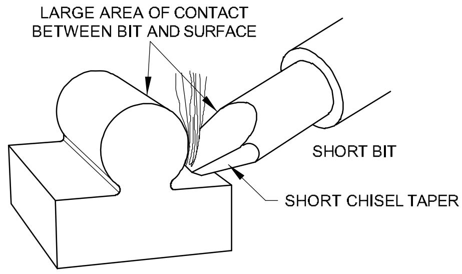


SHAPES OF SOLDERING BITS

Selecting the bit (Fig 2)**:** Select the bit to give a compromise between:

- the best approach to the work
- the shortest bit and bit taper
- the ideal contact with the surfaces.

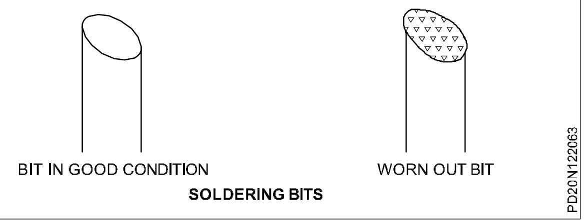
Fig 2



SELECT CORRECT SOLDERING BIT FOR THE JOB

Care of the bit (Fig 3)**:** Un-plated bits become pitted quickly and get covered in oxide. If the iron is in constant use, this will occur within a few hours.

Fig 3



SOLDERING BITS

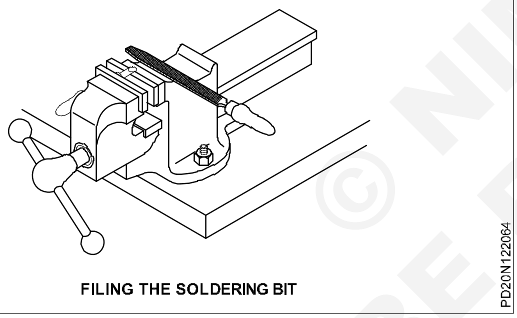
To make a good soldered joint, the bit must be maintained clean, smooth and correctly shaped.

Dressing the bit (Fig 4)**:** To dress an un-plated bit follow the procedure stated below.

- Switch off, unplug the iron and allow it to cool.
- Remove the bit from the iron, if possible.
- Mount the bit in a vice.
- File to shape.

Do not file the bit in an electronic assembly area. Copper dust from the bit may settle in the equipment and cause a short circuit. Iron-plated bits must not be filed. Renew when worn out.

Fig 4

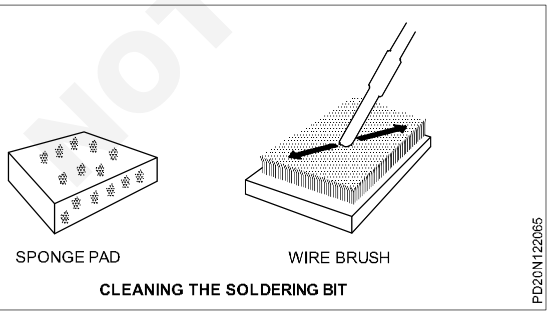


FILING THE SOLDERING BIT

Cleaning the bit: (Fig 5) The bit should be cleaned frequently. To clean the bit, rub the face of the un-plated bits on a wire brush or special sponge pad when the iron is hot.

Iron-plated bits must not be cleaned on a wire brush. Rub on a sponge pad.

Fig 5



CLEANING THE SOLDERING BIT

Wetting (soldering): To make a good joint, the solder must flow evenly over and between the surfaces to be soldered. Wetting is a term used to describe the extent to which this occurs.

Good wetting results can be obtained if:

- the surfaces are clean
- sufficient flux of the correct type is used
- the surfaces are hot enough
- the surfaces have been tinned.

Techniques of soldering

Soldering involves the following main operations.

- Tinning the soldering iron
- Cleaning the parts to be soldered
- Applying the solder

Tinning the soldering iron: To make the solder adhere to the tip of the soldering iron, the surface of the tip must be coated with the solder, and this operation is known as tinning.

First the tip is cleaned with a cloth and heated either directly or indirectly. The tip is then filed to remove the scales, and is wiped again with a cloth.

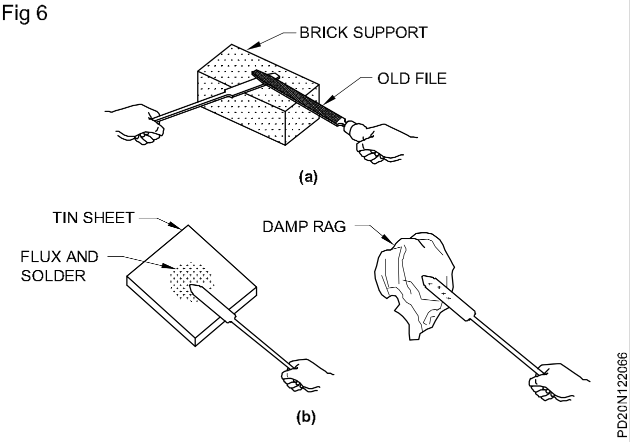
The right temperature for tinning could be judged by the change of colour of the tip when heated. If the surface of the copper tip tarnishes immediately, the temperature is high and needs to be cooled slightly by withdrawing the source of heat temporarily. A correctly heated tip tarnishes slowly.

After the soldering iron tip attains the correct temperature, place a small quantity of solder and the flux on a tin plate and rub the bit on the mixture. The solder should stick to the surface of the tip evenly. Wipe out the superfluous solder with a clean damp cloth.

The whole process of tinning is shown in Figures 6a and 6b.

The surface should present a bright silvery appearance when properly tinned.

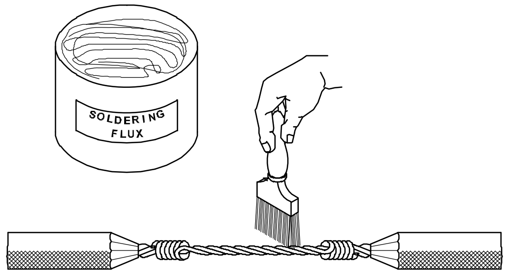
Fig 6



Cleaning the surface to be soldered: The parts to be soldered should be well cleaned for perfect soldering. The scales, dirt, oil and grease should be completely removed either by wiping or by rubbing with a sandpaper. Immediately after cleaning, the flux should be applied on the surface to avoid oxidization.

Applying the flux: The rosin which is recommended as a flux may be sprinkled over the surface to be soldered or may be applied with a brush as shown in the Fig 7.

Fig 7



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Applying the solder: The quantity of the solder to be applied depends upon the size of the job. For small jobs like printed circuit boards soldering or soldering joints in wires of diameter 2 mm or lower, an electric soldering iron is used whereas for soldering joints of large sized cables, pot and ladle are used.

Soldering precautions: Remove the iron as soon as the solder has flowed over the surfaces.

Excessive heating may damage:

- the wire and its insulation
- the component being soldered
- the adjoining components.

Safety

Soldering irons can be dangerous if not maintained or used proprerly. Follow the directions given below.

Inspect the iron regularly for physical damage, especially the power cord. Replace it, if found damaged.

Keep the iron in a stand when not in use. This prevents burns and fires and protects the iron from damage.

Do not subject the iron to rough treatment.

Keep the iron away from all parts of the body and from its own power cord.

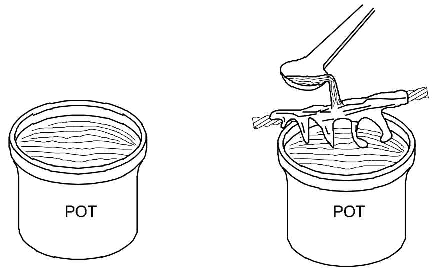
A proper earth connection must be made to all mains-connected irons. If you suspect that an iron is not earthed, do not use the iron.

Never flick excess solder off the bit. The hot solder may cause burns to someone or fall into a part of the work, and cause a short circuit.

Soldering with pot and ladle: (Fig 8) For larger sized jobs like underground cable jointing, a melting pot and ladle are used. The solder is kept in the pot and heated either by a blowlamp or by charcoal. Initially the surface to be soldered is cleaned and a coat of flux is given.

Then the surface to be soldered is heated by pouring molten solder over it in quick succession. The dripping solder is collected in a clean tray. After several pourings, the surface attains the same temperature as that of the molten solder. The flux is again applied and the solder is slowly poured on the surface as it forms an even layer. Superfluous solder collected in the tray is re-melted in the pot.

Fig 8



POT AND LADLE METHOD OF SOLDERING

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Safety

Ensure that the conductor is dry and clean before applying the molten solder, and that it is not allowed to enter the insulation.

Never drop anything, including the metal to be soldered into the bath. Splashes of hot molten solder can cause serious injury. Always wear protective clothing when working with solder baths, like gloves, apron, boots etc. and ensure that no unprotected part of the body touches the pot.

When pouring solder over a joint, keep the ladle low as far as possible to prevent splashing of the molten solder over the sides of the pot.

During the solidification period, the parts of the joint must not be disturbed under any circumstances. If they are disturbed, the strength, conductivity and appearance of the joint will be endangered. The result will be what is often called cold solder and the joint will be defective.

Cooling must not be accelerated. If cooling is accelerated, the solder will assume a crystalline form. This lowers the mechanical strength.

Do not allow the molten solder to fall on to the gas pipe or the electric cables nearby.

Beware of the naked flames to avoid a fire risk.

Reconditioning of solder which is subjected to repeated melting

In practice, when the solder is subjected to repeated melting during the soldering process, the tin content in the solder is considerably reduced due to:

- the slug formation of tin on the molten solder
- oxidization of tin due to its low boiling point.

As such the solder, which is subjected to repeated heating, will have a low percentage of tin as compared with the solder taken from the stores.

To recondition the solder and to bring up the tin percentage, tin is added to the solder at the end of each use. The quantity to be added depends upon the length of time the solder is kept in the molten state.

Soldering aluminium cables

Soldering of aluminium cables: Soldering aluminium conductors is more difficult than soldering copper conductors owing to the highly tenacious, refractory and stable nature of the oxide film which forms immediately on any aluminium exposed to air.

This oxide film does not allow the solder to wet the surface to be soldered, and also prevents the solder from entering the interior surface by capillary action. Hence special solders and fluxes are used for aluminium soldering.

Solder: A special soft solder having a small percentage of zinc is used for joining aluminium conductors. (Soft solders are alloys which have a melting point below 300°C.) IS 5479-1985 gives details of the chemical composition of soft solders and their grades used for soldering aluminium conductors. Details are given in Table 1.

The object of this small zinc content which is a common feature of aluminium solders is to fecilitate the alloying of the solder with an aluminium surface. A typical composition of solder with 51% lead, 31% tin, 9 % zinc and 9% cadmium with the brand name `ALCA P' solder is available in the market for soldering aluminium conductors. In addition a special solder by name Ker-al-lite is also available for soldering aluminium conductors.

Flux: In soldering aluminium conductors, organic fluxes of reaction type, free from chlorides and suitable for soft soldering are used.

The composition of the organic fluxes decomposes at approximately 250°C to effect the removal of the oxide film and also to assist in the spreading of the molten solder to enable tinning the de-oxidised surface immediately.

The major disadvantage of organic flux is that it tends to char at a temp. above 360°C. The charring, thus caused, renders the flux ineffective and gives rise to the danger of creating voids in the joint due to charred flux residues. For this reason, it is essential that the temp. of this solder during the operation is maintained well within 360°C. The commercial name of fluxes used for joining aluminium conductors are Kynal Flux and Eyre No.7.

Procedure of soldering aluminium cables

The procedure of soldering aluminium cables to standard copper lugs employing **Kynal's flux** and **Ker-al-lite** special solder is explained below.

Strip the cable in preparation for jointing in the usual manner.

Spread out the strands so as to effect a general loosening and slight displacement of the wires, and clean the surface preferably with a wire brush.

Apply a small quantity of flux by brushing well into the fanned-out ends of the conductor and baste (moisten) the fluxed conductor with a full ladle of molten solder.

Apply more flux and baste again with the molten solder. Continue to make repeated alternate applications of flux and solder until the wires exhibit a brightly tinned surface free from dull spots.

After the final basting, wipe off the surplus metal from the strands with a clean and dry piece of cloth.

Flux the lug inner surface and fill it with the molten solder.

Insert the tinned end of the cable inside the lug and hold both the cable and the lug firmly without shaking.

Allow the lug to cool and baste the surface quickly with the molten solder to remove the excess solder.

Wipe the lug surface with a clean cloth.

Apply a coating of graphite conducting grease on the lug before using.

Precautions to be followed while soldering aluminium

All surfaces must be scrupulously clean.

When a joint is being made between stranded conductors, the strands must be `stepped' to increase the surface area.

The surface must be fluxed before the heat is applied.

Safety

During the jointing operation copious fumes are given off when the flux is heated. These fumes contain small quantities of fluorine, and it is, therefore, advisable not to inhale them.

As smoking during the jointing operation results in the inhaling of toxic fumes, smoking during soldering should be avoided.

Table 1

Grade	% of alloying elements			Melting temp.	Flux type	Applications
	Zinc	Lead	Tin	in °C		
SnPb53Zn	1.75–2.25	52–54	45.71–45.21	170–215	Organic	Conductors of electrical cables
SnPb58Zn	1.75–2.25	57–59	40.66–40.6	175–220		-do-

Ohm's law - simple electrical circuits and problems

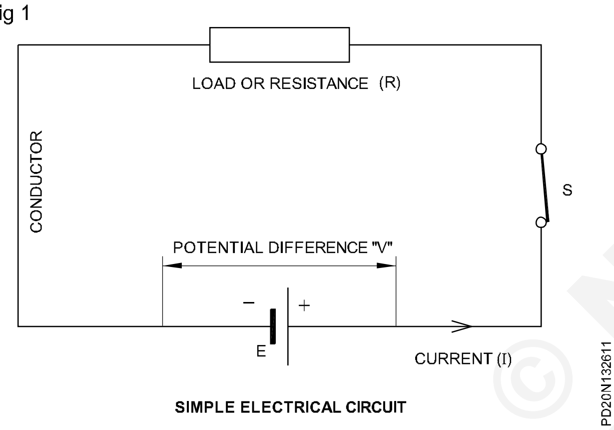
Objectives: At the end of this lesson you shall be able to
- **describe the essential factors in an electrical circuit**
- **state the relation between circuit factors through Ohm's law**
- **apply Ohm's law in an electric circuit.**
- **define electrical power and energy and calculate related problems**

Simple electric circuit

In the simple electric circuit shown in Fig 1, the current completes its path from the positive terminal of the battery via the switch and the load back to the negative terminal of the battery.

The circuit shown in Fig 1 is a closed circuit. In order to make a circuit to function normally the following three factors are essential.

Fig 1



SIMPLE ELECTRICAL CIRCUIT

- Electromotive force (EMF) to drive the electrons through the circuit.
- Current (I), the flow of electrons.
- Resistance (R) - the opposition to limit the flow of electrons.

Ohm's law

In 1826 George Simon Ohm discoverd that for metallic conductor, there is a substantially constant ratio of the potential difference between the ends of the conductor

Ohm's law gives the relation between the voltage, current and resistance of a circuit.

Ohm's law states that the ratio of the voltage (V) across any two points of a circuit to the current (I) flowing through is constant provided physical conditions, namely temperature etc. remain constant. This constant is denoted as resistance (R) of the circuit.

(or)

In simple,

Ohm's law states that in any electrical closed circuit, the current (I) is directly proportional to the voltage (V), and it is inversely proportional to the resistance 'R' at constant temperature.

(ie) I α V (When 'R'

is kept constant)

I α R (When 'V' is kept constant)

I α V/R (Relation between I,V and R)

$$I \propto \frac{V}{R}$$

It means I = V/R

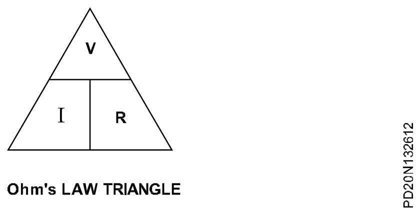
V = Voltage applied to the circuit in 'Volt'

I = Current flowing through the circuit in 'Amp'

R = Resistance of the circuit in Ohm (Ω)

The above relationship can be referred to in a **triangle** as shown in Fig 2. In this triangle whatever the value you want to find out, place the thumb on it then the position of the other factors will give you the required value.

Fig 2



Ohm's LAW TRIANGLE

For example for finding 'V' close the value 'V' then readable values are IR, so V = IR.

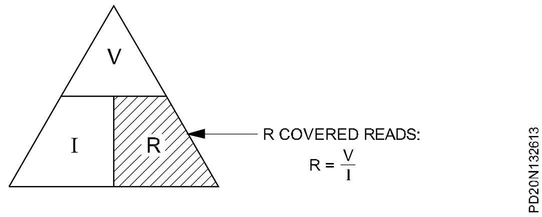
Again for finding 'R', close the value R, then readable values are V/I so R = V/I, like that $I = \frac{V}{R}$.

Written as a mathetical expression, Ohm's Law is

$$\text{Resistance} = \frac{\text{Voltage (V)}}{\text{Current (I)}} \text{ (Refer Fig 3)}$$

$$\text{(or) } R = \frac{V}{I} \text{ (Refer Fig 3)}$$

Fig 3

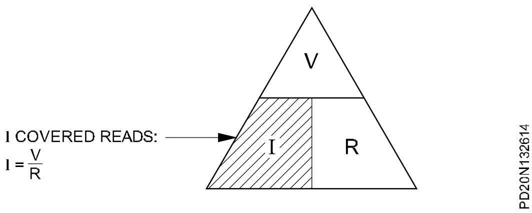


Of course, the above equation can be rearranged as:

$$\text{Current (I)} = \frac{\text{Voltage (V)}}{\text{Resistance (R)}}$$

$$\text{(or) } I = \frac{V}{R} \text{ (Refer Fig 4)}$$

Fig 4

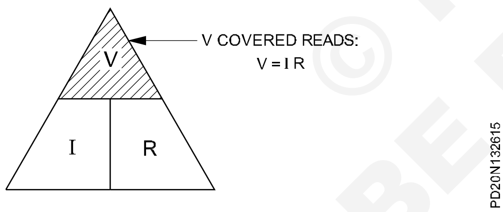


In the same way, 'V' can be found by covering 'V'

Voltage (V) = Current (I) x Resistance (R)

or V - IR (Refer Fig 5)

Fig 5

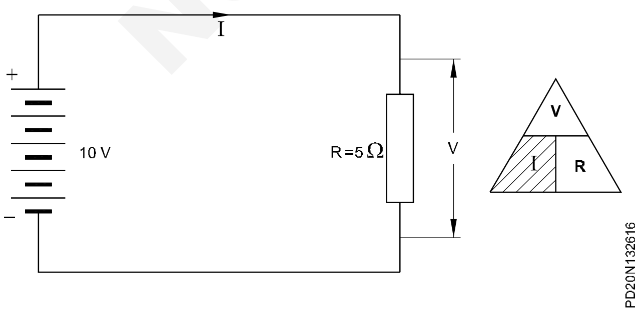


Application of Ohm's law in circuits

Example 1

Let us take a circuit shown in Fig 6 having a source of 10V battery and a load of 5 Ohms resistance. Now we can find out the current through the conductor.

Fig 6



$$I \propto \frac{V}{R}$$

$$I = \frac{V}{R}$$

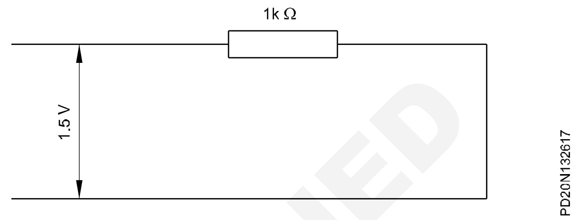
$$I = \frac{10}{5} = 2 \text{ amp}$$

Example 2

How much current (I) flows in the circuit shown in Fig 7

Given:

Fig 7



Voltage (V) = 1.5 Volts

Resistance (R) = 1 kOhm

= 1000 Ohms

Find : Current (I)

Known

$$I = \frac{V}{R}$$

Solution:

$$I = \frac{1.5\text{ V}}{1000\text{ Ohms}} = 0.0015 \text{ amp}$$

Answer:

The current in the circuit is 0.0015 A

or

the current in the circuit is 1.5 milliampere (mA)

(1000 milliamps = 1 ampere)

Problem

Find the value of voltage across a 10 Ohms resistor in the circuit shown in Fig 8. When the current of 2 Amps flows through the 10 Ohm resistor

Solution

Voltage across 10 Ohm

V= I x R

= 2 x 10

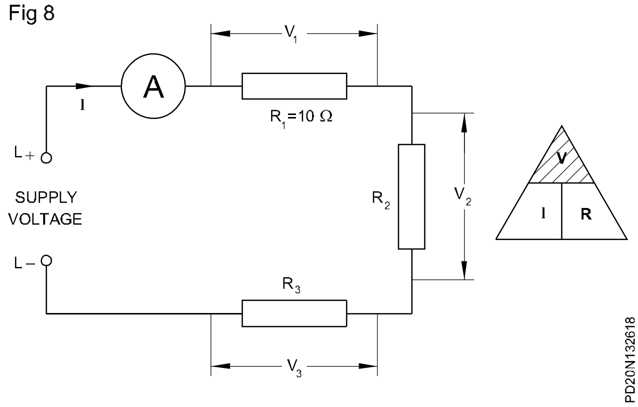
= 20 Volt

Similarly if the value of the other resistance is known we can find the voltage drop across them.

Extreme circuit conditions

Two important extreme conditions can occur in a circuit.

Fig 8



Open circuit

In an open circuit, there is an infinitely high resistance in the circuit. This condition can happen in a circuit when the switch is open. Therefore, no current of flow.

For example, a generator is said to be in an open circuit when the switch is open and running without supplying current to the circuit. A wall socket, too, is an open circuit if the control switch of the wall socket is 'OFF'or 'ON' position provided there is no appliance plugged to the wall socket.

Short circuit

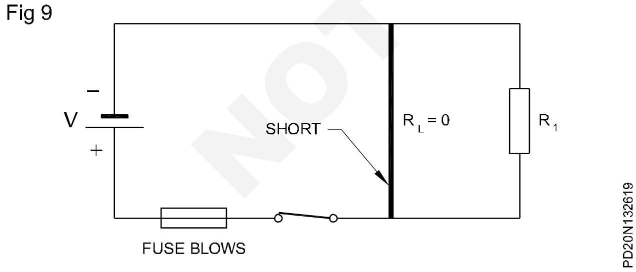
The other important extreme condition is the short circuit. A short circuit will occur, for example, when the two terminals of a cell are joined (Fig 9). A short circuit may also occur if the insulation between the two cores of a cable is defective.

The resulting negligible resistance will cause large currents which can become a hazard. A fuse, if provided in the circuit as shown in Fig 9, could then blow and automatically open the circuit.

Practical application

The knowledge gained by this exercise can be applied to calculate the current drawn by a particular load resistance when the supply voltage is known. This will enable the technician to select a proper size of cable for the circuit.

Fig 9



Electrical Power (P) & Energy (E)

The product of voltage (V) and current (I) is called electrical power. Electrical power (P) = Voltage x Current P=V x I

The unit of Electrical power is 'Watt' It is denoted by the letter 'P' It is measured by Watt meter. The following formulae can also be derived from formula of power (P) as

(i) $P = V \times I$

$= IR \times I$

$P = I^2 R$

(ii) $P = V \times I$

$= V \times \dfrac{V}{R}$

$P = \dfrac{V^2}{R}$

Electrical Energy (E)

The product of power (P) and time (t) is called as electrical energy (E)

Electrical Energy (E) = Power x time

$E = P \times t$

$= (V \times I) \times t$

$E = V \times I \times t$

The unit of electrical energy is "Watt hour" (Wh)

The commercial unit of Electrical energy is "Kilo watt hour" (KWH) or unit

B.O.T (Board of Trade) unit / KWH/Unit

One B.O.T (Board of Trade) unit is defined as that one thousand watt lamp is used for one hour time, it consumes energy of one kilowatt hour (1kWH). It is also called as **"unit"**

Energy = 1000W x 1Hr = 1000WH (or) 1kWH

Example - 1

How much electrical energy is consumed in an electric iron rated as 750W/250V used for 90 Minutes

Given:

Power (P)	= 750W
Voltage (V)	= 250V
Time	= 90min (or) 1.5Hr

Find:

Electrical Energy (E) = ?

Solution:

Electrical Energy (E)	= P x t
	=750 w x 1.5Hr
	= 1125 WH (or)
E	= 1.125 kWH

Example 2

Calculate the power of a lamp, which takes a current of 0.42 Amp at 240 V supply

Given:

Voltage (V) = 240 V

Current (I) = 0.5 A

Find:

Power(P) = ?

Solution:

P = V X I

= 240 x 0.42

= 100.8W

Hence, Power (P) = 100 W (approx)

Example 3:

Calculate the hot resistance (R) of the 200W/250V rated bulb?

Given:

Power (P) = 200 W

Voltage (V) = 250 V

Find:

Resistance (R) = ?

Solution:

$$P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{250 \times 250}{200}$$

(R) Resistance = 312.5 Ohm (Ω)

Example 4

In a house, the following electrical loads are daily used:-

(i) 5 Nos of 40W Tube Lights used for 5 hours/day

(ii) 4 Nos of 80W fans used for 8 hours/day

(iii) 1 No of 120W T.V. receiver used for 5 hours/day

(iv) 4 No of 60W lamps used for 4 hours/day

Calculate the total energy consumed in unit's per day and also the cost of electric bill for the month of January If the cost of energy is 1.50/unit

Given

Load details per day

Electric Device	Power	Numbers	Time in hours
(i) Tube light	40W	5	5 hr/day
(ii) Fans	80W	4	8 hr/day
(iii) T.V.	120W	1	6 hr/day
(iv) Lamps	60W	4	4 hr/day

cost of energy - Rs.1.50/unit

Find:

(i) Energy consumption in unit per day = ?

(ii) Cost of energy for the month of January = ?

Solution

Energy consumption/day

1. Tube light = 40W x 5 x 5 hr /day

$$= \frac{1000\ wh}{1000} = 1Kwh/day$$

2. Fans = 80W x 4x8 hr/day

$$= \frac{2560}{1000} = 2.56Kwh/day$$

3. T.V. = 120W x 1x6 hr/day

$$= \frac{720\ wh}{1000} = 0.72Kwh/day$$

4. Lamp = 60W x 4x4 hr/day

$$= \frac{960}{1000} = Kwh = \frac{0.96kwh/day}{5.24kwh/day}$$

(i) Total energy consumption in unit per day = 5.24 unit

(ii) Total energy consumption for the month of January (i.e 31 days) = 5.24 x 31 = 162.44 units

Cost of energy = Rs. 1.50/unit

Total electric bill for the month of January = 162.44 x 1.50 = Rs.243.66

Electricity Bill for the month = Rs. 244/-

Assignment :

Note : The instructor may ask the trainees to prepare electric bill for the current month for his house (or) any building.

Work, Power and Energy

Work is said to be done, when a force (F) displaces a body from one distance (s) to another (or)

Work done = Force x distance moved

w.d = F x S

It is generally denoted as "W"

The unit of work done is

(i) In Foot Pound Second (F.P.S) System is "Foot Pound (lb.ft)"

(ii) In Centimetre Gram Second (C.G.S) System "Gram Centimetre (gm.cm)" or

1 gm.cm = 1 dyne

1 dyne = 10^7 ergs

The smallest unit of work done is **"Erg"**

(iii) In Metre - Kilogram - Second (M.K.S.) System is "Kilogram Metre (Kg-M)'

1 Kilogram = 9.81Newton

(iv) In system of international unit (S.I. Unit) is 'Joule'

1 Joule = 1 Newton Metre (Nw-M)

Power (P)

The rate of doing work is called as Power (P)

Power (P) = work done / time taken

$$F = \frac{F \times S}{t}$$

It's unit is Lb.ft/sec in FPS system

gm-cm/sec is in C.G.S. System

(or)

Dyne/sec

(or)

Kg-M/sec in M.K.S System (or) NW - M/ sec

(1kg = 9.81 Newton)

Joule/sec in (S.I)

1 Joule/Sec = 1 watt

Electrical Power = VI Watt

The unit of Mechanical power is "Horse Power" (H.P)

Horse Power (HP) further classified into two:

They are:-

Indicated Horse Power - (IHP)

Brake Horse Power - (BHP)

Indicated Horse Power (IHP)

The power developed inside the engine (or) pump (or) motor is called Indicated Horse Power (IHP)

Brake Horse Power (BHP)

The useful Horse Power which is available at the shaft of the engine/motor/pump is called Brake Horse Power (BHP)

So, IHP is always greater than

BHP due to friction losses

IHP > BHP

The relation between Mechanical and Electrical Power

(ie) 1 HP (British) = 746 Watt

1 HP (Metric) = 735.5 Watt

One HP (Metric)

The amount of Mechanical Power required to move/ displace a body/substance by force of 75 Kg to one metre distance in one second is called as one HP (metric)

HP (Metric) = 75kg - M/Sec

One HP (British)

The amount of Mechanical power required to move/ displace a body/substance of force 550lb to one foot (ft) distance in one second is called as one HP (British)

1 HP (British) = 550 lb.ft/sec

Energy

$$E = \frac{\text{workdone}}{\text{time}} \times \text{time}$$

The capacity for doing work is called as electrical Energy

(or)

The product of power and time is known as Electrical energy

(ie) Energy = Power x time

Electric - energy = Power x time

= VI x t

S.I unit of energy is "Joule"

(ie) Energy = (Joule/sec) x sec

$$= \frac{\text{Joule}}{\text{Sec}} \times \text{Sec} = \text{joule}$$

(ie) The S.I of unit of work done and energy is same (Joule)

The energy can be divided into two main categories (ie)

(i) Potential Energy (eg. Loaded gun, energy (stored in spring etc)

(ii) Kinetic Energy (eg. Moving of car, raining etc).

Kirchhoff's law and its applications

Objectives: At the end of this lesson you shall be able to
- **state Kirchhoff's first law**
- **apply Kirchhoff's first law to find the circuit current**
- **state Kirchhoff's second law and apply the same to find the voltage drop in branches**
- **solve problems by applying Kirchhoff's laws.**

Kirchoff's laws are used in determinig the equivalent resistance of a complex network and the current flowing in the various conductors.

Kirchhoff's laws

Kirchhoff's first law: At each junction of currents, the sum of the incoming currents is equal to the sum of the outgoing currents. (Figs 1 & 2) (or) The algebric sum of all branch currents meeting at a point/node is zero

Fig 1

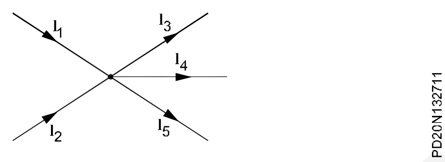
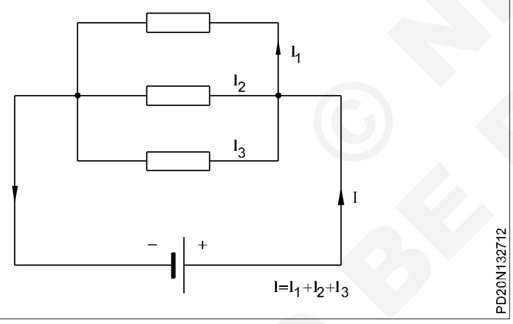


Fig 2



If all inflowing currents have positive signs and all out-flowing currents have negative signs, then we can state that

$$I_1 + I_2 = I_3 + I_4 + I_5$$

$$+I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

In the above example the sum of all the currents flowing at the junction (node) is equal to zero.

$$\Sigma I = 0$$

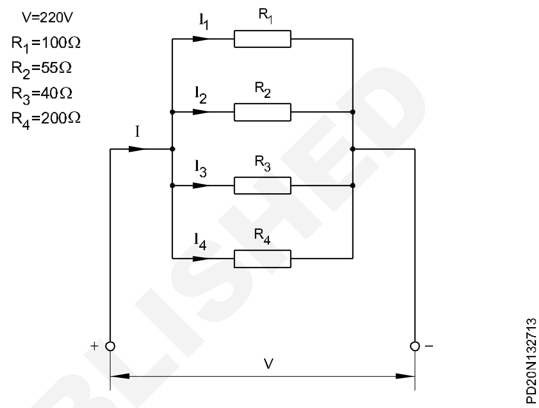
$$I = I_1 + I_2 + I_3 + \ldots\ldots\ldots\ldots\ldots\ldots$$

Example: Apply Kirchhoff's First Law to find the current shown in circuit Fig 3.

Find current

$$I, I_1, I_2, I_3, I_4$$

Fig 3



Solution

$$I_1 = \frac{V}{R_1} = \frac{220\ V}{100\ ohms} = 2.2A$$

$$I_2 = \frac{V}{R_2} = \frac{220\ V}{55\ ohms} = 4A$$

$$I_3 = \frac{V}{R_3} = \frac{220\ V}{40\ ohms} = 5.5A$$

$$I_4 = \frac{V}{R_4} = \frac{220\ V}{200\ ohms} = 1.1A$$

$$I = I_1 + I_2 + I_3 + I_4$$

$$= 2.2A + 4A + 5.5A + 1.1A = 12.8A$$

Checking the calculation

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$= \frac{1}{100} + \frac{1}{55} + \frac{1}{40} + \frac{1}{200}$$

$$= \frac{22 + 40 + 55 + 11}{2200} = \frac{128}{2200} = \frac{16}{275}$$

$$\frac{1}{R_{TOT}} = \frac{16}{275}$$

$$R_{TOT} = 17.19\ ohms$$

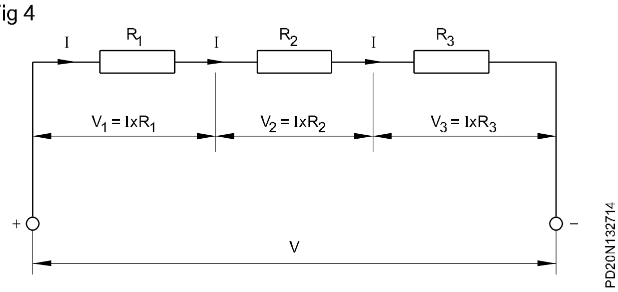
$$I = \frac{V}{R_{TOT}} = \frac{220V}{17.19 \text{ ohms}} = 12.798 \text{ A}$$

Kirchhoff's second law

A simple case: In closed circuits, the applied terminal voltage V is equal to the sum of the voltage drops V_1+V_2 and so forth. (Fig 4)

If all the generated voltages are taken as positive, and all the consumed voltages are taken as negative, then

Fig 4



it can be stated that:

in each closed circuit the sum of all voltages is equal to zero.

$$\Sigma V = 0$$

Example

Given

$V = 220V$
$R_1 = 36$ ohms
$R_2 = 40$ ohms
$R_3 = 60$ ohms
$R_4 = 50$ ohms

Find

$R, I, I_1, I_2,$

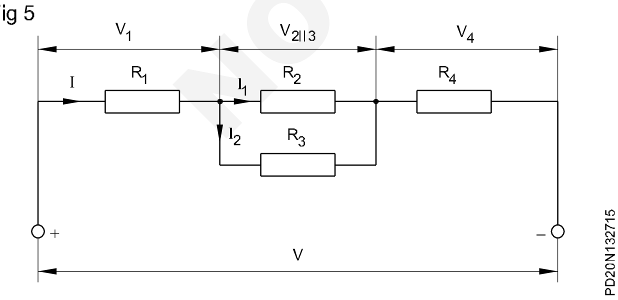
$V_1, V_{2||3}, V_4$

Solution

Apply Kirchhoff's First Law to find the voltage drops in the branches (Fig 5).

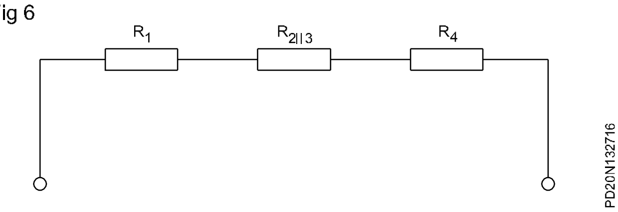
Calculate the total resistance R of the series circuit according to Kirchhoff's Second Law. (Fig 6)

Fig 5



First simplify by calculating the equivalent resistance for R_2, R_3 according to Kirchhoff's First Law.

Fig 6



$$R_{2||3} = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{40 \text{ ohms} \times 60 \text{ ohms}}{(40+60) \text{ ohms}}$$

$= 24$ ohms

$R_{TOT} = R_1 + R_{2||3} + R_4$

$= 36$ ohms $+ 24$ ohms $+ 50$ ohms

$= 110$ ohms

The total current I can now be calculated by means of Ohm's Law:

$$I = \frac{V}{R_{TOT}} = \frac{220 \text{ V}}{110 \text{ ohms}} = 2\text{A}$$

The partial voltages are accordingly:

$V_1 = I \times R_1 = 2A \times 36$ ohms $= 72$ V

$V_{2||3} = I \times R_{2||3} = 2A \times 24$ ohms $= 48$ V

$V_4 = I \times R_4 = 2A \times 50$ ohms $= 100$ V

Checking the calculation

$V = V_1 + V_{2||3} + V_4$

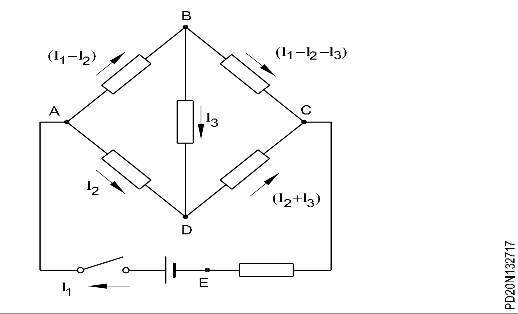
220 V $= 72V + 48V + 100$ V

220 V $= 220$ V

Suggested steps for the application of Kirchhoff's Laws to solve problems.

1. Mark the nodes (junction points) in the given network.
2. Mark the current direction over each element (resistor) in the circuit. The current direction is arbitrary. But it is often convenient to use a direction that goes from –ve to +ve through an emf.
3. Indicate the loop currents with I_1, I_2, I_3 etc. Apply Kirchhoff's First Law to the junction nearer to it. (Fig 7)
4. Once the current and its direction are marked over an element, keep it the same until the problem is solved.

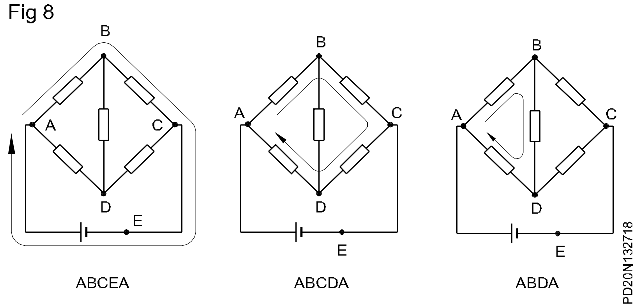
Fig 7



5 Select the windows, (closed loops) in the circuit and name the window. eg. Fig 8.

6 Each element should be included atleast once in any one of the closed loops selected in the above step.

Fig 8



7 Raise in potential is considered as +ve. A drop (fall) in potential is considered as –ve.

8 Trace around each loop and write Kirchhoff's Voltage Law equation. For such tracing to be complete, one should return to the starting point.

9 While tracing, the direction of movement is important.

For the source of emf

A **raise in potential** occurs when moving from the –ve to the +ve terminal of a source. Therefore the value is positive.

A **drop in potential** occurs when moving from a +ve to a –ve terminal of a source. Therefore the value is negative.

The current direction is not considered to fix the potential-raise or potential-drop across a source of emf.

For the resistors

A drop in potential occurs when moving across the resistor in the same direction as that of the current through the resistor. Therefore the value is negative.

A raise in potential occur when moving across the resistor in the opposite direction to that of the current through the resistor. Therefore, the value is positive.

The direction of movement while tracing the loop and related current direction in each element is important. The polarity of the source of emf is not considered to fix the potential raise or drop across a resistor.

10 Solve the equations to determine the current through each element.

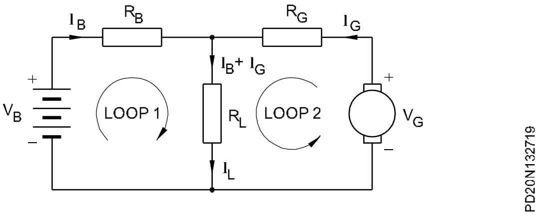
Example 1: A battery of open-circuit voltage V_B and internal resistance R_B is connected in parallel with a generator of open-circuit voltage V_G and internal resistance RG. This combination feeds load resistance R_L. For the following values find the battery current, generator current, load current and load voltage.

V_B = 13.2 V, V_G = 14.5 V, $_{RB}$ = 0.5 Ω and R_L = 2 Ω, R_G = 0.1 - 2 Ω

Solution

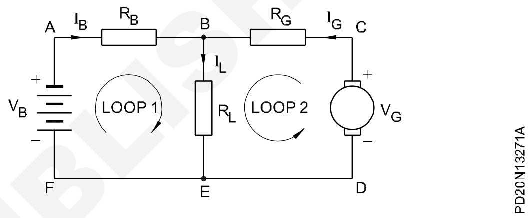
1 Draw a circuit diagram. (Fig 9)

Fig 9



2 It can be seen from Fig 9 that there are two `windows' loops in the circuit. this means that we must show two currents, one in each loop, in any arbitrary direction. (We shall show currents I_B and I_G in the direction we think the current might flow). (Fig 10)

Fig 10



3 Using Kirchoff's Current Law, we can identify the current through the load resistor as

$I_L = I_B + I_G$.

Indicate this current in Fig 10.

4 Show the polarity signs of the voltage drops across each resistor using the assumed directions of the current. (Fig 10)

5 Indicate, in each window, a current loop that goes around a complete circuit. The direction is arbitrary, but it is often convenient to use a direction that goes from - to + through an emf. (See loops 1 and 2 in Fig 8).

6 Trace around each loop, writing Kirchhoff's Voltage Law equation by applying the following basic principles

- If you encounter - V_G of the voltage source first then the +ve of the source while tracing through a loop take the source as +ve.
- If you encounter positive of the source first and then negative of the source while tracing through a loop take the source is negative.
- When you trace a voltage drop in the same direction of current take the voltage drop as negative.
- When you trace a voltage drop in the opposite direction of current take the voltage drop as positive.
- Form clear loops denoting the line of tracing starting with alphabet `A' then after completing the

path end with `A'.

Refer Fig 10. Let us start from first loop starting with A and ending with A.

i.e. ABEFA

Applying the above principles

A to B = $-\ I_B R_B$ (Voltage drop alongwith current direction)

B to E = $-\ I_L R_L$ -do-

E to F = 0

F to A = $+V_B$ (First negative and then positive of the source in the direction of current)

Hence for first loop, we have

$-I_B R_b - I_L R_L + V_B = 0$ ....Eqn. (1)

OR

$= I_B R_B + (I_B + I_G) R_L$ .... Eqn. (2)

For loop 2 we have C B E D C

$-I_G R_G - I_L R_L + V_G = 0$ .... Eqn. (3)

$-I_G R_G - (I_B + I_G) R_L + V_G = 0$

VG $= I_G R_G + (I_B + I_G) R_L$ .... Eqn. (4)

Insert in eqn. (2) and (4) the numerical values we have

$13.2 = 0.5 I_B + 2(I_B + I_G)$ .... Eqn. (5)

$14.5 = 0.1 I_B + 2(I_B + I_G)$ ... Eqn.(6)

Collect together like terms and solve for I_G I_B

$13.2 = 2.5 I_B + 2 I_G$ .... Eqn. (7)

$14.5 = 2 I_B + 2.1 I_G$ .... Eqn.(8)

Multiply eqn.(7) by 2 and eqn. (8) by 2.5 we have

$26.4 = 5 I_B + 4 I_G$ ..... Eqn.(9)

$36.25 = 5 I_B + 5.25 I_G$ .....Eqn.(10)

Subtract eqn.(9) from eqn. (10) we have

$36.25 = 5 I_B + 5.25 I_G$

$26.4 = 5 I_B + 4 I_G$

$9.85 = 1.25\ I_G$

$I_G = \frac{9.85}{1.25} = 7.88$ amps

Substituting the value $I_G = 7.88$ in eqn. (9) we have

$26.4 = 5 I_B + 4 \times 7.88$

$= 5 I_B + 31.52$

$26.4 - 31.52 = 5 I_B$

$-5.12 = 5\ I_B$

$I_B = \frac{-5.12}{5}$

$= -1.024$ amps

Minus sign in the answer indicates that the battery is not sending any current but receives a charging current of 1.024 amps.

Accordingly current supplied by the generator

I_G = 7.88 amps

Current taken by the battery I_B (Battery in getting charged) = 1.024 amps

Load current I_L $= I_B + I_G$

where I_B = –1.024 amps

I_G = +7.88

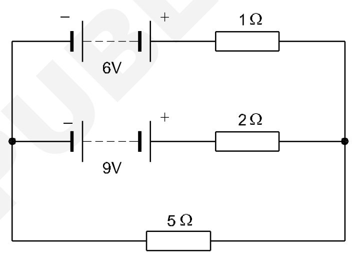
I_L = (–1.024 + 7.88)

= 6.856 amps

Voltage across the load $= I_L R_L$

= 6.856 x 2

Fig 11



= 13.712 volts

Example 2: For the given circuit in Fig 11, determine the following

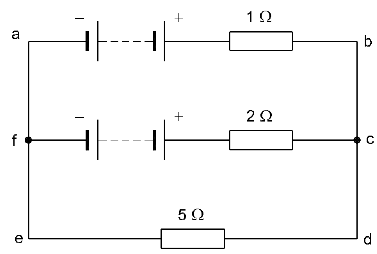
1 Mark the nodes and name the closed loops.

2 Name and mark the direction of current in the element following Kirchhoff's First Law.

3 Trace around each loop and write Kirchhoff's 2nd law.

4 Solve the problem using simultaneous equation to find the current delivered or received by the battery 6 V and 9 V.

Fig 12

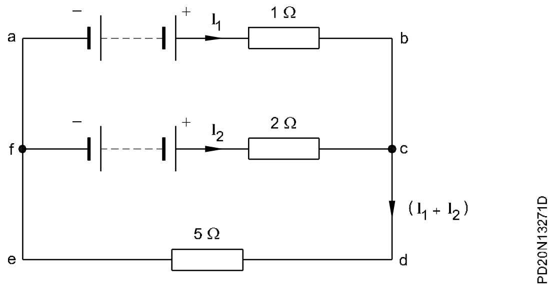


5 Find the current passing through the 5 ohm resistor.

6 Cross check your calculation.

i The nodes are marked and the closed loops are named (Fig 12)

Fig 13



Loop 1 = a b c d e f a

Loop2 = f c d e f

ii Direction of current is marked (Fig 13)

Loop 1 – a b c d e f a

$+6 - 1I_1 - 5(I_1 + I_2) = 0$

$+6 - I_1 - 5I_1 - 5I_2 = 0$

$+6 - 6I_1 - 5I_2 = 0$

$6I_1 + 5I_2 = 6$ .... Eqn.(1)

Loop 2- f c d e f

$+9 - 2I_2 - 5(I_1 + I_2) = 0$

$9 - 2I_2 - 5I_1 - 5I_2 = 0$

$9 - 5I_1 - 7I_2 = 0$

$5I_1 + 7I_2 = 9$ .... Eqn. (2)

iv Multiplying eqn. (2) by 6 and eqn. (1) by 5 we have

$5I_1 + 7I_2 = 9 \times 6$

$6I_1 + 5I_2 = 6 \times 5$

$30I_1 + 42\,I_2 = 54$ .... Eqn. (3)

$30I_1 + 25I_2 = 30$ .... Eqn. (4)

Substracting equation 4 from eqn.3 we have

$17I_2 = 24$

$I_2 = \frac{24}{17} = 1.41$ amps

Substituting I_2 = 1.41 in eqn. 1 we have

$6I_1 + 5(1.41) = 6$

$6I_2 + 7.05 = 6$

$6I_1 = 6 - 7.05 = -1.05$

$I_1 = -0.175$ amps.

As the current value of I_1 is minus sign the current is assumed to flow in opposite direction to the asumed direction

Only the 9V battery delivers current
while the current received by the 6 V battery
= 0.175 amps.

Current delivered by 9 V battery = 1.41 amps

Current passing through 5 ohms resistor

$I_1 + I_2 = -0.175 + 1.41$

$= 1.235$ amps

PD across 5 ohm resistor = 1.235 x 5 = 6.175 V.

Cross check

Taking loop 3 a b c f a

$+6 - I_1 + 2\,I_2 - 9 = 0$

$6-(-0.175)+2.82-9=0$

$8.995 - 9 = 0$

As the values are more or less the same verified by cross checking and found to be core.

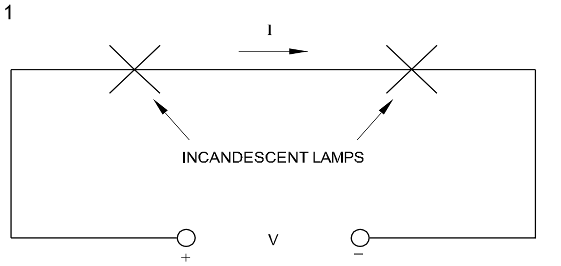
DC series and parallel circuits

Objectives: At the end of this lesson you shall be able to
- **state the characteristics of series circuit and determine the current and voltage across each resistors**
- **determine the total voltage sources in series circuit**
- **state the relation between EMF potential difference and terminal voltage**
- **determine the polarity of voltage drops with respect to ground**

The series circuit

If more than one resistors are connected one by one like a chain and if the current has only one path is called as series circuit. It is possible to connect two incandescent lamps in the way shown in Fig 1. This connection is called a series connection, in which the same current flows in the two lamps.

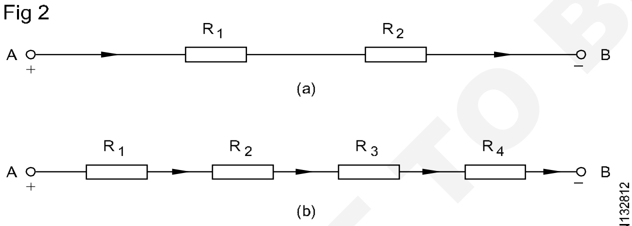
Fig 1



SERIES CIRCUIT WITH LAMPS

The lamps are replaced by resistors in Fig 2. Fig 2 (a) shows two resistors are connected in series between point A and point B. Fig 2(b) shows four resistors are in series. Of course, there can be any number of resistors in a series connection. Such connection provides only one path for the current to flow.

Fig 2



SERIES CIRCUIT WITH RESISTORS

Identifying series connections

In an actual circuit diagram, a series connection may not always be as easy to identify as those in the figure. For example, Fig 3(a), 3(b), 3(c) & 3(d) shows series resistors drawn in different ways. In all the above circuits we find there is only one path for the current to flow.

Current in series circuits

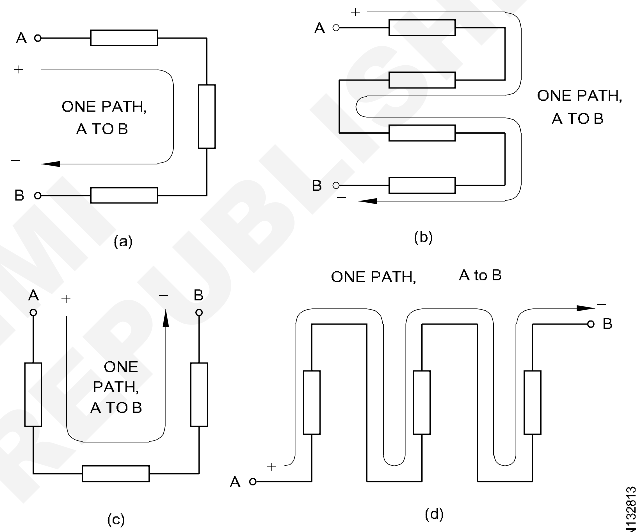
The current will be the same at any point of the series circuit. This can be verified by measuring the current in any two points of a given circuit as shown in Figs 4(a) and 4(b). The ammeters will show the same reading.

The current relationship in a series circuit is

$$I = I_{R1} = I_{R2} = I_{R3}. \text{ (Refer Fig 4a \& 4b)}$$

We can conclude that there is only one path for the current to flow in a series circuit. Hence, the current is the same throughout the circuit.

Fig 3



CURRENT IN SERIES CIRCUIT

Total resistance in series circuit

You know how to calculate the current in a circuit, by Ohm's law, if resistance and voltage are known. In a circuit consisting of two resistors R_1 and R_2 we know that the resistor R_1 offers some opposition to the current flow. As the same current should flow through R_2 in series it has to overcome the opposition offered by R_2 also.

If there are a number of resistors in series, they all oppose the flow of current through them.

The 2nd characteristic of a DC series circuit could be written as follows (R).

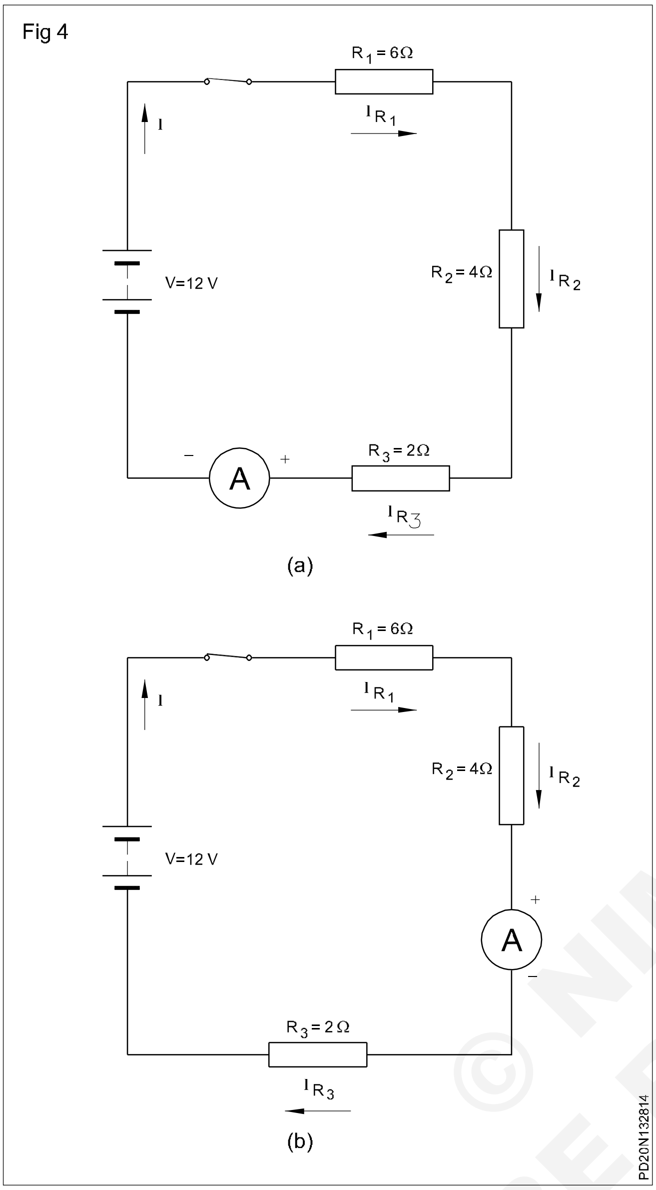
The total resistance in a series circuit is equal to the sum of the individual resistances around the series circuit. This statement can be written as

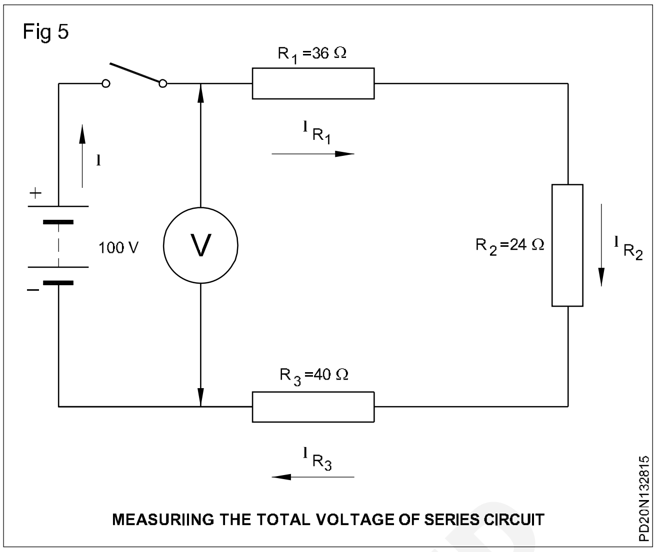
$R = R_1 + R_2 + R_3 + ...R_n$

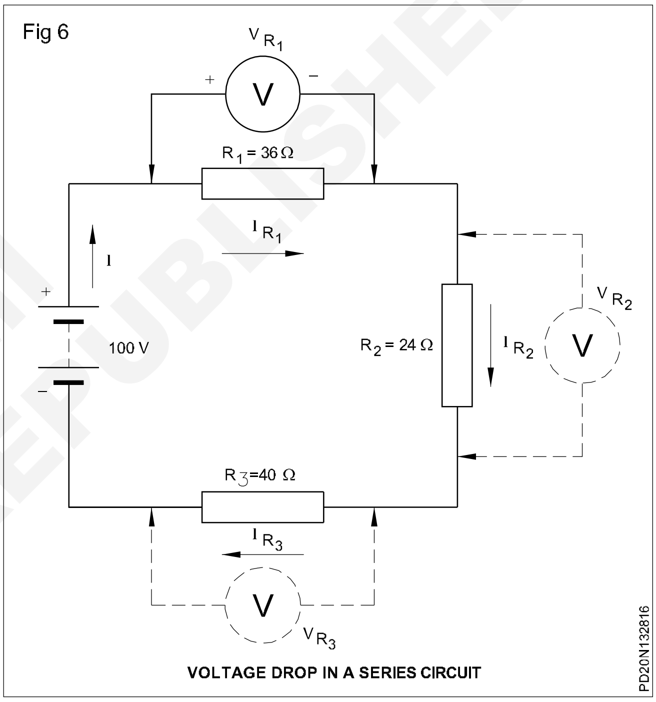
where R is the total resistance

$R_1, R_2, R_3,.......R_n$ are the resistors connected in series.

When a circuit has more than one resistor of the same value in series, the total resistance is $R = r \times N$







where 'r' is the value of each resistor and N is the number of resistors in series.

Voltage in series circuits

In DC circuit voltage divides up across the load resistors, depending upon the value of the resistor so that the sum of the individual load voltages equals the source voltage.

The 3rd characteristic of a DC circuit can be written as follows.

As the source voltage divides/drops across the series resistance depending upon the value of the resistances

$$V = V_{R1} + V_{R2} + V_{R3} + \ldots\ldots\ldots V_{RH}$$

the total voltage of a series circuit must be measured across the voltage source, as shown in Fig 5.

Voltages across the series resistors could be measured using one voltmeter at different positions as illustrated in Fig 6.

When Ohm's law is applied to the complete circuit having an applied voltage V, and total resistance R, we have the current in the circuit as

$$I = \frac{V}{R}$$

Application of Ohm's law to DC series circuits

Applying to Ohm's law to the series circuit, the relation between various currents could be stated as below

$$I = I_{R1} = I_{R2} = I_{R3}$$

This could be stated as $\frac{V}{R} = \frac{V_{R1}}{R_1} = \frac{V_{R2}}{R_2} = \frac{V_{R3}}{R_3}$

You can use any of the above formulae to calculate current in a series circuit.

We know the total supply voltage

$V = V_{R1} + V_{R2} + V_{R3}$

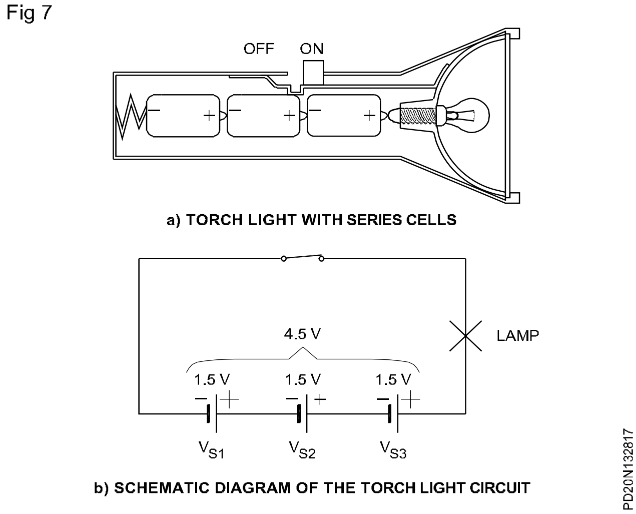
i.e. $IR = R_1 I_{R1} + R_2 I_{R2} + R_3 I_{R3}$

and Total resistance $R = R_1 + R_2 + R_3$.

Voltage sources in series

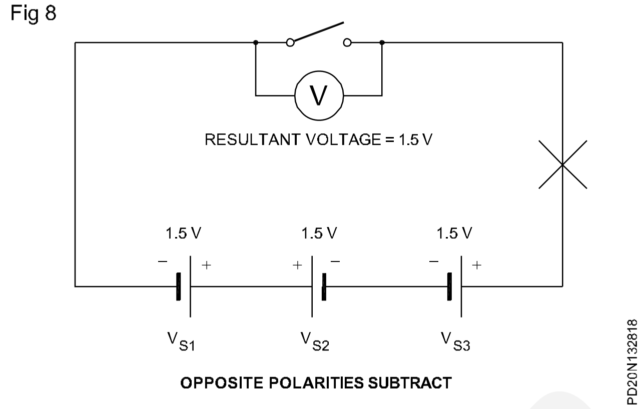
When cells are placed in a torch light, they are connected in series to produce a higher voltage as shown in Fig 7.

Fig 7



Series voltage sources are added when their polarities are in the same direction and or subtracted when their polarities are in the opposite direction. For example, if one of the ends of the cell, say V_{S2} in a torch light is wrongly placed in polarity as indicated in the schematic of Fig 8 its voltage to be subtracted as follows.

Fig 8



$V_{Total} = V_{S1} - V_{S2} + V_{S3}$

$= 1.5\text{ V} - 1.5\text{ V} + 1.5\text{ V}$

$= 1.5\text{ V}$

Use of series connection

1 Cells in torch light, car batteries, etc.

2 Cluster of mini-lamps used for decoration purposes.

3 Fuse in circuit.

4 Overload coil in motor starters.

5 Multiplier resistance of a voltmeter.

Polarity of IR voltage drops

Definitions

Electromotive force (emf)

We have seen that the electromotive force (emf) of a cell is the open circuit voltage, and the potential difference (PD) is the voltage across the cell when it delivers a current. The potential difference is always less than the emf.

Potential difference

PD = emf – voltage drop in the cell

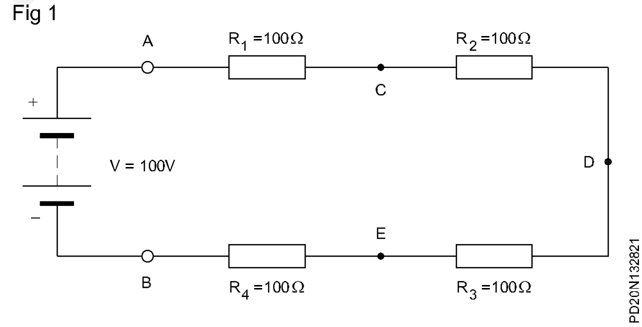
Potential difference can also be called by another term, the terminal voltage, as explained below.

Terminal voltage

It is the voltage available at the terminal of the source of supply. Its symbol is V_T. Its unit is also the volt. It is given by the emf minus the voltage drop in the source of supply,

i.e. $V_T = \text{emf} - IR$

Fig 1



where I is the current and R the resistance of the source.

Voltage drop (IR drop)

The voltage lost by resistance in a circuit is called the Voltage drop or IR drop.

Example 1

The resistances and applied voltage are known. (Fig 1)

The voltage drops across the resistors

The total resistance of the circuit in Fig 1 would be equal to R_T = 100 + 100 + 100 + 100 = 400 ohms.

The current flowing through the circuit would be

I = (100/400) = 0.25 amps.

But point A has a potential of 100 volts and point B has zero. Somewhere along the circuit between A and B, the 100 volts have been lost.

To find the voltage drop for each resistor is easy. First find the current, which we have calculated as 0.25 amps, then

V_{R1} = 0.25 x 100 = 25 V

V_{R2} = 0.25 x 100 = 25 V

V_{R3} = 0.25 x 100 = 25 V

V_{R4} = 0.25 x 100 = 25 V.

Add up all the voltage drops and they will total 100 volts which is the applied voltage of the circuit.

25 + 25 + 25 + 25 = 100 volts.

The sum of the voltage drops in a circuit must be equal to the applied voltage.

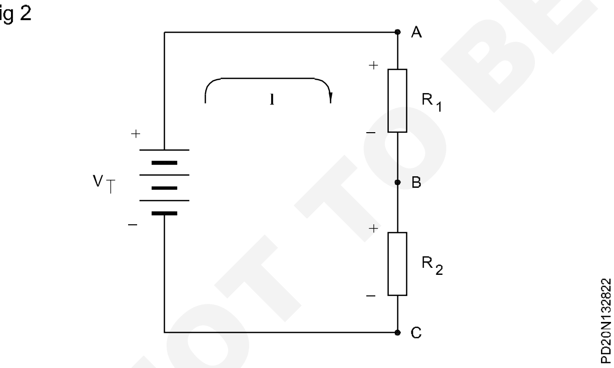
$V_{Total} = V_{R1} + V_{R2} + V_{R3} + V_{R4}$.

Polarity of voltage drops

When there is a voltage drop across a resistance, one end must be more positive or more negative than the other end. The polarity of the voltage drop is determined by the direction of conventional current. In Figure 2, the current direction is through R_1 from point A to B.

Therefore, the terminal of R_1 connected to point A has a more positive potential than point B. We say that the voltage across R_1 is such that point A is more positive

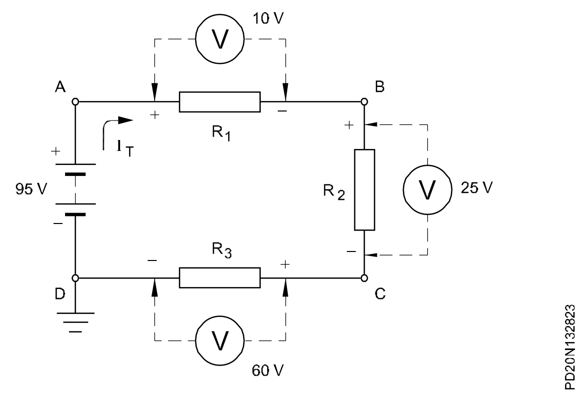
Fig 2



than point B. Similarly the voltage of point B is more positive than point C.

Another way to look at polarity between any two points is that the one nearer to the positive terminal of the voltage source is more positive; also, the point nearer to the negative terminal of the applied voltage is more negative. Therefore, point A is more positive than B, while C is more negative than B. (Fig 2)

Fig 3



Example 2

Find the voltage at the points A,B, C and D with respect to ground.

Mark the polarity of voltage drops in the circuit (Fig 3) and find the voltage values at points A, B, C and D with respect to ground.

Trace the complete circuit in the direction of current from the + terminal of the battery to A, A to B, B to C, C to D, and D to the negative terminal. Mark plus (+) where the current enters each resistor and minus (–) where the current leaves each resistor.

The voltage drops indicate (Fig 3) Point A is the nearest point to the positive side of the terminal; so voltage at A with respect to ground is

V_A = +95 V.

There is a voltage drop of 10 V across R_1; so voltage at B is

V_B = 95 – 10 = + 85 V.

There is a voltage drop of 25 V across R_2; so voltage at C is

V_C = 85 – 25 = + 60 V.

There is a voltage drop of 60V across R_3; so voltage at D is

V_D = 60 – 60 = 0 V.

Since the circuit is grounded at D, V_D must equal 0 V.

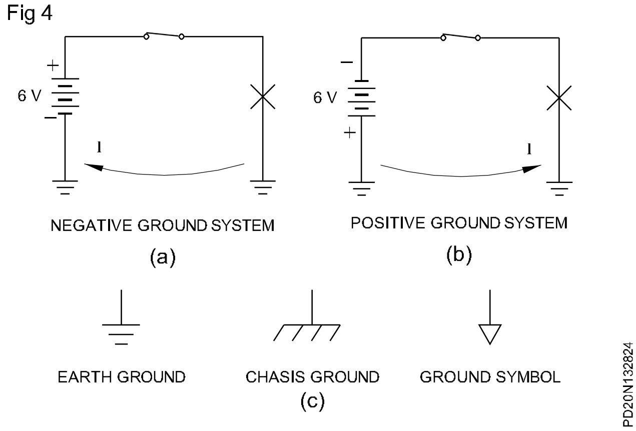
Positive and Negative grounds

In the electrical system of automobiles it is customary to connect one side of the battery to the metal chassis and call it the ground side. In this way metal chassis can be used as the **return path** for any circuit without providing an extra wire.

While most cars have 'negative grounds,' some (European) vehicles have a 'positive-ground' system. In the positive ground system reduced corrosion problems are claimed. Fig 4 shows both the systems.

In the negative ground system all wiring is at a positive potential with respect to the chassis, (as shown in Fig 4a)

Fig 4



whereas in a positive ground system (Fig 4b), all potentials are negative. Current flows in opposite directions in the two systems. But in both systems, the metal chassis is used as a common reference point to state the value of voltage at any point in the system.

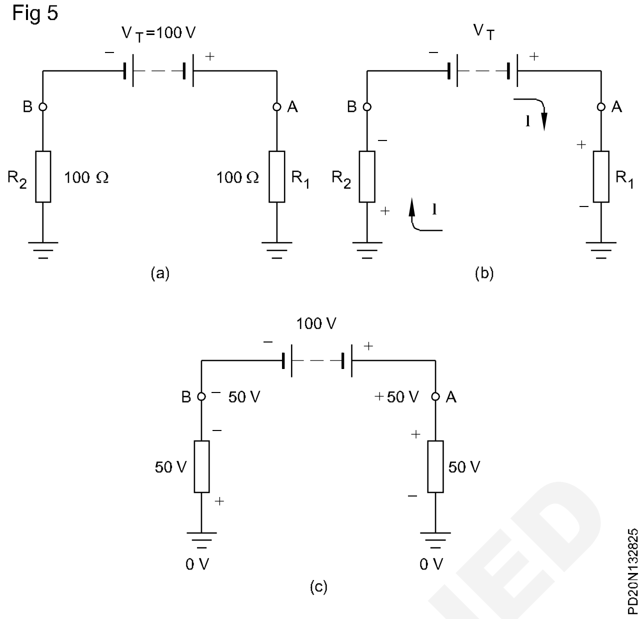
Figure 4c shows symbols for different types of ground systems.

Strictly speaking,the word ground being used for the metal chasis is not correct. A better symbol to use for chassis ground is shown in Fig 4c. This is because ground usually implies a connection to earth ground. (In a car the chassis is insulated from the ground by its rubber tires.) For example, one side of the domestic 240V AC outlet, the neutral is connected to earth by the system earthing method.

Marking the polarity of the voltage drop with respect to ground?

To mark the polarity of the voltage drops across the resistances R_1, R_2, find the voltage drops at points A and B in Fig 5(a), follow the steps as shown in Figures 5(b) and 5(c).

Fig 5



Practical application

The knowledge gained by this lesson will help you to:

- connect resistors in series to limit the current to the required level
- determine the current in the series circuit when PD and resistance value are known
- connect voltage sources like cells in a proper manner to have higher voltage
- determine with polarised meters, the polarity of IR drops, and, thereby, current direction in circuits
- detect faults in series-connected decorative lamp circuits.

DC parallel circuit

Objectives: At the end of this lesson you shall be able to
- **explain a parallel circuit**
- **determine the voltages in a parallel circuit**
- **determine the current in a parallel circuit**
- **determine the total resistances in a parallel circuit**
- **state the application of a parallel circuit.**

In an electrical circuit, if the current has more than one paths and equal voltage in each branch is called parallel circuit.

It is possible to connect three incandescent lamps as shown in Fig 1. This connection is called parallel connection in which, the same source voltage is applied across all the three lamps.

Voltage in parallel circuit

The lamps in Fig 1 are replaced by resistors in Fig 2. Again the voltage applied across the resistors is the same and also equal to the supply voltage.

We can conclude that the voltage across the parallel circuit is the same as the supply voltage.

Fig 2 could also be drawn as shown in Fig 3.

Mathematically it could be expressed as $V = V_1 = V_2 = V_3$.

Current in parallel circuit

Again referring to Fig 2 and applying Ohm's law, the individual branch currents in the parallel circuit could be determined.

Fig 1

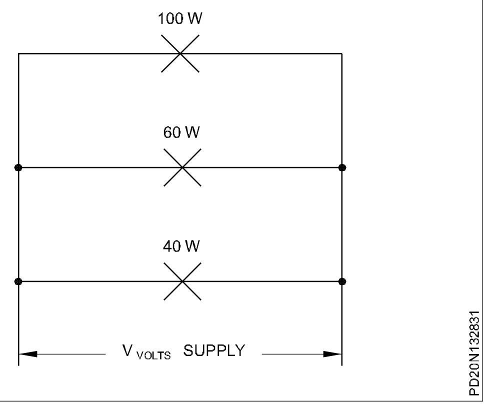


Fig 2

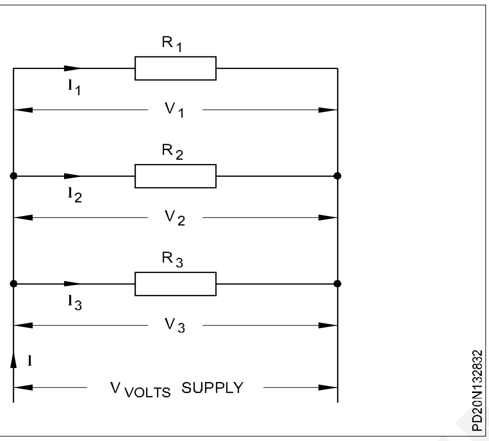
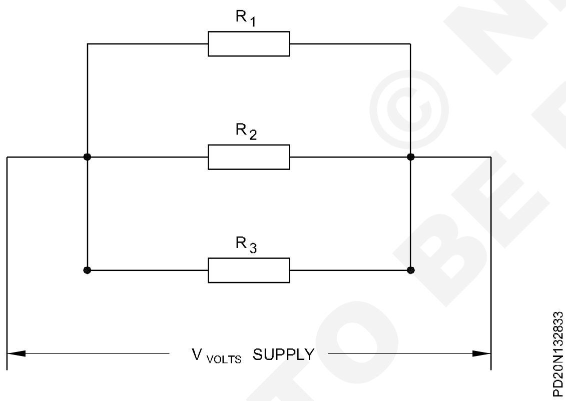


Fig 3



Current in resistor $R_1 = I_1 = \frac{V_1}{R_1} = \frac{V}{R_1}$.

Current in resistor $R_2 = I_2 = \frac{V_2}{R_2} = \frac{V}{R_2}$.

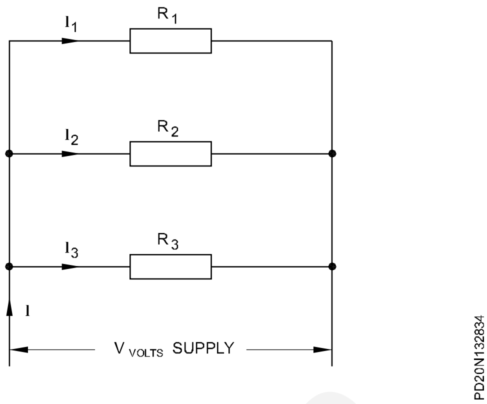
Current in resistor $R_3 = I_3 = \frac{V_3}{R_3} = \frac{V}{R_3}$

as $V_1 = V_2 = V_3$.

Refer to Fig 4 in which the branch currents I_1, I_2 and I_3 are shown to flow into resistance branches R_1, R_2 and R_3 respectively.

The total current I in the parallel circuit is the sum of the individual branch currents.

Fig 4



Mathematically it could be expressed as $I = I_1 + I_2 + I_3 + ... I_n$.

Resistance in parallel circuit

In a parallel circuit, individual branch resistances offer opposition to the current flow though the voltage across the branches will be same.

Let the total resistance in the parallel circuit be R ohms.

By the application of Ohm's law

we can write

$R = \frac{V}{I}$ ohms or $I = \frac{V}{R}$ amps.

where

R is the total resistance of the parallel circuit in ohms

V is the applied source voltage in volts, and

I is the total current in the parallel circuit in amperes.

We have also seen

$I = I_1 + I_2 + I_3$

or $\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$

As V is the same throughout the equation and dividing the above equation by V, we can write

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The above equation reveals that in a parallel circuit, the reciprocal of the total resistance is equal to the sum of the reciprocals of the individual branch resistances.

Special case: Equal resistances in parallel

Total resistance R, of equal resistors in parallel (Fig 5) is equal to the resistance of one resistor, r divided by the number of resistors, N.

$$R = \frac{r}{N}$$

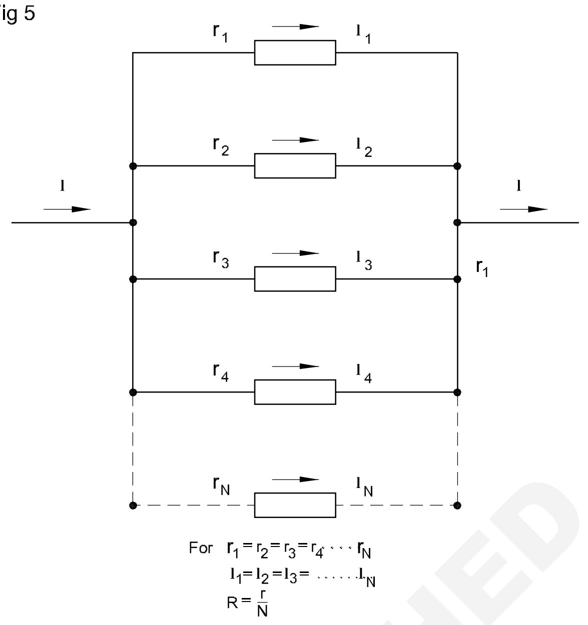
Applications of parallel circuits

An electric system in which one section can fail and other sections continue to operate has parallel circuits. As previously mentioned, the electric system used in homes consists of many parallel circuits.

An automobile electric system uses parallel circuits for lights, horn, motor, radio etc. Each of these devices operates independent of the others.

Individual television circuits are quite complex. However, the complex circuits are connected in parallel to the main power source. That is why the audio section of television receivers can still work when the video (picture) is inoperative.

Fig 5



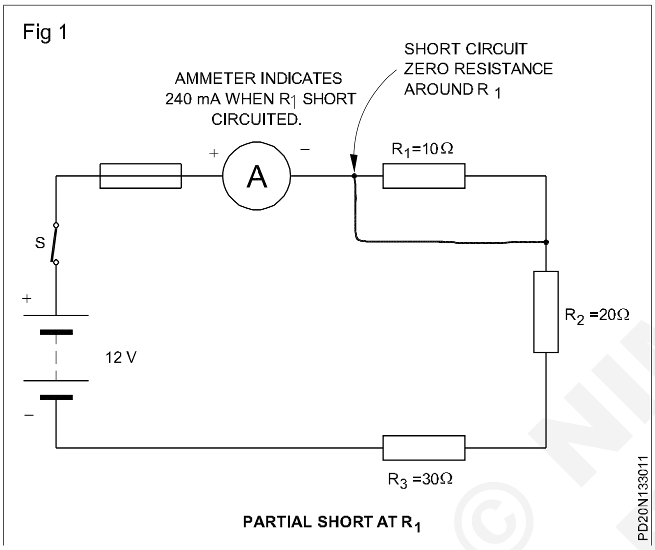
Open and short circuit in series and parallel network

Objectives: At the end of this lesson you shall be able to
- **state about short circuit in series circuit and its effect in series circuit**
- **state the effect of an open circuit in series circuit and its causes**
- **state the effect of shorts and open in parallel circuit.**

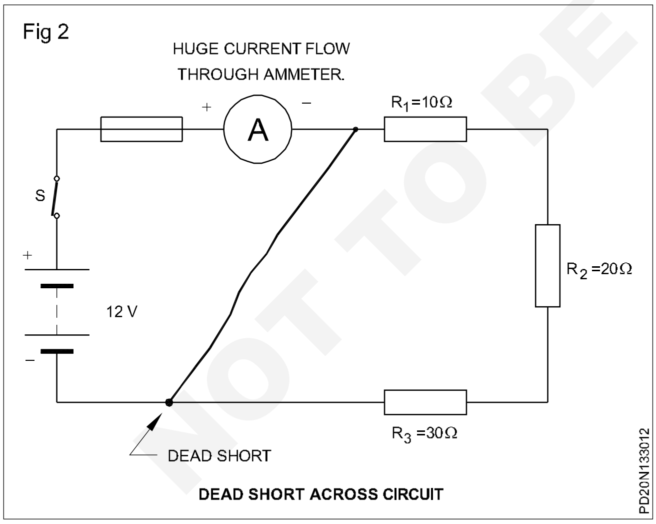
Short circuits

A short circuit is a path of zero or very low resistance compared to the normal circuit resistance.

In a series circuit, short circuits may be partial or full (dead short) as shown in Fig 1 and Fig 2 respectively.



PARTIAL SHORT AT R1



DEAD SHORT ACROSS CIRCUIT

Short circuits cause an increase in current that may or damage the series circuit.

Effects due to short circuit

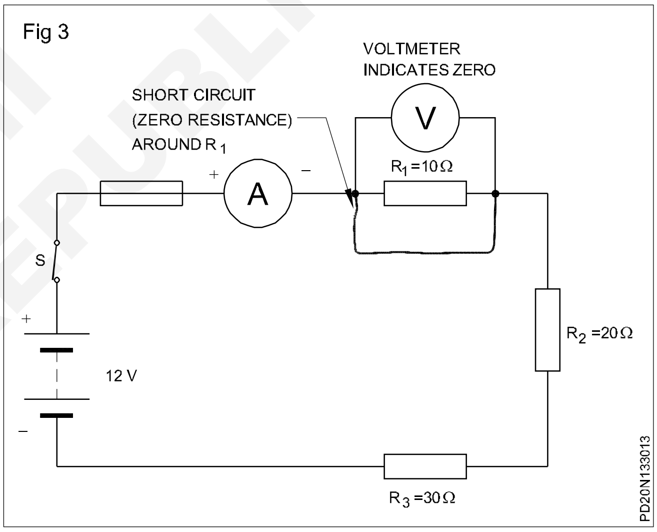
Excess current due to short circuit can damage the circuit components, power sources, or burn the insulation of connecting wires. Fire is also caused due to intense heat generated in the conductors.

Protection against dangers of short circuit

Dangers of short circuit can be prevented by means of fuses and circuit breakers in series with the circuit.

Detecting short circuit

When the ammeter in the circuit indicates excessive current then it indicates a short circuit in the circuit. The location of short in a circuit can be detected by connecting a voltmeter across each of the elements (resistors) and circuit source. If the voltmeter indicates zero volts or reduced voltage across the element, it is short circuited as shown in Fig 3.



Methods used to protect the circuit in case of a short circuit

As heavy currents flow through the short circuit, the circuit cables should be protected against the large currents. If the short circuit current is allowed to flow through the circuit, the cables which are rated for normal circuit current, will get heated up and become potential fire hazards.

To open the circuit automatically in cases of short circuits, fuses or circuit breakers are used in the circuit. The rating of the fuse wire or setting of the overload relay in circuit breakers will be selected depending upon the lowest rating of any one of the following used in the circuit.

i Load current in the circuit

ii Cable rating of the circuit

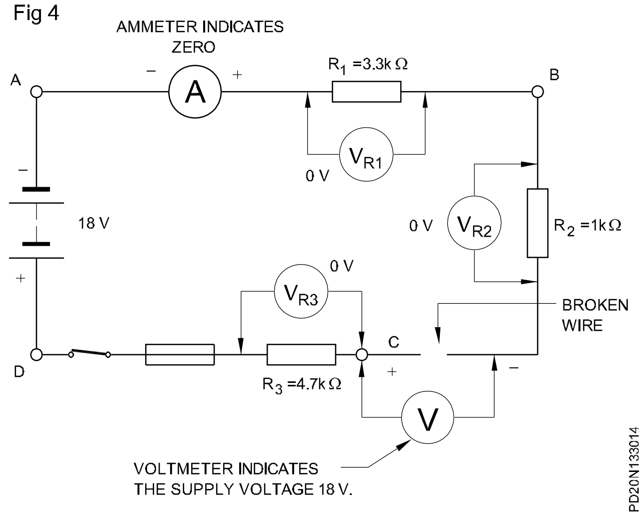
iii Series meter (ammeter etc.) rating of the circuit.

Open circuit in series circuit

An open circuit results whenever a circuit is broken or is incomplete, and there is no continuity in the circuit.

In a series circuit, open circuit means that there is no path for the current, and no current flows through the circuit. Any ammeter in the circuit will indicate no current as shown in Fig 4.

Fig 4



Causes for open circuit in series circuit

Open circuits, normally, happen due to improper contacts of switches, burnt out fuses, breakage in connection wires and burnt out resistors etc.

Effect of open in series circuit

a No current flows in the circuit.

b No device in the circuit will function.

c Total supply voltage/ source voltage appear across the open.

Determination the location of break in the circuit has occurred

Use a voltmeter on a range that can accommodate the supply voltage; connect it across each connecting wire in turn. If one of the wires is open as shown in Fig 4, the full supply voltage is indicated on the voltmeter. In the absence of a current, there is no voltage drop across any of the resistors. Therefore, the voltmeter must be reading full supply voltage across the open. part of the circuit

Voltmeter reading

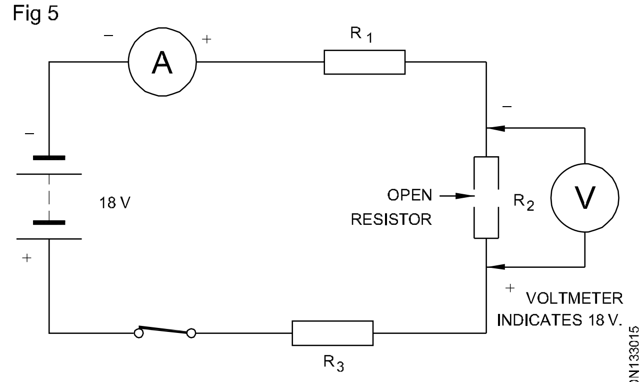
$= 18\ V – V_{R1} – V_{R2} – V_{R3}$

$= 18\ V – O\ V – O\ V – O\ V = 18\ V.$

If the circuit was open due to a defective resistor, as shown in Fig 5 (resistors usually open when they burn out), the voltmeter would indicate 18 V when connected across this resistor, R_2.

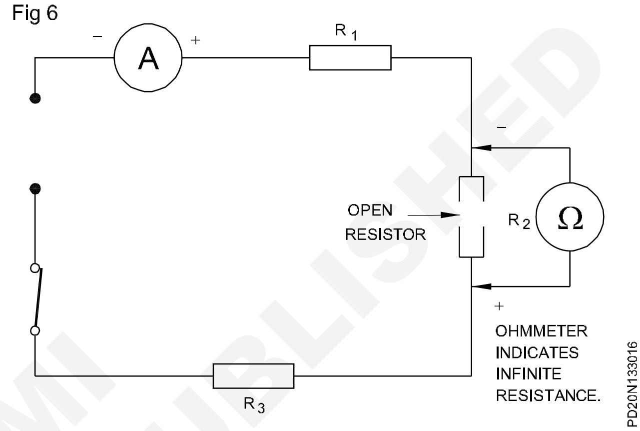
Alternatively, the open circuit may be found using an ohmmeter. With the voltage removed, the ohmmeter will show no continuity (infinite resistance), when connected across the broken wire or open resistor. (Fig 6)

Fig 5



OPEN CIRCUIT DUE TO OPEN RESISTOR R_2

Fig 6



Practical application

With the knowledge gained from this exercise:

- locate open and short circuit faults in a series circuit
- repair series-connected decoration bulb sets.

Shorts and opens in parallel circuits

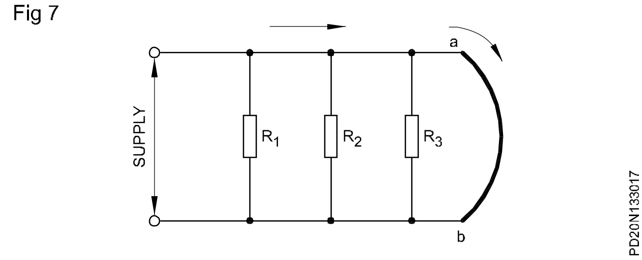
The two possible defects that can occur in an electrical circuit they are:

- short circuit
- open circuit

Shorts in parallel circuit:

Fig 1 shows a parallel circuit with short between points 'a' and 'b'.

Fig 7



This causes reduction of circuit resistance almost to zero.

Therefore, the voltage drop across 'ab' will be almost zero (by Ohms law).

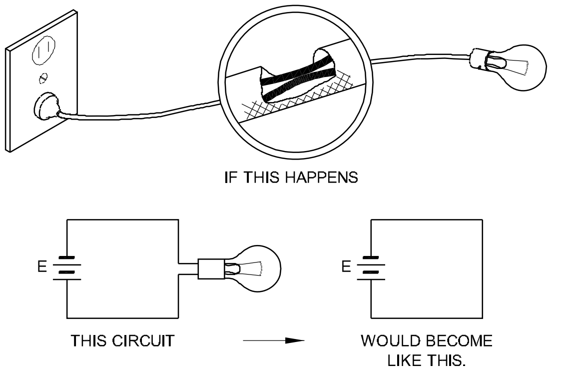
Thus current through the resistors R_1, R_2, R_3 will be negligible and not their normal current.

The result is that a very high current in the order of hundred times of the normal current will flow through the short circuit.

A short circuit exists when current can flow from the positive terminal of the power source through connecting wires and back to the negative terminal of the power source without going through any load. (Fig 2)

Short circuit may cause burning of the circuit elements like cables, switches etc.

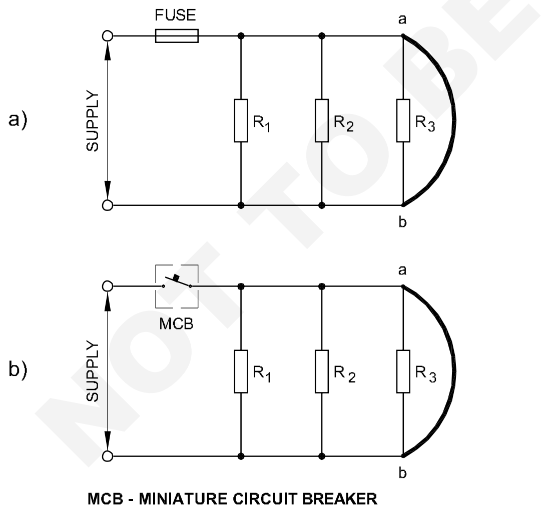
Fig 8



To avoid burning of circuit components safety devices like 'fuse', circuit breakers etc. are used to open the circuit. (Figs 3 a and 3b).

For a fuse to protect a parallel circuit, it should be placed in the circuit where the total current flows or else each branch must have a fuse. (Fig 4(a&b))

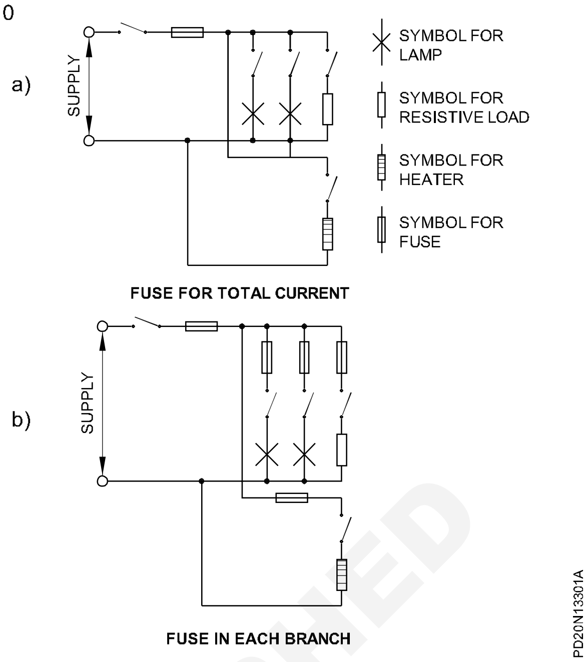
Fig 9



Opens in parallel circuit

An open in the common line at point A as shown in Fig 5 causes no current flow in that circuit whereas an open in the branch at point B causes no current flow only in that branch. (Fig 6)

Fig 10



However, the current in branches R_1 and R_3 will continue to flow so long as they are connected to the voltage source.

Full voltage of the source will be available at open circuit terminals. It is dangerous to meddle with the terminals which are open.

Practical application

Knowledge gained in this exercise can be applied to identify open circuits or short circuits in wiring installations.

Fig 11

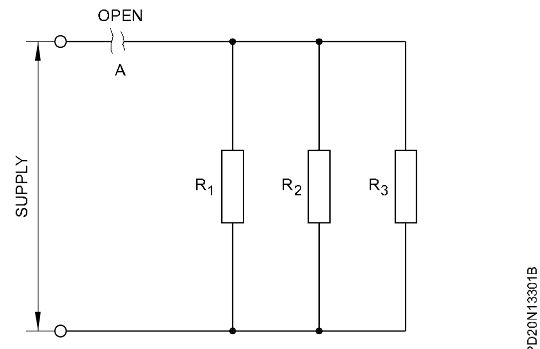
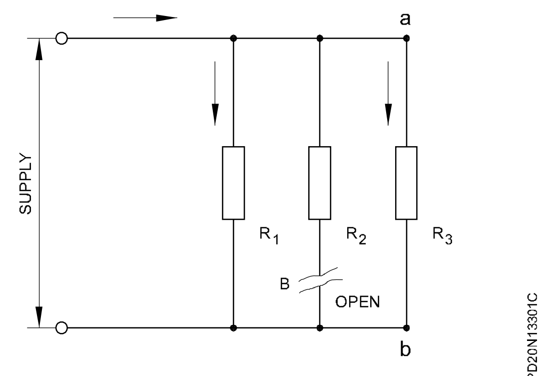


Fig 12



Laws of resistance and various types of resistors

Objectives: At the end of this lesson you shall be able to
- **state the laws of resistance, compare resistances of different materials**
- **state the relationship between the resistance and dimemsions of a conductor**
- **calculate the resistance and diameter of a conductor from the given data (i.e. dimensions etc.)**
- **explain various types of resistors.**

Laws of resistance: The resistance R offered by a conductor depends on the following factors.

- The resistance of the conductor varies directly with its length.
- The resistance of the conductor is inversely proportional to its cross-sectional area.
- The resistance of the conductor depends on the material with which it is made of.
- It also depends on the temperature of the conductor.

Ignoring the last factor for the time being,we can say that

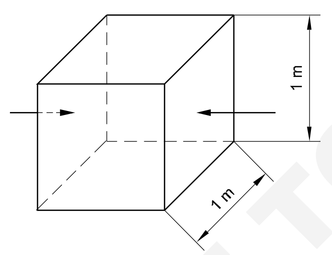
$$R = \frac{\rho L}{a}$$

where 'ρ' (rho - Greek alphabet) - is a constant depending on the nature of the material of the conductor, and is known as its **specific resistance** or **resistivity.**

If the length is one metre and the area, 'a' = 1 m^2, then R = r.

Hence, specific resistance of a material may be defined as `the resistance between the opposite faces of a metre cube of that material'. (or, sometimes, the unit cube is taken in centimetre cube of that material) (Fig 1).

Fig 1



We have $\rho = \frac{aR}{L}$

In the SI system of units

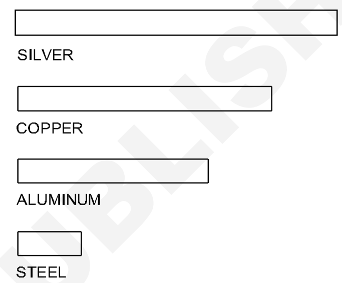
$$\rho = \frac{a\ \text{metre}^2 \times R\ \text{ohm}}{L\ \text{metre}}$$

$$= \frac{aR}{L}\ \text{ohm} - \text{metre}$$

Hence the unit of specific resistance is ohm metre (Ωm).

Comparison of the resistance of different materials: Fig 2 gives some relative idea of the more important materials as conductors of electricity. All the conductors shown have the same cross-sectional area and the same amount of resistance. The silver wire is the longest while that of copper is slightly short and that of aluminium is shorter still. The silver wire is more than 5 times longer than the steel wire.

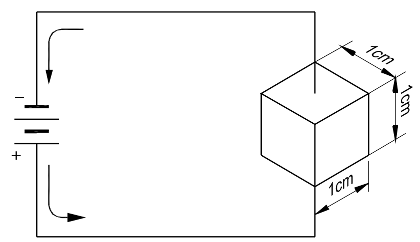
Fig 2



THE CONDUCTANCE OF DIFFERENT MATERIALS

Since different metals have different conductance ratings, they must also have different resistance ratings. The resistance ratings of the different metals can be found by experimenting with a standard piece of each metal in an electric circuit. If you cut a piece of each of the more common metals to a standard size, and then connect the pieces to a battery, one at a time, you would find that different amounts of current would flow. (Fig 3)

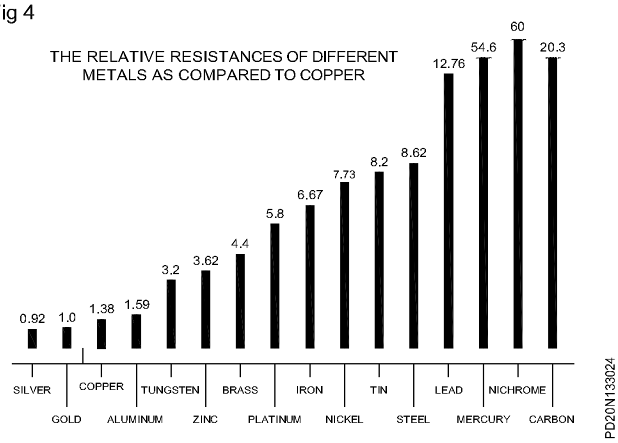
Fig 3



SPECIFIC RESISTANCE CIRCUIT

The bar graph (Fig 4) shows the resistance of some common metals as compared to copper. Silver is a better conductor than copper because it has less resistance. Nichrome has 60 times more resistance than copper, and copper will conduct 60 times as much current as Nichrome, if they were connected to the same battery,

Fig 4



one at a time.

Relationship between the resistance and the dimensions of a conductor: For a uniform wire of a given material, the value obtained by dividing the P.D. between any two points by the current is the resistance between those two points, and is directly proportional to the distance between them.

Also if two equal value resistors, each having resistance R, are connected in parallel it's equivalent R_T is given by

$$\frac{1}{R_T} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$$

Therefore $R_T = \frac{R}{2}$

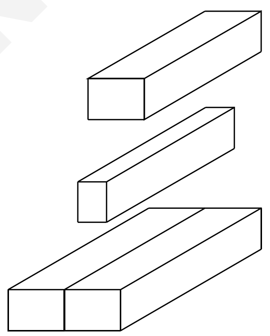
Hence, if two wires of the same material having the same length and diameter are connected in parallel the resistance of the two parallel wires is half that of one wire alone.

But the effect of connecting two wires in parallel is exactly similar to doubling the area of the conductor in just the same way as the effect of connecting, say, five wires in parallel is the same as increasing the cross-sectional area of a wire five times, and the result is to reduce the resistance to a fifth of that of one wire.

In general, we may, therefore, say that the resistance of a given length of a conductor is inversely proportional to its cross-sectional area.

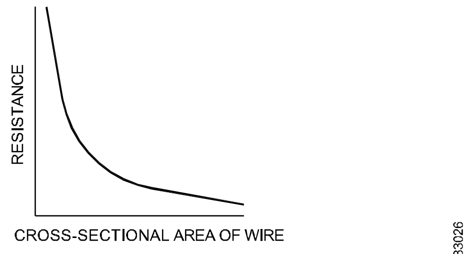
The other factor that influences the resistance is the nature

Fig 5



RESISTANCE IS INVERSELY PROPORTIONAL TO THE CROSS-SECTIONAL AREA OF THE CONDUCTOR.

Fig 6



INCREASING THE CROSS-SECTIONAL AREA OF A WIRE DECREASES ITS RESISTANCE

of the material. Hence, we may now say that resistance of a wire (Fig 5 & Fig 6)

$= \frac{\text{length}}{\text{area}}$ x (a constant) ρ given material

$$R(\text{ohms}) = \frac{L\,(\text{metres})}{a\ \text{metre}^2} \times \rho$$

So that ρ = Ra ÷ L ohm/ meter

where ρ (greek letter, pronounced 'rho') represents the constant.

L is the length of the wire in metres

a is the area in square metres.

Example: Calculate the length of a copper wire of 1.5 mm diameter which is to have a resistance of 0.3 ohms given that resistivity of copper is 0.017 microohm meter.

Solution

Cross-sectional area of wire

$= (\pi/4) \times (1.5)^2 = 1.766\text{mm}^2$

$= 1.766 \times 10^{-6}\text{m}^2$

$$R = \frac{\rho L}{a}$$

$$= 0.3 = \frac{0.017 \times 10^{-6} \times L}{1.766 \times 10^{-6}}$$

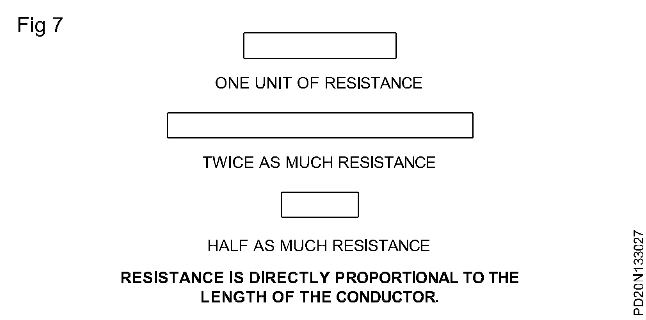
Ans: Length = 31.2 m.

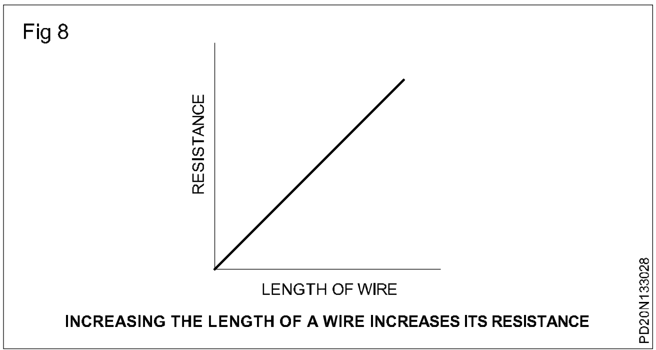
We can reduce all this into a simple statement: the larger the wire, the lower its resistacne; the smaller cross sectional area of the wire, the higher its resistance.

We can summarize with the universal rule: the electrical resistance of any metallic conductor is inversely proportional to its cross-sectional area.

All of this provides us with a useful rule in working with electrical conductors of any kind. Electrical resistance is directly porportional to the length of the conductor, provided, of course, the conductor is of the same diameter and is made of the same material throughout. (Figs 7 & 8)

Thus, the length of wire has a considerable influence on its ability to conduct electricity. The longer the wire, the more difficult it is for the current to get through it. In other words, the longer the wire the greater its resistance.





Calculation of resistance

Example 1: If a 15m eureka wire 0.14cm in diameter has a resistance of 3.75 ohms find the specific resistance of the material.

Solution

Length of wire L = 15m = 15 x 100 = 1500 cm

Diameter of wire = 0.14cm

Resistance = 3.75 ohm

Cross-sectional area of the wire

a = $\pi r^2 = \frac{\pi d^2}{4}$

$a = \frac{22}{7} \times \frac{(0.14)^2}{4}$

we know $R = \frac{\rho L}{a}$

Specific resistance = $\rho = \frac{R \times a}{L}$

$= \frac{3.75 \times 22 \times (0.14)^2}{15 \times 100 \times 7 \times 4}$ ohm/cm

$= \frac{3.75 \times 22 \times (0.14)^2 \times 10^6}{15 \times 100 \times 7 \times 4}$ micro ohm/cm

= 38.5 micro ohm cm

= 38.5 μ ohm cm.

Example 2: Calculate the resistance of a 2 km long wire composed of 19 strands copper conductor, each strand being 1.32mm in diameter. Resistivity of copper may be taken as 1.72 x 10^{-8} ohm-m. Allow 5% increase in length for the `lay' (twist) of each strand in the completed cable.

Solution

Allowing for twist, the length of strands,

= 2000 + 5% of 2000 metre

= 2100m

Area of cross-section of 19 strands of copper conductor is

= 19 x $\frac{\pi d^2}{4}$

$= 19 \times \pi \frac{(1.32 \times 10^{-3})^2 m^2}{4}$

Now

$= \frac{1.72 \times 10^{-8} \times 2100 \times 4 \times 7}{19 \times 22 \times (1.32)^2 \times 10^{-6}}$

= 1.388 ohms.

Example 3: Calculate in mm the dia. of a copper wire; the resistance of 3km of the wire is 14.4 ohms. Specific resistance of copper may be taken as 1.7 micro-ohm per centimetre cube.

Solution

Length = 3km = 3 x 1000 x 100

= 300 000 cm

Resistance = 14.4 ohms

ρ = 1.7μΩ/cm

$a = \frac{\rho L}{R}$

$= \frac{1.7 \times 300\,000}{10^{-5} \times 14.4}$

$= \frac{1.7 \times 3}{144} = \frac{5.1}{144} cm^2$

$= \frac{5.1}{1440}$ = cm² = 0.035 cm²

Now a $= \frac{\pi d^2}{4}$ or d² $= \frac{a \times 4}{\pi}$

$d = \sqrt{\frac{a \times 4}{\pi}}$

$= \sqrt{\frac{0.035 \times 4 \times 7}{22}}$

$= \sqrt{0.0445}$

= 0.21 cm

= 2.1 mm.

Resistors

Objectives: At the end of this lesson you shall be able to

- **explain the construction and characteristics of various types of resistors**
- **explain the functions and applications of the resistors in electrical and electronic circuits.**

Resistors : These are the most common passive component used in electrical and electronic circuits. A resistor is manufactured with a specific value of ohms (resistance). The purpose of using a resistor in circuit is either to limit the current to a specific value or to provide a desired voltage drop (IR). The power rating of resistors may be from fractional walts to hundreds of Watts.

There are five types of resistors

1 Wire-wound resistors

2 Carbon composition resistors

3 Metal film resistors

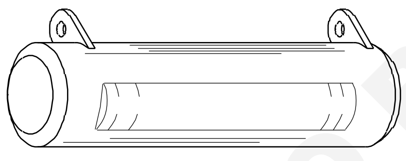
4 Carbon film resistors

5 Special resistors

1 Wire-wound resistors

Wire-wound resistors are manufactured by using resistance wire (nickel-chrome alloy called Nichrome) wrapped around an insulating core, such as ceramic porcelain, bakelite pressed paper etc. Fig 1, shows this type of resistor. The bare wire used in the unit is generally enclosed in insulating material. Wire wound resistors are used for high current application. They are available in wattage ratings from one watt to 100 watts or more. The resistance can be less than 1 ohm and go up to few thousand ohms.

Fig 1



WIRE-WOUND FIXED RESISTOR

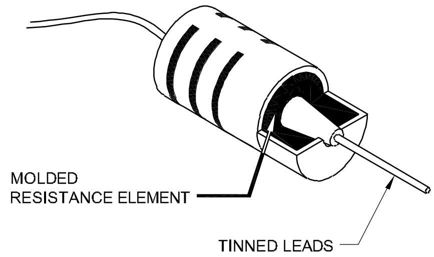
One type of wire-wound resistor is called as fusible resistor enclosed in a porcelain case. This resistor is designed to open the circuit when the current through it exceeds certain limit.

2 Carbon composition resistors

These are made of fine carbon or graphite mixed with powdered insulating material as a binder in the proportion needed for the desired resistance value. Carbon-resistance elements are fixed with metal caps with leads of tinned copper wire for soldering the connection into a circuit. Fig 2 shows the construction of carbon composition resistor.

Carbon resistor are available in values of 1 ohm to 22 megohms and of different power ratings, generally 0.1, 0.125, 0.25, 0.5, 1.0 and 2 watts.

Fig 2



CARBON COMPOSITION RESISTOR

3 Metal film resistors (Fig 3)

Fig 3

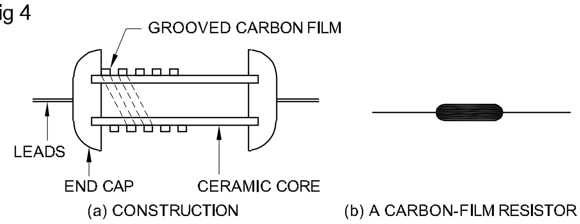
METAL FILM RESISTOR

Metal film resistors are manufactured by two processes. Thick film resistors are pasted with metal compound and powdered glass which are spread on the ceramic base and then backed.

Thin film resistors are processed by depositing a metal vapour on a ceramic base. Metal film resistors are available from 1 ohm to 10 MΩ, upto 1W. Metal film resistors can work from 120°C to 175°C.

4 Carbon film resistors (Fig 4)

Fig 4



CARBON – FILM RESISTOR

In this type, a thin layer of carbon film is deposited on the ceramic base/tube. A spiral groove is cut over the surface to increase the length of the foil by a specialised process.

Carbon film resistors are available from 1 ohm to 10 meg ohm and up to 1 W and can work from 85°C to 155°C.

All the above four types of resistors are coated with synthetic resin to protect them against mechanical damages and climatic influences, It is therefore, difficult to distinguish them from each other externally.

Specification of resistors : Resistors are specified normally with the four important parameters

1 Type of resistor

2 Nominal value of the resistors in ohm (or) kilo ohm (or) mega ohm.

3 Tolerance limit for the resistance value in percentage.

4 Loading capacity of the components in wattage

Example

100 ± 10% , 1W, where as nominal value of resistance is 100Ω.

The actual value of resistance may be between 90Ω to 110 Ω, and the loading capacity is maximum 1 watt.

The resistors can also be classified with respect to their function as

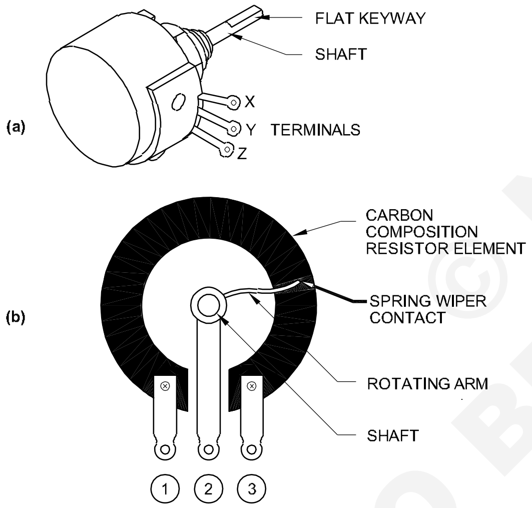
1 Fixed resistors

2 Variable resistors

Fixed resistors : The fixed resistors is one in which the is nominal value of resistance is fixed. These resistors are provided with pair of leads. (Fig 1 to 4)

Variable resistors (Fig 5) : Variable resistors are those whose values can be changed. Variable resistors includes those components in which the resistance value can be set at the different levels with the help of sliding contacts. These are known as potentio meter resistors or simply as a potentio meters.

Fig 5

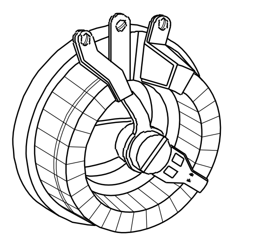


VARIABLE CARBON-RESISTANCE (a) EXTERNAL VIEW
(b) INTERNAL VIEW OF CIRCULAR RESISTANCE ELEMENT

PD20N133035

It is provided with 3 terminals as shown in Fig 5 and 6. They are available with carbon tracks (Fig 5) and wire wound (Fig 6) types. Trimmer potentio meters (or) resistor which can be adjusted with the help of a small screw drivers. (Fig 7).

Fig 6



WIRE-WOUND VARIABLE RESISTOR

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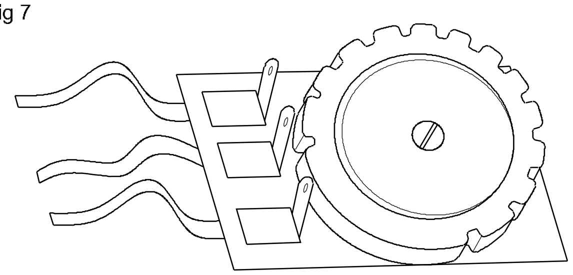
Fig 7



TRIMMER RESISTOR

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Resistance depends upon temperature, voltage, light : Special resistors are also produced whose resistance varies with temperature, voltage, and light.

PTC resistors (Sensistors) : Since, different materials have different crystal structure, the rate at which resistance increases with raising temperature varies from material to material. In PTC resistor (positive Temp. coefficient resistor), as the temp increases, the resistance increases non linearly. For example, the resistance of PTC at room temperature may be of nominal value 100 Ω when the temperature rises say 10°C, it may increase to 150 Ω and with further increase of another 10°C, it may increases to 500 Ω.

NTC Resistors (Thermistors) : In case of NTC resistors (Negative temperature co-efficient resistors) as the temperature increases, the value of resistance decreases non-linearly, For example, NTC resistor, which has nominal value of resistance is 500 Ω at room temperature may decrease to 400 Ω with the rise of 10°C temperature and further decrease to 150 Ω when the temperature rises to another 10°C.

The PTC and NTC resistors can perform switching operation at specific temperature. They are also used for measurements and temperature compensators.

VDR (Varistors) : The VDR (Voltage dependent resistor) resistance falls non-linearly with increasing voltage. For example, a VDR, may have 100 Ω resistance at 10 V, and it may decrease to 90 Ω at rise in 5V. By further increasing the voltage to another 5V, the resistance may fall to 50 Ω. The VDRS are used in voltage stabilisation, arc quenching and over voltage protection.

Light dependent resistor (LDR) : The LDRs are also known as photo- conductors. In LDRs the resistance falls with increase in intensity of illumination. The phenomena is explained as the light energy frees some electron in the materials of the resistors, which are then available as extra conducting electrons. The LDR shall have exposed surface to sense the light. These are used for light barriers in operating relays. These are also used for measuring the intensity of light.

Methods of measuring low and medium resistance

Objectives: At the end of this lesson you shall be able to
- **state the different methods of measuring resistance**
- **describe the ammeter & voltmeter method.**

Classification of resistance

A resistance is classified on its ohmic value as low, medium, or high.

Ranges

Low resistance	- one ohm and below one ohm
Medium resistance	- above one ohm up to 100,000 ohms(100 kΩ)
High resistance	- above 100 kΩ (i.e 100000Ω)

The above classification is not rigid.

Uses

Low resistance: Armature winding, ammeter shunt, cable length, contact resistance.

Medium resistance: All electrical apparatus normally used have resistance in this range - bulbs, heaters, relay, motor starters.

High resistance: Insulation resistance, carbon composition resistors above 100K in the circuit.

We shall limit for the present to the methods used for measuring low and medium resistances in the following section.

Question

1 The lamp resistance of a mini-torch light, operating on 1.5 volts is classified as ___________ resistance.

Methods of measuring low resistance: The following three methods are used to measure low resistance.

- Voltmeter and ammeter method.
- Comparison of unknown with standard using potentiometer.
- Kelvin bridge
- Shunt type Ohmmeter

Ammeter and voltmeter method: This method, which is the simplest of all, is very commonly used for the measurement of low resistance.

In Fig 1, R_m is the resistance to be measured and V is a high resistance voltmeter of resistance R_v. A current from a steady direct current supply is passed through R in series with a suitable ammeter. Then assuming the current through the unknown resistance to be the same as that measured by the ammeter A, the formula is given as

$$R_m = \frac{\text{Voltmeter reading}}{\text{Ammeter reading}}$$

R_m = Measured value

If the voltmeter resistance is not very large, compared with the resistor to be measured, the voltmeter current will be an appreciable fraction of the current **I**, measured by the ammeter, and a serious error may be introduced on this account.

Medium resistance: The following three methods are used to measure medium resistance.

- Series type Ohmmeter
- Voltmeter and ammeter method
- Substitution method
- Wheatstone bridge method

The first method has been considered in the section on low resistance measurement. Substitution method and the wheatstone bridge method is explained subsequently.

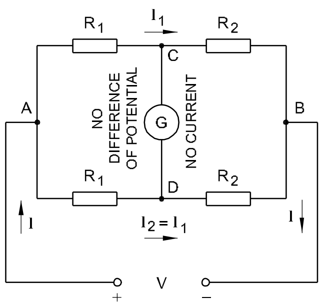
Wheatstone bridge - principle and its application

Objectives: At the end of this lesson you shall be able to
- **describe the method of obtaining equal potential points in two branches of a parallel circuit**
- **state wheatstone bridge circuit, construction, function and uses.**
- **determine the unknown resistance by the wheatstone bridge.**

Points of equal potential in parallel circuits: An electrical current flows only when a potential difference is present. Without a potential difference, current will not flow.

In the Fig 1, the resistances R_1 and R_2 in each of the parallel branches are equal. Therefore, the potential differences across the two resistors R_1 are equal, i.e. from A to C and from A to D. Hence, even when the points C and D are

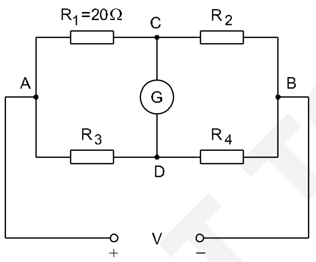
Fig 1



connected with the galvanometer no current will flow.

Four resistors R_1, R_2, R_3 and R_4 are arranged as shown in Fig 2. Select the values of R_2, R_3 and R_4 from the list so that no current flows between points C & D. Resistance

Fig 2



values are 20 ohms, 30 ohms, 40 ohms, 70 ohms, 15 ohms.

Equal resistance ratio in parallel circuit: One does not need equal resistances in the parallel circuits to obtain equal potential nodes. It suffices if the resistances are in the same ratio to each other.

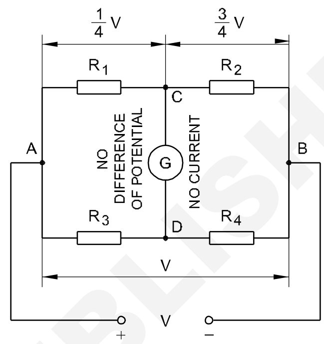
In the circuit diagram (Fig 3), the resistances in the top conductor branch are in the ratio 1 : 3.

The resistances in the bottom conductor branch are also in the ratio 1:3. The supply emf V, is therefore, divided in the both conductor branches in the same ratio 1:3. The first potential difference is

$$= \frac{1}{4} V \text{ and second} = \frac{3}{4} V$$

Again no current can flow in a conductor connected across

Fig 3

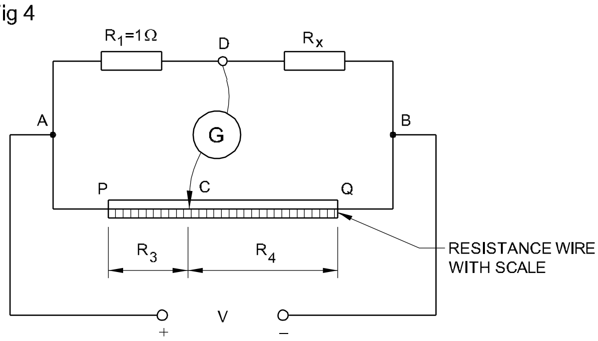


the points C and D.

A conductor between C and D is called a bridge connection.

The wheatstone bridge circuit

Fig 4



The equal resistance ratio in parallel circuits can be used for the measurement of resistance.

In the circuit arrangement shown in Fig 4, the sliding contact C slides along a resistance wire.

R_1 is a standard resistor, e.g. 1 ohm.

The sliding contact C is moved along the resistance wire until the detector or bridge galvanometer across C-D reads zero. Then the resistance ratios in the two parallel branches are equal.

$R_x : R_1 = R_4 : R_3$

If R_1 = 1 ohm then

$$R_3 = \frac{R_4}{R_5}$$

This circuit arrangement can, therefore, be used to measure an unknown resistance R_x. The resistance can be directly read from a scale on the resistance wire. (Fig 4)

For determining the unknown resistance by Wheatstone Bridge

- The current flowing through the bridge connection should be zero.
- The values of the other three resistances should be precisely known.

How to find no current flows through the bridge connection?: An instrument, that can indicate the flow of even a few micro amperes (millionth of an ampere), called galvanometer, is used. There are galvanometers that give full scale deflection for 25 microamperes.

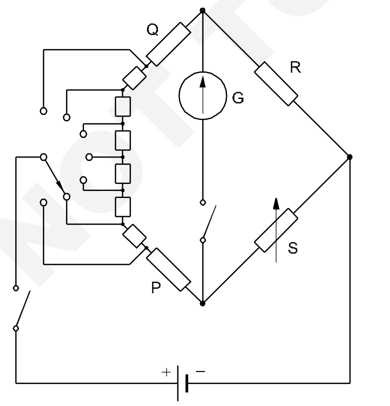
In the professional Wheatstone bridges, the galvanometer is provided with a parallel resistance and switch. The bridge connection is made only by pressing a push button. This enables the user to check a momentary deflection of the meter. In the case of excessive deflection, adjustment of the variable resistor is done. Final and precise adjustment of the variable resistance is made keeping the shunt resistor of the galvanometer open.

The three arms of the bridge are made of standard/ precision resistors. The contact resistance is kept very very low to increase the accuracy of the measurement made by the Wheatstone bridge.

In short, the use of the galvanometer is to ensure that the current through the bridge connection is zero, i.e. both parallel branches have equipotential points connected by the bridge connector.

This arrangement is named after its inventor and is called the Wheatstone Bridge.

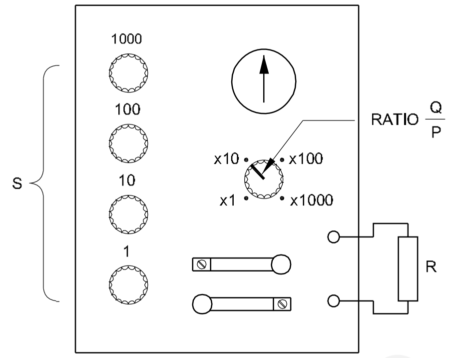
Fig 5



The Wheatstone Bridge is used for measurements in the range of about 1.0 ohm to 1.0 megohm. In Fig 5, resistors P,Q and S are internal to the instrument. R is the resistor of unknown value to be measured.

The instrument is adjusted until the ratio $\frac{Q}{P} = \frac{R}{S}$

Fig 6



This is indicated by a zero reading on the galvanometer with its switch in the closed position.

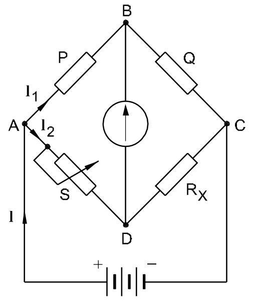
The resistors P and Q are called ratio arms. P and Q are varied in steps to give a range of values and the resistance value of 'S' is set by the decade resistance S.(Fig 6)

$R = \frac{Q}{P}$ multiplied by S.

The ratio $\frac{Q}{P}$ is arranged to be 1, 10, 100 or 1,000 for ease of calculation.

S is the variable resistance. Four decade resistances are connected in series. The value of S can be set in steps of one ohm from 1.0 ohm to 9999 ohms by suitably setting the four decade resistance units.

Fig 7



Example 1: The Wheatstone Bridge circuit is used to determine the value of the unknown resistor R_x. The bridge is balanced when P = 100 ohms, Q = 1000 ohms and S is adjusted to 130 ohms. Calculate the value of the unknown resistor R_x. (Fig 7)

Solution

At balance $V_{AB} = V_{AD}$

and $V_{BC} = V_{DC}$

therefore, $I_1P = I_2S$

and $I_1Q = I_2 R_X$

$$\frac{I_1}{I_2} = \frac{S}{P} = \frac{I_1}{I_2} = \frac{R_x}{Q}$$

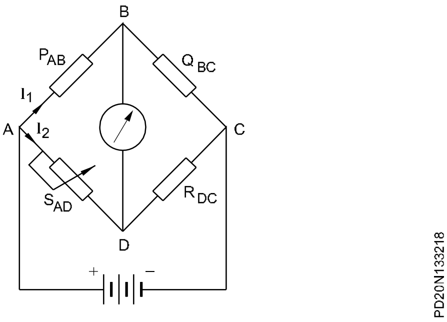
$$\frac{S}{P} = \frac{R_x}{Q}$$

$$R_x = \frac{S}{P} \times Q = \frac{130 \times 1000}{100}$$

R_x = 1300 Ω

Example 2 : In the Wheatstone Bridge network (Fig 8), ABCD is balanced when

Fig 8



P_{AB} = 500 ohms

Q_{BC} = 250 ohms and

S_{AD} = 12 ohms.

Determine the value of $R_{DC.}$

Solution

At balance $V_{AB} = V_{AD}$

and $V_{BC} = V_{DC}$

$I_1P = I_2S$

and $I_1Q = I_2R$

Therefore,

$$\frac{I_1}{I_2} = \frac{S}{P} = \frac{I_1}{I_2} = \frac{R}{Q}$$

$$\frac{S}{P} = \frac{R}{Q} \text{ and } R = \frac{S}{P} \times Q$$

$$R = \frac{12}{500} \times 250 = 6 \text{ ohms}$$

Effect of variation of temperature on resistance

Objectives: At the end of this lesson you shall be able to
- **explain on what factors electrical resistance of a conductor depends**
- **state the temperature co-efficient of resistance.**

The resistance of material largely depends on temperature and varies according to the material. The phenomenon is used to develop special resistors, PTC & NTC etc., but the overall effect of temperature normally increase the current in that conductor material.

When resistance r is a constant depending on the nature of the material of the conductor and known as its specific resistance or resistivity. Dependency of resistance on temperature is explained in detail below:-

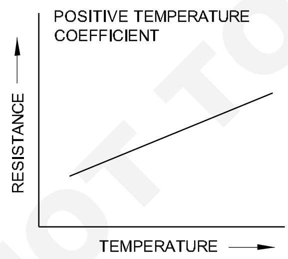
Effect of temperature on resistance: Actually, the relative values of resistance that were given earlier apply to the metals when they are at about room temperature. At higher or lower temperatures, the resistances of all materials change.

In most cases, when the temperature of a material goes up, its resistance goes up too. But with some other materials, increased temperature causes the resistance to go down.

The amount by which the resistance is affected by each degree of temperature change is called the temperature coefficient. And the words positive and negative are used to show whether the resistance goes up or down with the temperature.

When the resistance of the material goes up as temperature is increased, it has a positive temperature coefficient. It is appropriate in the case of pure metals such as silver,

Fig 1



RESISTANCE INCREASES WITH TEMPERATURE

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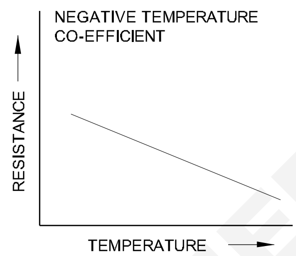
copper, aluminium, brass etc. (Fig 1)

In the case of certain alloys such as eureka, manganin, etc. increase in resistance due to increase in temperature is relatively less and irregular.

When a material's resistance goes down as the temperature is increased, it has a negative temperature coefficient. (Fig 2)

This applies in the case of electrolytes, insulators such as paper, rubber, glass, mica etc. and partial conductors

Fig 2



RESISTANCE DECREASES WITH TEMPERATURE

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such as carbon.

Temperature coefficient of resistance (a) of a conductor: Let a metallic conductor, having a resistance of R_0 at 0°C, be heated to t°C and let its resistance at this temperature be R_t. Then, considering normal ranges of temperature, it is found that the increase in resistance depends:

- directly on its initial resistance
- directly on the rise in temperature
- on the nature of the material of the conductor

Hence $(R_t - R_o) = R_o\, t\, \alpha$ .....(i)

where α (alpha) is constant and is known as the temperature coefficient of resistance of the conductor.

Rearranging Eq.(i), we get

$$\alpha = \frac{R_t - R_0}{R_0 \times t} = \frac{\Delta R}{R_0 \times t}$$

If $R_o = 1\Omega$, $t = 1°C$, then $\alpha = \Delta R = R_t - R_o$.

Hence, the temperature-coefficient of a material may be defined as: the change in resistance in ohm per °C rise in temperature.

From Eq.(i), we find that $R_T = R_o(1+\alpha\, t)$ .....(ii)

In view of the dependence of α on the initial temperature, we may define the temperature coefficient of resistance at a given temperature as the change in resistance per ohm per degree centigrade change in temperature from the given temperature.

In case R_o is not given, the relationship between the known resistance R_1 at t_1°C and the unknown resistance R_2 at t_2°C can be found as follows:

$R_2 = R_o(1 + \alpha_o t_2)$ and

$R_1 = R_o(1 + \alpha_o t_1)$.

Therefore $$\frac{R_2}{R_1} = \frac{1+\alpha_0 t_2}{1+\alpha_0 t_1}$$

Resistivities and temperature coefficients

Material Metals-Alloys	**Resistivity in ohm-metre at 20°C x 10^{-8}**	**Temperature coefficient at 20°C x 10^{-4}**
Aluminimum	2.8	40.3
Brass	6 – 8	20
Carbon	3000 –7000	–(5)
Constant or Eureka (+0.160 – 0.4)		49
Copper (annealed) 39.3		1.72
German silver	20.2	2.7
Iron	9.8	65
Manganin (84% Cu; 25% Mn; 4% Ni)	44 – 48	0.15
Mercury	95.8	8.9
Nichrome (60% Cu;25% Fe; 15% Cr)	108.5	1.5
Nickel	7.8	54
Platinum	9 –15.5	36.7
Silver	1.64	38
Tungsten	5.5	47
Insulators	**Resistivity in ohm-metre at 20°C**	**Temperature coefficient at 20°C**
Amber	5 x 10^{14}	
Bakelite	10^{10}	
Glass	10^{10}– 10^{12}	10^{12}
Mica	10^{15}	
Rubber	10^{16}	
Shellac	10^{14}	
Sulphur	10^{15}	

Example: The resistance of a field coil measures 55 ohms at 25°C and 65 ohms at 75°C. Find the temperature-coefficient of the conductor at 0°C.

$R_t = R_o(1 + \alpha_o t)$

$R_{25} = 55 = R_o(1 + 25\alpha_o)$ Eqn.1

$R_{75} = 65 = R_o(1 + 75\alpha_o)$ Eqn.2

Dividing Eqn.2 by Eqn.1 we get

$$\frac{R_{75}}{R_{25}} = \frac{65}{55} = \frac{1+75\alpha_0}{1+25\alpha_0}$$

$$\frac{13}{11} = \frac{1+75\alpha_0}{1+25\alpha_0}$$

Cross multipling we get

$13[1 + 25\alpha_o] = 11[1 + 75\alpha_o)$

$13 + 325\alpha_o = 11 + 825\alpha_o$

$13 - 11 = 825\alpha_o - 325\alpha_o$

$2 = 500\alpha_o$

$a_o = \frac{2}{500} = 0.004$ per °C.

Series and parallel combination circuit

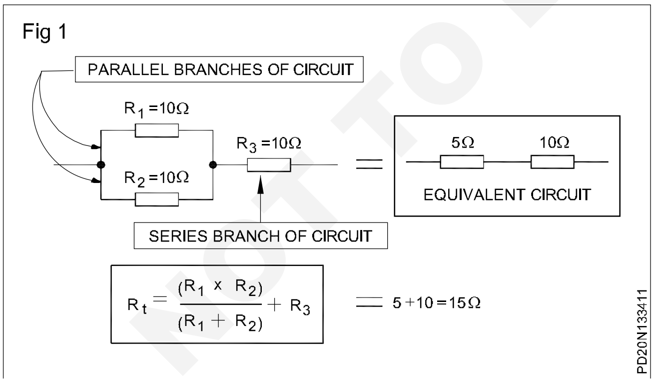
Objectives: At the end of this lesson you shall be able to
- **compare the characteristics of series and parallel circuits**
- **solve series-parallel circuit problems**

Comparison of characteristics of DC series and parallel ciruits

Sl. No.	Series circuit	Parallel circuit
1	The sum of voltage drops across the individual resistances equals the applied voltage.	The applied voltage is the same across each branch.
2	The total resistance is equal to the sum of the individual resistances that make up the circuit. $R_t = R_1+R_2+R_3+...$ etc	The reciprocal of the total resistance equals the sum of the reciprocal of the resistances. The resultant resistance is less than the smallest resistance of the parallel combination.
3	Current is the same in all parts of the circuit. resistance of each branch.	The current divides in each branch according to the resistance of each branch
4	Total power is equal to the sum of the power dissipated by the individual resistances.	(Same as series circuit) Total power is equal to the sum of the power dissipated by the individual resistanc-es.

Formation of series parallel circuit

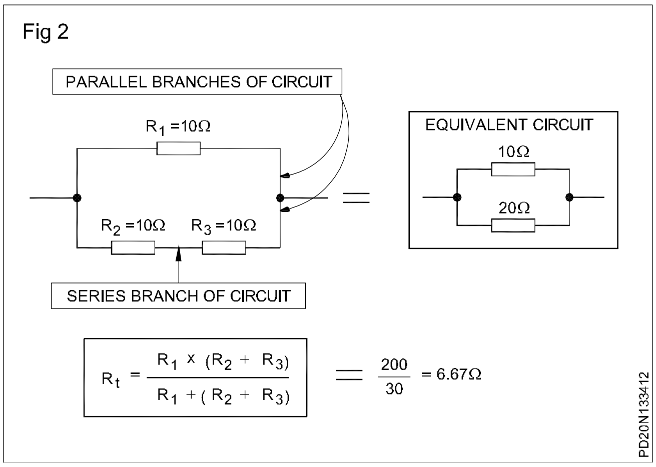
Apart from the series circuit and parallel circuits, the third type of circuit arrangement is the series-parallel circuit. In this circuit, there is at least one resistance connected in series and two connected in parallel. The two basic arrangements of the series-parallel circuit are shown here. In one, resistor R_1 and R_2 are connected in parallel and this parallel connection, in turn, is connected in series with resistance R_3. (Fig 1)



Thus, R_1 and R_2 form the parallel component, and R_3 the series component of a series-parallel circuit. The total resistance of any series-parallel circuit can be found by merely reducing it into a simple series circuit. For example, the parallel portion of R_1 and R_2 can be reduced to an equivalent 5-ohm resistor(two 10-ohm resistors in parallel).

Then it has an equivalent circuit of a 5-ohm resistor in series with the 10-ohm resistor(R_3), giving a total resistance of 15 ohms for the series-parallel combination.

A second basic series-parallel arrangement is shown in Fig 2 where basically it has two branches of a parallel circuit. However, in one of the branches it has two resistances in series R_2 and R_3. To find the total resistance of this series -parallel circuit, first combine R_2 and R_3 into an equivalent 20-ohm resistance. The total resistance is then 20 ohms in parallel with 10 ohms, or 6.67 ohms.



Combination circuits

A series-parallel combination appears to be very complex.

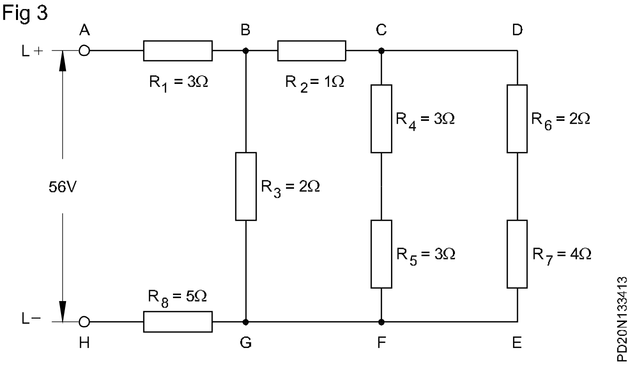
However, a simple solution is to break down the circuit into series/or parallel groups, and while solving problems, each may be dealt with individually. Each group may be replaced by one resistance, having the value equal to the sum of all resistances.

Each parallel group may be replaced by one resistance value equivalent to the combined resistance of that group. Equivalent circuits are to be prepared for determining the current, voltage and resistance for each component.

Example

Determine the combined resistance of the circuit shown in Fig 3.

Fig 3



Procedure

1 Combine R_6 and R_7.

$R_a = R_6 + R_7$

$R_a = 2 + 4$

R_a = 6 ohms.

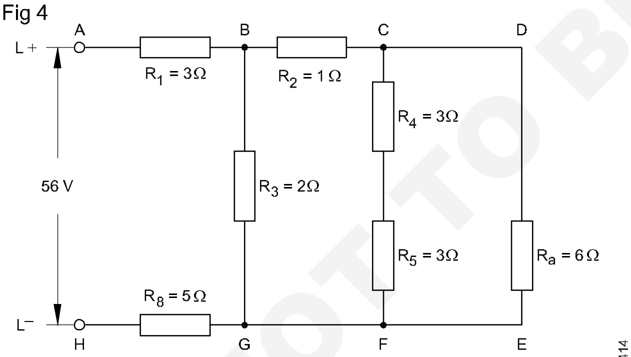
2 Draw an equivalent circuit with resistance Ra. (Fig 4)

3 Combine R_4 and R_5 of Fig 4.

$R_b = R_4 + R_5$

$R_b = 3 + 3$

Fig 4



EQUIVALENT CIRCUIT OF FIG 3. R_6 AND R_7 ARE REPLACED WITH ONE RESISTOR (R_a) OF 6Ω

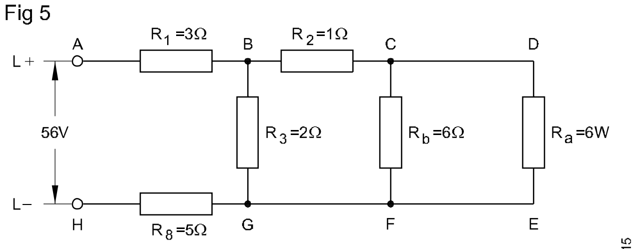
R_b = 6 ohms.

4 Draw an equivalent circuit as per Fig 5.

5 Combine R_a and R_b and call the equivalent resistance value as R_C. (Fig 5)

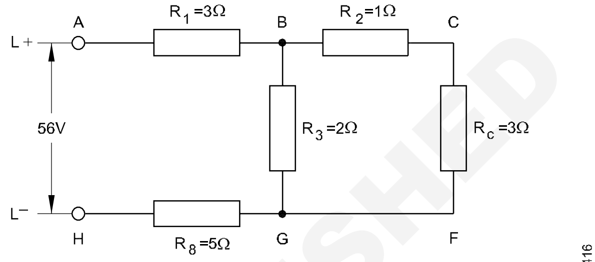
$$R_c = \frac{R_a \times R_b}{R_a + R_b} = \frac{6 \times 6}{6 + 6}$$

Fig 5



EQUIVALENT CIRCUIT TO FIG 3.R_4 AND R_5 ARE REPLACED WITH ONE RESISTOR(R_b) OF 6Ω

Fig 6



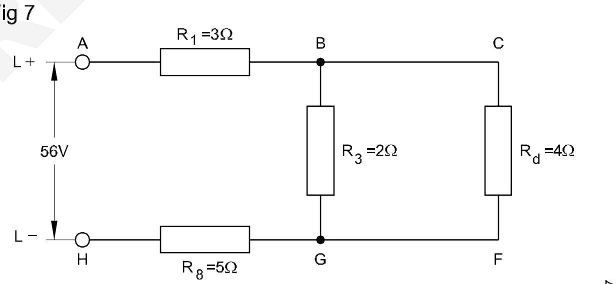
EQUIVALENT CIRCUIT TO FIG 3, R_4, R_5, R_6, R_7 ARE REPLACED WITH ONE RESISTANCE (R_c) OF 3Ω .

$$= \frac{36}{12} = 3 \text{ ohms}$$

6 Draw the equivalent circuit. (Fig 6)

7 Combine R_2 and R_c and call the equivalent resistance R_d.

Fig 7



EQUIVALENT CIRCUIT TO FIG 3, R_2, R_4, R_5, R_6, R_7 ARE REPLACED WITH ONE RESISTANCE (R_d) OF 4Ω .

$R_d = R_2 + R_c$

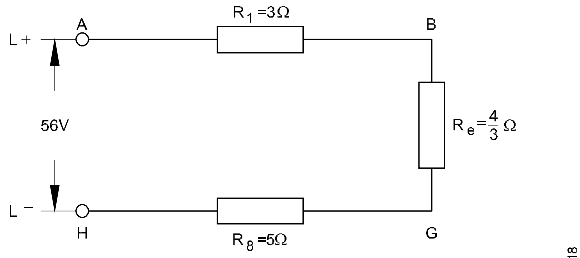
$R_d = 1 + 3$ R_d = 4 ohms.

8 Draw an equivalent circuit. (Fig 7)

9 Now combine R_3 and R_d and call it R_e

$$R_e = \frac{R_3 \times R_d}{R_3 + R_d} = \frac{2 \times 4}{2 + 4}$$

Fig 8



EQUIVALENT CIRCUIT IN FIG 3, R_2, R_3, R_4, R_5, R_6, AND R_7 ARE REPLACED WITH ONE RESISTANCE (R_e) EQUAL TO $\frac{4}{3}\Omega$.

$$= \frac{8}{6} = \frac{4}{3} = 1\ 1/3 \text{ ohms.}$$

10 Draw an equivalent circuit. (Fig 8)

11 Combine R_1, R_e, and R_8.

$$R_t = R_1 + R_e + R_8$$

$$R_t = 3 + 1\frac{1}{3} + 5$$

$$R_t = 9\frac{1}{3} \text{ ohms.}$$

The total combined resistance of the circuit is $9\frac{1}{3}$ ohms.

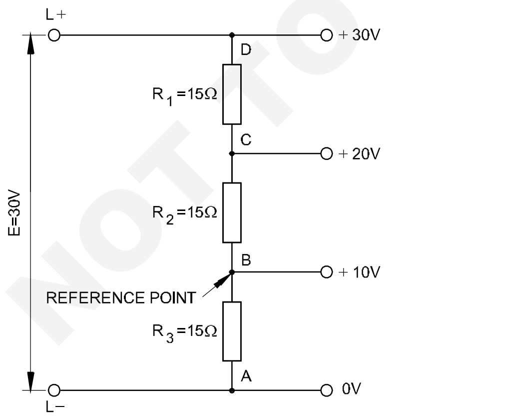
Application

Series-parallel circuits can be used to form a non-standard resistance value which is not available in the market and can be used in the voltage divider circuits.

Voltage divider

If one wants to have different voltages for different parts of a circuit, he can construct a voltage divider. In effect, a voltage divider is nothing more than a series-parallel circuit.

Fig 9



VOLTAGE VALUES ARE GIVEN FOR VOLTAGE DROP TESTS TAKEN ACROSS RESISTORS FROM A TO B (+ 10V), B TO C (+ 10V) AND B TO D (+ 20V). NOTE THAT THE CIRCUIT IS GROUNDED AT REFERENCE POINT B.

A good voltage divider cannot be designed without first looking at the load resistance. Note in Fig 9 that a voltage divider is made with three 15 ohm resistors to get 10 volts drop across each one.

However, as soon as another resistor (load) is added as in Fig 10, there is a further change. The load resistor serves to drop the total resistance of the lower part of the voltage divider. Use this formula for finding the equivalent resistance (R_{eq}) of resistors of equal value in a parallel circuit:

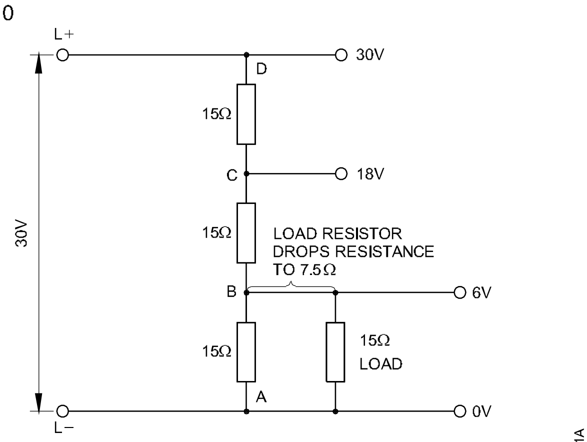
$$R_{eq} = \frac{r}{N}$$

$$R_{eq} = \frac{15}{2} = 7.5 \text{ ohms.}$$

The equivalent resistance of these two 15 ohm resistors in the lower part of the voltage divider is 7.5 ohms. What will happen to the current and voltage in the circuit as a result of this resistance change?

Remember that, as resistance goes down, current goes up. Therefore, with the addition of the load resistor, the circuit will now carry higher amperage but the voltage between points A and B as well as A and C changes. It is important, then, when constructing a voltage divider circuit, to watch the resistance values which change both voltage and current values. Study Fig 10 carefully to make sure you understand how a voltage divider works.

Fig 10



THREE 15 OHMS RESISTORS AND ONE 15 OHM LOAD RESISTOR SERVE AS A VOLTAGE DIVIDER THAT ROUTES DIFFERENT VOLTAGES TO DIFFERENT PARTS OF THE CIRCUIT.

Magnetic terms, magnetic material and properties of magnet

Objectives: At the end of this lesson you shall be able to
- **state the different kinds of magnets and state the classification of magnetic material.**
- **state the molecular theory of magnetism**
- **describe the earth as a magnet**
- **state the classifications of magnets.**

Magnetism and magnets: Magnetism is a force field that acts on some materials and not on other materials. Physical devices which possess this force are called magnets. Magnets attract iron and steel, and when free to rotate, they will move to a fixed position relative to the north pole.

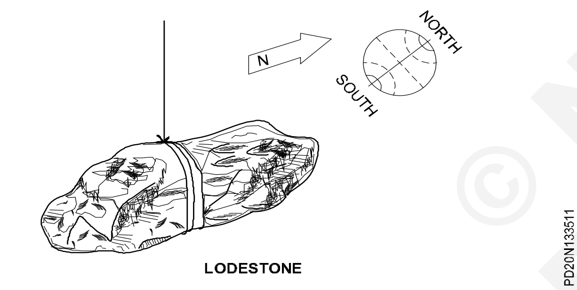
Classification of magnets

Magnets are classified into two groups.

- Natural magnets
- Artificial magnets

Lodestone (an iron compound) is a natural magnet which was discovered centuries ago. (Fig 1)

Fig 1



There are two types of artificial magnets. Temporary and permanent magnets.

Temporary magnets or electromagnets: If a piece of magnetic material, say, soft iron is placed in a strong magnetic field of a solenoid it becomes magnetised by induction. The soft iron itself becomes a temporary magnet as long as the current continues to flow in the solenoid. As soon as the source producing the magnetic field is removed, the soft iron piece will loose its magnetism.

Permanent magnets: If steel is substituted for soft iron in the same inducing field as in the previous case, due to the residual magnetism, the steel will become a permanent magnet even after the magnetising field is removed. This property of retention is termed retentivenes. Thus, permanent magnets are made from steel, nickel, alnico, tungsten all of which have higher retentiveness.

Molecular theory of magnetism: In magnetic materials such as iron, steel, nickel, cobalt and their alloys, which are ferromagnetic materials, the molecules themselves are tiny magnets, each of them having a north pole and south pole. This is basically due to their special crystalline structure and to the continuous movements of electrons in their atoms.

Under ordinary conditions, these molecules arrange themselves in a disorderly manner, the north and south pole of these tiny magnets pointing in all directions and neutralizing one another. Thus a non-magnetized ferromagnetic bar is one in which there is no definite arrangement of the magnetic poles as shown in Fig 2. When iron or steel is magnetized, the molecules are moved into a new arrangement as shown in Fig 3, which is caused by the force used to magnetize them.

Fig 2

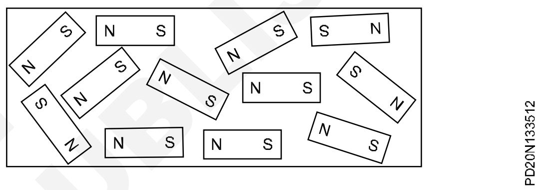
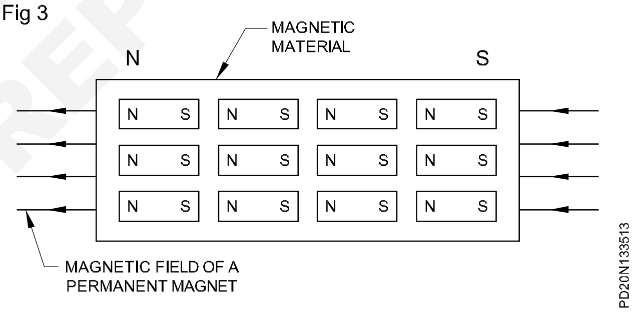
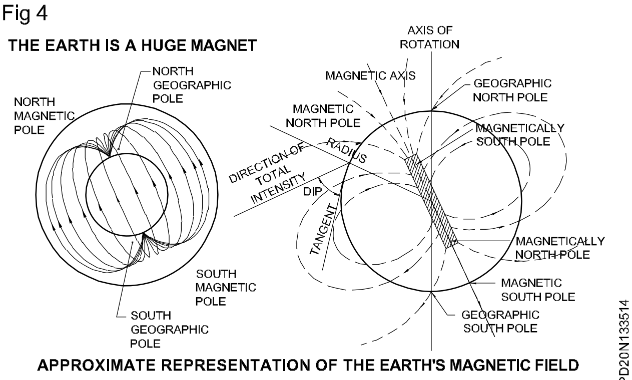


Fig 3



The earth's magnetic field: Since the earth itself is a large spinning mass, it too produces a magnetic field. The earth acts as though it has a bar magnet extending through its centre, with one end near the north geographic pole and the other end near the south geographic pole. (Fig 4)

Fig 4



Classification of magnetic substances

Materials can be classified into three groups as follows.

Ferromagnetic substances: Those substances which are strongly attracted by a magnet are known as ferromagnetic substances. Some examples are iron, nickel, cobalt, steel and their alloys.

Paramagnetic substances: Those substances which are slightly attracted by a magnet of common strength are called paramagnetic substances. Their attraction can easily be observed with a powerful magnet. In short, paramagnetic substances are similar in behaviour to ferromagnetic materials. Some examples are aluminium, manganese, platinum, copper etc.

Diamagnetic substances: Those substances which are slightly repelled by a magnet of powerful strength only are known as diamagnetic substances. Some examples are bismuth, sulphur, graphite, glass, paper, wood, etc. Bismuth is the strongest of the diamagnetic substances.

There is no substance which can be properly called non-magnetic. It may also be noted that water is a diamagnetic material, and air is a paramagnetic substance.

Magnetic terms and properties of magnet

Objectives: At the end of this lesson you shall be able to
- **define the terms magnetic field, magnetic line, magnetic axis, magnetic neutral axis and unit pole**
- **explain the properties of a magnet**
- **describe magnetic shielding**
- **describe the shape of magnets and the method of magnetizing**
- **state the application, care and maintenance of a permanent magnet.**

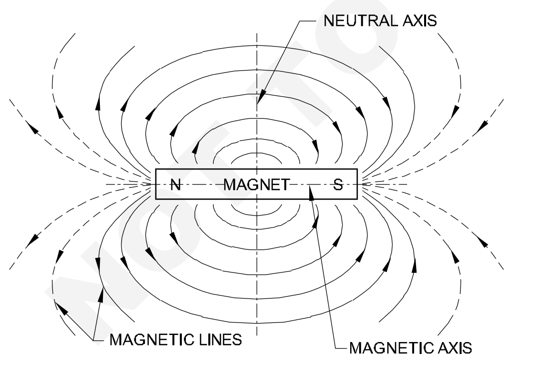
Magnetic fields: The force of magnetism is referred to as a magnetic field. This field extends out from the magnet in all directions, as illustrated in Fig 1. In this figure, the lines extending from the magnet represent the magnetic field.

The space around a magnet in which the influence of the magnet can be detected is called the magnetic field.

Magnetic lines: Magnetic lines of force (flux) are assumed to be continuous loops, the flux lines continuing on through the magnet. They do not stop at the poles.

The magnetic lines around a bar magnet are shown in Fig 1.

Fig 1



MAGNETIC FIELD OF A MAGNET. THE FLUX IS MOST DENSE AT THE POLES.

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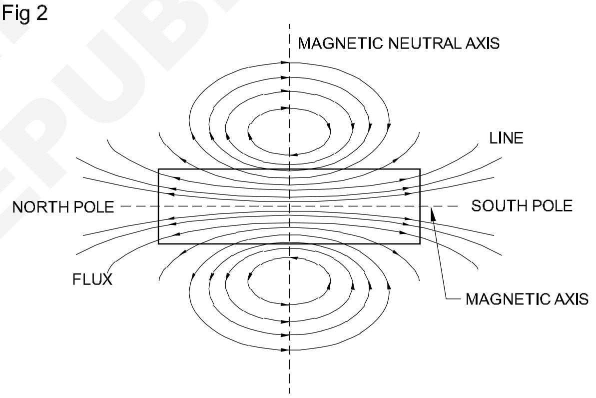
Magnetic axis: The imaginary line joining the two poles of a magnet are called the magnetic axis. It is also known as the magnetic equator.

Magnetic neutral axis (Fig 2): The imaginary lines which are perpendicular to the magnetic axis and pass through the centre of the magnet are called the magnetic neutral axis.

Fig 2



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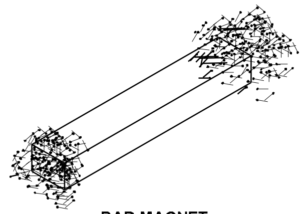
Unit pole: A unit pole may be defined as that pole which, when placed one metre apart from an equal and similar pole, repels it with a force of 10 newtons.

Properties of a magnet

The following are the properties of magnets.

Attractive property : A magnet has the property of attracting magnetic substances (such as iron, nickel and cobalt) and its power of attraction is greatest at its poles. (Fig 3)

Fig 3



BAR MAGNET

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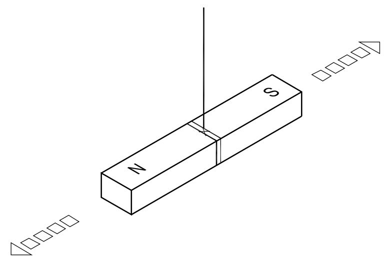
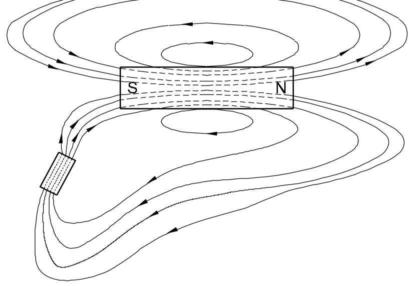
Directive property: If a magnet is freely suspended, its poles will always tend to set themselves in the direction of north and south. (Fig 4)

Fig 4



Induction property: A magnet has the property of producing magnetism in a nearby magnetic substance by induction. (Fig 5)

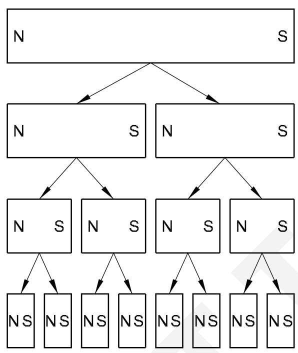
Fig 5



SOFT IRON PROVIDES A PATH FOR MAGNETIC LINES OF FORCE.

Poles-existing property: A single pole can never exist in a magnet. If it is broken into its molecules, each molecule will have two poles. (Fig 6)

Fig 6



MAGNET WHEN DIVIDED

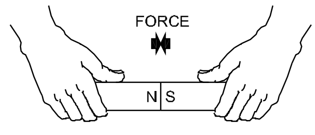
Demagnetising property: If a magnet is handled roughly by heating, hammering, etc. it will lose its magnetism.

Property of strength: Every magnet has two poles. The two poles of a magnet have equal pole strength.

Saturation property: If a magnet of higher strength is further subjected to magnetization, it will never acquire more magnetization due to its being already saturated.

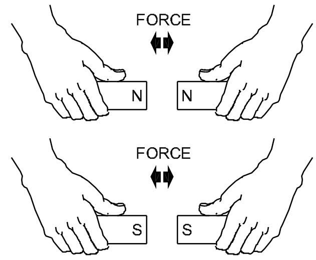
Property of attraction and repulsion: Unlike poles (i.e. north and south) attract each other, (Fig 7) while like poles (north/north and south/south) repel each other. (Fig 8)

Fig 7



ATTRACTION

Fig 8



REPULSION

Assumed physical properties of magnetic lines of force: The lines of force always travel from the north to the south pole outside the magnet through air and from the south to the north pole inside the magnet.

All the magnetic lines of force complete their circuit (form a loop).

The magnetic lines do not cross each other. The lines of force travelling in one direction have a repulsive force between them, and, therefore, do not cross.

The magnetic lines prefer to pass and complete their circuit through a magnetic material.

They behave like a magnetic elastic band.

Magnetic shielding: Magnetic flux lines can pass through all materials. Magnetic materials have a very low reluctance to flux lines. The lines of flux will be attracted through a magnetic material even if they have to take a longer path. (Fig 9) This characteristic allows us to shield things from magnetic lines of force by enclosing them with a magnetic material. This is the way anti-magnetic watches are made. Measuring instruments which are to be shielded are enclosed inside an iron case. (Fig 10)

Shapes of magnets: Magnets are available in various shapes, with the magnetism concentrated at their ends known as poles. The common shapes are listed here.

– Bar magnet

– Horseshoe magnet

– Ring magnet

– Cylindrical type magnet

– Specially shaped magnets

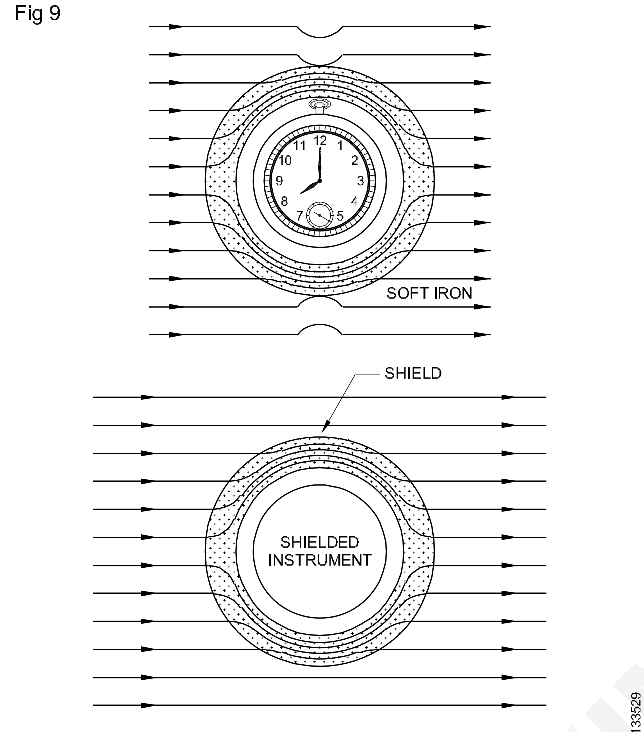
Bar magnet: It is in the form of a rectangular block with the magnetism concentrated at the ends, north pole and south pole. (Fig 11a)

Horseshoe magnet : A rectangular iron rod bent to the shape of a horseshoe with the magnetism concentrated at their ends forming the north pole and south pole. (Fig 11b)

Ring magnet: A ferrous metal formed into a ring as shown in Fig 11c is a ring magnet.

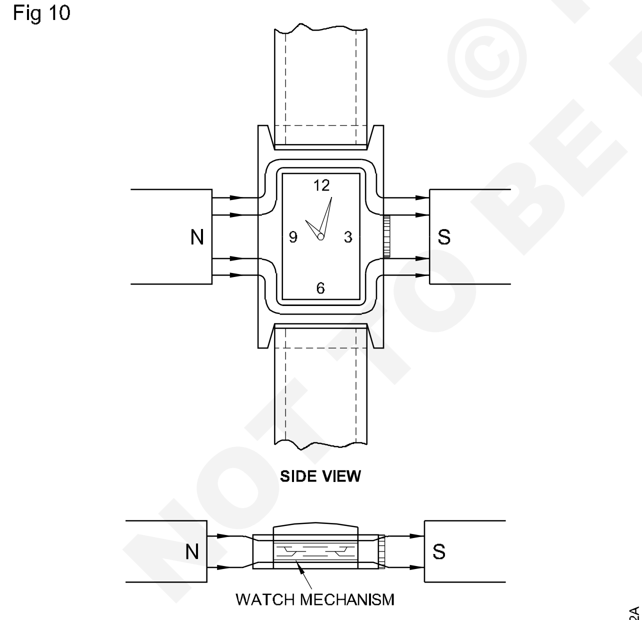
Cylindrical type magnet: It is formed by a cylindrical iron rod with concentration of magnetism at the north and south pole ends as shown in Fig 11d.

Fig 9



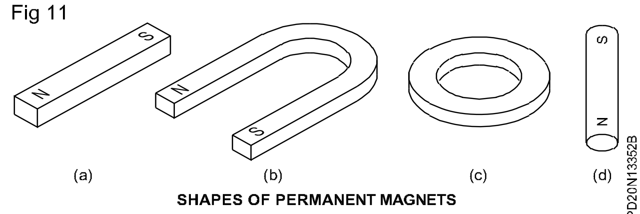
MAGNETIC SHIELD. THE SHIELD PROVIDES A LOW- RELUCTANCE PATH AROUND THE PROTECTED AREA.

Fig 10



MAGNETIC MATERIALS SHIELD A WATCH FROM MAGNETIC FIELDS. THE SHIELD BECOMES ONLY TEMPORARILY MAGNETIZED. THE FLUX LINES CANNOT REACH THIS WATCH MECHANISM.

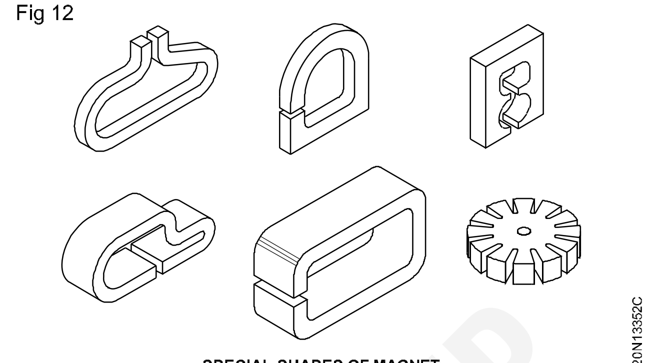
Fig 11



SHAPES OF PERMANENT MAGNETS

Specially shaped magnets: Permanent magnets for special purposes like, for the use of magnet in automobiles, cycle dynamos, electrical instruments and energy meters, are made to special shapes depending upon the purpose for which they are needed. (Fig 12)

Fig 12



SPECIAL SHAPES OF MAGNET

Methods of magnetizing: There are three principal methods of magnetizing a material.

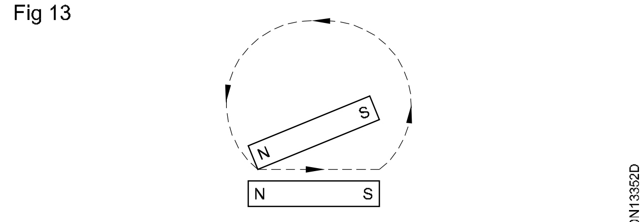
- Touch method
- By means of electric current
- Induction method.

Touch method: This method can be further divided into:

- single touch method
- double touch method, and
- divided touch method

Single touch method: In the single touch method, the steel bar to be magnetized is rubbed with either of the poles of a magnet, keeping the other pole away from it. Rubbing is done only in one direction as shown in Fig 13. The process should be repeated many times for inducing magnetization of the bar.

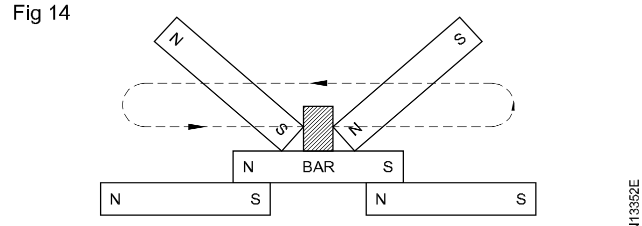
Fig 13



STEEL BAR

Double touch method: In this method the steel bar to be magnetized is placed over the two opposite pole ends of a magnet, and the rubbing magnets are placed together over the centre of the bar with a small wooden piece in between, as shown in Fig 14. They are never lifted off the surface of the steel bar, but rubbed again and again from

Fig 14

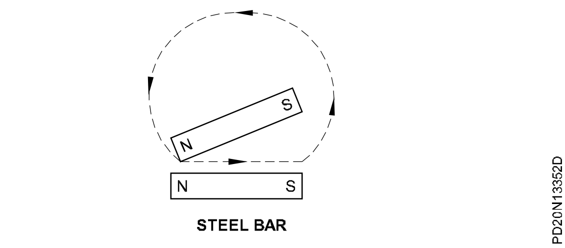


DOUBLE-TOUCH METHOD

end to end, finally ending at the centre where the rubbing was started.

Divided touch method: Here the two different poles of the rubbing magnets are placed as in the previous case. They are then moved along the surface of the steel bar to the opposite ends. The rubbing magnets are then lifted off the surface of the steel bar and placed back in the centre of the bar. The whole process is repeated again and again as shown in Fig 15.

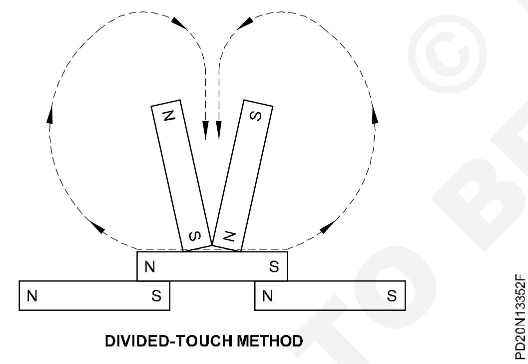
Fig 13



The steel bar thus magnetized becomes a permanent magnet but the degree of magnetization is very low.

By electric current: The bar to be magnetized is wound with an insulated copper wire, and then a strong electric current (DC) from a battery is passed through the wire for some time. The steel bar then becomes highly magnetized. If the bar is of soft iron, the magnetism remains as long as the current continues but almost completely disappears as soon as the current ceases. The magnet made by such an arrangement is called an electromagnet and is generally used in laboratories. (Fig 16)

Fig 15

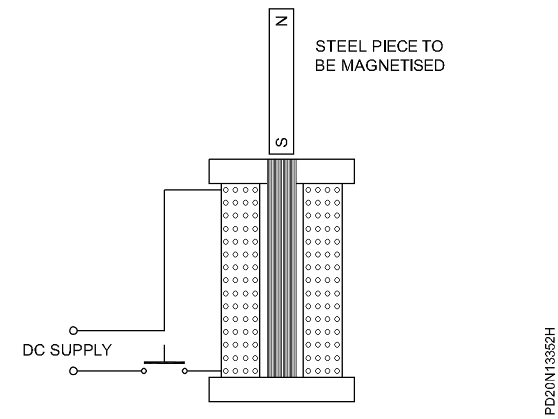


Induction method: This is a commercial method of making permanent magnets. In this method a pole charger is used which has a coil of many turns and an iron core inside it as shown in Fig 17. The direct current supply is fed to the coil through a push-button switch.

The steel piece to be magnetized is placed on the iron core kept inside the coil, and direct current is passed through the coil. The iron core now becomes a powerful magnet, and thus the steel piece is magnetised by induction. The magnetised piece is then removed after switching off the supply.

This is a commercial process for making permanent magnets for speakers, telephones, microphones, earphones, electrical instruments, magnets,compasses etc.

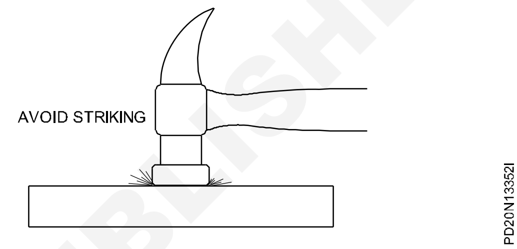
Fig 17



Care and maintenance of permanent magnets: Permanent magnets should not be thrown or dropped.

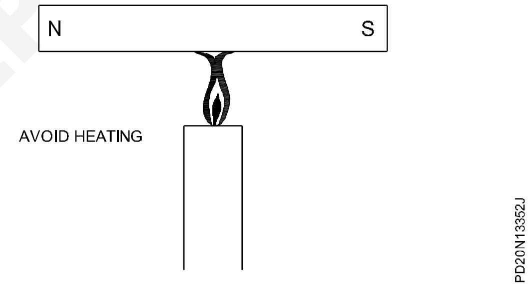
They should not be hammered. (Fig 18)

Fig 18



They should not be heated. (Fig 19)

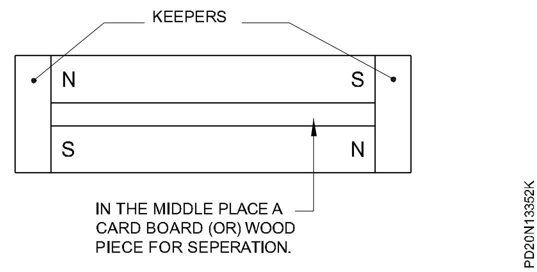
Fig 19



Bar magnets should be placed side by side with their ends facing opposite polarity, with keepers at their ends.

Keepers should be used while storing the magnets. (Fig 20)

Fig 20



As far as possible, the north and south poles of the magnet should be kept in the direction of the south and north directions of the earth respectively.

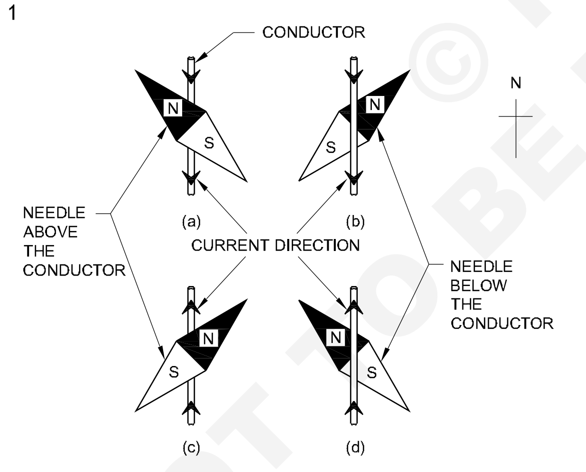
Principles and laws of electro magnetism

Objectives: At the end of this lesson you shall be able to
- **state the oersted principle**
- **explain what is meant by electromagnetism**
- **describe the magnetic field in current-carrying conductors, loop, coil, magnetic core -**
- **right Hand Grip rule, Corkscrew rule and Right Hand palm rule**
- **state the interaction of the magnetic field**
- **state the magnetic materials for a temporary magnet.**

Oersted's experiment: Oersted, a Danish scientist discovered in 1819, while giving a demonstration lecture, that there is a close relationship between electricity and magnetism. He observed that when a magnetic needle is placed under and parallel to a conductor, and then the current switched on, the needle tends to deflect at right angles to the wire.

Suppose, a wire in which the current is to be passed, is arranged in the direction north to south by placing the needle above the wire as in Fig 1a. Then the north pole of the needle will be deflected to the west, nearly perpendicular to the wire. The deflection will be to the east, as in Fig 1b by placing needle below the wire. When the direction of the flow of current is reversed, the deflections of the needle will be in the opposite direction as shown in Fig 1c and 1d.

Fig 1



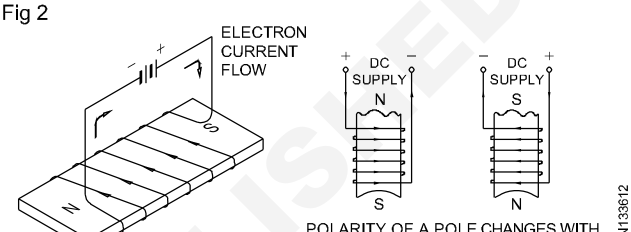
DEFLECTION OF MAGNETIC NEEDLE BY AN ELECTRIC CURRENT

In these cases the deflection of the needle shows that the lines of force are produced around the current-carrying conductor as shown in Fig 3.

Electromagnetism: On passing a current through a coil of wire, a magnetic field is set up around the coil. If a soft iron bar is placed in the coil of wire carrying the current, the iron bar becomes magnetized. This process is known as `electromagnetism'. The soft iron bar remains as a magnet as long as the current is flowing in the circuit. It loses its magnetism when the current is switched off from the coil.

The polarity of this electromagnet depends upon the direction of the current flowing through it. If the direction of the current is altered, the polarity of the magnetic field will also be changed as shown in Fig 2.

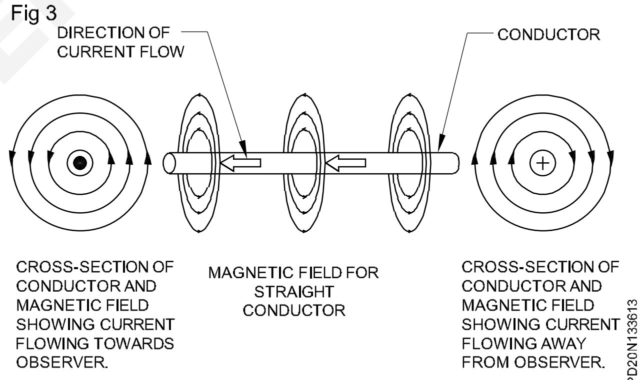
Fig 2



POLARITY OF A POLE CHANGES WITH CHANGE OF CURRENT IN THE COIL

Electromangetism in a wire (current-carrying conductor): A magnetic field is formed around a conductor carrying current. The field is so arranged around the conductor as to form a series of loops. (Fig 3)

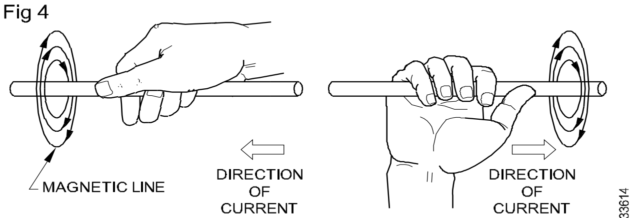
Fig 3



The direction of the magnetic field depends on the direction of the current flow. A compass moved around the wire will align itself with the flux lines.

The Right Hand Grip Rule can be used to determine the direction of the magnetic field. If you wrap your fingers around the wire with your thumb pointing in the direction of current flow, your fingers will point in the direction of the magnetic field as shown in Fig 4.

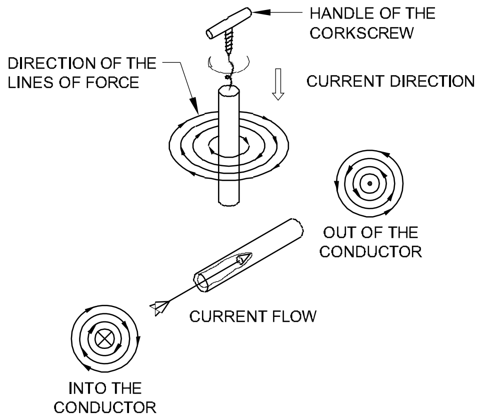
Fig 4



RIGHT HAND GRIP RULE SHOWING THE DIRECTION OF CURRENT AND DIRECTION OF MAGNETIC LINES

Assume a right handed corkscrew to be along the wire so as to advance in the direction of the current. The motion of the handle gives the direction of magnetic lines of force around the conductor (Fig 5)

Fig 5



CORKSCREW RULE

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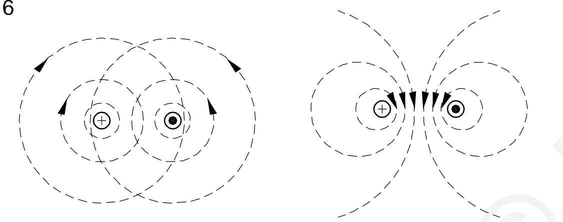
If two wires carrying current in opposite directions are brought close to each other, their magnetic fields will oppose one another, since the flux lines are going in the opposite directions. The flux lines cannot cross, and the fields move the wires apart. (Fig 6)

Fig 6



PARALLEL CONDUCTORS CARRYING CURRENT IN OPPOSITE DIRECTION

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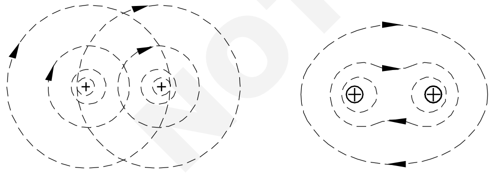
When wires carrying current in the same direction are brought together, their magnetic fields will aid one another, since the flux lines are going in the same direction. The flux lines join and form loops around both the wires, and the fields bring the wires together. The flux lines of both wires add to make a stronger mangetic field. Three or four wires put together in this way would make a still stronger field. (Fig 7)

Fig 7



PARALLEL CONDUCTORS CARRYING CURRENT IN SAME DIRECTION

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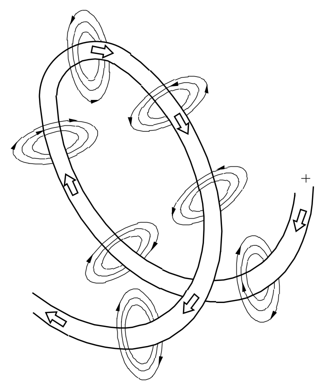
Electromagnetism in a loop: If the wire is made to form a loop, the magnetic fields around the wire will all be so arranged that they each flow into the loop on one side, and come out on the other side. In the centre of the loop, the flux lines are compressed to create a dense and strong field. This produces magnetic poles, with north on the side that the flux lines come out and south on the side that they go in as shown in Fig 8.

Fig 8



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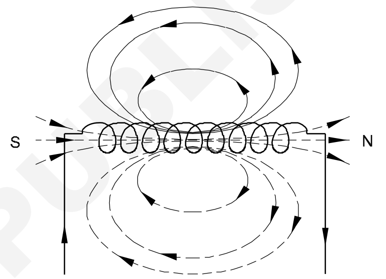
Electromagnetism in a coil: If a number of loops are wound in the same direction to form a coil, more fields will add to make the flux lines through the coil even more dense. The magnetic field through the coil becomes even stronger. The greater the number of loops, the stronger the magnetic field becomes. If the coil is compressed tightly, the fields would join even more to produce an even stronger electromagnet as shown in Fig 9.

Fig 9



SOLENOID

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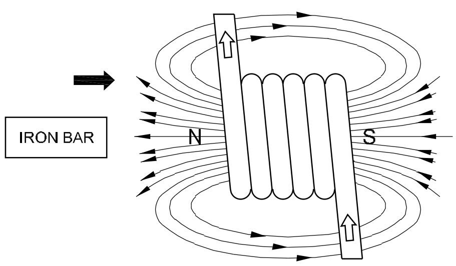
A helically wound coil that is made to produce a strong magnetic field is called a solenoid. The flux lines in a solenoid act in the same way as in a magnet. They leave the N pole and go around to the S pole. When a solenoid attracts an iron bar, it will draw the bar inside the coil. (Fig 10)

Fig 10



SOLENOID

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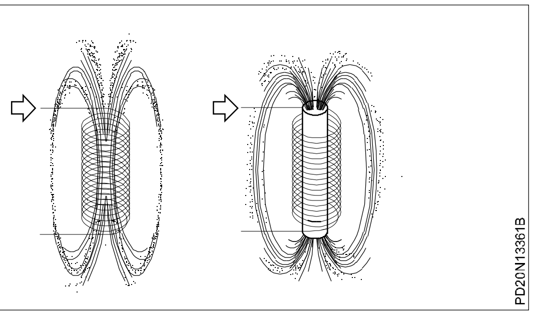
The magnetic core: The magnetic field of a coil can be made stronger still by keeping an iron core inside the coil of wire. Since the soft iron is magnetic and has a low reluctance, it allows more flux lines to be concentrated in it than it would in the air. The greater the number of flux lines, the stronger the magnetic field. (Fig 11)

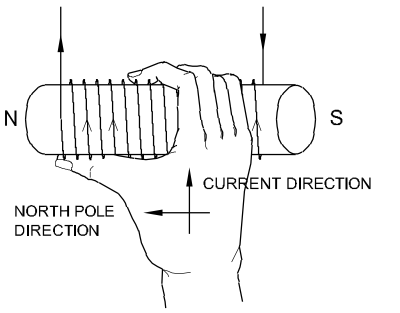
Soft iron is used as a core in an electromagnet because hard steel would become permanently magnetized.

Fig 11



The direction of the magnetic field can be found from palm rule right hand palm rule. (Fig 12)

Fig 12



RIGHT HAND PALM RULE

The Right Hand Palm Rule : Hold the right hand palm over the solenoid in such a way the fingers point in the direction of current in the solenoid conductors then the thumb indicates the direction of magnetic field (North Pole) of the solenoid.

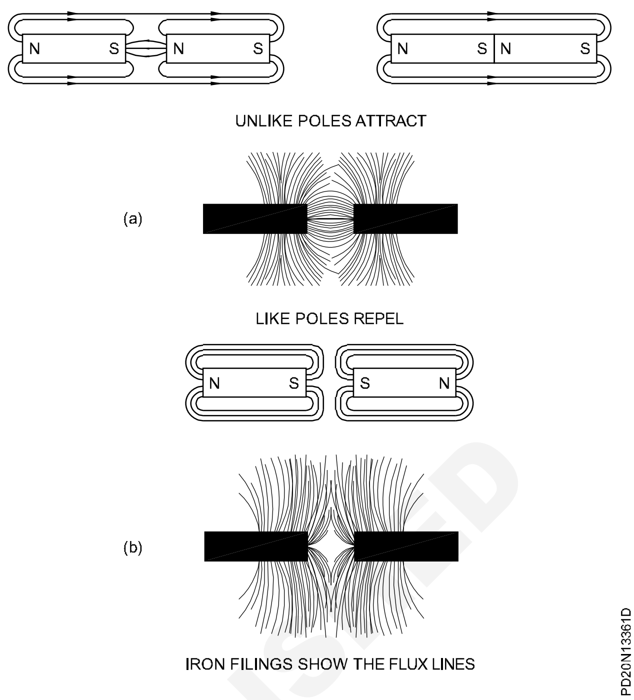
Interaction of magnetic fields: When two magnets are brought together, their fields interact. The magnetic lines of force will not cross one another. This fact determines how the fields act together.

If the lines of force are going in the same direction, they will attract each other and join together as they approach each other. This is why unlike poles attract. (Fig 13a)

If the lines of force are going in opposite directions, they cannot combine. And, since they cannot cross, they apply a force against each other. This is why like poles repel.

The interaction of the flux lines can also be shown with iron filings. (Fig 13b)

Fig 13



Magnetic materials for temporary magnets: Electromagnets are generally known as temporary magnets. The magnetic strength of such magnets can be varied by varying the current passing through them. Soft iron is used in electromagnets as a magnetic core. Silicon steel is very much used in bigger magnets (steel with 2.4% silicon). Nowadays other metals like permalloy, mumetal are also used for some applications.

Permalloy is an alloy of iron and nickel which can be magnetized by a very weak magnetic field and is useful for telephones.

Mumetal is an alloy of nickel, copper, chromium and iron. It has very high permeability and resistivity. Eddy current loss is very low. It is used in instrument transformers and for screening magnetic fields.

The magnetic circuits - self and mutually induced emfs

Objectives: At the end of this lesson you shall be able to
- **define the magnetic terms in a magnetic circuit (like M.M.F., reluctance, flux, field strength, flux density, permeability, relative permeability)**
- **state hysterisis and explain hysterisis loop**
- **describe pulling power of magner.**

MagnetoMotive Force (MMF): The amount of flux density set up in the core is dependent upon five factors - the current, number of turns, material of the magnetic core, length of core and the cross-sectional area of the core. More current and the more turns of wire we use, the greater will be the magnetising effect. We call this product of the turns and current the magnetomotive force (mmf), similar to the electromotive force (emf). (Fig 1 & 2)

Fig 1

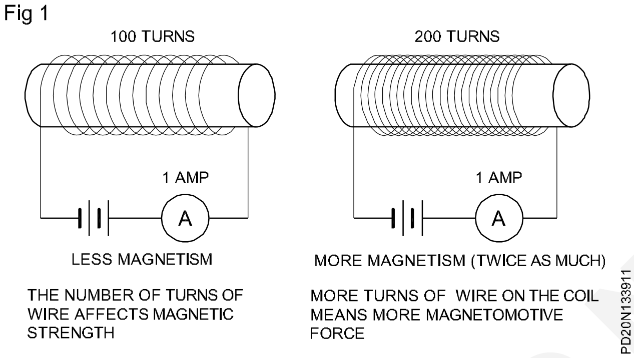
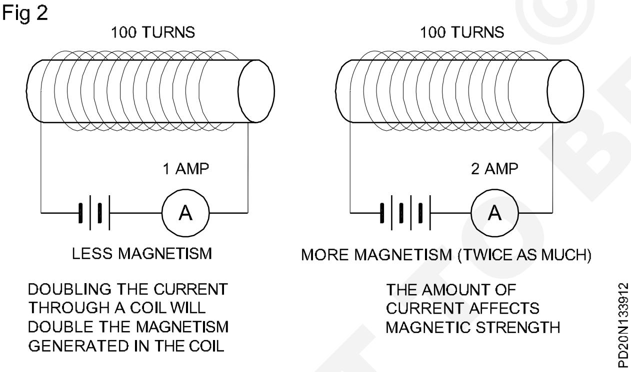


Fig 2



MMF = NI ampere-turns

where mmf - is the magnetomotive force in ampere turns

N - is the number of turns wrapped on the core

I - is the current in the coil, in amperes, A.

If one ampere current is flowing through a coil having 200 turns then the mmf is 200 ampere turns.

Reluctance: In the magnetic circuit there is something analogous to electrical resistance, and is called reluctance, (symbol S). The total flux is inversely proportional to the reluctance and so if we denote mmf by ampere turns. we can write

$\phi = \dfrac{NI}{S}$ Where ϕ is flux and reluctances $S = \dfrac{\ell}{\mu_o \mu_r a}$

where S - reluctance

l - length of the magnetic path in metres

μ_o - permeability of free space

μ_r - relative permeability

a - cross-sectional area of the magnetic path in sq.mm.

The unit of reluctance is ampere turns/Wb.

Magnetic flux:The magnetic flux in a magnetic circuit is equal to the total number of lines existing on the cross-section of the magnetic core at right angle to the direction of the flux. Its symbol is Ø and the SI unit is weber.

$$\phi = \frac{NI}{S}$$

$$= \frac{NIa\mu_o\mu_r}{\ell}$$

where

ϕ - total flux

N - number of turns

I - current in amperes

S - reluctance

μ_o - permeability of free space

μ_r - relative permeability

a - magnetic path cross-sectional area in m^2

B - length of magnetic path in metres.

Magnetic field strength: This is also known sometimes as field intensity, magnetic intensity or magnetic field, and is represented by the letter H. Its unit is ampere turns per metre.

$$H = \frac{\text{M.M.F}}{\text{Length of coil in meters}} = \frac{NI}{\ell}$$

Flux density (B): The total number of lines of force per square metre of the cross- sectional area of the magnetic core is called flux density, and is represented by the symbol B. Its SI unit (in the MKS system) is tesla (weber per metre square).

$B - \dfrac{\phi}{A}$ Weber/ m^2

where ϕ - total flux in webers

A - area of the core in square metres

B - flux density in weber/metre square.

Permeability: The permeability of a magnetic material is defined as the ratio of flux created in that material to the flux created in air, provided that mmf and dimensions of the magnetic circuit remain the same. It's symbol is μ and

$\mu = B/H$

where B is the flux density

H is the magnetising force.

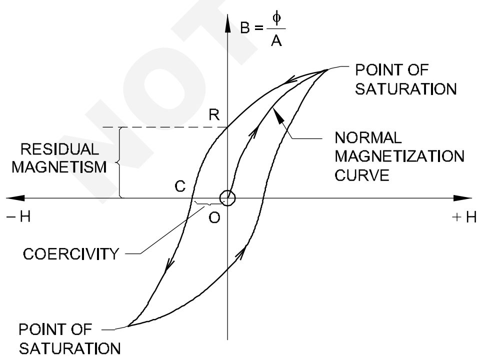
Being a ratio it has no unit and it is expressed as a mere number. The permeability of air μ air = unity. The relative permeability μr of iron and steel ranges from 50 to 2000. The permeability of a given material varies with its flux density.

Hysteresis: Consider the graphical relation between B and H for a magnetic material. Since μ = B/H, the graphical relationship shows how the permeability of a material varies with the magnetizing intensity H.

Assume that the magnetic core is initially completely demagnetised. As we increase the current, $H = \dfrac{NI}{\ell}$ increases and there will be an increase in the flux density, B. Since the number of turns and the length of core of a coil are fixed, H is directly proportional to the current or ammeter reading. The flux density can be measured by inserting the probe of a flux meter into a small hole drilled in the core.

A plot of the values of B and H gives the normal magnetization curve, as shown in Fig 3.There is evidently a linear portion where B is relatively proportional to H. But then a condition of saturation occurs when a very large increase in H is required to significantly increase B. This point in the curve is called as **saturation point.**

Fig 3



HYSTERESIS LOOP FOR MATERIAL USED IN AN AC CIRCUIT

If the current is now gradually reduced towards zero, H returns to zero, but B does not. The core exhibits retentiveness and retains some residual magnetism. The **retentiveness** is represented by the distance OR.

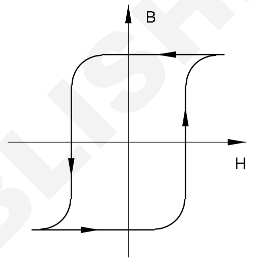
If the connections to the coil are reversed, and the current is again increased, it is found that a certain amount of H is required to bring the magnetism in the core down to zero. This is called the **coercivity** and is represented by the distance OC.

Further, any increase in the current in the opposite direction increases the magnetism in the core as before in the opposite direction, until once again saturation occurs.

Hysteresis loop: Reduction of the current and subsequent reversal of the direction will produce a closed figure called a B-H curve or hysteresis loop. The name comes from the Greek word `hysteros' meaning `to lag behind'. That is, the state of the flux density is always lagging behind the efforts of the magnetising intensity.

The shape of a B-H loop is an indication of the magnetic properties of the material. (Fig 4)

Fig 4



HYSTERSIS LOOP FOR PERMANENT MAGNET

Hysteresis results in the dissipation of energy which appears in the form of heat. The energy wasted in this manner is proportional to the area of the loop. Thus, the energy expanded, in joules per cubic metre of material in one cycle, is equal to the area of the loop in M.K.S. units.

Energy expended/cycle/m^2 in joules= Area of hysteresis loop in m^2.

The shape of the hysteresis loop depends on the nature of the iron or steel. Iron is subject to rapid reversal of magnetism and in this case the area of loop is very small.

Numerically the loss is given by the equation,energy dissipated per second = $\eta f B_m^{1.6}$ joules/m^3

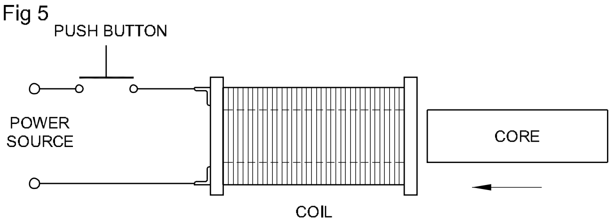
where η - constant, called hysteresis coefficient

B_m - maximum flux density

f - frequency.

Pulling power of solenoid: When the coil is energised, it produces a magnetic field which also magnetises the iron core. The iron core is attracted to the coil and they

Fig 5



CORE MOVES INWARD BY SUCKING ACTION WHEN COIL IS ENERGIZED snap together. Once the core is in the centre of the coil, the magnetic field is concentrated with that core and there is no room for further movement.

The pulling power of a solenoid depends on the number of turns of the coil, the current, material, flux density of the magnetic core, length and cross-sectional area of the core. The strength of an electromagnet depends upon its ability to conduct magnetism. The ability of conduction depends on mmf, reluctance and permeability of the magnetic path. (Fig 5)

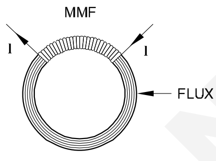
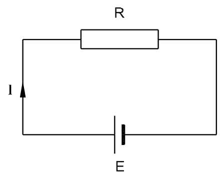
Electromagnet applications - Electromagnetic induction

Objectives: At the end of this lesson you shall be able to
- **compare the magnetic circuit and electric circuit**
- **state the applications of an electromagnet (Bell & Buzzer tubelight choke)**
- **state the principle and laws of electromagnetic induction**
- **explain the energy stored in induction coil**
- **explain about the series and parallel connection of inductors and types of inductors**
- **state function of choke in a flourscent light circuit**
- **state the factors that contribute to induced voltage**
- **explain about the counter EMF-induced reactance-time constant.**

Comparison between magnetic and electric circuits

Similarities (Fig 1a & 1b)

Fig 1

	Magnetic Current	Electrical Current
1	Flux = $\frac{\text{mmf}}{\text{reluctance}}$ 	Current = $\frac{\text{emf}}{\text{resistance}}$ 
2	M.M.F. (Ampere-turns)	E.M.F. (Volts)
3	Flux ϕ (Webers)	Current I (amperes)
4	Flux density B (Wb/m^2)	Current density (A/m^2)
5	Reluctance $S = \frac{\ell}{\mu_A}$ or $S = \frac{\ell}{\mu_0 \mu_r a}$	Resistance
6	Permeance = (1/reluctance)	Conductance (= 1/resistance)
7	Reluctivity $\mu_o \mu_r A$	Resistivity
8	Permeability (=1/reluctivity)	Conductivity(=1/resistivity)

Practical applications of electromagnets: Electromagnets are used in the manufacture of all types of electrical machines, such as motors, generators, transformers, convertors, some electrical measuring instruments, protective relays, for medical purposes (like removing iron pieces from eyes) and in many other electrical devices like bells, buzzers, circuit-breakers, relays, telegraphic circuits, lifts and other industrial uses. (Figs 2, 3, 4, 5 & 6)

a Bells (Fig 2)

b Buzzers

c Circuit-breakers (Fig 3)

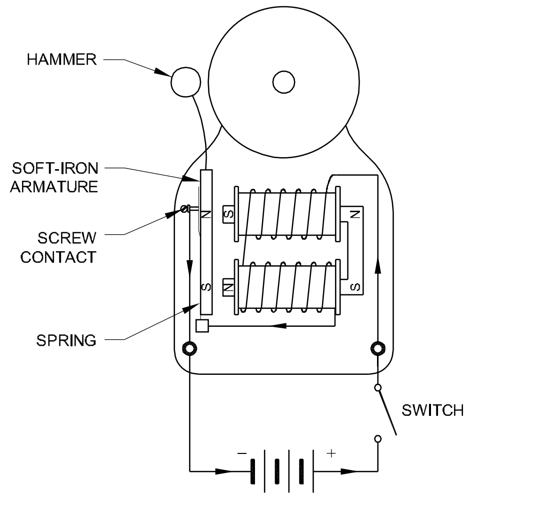
d Relays (Fig 4)

e Telegraphic circuits

f Lifts (Fig 5)

g Industrial uses (Fig 6)

Fig 1



ELECTRIC BELL

Fig 2

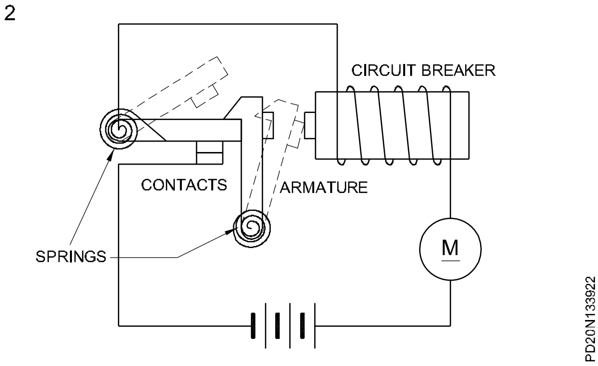
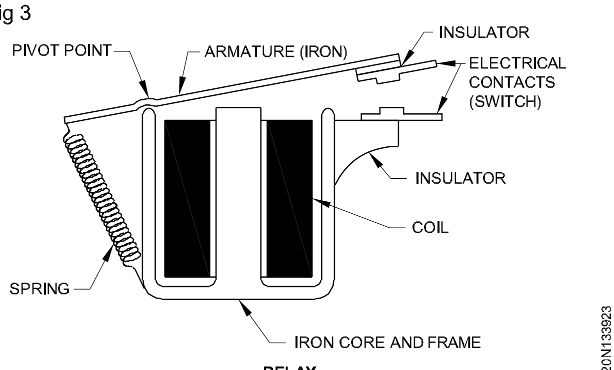
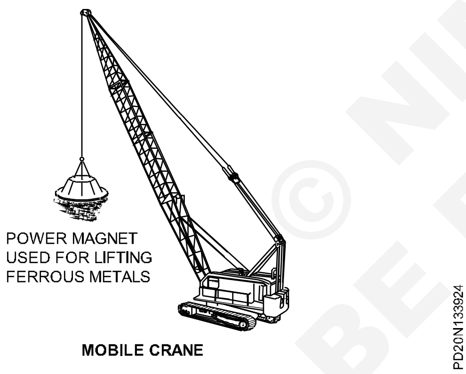


Fig 3



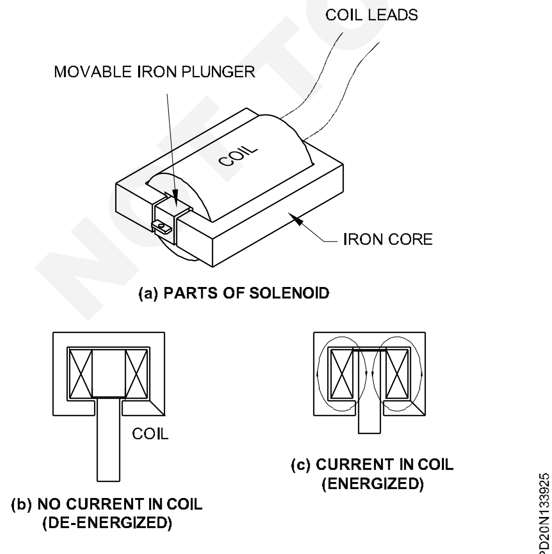
RELAY

Fig 4



MOBILE CRANE

Fig 5



Principles and laws of electromagnetic induction

Faraday's Laws of Electromagnetic Induction are also applicable for conductors carrying alternating current.

Faradays' Laws of Electromagnetic Induction

Faraday's First Law states that whenever the magnetic flux is linked with a circuit changes, an emf is always induced in it.

The Second Law states that the magnitude of the induced emf is equal to the rate of change of flux linkage.

Dyanamically Induced EMF

Accordingly induced emf can be produced either by moving the conductor in a stationery magnetic field or by changing magnetic flux over a stationery conductor. When conductor moves and produces emf, the emf is called as dynamically induced emf Ex. generators.

Statically Induced EMF

When changing flux produces emf the emf is called as statically induced emf as explained below. Ex: Transformer.

Statically induced emf: When the induced emf is produced in a stationery conductor due to changing magnetic field, obeying Faraday's laws of electro magnetism, the induced emf is called as statically induced emf.

There are two types of statically induced emf as stated below:-

1 **Self induced emf** produced with in the same coil

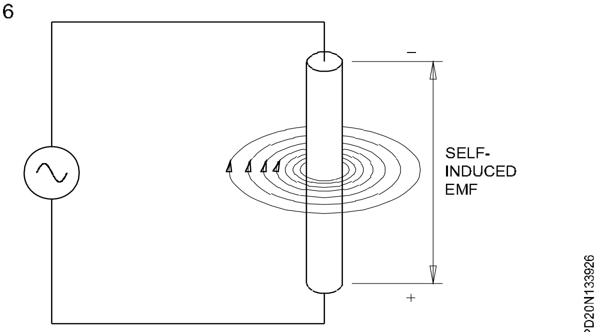
2 **mutually induced emf** produced in the neighbouring coil

Self-induction: The production of an electromotive force in a circuit, when the magnetic flux linked with the circuit changes as a result of the change in a current inducing in the same circuit.

At any instant, the direction of the magnetic field is determined by the direction of the current flow.

With one complete cycle, the magnetic field around the conductor builds up and then collapses. It then builds up in the opposite direction, and collapses again. When the magnetic filed begins building up from zero, the lines of force or flux lines expand from the centre of the conductor outward. As they expand outward, they can be thought of as cutting through the conductor.

Fig 6

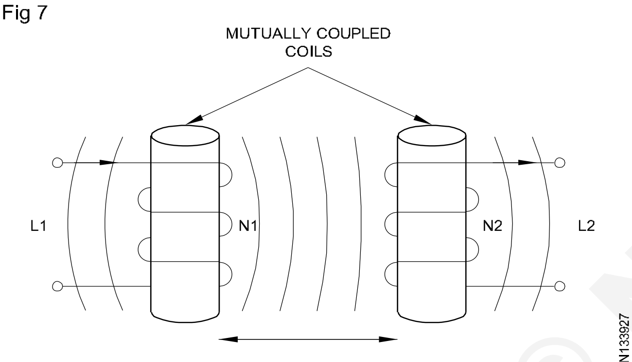


According to Faraday's Laws, an emf is induced in the conductor. Similarly, when the magnetic field collapses, the flux lines cut through the conductor again, and an emf is induced once again. This is called self-induction. (Fig 7)

Mutual Inductance: When two or more coils one magnetically linked together by a common magnetic flux, they are said to have the property of mutual inductance. It is the basic operating principal of the transformer, motor generaters and any other electrical component that interacts with another magnetic field. It can define mutual induction on the current flowing in one coil that induces a voltage in an adjacement coil.

In the Fig,8 current flowing in coil L1 sets up a magnetic field around it self with some of its magnetic field line passing through coil L2 giving in mutual inductance coil one L on has a current of I, and N, turns while coil two L2, has N2 turns therefore mutual inductance M, of coil two that exists with respect to coil one L, depend on their position with inspect to each other.

Fig 7



MUTUAL INDUCTANCE BETWEEN COILS

The mutual inductance M that exists between the two coils can be greately measured by positioning them on a common soft iron cone or by measuring the number of turns of either coil on would he found in a transformer.

The two coils are tightly wound one on top of the other over a common soft iron core unity in said to exist between them as any losses due to the leakage of flux will be extremely small. Then assuring a perfect flux leakage between the two coils the mutual inductance M that exists between them can be given on:

$$M = \frac{Mo\,Mr\,N1\ N2\ A}{l}$$

Value

m.o is the permeability of free space $(4\pi \times 10^{-7})$

μr - is the relative permability of soft iron cone
N is the no. of turns of coil

A is the cross sectional area in m^2

l is the coil length in meters

Inductance: Inductance (L) is the electrical property of an electrical circuit or device to oppose any change in the magnitude of current flow in a circuit.

Devices which are used to provide inductance in a circuit are called inductors. Inductors are also known as chokes, coils, and reactors. Inductors are usually coils of wire.

Factors determining inductance: The inductance of an inductor is primarily determined by four factors.

- Type of core permeability of the core $m_{r.}$
- Number of turns of wire in the coil 'N'.
- Spacing between turns of wire (Spacing factor).
- Cross-sectional area (diameter of the coil core) 'a' or 'd'.

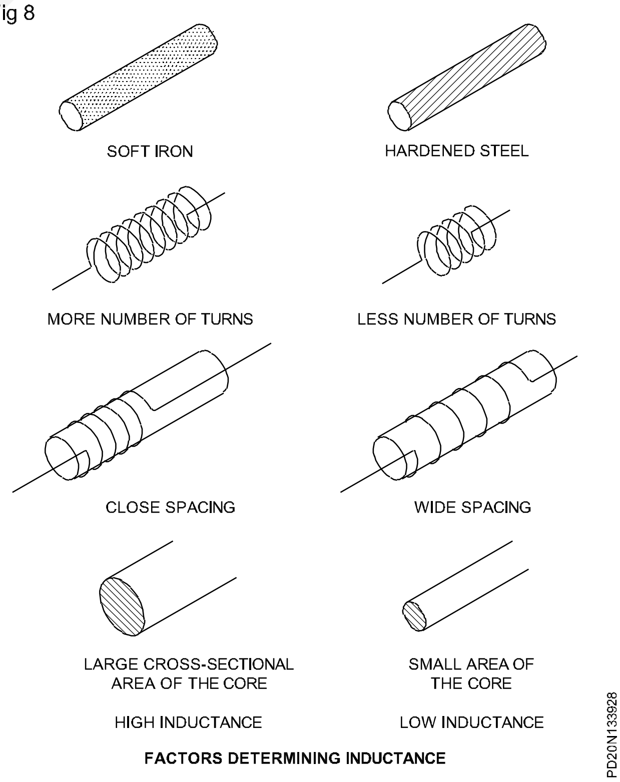
The amount of inductance in a coil of wire is affected by the physical make up of the coil. (Fig 8.)

Core (Fig 9a): If soft iron is used as a core material instead of hardened steel, the coil will have more inductance.

If all the factors are equal, an iron core inductor has more inductance than an air core inductor. This is because iron has a higher permeability, that is, it is able to carry more flux. With this higher permeability there is more flux change, and thus more counter induced emf (cemf), for a given change in current.

Number of turns (Fig 9b): Adding more turns to an inductor increases its inductance because each turn adds more magnetic field strength to the inductor. Increasing the magnetic field strength results in more flux to cut the conductors (turns) of the inductor.

Fig 8



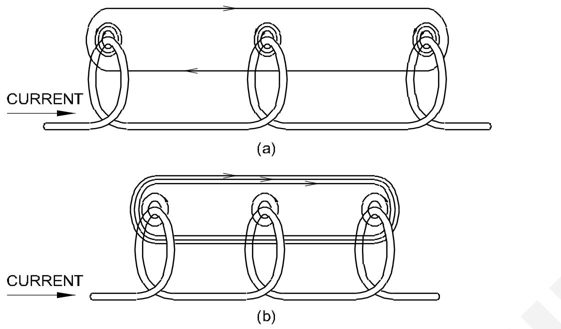
FACTORS DETERMINING INDUCTANCE

Spacing between turns of wire (Fig 9c): When the distance between the turns of wire in a coil is increased, the inductance of the coil decreases. Fig 10 illustrates why this is so. With widely spaced turns Fig 10 many of the flux lines from adjacent turns does not link to gether. Those lines that do not link together produce no voltage in other turns. As the turns come closer together Fig 10 only a fewer lines of flux fail to link up.

Cross sectional area (Fig 9d):For a given material having same number of turns, the inductance will be high with large cross-sectional area and will be low for smaller cross-sectional area.

Symbol and unit of Self-inductance: The property of a coil or conductor to self-induce an emf, when the current though it is changing, is called the coil's (conductor's) self-inductance of simply inductance. The letter symbol for inductance is L; its basic unit is henry, H.

Fig 9



WIDELY SPACED TURNS PROVIDE LESS INDUCTANCE THAN CLOSELY SPACED TURNS

EFFECT OF TURN SPACING

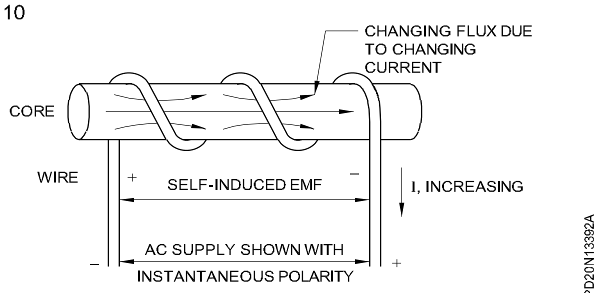
Henry: A conductor or coil has an inductance of one henry if a current that changes at the rate of one ampere per second produces a induced voltage (cemf) of 1 volt.

The inductance of straight conductors is usually very low, and for our proposes can be considered zero. The inductance of coiled conductors will be high, and it plays an important role in the analysis of AC circuits.

What will be the direction of the induced emf? (Lenz's Law): The direction of the self-induced emf is explained by Lenz's Law.

A change in current produces an emf whose direction is such that it opposes the change in current. In other words, when a current is decreasing, the induced emf is in the same direction as the current and tries to oppose the current from decreasing. And when a current is increasing, the polarity of the induced emf is opposite to the direction of the current and tries to prevent the current from increasing (Fig 11).

Fig 10



The magnitude of induced emf:The magnitude of self-induced emf depends on the rate at which the magnetic field changes. However magnetic field is proportional to current.

$$v = L \times \frac{di}{dt}$$

where

- v is the emf induced in volts, V (some times called as counter emf (cemf)
- L is the inductance in henrys, H
- di is the change in current in amperes, A.
- dt is the change in time in seconds s,

$\frac{di}{dt}$ is the rate of change of current in amperes/second, A/s.

Coefficient of self-inductance : It is defined as the flux linkage of weber turns per ampere in the coil.

By definition $L \times \frac{N\phi}{I}$ henry

where 'N' is the number of turns

'f' is the flux in webers

I is the current in amperes

Energy storage: An inductor stores energy in the magnetic field created by the current. The energy stored is expressed as follows.

$$W = \frac{1}{2} LI^2$$

where I is in amperes,

L is in henries and

W is energy in joules or watt-second

To obtain the desired value of inductors, some series and parallel combination of inductors can be used.

Series and Parallel Inductors

Series inductors: When inductors are connected in series, as in Fig 12a, the total inductance L_T is the sum of the individual inductances. The formula for L_T is expressed in the following equation for the general case of n inductors in series.

$$L_T = L_1 + L_2 + L_3 + ...L_n$$

Notice that inductance in series to resistance in series.

Parallel inductors: When inductors are connected in parallel, as in Fig 12b, the total inductance is less than the smallest inductance. The formula for total inductance in parallel is similar to that for total parallel resistance.

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots\ldots\ldots\ldots\ldots\ldots \frac{1}{L_n}$$

Fig 11

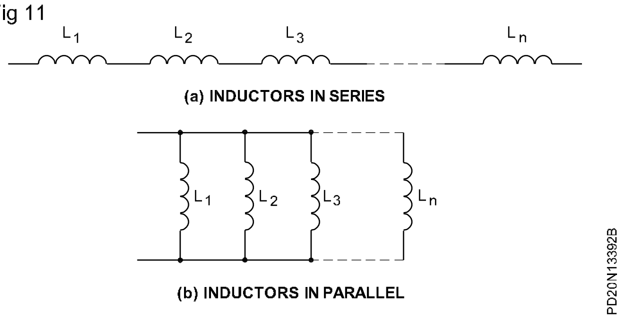
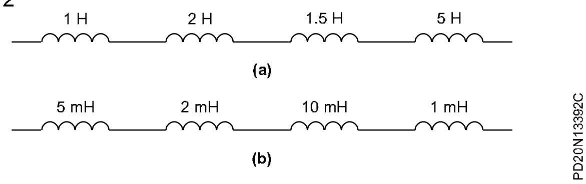


Fig 12



Example 1: Determine the total inductance for each of the series connections in Fig 13.

Solution

a) L_T = 1H + 2H + 1.5H + 5H = 9.5H

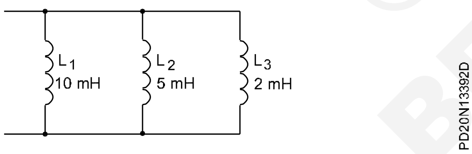
b) L_T = 5mH + 2mH + 10mH + 1mH = 18mH

Note 1000mH = 1 H

Example 2: Determine L_T in Fig 14.

Solution

Fig 13



$$L_T = \frac{1}{\left(\frac{1}{10}\text{mH}\right) + \left(\frac{1}{5}\text{mH}\right) + \left(\frac{1}{2}\text{mH}\right)}$$

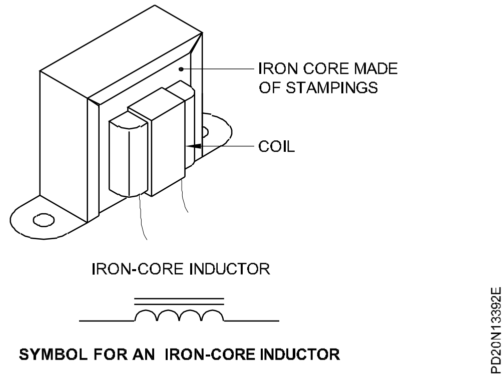
$$= \frac{1}{0.1 + 0.2 + 0.5}$$

$$L_T = \frac{1}{0.8} = 1.25 \text{ mH.}$$

Types of Inductor: Basically, all inductors are made by winding a length of conductor around a core (Fig 15). The conductor is usually a solid copper or aluminum wire coated with enamel insulation, and the core is made either of magnetic material, such as powered iron, or of insulating material.

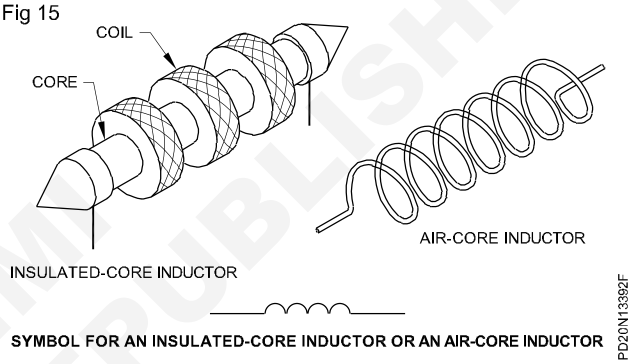
When an inductor is wound around an insulating core, the core is used only for a support, since it has no magnetic

Fig 14



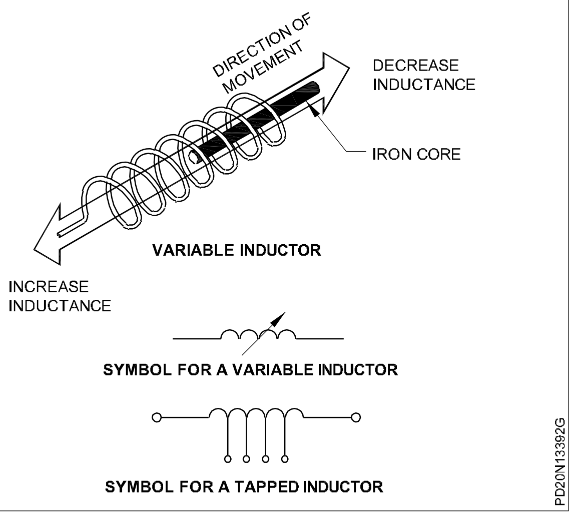
properties. If heavy wire is used in making the inductor, a core is actually not needed; the regid loops of wire support themselves. When a magnetic core is not used, the inductor is usually referred to as an air-core inductor. (Fig 16)

Fig 15



Inductor with set values of inductance that cannot be changed are called fixed inductors. Inductors whose inductance can be varied over some range are called variable inductors. Usually, variable inductors are made so that the core can be moved into and out of the winding. The position of the core will determine the inductance value. (Fig 17)

Fig 16



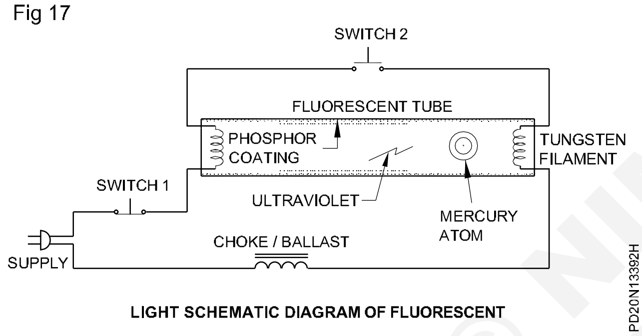
Inductors are also frequently called chokes or coils. All these three terms mean the same thing.

Fixed inductors are used as ballast in gas discharge lamps. They are also used in electronics as power supply filters. Variable inductors and tapped inductors are used for obtaining variation of current in welding transformers to suit the electrode size and weld material.

Function of choke in a fluorescent lamp circuit: Fig 18 shows a fluorescent lamp circuit. The inductor (ballast) is used to induce a momentary high voltage to fire the lamp. The ballast then limits the current through the lamp, after the lamp is lit, because of the coil's inductive reactance. The operation of the lamp circuit is as follows.

The fluorescent lamp is a glass tube with a tungsten filament sealed at each end. The inner surface of the tube is coated with a phosphor material this determines the colour of the light produced. Most of the air is removed during manufacture and a small amount of argon gas and mercury are admitted to the sealed tube.(Fig 18)

Fig 17



LIGHT SCHEMATIC DIAGRAM OF FLUORESCENT

When the momentary contact of the switch 2 is pushed (CLOSED), and held closed for several seconds, a complete series path exists for current to flow through the two filaments to become heated, emitting electrons. A dull glow is observed at each end of the tube. When the switch 2 is released (OPEN), the current through the ballast is interrupted, causing a high voltage to be momentarily induced. This voltage, along with the 240V input, is sufficient to cause the lamp to 'fire'. This means that the current is conducted through the ionized gas in the tube from one filament to the other.

It should be noted that the ballast gets its name from the second function it provides. After the lamp is lit, a typical 40W lamp requires only 110V to maintain proper current through the lamp. The opposition to alternating current caused by the inductance, its inductive reactance, help in the applied 240V dropping to the required value across the lamp.

Flourecent lamps that use a single on/off switch1 in the supply line for control purposes employ a starter inplace of the switch 2.

When a fluorescent lamp circuit is connected to DC supply, the choke serves the first purpose only. An additional resistor is to be connected in series to limit the current through the lamp.

Disadvantage of Inductance:

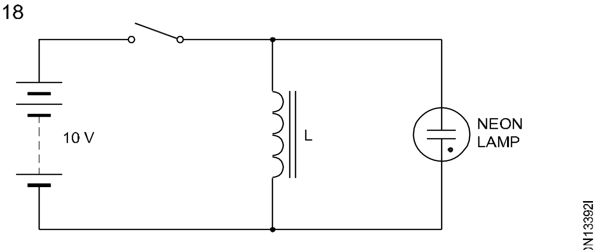
Inductance increases arcing in switch contact which is a major disadvantage. A large voltage across the contacts, while opening the switch of the inductive circuit, sets an arc, and the stored energy in the magnetic field increases the arcing. Additional measures are required to suppress the arc in such circuits.

Factors that contribute to induced voltage: The ability of a coil to induce high voltage can be observed by connecting a neon lamp across a coil as in Fig 19.

A neon lamp used as an indicator requires a minimum of about 70V to 'fire' or light. It is observed that a battery does not light the lamp as the voltage is only 10V at the time of switching ON. But when the switch is opened the lamp flashes indicating the presence of high voltage, more than 70 V.

A major application of the high voltage induced in a coil by interrupting the current through the coil is in fluorescent lamp circuits and ignitors of petrol engines.

Fig 18



L - CHOKE OF 40W FLUORESCENT TUBELIGHT

Counter emf - inductive reactance - time constant

Objectives: At the end of this lesson you shall be able to
- **explain the term Counter EMF (CEMF)**
- **explain about the inductive reactance**
- **state the reasons for the difference between ohmic resistance and impedance of a coil**
- **explain time constant of an inductive circuit.**

Counter EMF and LENZ's law: The voltage induced in a conductor or coil by its own magnetic field is called a counter electromotive force (cemf). Since the induced emf (voltage) is always opposing, or countering, the action of the source voltage, it is known as cemf. Counter electromotive force is sometimes referred to as back electromotive force (bemf).

In any type of inductive circuit there is an important relationship between the direction of the current change and the induced voltage. Lenz's law states that a cemf always has a polarity which opposes the force that created it.

Capacitors - types - functions , grouping and uses

Objectives: At the end of this lesson you shall be able to
- **describe capacitor its construction and charging**
- **explain capacitance and the factors determining**
- **state the different types and application of capacitors**
- **state the testing and defects of capacitors**

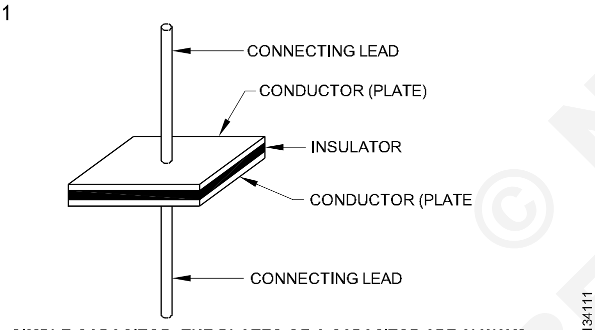
Capacitor:

Capacitor is a passive two terminal electrical/electronic component that stores potential energy in the form of electrostatic field

The effect of capacitor is called as capacitance. It consists of two conducting plates separated by an insulating material called as dielectric. In simple, capacitor is a device designed to store electric charge.

Construction: A capacitor is an electrical device consisting of two parallel conductive plates, separated by an insulating material called the dielectric. Connecting leads are attached to the parallel plates. (Fig 1)

Fig 1



SIMPLE CAPACITOR. THE PLATES OF A CAPACITOR ARE ALWAYS INSULATED FROM EACH OTHER

Function: In a capacitor the electric charge is stored in the form of an electrostatic field between the two conductors or plates, due to the ability of dielectric material to distort and store energy while it is charged and keep that charge for a long period or till it is discharged through a resistor or wire. The unit of charge is coulomb and it is denoted by the letter `C'.

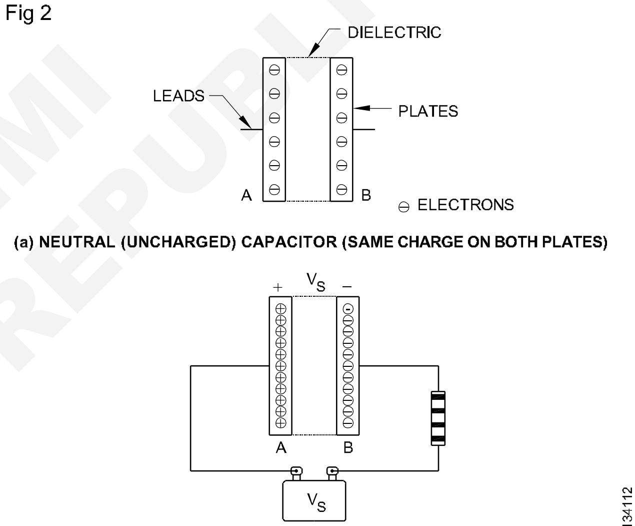
How a capacitor stores charge?: In the neutral state, both plates of a capacitor have an equal number of free electrons, as indicated in Fig 2a. When the capacitor is connected to a voltage source through a resistor, the electrons (negative charge) are removed from plate A, and an equal number are deposited on plate `B'. Plate A becomes positive with respect to plate B as shown in Fig 2b.

The current enters and leaves the capacitor, but the insulation between the capacitor plates prevents the current from flowing through the capacitor.

As electrons flowing into the negative plate of a capacitor have a polarity opposite to that of the battery supplying the current, the voltage across the capacitor opposes the battery voltage. The total circuit voltage, therefore, consists of two series-opposing voltages.

As the voltage across the capacitor increases, the effective circuit voltage, which is the difference between the battery voltage and the capacitor voltage, decreases. This, in turn, causes a decrease in the circuit current.

Fig 2



(a) NEUTRAL (UNCHARGED) CAPACITOR (SAME CHARGE ON BOTH PLATES)

(b) CAPACITOR CHARGED TO V NO MORE ELECTRONS FLOW

When the voltage across the capacitor equals the battery voltage, the effective voltage in the circuit is zero, and so the current flow stops. At this point, the capacitor is fully charged, and no further current can flow in the circuit.

Capacitance : The ability or capacity to store energy in the form of electric charge is called capacitance. The symbol used to represent capacitance is C.

Unit of capacitance: The base unit of capacitance is the **Farad.** The abbreviation for **Farad** is **F**. One farad is that amount of capacitance which stores 1 coulomb of charge when the capacitor is charged to 1 V. In other words, a Farad is a coulomb per volt (C/V).

Farad

A farad is the unit of capacitance (C), and a coulomb is the unit of charge(Q), and a volt is the unit of voltage(V). Therefore, capacitance can be mathematically expressed

as $C = \frac{Q}{V}$

This relationship is very useful in understanding voltage distribution in series-capacitor circuits. The other forms of equation are $V = \frac{Q}{C}$

Example 1: What is the capacitance of a capacitor that requires 0.5 C to charge it to 25V?

Given: Charge(Q) = 0.5C

Voltage(V) = 25V

Find :

Capacitance(C)

$$C = \frac{Q}{V}$$

Solution $C = \frac{0.5\,C}{25\,V} = 0.02F$

Answer: The capacitance is 0.02F.

Capacitive reactance

Similar to resistors and inductors, a capacitor also offers opposition to the flow of AC current. This opposition offered to the flow of current by a capacitor is called **capacitive reactance** abbreviated as X_C.

Recall expressions,

$$I = \frac{Q}{t} = \text{ and } Q = CV.$$

Substituting Q = CV in I = Q/t

$$I = \frac{CV}{t}$$

This means,

$I \propto C$, $I \propto V$ and $I \propto f$ (Because, 1/t = f)

From the above equation, the amount of AC current that a capacitor conducts depends on;

- the frequency (f) of the applied voltage
- the capacitance (C) of the capacitor
- the amplitude of the applied voltage(V).

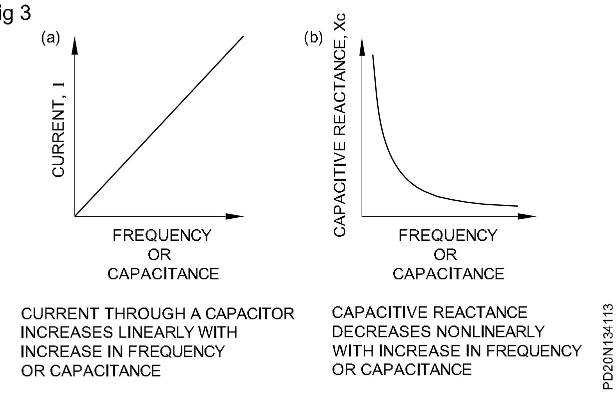
Fig 3a shows the graph of variation of current(I) through a capacitor with frequency or capacitance when the applied voltage is kept constant.

Since current flow through a capacitor is directly proportional to frequency and capacitance, the opposition to current flow by the capacitor is inversely proportional to these quantities.

Capacitive reactance, X_C can be mathematically represented as;

$$X_C = \frac{1}{2\pi fc}$$

Fig 3



where

X_C is the capacitive reactance in ohms

f is the frequency of the applied voltage in Hz

and C is the capacitance in farads.

Fig 3b shows the graph of variation of X_C with frequency or capacitance.

Capacitive reactance, X_C, expressed in ohms, acts just like a resistance in limiting the AC current flow.

Sub-units of a farad: Most capacitors that you will use in electronics work, have capacitance values in microfarads (μF) and picofarads (pF). A microfarad is one-millionth of a farad ($1\mu F = 1 \times 10^{-6}$ F), and a picofarad is one-trillionth of a farad (1 PF = $1 \times 10^{-12}{}_{P}$F) one nano farad ($1nF = 1 \times 10^{-9}$ F).

Factors determining capacitance: The capacitance of a capacitor is determined by four factors.

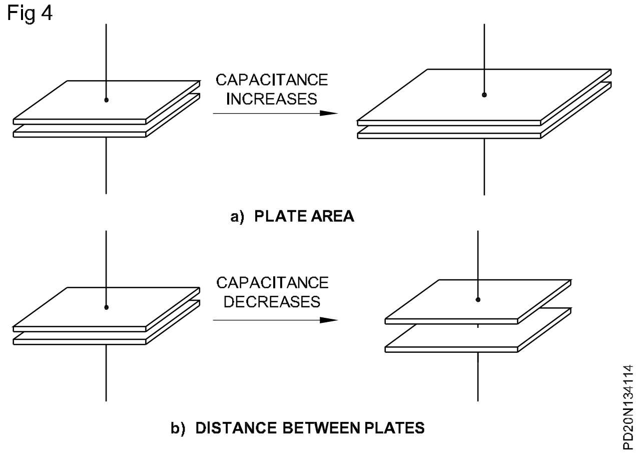
- Area of the plates ($C \propto A$)
- Distance between the plates ($C \propto d$)
- Type of dielectric material
- Temperature
- Resistance of the plates

Area of the plates: The capacitance of a capacitor is directly proportional to the area of its plates (or the area of its dielectric). All other factors remaining the same, doubling the plate area doubles the capacitance.

Thus, when the dielectric area is increased, the amount of energy stored in the dielectric is increased and the capacitance is also increased. (Remember, capacitance is defined as the ability to store energy.) (Fig 4a)

Distance between the plates: Other factors being equal, the amount of capacitance is inversely proportional to the distance between the plates. The strength of the electric field between the plates decreases, when the distance between the plates increases. The force on the electrons in the dielectric decreases accordingly. Again the amount of energy stored in the capacitor, for a given voltage applied to the capacitor, would decrease. Thus, the capacitance decreases. (Fig 4b)

Fig 4



Type of dielectric material: In general, those materials which undergo the greatest distortion store the most capacitance. The ability of a dielectric material to distort and store energy is indicated by its **dielectric constant (K)**.

The dielectric constant of a material is a mere number (that is, it has no units). It compares the material's ability to distort and store energy, when in an electric field, with the ability of air to do the same.

Since air is used as the reference, it has been given K equal to 1. Mica, often used as a dielectric, has a dielectric constant approximately 5 times that of air. Therefore, for mica, K = 5 (approximately). Suppose all the other factors (plate area, distance between plates, and temperature) are the same, then a capacitor with a mica dielectric will have 5 times as much capacitance as the one using air as its dielectric.

Dielectric constants for materials commonly used for dielectrics range from 1 for air to more than 4000 for some types of ceramics.

Temperature: The temperature and resistance of the capacitor is the least significant of the four factors. It need not be considered for many general applications of capacitors.

Types of capacitors: Capacitors are manufactured in a wide variety of types, sizes and values. Some are fixed in value, in others the value is variable.

Fixed capacitors

Ceramic capacitors: Ceramic dielectrics provide very high dielectric constants (1200 is typical). As a result, comparatively high capacitance values can be achieved in a small physical size.

Ceramic capacitors are illustrated in Figs 5a) and (b). These discs are made by using ceramic as an insulator with a silver deposit on each side of the plates. These are used for small values of capacitance and an ordinary TV set might contain several dozens in its circuitry.

Ceramic capacitors are typically available in capacitance values ranging from 1μF to 2.2μ F with voltage ratings up to 6 KV. A typical temperature coefficient for ceramic capacitors is 200,000 PPM/°C.

Mica capacitors: There are two types of mica capacitors, stacked foil as shown in Fig 5(c). It consists of alternate layers of metal foil and thin sheets of mica. The metal foil forms the plate, with alternate foil sheets connected together to increase the plate area, thus increasing the capacitance.

The mica foil-stack is encapsulated in an insulating material such as bakelite, as shown in Fig 5d of the figure. The silver-mica capacitor is formed in a similar way by stacking mica sheet with silver electrode material screened on them.

Mica capacitors are available with capacitance values ranging from 1 pF to 0.1 pF and voltgage ratings from 100 to 2500 V DC. Temperature coefficients from −20 to +100 PPM/°C are common. Mica has a typical dielectric constant of 5.

Electrolytic capacitors: Electrolytic capacitors are polarised so that one plate is positive and the other negative.

These capacitors are used for high capacitance values up to over 200,000μ F, but they have relatively low breakdown voltages (350 V is a typical maximum) and high amounts of leakage.

Electrolytic capacitors are available in two types: aluminium and tantalum. The basic construction of an electrolytic capacitor is shown in Figs 5(e) and (f).

The capacitor consists of two strips of either aluminum or tantalum foil separated by a paper or gauze strip, saturated with an electrolyte. During manufacturing, an electrochemical reaction is induced which causes an oxide layer (either aluminum oxide or tantalum oxide) to form on the inner surface of the positive plate. This oxide layer acts as the dielectric.

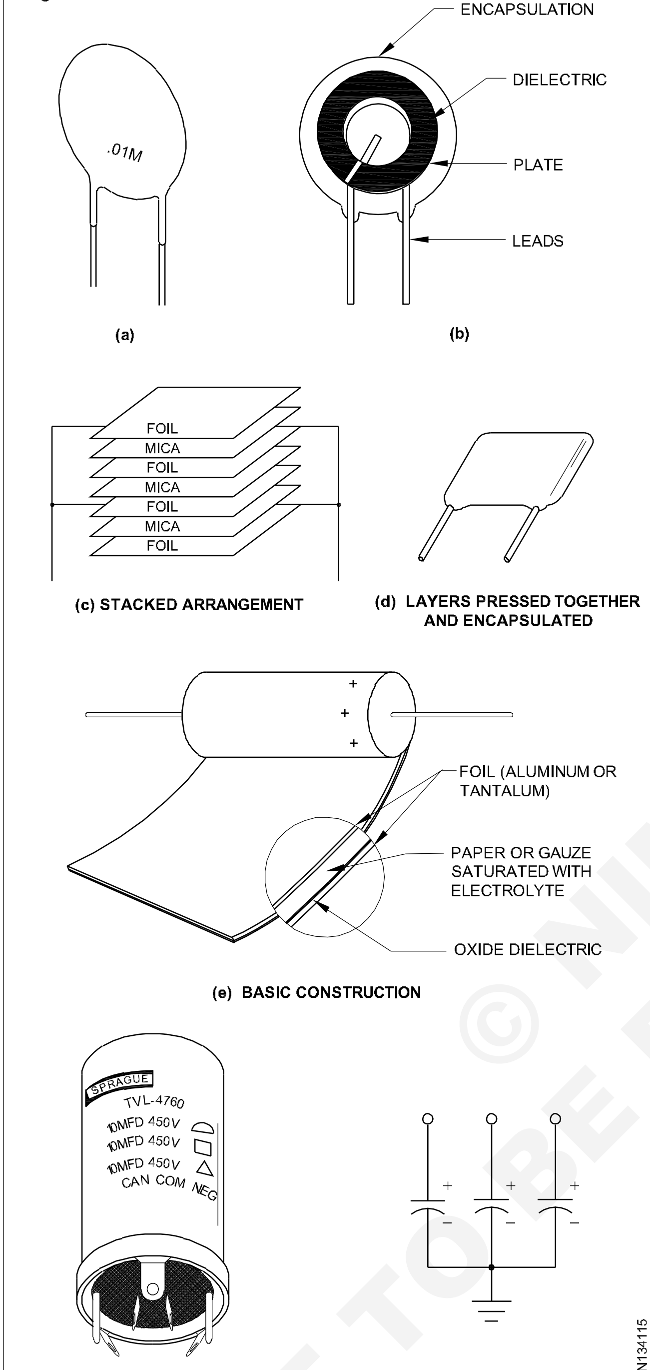
One particular point you must always remember about the electrolytic capacitor is that one end is positive (+) and the other negative (−). You must always observe this polarity when connecting in your circuit. The symbol on a drawing will have positive and negative marks. These polarity marks will tell you it is an electrolytic capacitor.

Since an electrolytic capacitor is polarized, the positive plate must always be connected to the positive side of a circuit. Be very careful to make the correct connection and to install the capacitor only in a DC, not AC, circuit.

Reverse polarity on an electrolytic capacitor causes excessively high current in the capacitor. It causes the capacitor to heat up, and possibly to explode. Thus, the common electrolytic capacitor is limited to use in DC circuits.

Special electrolytic capacitors are manufactured for use in AC circuits. These capacitors are usually listed in catalogues as `non-polarised' or `AC' electrolytic capacitors. An AC electrolytic capacitor is really two electric capacitors packaged in a single container.(Fig 6)

Fig 5



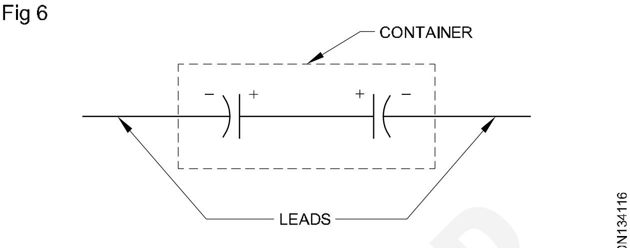
(f) ELECTROLYTIC CAPACITOR AND SYMBOL

The two internal capacitors are in series, with their positive ends connected together. Regardless of the polarity on the leads of the AC electrolytic capacitor, one of the two internal capacitors will be correctly polarized.

Paper/plastic capacitors: There are several types of plastic-film capacitors and the older paper dielectric capacitors. Polycarbonate, parylene, polyester, polystyrene, polypropylene, mylar, and paper are some of the more common dielectric materials used. Some of these types have capacitance values up to 100µF.

Fig 7 show a common basic construction used in many plastic-film and paper capacitors. A thin strip of plastic-film dielectric is sandwiched between two thin metal strips which act as plates. One lead is connected to the inner plate and the other to the outer plate as indicated. The strips are then rolled in a spiral configuration and encapsulated in a moulded case. Thus a large plate area can be packaged in a relatively small physical size, thereby achieving larger capacitance values. Fig 7b shows a construction view for one type of plastic-film capacitor.

Fig 6



NON-POLARIZED CAPACITOR.

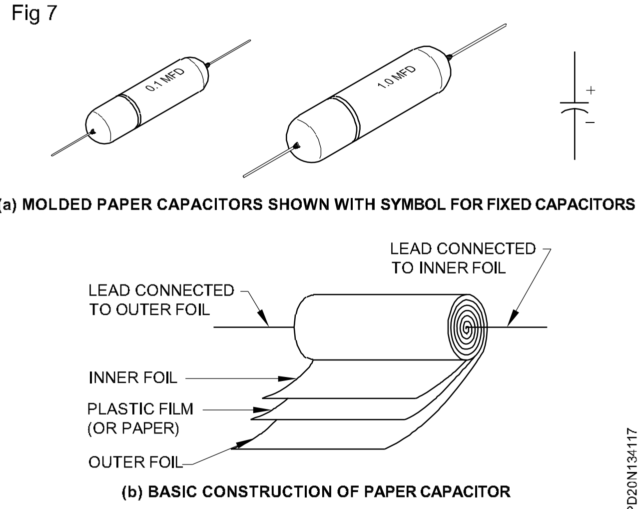
Variable capacitors

Variable capacitors are used in a circuit when there is a need to adjust the capacitance value either manually or automatically. For example, in radio or TV tuners. The major types of variable or adjustable capacitors are now discussed.

Air capacitor: Variable capacitors with air dielectrics, such as the one shown in Fig 8(b), are sometimes used as tuning capacitors in applications requiring frequency selection. This type of capapcitor is constructed with several plates that mesh together. One set of plates can be moved relative to the other, thus changing the effective plate area and the capacitance. The movable plates are linked together mechanically so that they move when a shaft is rotated.

The schematic symbol for a variable capacitor is shown in Fig 8(a).

Fig 7

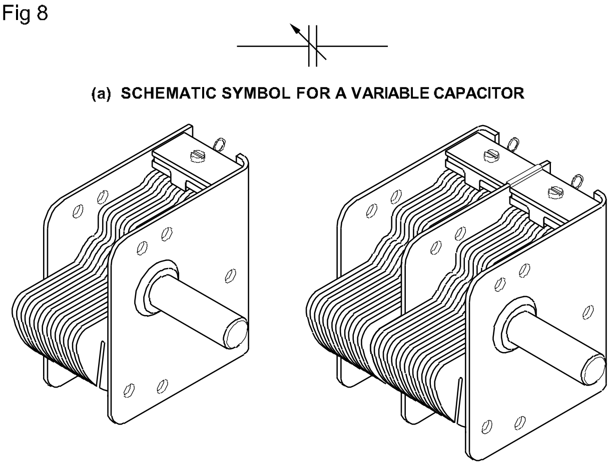


(b) BASIC CONSTRUCTION OF PAPER CAPACITOR

Trimmers and padders: These adjustable capacitors normally have screwdriver adjustments, and are used for very fine adjustments in a circuit. Ceramic or mica is a common dielectric in these types of capacitors, and the capacitance usually is changed by adjusting the plate separation.(Fig 9)

Varactors: A varactor is a semiconductor device that exhibits a capacitance characteristic which is varied by changing the voltage across its terminals. This device is usually covered in greater detail in a course on electronic devices.

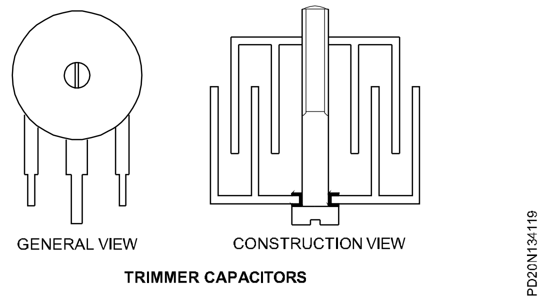
Fig 8



(a) SCHEMATIC SYMBOL FOR A VARIABLE CAPACITOR

(b) SINGLE AND TWO-GANG VARIABLE CAPACITORS WITH AIR DIELECTRIC

Fig 9



TRIMMER CAPACITORS

Application of capacitors with type and ratings - Chart I

Type	Capacitance	Voltage WVDC (Working voltage DC)	Applications
Monolithic	1 pF-10μF	50-200	UHF,RF coupling.
Disc and tube ceramics	1pF - 1μF	50-500	General, VHF.
Paper	0.001-1μF	200-1600	Motors, power supplies.
Film - polypropylene	0.001-0.47μF	400-1600	TV vertical circuits, RF.
Polyester	0.001-1μF	100-600	Enetertainment- electronics.
Polystyrene	0.001-1μF	100-200	General, high stability.
Polycarbonate	0.01 -18μF	50-200	General.
Metallized polypropylene	4-60μF	400 VAC 50Hz	AC motors.
Metallized polyester	0.01-10μF	100-600	Coupling, RF filtering.
Electrolytic-aluminum	1-500,000μF	5-500	Power supplies, filters.
Electrolytic-tantalum	0.1-1000μF	3-125	Small space requirement, high reliability, low leakage.
Electrolytic- Non-polarised (either Al or Ta)	0.47-220μF	16-100	Loudspeaker cross-overs.
Mica	330pF-0.05μF	50-100	High frequency.
Silver-mica	5-820pF	50-500	High frequency.
Variable-ceramic	1-5 to 16-100pF	200	Radio, TV, communications.
Film	0.8-5 to 1.2-30pF	50	oscillators, antenna, RF circuits.
Air	10-365pF	50	Broadcast receivers.
Teflon	0.25-1.5pF	2000	VHF, UHF.

Common defects in capacitors

Short circuited capacitors: In the course of normal usage, capacitors can become short-circuited/shorted. This is because of the deterioration of the dielectric used due to ageing.

Usually such a defect occurs when the capacitor is used over a period of years under the stress of changing voltage across it. This period gets reduced if the capacitor is operated at higher temperatures.

Short-circuiting of capacitors is more common in paper and electrolytic capacitors than in the other types.

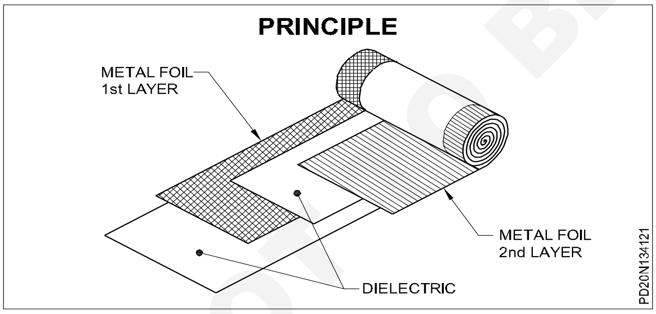
Short circuiting of capacitor also occurs due to puncturing of the dielectric when voltages much higher than its rated and applied. A shorted capacitor cannot store energy.

Open capacitors: A capacitor may become open due to loose/broken lead connections or due to the electrolyte. In electrolytic capacitors, the electrolyte develops high resistance with age, particularly when operated at high temperatures. After a few years of usage, the electrolyte may dry up resulting in open-circuit of the capacitor. An open capacitor cannot store energy.

The storage (shelf) life of wet type electrolytic capacitors is small because the electrolyte dries up over period of time.

Leaky capacitors/leakage resistance: Theoretically, the current that flows in a pure capacitive circuit results from the charge and discharge currents of the capacitors. The dielectric, which is an insulator, should prevent any current flow between the plates. However, even the best dielectric conduct very small current.

The dielectric, then has some high value of resistance, known as leakage resistance. This leakage resistance, as shown in Fig 10, allows some leakage current to flow. This leakage current tends to reduce the capacitance value.



In a good capacitor, the leakage resistance is generally of the order of several tens of megohms and hence can be considered negligible for most applications. As the capacitor ages, the leakage resistance could reduce. Generally, the leakage resistance is lower with high value capacitors than with low value capacitors.

The reason for this is that, larger capacitors have larger plate areas that are closer together. Therefore their dielectrics must have large areas and be thin. Recall, resistance reduces as the -sectional area is increased or when the length or thickness is decreased.

So, larger the capacitor, lower the leakage resistance, and higher is the leakage current.

Normal leakage resistance across a good capacitor has to be very high. Depending upon the type of dielectric used, the normal resistance varies.

For paper, plastic, mica and ceramic capacitors the normal resistance will be of the order of 500 to 1000 M or more. For electrolytic capacitors the normal resistance will be of the order of 200 KΩ to 500 KΩ.

A capacitor is said to have become leaky when the resistance across it is less than normal when read with any average quality ohmmeter.

Checking capacitors: The two simple methods to check a capacitor is by carrying out,

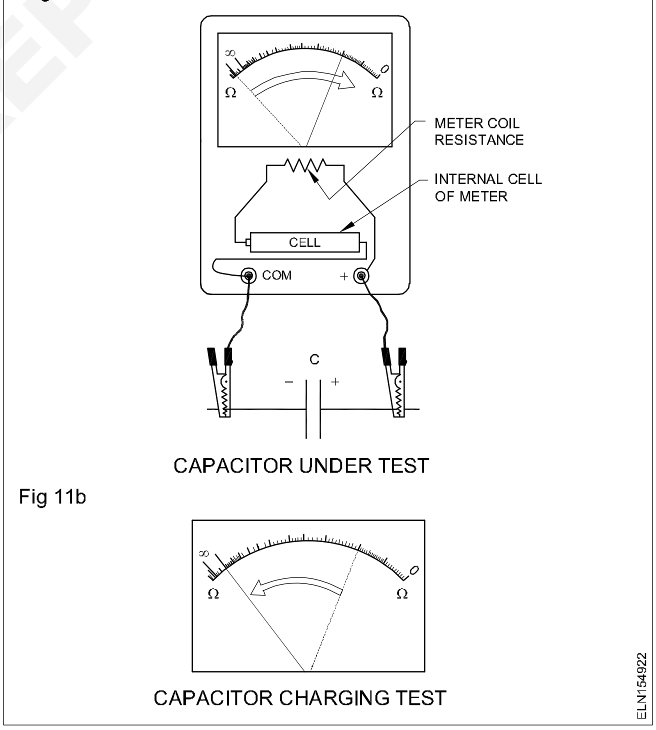
i capacitor action-normal resistance test, using a ohm-meter/multimeter (This test is also referred as quick test)

ii charging-holding test, using a battery and voltmeter/multimeter.

Capacitor action-normal charging test: When an ohmmeter is connected across a fully discharged capacitor, initially, the battery insider the meter charges the capacitor. During this charging, at the first instance, a reasonably high charging current flows.

Since more current through the ohm meter means less resistance, the meter pointer moves quickly towards zero ohms of the meter scale as shown in Fig 11a.

Fig 11



As the initial charging, the charging current to the capacitor slowly decreases (as the voltage across the capacitor increases towards the applied voltage). Since less and less current through the ohmmeter means high and higher resistance the meter pointer slowly moves towards infinite resistance of the meter scale as shown is Fig 11b. Finally, when the capacitor is completely charged to the ohmmeter internal battery voltage, the charging current is almost zero and the ohmmeter reads the normal resistance of the capacitor which is a result of just the small leakage current through the dielectric.

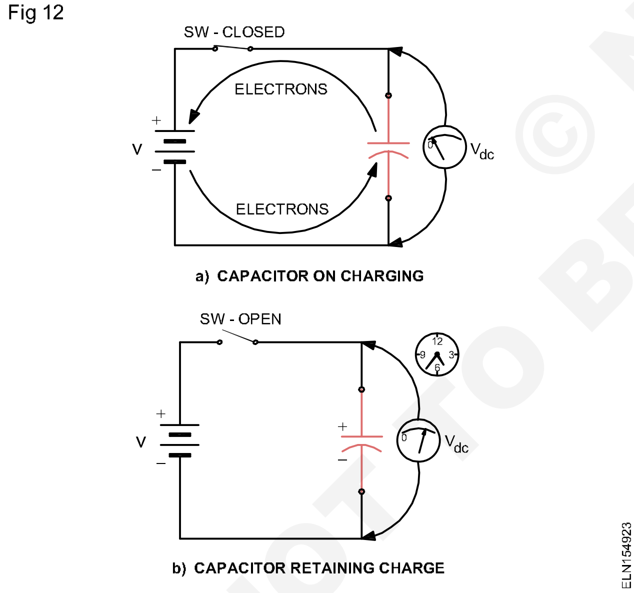
This changing effect commonly known as Capacitor action indicates, whether the capacitor can store charge, whether the capacitor is excessively leaky, whether the capacitor is fully short-circuited or whether the capacitor is fully open-circuited.

The capacitor-action test is most suitable for high value capacitors and specially electrolyte capacitors. When small value capacitors such as ceramic disc or paper capacitors are tested for capacitor-action, due to the extremely low charging current the capacitor-action can not be observed on the meter dial. For such small capacitors the capacitor-charging-holding test is preferred. However, if small capacitors are subjected for the capacitor-action test, if the meter shows high resistance the capacitor can be taken as not shorted and hence may be taken as good.

Charging-holding test on capacitors: In this test, a given capacitor is charged to some voltage level using an external battery as shown in Fig 12a.

Once the capacitor is charged to the applied voltage level, the battery is disconnected and the voltage across the capacitor is monitored as shown in Fig 12b. The voltage is monitored for a period of time to confirm whether he capacitor is able to hold the charge atleast for a small period of time (of the order of few seconds).

Fig 12



In this test, when the capacitor is tried for charging, if the capacitor does not charge at all even after connecting the battery for a considerable period of time, it can be concluded that the capacitor is either short-circuited or fully open circuited.

If the capacitor is unable to hold the charge even for a considerably small period of time, then it can be concluded that the capacitor is excessively leaky.

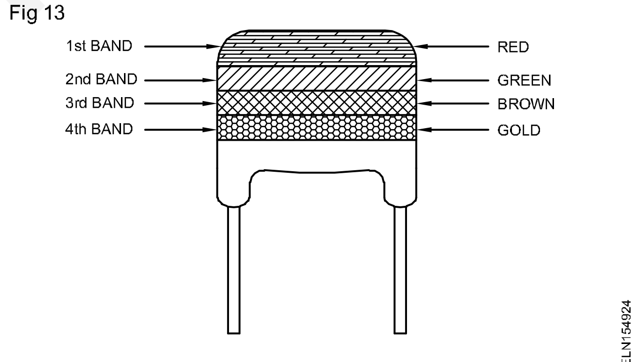
The following points are important and are to be noted to get correct results from the test.

- If the capacitor to be tested is marked + and – at its terminals (polarized-capacitor) then connect the battery with the same polarity. If a polarized capacitor is tried for changing with wrong polarity, the capacitor may get permanently damaged.
- Use a FET input voltmeter or high ohm/volt voltmeter to monitor the holding of voltage across the charged capacitor. This is because a low ohm/volt voltmeter will draw current from the charged capacitor resulting in a early discharge of stored charges on capacitor.

Note: FET voltmeters have input resistance in the order of 6 to 10 Megohms and draws only micro ampere current for full scale deflection.

For determining values of capacitors by colour code of capacitor is given in chart-2 for reference (Fig 13).

Fig 13



Capacitors colour code chart-2

Colour	Significant figures	Multiplier	Tolerance		Dipped tantalum voltage rating
			Over 10pF	Under 10pF	
Black	0	1	±20%	± 2 pF	4 VDC
Brown	1	10	±1%	± 0.1 pF	6 VDC
Red	2	10^2 or 100	±2%	-	10 VDC
Orange	3	10^3 or 1000	±3%	-	15 VDC
Yellow	4	10^4 or 10,000	+100%	-	20 VDC
			- 0%		
Green	5	10^5 or 100,000	±5%	± 0.5 pF	25 VDC
Blue	6	10^6 or 1,000,000	-	-	35 VDC
Violet	7	10^7 or 10,000,000	-	-	50 VDC
Grey	8	10^{-2} or 0.01	+80%	± 0.25 PF	-
		-20%			
White	9	10^{-1} or 0.1	±10%	± 1 pF	3 VDC
Gold	-	-	-	-	-
Silver	-	-	-	-	-
None	-	-	±10%	± 1 pF	-

Note: Main types of fixed value capacitors are given in Chart 3. Constructional details of fixed value capacitors are shown in Chart 4.

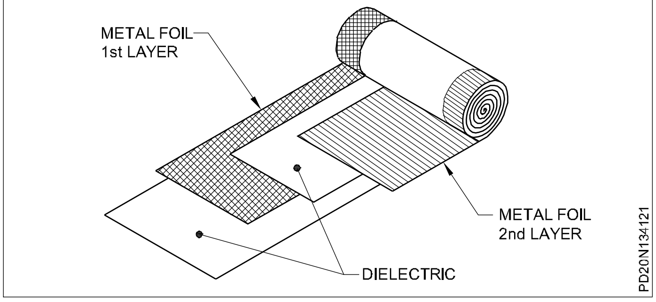
CHART - 3
Main types of fixed value capacitors

Type	Main sub-types	Dielectric used	Construction	Available capacitances	Rated voltage	Applications
Paper	Foil type & Metallized type	Impregnated special craft paper Special tissue paper	Rolled foils	0.001-1μF	200-1600VDC	Motor - starting, PF correction power supply- filters.
Plastic film	Foil type & Metalised type	i) Polystyrene ii) Polyster (Mylar capacitor)- iii) Poly propylene- iv) Poly carbonate v) Metallized polypropyene- vi) Metallized polyester- vii) Polystyrol (Styroflex)	- Rolled foils	0.001-1μF 0.001-1μF 0.001-0.47μF 0.01-18μF 4-60μF 0.01-10μF	100-200VDC 100-600VDC 400-1600 VDC 50-200 VDC 400 VAC, 50 Hz 100-600 VDC	General purpose, high stability. General purpose. RF circuits. General purpose. AC motors. Coupling, RF filtering.
Ceramic	Disc type Tube type Monolithic (chip type) Feed-through-stand-off-button type	Class-1 (Non ferro-electric) -Steatite (Talc) -Mix of MgO, TiO_2 -TiO_2, CaO Class-2 (Ferro-electric) -Barium titanate -Ba, Sr, TiO_2+Mg, Zr	Drawn ceramic films Moulded tubes Substrate-Screening-sintering	1PF -1μF 1PF-1000PF 1pF-10μF	50-500 VDC 500-5K VDC 50-200 VDC	General purpose, RF. General, VHF. VHF, RF coupling. Coupling in VHF range. Decoupling in VHF range. HF circuit feeders.
Electro-lytic	Aluminium (polor, non-polar)(Wet, dry type) Tantalum (polar, non-polar)(Wet, dry type)	Aluminium oxide Tantalum pentoxide	Rolled foil - metallic can Rolled foil - Can/cup/tank	1-500,000μF 0.1-1000μF	5-500 VDC 3-125 VDC	Power supplies, filters. Space electronics. Nonpolar Al and Ta capacitors are used in loudspeaker cross-overs.
Mica	Stacked mica- Silvered mica Button type	White mica, Rose mica, Amber mica	Stacked	5 pF-10,000pF 5pF-3300pF	50-100 50-500	High frequency High frequency H.F line feeders
Glass		Thin layer of glass	Stacked	5 pF-5000pF		VHF applications
Vitreous Enamel		Mixture of silica, Potassium, lead oxide and fluorides	Deposited in layers		50-500	

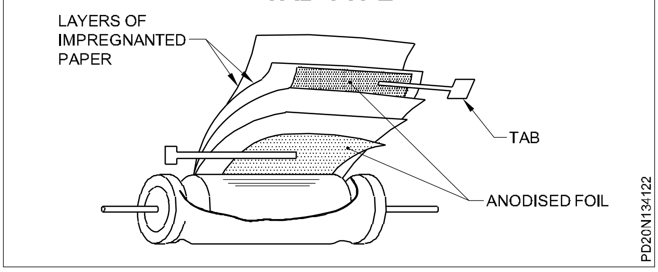
CHART - 4
Constructional details of fixed value capacitors

Paper Capacitors

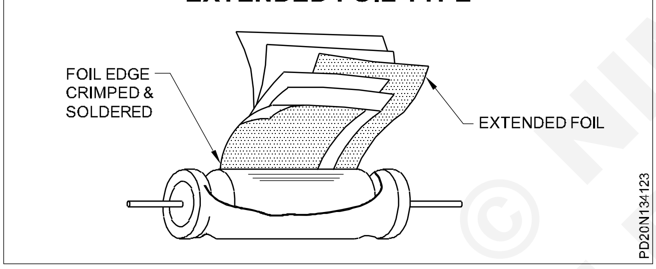
PRINCIPLE



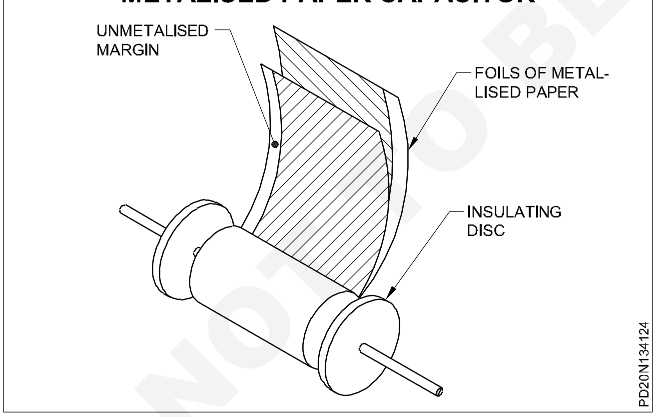
TAD TYPE



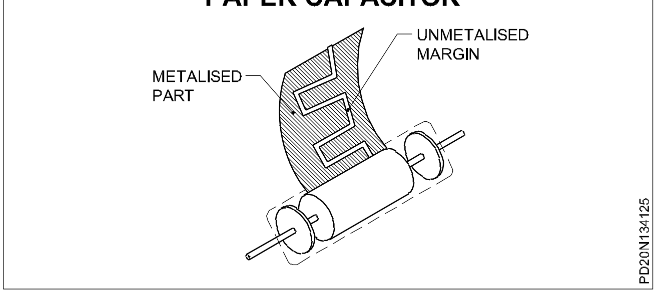
EXTENDED FOIL TYPE



METALISED PAPER CAPACITOR

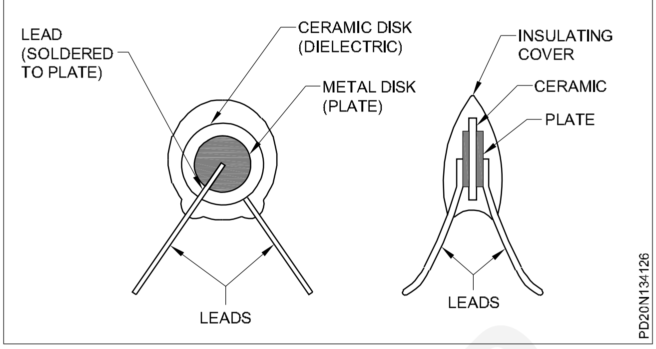


CASTELLATED TYPE PAPER CAPACITOR

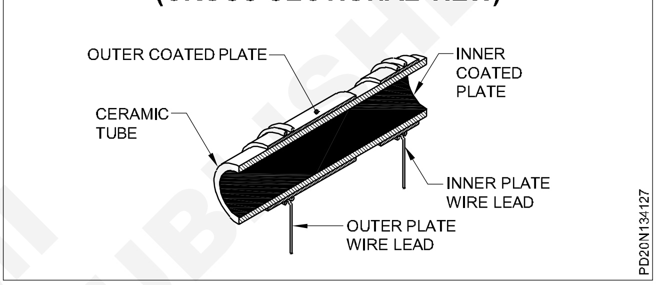


Ceramic Capacitors

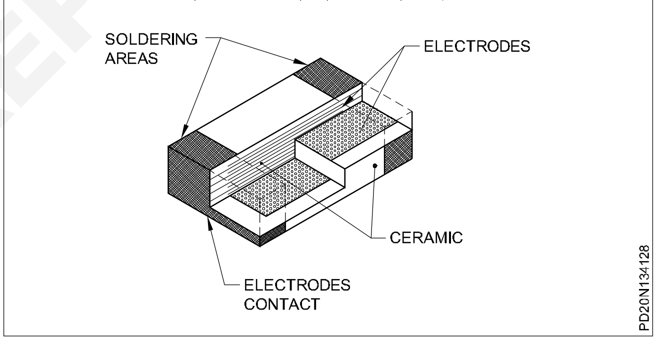
CERAMIC CAPACITORS



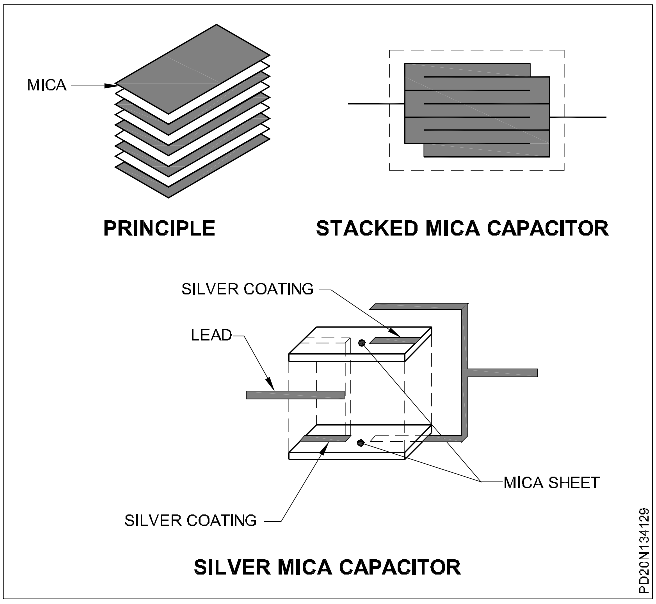
TUBULAR CERAMIC CAPACITOR (CROSS SECTIONAL VIEW)



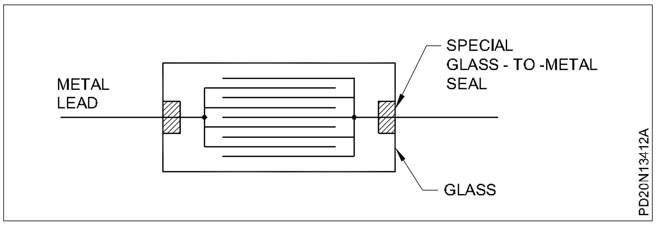
CERAMIC CAPACITOR

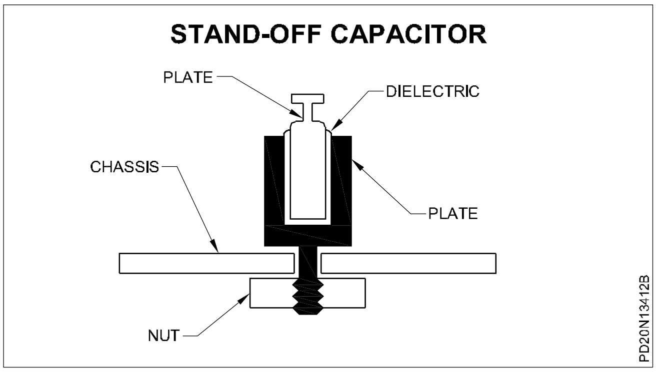


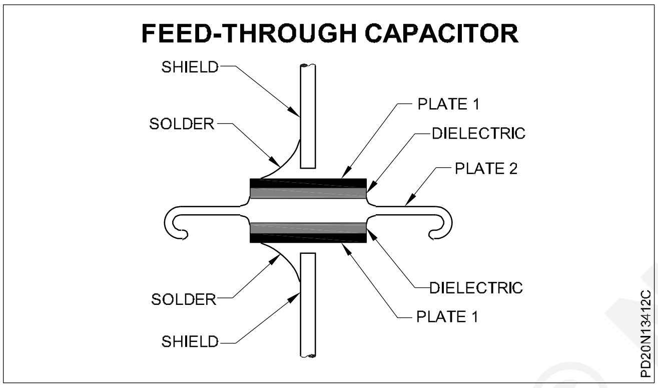
MICA Capacitors



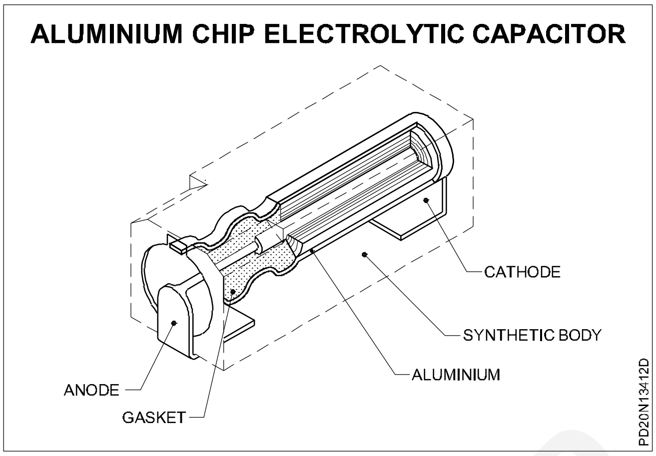
Glass Capacitors

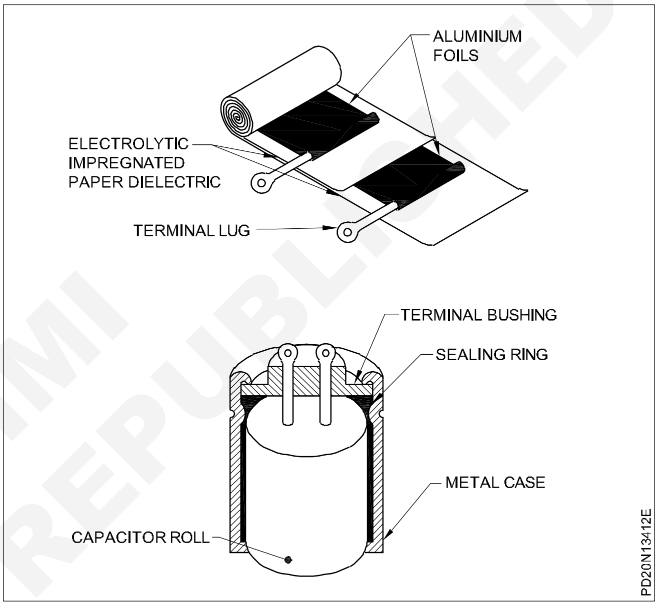




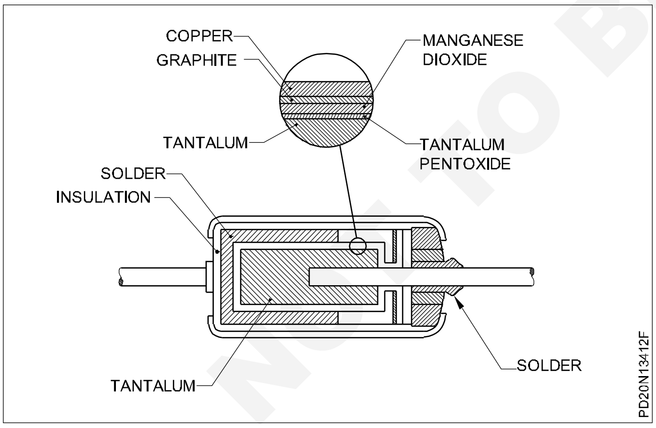


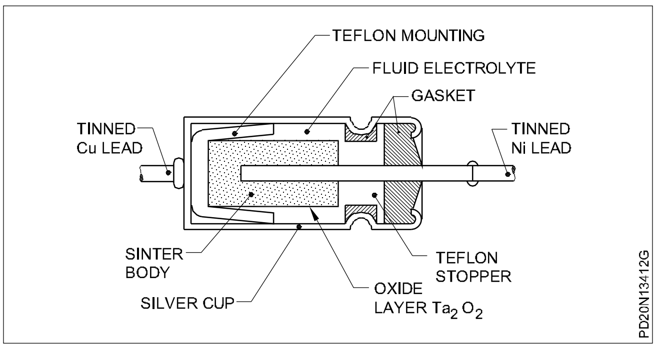
Electrolytic Capacitors Aluminium Type

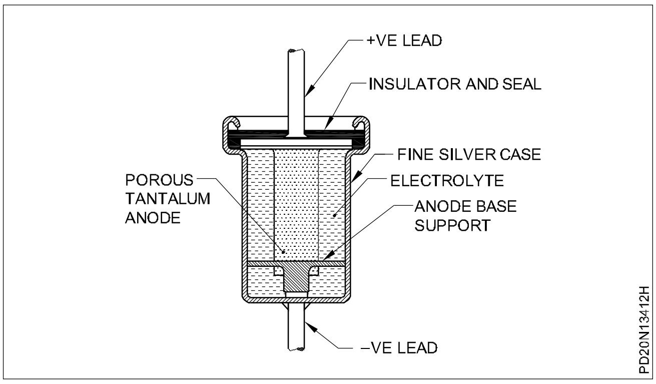


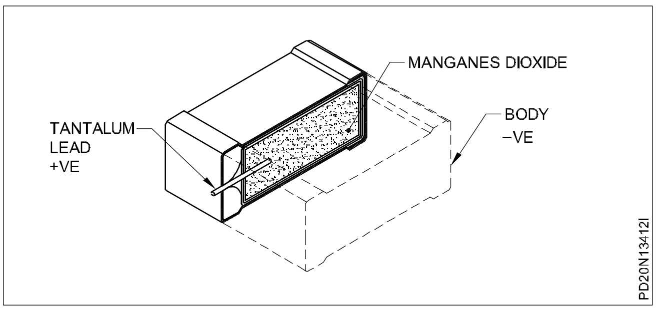


Tantalum Capacitors









Grouping of capacitors

Objectives: At the end of this lesson you shall be able to
- **state the necessity of grouping capacitors and method of connection**
- **state the conditions for connecting capacitors in parallel and in series**
- **explain the values of capacitance and voltage in parallel and series combination**

Necessity of grouping of capacitors: In certain instances, we may not be able to get a required value of capacitance and a required voltage rating. In such instances, to get the required capacitances from the available capacitors and to give only the safe voltage across capacitor, the capacitors have to be grouped in different fashions. Such grouping of capacitors is very essential.

Methods of grouping: There are two methods of grouping.

- Parallel grouping
- Series grouping

Parallel grouping

Conditions for parallel grouping

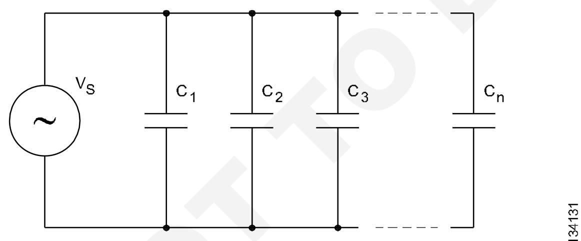
- Voltage rating of capacitors should be higher than the supply voltage Vs.
- Polarity should be maintained in the case of polarised capacitors (electrolytic capacitors).

Necessity of parallel grouping: Capacitors are connected in parallel to achieve a higher capacitance than what is available in one unit.

Connection of parallel grouping: Parallel grouping of capacitors is shown in Fig 1 and is analogous to the connection of resistance in parallel or cells in parallel.

Total capacitance: When capacitors are connected in parallel, the total capacitance is the sum of the individual

Fig 1



CAPACITORS IN PARALLEL

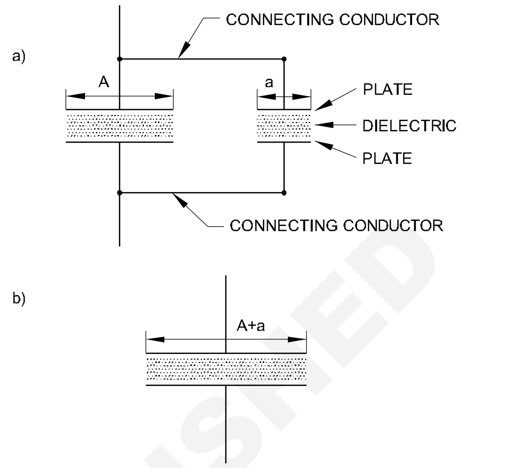
capacitances, because the effective plate area increases. The calculation of total parallel capacitance is analogous to the calculation of total resistance of a series circuit.

By comparing Figs 2a and 2b, you can understand that connecting capacitors in parallel effectively increases the plate area.

General formula for parallel capacitance: The total capacitance of parallel capacitors is found by adding the individual capacitances.

$C_T = C_1 + C_2 + C_3 + ... + C_n$

Fig 2



CAPACITORS IN PARALLEL. THE EQUIVALENT CAPACITANCE IN (b) IS EQUAL TO THE SUM OF THE CAPACITANCES IN (a).

where C_T is the total capacitance,

C_1, C_2, C_3 etc. are the parallel capacitors.

The voltage applied to a parallel group must not exceed the lowest breakdown voltage for all the capacitors in the parallel group.

Example: Suppose three capacitors are connected in parallel, where two have a breakdown voltage of 250 V and one has a breakdown voltage of 200 V, then the maximum voltage that can be applied to the parallel group without damaging any capacitor is 200 volts.

The voltage across each capacitor will be equal to the applied voltage.

Charge stored in parallel grouping: Since the voltage across parallel-grouped capacitors is the same, the larger capacitor stores more charge. If the capacitors are equal in value, they store an equal amount of charge. The charge stored by the capacitors together equals the total charge that was delivered from the source.

$Q_T = Q_1 + Q_2 + Q_3 + ... + Q_n$

where Q_T is the total charge

Q_1, Q_2, Q_3.....etc. are the individual charges of the capacitors in parallel.

Using the equation Q = CV,

the total charge $Q_T = C_T V_S$

where V_S is the supply voltage.

Again $C_T V_S = C_1 V_S + C_2 V_S + C_3 V_S$

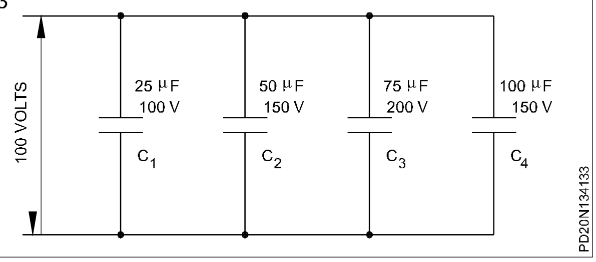
Because all the V_S terms are equal, they can be cancelled.

Therefore, $C_T = C_1 + C_2 + C_3$

Example: Calculate the total capacitance, individual charges and the total charge of the circuit given in Fig 3.

Solution

Fig 3



Total capacitance = C_T

$C_T = C_1 + C_2 + C_3 + C_4$

C_T = 250 micro farads.

Individual charge = Q = CV

$Q_1 = C_1V$

$= 25 \times 100 \times 10^{-6}$

$= 2500 \times 10^{-6}$

$= 2.5 \times 10^{-3}$ coulombs.

$Q_2 = C_2V$

$= 50 \times 100 \times 10^{-6}$

$= 5000 \times 10^{-6}$

$= 5 \times 10^{-3}$ coulombs.

$Q3 = C_3V$

$= 75 \times 100 \times 10^{-6}$

$= 7500 \times 10^{-6}$

$= 7.5 \times 10^{-3}$ coulombs.

$Q_4 = C_4V$

$= 100 \times 100 \times 10^{-6}$

$= 10000 \times 10^{-6}$

$= 10 \times 10^{-3}$ coulombs.

Total charge $= Q_t = Q_1 + Q_2 + Q_3 + Q_4$

$= (2.5\times10^{-3}) + (5\times10^{-3})$

$+(7.5\times10^{-3}) + (10\times10^{-3})$

$= (2.5+5+7.5+10) \times 10^{-3}$

$= 25 \times 10^{-3}$ coulombs.

or $Q_T = C_TV$

$= 250 \times 10^{-6} \times 100$

$= 25 \times 10^{-3}$ coulombs.

Series grouping

Necessity of grouping of capacitors in series: The necessity of grouping capacitors in series is to reduce the total capacitance in the circuit. Another reason is that two or more capacitors in series can withstand a higher potential difference than an individual capacitor can. But, the voltage drop across each capacitor depends upon the individual capacitance. If the capacitances are unequal, you must be careful not to exceed the breakdown voltage of any capacitor.

Conditions for series grouping

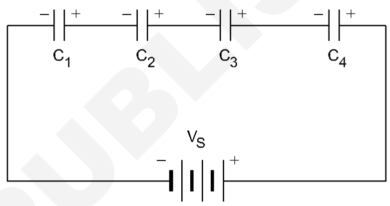
- If different voltage rating capacitors have to be connected in series, take care to see that the voltage drop across each capacitor is less than its voltage rating.
- Polarity should be maintained in the case of polarised capacitors.

Connection in series grouping: Series grouping of capacitors, as shown in Fig 4 is analogous to the connection of resistances in series or cells in series.

Total capacitance: When capacitors are connected in series, the total capacitance is less than the smallest capacitance value, because

- the effective plate separation thickness increases
- and the effective plate area is limited by the smaller plate.

Fig 4

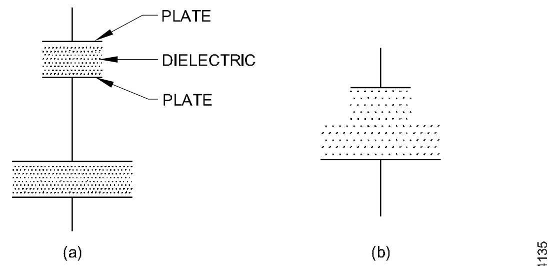


SERIES CONNECTION OF CAPACITORS

The calcualtion of total series capacitance is analogous to the calculation of total resistance of parallel resistors.

By comparing Figs 5a and 5b you can understand that connecting capacitors in series increases the plate separation thickness, and also limits the effective area so as to equal that of the smaller plate capacitor.

Fig 5



THE EQUIVALENT CAPACITANCE IN (b) IS LESS THAN THE LOWER OF THE TWO CAPACITANCES IN (a).

General formula for series capacitance: The total capacitance of the series capacitors can be calculated by using the formula

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots + \frac{1}{C_n}}$$

or

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots + \frac{1}{C_n}$$

If there are two capacitors in series

$$C_T = \frac{C_1\,C_2}{C_1 + C_2}$$

If there are three capacitors in series

$$C_T = \frac{C_1\,C_2\,C_3}{(C_1C_2) + (C_2C_3) + (C_3C_1)}$$

If there are `n' equal capacitors in series

$$C_T = \frac{C}{n}$$

Maximum voltage across each capacitor: In series grouping, the division of the applied voltage among the capacitors depends on the individual capacitance value according to the formula

$$V = \frac{Q}{C}$$

The largest value capacitor will have the smallest voltage because of the reciprocal relationship.

Likewise, the smallest capacitance value will have the largest voltage.

The voltage across any individual capacitor in a series connection can be determined using the following formula.

$$V_X = \frac{C_T}{C_X} \times V_S$$

where V_x - individual voltage of each capacitor

C_x - individual capacitance of each capacitor

V_s - supply voltage.

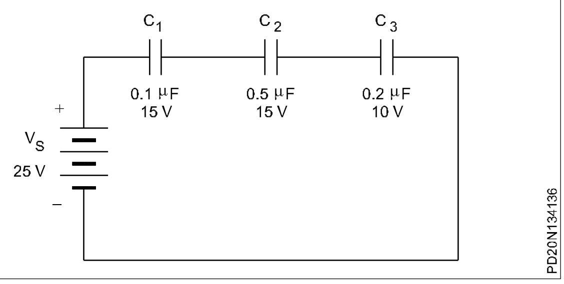
The potential difference does not divide equally if the capacitances are unequal. If the capacitances are unequal you must be careful not to exceed the breakdown voltage of any capacitor.

Example: Find the voltage across each capacitor in Fig 6.

Solution

Total capacitance: C_T

Fig 6



$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C_T} = \frac{1}{0.1} + \frac{1}{0.5} + \frac{1}{0.2}$$ macro farad

$$\frac{1}{C_T} = \frac{10}{1} + \frac{2}{1} + \frac{5}{1}$$

$$\frac{1}{C_T} = \frac{17}{1}$$ and CT = 0.0588 micro farad

$$V_1 = \frac{C_T}{C_1} \times V_S$$

$$V_1 = \frac{0.0588}{0.1} \times 25$$

V_1 = 14.71 V_S

$$V_2 = \frac{C_T}{C_2} \times V_S$$

$$V_2 = \frac{0.0588}{0.5} \times 25$$

V_2 = 2.94 volts

$$V_3 = \frac{C_T}{C_3} \times V_S$$

$$V_3 = \frac{0.0588}{0.2} \times 25$$

V_3 = 7.35 volts

Charge stored in series grouping: Based on previous knowledge, we know that

– the current is the same at all points in a series circuit the current is defined as the rate of flow of charge.

(I = Q/t) or Q = It

The same current is flowing for the same period through the different capacitors of the series circuit. So the charge of each capacitor will be equal (same), and also equal to the total charge Q_T.

$Q_T = Q_1 = Q_2 = Q_3 = ... = Q_n$

But the voltage across each one depends on its capacitance value.

$(V = \frac{Q}{C})$

By Kirchoff's voltage law, which applies to capacitive as well as to resistive circuits, the sum of the capacitor voltages equals the source voltage.

$V_9 = V_1 + V_2 + V_3 + ... + V_n$

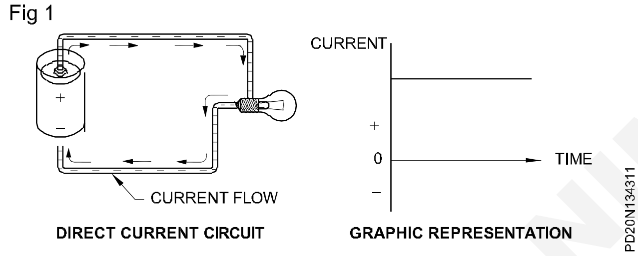
Alternating current - terms & definitions - vector diagrams

Objectives: At the end of this lesson you shall be able to
- **state the features of direct current**
- **list out the advantages of DC over AC**
- **compare the features of DC and AC**
- **explain the generation of alternating current and terms used**
- **state the advantages of AC over DC**

Direct current (DC): Electric current can be defined as the flow of electrons in a circuit. Based on the electron theory, electrons flow from the negative (–) polarity to the positive (+) polarity of a voltage source.

Direct current (DC) is the current that flows only in one direction in a circuit. (Fig 1) The current in this type of circuit is supplied from a DC voltage source. Since the polarity of a DC source remains fixed, the current produced by it flows in one direction only.

Fig 1

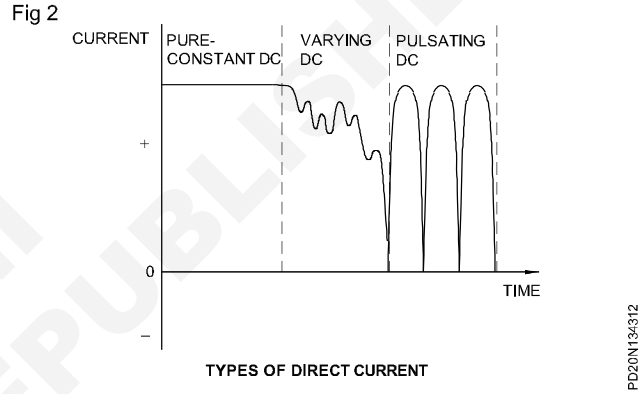


Dry cells are commonly used as a DC voltage source. Both the voltage and polarity of the dry cell are fixed. When connected to a load, the current produced flows in one direction at some steady or constant value.

A direct current flow need not necessarily be constant, but it must travel in the same direction at all times. There are several types of direct current, and all of them depend upon the value of the current in relation to time. (Fig 2)

A constant DC current shows no variation in value over a period of time. Both varying and pulsating DC currents have a changing value when plotted against time. The pulsating DC current variations are uniform, and repeat at regular intervals.

Fig 2



Advantages of DC over AC

1 DC needs only two wires of transmission, while a 3 phase AC may need upto 4 wires.

2 The corona loss associated with DC is negligible while for AC it increases with its frequency.

3 The skin effect is also observed in AC leading to problems in transmission conductor designs.

4 No inductive and capacitive losses.

5 No proximity effect.

Comparison of AC and DC

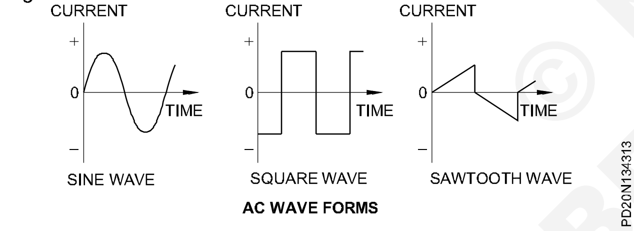
	Alternating current	Direct current
Amount of energy that can be carried	Safe to transfer over longer city distances and can provide more power.	Voltage of DC cannot travel very far until it begins to lose energy.
Cause of the direction of flow of electrons	Rotating magnet along the wire.	Steady magnetism along the wire.
Frequency	The frequency of alternating current is 50Hz or 60Hz depending upon the country.	The frequency of direct current is zero.
Direction	It reverse its direction while flowing in a circuit.	It flows in one direction in the circuit.

	Alternating current	Direct current
Current	It is the current of magnitude varying with time.	It is the current of constant magnitude.
Flow of electrons	Electrons keep switching directions - forward and backward.	Electrons move steadily in one direction or 'forward'.
Obtained from	AC generator and mains.	Cell or battery.
Passive parameters	Impedence.	Resistance only.
Power factor	Lies between 0 to 1.	It is always 1.
Types	Sinusoidal, trapezoidal, triangular, square	Pure and pulsating.

Alternating current (AC): An alternating current (AC) circuit is one in which the direction and amplitude of the current flow change at regular intervals. The current in this type of circuit is supplied from an AC voltage source. The polarity of an AC source changes at regular intervals resulting in a reversal of the circuit current flow.

Alternating current usually changes in both value and direction. The current increases from zero to some maximum value, and then drops back to zero as it flows in one direction. This same pattern is then repeated as it flows in the opposite direction. The wave-form or the exact manner in which the current increases and decreases is determined by the type of AC voltage source used. (Fig 3)

Fig 3



AC WAVE FORMS

Alternating current generation: Alternating current is used wherever a large amount of electrical power is required. Almost all of the electrical energy supplied for domestic and commercial purposes is alternating current.

AC voltage is used because it is much easier and cheaper to generate, and when transmitted over long distances, the power loss is low.

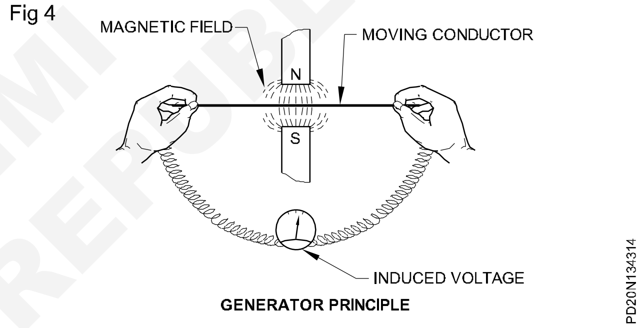
AC equipment is generally more economical to maintain and requires less space per unit of power than the DC equipment.

Alternating current can be generated at higher voltages than DC, with fewer problems of heating and arcing. Some standard values of voltages are 1.1KV, 2.2.KV, 3.3KV for low capacity and 6.6KV (6600V), 11KV(11000V) and 33KV(33000V) for high capacity requirements. The values are increased to 66 000, 110 000, 220 000, 400 000 volts for transmission over long distances. At the load area, the voltage is decreased to working values of 240V and 415V.

The basic method of obtaining AC is by the use of an AC generator. A generator is a machine that uses magnetism to convert mechanical energy into electrical energy. The generator principle, simply stated, is that a voltage is induced in a conductor whenever the conductor is moved through a magnetic field so as to cut the lines of magnetic force.

Fig 4 shows the basic generator principle. A change in a magnetic field around a conductor tends to set electrons in motion. The mere existence of a magnetic field is not enough; there must be some form of change in the field.

Fig 4



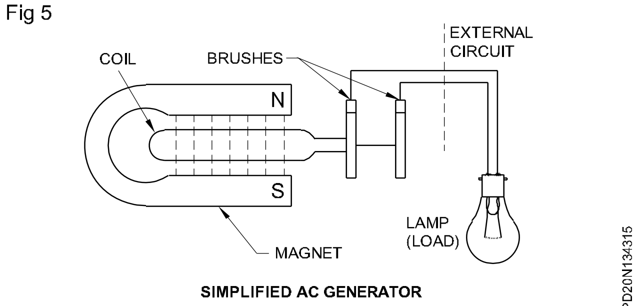
GENERATOR PRINCIPLE

If we move the conductor through the magnetic field, a force is exerted by the magnetic field on each of the free electrons within the conductor. These forces add together and the effect is that voltage is generated or induced into the conductor.

An AC generator produces an AC voltage by causing a loop of wire to turn within a magnetic field. This relative motion between the wire and the magnetic field causes a voltage to be induced between the ends of the wire. This voltage changes in magnitude and polarity as the loop is rotated within the magnetic field. (Fig 5)

The force required to turn the loop can be obtained from various sources. For example, very large AC generators are turned by steam turbines or by the movement of water.

Fig 5



SIMPLIFIED AC GENERATOR

The voltage produced by a single loop generator is too weak to be of much practical value. A practical AC generator has many more turns of wire wound on an armature. The armature is made up of a number of coils wound on an iron core.

The AC voltage induced in the armature coils is connected to a set of slip rings from which the external circuit receives the voltage through a set of brushes. An electromagnet is used to produce a stronger magnetic field.

The sine wave: The shape of the voltage wave-form generated by a coil rotating in a magnetic field is called a sine wave. The generated sine wave voltage varies in both voltage value and polarity.

If the coil is rotated at a constant speed, the number of magnetic lines of force cut per second varies with the position of the coil. When the coil is moving parallel to the magnetic field, it cuts no lines of force.

Therefore, no voltage is generated at this instant. When the coil is moving at right angles to the magnetic field, it cuts the maximum number of lines of force.

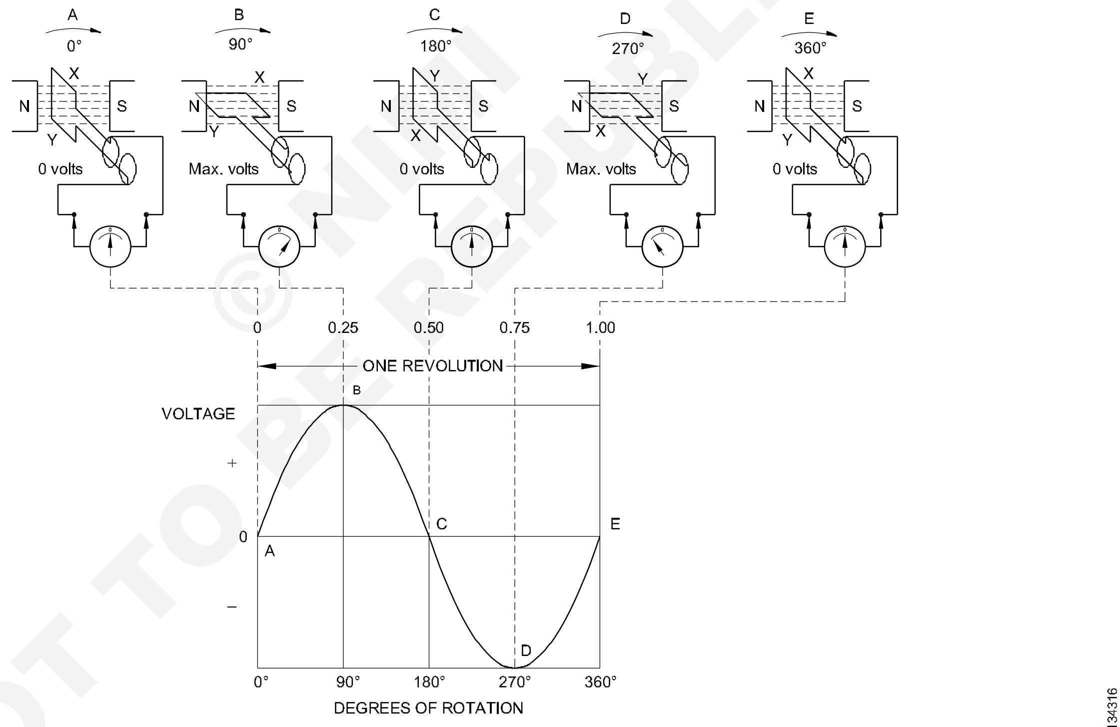
Therefore, maximum or peak voltage is generated at this instant. Between these two points the voltage varies in accordance with the sine of the angle at which the coil cuts the lines of force.

The coil is shown in five specific positions in Fig 6. These are intermediate positions which occur during one complete revolution of the coil position. The graph shows how the voltage increases and decreases in amount during one rotation of the loop.

Note that the direction of the voltage reverses each half-cycle. This is because, for each revolution of the coil, each side must first move down and then up through the field.

The sine wave is the most basic and widely used AC wave-form. The standard AC generator (alternator) produces a voltage of sine wave-form. Some of the important electrical characteristics and terms used when referring to AC sine wave voltage or current are as follows.

Fig 6

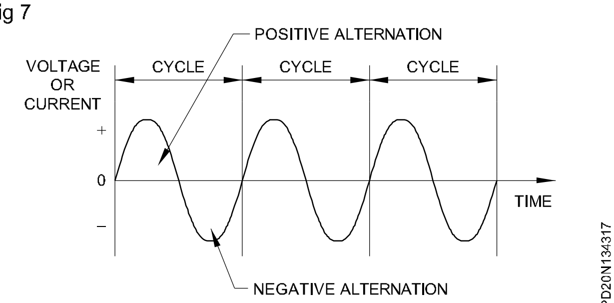


GENERATION OF AN ALTERNATING VOLTAGE: AS THE LOOP ROTATES THROUGH THE MAGNETIC FIELD. THE AMOUNT AND POLARITY OFTHE VOLTAGE CHANGES WITH ANGLE AND DIRECTION OF MOTION.

Cycle: One cycle is one complete wave of alternating voltage or current. During the generation of one cycle of output voltage, there are two changes or alternations in the polarity of the voltage.

These equal but opposite halves of a complete cycle are referred to as alternations. The terms positive and negative are used to distinguish one alternation from the other. (Fig 7)

Fig 7

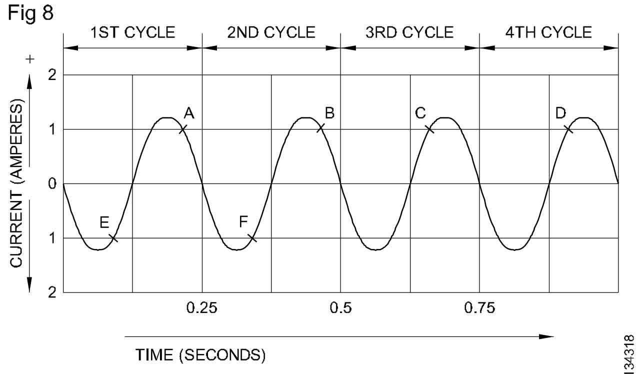


Period: The time required to produce one complete cycle is called the period of the wave-form. In Fig 8, it takes 0.25 seconds to complete one cycle. Therefore, the period (T) of that wave-form is 0.25 seconds.

The period of a sine wave (any symmetrical wave-form) need not necessarily be measured between the zero crossings at the beginning and the end of a cycle. It can be measured from any point in a given cycle to the corressponding point in the next cycle. (See Fig 8-AB, CD or EF.)

Frequency: The frequency of an AC sine wave is the number of cycles produced per second.(Fig 8) The SI unit of frequency is the hertz (Hz). For example, the 240V AC at your home has a frequency of 50 Hz.

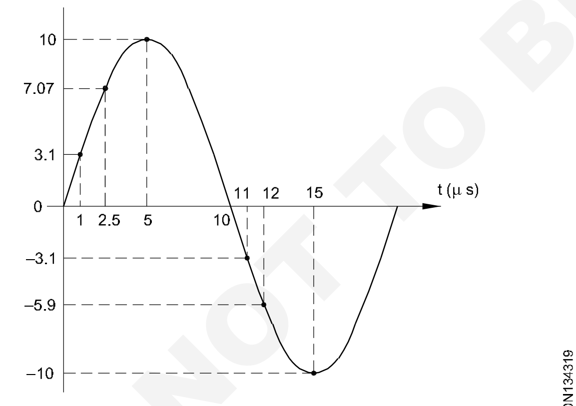
Fig 8



CYCLE, PERIOD, AND FREQUENCY. THE WAVEFORM HAS A PERIOD OF 0.25 SECONDS AND FOUR CYCLES PER SECOND.

Instantaneous value: The value of an alternating quantity at any particular instant is called instantaneous value. The instantaneous values of a sine wave voltage is shown in Fig 9. It is 3.1 volts at 1μs, 7.07 V at 2.5μs, 10V at 5μs, 0V at 10μs, 3.1 volt at 11 μs and so on.

Fig 9

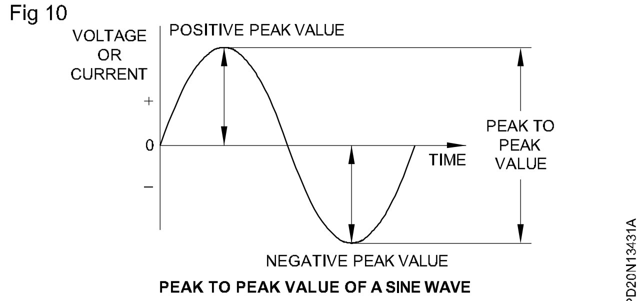


EXAMPLE OF INSANTANEOUS VALUES OF A SINE WAVE VOLTAGE

AC voltage and current values: Since the value of a sine wave of voltage or current continuously changes, one must be specific, while referring to and describing the values of the wave-form . There are several ways of expressing the value of a sine wave.

Peak value or maximum value: Each alternation of the sine wave is made up of a number of instantaneous values. These values are plotted at various heights above and below the horizontal line to form a continuous wave-form. (Fig 10)

Fig 10



PEAK TO PEAK VALUE OF A SINE WAVE

The peak value of a sine wave refers to the maximum voltage or current value. Note that two equal peak values occur during one cycle.

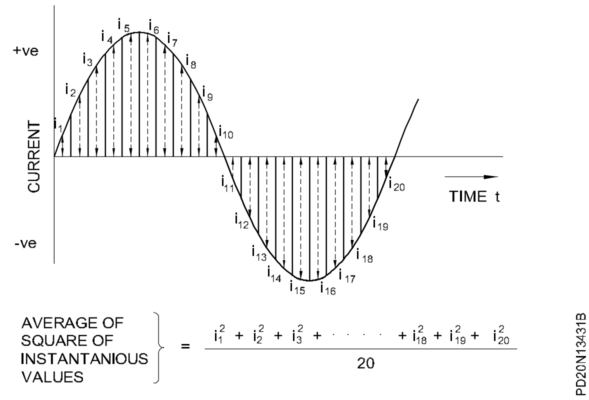
Peak-to-peak value: The peak-to-peak value of a sine wave refers to its total overall value from one peak to the other. (Fig 10) It is equal to two times the peak value.

Effective value: The effective value of an alternating current is that value which will produce the same heating effect as a specific value of a steady direct current. In other words, an alternating current has an effective value of 1 ampere, if it produces heat at the same rate as the heat produced by 1 ampere of direct current, both flowing in the same value of resistance.

Another name for the effective value of an alternating current or voltage is the root mean square (rms) value. This term was derived from a method used to compute the value. The rms is calculated as follows.

The instantaneous values for one cycle are selected for equal periods of time. Each value is squared, and the average of the squares is calculated (values are squared because the heating effect varies as square of the current or voltage). The square root of this is the rms value. (Fig 11)

Fig 11



By using this method it can be proved that the effective value of a sine wave of current is always equal to 0.707 times its peak value. A simple equation for calculating the effective value of sine wave is:

for voltage, $V = 0.707\ V_m$

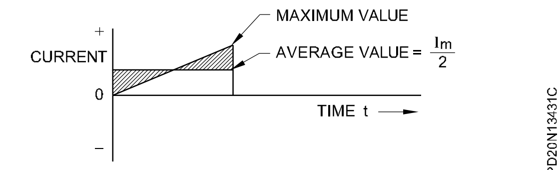
for current, $I = 0.707\ I_m$

where subscript m refers to the maximum value.

When an alternating current or voltage is specified, it is always the effective value that is meant, unless otherwise stated. Standard AC meters indicate effective values only.

Average value: It is sometimes useful to know the average value for one half cycle. If the current is changed at the same rate over the entire half cycle as in Fig 12, the average value would be one half of the maximum value.

Fig 12



However, because the current does not change at the same rate, another method is used. Find the area covered by the curve over the horizontal axis, then divide that area by the base horizontal length. It has been determined that the average value is equal to 0.637 times the maximum value for sine wave-form i.e.

for voltage, $V_{av} = 0.637\ V_m$

for current, $I_{av} = 0.637 I_m$

where subscript av refers to the average value and subscript m refers to the maximum value.

Form factor (k_f): Form factor is defined as the ratio of effective value to average value of half cycle.

For sinusoidal AC

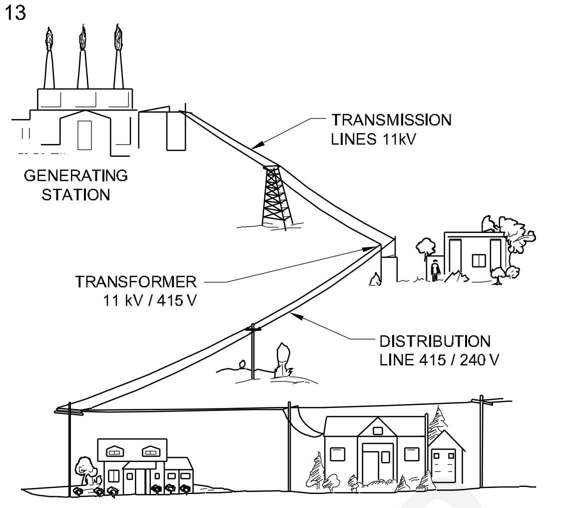
$$k_f = \frac{0.707\ I_m}{0.6637\ I_m} = 1.11$$

where the subscript m refers to the maximum value.

Advantages of AC over DC:

1. AC voltages can be raised or lowered with ease. This makes it ideal for transmission purposes.
2. Large amounts of power can be transmitted at high voltage and low currents with minimum loss.
3. Because the current is low, smaller transmission wires can be used to reduce installation and maintenance costs. (Fig 13)

Fig 13



TRANSMISSION AND DISTRIBUTION LINES FROM GENERATING STATION TO RESIDENCES

DC generators limit their output voltage to 6000V or less. The voltage cannot be raised or lowered through the transformers. Long distance transmission requires heavy cables. AC generators are built with a capacity up to 500000 kilowatts. The DC generators capacity is limited to 10000 kw.

AC motors are less expensive to build, install and maintain than the DC motors. DC motors have one distinct advantage over AC motors: they have better speed control.

- AC is easy to generate than DC.
- It is cheaper to generate AC than DC.
- AC generators take higher efficiency than DC.
- The loss of energy during transmission in negligible for AC in long distance.
- The AC can be easily converted to DC.
- It can easily stepup or stepdown using transformer.
- The value or magnitude of AC can be decreased easily without loss of excess of energy using choke.

Neutral and earth conductors

Objectives: At the end of this lesson you shall be able to
- **describe the purpose of earthing**
- **describe the two types of earthing**
- **differentiate between `neutral' and `earth wire'.**

Earthing: The importance of earthing lies in the fact that it deals with safety. One of the most important, but least understood, considerations in the design of electrical systems is that of earthing (grounding). The word `earthing' comes from the fact that the technique itself involves making a low-resistance connection to the earth or to the ground. The earth can be considered to be a large conductor which is at zero potential.

Purpose of earthing: The purpose of earthing is to provide protection to personnel, equipment and circuits by eliminating the possibility of dangerous or excessive voltage.

There are two distinct considerations in the earthing of an electrical system: earthing of one of the conductors of the wiring system, and earthing of all metal enclosures which contain electrical wires or equipment. The two types of earthing are:

- System earthing
- Equipment earthing.

System earthing: This consists of earthing one of the wires of the electrical system, such as the neutral, to limit the maximum voltage to earth under normal operating conditions.

Equipment earthing: This is a permanent and continuous bonding together (i.e. connecting together) of all non-current carrying metal parts of the electrical equipment to the system earthing electrode.

What is an earthing electrode?: A metal plate, pipe or other conductors electrically connected to the general mass of the earth is known as an earthing electrode. Earth electrodes shall be provided at generating stations, substations and consumer premises (in accordance with the requirements of IS : 3043-1966).

The neutral used in single phase system is to provide return path for load current to the source. Various method of neutral earthing is provided to serve neutral in single phase distribution at substation according to the requirements.

What is an `earth wire'?: A conductor connected to earth and usually situated in proximity to the associated line conductors which is used for equipment earthing is called an earth wire.

The purpose of equipment earthing: By connecting the metal work not intended to carry current to earth, a path is provided for leakage current which can be detected, and, if necessary, interrupted by the following devices.

- Fuses
- Circuit breakers.

Identification: All cores of cables and conductors should be identified at the points of termination, and preferably throughout their length to indicate their function.

Methods of identification may include coloured insulation applied to conductors in manufacture or the application of coloured tape, sleeves or discs (Fig 1). The colours used must be of those specified for the function in Table 52A of IEE wiring regulations.

Fig 1

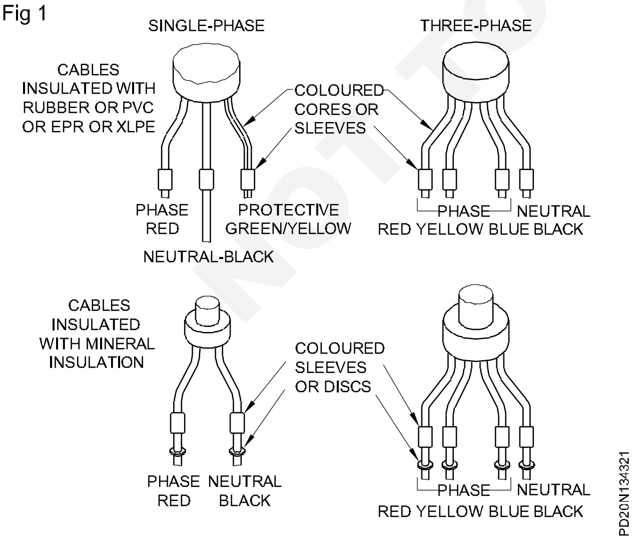


Table 52A of IEE regulations

Colour identification of cores of non-flexible cables and bare conductors for fixed wiring	
Function	**Colour identification**
Protective (including earthing)conductor	Green-and-yellow
Phase of ac. single- or three-phase circuit	Red(or yellow or blue*)
Neutral of ac single- or three-phase circuit	Black
Phase R of 3-phase ac circuit	Red
Phase Y of 3-phase ac circuit	Yellow
Phase B of 3-phase ac circuit	Blue
Positive of dc 2-wire circuit	Red
Negative of dc 2-wire circuit	Black
Outer (positive or negative) of dc 2-wire circuit derived from 3-wire system	Red
Positive of 3-wire dc circuit	Red
Middle wire of 3-wire dc circuit	Black
Negative of 3-wire dc circuit	Blue
As alternatives to the use of red, if desired, in large installations, on the supply side of the final distribution board.	

Flexible cables and flexible cords: Every core of a flexible cable or flexible cord shall be identifiable throughout its length as appropriate to its function, as indicated in Table 52B of IEE Regulations.

Flexible cables or flexible cords having the following core colours shall not be used; green alone, yellow alone, or any bi-colour other than the colour combination green and yellow. When armoured PVC insulated auxiliary cables or paper insulated cables are used an alternative identification system may be used using numbers, where 1, 2 & 3 signify phase conductors and O the neutral conductor. The number 4 is used to identify any special purpose conductor (Fig 2).

Fig 2

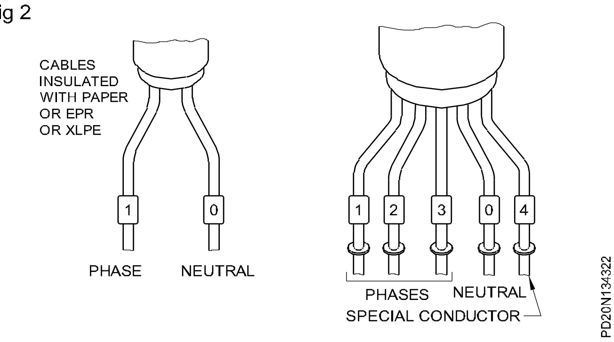


Table 52B of IEE regulations

Colour identification of cores of flexible cables and flexible cords		
No. of cores	**Function of core**	**Colour(s) of core**
1	Phase Neutral Protective (combination)	Brown Blue Green and yellow
2	Phase Neutral	Brown Blue
3	Phase Neutral Protective (combination)	Brown Blue Green and yellow
4 or 5	Phase Neutral Protective	Brown or black Blue Green and yellow (combination)

The colour combination of green and yellow is to be used exclusively for the identification of protective conductors.

Where electrical conduits need to be easily identified from the pipelines of other services such as gas, oil, water, steam, etc. they should be painted orange.

Use of vector diagram

Objectives: At the end of this lesson you shall be able to
- **distinguish between scalar and vector quantity**
- **illustrate the method of drawing vector diagram for two vectors.**

Definition of scalar and vector quantity and phasor

Scalar quantity:A scalar quantity is a quantity which is determined by the magnitude alone, for example energy, volume, temperature etc.

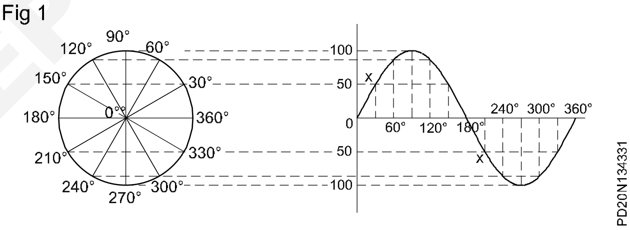
Vector quantity: A vector quantity is a quantity which is represented by straight line with an arrow head to represent the magnitude and direction of it. For example, - force, velocity, weight.

Phasor: Phasor is a vector that is rotating at a constant angular velocity. A straight line with an arrow head is used to represent graphically the magnitude and phase of a sinusoidal alternating quantity (i.e. current, voltage and power) is called phasor.

Plotting a curve of alternating voltage: If the maximum voltage of the alternator is known, the generated voltage can be plotted to form a curve. Draw a circle with the radius representing the maximum value of voltage.

Any convenient scale may be used. Divide the circle into equal parts. (Fig 1) Draw a horizontal line to scale, along which one voltage cycle will be plotted. Divide the line into the same number of equal parts as in the circle. Draw horizontal and vertical lines, as illustrated by the dashed lines in Fig 1. The intersection of the lines represents the value of voltage at that instant. For example, a horizontal and a vertical line intersect at point X.

Fig 1



Using the same scale as used for the radius of the circle, the vlaue of voltage can be measured. This value is the emf produced when the coil is cutting the lines of force at a 30-degree angle.

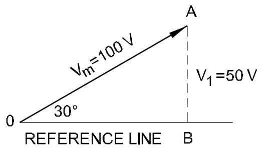
Use of vector diagrams: The change which occurs in the value of an alternating voltage and/or current during a cycle can also be shown by using vector diagrams.

A vector is a line segment that has a define length and direction. A vector diagram is two or more vectors joined together to convey information. Vector diagrams drawn to scale can be used to determine instantaneous values of current and/or voltage.

Scalar quantity	Vector quantity
1. Scalar quantity can be presented by magnitude only, for example - energy, volume etc.	Vector quantity must represent magnitude and direction also, for example - force velocity etc.
2. Addition and substraction of scalar quantities can be done algebraically	Addition and subtraction of vector quantities cannot be done algebracially but by vector summation.

Fig 1 can be analyzed by means of vector diagrams according to the following procedure. Draw a horizontal line as a reference line (Fig 2). Starting at point O and 30 degrees from the reference line, draw OA to scale to represent a maximum voltage (Vm) of 100 volts. From the end of vector OA, draw a vertical dashed line is labelled AB and represents the instantaneous value of voltage (V_i) when the coil is cutting the lines of force at a 30 degree angle. Measure vector AB. It should scale to 50 volts.

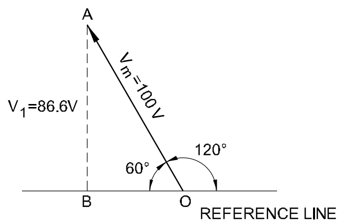
Fig 2



VECTOR DIAGRAM DRAWN TO SCALE TO DETERMINE THE VOLTAGE WHEN THE COIL IS MOVING AT A 30° ANGLE TO THE LINES OF FORCE

The same procedure can be followed for any degree of rotation. The vector diagram shown in Fig 3 is used to determine the value of voltage when the coil has rotated 120 degrees.

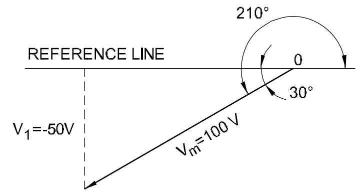
Fig 3



VECTOR DIAGRAM DRAWN TO SCALE. THE COIL HAS ROTATED 120° AND IS CUTTING THE FLUX AT 60°

Although the coil has rotated 120 degrees, the angle it is making with the lines of force is only 60 degrees. It is this angle that determines the value of the instantaneous voltage. For example, if the coil rotates 210 degrees, it cuts the lines of force at angle of 30 degrees. (Fig 4)

Fig 4

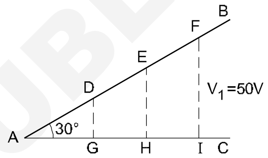


VECTOR DIAGRAM DRAWIN TO SCALE. THE COIL HAS ROTATED 210° AND IS CUTTING THE FLUX AT 30°. THE EMF HAS REVERSED DIRECTION, INDICATED BY THE -VE SIGN.

Referring back to Fig 1, it can be seen that each division of the circle can represent vector OA. Vector AB can be represented by points along the voltage curve. The angle between the horizontal diameter of the circle and the radius v_m is the angle at which the coil is cutting the flux. Although vector diagrams are seldom used alone, they are a simple way of presenting a visual illustration of a problem. Vector diagrams are usually used with trigonometric functions.

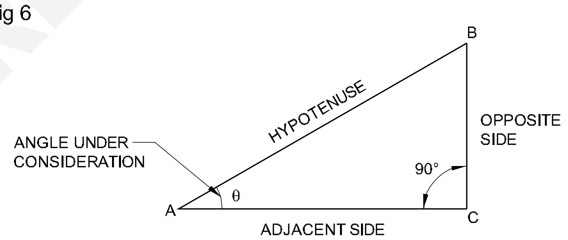
Many electrical problems are solved through the use of trigonometry. The vector diagrams used with trigonometric functions are generally in the form of triangles and/or parallelograms.(Fig 5 & 6)

Fig 5



VECTOR DIAGRAM FORMING THREE 30° - 60° - 90° TRIANGLES

Fig 6



AC simple circuit - with inductance only

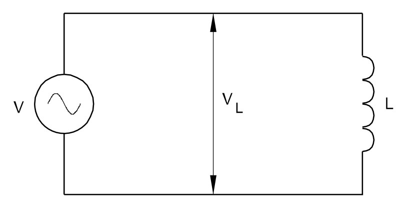
Objectives: At the end of this lesson you shall be able to

- **state phase relation between V and I in a pure inductive circuit**
- **state about inductive reactance**
- **state power in pure inductive circuit**
- **define power factor.**

Circuit with pure inductance only: Inductance affects the operation of pure DC circuits only at the instant they are opened and the instant they are closed. In an AC circuit, the current is always changing, and the inductance is always opposing the change. The inductance, therefore, has a constant effect on circuit operation.

A circuit with pure inductance alone can never be formed, because the source, the connecting wires, and the inductor all have some resistance. However, if these resistances are very small and have a much smaller effect on the circuit current than does the inductance, the circuit can be considered as containing only inductance. (Fig 1)

Fig 1



CIRCUIT DIAGRAM

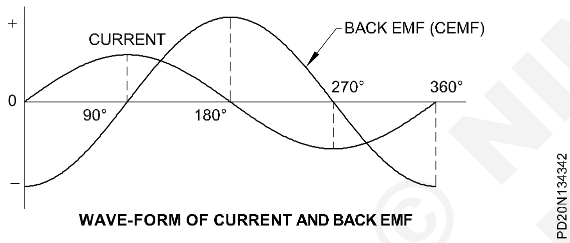
In any AC circuit that contains only inductance, there are three varying quantities. These are (1) the applied voltage, (2) the induced back emf, and (3) the circuit current.

Phase relationship between voltage and current: The phase relationships in an inductance can most easily be understood by considering first the current and the back emf. You know two things about the current and the back emf. One is that the counter emf is maximum when the rate of change of current is the greatest, and is zero when the current is not changing.

The second relationship is that the direction of the cemf is such that it always opposes the current change.

The wave-form in Fig 2 shows one cycle of AC current. The rate of change is greatest where the slope of the wave-form is greatest. You can see that this occurs at those points where the wave-form passes through zero; or at 0,180, and 360 degrees. This means that the highest cemf is generated at 0,180 and 360 degrees, as shown by the wave-forms in Fig 2. Around 90 and 270 degrees, the change is very little; as a matter of fact, at exactly 90 and 270 degrees, where the current change is from rising to falling, the current is momentarily steady. Therefore, the flux lines do not change at those points, and no cemf is induced.

Fig 2



WAVE-FORM OF CURRENT AND BACK EMF

What should be the amount and direction of counter emf (back emf) when the current is passing through zero and in the positive direction?

Since at 0 degrees the current is passing through zero in a positive direction, the cemf must be maximum in the negative direction, in as much as it always opposes the increase in current. Similarly, when the current begins to decrease at 90 degrees, the cemf must be increasing in the positive direction to aid the current flow.

As shown, therefore, the cemf follows Lenz's Law by lagging the current by 90 degrees. You know that the applied voltage is 180 degrees out of phase with the cemf, and so the applied voltage must lead the current by 90 degrees. This is shown in the wave-form in Fig 3. The relationships between the three quantities (current, cemf, and applied voltage) is shown in the wave-forms in Fig 4. We know they are not in phase as in the case of resistive circuits.

Fig 3

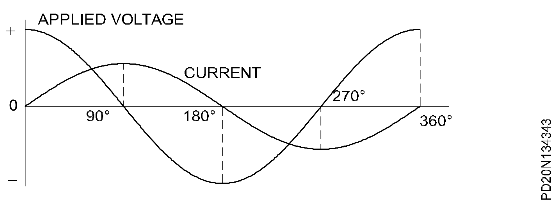
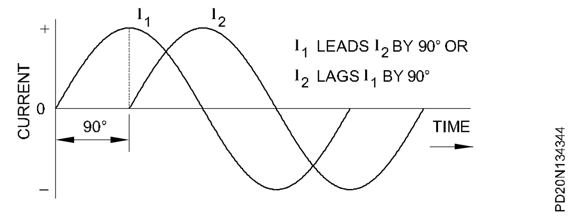


Fig 5



In an inductance: (1) the applied voltage leads the current by 90°; (2) the back emf lags the current by 90° and (3) the applied voltage and the back emf are 180° out of phase.

This is known as 'phase difference'.

Phase difference: If two alternating quantities attain maximum value in the same direction after passing through zero value at different times, they are said to have a phase difference.

Phase difference can be expressed in fractions of a cycle. For more accuracy, phase difference is given in degrees. The terms `lead' and `lag' are used to describe the relative positions in time of two voltages or currents that are not in phase. The one that is ahead in time is said to lead, while the one behind lags. (Figs 5 and 6)

Fig 5

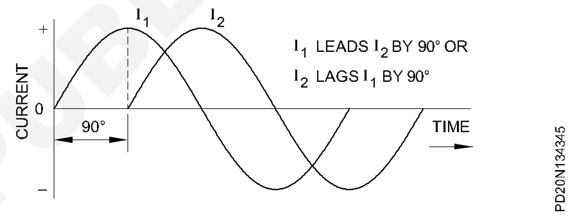
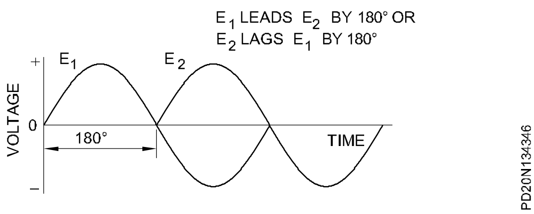


Fig 6



When maximum and minimum points of one voltage or current occur before the corresponding points of another voltage or current, the two are out of phase. When such a phase difference exists, one of the voltages or currents leads, and the other lags.

Phase difference can also be illustrated by a vector diagram. While representing phase difference, the reference quantity is shown on the +ve side of the x axis.(Figs 7 & 8)

Fig 7

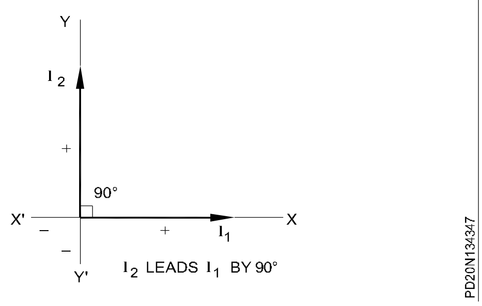
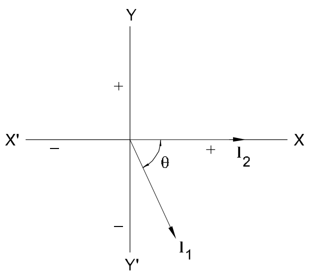


Fig 8



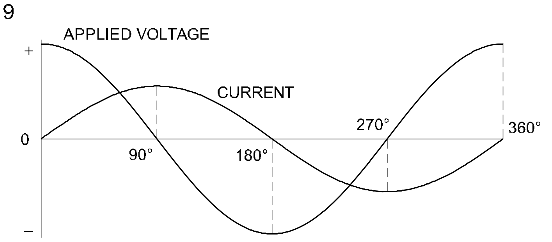
I_1 LAGGING I_2 BY ANGLE θ

The quantity of lead is shown by an angle in an anticlockwise and a lagging quantity is shown by a clockwise angle.

Phase relationship between current and voltage in a circuit with inductance only

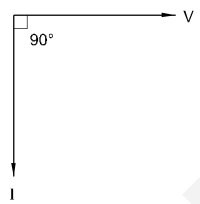
When AC voltage is applied to an inductive circuit, the current lags behind the applied voltage by a quarter cycle or by 90°. (Fig 9)

Fig 9



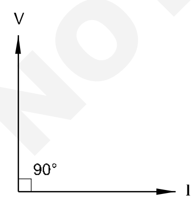
In a purely inductive circuit, the current lags behind the applied voltage by 90°. This is illustrated in the Fig 9 as wave-form. This also can be stated as voltage leads current. The vector diagram for both expressions is given in Figs 10 and 11.

Fig 10



I LAGS BEHIND V BY 90°

Fig 11



V LEADS I BY 90°

Inductive reactance: The cemf acts just like a resistance to limit the current flow. But cemf is discussed in terms of volts, so it cannot be used in Ohm's Law to compute the current. However, the effect of cemf can be given in terms of ohms. This effect is called inductive reactance, and is abbreviated as X_L. Since the cemf generated by an inductor is determined by the inductance (L) of the inductor, and the frequency (f) of the current, the inductive reactance must also depend on these things. The inductive reactance can be calculated by the equation

$$X_L = 2\pi fL$$

where X_L is the inductive reactance in ohms; f is the frequency of the current in cycles per second; and L is the inductance in henrys. The quantity 2π together actually represents the rate of change of the current, usually denoted by the Greek letter `ω' (Omega).

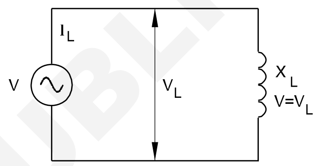
Since 2π = 2(3.14) = 6.28, the Eqn. becomes similarly

$$L = \frac{X_L}{6.28\,f}$$

$$f = \frac{X_L}{6.28\,L}$$

In a circuit containing only inductance, Ohm's Law can be used to find the current and voltage by substituting X_L for R. (Fig 12)

Fig 12



CIRCUIT WITH ONLY X_L

$$I_L = \frac{V_L}{X_L}$$

$$X_L = \frac{V_L}{I_L}$$

$$V_L = I_L X_L$$

where I_L = current through the inductance, in amperes

V_L = voltage across the inductance, in volts

X_L = inductive reactance in ohms

Example: An AC circuit consists of a 20-mH coil operating at a frequency of 1000 kHz. What is the inductive reactance of the coil?

X_L = 6.28fL

= $6.28(1000 \times 10^3)(20 \times 10^{-3})$

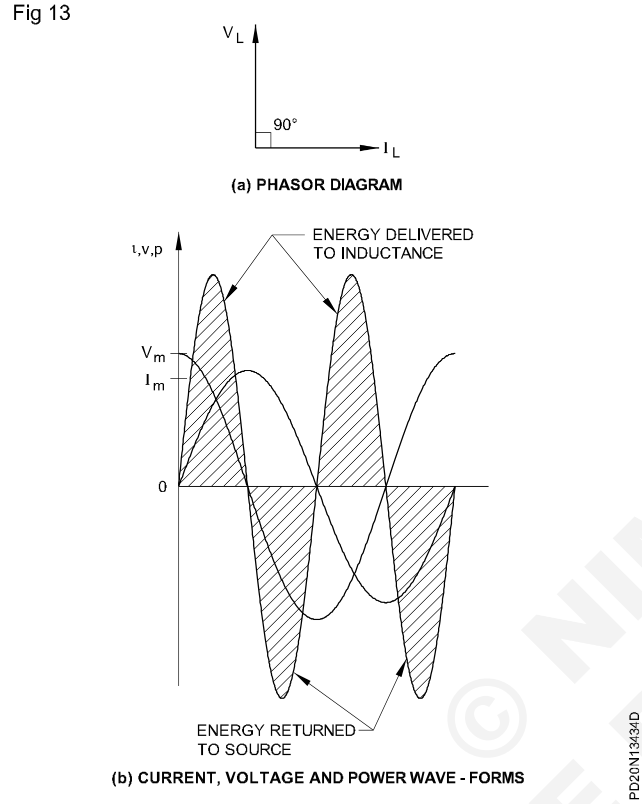
= 12.56×10^4 = 125600 ohms.

Example: What must the inductance of a coil be so that it has a reactance of 628 ohms at a frequency of 40KHz?

$$L = \frac{X_L}{6.28f} = \frac{628}{6.28(40 \times 10^3)} = 2.5 \times 10^{-3} = 2.5\text{ mH}$$

Power in pure inductance: If an AC circuit contains only inductance, the voltage and current are 90° out of phase, as shown by the phasor and wave diagrams in Fig 13. The result of multiplying the V and I wave-forms is a power curve that again has a frequency twice that of the source is as shown in Fig 13. However, over a complete cycle of input voltage, the power curve has an average value of zero. That is, the power curve shows an equal alternation of positive and negative power above and below the zero time axis.

Fig 13



(a) PHASOR DIAGRAM

(b) CURRENT, VOLTAGE AND POWER WAVE - FORMS

Positive and negative power: (Fig 13) The shaded portion of the power curve above the zero axis represents energy being delivered to the inductor (or load) from the source. This positive power actually represents a storage of energy in the magnetic field of the inductance.

The shaded portion of the power curve below the zero axis represents energy returned to the source from the inductor. This negative power indicates that a flow of energy is taking place in the opposite direction(from load to source) when the coil's magnetic field collapses.

The average true power, P, is zero, in a pure inductance.

In AC circuits,

Power = VI Cos ϕ watts

where ϕ is the phase angle between voltage and current.

As the phase angle between V & I in pure inductive circuit is 90°, Cos 90° is zero.

Therefore P = V x I x (zero) = zero.

The term Cos ϕ is known as `power factor'.

Reactive power: However, the source must be capable of delivering power for a quarter of a cycle, even though this power will be returned during the next quartercycle. This stored or transferred power is called reactive power, P_q.

In the case of a purely inductive circuit, the reactive power is given by

$P_q = V_L I_L$ volt-amperes reactive (var)

where P_q is the reactive power in volt-amperes reactive, var

V_L is the voltage across the inductance in volts

I_L is the current through the inductance in ampere.

Since $V_L = I_L X_L$

then $P_q = I_L^2 X_L$ var.

where X_L is the inductive reactance in ohms. Note how the equations for relative power are similar to those for true power with X_L used in place of R. But we must remember to use var for the unit of reactive power, not watts.

Example: Calculate the reactive power of a circuit that has an inductance of 4 H when it draws 1.4 amps from a 50Hz supply.

Solution

X_L = 2πfL = 2π x 50Hz x 4H = 1256 ohms

$P_q = I_L^2 X_L$ = (1.4A)^2 x 1256 ohms = 2462 vars

= 2.462 kvar

Note that 1 kvar = 1 kilo-var = 1000 vars.

A.C. circuit with R & L in series

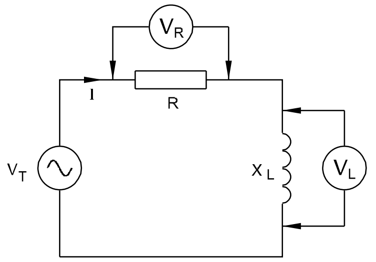
Objectives: At the end of this lesson you shall be able to
- **state the voltage and current relationship**
- **determine impedance of a series circuit with RL in series**
- **calculate power in a series circuit (with RL in series)**
- **calculate the power factor in RL series circuit.**

When resistance and inductance are connected in series, or in the case of a coil with resistance, the rms current I_L is limited by both X_L, and R however the current I is the same in X_L and R since they are in series, the voltage drop across R is V_R = IR and the voltage drop across X_L is V_L = IX_L. The current I through X_L must lag V_L by 90° because this is the phase angle between current through an inductance and its self-induced voltage. The current I through R,and its

IR voltage drop,are in phase and so the phase angle is 0°.

Now let us apply the principle of phasor representation to a series circuit containing pure resistance and pure inductance. (Fig 1)

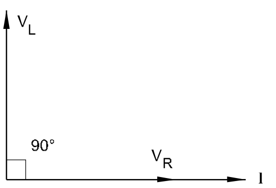
Fig 1



CIRCUIT WITH R & L IN SERIES

Since we are considering a series circuit, it is convenient if we draw the current phasor in the horizontal reference position because it is `common' to both the resistor and inductor. Superimposed upon this phasor is the voltage phasor across the resistor V_R. This is because the current and voltage are always in phase with each other in a pure resistor. (Fig 2)

Fig 2



VECTOR DIAGRAM OF R & L SERIES CIRCUIT

Similarly, the voltage phasor across the inductor V_L is drawn 90° ahead of the current I in other words leading the current phasor. This is because, as we know, the current always lags the inductor voltage by 90° in a pure inductance.

However, these two voltages are 90° out of phase with each other. This means that the total voltage across the series combination cannot be obtained simply by adding V_R to V_L algebraically. We must take into account the angle between them.

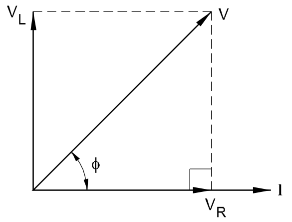
The applied voltage V is the (phasor) sum of V_R and V_L with the phase angle added.

This phasor addition can be carried out simply by constructing a parallelogram (a square in this case) and drawing the diagonal. This is shown in Fig 3. Clearly, the phasor sum V is less than the algebraic sum of V_L and V_R. Also, because V is the hypotenuse of a right-angled triangle, V is given by

$V^2 = V_R^2 + V_L^2$

Impedance of a series RL circuit: The total opposition to current in a series, RL circuit, is called the impedance Z. It is the ratio of the total applied voltage V to the current I. Impedance is measured in ohms as are resistance and inductive reactance. But, as shown by the following, impedance is the vector sum of resistance and reactance.

Fig 3

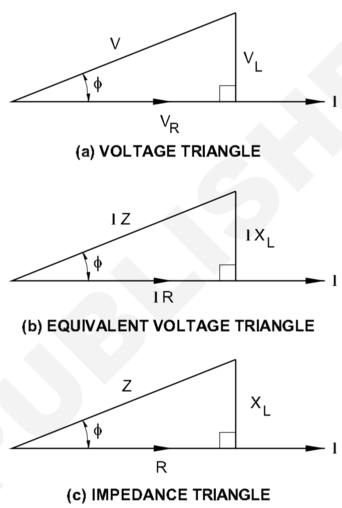


PHASOR DIAGRAM OF R & L SERIES CIRCUIT

Consider the `voltage triangle' for a series, RL circuit, as shown in Fig 4a. This is similar to the phasor diagram in Fig 3 with V_L transferred to make a closed triangle.

Given $V^2 = V_R^2 + V_L^2$ and V_R = IR and $V_L = IX_L$

Fig 4



then $V = \sqrt{(IR)^2 + (IX_L)^2}$

$$= \sqrt{I^2R^2 + (I^2X_L)^2}$$

$$= \sqrt{I^2(R^2 + X_L^2)}$$

$$= I\sqrt{R^2 + X_L^2} \text{ and } \frac{V}{I} = \sqrt{R^2 + X_L^2}$$

But $\frac{V}{I}$ is the impedance Z.

Therefore, $Z = \sqrt{R^2 + X_L^2}$ ohms

where Z is the impedance in ohms

R is the resistance in ohms

X_L is the inductive reactance in ohms

and $I = \frac{V}{Z}$ amperes (A).

We can also see from Fig 4b & 4c that, if the impedance and phase angle are known, we can obtain the resistance and inductive reactance.

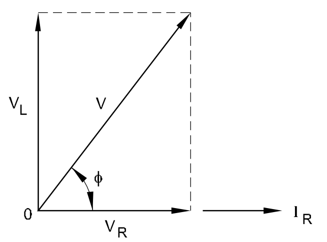
$R = Z \cos \phi$

$X_L = Z \sin \phi$

where ϕ is the angle between Z and R.

Power in a series RL circuit: We have seen that inductance is always accompanied by resistance. Thus coils in motors, generators, relay coils etc. contain both resistance and inductance. When an AC voltage is applied, the current I is neither in phase nor 90° out of phase with the applied voltage V as shown in Fig 5.

Fig 5



CURRENT REFERENCE VECTOR

This means, unlike pure resistance and pure reactance, the product of the voltmeter and ammeter readings in Fig 6 is a combination of the true and (quadrature) reactive power. We call the product of total V and total I apparent power Ps. Since it is neither true power in watts nor reactive power in vars, we use a new unit - the volt ampere, VA to measure the apparent power.

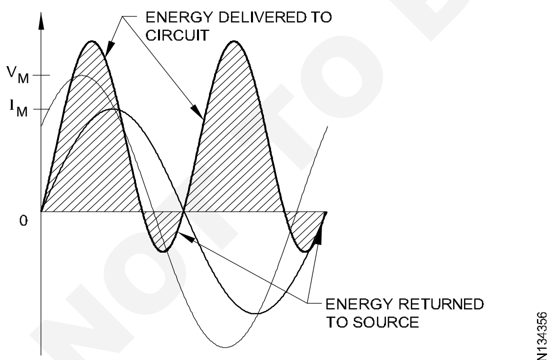
P = V x I volt-amperes (VA)

where P is the apparent power in volt amperes VA,

V is the total applied voltage in volts V,

I is the total circuit current in amperes A.

Fig 6



CURRENT, VOLTAGE, AND POWER WAVE - FORMS

Power triangle: In AC circuit we had identified three types of power.

- True power in watts as in circuit with resistors only.
- Reactive power in vars as in the case of pure inductive or pure capacitive circuit.
- Apparent power in VA as in the case of circuits with R and L or R & C. All the three are interrelated.

We know in a series RL circuit

$$V = \sqrt{V_R^2 + V_L^2}$$

Therefore $V \times I = \sqrt{(V_R \times I)^2 + (V_L \times I)^2}$

But V x I = apparent power in VA

V_R x I = true power in watts

V_L x I = reactive power in vars

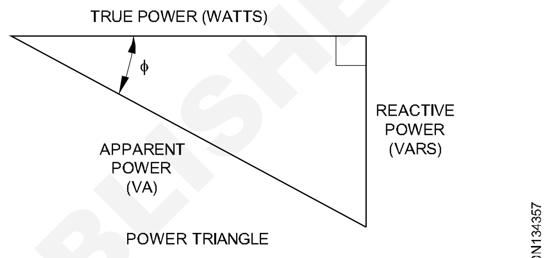
Therefore,

(apparent power)^2 = (true power)^2 + (reactive power)^2

or $\quad VA = \sqrt{(W^2) + (VAR^2)}$

This relation can be represented in a power triangle, as in Fig 7.

Fig 7



POWER TRIANGLE RELATIONS FOR A SERIES RL CIRCUIT

Fig 7 shows the apparent power as represented by the hypotenuse of the right angled triangle. The true power is the product of the current and voltage in phase with each other, and is drawn horizontally. The out-of-phase product of V_L and I gives the reactive power, and is drawn vertically downward. This is a convention used to show a lagging, inductive, reactive power corresponding to a lagging current. (A capacitive reactive power is drawn vertically upward, corresponding to a leading current.)

We can also have other relations.

W = VA Cos ϕ

VAR = VA Sin ϕ

Power factor: The ratio of the true power delivered to an AC circuit compared to the apparent power that the source must supply is called the power factor of the load.

If we examine any power triangle, as in Fig 7, we see that the ratio of the true power to the apparent power is cosine of the angle Ø.

$$\text{Power factor} = \frac{W}{VA} = \cos \phi$$

As W = V_R x I and

VA = V x I also

V_R = I x R

= I x Z

power factor must also be equal to $\frac{V_R}{V}$ and to $\frac{R}{Z}$

Power factor (PF) $= \frac{W}{VA} = \frac{V_R}{V} = \frac{R}{Z} \cos\phi$

What should be the power factor for a circuit containing pure resistance only?. As the phase angle Ø between current and voltages is $\phi = 0$.

Cos ϕ = 1 and PF = 1.

Similarly the power factor for circuit containing pure inductance or pure capacitance only is zero as

Cos ϕ = Cos 90° = zero.

Example: An inductive coil with a resistance of 10 ohms and inductance of 0.05 henry is connected across 240 volt 50 cycle AC mains.

Calculate

i) current taken by the coil

ii) power factor of the circuit

iii) power consumed, and answer

iv) whether the current in the circuit is lagging or leading.

Solution

$X_L = 2\pi fL = 2 \times 3.142 \times 50 \times 0.05 = 15.7$ ohms

$$Z = \sqrt{R^2 + X_L^{\ 2}} = \sqrt{(10)^2 + (15.7)^2}$$

$$= \sqrt{346.49} = 18.6 \text{ ohms } 7$$

i I = (240/18.6) = 12.9 Amps

ii Power factor $= \frac{R}{Z} = \frac{10}{18.6} = 0.537$

iii Power consumed $= I^2R = (12.9)^2 \times 10$

$= 166.72 \times 10$

$= 1667$ W.

iv The current is lagging in the circuit.

Example: An inductive circuit has a resistance of 2 ohms in series with an inductance of 0.015 henry. Find (i) current and (ii) power factor when connected across 200 volt 50 cycles per second supply mains.

Solution

$X_L = 2\pi fL = 2 \times 3.142 \times 50 \times 0.015 = 4.71$ ohms

$$Z = \sqrt{R^2 + X_L^{\ 2}} = \sqrt{(2)^2 + (4.71)^2}$$

$$= \sqrt{4 + 17.39} = \sqrt{26.19}$$

i. $I = \frac{200}{5.11} = 39.13$ amps

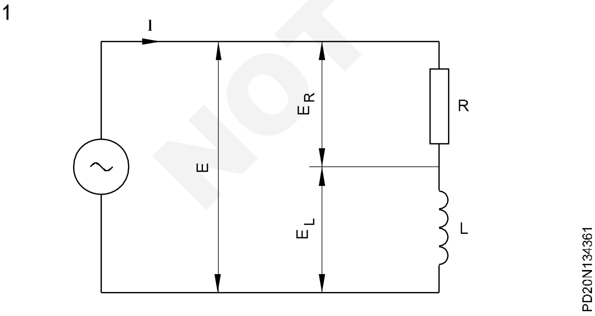
ii. Power factor $= \frac{R}{Z} = \frac{2}{5.11} = 0.39$

Phase relation between V & I in R - L series circuit

Objectives: At the end of this lesson you shall be able to
- **explain how to add and subtract vector quantities**
- **represent voltage of R-L circuit by vector .**

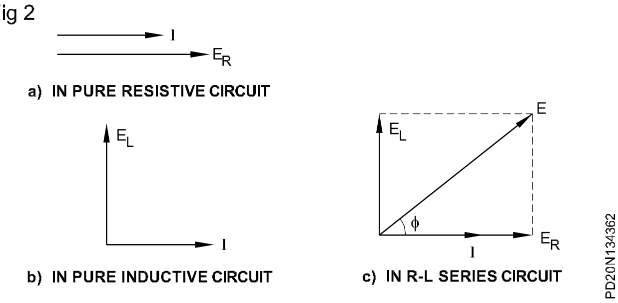
Consider circuit diagram as shown in Fig 1.

Fig 1



When an alternating voltage is applied to a pure inductor, the resultant alternating current through the inductor is lagging by 90° with the supply voltage due to presence of counter emf. (Fig 2b). As current I is shown first Fig 2(a) the voltage across resistor 'R' i.e. this in phase with current. (Fig 2a & 3b)

Fig 2



The voltage across inductor (L) E_L is 90° leading with current I. (Figs 2b and 3c). Hence the applied voltage E is obviously the resultant of E_R & E_L. It is obtained by simply summing up the instantaneous values of E_R and E_L. (Figs 2c & 3d)

Addition and subtraction of vectors by parallelogram method

Addition of two vectors: Two vectors OA & OB are acting on the same point '0' at an angle a as shown in

Fig 3

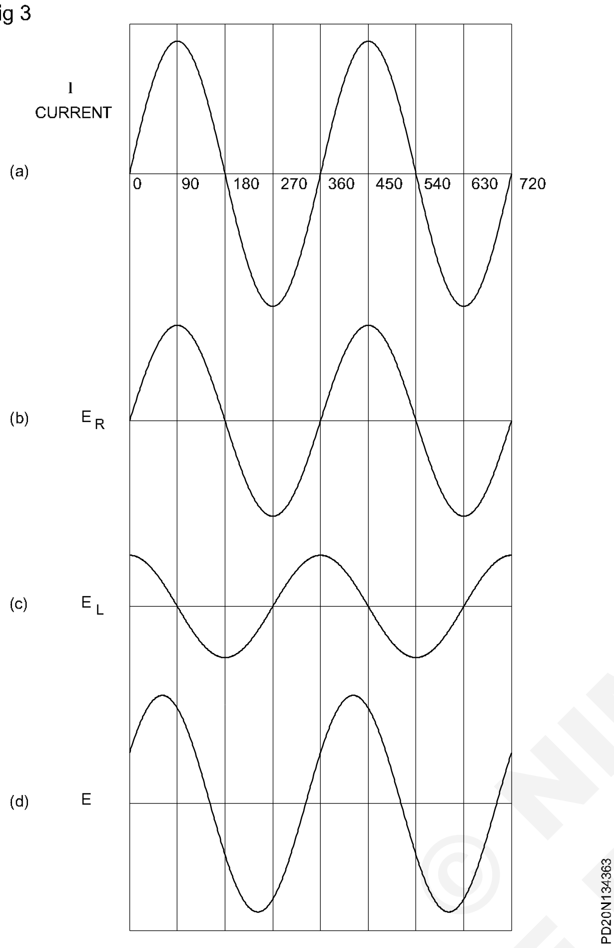
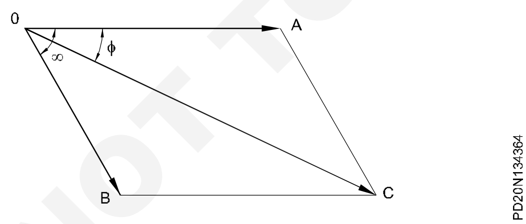


Fig 4. Both vectors can be added by the parallelogram method. On completion of parallelogram OACB, draw the diagonal 'OC' from point 0.

Fig 4



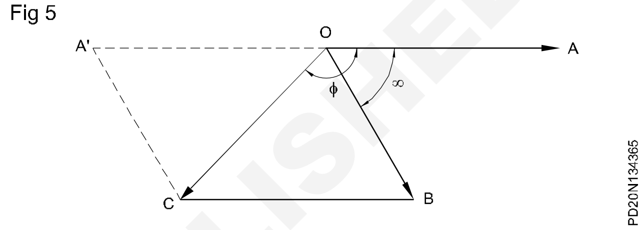
Now 'OC' represents the resultant vector of both vectors.

Subtraction of two vectors: If vector OA is to be subtracted from vector OB (as shown in Fig 5) $(\overline{OB} - \overline{OA})$ then OA is produced backward so that OA' = OA complete parallelogram OBCA'. The diagonal OC drawn from point '0" of the parallelogram represents the resultant of OA & OB.

$$\overline{OC} = (\overline{OB} - \overline{OA})$$

Addition of voltage across resistance and inductance connected in series by vector method to compare with supply voltage.

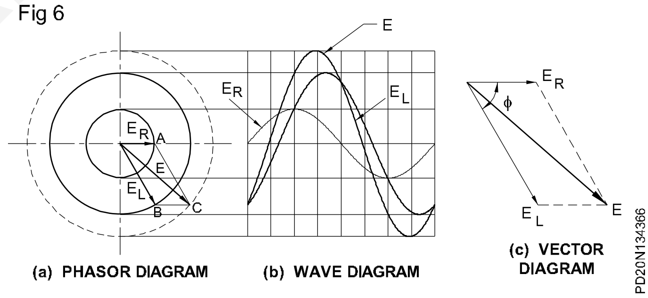
Fig 5



Phasor is representation of sinusoidal quantities. Hence two electrical quantities can be represented by a phase diagram as shown in Fig 6a and wave form a shown by Fig 6b.

Two electrical quantities both (E_R & E_L) voltage can be added by the vector diagram methods as shown in Fig 6c.

Fig 6

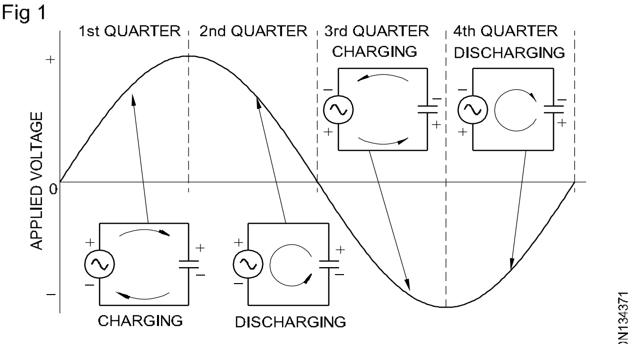


AC Simple circuit - with capacitor only

Objectives: At the end of this lesson you shall be able to
- **explain AC circuit with capacitor only**
- **state phase relation between V and I**
- **state power in pure capacitance only.**

Circuit with capacitance only: In an AC circuit, the applied voltage as well as the current it produces, periodically changes direction. (Fig 1) A capacitor in an AC circuit is first charged by the voltage being applied in one direction. Then, when the applied voltage starts to decrease, less current flows, but the capacitor is still being charged in the same direction. As a result, as the applied voltage continues to drop, the voltage developed across the capacitor becomes greater.

Fig 1



AC CIRCUIT WITH CAPACITOR ONLY

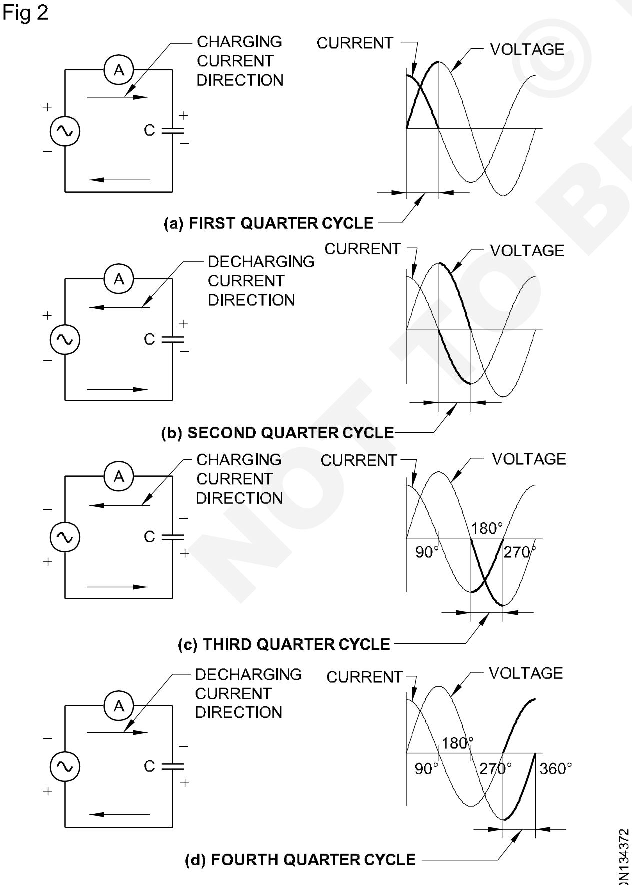
The capacitor then acts as the source, and starts discharging. The capacitor becomes fully discharged when the applied voltage drops to zero and reverses its direction. Then the capacitor starts charging again, but in the same direction in which it was previously discharging.

This continues until the applied voltage again starts to drop, and the events repeat themselves. This alternate charging and discharging, first in one direction, and then in the other, occur during every cycle of the applied AC. An AC current, therefore, flows in the circuit continuously.

It can be said, then, that although a capacitor blocks DC it passes AC.

Voltage and current realtionship: When an AC voltage source is connected across a capacitor, maximum current flows in the circuit the instant the source voltage begins its sinusoidal rise from zero. (Fig 2a)

Fig 2



ENERGY TRANSFER IN A CAPACITOR CIRCUIT

This is because the plates are in neutral state and present no opposing electrostatic forces to the source terminals. Therefore, as you can see by Ohm's Law, if the opposition to the current flow is very, very low, a small applied voltage can cause considerable current to flow.

As the source voltage rises, however, the charges on the capacitor plates, (which result from the current flow) build up. The charge voltage, then, presents an increasing opposition to the source voltage and so the current decreases.

When the source voltage reaches its peak value, the charge voltage across the capacitor plates is maximum. This charge is sufficient to completely cancel the source voltage, so that the current flow in the circuit stops.

As the source voltage begins to decrease, the electrostatic charge on the capacitor plates becomes greater than the potential of the source terminals, and so the capacitor starts to discharge. (Fig 2b)

Is the current flow in the same direction when the voltage decreases?

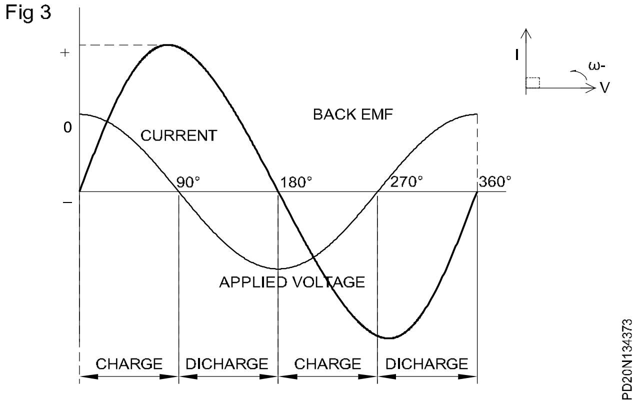
The direction of electron flow is opposite to the direction taken by the electrons during capacitor charging. Thus, at the point that the applied voltage passes through its maximum value and begins decreasing, the current in the circuit passes through zero and changes direction. As can be seen from the graph, this constitutes a 90-degree phase difference, with the current leading the applied voltage.

This 90-degree difference is maintained throughout the complete cycle of applied voltage. When the applied voltage has dropped to zero, the circuit current has increased to its maximum in the opposite direction, and when the voltage reverses the direction, the current begins decreasing. (Fig 2c) Therefore, the voltage applied to a capacitor is said to lag the current through the capacitor by 90 degrees. Or, the current through a capacitor leads the applied voltage by 90 degrees.

Hence the current increases from zero to maximum when voltage starts decreasing from the peak value in the opposite direction to zero. (Fig 2d)

The phase relation between voltage and current in a pure capacitor circuit is shown in the wave-form and vector diagram. (Fig 3)

Fig 3



Capacitive reactance: The opposition offered to the flow of current by a capacitor is called capacitive reactance, and is abbreviated Xc. Capacitive reactance can be calculated by:

$$X_C = \frac{1}{2\pi fC} = \frac{1}{\omega c}$$

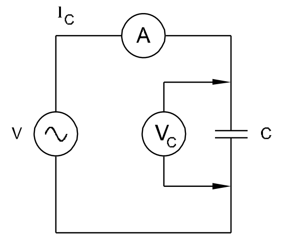
where 2π is approximately 6.28

f is the frequency in Hz

C is the capacitance in farad and $\omega = 2.\pi.f$.

Like its inductive counterpart - inductive reactance, capacitive reactance is expressed in ohms. Ohm's Law can also be applied to a circuit containing capacitive reactance only. (Fig 4)

Fig 4



$V_C = I_c X_c$

$$I_c = \frac{V_c}{X_c}, \qquad X_c = \frac{V_c}{I_c}$$

where, I_c is current through capacitor in amps

V_C is the voltage across the capacitor in volts

X_C is the capacitive reactance in ohms.

Example: A 10 micro-farad capacitor is connected to a 200V 50Hz supply. Find the current taken.

Solution

$$I_c = \frac{V_c}{X_c}, \qquad V_C = V$$

where X_c is the capacitive reactance.

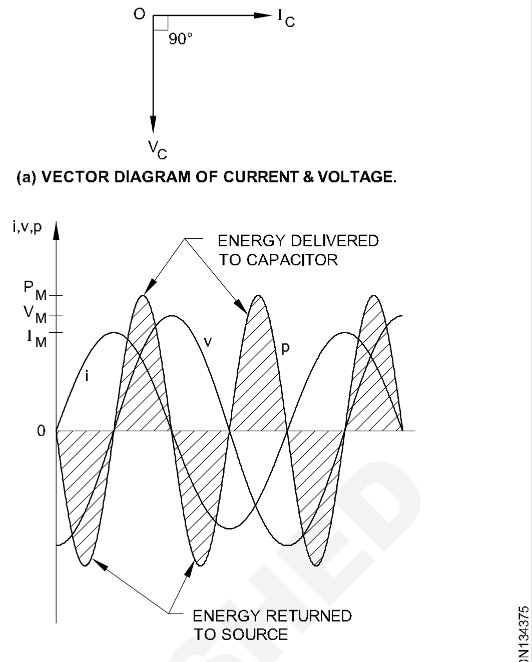
$$X_c = \frac{1}{2\pi fc} = \frac{10^6}{2\pi \times 50 \times 10}$$

$$X_c = \frac{1000}{\pi} = 318.4 \text{ ohms}$$

$$I_C = \frac{200}{318.4} = 0.628 \text{ amps}$$

Power in pure capacitance: For pure capacitance, the voltage and current are 90° out of phase with each other, the current leading as shown by the phase diagram in Fig 5a.

Fig 5



(b) CURRENT, VOLTAGE AND POWER FORMS.

The product of v and i gives a power curve as shown in Fig 5b. We see that the energy delivered to the capacitor and stored in the electric field is represented as a positive quantity. A quarter of a cycle later, all of this energy is returned to the source, as the capacitor discharges. Thus the average true power, P, is zero in a pure capacitance.

However, reactive power P_q is drawn by the capacitor, and the source must be able to supply this power.

For a purely capacitive circuit, the reactive power is given by

$P_q = V_c I_c$ volt-amperes reactive (var)

where

P_q is the reactive power in volt-amperes reactive, var

V_c is the voltage across the capacitance in volts

I_c is the current through the capacitance in amperes.

Since $V_c = I_c X_c$

then $P_q = I_c^2 X_c$ var

and $$P_q = \frac{V_c^{\,2}}{X_c}$$

where X_c is the capacitive reactance in ohms.

Again the equations for reactive and true power are similar with X_c used in place of R. We must use vars, not watts, for the reactive power.

As in the case of pure inductive circuit, the power factor of the pure capacitive circuit is also zero.

Why is it so?

This is because the angle between the current and voltage in a capacitive circuit is 90°. Result $\cos \phi = 0$.

Example: A reactive power of 100 vars is drawn by a 10 micro farad capacitor due to a current of 0.87A. Calculate the frequency.

Solution

$$X_c = \frac{P_q}{I_c^2} = \frac{100 \text{ vars}}{(0.87)^2} = 132 \text{ ohms}$$

Therefore, $f = \frac{1}{2.\pi.X_c.C}$

$$= \frac{1}{2\pi \times 132 \text{ ohms} \times 10 \times 10^{-6}\text{F}}$$

= 120 Hz.

Power and power factor in AC single phase circuit

Objective: At the end of this lesson you shall be able to

- **calculate power and power factor of a single phase AC circuit from the given relevant values.**

Power in pure resistance circuit: Power can be calculated by using the following formulae.

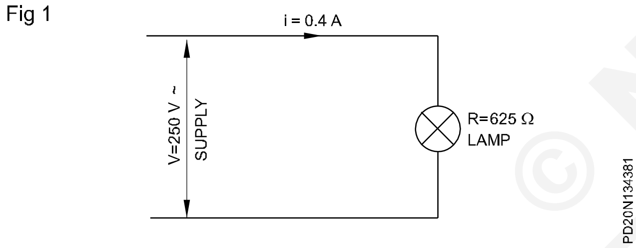
1) $P = V_R x\ I_R$ watts

2) $P = I^2_R\ R$ watts

3) $P = \frac{E^2}{R}$ watts

Example 1: Calculate the power taken by an incandescent lamp rated 250V when it carries a current of 0.4A if the resistance is 625 ohms.(Fig 1)

Fig 1



$P = V_R x\ I_R$

= 250 x 0.4

= 100 watts.

Alternately

$P = I^2R$

= 0.4 x 0.4 x 625

= 100 watts

$$\text{or } P = \frac{E^2}{R} = \frac{250^2}{625}$$

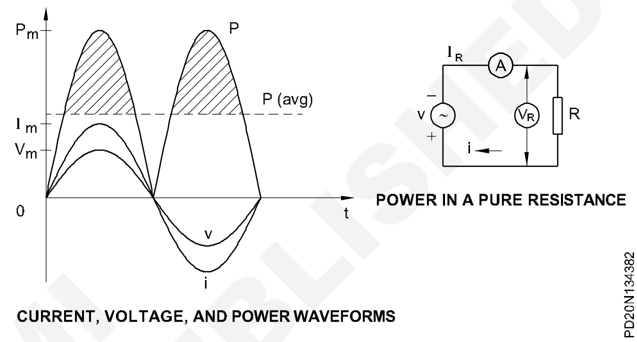
$$P = \frac{250 \times 250}{625}$$

= 100 watts.

Since the current and voltage are in phase, the phase angle is zero and the power factor is unity. Therefore, the power can be calculated with voltage and current itself.

Example 2: A wattmeter connected in an AC circuit indicates 50W. The ammeter connected in series with the load reads 1.5A. Determine the resistance of the load.

Fig 2



Solution

Known: $P = I_R^2R$

The circuit arrangement and wave-forms of I, V and P are shown in Fig 2.

Given: I = 1.5 amperes

P = 50 watts.

Therefore,

$$R = \frac{P}{I^2R} = \frac{50W}{(1.5)^2} = 22.2 \text{ ohms}$$

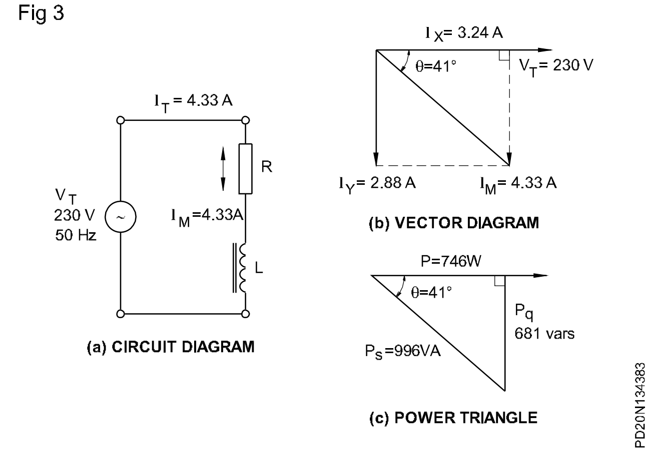
Power in pure inductance: If an AC circuit contains only inductance, the voltage and current are 90° out of phase, and the circuit of the instantaneous values of voltage and current gives with positive and negative power. Net result is the power consumed in a pure inductive circuit is zero.

Power in pure capacitance: If an AC circuit contains only capacitor, the voltage and current are 90°. Out of phase and the product of instantaneous values of voltage and current gives both positive and negative power. Net result is the power consumed in a pure capacitive circuit is zero.

Most industrial installations have a lagging PF because of the large number of AC induction motors that are inherently inductive.

Effect of a low power factor: To show the important effect of the power factor, let us consider a 240V, 50 Hz, 1 hp motor. Let us assume that it is 100% efficient so that it draws a true power of 746 W. Such a motor has a typical power factor of 0.75 lagging. (Fig 3)

Fig 3



To deliver 746 W from 240V at a power factor of 0.75 requires a current of

$$I = \frac{P}{V \times \mathrm{Cos}\,\theta} \; A$$

$$= \frac{746W}{240V \times 0.75} = 4.144 \text{ A}$$

Now let us assume that we can modify the motor in some way to make the power factor unity (I). The current now required is

$$I = \frac{P}{V \times \mathrm{Cos}\,\theta}$$

$$I = \frac{746W}{240V x1} = 3.108A$$

Evidently, it requires a higher current to deliver a given quantity of true power if the power factor of the load is less than unity. This higher current means that more energy is wasted in the feeder wires serving the motor. In fact, if an industrial installation has a power factor less than 85% (0.85) overall, a `power factor penalty' is assessed by the electric utility company. It is for this reason that power factor correction is necessary in large installations.

Power factor correction: In order to make the most efficient use of the current delivered to a load we desire a high PF or a PF that approaches unity.

A low PF is generally due to the large induction loads such as discharge lamps, induction motors, transformers etc. which take a lagging current and produce heat which returns to the generating station without doing any useful work as such it is essential to improve or correct the low PF so as to bring the current as closely in phase with the voltage as possible. That is the phase angle θ is made as small as possible. This is usually done by placing a capacitor load which produces a leading current.

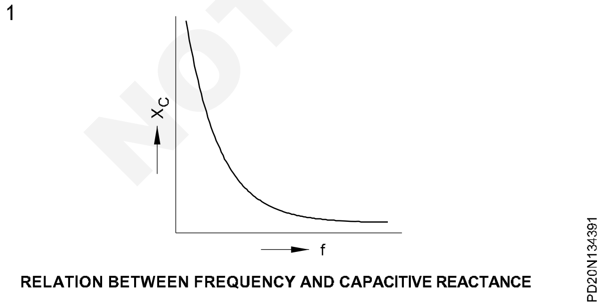
The capacitor is to be connected in parallel with the inductive load.

R - C Series circuit

Objectives: At the end of this lesson you shall be able to
- **state the effect of frequency on X_c in R-C in series circuit**
- **calculate power factor**
- **determine the power factor and phase angle**
- **state the R-C time constant while charging 'C' and dischanging**

In a circuit with capacitance, the capacitive reactance (X_C) decreases when the supply frequency (f) increases as shown in Fig 1.

Fig 1



RELATION BETWEEN FREQUENCY AND CAPACITIVE REACTANCE

$$X_C \propto \frac{1}{f}$$

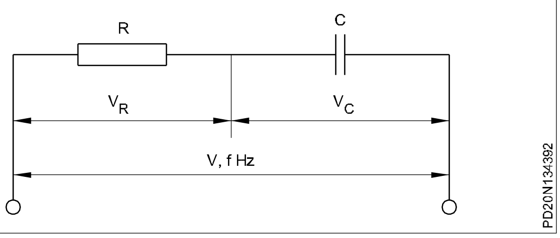
When the capacitive reactance X_C increases the circuit current decreases.

$$I \propto \frac{1}{X_C}$$

Therefore the increase in frequency (f) results in the increase of the circuit current in the capacitive circuit. When resistance (R), capacitance (C) and frequency f are known in a circuit, the power factor cos q can be determined as follows. (Fig 2)

$$X_C = \frac{1}{2\pi fC}$$

Fig 2

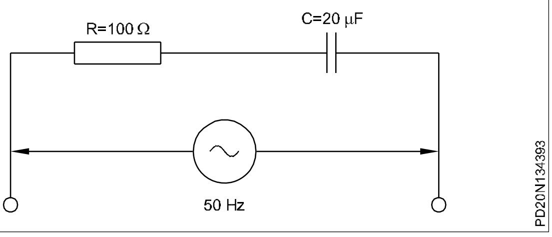


$$Z = \sqrt{R^2 + X_C^2}$$

$$\text{Power factor, } \cos\theta = \frac{R}{Z}$$

Example 1: A capacitance of 20 μ f and a resistance of 100Ω are connected in series across a supply frequency of 50 Hz. Determine the power factor. (Fig 3)

Fig 3



Solution

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2 \times \frac{22}{7} \times 50 \times 20 \times 10^{-6}}$$

$$= \frac{7 \times 10^{-6}}{2 \times 22 \times 50 \times 20}$$

$$= \frac{7000000}{44000}$$

= 159.1 Ω, say 160 Ω.

$$Z = \sqrt{R^2 + X_C^2}$$

$$= \sqrt{10000 + 25600}$$

$$= \sqrt{36600} = 191.3\Omega$$

$$\text{P.F.} = \frac{R}{Z} = \frac{100}{191.3} = -.522$$

Capacitive reactance X_C in a capacitive circuit can be determined with the formula

$$X_C = \frac{1}{2\pi fC}$$

where X_C = capacitive reactance in ohm

f = frequency in Hz

C = Capacitance in farad

Power consumed in a R-C series circuit can be determined using the formula

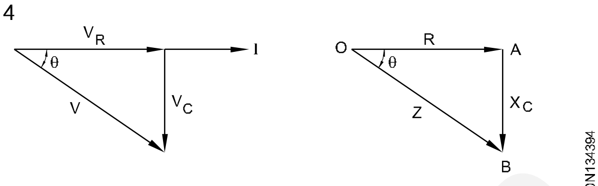
P = VI cos θ where P = power in watts

I = current in ampere

cos θ = power factor.

Vector diagram of voltages and their use to determine pf angle θ. (Fig 4)

Fig 4



a) VOLTAGE TRIANGLE   b) IMPEDENCE TRIANGLE

$V_R = I_R$ drop across R (in phase with I)

$V_C = IX_C$ drop across capacitor (lagging I by 90°)

$$V = \sqrt{V_R^2 + V_C^2} = \sqrt{(IR)^2 + (IX_C)^2} = I\sqrt{R^2 + X_C^2}$$

$$\therefore I = \frac{V}{\sqrt{R^2 + X_C^2}} = \frac{V}{Z}$$

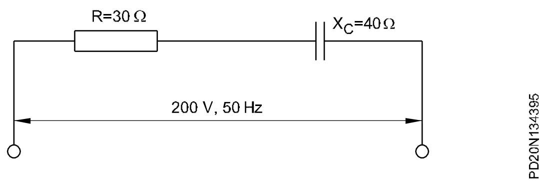
$\therefore Z = \sqrt{R^2 + X_C^2}$ where Z is the impedance of the circuit.

Power factor, cos θ = R/Z.

From pf cos θ the angle θ can be known referring to the Trignometric table.

Example 2: In RC series circuit shown in the diagram (Fig 5) obtain the following.

Fig 5



- Impedance in ohms
- Current in amps
- True power in watts
- Reactive power in var
- Apparent power in volt amp.
- Power factor

Solution

1 Impedence (Z)

$$= \sqrt{R^2 + X_C^2} = \sqrt{30^2 + 40^2} = \sqrt{2500} = 50\Omega$$

2 Current $I = \frac{V}{Z} = \frac{200}{50} = 4A$

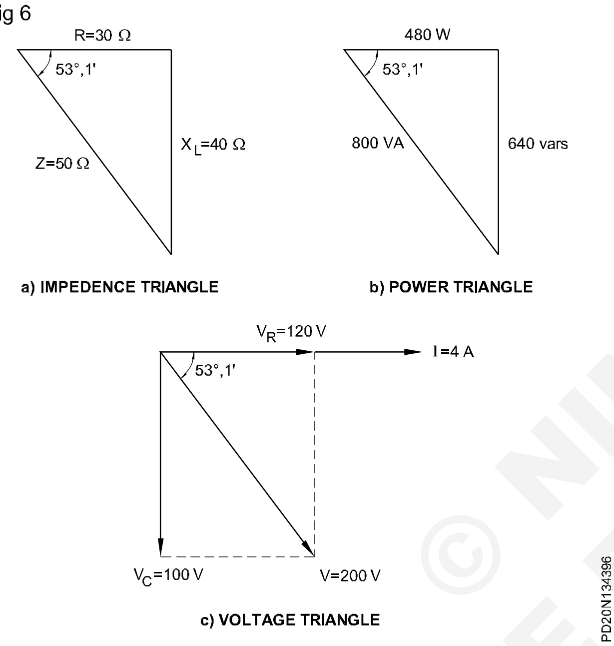
3 True power $W = I^2R = 4^2 \times 30 = 480W$
(Power consumed by capacitoir = zero)
$V_C = IX_C = 4 \times 40 = 160$ V

4 Reactive power $VAR = V_C I = 160 \times 4 = 640$ VAR
Apparent power VI = 200 x 4 = 800 VA

$$PF \square \cos\theta = \frac{R}{Z} = \frac{30}{50} = 0.6$$

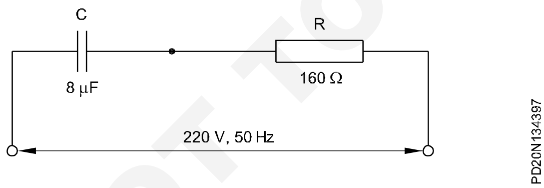
The impedance triangle, power triangle and voltage triangle for exercise 2 are showm in Fig 6

Fig 6



Example 3: An 8 μf capacitor is connected in series with an ohmic resistance of 160 Ω. A voltage of 220V AC, 50 Hz is applied to the circuit (Fig 7)

Fig 7



Calculate

a) the capacitive reactance

b) the impedance

c) the current

d) the active power

e) the reactive power.

Solution

a) $X_C = \frac{1}{2\pi fC} = \frac{10^6}{314 \times 8} = 400\Omega$

b) $Z = \sqrt{R^2 + X_C^2} = \sqrt{160^2 + 400^2}$

$= \sqrt{185600} = 430\,\Omega$

c) $I = \frac{V}{Z} = \frac{220}{430} = 0.51A$

d) $W = I^2R = 0.51^2 \times 160 = 41.62W$

e) VAR = V x I Sin θ = 220 x 0.51 x 0.9291

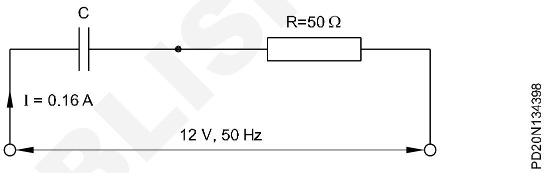
= 102.2 VAR

$$\cos\theta = \frac{R}{Z} = \frac{160}{430} = 0.37$$

(θ = 18°18',Referring to the sine table,

sin θ = sin 18°18' = 0.9291.

Fig 8



Example 4: In the circuit shown in Fig 8, calculate a) the capacitive reactance and b) the capacitance of the capacitor.

Solution

$V_R = IR = 0.16 \times 50 = 8V$

$$V_C = \sqrt{V^2 - V_R^2} = \sqrt{12^2 - 8^2} = \sqrt{80} = 9V \text{ (App)}$$

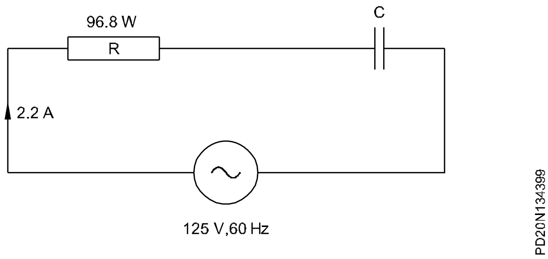
$$X_C = \frac{V}{I} = \frac{9}{0.16} = 56\Omega$$

$$X_C = \frac{1}{2\pi fC}$$

$$C = \frac{1}{2\pi fX_C} = \frac{1}{314 \times 56} = \frac{10^6}{314 \times 56} = 57\,\mu F$$

Example 5: A voltage of 125V at 60Hz is applied across a non-inductive resistance connected in series with a condenser. The current in the circuit is 2.2A. The power loss in the resistor is 96.8W and that in the condenser is negligible. Calculate the resistance and capacitance. (Fig 9)

Fig 9



Solution : Power loss I^2R = 96.8W

$$\therefore R = \frac{96.8}{I^2} = \frac{96.8}{2.2^2} = 20\Omega$$

Impedence $Z = \frac{V}{I} = \frac{125}{2.2} = 56.82\Omega$

Capacitance reactance $X_C = \sqrt{Z^2 - R^2}$

$$= \sqrt{56.82^2 - 20^2}$$

$$= 53.2\Omega$$

$X_C = 1 / (2\pi fC)$

$2\pi fC = 1 / X_C$

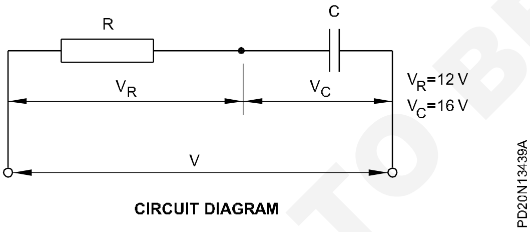
2 x 3.14 x 60 x C = 1/53.2

C = 1 / (53.2 x 2 x 3.14 x 60)

= 0.00005 F = 50 mF

Example 6: In the circuit shown (Fig 10)

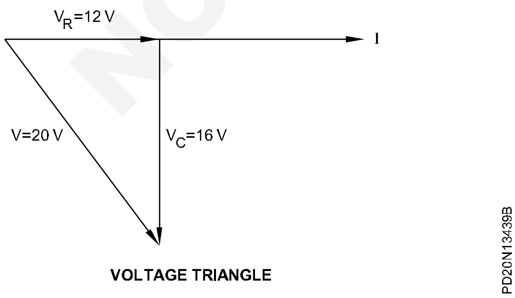
Fig 10



a) calculate the voltage V

b) draw the voltage triangle (Fig 11).

Fig 11



Solution

a) $V = \sqrt{V_R{}^2 + V_C{}^2} = \sqrt{12^2 + 16^2} = \sqrt{144 + 256}$

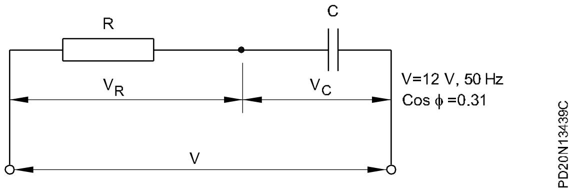
$= \sqrt{400}$ = 20V

Example 7: In the circuit shown, Fig 12 calculate

a) the resistor voltage

b) the capacitor reactance voltage.

Fig 12



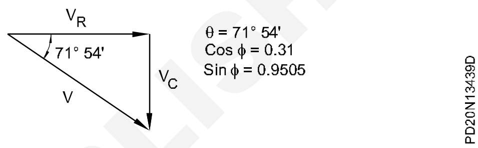
Solution

a) V_R = V cos θ = 12 x 0.31 = 3.72V

b) V_C = V sin θ = 12 x 0.9595 x 11.4V

Vector diagram Fig 13

Fig 13



'Time constant': One time constant is that time in seconds required for a completely discharged capacitor to charge 63% of the source voltage (charging voltage).

τ = R x C

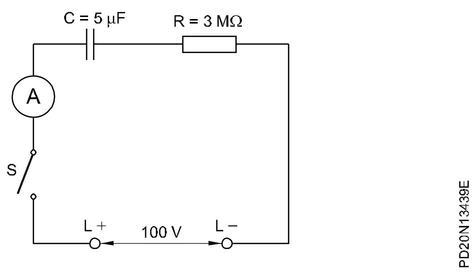
where τ = one time constant in seconds

R = resistance in ohms

C = capacitance in farad.

As shown in the (Fig 14), if

Fig 14



C= 5 μF, R = 3 M Ω, then

$\tau = 5 \times 10^{-6} \times 3 \times 10^{6}$ = 15 seconds

charging voltage = 100 V

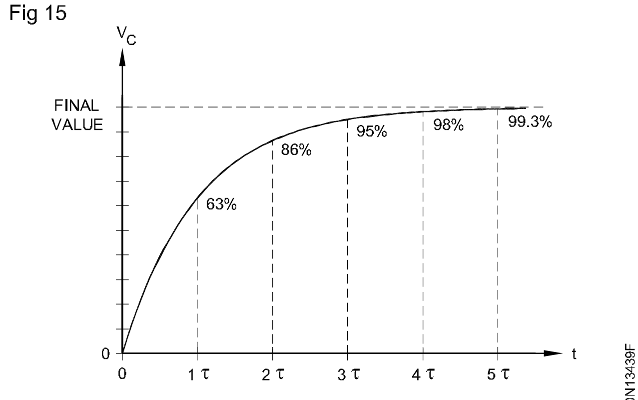
one time (τ) constant = 15 seconds. V_e= 63V

After 5 time constant a capacitor is 99.3% charged, for practical purposes it is taken that the capacitor is fully charged. A capacitor charges in 5 time constant.

A charging curve is shown in Fig 15.

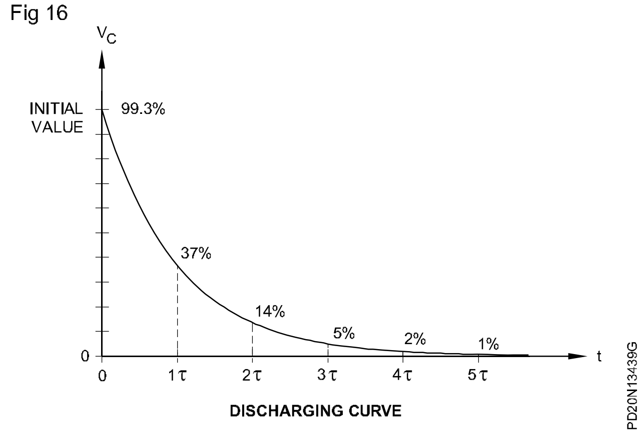
During discharging, a fully charged capacitor discharges in five time constant. A discharging curve is shown in Fig 16.

Fig 15



CHARGING CURVE

Fig 16



DISCHARGING CURVE

τ (sec)	**Time taken** (V)	**Charging voltage plates** (V)	**Voltage across the capacitor**
At the time of switching on		100	0
1τ	15	63% of 100 = 63	0 + 63 = 63
2τ	30	63% of (100-63) = 23.3 say 23	63 + 23 = 86
3τ	45	63% of 100-86) = 8.82 say 9	86 + 9 = 95
4τ	60	63% of (100-95) = 3.15 say 3	95 + 3 = 98
5τ	75	63% of (100-98) = 1.26 say 1.3	98 + 1.13 = 99.3

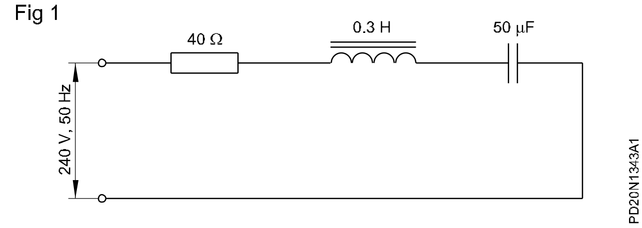
R L C series circuit

Objectives: At the end of this lesson you shall be able to
- **calculate the resultant reactance and impedance of the RLC series circuit**
- **state the impedance, voltage and power triangle.**
- **explain the necessary conditions for series resonance.**

Assume an AC single phase circuit consisting a resistance, inductor and capacitor in series. Various parameters could be calculated as shown in the example.

Example : The value of the components shown in Fig 1 is R = 40 ohms L = 0.3 H and C = 50μf. The supply voltage is 240 V 50 Hz. Calculate the inductive reactance, capacitance reactance, net reactance, impedance, current in the circuit, voltage drops across the R, L and C power factor, active power, reactive power and apparent power. Also draw the impedance triangle, voltage triangle and power triangle.

Fig 1



Calculate the resultant reactance in RLC circuit : Inductance and capacitance have directly opposite effects in an AC circuit. The voltage drop caused by the inductive reactance of the coil leads the line current by 90°. The voltage drop across the inductor coil and the capacitor are 180 degrees apart and oppose each other. To calculate the net reactance in the above example:

Inductive reactance

X = 2πfL = 314 x 0.3 = 94.2Ω

Capacitive reactance

$$X = \frac{1}{2\pi fC} = \frac{1}{314 \times 0.00005} = \frac{1}{0.0157} = 63.69\,\Omega$$

Net reactance - X_L - X_C = 94.2 - 63.69 = 30.51Ω

Calculate the impedance: From the circuit given above the impedance can be found. The impedance is the resultant combination resistance and reactance. In this circuit, the impedance is the combination of the 40 ohms resistance and 30.51 Ω resultant reactance. The impedance for this circuit is

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{40^2 + 30.51^2}$$

$$= \sqrt{1600 + 930.86} = \sqrt{2530.86} = 50.30\,\Omega$$

Draw the impedance triangle: Draw the horizontal line (X axis) indicating the circuit current.

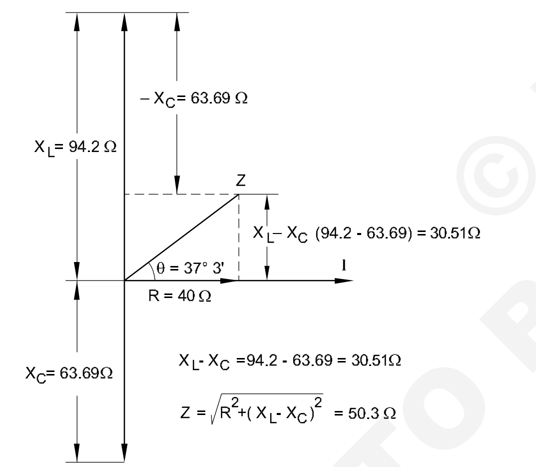
Draw along with current vector the value of R to a suitable scale i.e. 1cm = y ohm.

draw the vertical line perpendicular to the current vector in +y axis indicating the value of inductive reactance to the scale selected (1cm = y ohm)

draw a vertical the perpendicular to the current vector in _y axis indicating the value of capacitive reactance to the scale selected (1cm = y ohm).

Substract the value of X_C from, X_L as shown in Fig 2 the net reactance value is equal to 30.51 ohms. Complete the vectors by closing the parallelogram the reactance of the parallelogram is the impedance of the series RLC circuit.

Fig 2



IMPEDENCE TRIANGLE

Mathematically what we determined the values of net reactance and impedance could also be determined by the above vectorial method.

Measurement of current and voltage drop in RLC circuit. The voltage drop across R = E_R across L = E_L and drop across C = E_C and the formula for finding their values and given below.

$E_R = IR$

$E_L = IX_L$

$E_C = IX_C$

Current in given RLC series circuit: Current in this series circuit is $I = E/Z = 240/50.3 = 4.77$ amps.

Identifying whether the current flow is leading or lagging the voltage in a RLC series circuit: As this is a series circuit, the current is the same in all parts of the circuit, but the voltage drop across the resistor, the inductor coil and capacitor are

$E_R = IR = 4.77 \times 40 = 190.8$ volts

$E_L = IX_L = 4.77 \times 94.2\,\Omega = 449.33$ volts

$E_C = IX_C = 4.77 \times 63.69 = 303.80$ volts.

The vector sum of the voltage of 190.8 volts across the resistor and 145.53 volts across the net reactance of 30.51Ω is equal to the line voltage of 240 volts as shown below.

$$E = \sqrt{E^2R + (E_L - E_C)^2}$$

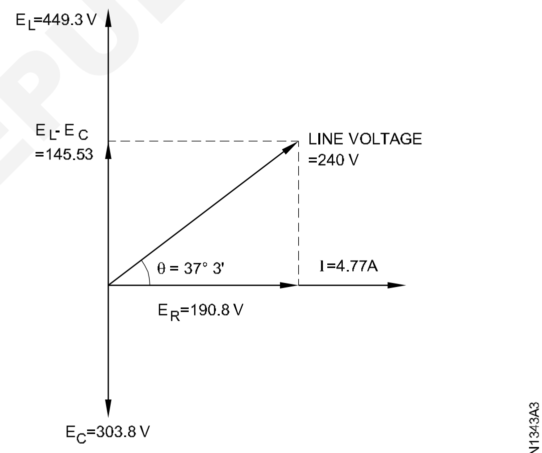
$$= \sqrt{190.8^2 + (449.33 - 303.80)^2}$$

$$= \sqrt{190.8^2 + 145.53^2}$$

E = 240 volts.

The voltage vector diagram could be drawn as shown in Fig 3.

Fig 3



VECTOR DIAGRAM

In this type of series circuit, the current is used as a horizontal reference line. The voltage value of 145.53 volts across the portion of the inductive reactance which is not cancelled out by the voltage across the capacitive reactance. The PF = E_R/E = 190.8/240 = 0.795 lag or PF = R/Z = 40/50.30 = 0.795 lag PF. In this circuit the phase angle is 37.3° lagging. This means that current lags the line voltage.

In an RLC series circuit, if X_L is greater then the voltage appearing across the inductor is high and that can be found out by IX_L. In the same way if the X_C value is greater in an RLC series circuit, the voltage appearing across the capacitor is more and can be found out by IX_C.

In the example given above, the voltage drop across resistance 40 Ω = 190.8 volts.

Voltage drop across inductance 0.3 H = 449.33 volts. Voltage drop across capacitor of 50 mf = 303.80 volts.

From these values it is clear that the voltage drop across the inductor and capacitor is higher than the supply voltage. Hence while connecting the meter to measure the voltage drop across inductor and capacitor it should be noted that the range of this should be high (in this case 0 - 500 volts)

Calculate the power factor: Power factor of the RLC series circuit can be found from the impedance triangle or voltage triangle as shown below

$$\text{Power factor} = \cos\theta = \frac{R}{Z} \text{ or } \frac{E_R}{V}$$

$$\text{Power factor} = \frac{R}{Z} = \frac{40}{50.3} = 0.795$$

$$= \frac{E_R}{V} = \frac{190.8}{240} = 0.795$$

Calculate the active power (R_A): Active power can be calculated by using any one of the formulae given below

$P = EI \cos\theta = I^2R$

$= EI \cos\theta = 240 \times 4.77 \times 0.795$

= 910 walts

$= I^2R = 4.77^2 \times 40$

= 910 watts.

Calculate the reactive power P_q: Reactive power can be calculated using the formula

$P_q = EI \sin\theta$ Vars

$= 240 \times 6.77 \times 0.6074$

= 695 Vars

$\cos\theta = 0.795$

$\theta = 37°3'$

$\sin\theta = \sin 37°3'$

$= 0.6074$

Calculate the apparent power (P_{APP}): Apparent power can be calculated using the formula

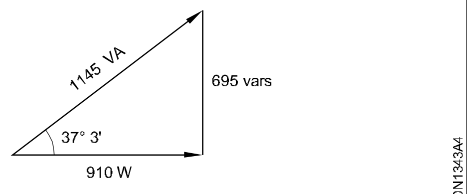
$P_{APP} = EI$ volt-amperes

$= 240 \times 4.77$

= 1145 Volt-amperes.

Draw the power triangle: Power triangle is shown in Fig 4.

Fig 4



POWER TRIANGLE

Resonance circuit: When the value of X_L and X_C are equal, the voltage drop across them will be equal and hence they cancel each other. The value of voltage drops V_L and V_C may be much higher than the applied voltage.

The impedance of the circuit will be equal to the resistance value. Full value of applied voltage appears across R and the current in the circuit is limited by the value of resistance only. Such circuits are used in electronic circuits like radio/TV turning circuits. When $X_L = X_C$ the circuit is said to be in resonance.

As current will be maximum in series resonant circuits it is also called acceptor circuits. For a known value of L and C the frequency at which this occurs is called as resonant frequency. This value can be calculated as follows when $X_C = X_L$

$$2\pi fL = \frac{1}{2\pi fC}$$

$$\text{Hence resonant frequency } f = \frac{1}{2\pi\sqrt{LC}}$$

Power factor angle is commonly denoted by Theta θ. In some pages of this text it is denoted by Phi ϕ. As such these terms are used alternatively in this text.

Power, energy and power factor in AC single phase system - Problems

Objectives: At the end of this lesson you shall be able to
- **state the relationship between power and power factor in single phase circuits**
- **state the connection diagram for measuring power factor using a direct reading meter.**
- **calculate the problem related to P.F and power in A.C circuits**

The power in a DC circuit can be calculated by using the formulae.

- $P = E \times I$ watts
- $P = E^2/R$ watts.

The use of the above formulae in AC circuits will give true power only if the circuit contains pure resistance. Note that the effect of reactance is present in AC circuits.

Power in AC circuit: There are three types of power in AC circuits.

- Active power (True power)
- Reactive power
- Apparent power

Active power (True power)**:** The calculation of active power in an AC circuit differs from that in a direct current circuit. The active power to be measured is the product of $V \times I \times \cos\theta$ where $\cos\theta$ is the power factor (cosine of the phase angle between current and voltage).This indicates that with a load which is not purely resistive and where the current and voltage are not in phase, only that part of the current which is in phase with the voltage will produce power. This can be measured with a wattmeter.

Reactive power (P_r): With the reactive power (wattless power)

$$P_r = V \times I \times \sin\theta$$

only that part of the current which is 90° out of phase (90° phase shift) with the voltage is used in this case. Capacitors and inductors, on the other hand, alternatively store energy and return it to the source. Such transferred power is called reactive power measured in volt/ampere reactive or vars. Unlike true power, reacitve power can do no useful work.

Apparent power: The apparent power, $P_a = V \times I$.

The measurement can be made in the same way as for direct current with a voltmeter and ammeter.

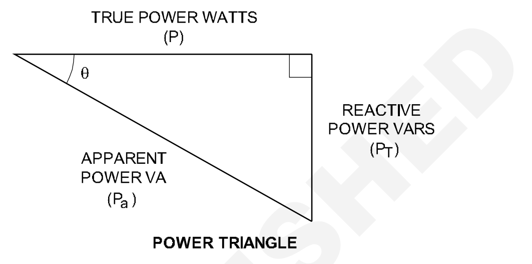
It is simply the product of the total applied voltage and the total circuit current and its unit is volt-ampere (VA).

The power triangle: A power triangle identifies three different types of power in AC circuits.

- True power in watts (P)
- Reactive power in vars (P_r)
- Apparent power VA (P_a)

The relationship among the three types of power can be obtained by referring to the power triangle. (Fig 1)

Fig 1



POWER TRIANGLE

Therefore

$P_a^2 = P^2 + P_r^2$ volt-amperes (VA)

where `P_a' is the apparent power in volt-ampere (VA)

`P' is the true power in watts (W)

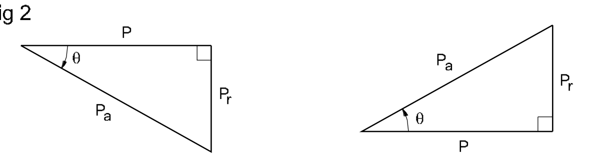
P_q is the reactive power in volt-amperes reactive. (VAR)

Power factor: The ratio of the true power delivered to an AC circuit compared to the apparent power that the source must supply is called the power factor of the load. If we examine any power triangle (Fig 2), you may see the ratio of the true power to the apparent power is the cosine of the angle θ.

$$\text{Power factor} = \frac{P}{P_a} = \cos\theta$$

From the equation, you can observe that the three powers are related and can be represented in a right-angled power triangle, from which the power factor can be obtained as the ratio of true power to apparent power. For inductive loads, the power factor is called lagging to distinguish it from the leading power factor in a capacitive load. (Fig 2)

Fig 2



(a) POWER TRIANGLE FOR A SERIES OR PARALLEL RL CIRCUIT.

(b) POWER TRIBNGLE FOR A SERIES OR PARALLEL RC CIRCUIT.

POWER TRIANGLES SHOWING THAT $\frac{P}{P_a}$ =COS θ

A circuit's power factor determines how much current is necessary from the source to deliver a given true power. A circuit with a low power factor requires a higher current than a unity power factor circuit.

Single phase energy

The product of true power and time is known as energy.

(ie) Energy = T.Power x time

= Voltage x current x power factor x time

= VI Cos θ x t (time is in hour)

The unit of energy is watt hour and commercial unit is represented in 'KWH' (or) unit. (Board of trade unit. B.O.T)

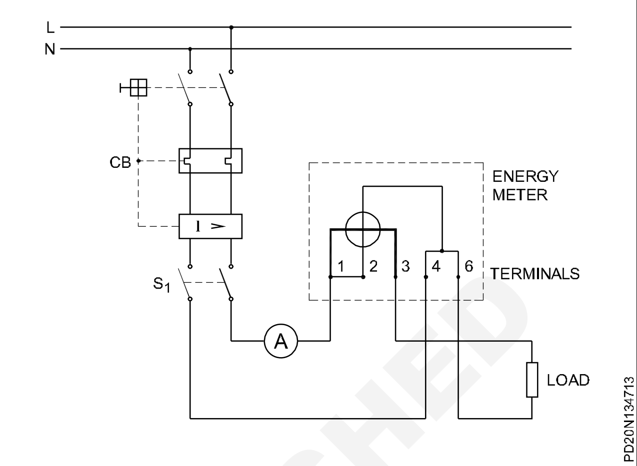
The energy depends upon the following factors:

- Voltage
- Current
- Power factor (load)
- Time

Single phase energy can be measured by energy meter. It contains 4 terminals (Incoming 2 and outgoing 2 common neutral)

The connection is shown in Fig 3.

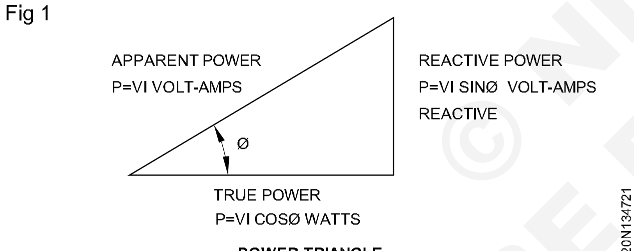
Fig 3



Power in AC circuit having R L and C in series

As we have already studied, the power triangle has three components as shown in Fig 1.

Fig 1



POWER TRIANGLE

The above formula could be used in any AC single phase circuit. But the value of capacitive reactance and the inductive reactance decides whether the circuit is capacitive or inductive. When the value of the capacitive reactance is more than the value of inductive reactance, the PF will be leading or vice versa.

A series AC circuit consisting of 100 ohms, an inductance of 0.2 H and a capacitance of 120 µF are connected across 200 V 50c/s. Calculate the impedance, current, power factor and power absorbed.

The capacitive reactance = 1/ 2πfc ohms.

$$X_C = \frac{1 \times 10^6}{2 \times \pi \times 50 \times 120} = 26.53 \text{ ohms}$$

The inductive reactance

X_L = 2πfL.

X_L = 2 x π x 50 x 0.2 = 62.83 ohms.

Therefore, $X_L - X_C$ = 62.83 – 26.53 = 36.30 ohms.

The impedance = $\sqrt{R^2 + (X_L - X_C)^2}$

$$= \sqrt{100^2 + (62.83 - 26.53)^2}$$

$$= \sqrt{100^2 + (36.3)^2} = 106.4\text{ohms}$$

$$\text{The current} = \frac{\text{Voltage}}{\text{Impedence}} = \frac{200}{106.4} = 1.88\text{A}$$

$$\text{The power factor} = \frac{R}{Z} = \frac{100}{106.4} = 0.94 \text{ (lagging)}$$

As the value of X_L is greater than that of X_c the circuit is having a lagging PF.

The power absorbed = V I cos θ

= 200 x 1.88 x 0.94 = 353.4 W.

Example 1

Calculate the current and its power factor when a resistance of 10 ohms, an inductance of 0.1 H and a condenser of 100µF capacitance are connected in series across 220 V 50 c/s supply mains.

Solution

R = 10 ohms

L = 0.1 H

C = 100 µF

X_C = 1/ 2πfC

$$X_C = \frac{10^6}{2 \times 3.14 \times 50 \times 100}$$

= 31.85 ohms.

$X_L = 2\pi FL$

= 2 x 3.14 x 50 x 0.1

= 31.4 ohms.

$X = X_C - X_L = 31.85 - 31.4$

= 0.45 ohms.

$$Z = \sqrt{10^2 + (0.45)^2} = 10 \text{ ohms (approx.)}$$

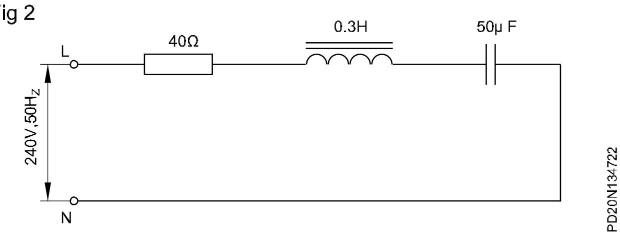
I = 220/ 10 = 22 A

PF = cos θ = R/Z = 10/10 = 1.Unity PF approx.

Example 2

In the circuit given in Fig 2.

Fig 2



Calculate:-

a the resulting reactance

b the impedance

c the current

d voltage drop across R,L&C

e draw the vector diagram

f Compare the calculated supply voltage with the applied supply voltage

g power factor

h power factor angle.

Solution

a Inductive reactance

$X_L = 2\pi fL = 2 \times 3.14 \times 50 \times 0.3 = 94.2$ ohms

$X_C = 1/2\pi fC$

$$X_C = \frac{1}{2\pi \times 50 \times 50 \times 10^{-6}} = \frac{10^6}{15714} = 63.69 \text{ ohms}$$

Net reactance = $X_L - X_C$ = 94.2 – 63.69 = 30.51 ohms.

The impedance for this circuit is Z

b $$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{40^2 + (30.51)^2}$$

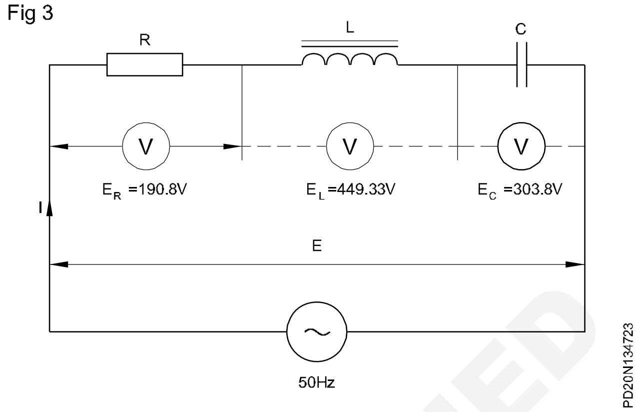
$$= \sqrt{1600 + 930.86} = \sqrt{2530.86} = 50.30 \text{ ohms}$$

c Current in given RLC series circuit

Current in this series circuit is I = E/ Z = 240/50.3= 4.77 amps.

d Voltage drop across R, L and C. (Fig 3)

Fig 3



E_R = IR = 4.77 X 40 = 190.8 volts

$E_L = IX_L$ = 4.77 X 94.2 ohms = 449.33 volts

$E_C = IX_C$ = 4.77 X 63.69 = 303.80 volts.

The vector sum of the voltage of 190.8 volts across the resistor and the difference between the drops across inductor and the capacitor ($E_L - E_C$) 145.53 volts is equal to the line voltage of 240 volts where

$$E = \sqrt{E_R^2 + (E_L - E_C)^2} = \sqrt{190.8^2 + (449.33 - 303.80)^2}$$

Therefore E = 240 volts.

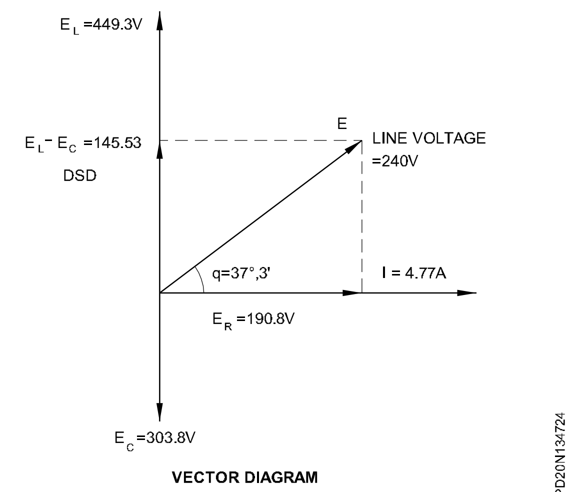
e Vector diagram is shown in Fig 4.

f The calculated voltage and the applied voltages are equal i.e say 240V

g The power factor Cos θ = E_R/ E = 190.8/240 = 0.798.

h The power factor angle is 37°3'.(Refer to Natural cosine table.)

Fig 4



Application

These AC circuits having R, L and C in series are used in electronic tuning circuits in radio or TV to select the desired station/channel. A variable condenser called gang condenser is used to change the value of X_C equal to X_L at a desired station/channel frequency allowing only resistance in the circuit which, in turn, allows maximum current to flow in the circuit.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

when $X_L = X_C$

Z = R

Current I = V/ R which is maximum.

At this condition the circuit is said to be resonant.

The frequency at resonance

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

as $X_L = X_C$

$2\pi f_R L = 1/2\pi/RC$

Hence

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

AC Parallel circuit problem

In practice all industrial and domestic electrical circuits are connected in parallel as we follow the constant voltage system. In a parallel circuit, the voltage across any branch circuit is the same as the supply voltage. However, the arithmetical sum of the branch currents does not necessarily equal the total current. This is true because the branch current values may be out-of-phase due to the fact that the loads connected may be resistive, inductive, (V lead I) or capacitive (I lead V).

Therefore, the total current must be obtained by adding or subtracting vectors of the branch currents either mathematically (admittance method) or graphically (vector method).

Vector method of solving AC parallel circuit

While drawing vectors for the AC parallel circuit, the following rules need to be followed.

i Draw the line voltage as the horizontal reference line as this voltage is the same across all branch circuits (X axis).

ii Draw the current in the pure resistive branch circuit in phase with the reference vector (X axis) to a scale.

iii Draw the current in the pure inductive branch circuit at 90° lagging the reference vector (Y axis) to the same scale as in I .

iv Draw the current in the pure capacitive branch circuit at 90° leading the reference vector (Y axis) to the same scale as in I.

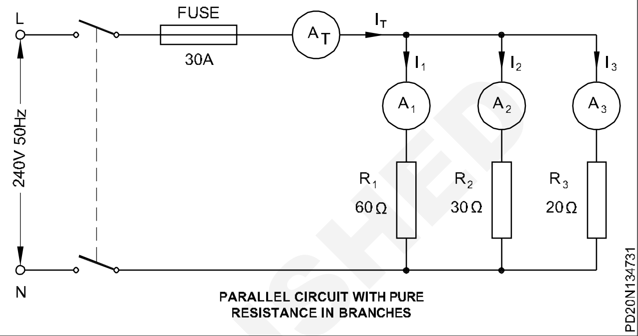
v Use vector subtraction and addition methods to obtain the total current.

Example 1

Parallel circuit with pure resistance

Let us consider an AC parallel circuit having three branches of pure resistance as shown in Fig 1.

Fig 1



Determine the following for the circuit shown in Fig 1.

i The current taken by each branch (I_1, I_2 & I_3).

ii Vector diagram of branch currents and voltage.

iii The line current I_T.

iv The combined resistance.

v The power factor angle and the power factor.

vi The total power taken by the parallel circuit.

solution

i The branch current $I_1 = \frac{V}{R_1}$

$$= \frac{240}{60} = 4 \text{ amps}$$

Pure resistive, hence, in phase with the voltage.

The branch current $I_2 = \frac{V}{R_2}$

$$= \frac{240}{30} = 8 \text{ amps}$$

Pure resistive, hence, in phase with the voltage.

The branch current $I_3 = \frac{V}{R_3}$

$$= \frac{240}{20} = 12 \text{ amps}$$

Pure resistive, hence, in phase with the voltage.

ii Now draw the vector diagram following the rules mentioned above.

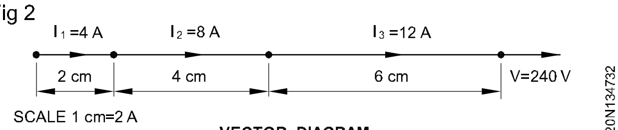
Decide a scale 1cm = 2 amps. (Fig 2)

iii Total current I_T is the sum of the branch currents I_1, I_2 and I_3 as they are in phase with each other.

$I_T = I_1 + I_2 + I_3$

$= 4 + 8 + 12 = 24$ amps.

Fig 2



VECTOR DIAGRAM

iv As all branches have pure resistance load, the total resistance R_T is equal to the total impedance Z.

The total resistance $R_T = Z = \dfrac{V}{I_T}$

$= \dfrac{240}{24} = 10$ ohms.

v The power factor angle between the applied voltage and the current is found to be zero as per the vector diagram.

Power factor angle = 0

Power factor = cos ø

= cos 0 = 1 unity.

vi Total power taken by the circuit

$I_T^2 R_T = VI_T \cos ø = 24^2 \times 10$

$= 240 \times 24 = 5760$ watts.

(Total current I_T is in phase with the voltage.)

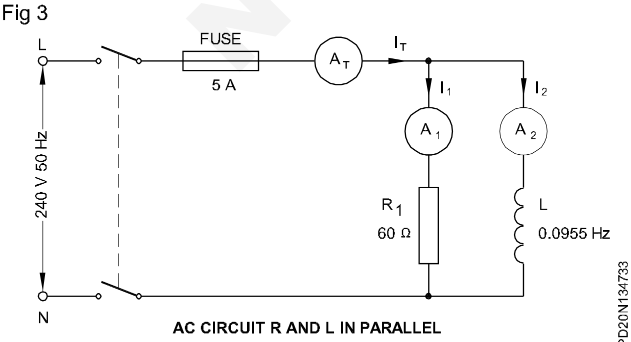
Example 2

Parallel circuit with R and X_L in branches

Now consider a parallel circuit having one branch consisting of a pure resistance and the other branch having pure inductance.

Determine the following for the circuit shown in Fig 3.

Fig 3



AC CIRCUIT R AND L IN PARALLEL

i The branch currents.

ii Draw the vector diagram.

iii The total current.

iv The power factor angle and the power factor.

v The combined impedance.

vi The power in the circuit.

SOLUTION

i The branch current $I_1 = \dfrac{V}{R_1}$

$= \dfrac{240}{60} = 4$ amps

Pure resistive, hence, in phase with the voltage.

To calculate the branch current I_2 first find out the inductive reactance X_L.

$X_L = 2\pi FL = 2 \times \dfrac{22}{7} \times 50 \times 0.0955$

$= 30$ ohms.

So the branch current $I_L = \dfrac{V}{X_L} = \dfrac{240}{30} = 8$ amps.

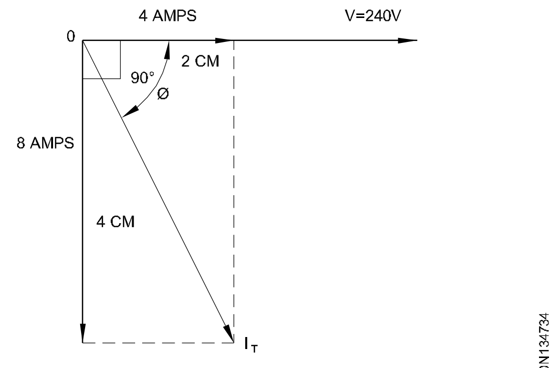
Pure inductive, hence, lags the applied voltage by 90°.

ii Draw the vector diagram by following the rules: Scale 1 cm = 2 amps. (Fig 4)

Complete the parallelogram to find the total current I_T.

Measure the angle ø and the length of $0I_T$.

Fig 4



VECTOR DIAGRAM - R AND L IN PARALLEL

iii Measured angle is 63º 26’

Power factor = Cos 63º 26’

= 0.447 lagging.

iv Length of $0I_T$ = 4.47 cm.

Hence, I_T = 4.47 x 2 = 8.94 amps.

The combined impedance of the circuit = Z.

v Power taken by the circuit

$P = VI \cos ø = I_1^2R$

= 240 x 8.94 x 0.447 = 4^2 x 60

= 959 watts approx. 960 watts.

Example 3

Parallel circuit with R and X_C

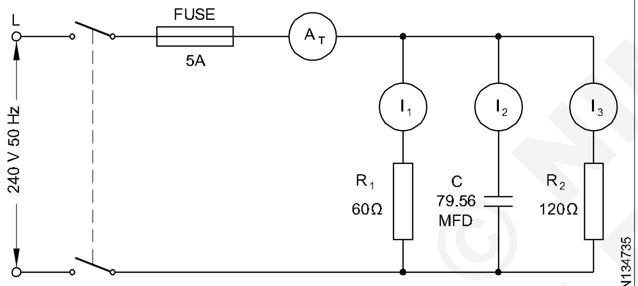
Now consider a parallel circuit having pure resistance in two branches and a pure capacitance in the third branch.

Find the following for the circuit shown in Fig 5.

i The branch currents.

ii Vector diagram of the branch currents.

Fig 5



AC CIRCUIT - R, L AND C IN PARALLEL

iii Total current I_T.

iv Power factor angle.

v Power factor.

vi Power in the circuit.

Solution

i The branch current $I_1 = \frac{V}{RI} = \frac{240}{60}$ = 4 amps

Pure resistive, hence, in phase with the voltage.

To calculate the branch current I2 first find out the capacitive reactance X_C.

$$X_C = \frac{1}{2\pi FC} = \frac{1}{2 \times 3.142 \times 50 \times 79.56 \times 10^{-6}} = 40\Omega$$

So the branch current $I_2 = \frac{V}{X_C} = \frac{240}{40}$ = 6 amps

Pure capacitive, hence, current leads the applied voltages by 90º.

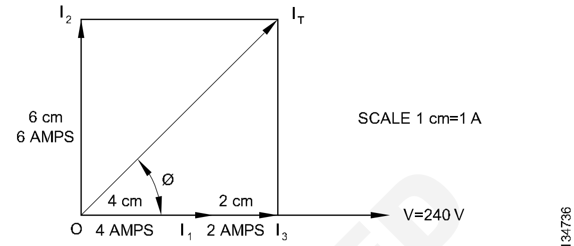
The branch current $I_3 = \frac{V}{R} = \frac{240}{120}$ = 2 amps

ii Draw the vector diagram to scale.

Complete the parallelogram to find the total current I_T. (Fig 6)

iii Measured length OI_T = 8.5cm.

Fig 6



VECTOR DIAGRAM - R, L AND C IN PARALLEL

Total current I_T. = 8.5 x 1 = 8.5 amps.

iv Measure the angle between the total current and the voltage.

Measured angle θ = 45º leading.

v Power factor cos ø = cos 45º = 0.707.

vi Power taken by the circuit.

$P = VI \cos \theta = (I_1^2R_1 + I_3^2R_2)$ = 240 x 85 x 0.707

= (4^2 x 60 + 2^2 x 120)

1442 approx.1440 watts.

Example 4

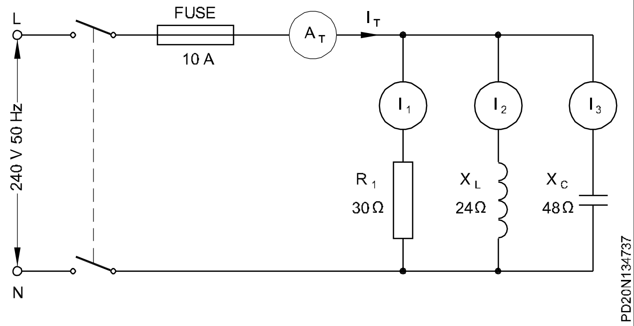
Parallel circuit with R, X_L and X_C

Now consider a parallel circuit having pure resistance in one branch, pure inductance in the 2nd branch and a pure capacitance in the 3rd branch as shown in Fig 7.

Find the following for the circuit shown in Fig 7.

i The branch currents.

Fig 7



ii The vector diagram.

iii Total current I_T.

iv Power factor angle.

v Power factor.

vi Power taken by the circuit.

vii Impedance of the circuit.

SOLUTION

i The branch current

$$I_1 = \frac{V}{R_1} = \frac{240}{30} = 8 \text{ amps in phase with V.}$$

The branch current

$$I_2 = \frac{V}{X_L} = \frac{240}{24} = 10 \text{ amps lagging 'V' by } 90^\circ.$$

The branch current

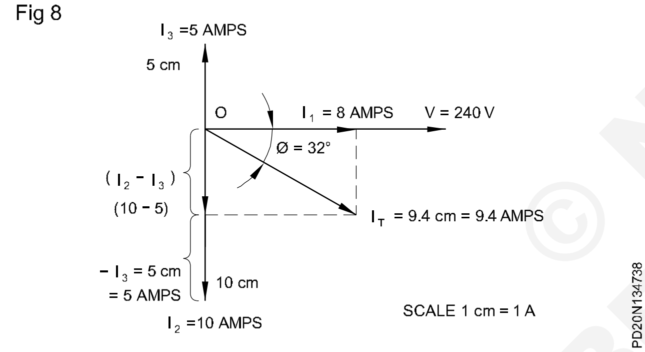
$$I_3 = \frac{V}{X_C} = \frac{240}{48} = 5 \text{ amps leading 'V' by } 90^\circ.$$

ii Draw the vector diagram to scale.

Scale 1 cm = 1 ampere

Complete the parallelogram to find the total current I_T (Fig 8).

Fig 8



iii Measured OI_T = 9.4 cm.

Total current

I_T = 9.4 x 1 = 9.4 amps.

iv Measure the angle between voltage and the total current.

Measured angle = 32º lagging.

v Power factor cos θ = cos 32º = 0.85.

vi Power taken by the circuit

$$VI \cos\theta = I_1^2 R$$

$$= 240 \times 9.4 \times 0.85 = 8^2 \times 30$$

$$= 1918 \text{ approx. } 1920 \text{ watts.}$$

vii Combined impedance Z

$$Z = \frac{V}{I_T} = \frac{240}{9.4} = 25.5 \text{ ohms}$$

Admittance method of solving AC parallel circuit

In solving problems in AC circuit of parallel groups either the vector or the admittance method could be used. However, there will be considerable difficulty in solving problems by vector method if series parallel combination groups are to be dealt with.

Though admittance method requires simple knowledge of mathematics, the numbers to be handled are decimals, their addition, subtraction, square and roots will make the solutions a little more cumbersome.

Let us find how this method could be used to solve problems in parallel AC circuits.

When several impedances say Z_1, Z_2 and Z_3 are connected in parallel, their combined impedance Z could be found by

$$Z = \frac{1}{\frac{1}{z_1} + \frac{1}{z_2} + \frac{1}{z_3}} \text{(Equation .... 1)}$$

$$\frac{1}{z} = \frac{1}{\frac{1}{z_1} + \frac{1}{z_2} + \frac{1}{z_3}} \text{...............} + \frac{1}{z_n} \text{ (Vector sum)}$$

Alternatively

$$Y = Y_1 + Y_2 + Y_3 \text{ Where } \frac{1}{Z} = Y$$

where the reciprocal impedance is called admittance, the unit is Siemens and the symbol is Y.

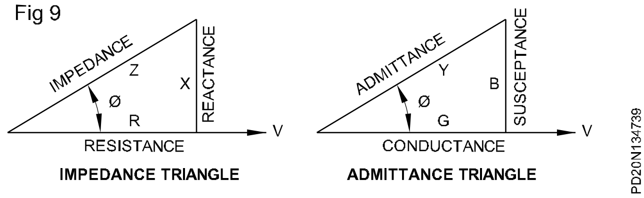
Just like impedance, the admittance also has two components as shown in Fig 9.

One component which is in phase with the voltage is called conductance, the unit is Siemens, and the symbol is G.

The other component which is in quadrature with the applied voltage V is called susceptance, the unit is Siemens and the symbol is B.

Admittance Y = $Y_1 + Y_2 + Y_3$ vectorially.

Fig 9



From the admittance triangle we have

$$Y = \sqrt{G^2 + B^2} \text{ .... Eqn.}$$

$$G = Y \cos\theta \text{ .... Eqn.}$$

$$\text{Where } Y = \frac{1}{Z} \text{ and } \sin\theta = \frac{R}{Z}$$

Hence $G = Y \times \frac{R}{Z} = \frac{R}{Z^2} = \frac{R}{R^2 + X^2}$ .... Eqn.

$B = Y \sin\theta$ .... Eqn.

Where $Y = \frac{1}{Z}$ and $\sin\theta = \frac{X}{Z}$

Hence $B = \frac{1}{Z} \times \frac{X}{Z} = \frac{R}{Z^2} = \frac{R}{R^2 + X^2}$ .... Eqn.

Further when several resistances, reactances are connected in parallel the conductances of individual branches can be added to get the total conductance

$G = G_1 + G_2 + G_3 + ...+G_m$

Likewise when several reactances are connected in parallel, the susceptance of individual branches can be added algebraically to get the total susceptance. The susceptance due to inductive reactances are taken as +ve sign where the susceptance due to capacitive reactances are taken as –ve sign.

$B = b_1 + b_2 + (-b_3)$ ....

Example 1

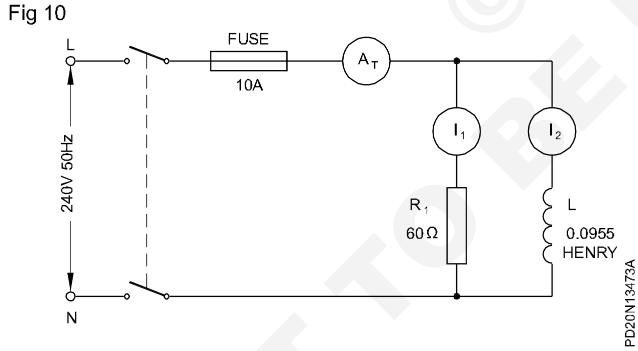
Parallel circuit with R and XL in branches.

Determine the following for the circuit shown in Fig 10.

i Conductance in branch circuits:

The conductance $G = g_1 + g_2$

Fig 10



where g_1 and g_2 are the conductance of branch 1 and 2 respectively.

In branch 1

$$g_1 = \frac{R_1}{R_1^2 + X_1^2} = \frac{60}{60^2 + 0^2}$$

$$= \frac{60}{60^2} = \frac{1}{60} = 0.01667 \text{ Siemens}$$

$$b_1 = \frac{X}{R_1^2 + X_1^2} = \frac{0}{60^2 + 0^2}$$

In branch 2

$$X_L = 2\pi fL = 2 \infty \frac{22}{7} \infty 50 \infty 0.0955 = 30 \text{ ohms}$$

$$g_2 = \frac{R_1}{R_2^2 + X_2^2} = \frac{0}{0^2 + 30^2} = 0$$

$$b_2 = \frac{X}{R_L^2 + X^2} = \frac{30}{0^2 + 30^2} = \frac{1}{30} = 0.033\text{Siemens}$$

Admittance $Y = \sqrt{G^2 + B^2}$

where $G = g_1 + g_2 = 0.01667 + 0 = 0.01667$ Siemens

and $B = b_1 + b_2 = 0 + 0.0333 = 0.0333$ Siemens

i.e $Y = \sqrt{0.01667^2 + 0.0333^2} = 0.0372$ Siemens

= 0.0372 Siemens

The branch current $I_1 = \frac{V}{Z_1}$

$\frac{V}{R} = \frac{240}{60} = 4$amps in phase with the voltage

The branch current $I_2 = \frac{V}{Z_2}$

$\frac{V}{X_L} = \frac{240}{30} = 8$amps

lagging behind the applied voltage by 90°.

Total current = $I_T = \sqrt{I_1^2 + I_2^2}$

$= \sqrt{4^2 + 8^2} = \sqrt{16 + 64}$

= 8.94 amps

Alternatively, $I = \frac{V}{Z}$ = VY = 240 x 0.0372

= 8.94 amps.

Power factor $= \frac{G}{Y} = \frac{I_1}{I_T}$

$= \frac{0.01667}{0.0372} = \frac{4}{8.94}$ = 0.448 approx. 0.447.

So power factor angle = 63° 26'.

Impedance of the circuit $Z = \frac{1}{Y} = \frac{1}{0.0372} = 26.88$ ohms

Power taken by the circuit = VI cos ø

= 240 x 8.94 x 0.447

= 959 watts.

Example 2

In Fig 11, Parallel circuit with R, X_L and X_c

Find the following.

i Conductance and susceptance of each branch.

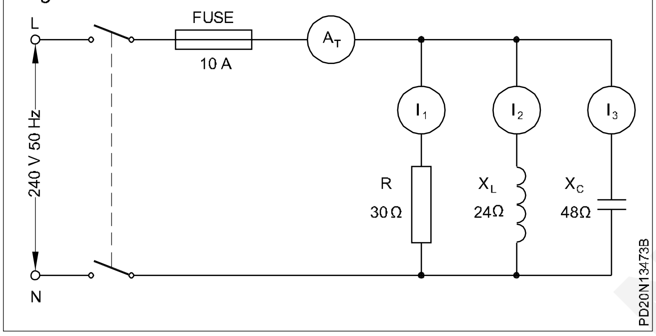
ii Total G, B and Y.

iii Branch currents.

iv PF and PF angle.

v Power taken by the circuit.

Fig 11



i Conductance in branch circuits

$$g_1 = \frac{R_1}{Z_1^2} = \frac{30}{30^2} = \frac{1}{30}$$

= 0.0333 siemens

$$g_2 = \frac{R_2}{Z_2^2} = \frac{0}{24^2} = 0$$

$$g_3 = \frac{R_3}{Z_3^2} = \frac{0}{48^2} = 0$$

Susceptance in branch cirucits

$$b_1 = \frac{X_1}{Z_1^2} = \frac{0}{30^2} = 0$$

$$b_2 = \frac{X_2}{Z_2^2} = \frac{24}{24^2} = \frac{1}{24}$$

= 0.04167 siemens

$$b_3 = \frac{-X_3}{Z_1^2} = \frac{-48}{-48^2} = -\frac{1}{48}$$

= - 0.02083 siemens

ii Total conductance G = $g_1 + g_2 + g_3$

= 0.0333 + 0 + 0

= 0.0333 Siemens.

Total susceptance B = $b_1 + b_2 + b_3$

= 0 + 0.04167 + (– 0.02083)

= 0.02084 Siemens.

$$Y = \sqrt{G^2 + B^2}$$

$$= \sqrt{0.333^2 + 0.02084^2}$$

= 0.03928 Siemens.

iii The branch current $I_1 = \frac{V}{Z_1}$

$$= \frac{V}{R} = \frac{240}{30}$$ = 8 amps in phase with V

The branch current $I_2 = \frac{V}{Z_2}$

$$\frac{V}{X_L} = \frac{240}{24} = 10$$ amps lagging 90° with V

The branch current $I_3 = \frac{V}{X_3}$

$$= \frac{240}{48}$$ = 5 amps lagging 90° with V

Total current

$$I_T = \sqrt{I_1^2 + (I_2 - I_3)^2}$$

$$= \sqrt{8^2 + (10-5)^2} = \sqrt{89}$$

= 9.43 amps

Alternatively

I_T = VY = 240 X 0.03928

= 9.43 amps.

iv Power factor $= \frac{G}{Y} = \frac{I_R}{I_T}$

$= \frac{0.0333}{0.03929} = \frac{8}{9.43}$

= 0.848.

v Power factor angle = 32° lagging.

Power taken by the circuit = VIcos ø

= 240 x 9.43 x 0.848

= 1919 watts.

Total impedance = Z = $\frac{1}{Y}$

$\frac{1}{0.03929}$ = 25.5.ohms

Check these answers with the answers obtained by the vector method.

Measurement of 3 phase power by single and two wattmeters

Objectives: At the end of this lesson you shall be able to

- **explain the measurement 3 phase power using single wattmeter**
- **explain the measurement of 3 phase power using two wattmeters**
- **calculate the power factor by two wattmeter method power measurement.**

The measurement of power: The number of wattmeters used to obtain power in a three-phase system depends on whether the load is balanced or not, and whether the neutral point, if there is one, is accessible

- Measurement of power in a star-connected balanced load with neutral point is possible by a single wattmeter
- Measurement of power in a star or delta-connected, balanced or unbalanced load (with or without neutral) is possible with two wattmeter method

Single wattmeter method: Fig 1 shows the circuit diagram to measure the three-phase power of a star-connected, balanced load with the neutral point accessible the current coil of the wattmeter being connected to one line, and the voltage coil between that line and neutral point. The wattmeter reading gives the power per phase. So the total is three times the wattmeter reading.

$P = 3E_PI_P \cos\varphi = 3P = 3W$

The two wattmeter method of measuring power

Power in a three-phase, three-wire system is normally measured by the `two-wattmeter' method. It may be used with balanced or unbalanced loads, and separate connections to the phases are not required. This method is not, however, used in four-wire systems because current may flow in the fourth wire, if the load is unbalanced and the assumption that $I_U + I_V + I_W = 0$ will not be valid.

The two wattmeters are connected to the supply system (Fig 2). The current coils of the two wattmeters are connected in two of the lines, and the voltage coils are connected from the same two lines to the third line. The total power is then obtained by adding the two readings:

$P_T = P_1 + P_2$.

Consider the total instantaneous power in the system $P_T = P_1 + P_2 + P_3$ where P_1, P_2 and P_3 are the instantaneous values of the power in each of the three phases.

$$P_T = V_{UN}\, i_U + V_{VN}\, i_V + V_{WN}\, I_W$$

Since there is no fourth wire, $i_U+i_V+i_W = 0$; $i_V = -(i_U + i_W)$.

$$\begin{aligned} P_T &= V_{UN}i_U - V_{VN}(i_U+i_W) + V_{WN}\, i_W \\ &= i_U(V_{UN} - V_{VN}) + i_W(V_{WN} - V_{UN}) \\ &= i_UV_{UV} + i_WV_{WV} \end{aligned}$$

Now i_UV_{UV} is the instantaneous power in the first wattmeter, and i_WV_{WV} is the instantaneous power in the second wattmeter. Therefore, the total mean power is the sum of the mean powers read by the two wattmeters.

It is possible that with the wattmeters connected correctly, one of them will attempt to read a negative value because of the large phase angle between the voltage and current for that instrument. The current coil or voltage coil must then be reversed and the reading given a negative sign when combined with the other wattmeter readings to obtain the total power.

At unity power factor, the readings of two wattmeter will be equal. Total power = 2 x one wattmeter reading.

When the power factor = 0.5, one of the wattmeter's reading is zero and the other reads total power.

When the power factor is less than 0.5, one of the wattmeters will give negative indication. In order to read the wattmeter, reverse the pressure coil or current coil connection. The wattmeter will then give a positive reading but this must be taken as negative for calculating the total power.

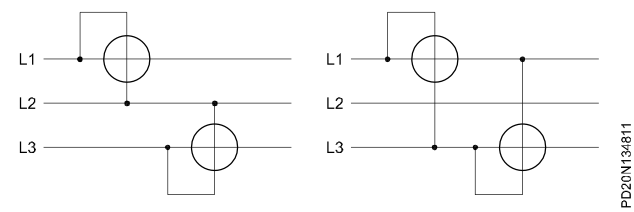
When the power factor is zero, the readings of the two wattmeters are equal but of opposite signs.

Self-evaluation test

1 Draw a general wiring diagram for the two-wattmeter method of three-phase power measurement.

2 Why is it desirable, in practice, to use the two-wattmeter method? (Fig 3)

Fig 1



3 Why can the two-wattmeter method not be used in a three-phase, four-wire system with random loading?

4 Which of the above circuits is used for the two-wattmeter method of power measurement?

Power factor calculation in the two -wattmeter of measuring power

As you have learnt in the previous lesson, the total power $P_T = P_1 + P_2$ in the two-wattmeter method of measuring power in a 3-phase, 3-wire system.

From the readings obtained from the two wattmeters, the tan ϕ can be calculated from the given formula

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}\,(W_1 - W_2)}{(W_1 + W_2)}$$

from which ϕ and power factor of the load may be found.

Example 1: Two wattmeters connected to measure the power input to a balanced three-phase circuit indicate 4.5 KW and 3 KW respectively. Find the power factor of the circuit.

Solution

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}$$

$P_1 = 4.5$ KW

$P_2 = 3$ KW

$P_1 + P_2 = 4.5 + 3 = 7.5$ KW

$P_1 - P_2 = 4.5 - 3 = 1.5$ KW

$$\tan\phi = \frac{\sqrt{3} \times 1.5}{7.5} = \frac{\sqrt{3}}{5} = 0.3464$$

$\phi = \tan^{-1} 0.3464 = 19^0 6'$

Power factor Cos $19^0 6' = 0.95$

Example 2: Two wattmeters connected to measure the power input to a balanced three-phase circuit indicate 4.5 KW and 3 KW respectively. The latter reading is obtained after reversing the connection of the voltage coil of that wattmeter. Find the power factor of the circuit.

Soultion

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}$$

$$= \frac{\sqrt{3}(4.5 - (-3))}{(4.5 + (-3))}$$

$$= \frac{\sqrt{3}(4.5 + 3)}{(4.5 - 3)}$$

$$= \frac{\sqrt{3} \times 7.5}{1.5} = \sqrt{3} \times 5$$

$$= 1.732 \times 5 = 8.66.$$

$\phi = \tan^{-1} 8.66 = 83^o.27'$

since power factor (Cos $83^o 27'$) = 0.114.

Example 3: The reading on the two wattmeters connected to measure the power input to the three-phase, balanced load are 600W and 300W respectively.

Calculate the total power input and power factor of the load.

Solution

Total power = $P_T = P_1 + P_2$

$P_1 = 600$W.

$P_2 = 300$W.

$P_T = 600 + 300 = 900$

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(600 - 300)}{600 + 300} = \frac{\sqrt{3} \times 300}{900}$$

$$= \frac{\sqrt{3}}{3} = \frac{1}{\sqrt{3}} = 0.5774$$

$\phi = \tan^{-1} 0.5774 = 30^o$

Power factor = Cos $30^o = 0.866$.

Example 4: Two wattmeters connected to measure the power input to a balanced, three-phase load indicate 25KW and 5KW respectively.

Find the power factor of the circuit when (i) both readings are positive and (ii) the latter reading is obtained after reversing the connections of the pressure coil of the wattmeter.

Solution

a $P_1 = 25$ KW

$P_2 = 5$ KW

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(25 - 5)}{25+5}$$

$$= \frac{\sqrt{3}\times 20}{30} = \frac{\sqrt{3}\times 2}{3} = \frac{2}{\sqrt{3}} = 1.1547$$

ϕ $= \tan^{-1} 1.1547 = 49^{o}6'$

Power factor ($\cos\phi$) $= \cos 49^{o}6' = 0.6547$

b $P_1 = 25$ KW

$P_2 = -5$ KW

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(25 - (-5))}{25+(-5)}$$

$$= \frac{\sqrt{3}\ (25+5)}{25-5} = \frac{\sqrt{3}\times 30}{20}$$

$$= \frac{\sqrt{3}\times 3}{2} = 2.5980$$

ϕ $= \tan^{-1} 2.5980 = 68^{o}57'$

Power factor $= \cos 68^{o}57' = 0.3592$

Power factor meter

Objectives: At the end of this lesson you shall be able to
- **state the disadvantage of the indirect method of measuring power factor**
- **state the different types of power factor meters**
- **explain the construction and connection of 3-phase dynamometer type power factor meter**
- **explain the construction, connection and operation of a 3-phase moving iron type power factor meter**
- **explain the construction, connection and operation of a single phase moving iron type power factor meter.**

Power factor of a single phase AC circuit can be calculated by the formula

$$P.F. = \frac{\text{Power}}{EI}$$

provided an ammeter, a voltmeter and a wattmeter are connected to the circuit.

On the other hand, for measuring power factor in a balanced 3-phase circuit we have to use the formula

$$P.F. = \frac{\text{3 - phase power}}{3E_{PH}I_{PH}} \text{ or } \frac{\text{3 - phase power}}{\sqrt{3}E_L I_L}$$

However when the, 3-phase circuit is unbalanced, the above formula cannot be used.

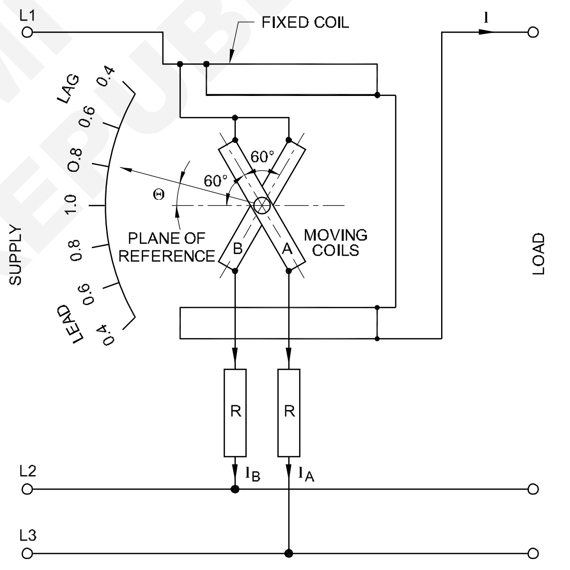
This indirect method has the following disadvantages.

- Low accuracy due to the number of meters
- Reading errors
- Cumbersome connections
- Involves calculation every time when the load changes and hence not suitable for changing load.

To get the instantaneous reading of the power factor, direct reading P.F. meters are used which are reasonably accurate.

3-phase dynamometer type power factor meter for balanced load: Fig 1 shows the construction and connections of a 3-phase power factor meter used for balanced loads.

Fig 1



DYNAMOMMETER TYPE THREE PHASE POWER FACTOR METER

In this meter, the field coils are connected in series with the load along with one phase. The two moving coils are rigidly attached to each other at an angle of 120°. These coils are connected to two different phases. A resistance is connected in series with each coil.

Phase splitting through reactance is not necessary since the required phase displacement between currents in the two moving coils can be obtained by the supply itself.

Operation of the meter is in the same way as in a single phase meter. However this meter is suitable only for balanced loads.

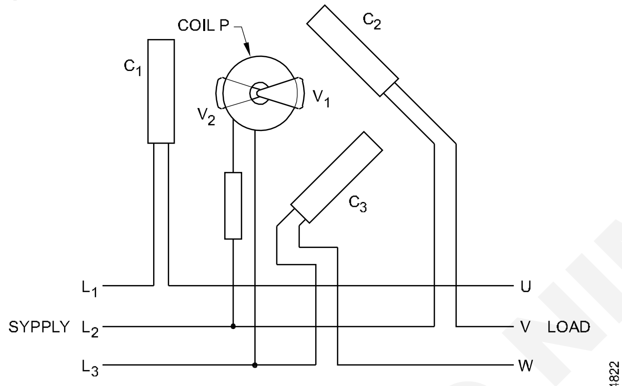
Since the currents in the two moving coils are both affected in the same way by any change in frequency or wave-form, this meter is independent of frequency and wave-form.

Moving iron power factor meters: This type of power factor meter is more popular than the dynamometer type due to the following advantages.

- Torque-weight ratio (working forces) is large compared to the dynamometer type meter.
- As all the coils are fixed there is no ligament connection necessary.
- The scale can be extended to 360°.
- This meter is simple and robust in construction.
- Comparatively cheaper in cost.

Fig 2 shows the construction and connection of a moving iron type power factor meter used for balanced loads.

Fig 2



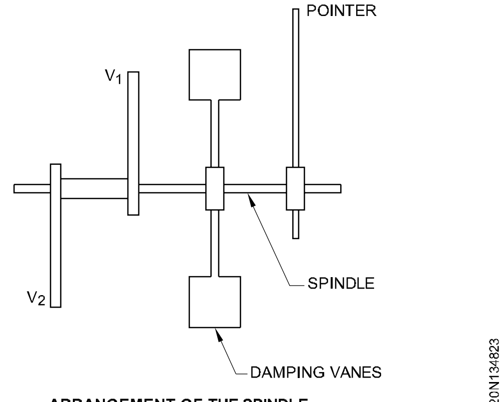
MOVING IRON TYPE POWER-FACTOR METER FOR A BALANCED 3-PHASE LOAD

There are three similar coils at C_1, C_2 and C_3 placed 120° degrees apart and connected to 3-phase supply directly (Fig 2) or through the secondary of the current transformers. Coil P is placed in the middle of the three coils C_1, C_2 and C_3 and connected in series with a resistance across two lines of the supply. Inside the coil B there are are two vanes V_1, and V_2 mounted at the ends of a freely moving spindle but kept at 180° to each other. The spindle also has damping vanes and the pointer (Fig 3).

The rotating magnetic field produced by the three coils C_1, C_2 and C_3 interacts with the flux produced by the coil P. This causes the moving system to take up an angular position depending upon the phase angle of the current.

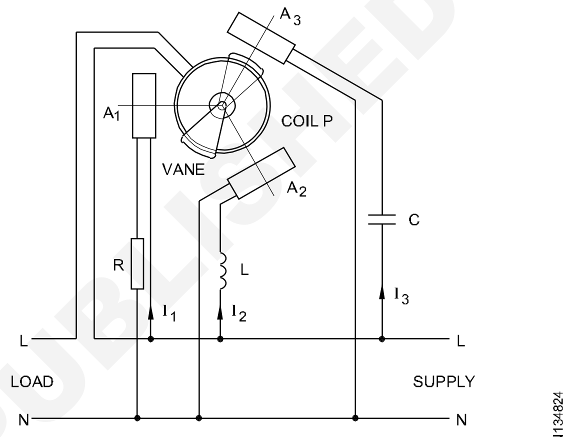
Single phase moving iron power factor meter: A single phase moving iron power factor meter (Fig 4) uses a phase splitting network comprising of a capacitor, an inductor and a resistor.

Fig 3



ARRANGEMENT OF THE SPINDLE

Fig 4



SINGLE PHAGE MOVING IRON TYPE POWER FACTOR METER

3-phase power factor meters for unbalanced load: For measurement of power factor in 3-phase unbalanced systems 2-element or 3-element power factor meters with each element with a current coil and pressure coil is used. The pressure coils are (moving coils) similar to that of single phase P.F. meters are mounted one below the other on a single spindle. The pointer shows the resultant power factor.

Low power factor meter: Power factor meters are generally available to read power factor from 0.5 lag-unity - 0.5 lead. Low power factor meters specially constructed to read power factor 0.0 lag to unity power factor are also used.

Phase-sequence indicator (Meter)

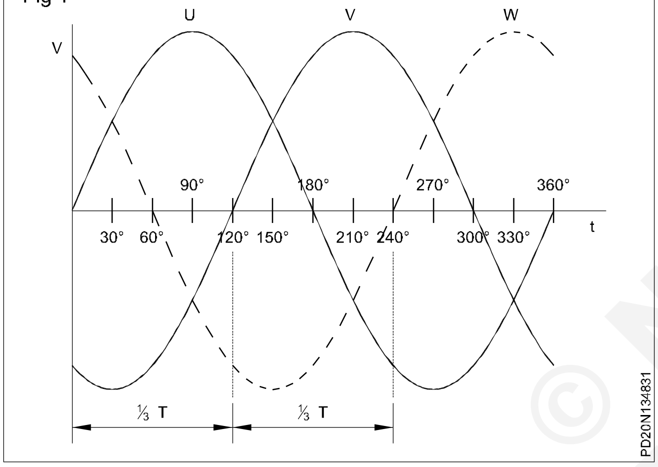
Objectives: At the end of this lesson you shall be able to
- **describe the method of finding the phase sequence of a 3-phase supply using a phase-sequence indicator**
- **state the method of using phase sequence indicator with choke & lamp and capacitor & lamp.**

Review

A three-phase alternator contains three sets of coils positioned 120° apart and its output is a three-phase voltage as shown in Fig 1. A three-phase voltage consists of three voltage waves, 120 electrical degrees apart.

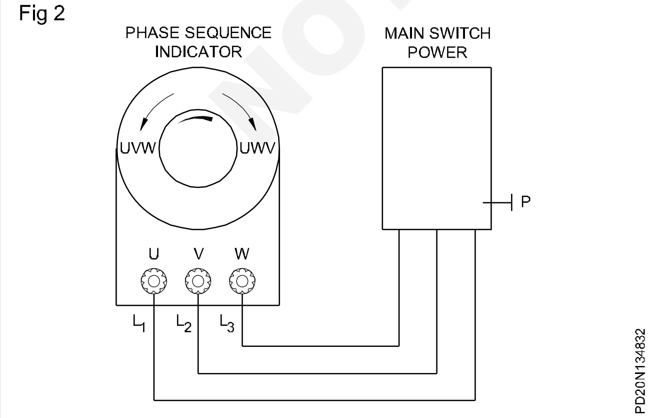
At a time 0, phase U is passing through zero volts with positively increasing voltage. (Fig 1) V follows with its zero crossing of the period later and the same applies to W with respect to V. The order in which the three-phases attain their maximum or minimum values is called the phase sequence. In the illustration given here the phase sequence is U,V,W.

Fig 1



Importance of correct phase sequence: Correct phase sequence is important in the construction and connection of various three-phase systems. For example, correct phase sequence is important when the outputs of three-phase alternators must be paralleled into a common voltage system. The phase `U' of one alternator must be connected to phase `U' of another alternator. The phase `V' to phase `V' and phase `W' to phase `W' must be similarly connected to each other.

Fig 2



In the case of an induction motor, reversal of the sequence results in the reversal of the direction of motor rotation which will drive the machinery the wrong way.

Phase-sequence indicator(meter)**:** A phase-sequence indicator (meter) provides a means of ensuring the correct phase-sequence of a three-phase system. The phase-sequence indicator consists of 3 terminals `UVW' to which three-phases of the supply are connected. When the supply is fed to the indicator a disc in the indicator moves either in the clockwise direction or in the anticlockwise direction.

The direction of the disc movement is marked with an arrowhead on the indicator. Below the arrowhead the correct sequence is marked (Fig 2). The phase sequence of the three-phase system may be reversed by interchanging the connections of any two of the three phases.

Phase-sequence indicator using choke and lamps: The phase-sequence indicator consists of four lamps and an inductor connected in a star formation (Y). A test lead is connected to each leg of the `Y'. One lamp is labelled U-V-W, and the other is labelled U-W-V. When the three leads are connected to a three-phase line, the brighter lamp indicates the phase sequence (Fig 3).

Phase-sequence indicator using capacitor & lamps: The phase-sequence indicator consists of four lamps and a capacitor connected in a star formation (Y). A test lead is connected to each leg of the `Y'. One pair of lamps are labelled U-V-W,and the other pair are labelled U-W-V. When the three leads are connected to a 3-phase line, the brighter lamp indicates the phase sequence. (Fig 4)

Fig 3

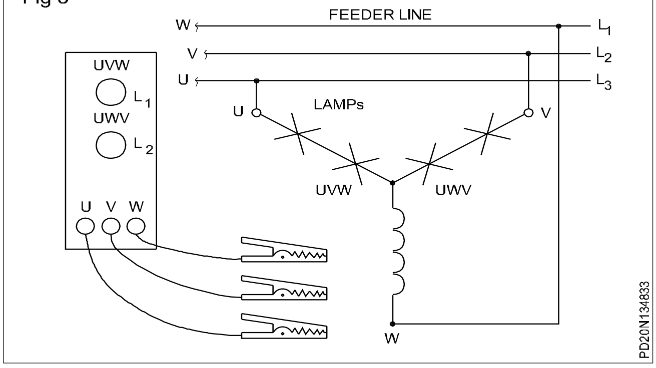
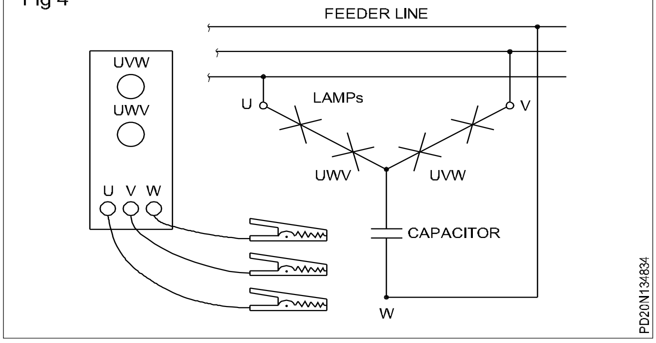


Fig 4



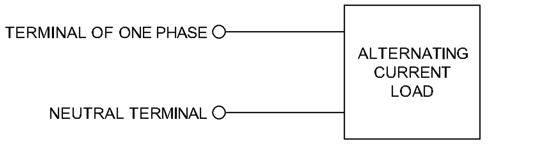
3-Phase AC fundamentals

Objectives: At the end of this lesson you shall be able to
- **state and describe the generation of 3-phase system with single loops**
- **state the advantages of the 3-phase system over a single phase system**
- **state and explain the 3-phase, 3-wire, and 4-wire system**
- **state and explain the relation between phase and line voltage.**

Introduction

When a piece of electrical equipment is plugged into the socket of a normal alternating current supply (e.g. a ring main circuit), it is connected between the terminal of one phase and the neutral wire. (Fig 1)

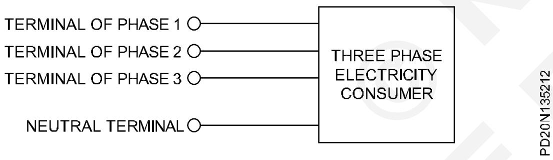
Fig 1



Thus a normal domestic alternating current circuit may also be described as a single-phase circuit.

Similarly, a three-phase power consumer is provided with the terminals of three phases. (Fig 2)

Fig 2



One great advantage of a three-phase AC supply is that it can produce a rotating magnetic field when a set of stationary three-phase coils is energized from the supply. This is the basic operating principle for most modern rotating machines and, in particular, the three-phase induction motor.

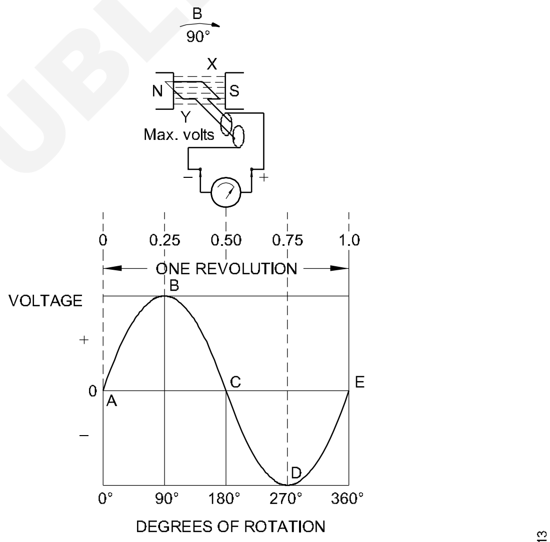
Further, lighting loads can be connected between any one of the three phases and neutral.

Review: Further to the above two advantages the following are the advantages of polyphase system over single phase system.

- 3-phase motors develop uniform torque whereas single phase motors produce pulsating torque only
- Most of the 3-phase motors are self starting whereas single phase motors are not
- Power factor of 3-phase motors are reasonably high when compared to single phase motors
- For a given size the power out put is high in 3-phase motors whereas in single phase motors the power output is low.
- Copper required for 3-phase transmission for a given power and distance is low when compared to single phase system.
- 3-phase motor like squirrel cage induction motor is robust in construction and more are less maintenance free.

The basic principle used in generating an alternating voltage is that of rotating a wire loop at a constant angular speed in a uniform magnetic field. (Fig 3) The alternating voltage thus produced varies sinusoidally with time.

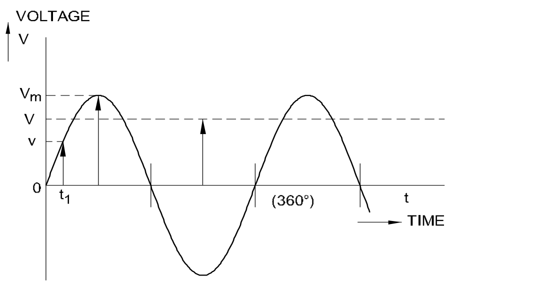
Fig 3



(AS THE LOOP ROTATES THROUGH THE MAGNETIC FIELD, THE MAGNITUDE AND DIRECTION OF THE VOLTAGE CHANGES.)
GENERATION OF AN ALTERNATING VOLTAGE

The effective (RMS) value is the same as that of a direct current that would produce the same heating effect, RMS voltage and frequency are usually quoted for a sinusoidal alternating voltage (Fig 4).

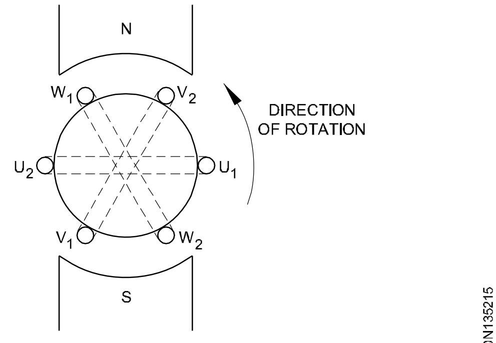
Fig 4



V_m = PEAK VOLTAGE
V = RMS VALUE
v = INSTANTANEOUS VOLTAGE AT TIME t_1

Three-phase generation: To generate three-phase voltages, a similar method to that used for generating single-phase voltages is employed but with the difference that, this time, three wire loops U_1, U_2, V_1, V_2 and W_1, W_2 rotate at a constant angular speed about the same axis in the uniform magnetic field. U_1, U_2, V_1, V_2 and W_1 , W_2, are displaced 120° in position with respect to each other, permanently. (Fig 5)

Fig 5

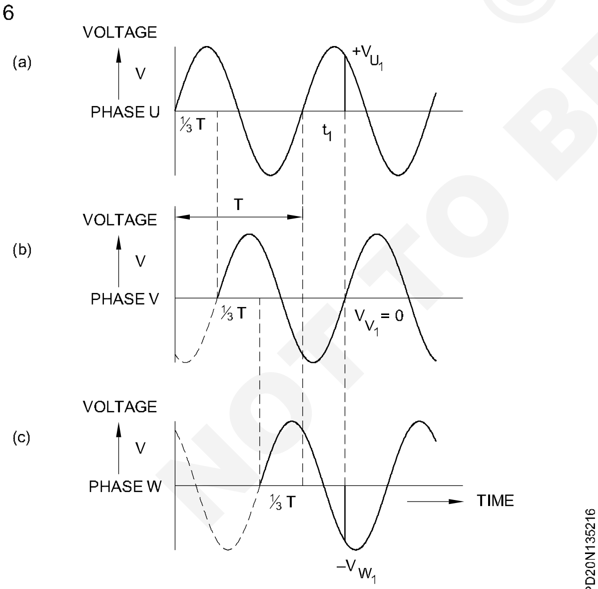


SIMPLIFIED THREE – PHASE ALTERNATOR

For each wire loop, the same result is obtained as for the alternating voltage generator. This means that an alternating voltage is induced in each wire loop. However, since the wire loops are displaced by 120° from each other, and a complete revolution (360°), takes one period, the three induced alternating voltages are delayed in time by a third of a period with respect to each other.

Because of the spatial displacement of the three wire loops by 120°, three alternating phase voltages result, which are displaced by one third of a period, T, with respect to each other. (Fig 6)

Fig 6



To distinguish between the three phases, it is a common practice in (heavy current) electrical engineering to designate them by the capital letters U,V and W or by a colour code red, yellow and blue. At a time 0, U is passing through zero volts with positively increasing voltage. (Fig 6a) V follows with its zero crossing 1/3 of the period later (Fig 6b), and the same applies to W with respect to V. (Fig 6c)

In three-phase networks, the following statements can be made about the three-phase voltages.

- The three-phase voltages have the same frequency.
- The three-phase voltages have the same peak value.
- The three-phase voltages are displaced by one third of a period in time with respect to each other.
- At every instant in time, the instantaneous sum of the three voltages

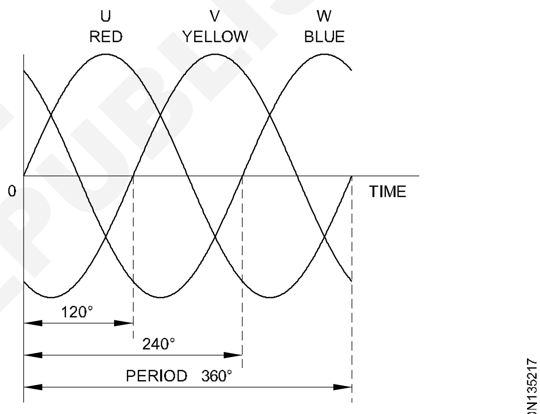
$$V_U + V_V + V_W = 0.$$

The fact that the sum of the instantaneous voltages is zero is illustrated in Fig 6. At time t_1, U has the instantaneous value V_U. At the same time, $V_V = 0$, and the instantaneous value for W is $-V_W$. Because V_U and V_W have the same value but are opposite in sign, it follows that

$$V_{U1} + V_{V1} + V_{W1} = 0.$$

The three voltages of the same amplitude and frequency are shown together in Fig 7.

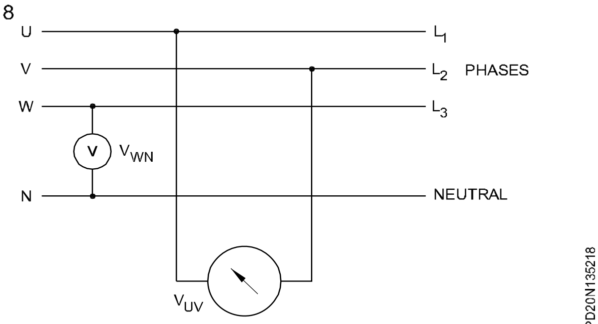
Fig 7



COMBINED WAVE - FORMS OF THREE PHASE SUPPLY

Three-phase network: A three-phase network consists of three lines or phases. In Fig 8, these are indicated by the capital letters U, V and W.

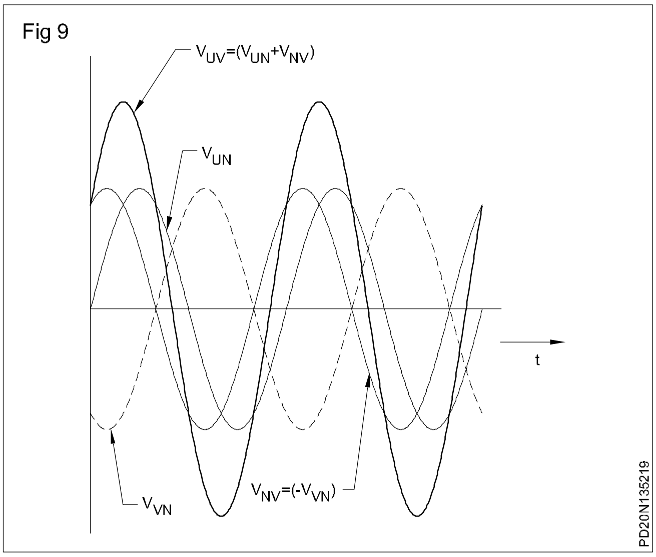
Fig 8



The return lead of the individual phases consists of a common neutral conductor N, which is described later in more detail. Voltmeters are connected between each of the lines U, V and W, and the neutral line N. They indicate the RMS (effective) values of the voltages between each of the three phases and neutral.

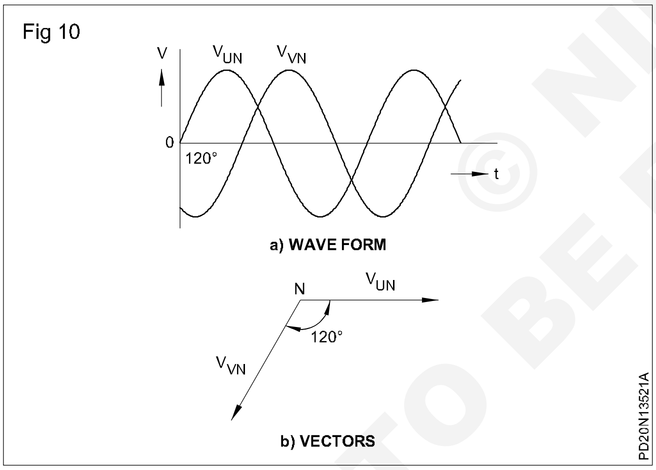
These voltages are designated as phase voltages V_{UN}, V_{VN} and V_{WN}.

The individual, phase voltages all have the same magnitude. They are simply displaced from each other by one third of a period in time. (Fig 9)

Fig 9


The individual instantaneous, peak and RMS values are the same as for a single-phase alternating voltage.

Line and phase voltage: If a voltmeter is connected directly between line U and line V (Fig 10), the RMS value of the voltage V_{UV} is measured, and this is different from any of the three phase voltages.

Fig 10


Its magnitude is directly proportional to the phase voltage. The relationship is shown in Fig 9, where the time-variation wave- forms of V_{UV} and the phase voltages V_{UN} and V_{VN} are drawn.

V_{UV} has a sinusoidal wave-form and the same frequency as the phase voltages. However, V_{uv} has a higher peak value since it is computed from the phase voltages V_{UN} and V_{VN}. The varying positive and negative instantaneous values of V_{UN} and V_{VN} at a particular time produce the instantaneous value of V_{UV}. V_{UV} is the phasor sum of the two phase voltages V_{UN} and V_{NV}.

This combination of phase-displaced alternating voltages is called phasor addition.

The voltage across phase-to-phase is called the line voltage.

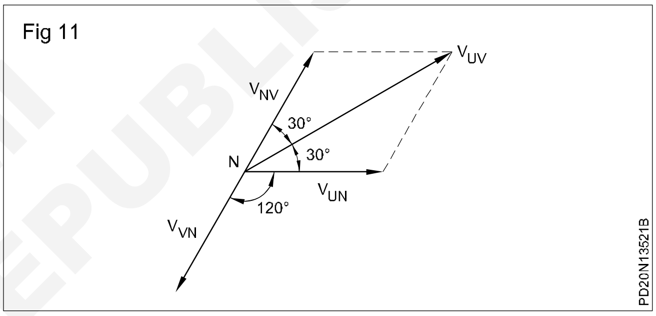
Relationship between line and phase voltage: The possibility of combining pairs of phases in a generator is a basic property of three-phase electricity. The understanding of this relationship will be enhanced by studying the following illustrative example which explains the concept of phase difference in a very simple way.

The phase voltages V_{UN} and V_{VN} are separated in phase by one third of a period, or 120^o between the two phasors. (Fig 10)

The phasor sum of the two phase voltages V_{UN} and V_{NV} can be obtained geometrically, and the resultant phasor so obtained is the line voltage V_{UV} through the relation $V_{UV} = V_{UN} + V_{NV}$.

Note that to obtain the line voltage V_{UV} the measurement is made from the U terminal through the common point N to the V terminal, for a star connection.

This fact is illustrated in Fig 11. Starting with the phasors V_{UN} and V_{VN} (Fig 10), the phasor $-V_{VN} = V_{NV}$ is produced from the point N. The diagonal of the parallelogram with sides V_{UN} and V_{NV} is the phasor representing the resulting line voltage V_{UV}.

Fig 11


It can be concluded, therefore, that in a generator the line voltage V_L is related to the phase voltage V_P by a multiplying factor. This factor can be shown to be $\sqrt{3}$, so that $V_L = \sqrt{3} \times V_P$

In a three-phase generating system, the line voltage is always $\sqrt{3}$ times the phase-to-neutral voltage. The factor relating the line voltage to the phase voltage is $\sqrt{3}$.

It was shown that the line voltage is greater than the phase voltage. Here is a numerical example.

The RMS phase voltage in a three-phase system is 240V. Since the ratio of line voltage to phase voltage is $\sqrt{3}$ the RMS line voltage is

$$V_L = \sqrt{3} \times V_P = \sqrt{3} \times 240$$

$$= 415.68V$$

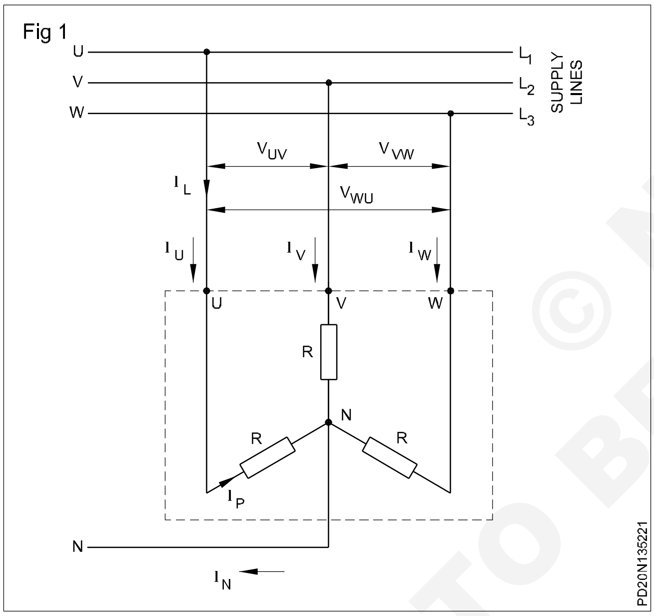
or rounded down, V_L = 415V.

Systems of connection in 3-phase AC

Objectives: At the end of this lesson you shall be able to
- **explain the star and delta systems of connection**
- **state phase relationship between line and phase voltages and current in a star connection delta connection**
- **state the relationship between phase and the voltage and current in star and delta connection**

Methods of 3-phase connection: If a three-phase load is connected to a three-phase network, there are two basic possible configurations. One is `star connection' (symbol Y) and the other is `delta connection' (symbol Δ).

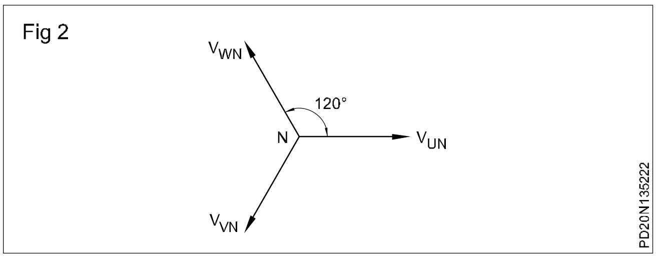
Star connection: In Fig 1 the three-phase load is shown as three equal magnitude resistances. From each phase, at any given time, there is a path to the terminal points U, V, W of the equipment, and then through the individual elements of the load resistance. All the elements are connected to one point N: the `star point'. This star point is connected to the neutral conductor N. The phase currents i_U, i_V, and i_W flow through the individual elements, and the same current flows through the supply lines, i.e. in a star connected system, the supply line current (I_L) = phase current (I_P).



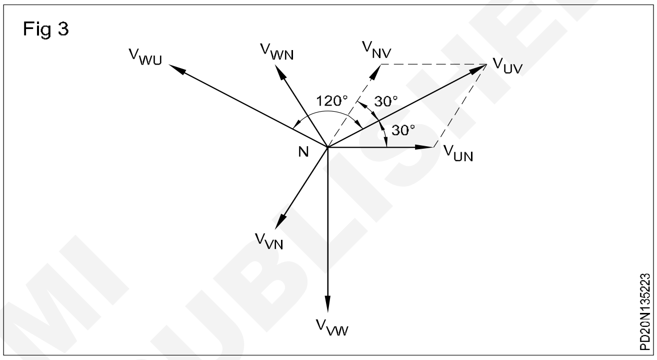
The potential difference for each phase, i.e. from a line to the star point, is called the phase voltage and designated as V_P. The potential difference across any two lines is called the line voltage V_L. Therefore, the voltage across each impedance of a star connection is the phase voltage V_P. The line voltage V_L appears across the load terminals U-V, V-W and W-U and designated as V_{UV}, V_{VW} and V_{WU} in the Fig 1. The line voltage in a star-connected system will be equal to the phasor sum of the positive value of one phase voltage and the negative value of the other phase voltage that exist across the two lines (Fig 2).

Thus

$$V_L = V_{UV} = (\text{phasor } V_{UN}) - (\text{phasor } V_{VN})$$
$$= \text{phasor } V_{UN} + V_{VN}.$$



In the phasor diagram (Fig 3)



$$V_L = V_{UV} = V_{UN}\cos 30^o + V_{NV}\cos 30^o$$

But $\cos 30^o = \dfrac{\sqrt{3}}{2}$.

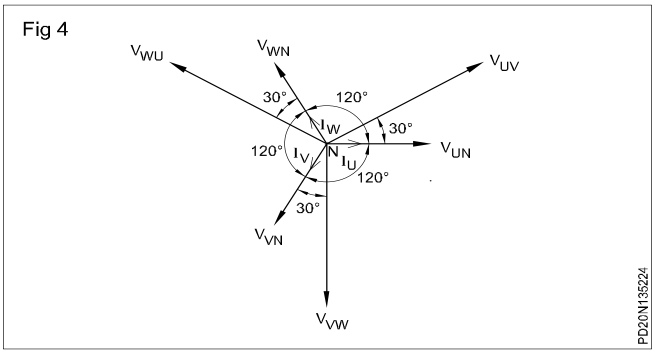
Thus as $V_{UN} = V_{VN} = V_P$

$$V_L = \sqrt{3}\,V_P.$$

This same relationship is applied to V_{UV}, V_{VW} and V_{WU}.

In a three-phase star connection, the line voltage is always $\sqrt{3}$ times the phase-to-neutral voltage. The factor relating the line voltage to the phase voltage is $\sqrt{3}$ (Fig 3).

The voltage and current relationship in a star connection is shown in the phasor diagrams. (Fig 4) The phase voltages are displaced 120° in phase with respect to each other.



Derived from these are the corresponding line voltages. The line voltages are displaced 120^0 in phase with respect to each other. Since the loads in our example are provided by purely resistive impedances, the phase currents I_P (I_U, I_V, I_W) are in phase with the phase voltages V_P (V_{UN}, V_{VN} and V_{WN}). In a star connection, each phase current is determined by the ratio of the phase voltage to the load resistance R.

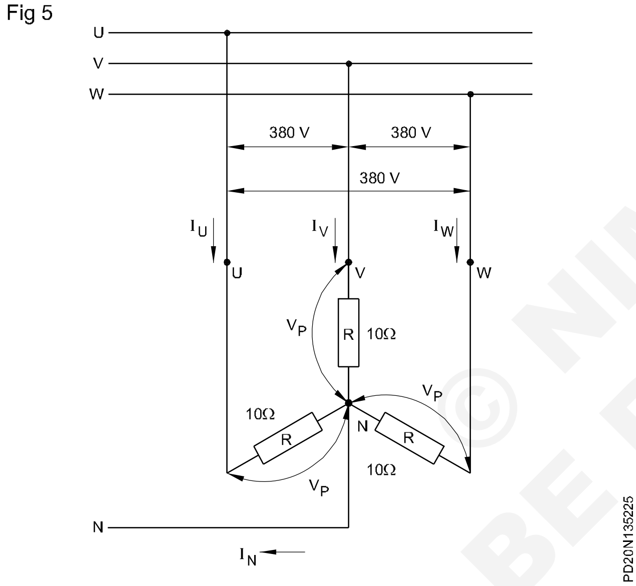
***Example 1**:* What is the line voltage for a three-phase, balanced star-connected system, having a phase voltage of 240V?

$$V_L = \sqrt{3}V_P = \sqrt{3} \text{x } 240$$
$$= 415.7\text{V}$$

***Example 2**:* What is the magnitude of each of the supply line currents for the circuit shown in Fig 5?

Because of the arrangements of a star connection there is a voltage

Fig 5



$$V_P = \frac{380}{1.73} = 220 \text{ V}$$

across each of the purely resistive loads R.

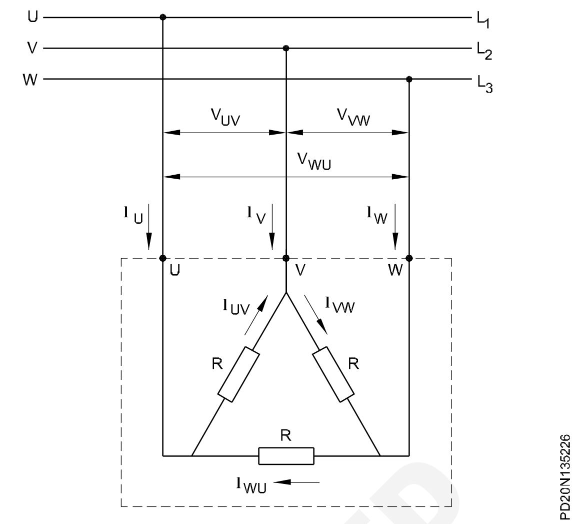
The three-supply line currents have the same magnitude since the star-connected load is balanced, and they are given by

$$I_U = I_V = I_W = \frac{V_P}{R} = \frac{220}{10} = 22\text{A} = I_L = I_P$$

Delta connection: There is a second possible arrangement for connecting a three-phase load in a three-phase network. This is the delta or mesh connection (Δ).(Fig 6)

The load impedances form the sides of a triangle. The terminals U, V and W are connected to the supply lines of the L_1, L_2 and L_3.

Fig 6



In contrast to a star connection, in a delta connection the line voltage appears across each of the load phases.

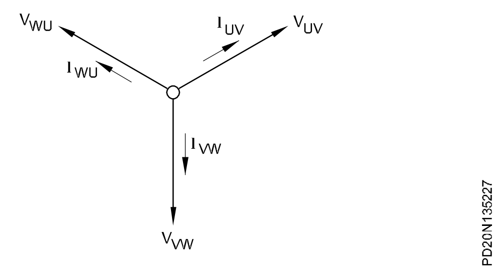
The voltages, with symbols V_{UV}, V_{VW} and V_{WU} are, therefore, the line voltages.

The phase currents through the elements in a delta arrangement are composed of I_{UV}, I_{VW} and I_{WU}. The currents from the supply lines are I_U, I_V and I_W, and one line current divides at the point of connection to produce two phase currents.

The voltage and current relationships of the delta connection can be explained with the aid of an illustration. The line voltages V_{UV}, V_{VW} and V_{WU} are directly across the load resistors, and in this case, the phase voltage is the same as the line voltage. The phasors V_{UV}, V_{VW} and V_{WU} are the line voltages. This arrangement has already been seen in relation to the star connection.

Because of the purely resistive load, the corresponding phase currents are in phase with the line voltages. (Fig 7)

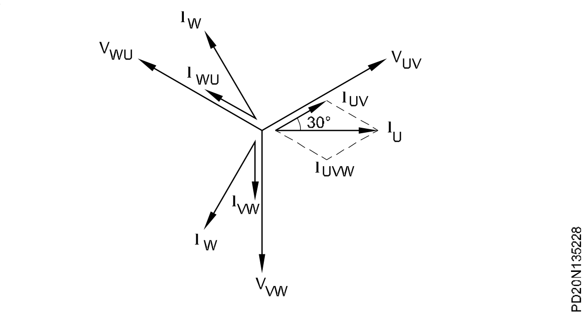
Fig 7



Their magnitudes are determined by the ratio of the line voltage to the resistance R.

On the other hand, the line currents I_U, I_V and I_W are now compounded from the phase currents. A line current is always given by the phasor sum of the appropriate phase currents. This is shown in Fig 8. The line current I_U is the phasor sum of the phase currents I_{UV} and I_{UW}. (See also Fig 8)

Fig 8



Hence, $I_U = I_{UV} \cos 30^\circ + I_{UW} \cos 30^\circ$

But $\cos 30^\circ = \frac{\sqrt{3}}{2}$.

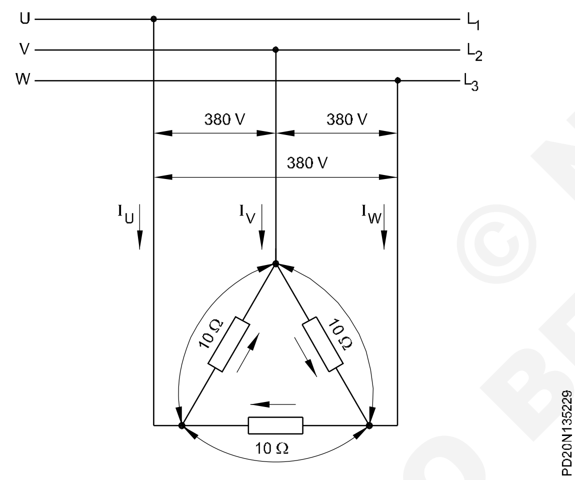
Thus $I_L = \sqrt{3}\, Iph$

Thus, for a balanced delta connection, the ratio of the line current to the phase current is $\sqrt{3}$.

Thus, line current = $\sqrt{3}$ x phase current.

Example 3: What are the values of the line currents, I_U, I_V and I_W in the above example? (Fig 9)

Fig 9



Solution

Since the load is balanced (i.e. the resistance of each phase is the same), the phase currents are of equal magnitude, and are given by the ratio of the line voltage to the load phase resistance

$$I_{UV} = I_{VW} = I_{WU} = \frac{V_P}{R} = \frac{V_L}{R} = \frac{380}{10} = 38A.$$

Thus, the phase current in the case of delta is 38A. Expressed in words:

$$\text{Phase current} = \frac{\text{lineor phase voltage}}{\text{phase resistance}}$$

The line current is $\sqrt{3}$ times the phase current.

Therefore the line current is

$I_U = I_V = I_W = \sqrt{3}$ x 38A = 1.73 x 38A = 66A.

Example 4: Three identical coils, each of resistance 10 ohms and inductance 20mH is delta connected across a 400-V, 50Hz, three-phase supply. Calculate the line current.

For a coil,

reactance $X_L = 2\pi fL = 2 \times 3.142 \times 50 \times \frac{20}{1000} = 6.3$ ohms.

Impedance of a coil is thus given by

$$Z = \sqrt{(R^2 + X^2} = \sqrt{(10^2 + 6.3^2)} = 11.8 \text{ ohms.}$$

For a delta connected system, according to equation

$V_L = V_P$.

Thus $V_P = 400V$.

Hence the phase current is given by

$$I_P = \frac{V_P}{Z} = \frac{400}{11.8} = 33.9 \text{ A.}$$

But for a delta connected system, according to equation,

$I_L = \sqrt{3} I_P = \sqrt{3}$ x 33.9 = 58.7A.

Application of star and delta connection with balanced loads

An important application is the `star-delta change over switch' or star-delta starter.

For a particular three-phase load, the line current in a delta connection is three times as great as for a star connection for a given line voltage, i.e. for the same three-phase load (D line current) = 3 (Y - line current).

This fact is used to reduce the high starting current of a 3-phase motor with a star-delta change over switch.

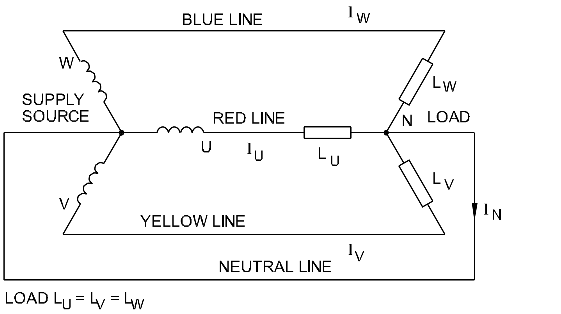
Application of star connection: Alternators and secondoary of distribution transformers, have their three, single-phase coils interconnected in star.

Neutral in 3-phase system

Objectives: At the end of this lesson you shall be able to
- **explain the current in neutral of a 3-phase star connection**
- **state the method of producing artificial neutral in a 3-phase delta connection**
- **state the method of earthing the neutral**
- **explain the behaviour of 3ϕ system when neutral open.**

Neutral: In a three-phase star connection, the star point is known as neutral point, and the conductor connected to the neutral point is referred as neutral conductor (Fig 1).

Fig 1



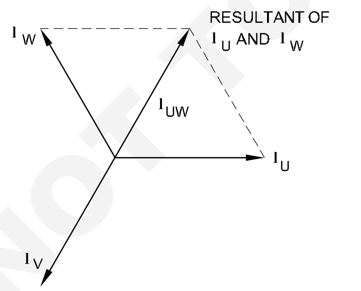
THREE-PHASE SUPPLY AND LOAD

Current in the neutral conductor: In a star-connected, four-wire system, the neutral conductor N must carry the sum of the currents I_U, I_V and I_W. One may, therefore, get the impression that the conductor must have sufficient area to carry a particularly high current. However, this is not the case, because this conductor is required to carry only the phasor sum of the three currents.

I_N = phasor sum of I_U, I_V and I_W

Fig 2 shows this phasor addition for a situation where the loads are balanced and the currents are equal. The result is that the current in the neutral line I_N is zero. This can also be shown for the other instantaneous values.

Fig 2

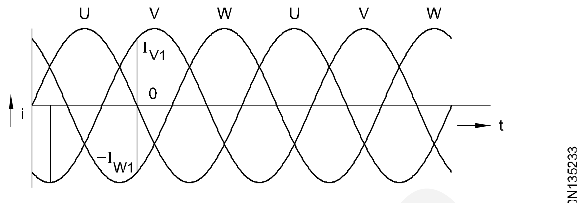


FOR A BALANCED LOAD THE RESULTANT OF I_W AND I_U IS EQUAL IN MAGNITUDE BUT OPPOSITE TO I_V.

At a particular instant in time, t_1, the instantaneous value i_U= 0 (Fig 3), i_V and i_W, have equal magnitudes, but they have opposite signs,i.e. they are in opposition and the phasor sum is zero. Taking the other values of t, it can be seen that the sumof the three phase currents to equal to zero.

Therefore, for a balanced load the neutral conductor carries no current.

Fig 3



RESULTANT OF THREE-PHASE CURRENTS

With unequal value the phase currents are different in magnitude and the neutral current is not zero. Then a `neutral' current I_N does flow in the neutral conductor, but this, however, is less than any of the supply line currents. Thus, neutral conductors, when they are used, have a smaller cross-section than the supply lines.

Effect of imbalance: If the load is not balanced and there is no neutral conductor, there is no return path for the sum of the phase currents which will be zero. The phase voltages will not now be given by the line voltage divided by $\sqrt{3}$, and will have different values.

Earthing of neutral conductor: Supply of electrical energy to commercial and domestic consumers is an important application of three-phase electricity. For `low voltage distribution' - in the simplest case, i.e. supply of light and power to buildings - there are two requirements.

1 It is desirable to use conductors operating at the highest possible voltage but with low current in order to save on expensive conductor material.

2 For safety reasons, the voltage between the conductor and earth must not exceed 250V.

A voltage distribution system according to criterion 2, only possible with a low line voltage below 250 V. However, this is contrary to criterion 1. On the other hand, with a star connection, a line voltage of 415V is available. In this case, there is only 240V between the supply line and the neutral conductor. Criterion 1 is satisfied and, to comply with 2, the neutral conductor is earthed.

Indian Electricity Rules: I.E.Rules insist that the neutral conductor must be earthed by two separate and distinct connections to earth. Rule No.61(1)(a), Rule No.67(1)(a) and Rule No.32 insist on the identification of neutral at the point of commencement of supply at the consumer's premises, and also prevent the use of cut outs or links in the neutral conductor. BIS stipulate the method of earthing the neutral. (Code No.17.4 of IS 3043-1966)

Cross-sectional area of neutral conductor: The neutral conductor in a 3-phase, 4-wire system should have a smaller cross-section. (half of the cross-section of the supply lines).

Artificial neutral: Normally neutral conductors are available with a 3-phase, 4-wire system only. Neutral conductors are not drawn for a 3-phase, 3-wire system. Neutral conductors are also not available with the delta-connected supply system.

A neutral conductor is required for measuring phase voltage, energy, power to connect indicating lamps, etc. An artificial neutral for connecting indicating lamps can be formed by connecting them in star. (Fig 4) Artificial neutral for instruments can be formed by connecting additional resistors in star. (Fig 5)

Fig 4

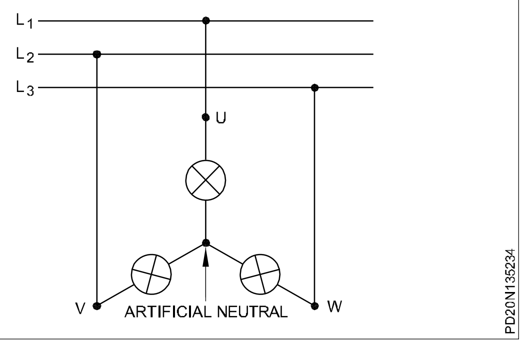
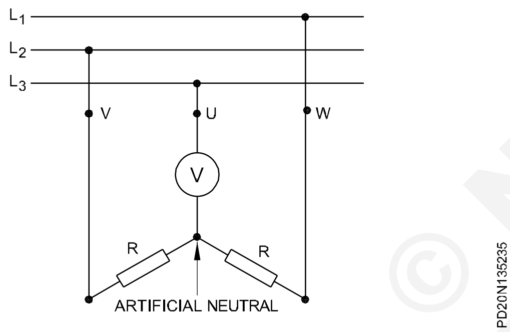


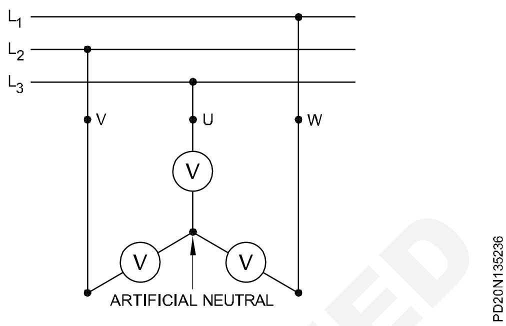
Fig 5



In this method, the value of R must be equal to the resistance of the voltmeter. The same method can be used while measuring power or energy by connecting resistors of equal resistance as of potential coil.

When three instruments of a similar kind are in use, their pressure coils can be connected to form an artificial neutral. (Fig 6)

Fig 6



This type of neutral cannot allow a large current. When earthing of a delta-connected system is required, neutral earthing compensators are used. These can sink or source large currents while keeping neutral to phase voltages constant.

IS 3043 Code No.17, provide a method to obtain neutral for earthing purposes by an earthing compensator.

Power in star and delta connections

Objectives: At the end of this lesson you shall be able to
- **explain active, appparent and reactive power in AC 3 phase ϕ**
- **explain behaviour of unbalanced and balance load**
- **state the method of earthing the neutral**
- **determine the power in 3-phase star and delta connected balanced load.**

Fig 1 shows the load of three resistances in a star connection. So the power must be three times as great as the single phase power.

$$P = 3V_pI_p.$$

If the quantities V_P and I_P in the individual phases are replaced by the corresponding line quantities V_L and I_L respectively, we obtain:

$$P = 3\frac{V_L}{\sqrt{3}}I_L.$$

(Because $V_P = V_L \div \sqrt{3}$ and $I_p = I_L$)

Since $3 = \sqrt{3} \times \sqrt{3}$, this equation can be simplified to the form

$$P = \sqrt{3}\, V_L I_L$$

Note that power factor in resistance circuit is unity. Hence power factor is not taken into account.

Quantity	P	V_L	I_L
Unit	W	V	A

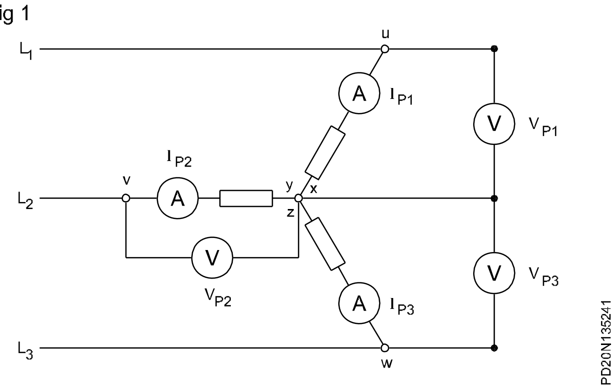
The power in this purely resistive load(ϕ=0°, cosϕ= 1) is entirely active power which is converted into heat. The unit of active power is the watt (W).

As the last formula shows, three-phase power in a star-connected load circuit can be calculated from the line quantities, and there is no need to measure the phase quantities.

$P = \sqrt{3}\, V \times I$ (Formula holds good for pure resistive load)

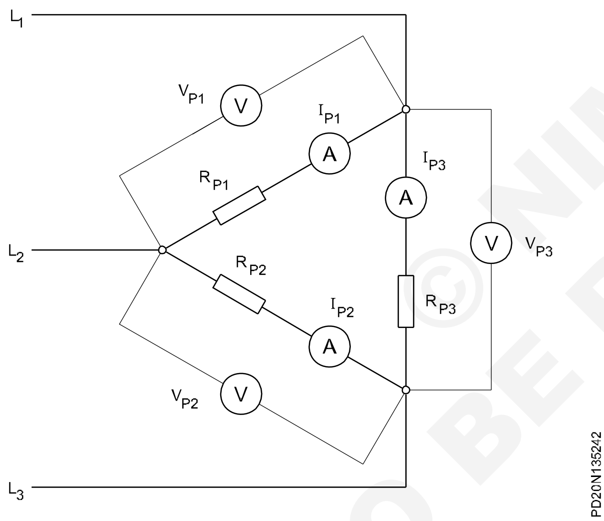
It is always possible, in practice, to measure the line quantities but the accessibility of the star point cannot always be guaranteed, and so it is not always possible to measure the phase voltages.

Fig 1



Three-phase power with a delta-connected load: Fig 2 shows the load of three resistances connected in delta. Three times the phase power will be dissipated.

Fig 2



$$P = 3P_P = 3V_P I_P$$

If the quantities V_P and I_P are replaced by the corresponding line quantities V_L and I_L, we obtain:

Since, $V_L = V_P$

$I_L = \sqrt{3}\, I_P$ and $I_P = \dfrac{I_L}{\sqrt{3}}$

but since $3 = \sqrt{3} \times \sqrt{3}$ this equation can be simplified to the form:

$P = \sqrt{3}\ _L I_L$.(Formula holds good for pure resistive load)

If we compare the two power formulae for the star and delta connections, we see that the same formula applies to both. In other words, the way in which the load is connected has no effect on the formula to be used, assuming that the load is balanced.

Active,reactive and apparent power: As you already know from AC circuit theory, load circuits which contain both resistance and inductance, or both resistance and capacitance, take both active and reactive power because of the phase difference existing between the voltage and current in them. If these two components of power are added geometrically, we obtain the apparent power. Precisely the same happens in each phase of the three-phase systems. Here we have to consider the phase difference f between the voltage and current in each phase.

Applying the factor $\sqrt{3}$ the components of power in a three-phase system follow from the formulae derived for single-phase, AC circuits, namely:

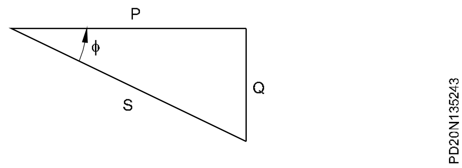
Apparent power	$S = VI$	$S = \sqrt{3}\, V_L I_L$	VA
Active power	$P = VI \cos\phi$	$P = \sqrt{3}\, V_L I_L \cos\phi$	W
Reactive power	$Q = VI \sin\phi$	$Q = \sqrt{3}\, V_L I_L \sin\phi$	var

Finally, the well known relationships found in single-phase AC circuits apply also to three-phase circuits.

$$\cos\phi = \frac{\text{active power}}{\text{apparent power}} = \frac{P}{S}$$

$$\sin\phi = \frac{\text{reactive power}}{\text{apparent power}} = \frac{Q}{S}$$

Fig 3



This can also be seen from Fig 3.

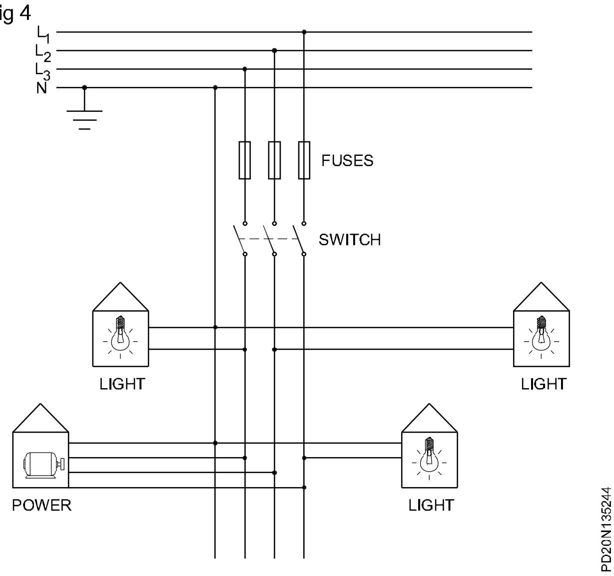
Cos ϕ is called the power factor, while sin ϕ is sometimes called the reactive power factor.

Unbalanced load: The most convenient distribution system for electrical energy supply is the 415/240 V four-wire, three-phase AC system.

This offers the possibility of supplying three-phase, as well as single-phase current, to users simultaneously. Supply to buildings can be arranged as in the given example. (Fig 4)

The individual houses utilize one of the phase voltages. L_1, L_2 and L_3 to N are distributed in sequence (light current). However, large loads (eg.three-phase AC motors) may be fed with the line voltage (heavy current).

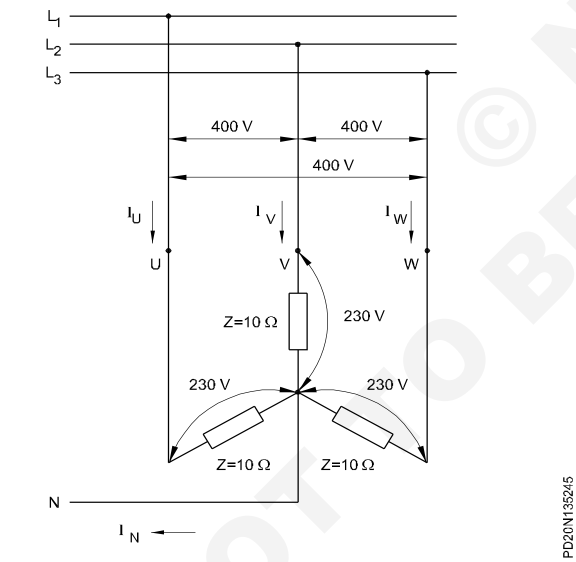
Fig 4



However, certain equipment which needs single or two phase supply can be connected to the individual phases so that the phases will be differently loaded, and this means that there will be unbalanced loading of the phases of the four-wire, three-phase network.

Balanced load in a star connection: In a star connection, each phase current is determined by the ratio of phase voltage and load impedance `Z'.

Fig 5



This fact will now be confirmed by a numerical example.

A star-connected load consisting of impedances `Z' each of 10 ohms, is connected to a three-phase network with line voltage V_L = 415V. (Fig 5)

Because of the arrangements of a star connection, the phase voltage is 240V (415/ $\sqrt{3}$).

The three load currents taken froms supply have the same magnitude since the star-connected load is balanced, and they are given by

$$I_U = I_V = I_W = V_P \div Z.$$

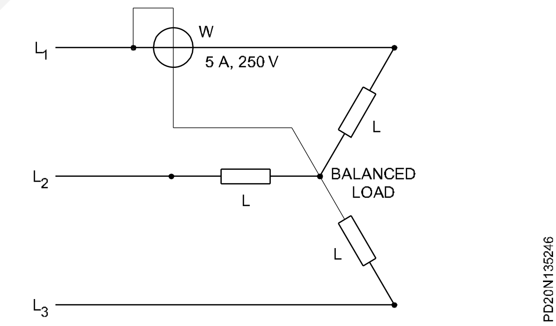
The measurement of power: The number of wattmeters used to obtain power in a three-phase system depends on whether the load is balanced or not, and whether the neutral point, if there is one, is accessible.

- Measurement of power in a a star-connected balanced load with neutral point is possible by a single wattmeter.
- Measurement of power in a star or delta-connected, balanced or unbalanced load (with or without neutral) is possible with two wattmeter method.

Single wattmeter method: Fig 6 shows the circuit diagram to measure the three-phase power of a star-connected, balanced load with the neutral point accessible the current coil of the wattmeter being connected to one line, and the voltage coil between that line and neutral point. The wattmeter reading gives the power per phase. So the total is three times the wattmeter reading.

$$\text{Power/phase} = 3V_P I_P \cos\theta = 3P = 3W.$$

Fig 6



The two-wattmeter method of measuring power

Objectives: At the end of this lesson you shall be able to:
- **measure 3-phase power using two single phase wattmeter**
- **calculate power factor from meter reading.**
- **explain the `two-wattmeter' method of measuring power in a three-phase, three-wire system**

Power in a three-phase, three-wire system is normally measured by the `two-wattmeter' method. It may be used with balanced or unbalanced loads, and separate connections to the phases are not required. This method is not, however, used in four-wire systems because current may flow in the fourth wire, if the load is unbalanced and the assumption that $I_U + I_V + I_W = 0$ will not be valid.

The two wattmeters are connected to the supply system as shown in Fig 1. The current coils of the two wattmeters are connected in two of the lines, and the voltage coils are connected from the same two lines to the third line. The total power is then obtained by adding the two readings:

$$P_T = P_1 + P_2.$$

Fig 1

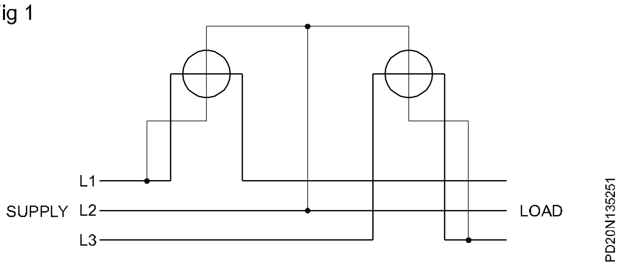
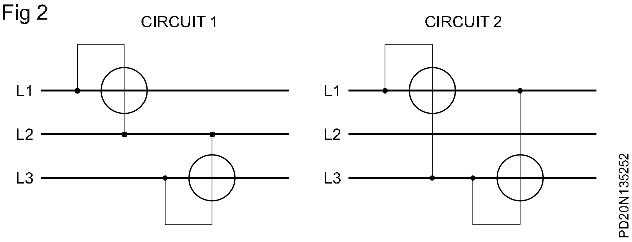


Fig 2



Consider the total instantaneous power in the system $P_T = P_1 + P_2 + P_3$ where P_1, P_2 and P_3 are the instantaneous values of the power in each of the three phases.

$$P_T = V_{UN}\, i_U + V_{VN}\, i_V + V_{WN}\, I_W$$

Since there is no fourth wire, $i_U + i_V + i_W = 0$; $i_V = -(i_U + i_W)$.

$$P_T = V_{UN} i_U - V_{VN}(i_U + i_W) + V_{WN}\, i_W$$
$$= i_U(V_{UN} - V_{VN}) + i_W(V_{WN} - V_{UN})$$
$$= i_U V_{UV} + i_W V_{WV}$$

Now $i_U V_{UV}$ is the instantaneous power in the first wattmeter, and $i_W V_{WV}$ is the instantaneous power in the second wattmeter. Therefore, the total mean power is the sum of the mean powers read by the two wattmeters.

It is possible that with the wattmeters connected correctly, one of them will attempt to read a negative value because of the large phase angle between the voltage and current for that instrument. The current coil or voltage coil must then be reversed and the reading given a negative sign when combined with the other wattmeter readings to obtain the total power.

At unity power factor, the readings of two wattmeter will be equal. Total power = 2 x one wattmeter reading.

When the power factor = 0.5, one of the wattmeter's reading is zero and the other reads total power.

When the power factor is less than 0.5, one of the wattmeters will give negative indication. In order to read the wattmeter, reverse the pressure coil or current coil connection. The wattmeter will then give a positive reading but this must be taken as negative for calculating the total power.

When the power factor is zero, the readings of the two wattmeters are equal but of opposite signs.

Self-evaluation test

1 Draw a general wiring diagram for the two-wattmeter method of three-phase power measurement.

2 Why is it desirable, in practice, to use the two-wattmeter method? (Fig 2)

3 Why can the two-wattmeter method not be used in a three-phase, four-wire system with random loading?

4 Which of the above circuits is used for the two-wattmeter method of power measurement?

Power factor calculation in the two-watmeter method of measuring power

As you have learnt in the previous lesson, the total power $P_T = P_1 + P_2$ in the two-wattmeter method of measuring power in a 3-phase, 3-wire system.

From the readings obtained from the two wattmeters, the tan f can be calculated from the given formula

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}$$

from which f and power factor of the load may be found.

***Example 1**:* Two wattmeters connected to measure the power input to a balanced three-phase circuit indicate 4.5 KW and 3 KW respectively. Find the power factor of the circuit.

Solution

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}$$

$P_1 = 4.5$ KW

$P_2 = 3$ KW

$P_1 + P_2 = 4.5 + 3 = 7.5$ KW

$P_1 - P_2 = 4.5 - 3 = 1.5$ KW

$$\tan\phi = \frac{\sqrt{3} \times 1.5}{7.5} = \frac{\sqrt{3}}{5} = 0.3464$$

$\phi = \tan^{-1} 0.3464 = 19^0 6'$

Power factor Cos $19^0 6' = 0.95$

***Example 2**:* Two wattmeters connected to measure the power input to a balanced three-phase circuit indicate 4.5 KW and 3 KW respectively. The latter reading is obtained after reversing the connection of the voltage coil of that wattmeter. Find the power factor of the circuit.

Solution

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}$$

$$= \frac{\sqrt{3}(4.5 - (-3))}{(4.5 + (-3))}$$

$$= \frac{\sqrt{3}(4.5 + 3)}{(4.5 - 3)}$$

$$= \frac{\sqrt{3} \times 7.5}{1.5} = \sqrt{3} \times 5$$

$$= 1.732 \times 5 = 8.66.$$

$\phi = \tan^{-1} 8.66 = 83^\circ.27'$

since power factor (Cos $83^\circ 27'$) = 0.114.

Question 1: The reading on the two wattmeters connected to measure the power input to the three-phase, balanced load are 600W and 300W respectively.

Calculate the total power input and power factor of the load.

Question 2: Two wattmeters connected to measure the power input to a balanced, three-phase load indicate 25KW and 5KW respectively.

Find the power factor of the circuit when (i) both readings are positive and (ii) the latter reading is obtained after reversing the connections of the pressure coil of the wattmeter.

Solution

1 Total power = $P_T = P_1 + P_2$

P_1 = 600W.

P_2 = 300W.

P_T = 600 + 300 = 900 W

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(600 - 300)}{600 + 300} = \frac{\sqrt{3} \times 300}{900}$$

$$= \frac{\sqrt{3}}{3} = \frac{1}{\sqrt{3}} = 0.5774$$

$\phi = \tan^{-1} 0.5774 = 30^\circ$

Power factor = Cos 30° = 0.866.

2 a) P_1 = 25 KW

P_2 = 5 KW

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(25 - 5)}{25 + 5}$$

$$= \frac{\sqrt{3} \times 20}{30} = \frac{\sqrt{3} \times 2}{3} = \frac{2}{\sqrt{3}} = 1.1547$$

$\phi = \tan^{-1} 1.1547 = 49^\circ 6'$

Power factor ($\cos\phi$) = Cos $49^\circ 6'$ = 0.6547

b) P_1 = 25 KW

P_2 = –5 KW

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(25 - (-5))}{25 + (-5)}$$

$$= \frac{\sqrt{3}\ (25 + 5)}{25 - 5} = \frac{\sqrt{3} \times 30}{20}$$

$$= \frac{\sqrt{3} \times 3}{2} = 2.5980$$

$\phi = \tan^{-1} 2.5980 = 68^\circ 57'$

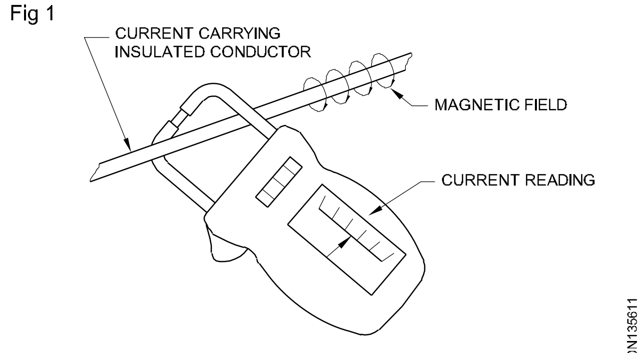
Power factor = Cos $68^\circ 57'$ = 0.3592

Tong - tester (clamp - on ammeter)

Objectives: At the end of this lesson you shall be able to
- **state the necessity of tong-testers**
- **state the construction and working of a tong-tester**
- **state the precautions to be observed while using a tong-tester.**

A tong-tester is an instrument devised for the measurement of A.C current, without interrupting the circuit. It is also called clip-on ammeter, or sometimes a clamp-on ammeter (Fig 1).

Fig 1



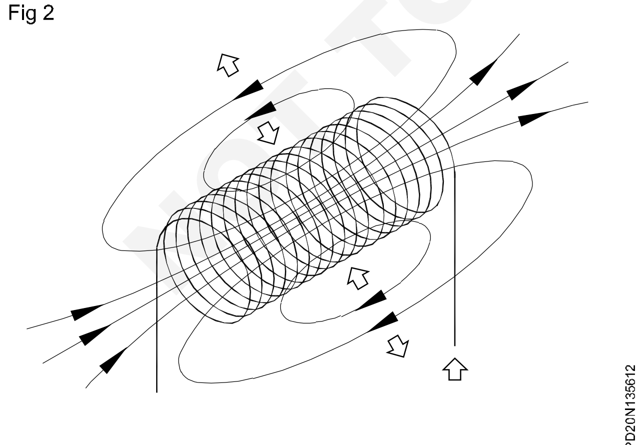
TONG-TESTER

Working principle

The instrument can function only when current passes through its deflecting system. It works under the mutual induction principle.

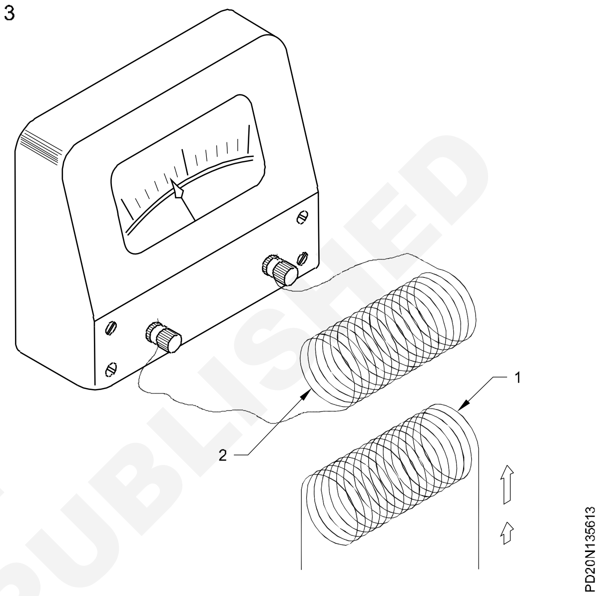
Electromagnetic induction: When a changing flux is linked with the coil, an emf is induced in the coil. The current in a coil so produced changes as that of the changing magnetic flux. If an alternating current is flowing through the coil, the magnetic flux produced is also alternative i.e. changing continuously.(Fig 2)

Fig 2



Placing another coil (2) in the changing flux of coil (1), an emf will be induced. (Fig 3)

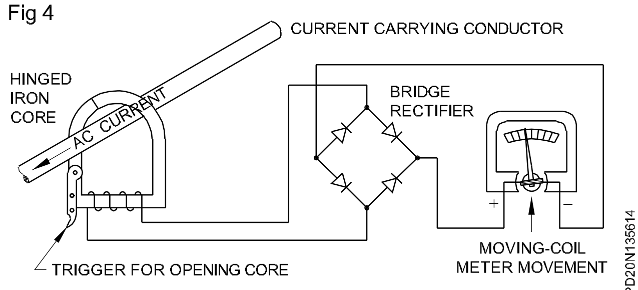
Fig 3



This induced emf will send the current, causing deflection of the meter. Introduction of a magnetic core between the coils increases the induced emf. The coil (1) is called primary and the coil (2) is called secondary.

Construction: Fig 4 shows a tong-tester (the clamp-on ammeter) circuit. The split-core meter consists of a secondary coil with the split-core and a rectifier type instrument connected to the secondary. The current to be measured in the conductor serves as the primary of one turn coil. It induces a current in the secondary winding and this current causes the meter to deflect.

Fig 4



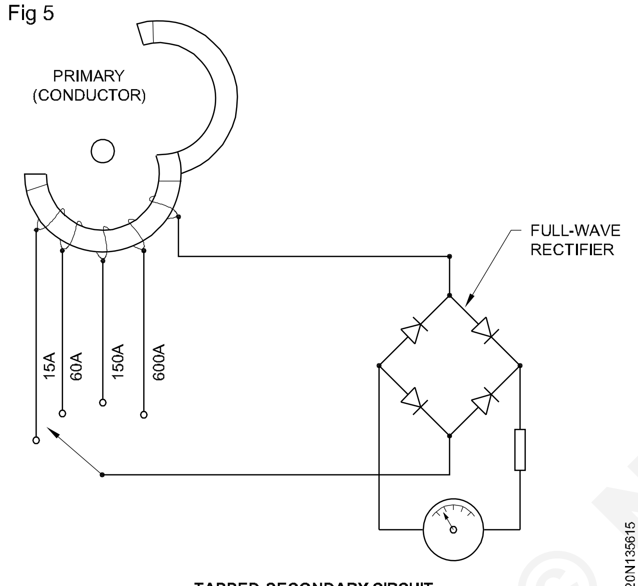
The core is so designed that there is only one break in the magnetic path. The hinge and the opening both fit tightly when the instrument closes around the conductor. The tight fit of the instrument ensures minimum variation in the response of the magnetic circuit.

To measure current with a clamp-on meter, open the jaws of the instrument and place them around the conductor in which you want to measure the current. Once the jaws are in place, allow them to close securely. Then, read the indicator position on the scale.

When the core is clamped around a current-carrying conductor, the alternating magnetic field induced in the core, produces a current in the secondary winding.

This current causes a deflection on the scale of the meter movement. The current range can be changed by means of a `range switch', which changes the taps on the transformer secondary (Fig 5).

Fig 5



TAPPED-SECONDARY CIRCUIT

Safety: The secondary winding of the current transformer should always be either shunted or connected to the ammeter; otherwise, dangerous potential differences may occur across the open secondary.

Before taking any measurement, make sure the indication is at zero on the scale. If it is not, reset by the zero-adjustment screw. It is usually located near the bottom of the meter.

Looping the conductor more than once through the core is another means of changing the range. If the current is far below the meter's maximum range, we can loop the conductor through the core two or more times (Fig 6).

Application

1 For measuring the incoming current in the main panel board.

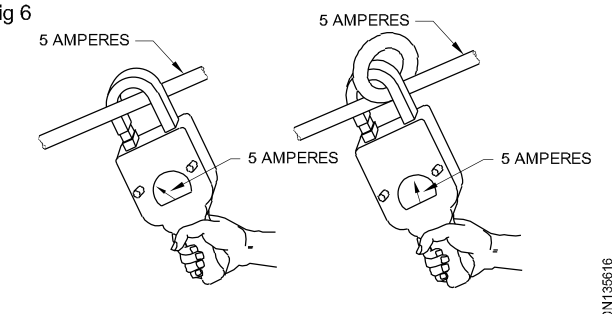
2 Primary current of AC welding generators.

3 Secondary current of AC welding generators.

4 Newly rewinded AC motor phase current and line current.

5 Starting current of all AC machines.

Fig 6



SINGLE PASS DOUBLE PASS

6 Load current of all AC machines and cables.

7 For measuring the unbalanced or balanced loads.

8 For finding the faults in AC, 3-phase induction motors.

Precaution

1 Set the ampere range from higher to low if the measuring value is not known.

2 The ampere-range switch should not be changed when the clamp is closed.

3 Before taking any measurement make sure the indication is at zero on the scale.

4 Do not clamp on a bare conductor for current measurement.

5 Seating of the core should be perfect.

Basic concept of digital Multifunction Meter

Multifunction meter: Types, working and its application

A Multifunction Meter or MFM is basically used for monitoring electrical installations. Like voltage, current, active power, reactive power, apparent power, power factor, active energy, phase angle, harmonic distortion, etc.

The biggest advantage of a multifunction meter is it can measure three phases at the same time

Working principle of a Multifunction Meter

Unlike popular belief, the working principle of a multifunction meter is very different from that of a traditional induction meter.

A multifunction meter is much more 'intelligent' in comparison. It samples user power supply voltage and current in real-time and then uses a special electronic circuit including a microcontroller to process the sampled voltage and current signals.

This is then converted into electrical energy. The pulse output (when provided) is proportional to the final processed signals (kWh units). What industries use multifunction meters?

Multifunction meters are widely used in the industry in Motor control centers, control panels, gen set panels, power distribution panels across India and the world.

Basic concept of accuracy class of meters

An accuracy class in an electricity meter refers to the level of precision with which the meter measures the amount of electricity consumed by a consumer. The class is typically represented by a letter, with Class A meters being the most accurate, followed by Class B, and so on. The accuracy of a meter is usually specified as a percentage of reading over a certain range of loads. For example, a Class A meter may be accurate to within 0.2% of the actual consumption over a range of 1% to 120% of the full-scale reading.

The accuracy class of an electric meter is usually marked on the nameplate.

If not stated the meter is usually a class 2 meter (which allows ± 2½ %)

Most normal domestic single phase electro-mechanical meters are class 2.0 solid state meters are often class 1.0

It means that a maximum error of ± 2 or ± 1 % is allowed over the full load range of the meter. Most meters are well within the 0.5 % error margin.

Three phase installations 63 or 100 Amps may have class 1.0 or class 2.0 meters fitted.

Special meters on large customers are often class 0.5s or 0.2s These meters are often connected to current transformers and voltage transformers.

Communication from MFM to SCADA system

Most of the energy meters and multi-function meters installed for measuring the energy consumption (Energy, Power, Power factor) in a household or any other commercial buildings communicate to the centralized SCADA systems using RS-485 standard of serial communication.

Index Terms-Multi Function Meter, RS-485 Standard, Modbus Protocol, Serial Communication, SCADA, Smart building

Energy monitoring involves various technologies such as data collection, communication, and databases.

Majority of existing buildings already have the multifunction meters. RS485 is one of the most optimal communication. In the present scenario many existing buildings are aiming to install energy monitoring system so as to move towards the concept of smarter buildings.

Smart building is a system of interconnected systems which has high-level control and sensors along with automation, communication, and analytics capabilities.

Data extraction from multi-function meters have RS485 protocol. On the micro controller, software is installed which can communicate with the meters using the RS485 Modbus protocol in RTU mode and read the data from the slave meters.

Capacitor Bank

Capacitor bank is an assembly of number of capacitors which are used to contribute kVAr in the elctrical system and finally improve the power factor. Shunt capacitors bank are arrangements of series/paralleled connected units.

a Groundded Wye - Connected Banks

Grounded wye capacitor banks are composed series and parallel-connected capacitor units per phase provide a low o\impedance path to ground. Fig 3 shows typical bank arrangements.

b Ungrounded Wye - Connected Banks

Typical bank arrangements of Ungrounded Wye SCB are shown in Fig 4. Ungrounded wye banks do not permit zero sequence currents, third harmonic currents or large caapcitor discharge currents during system ground faults to flow.

i Multiple units in series phase to neutral

ii Multiple units in series phase to neutral

Double Wye

When a capacitor bank becomes too larger for the maximum 4650 kVAr per group the bank may be split into two wye sections.

Resistors - Colour Codes , types and Characteristics

Objectives: At the end of this lesson you shall be able to
- **explain the construction and characteristics of various types of resistors**
- **explain the functions and applications of the resistors in electronic circuits.**

Resistors: These are the most common passive component used in electronic circuits. A resistor is manufactured with a specific value of ohms (resistance). The purpose of using a resistor in circuit is either to limit the current to a specific value or to provide a desired voltage drop (IR). The power rating of resistors may be from 0.1 W. to hundreds of Watts.

There are four types of resistors

1 Wire-wound resistors

2 Carbon composition resistors

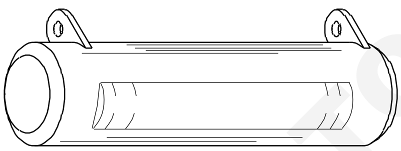
3 Metal film resistors

4 Carbon film resistors

1 Wire-wound resistors

Wire-wound resistors are manufactured by using resistance wire (nickel-chrome alloy called Nichrome) wrapped around an insulating core, such as ceramic porcelain, bakelite pressed paper etc.Fig 1, shows this type of resistor.The bare wire used in the unit is generally enclosed in insulating material. Wire wound resistors are used for high current application. They are available in wattage ratings from one watt to 100 watts or more. The resistance can be less than 1 ohm and go up to several thousand ohms. They are also used where accurate resistance values are required.

Fig 1



WIRE-WOUND FIXED RESISTOR

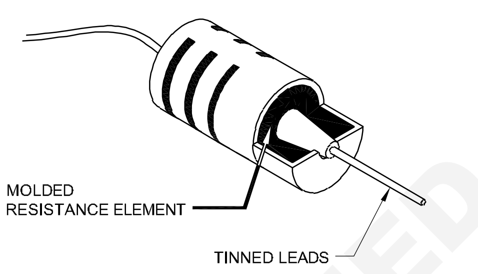
One type of Wire-wound resistor is called as fusible resistor enclosed in a porcelain case. The resistance is designed to open the circuit when the current through it exceeds certain limit.

2 Carbon composition resistors

These are made of fine carbon or graphite mixed with powdered insulating material as a binder in the proportion needed for the desired resistance value. Carbon-resistance elements are fixed with metal caps with leads of tinned copper wire for soldering the connection into a circuit. Fig 2 shows the construction of carbon composition resistor.

Carbon resistor are available in values of 1 ohm to 22 megohms and of different power ratings, generally 0.1, 0.125, 0.25, 0.5 and 2 watts.

Fig 2



CARBON COMPOSITION RESISTOR

3 Metal film resistors (Fig 3)

Metal film resistors are manufactured by two processes. Thick film resistors are pasted with metal compound and powdered glass which are spread on the ceramic base and then backed.

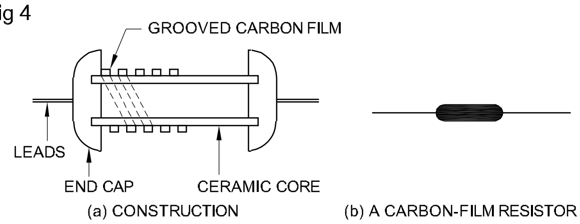
Fig 3

METAL FILM RESISTOR

Thin film resistors are processed by depositing a metal vapour on a ceramic base. Metal film resistors are available from 1 ohm to 10 MΩ, upto 1W. Metal film resistors can work from 120°C to 175°C.

4 Carbon film resistors (Fig 4)

Fig 4



CARBON – FILM RESISTOR

In this type, a thin layer of carbon film is deposited on the ceramic base/tube. A spiral groove is cut over the surface to increase the length of the foil by a specialised process.

Carbon film resistors are available from 1 ohm to few Meg ohm and up to 2W and can work from 85°C to 155°C.

All the above four types of resistors are coated with synthetic resin to protect them against mechanical damages and climatic influences, It is therefore, difficult to distinguish them from each other externally.

Specification of resistors: Resistors are specified normally with the four important parameters

1 Type of resistor

2 Nominal value of the resistors in ohm (or) kilo ohm (or) mega ohm.

3 Tolerance limit for the resistance value in percentage.

4 Loading capacity of the components in wattage

Example

100 ± 10% , 1W, where as nominal value of resistance is 100Ω.

The actual value of resistance may be between 90 Ω to 110 Ω, and the loading capacity is maximum 1 watt.

The resistors can also be classified with respect to their function as

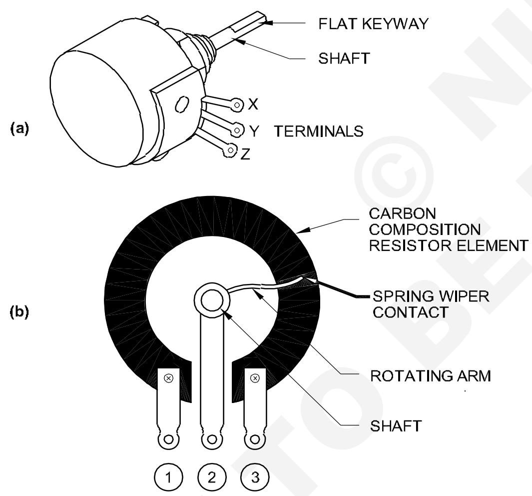
1 Fixed resistors

2 Variable resistors

Fixed resistors : The fixed resistors is one in which the nominal value of resistance is fixed. These resistors are provided with pair of leads. (Fig 2 to 4)

Variable resistors (Fig 5) : Variable resistors are those whose values can be changed. Variable resistors includes those components in which the resistance value can be set at the different levels with the help of sliding contacts. These are known as potentiometer resistors or simply as a potentiometers.

Fig 5



VARIABLE CARBON-RESISTANCE (a) EXTERNAL VIEW
(b) INTERNAL VIEW OF CIRCULAR RESISTANCE ELEMENT

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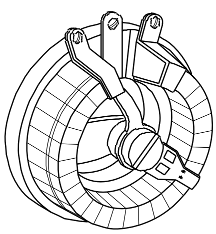
It is provided with 3 terminals as shown in Fig 5 and 14. They are available with carbon tracks (Fig 5) and wire wound (Fig 6) types. Trimmer potentiometers (or) resistor which can be adjusted with the help of a small screw driver. (Fig 7).

Fig 6



WIRE-WOUND VARIABLE RESISTOR

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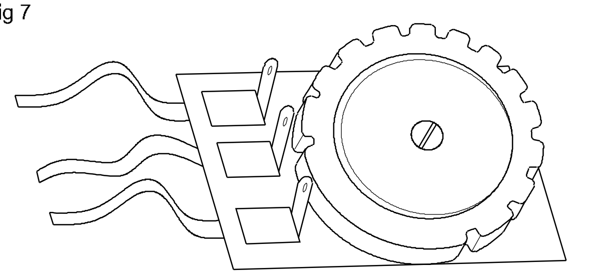
Fig 7



TRIMMER RESISTOR

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Resistance depends upon temperature, voltage, light: Special resistors are also produced whose resistance varies with temperature, voltage, and light.

PTC resistors (Sensistors) : Since, different materials have different crystal structure, the rate at which resistance increases with raising temperature varies from material to material. In PTC resistor (positive temperature coefficient resistor), as the temperature increases, the resistance increases non linearly. For example, the resistance of PTC at room temperature may be of nominal value 100 Ω when the temperature rises say 10°C, it may increase to 150 Ω and with further increase of another 10°C, it may increases to 500 Ω.

NTC Resistors (Thermistors) : In case of NTC resistors (Negative temperature co-efficient resistors) as the temperature increases, the value of resistance decreases non-linearly, For example, NTC resistor, which has nominal value of resistance is 500 Ω at room temperature may decrease to 400 Ω with the rise of 10°C temperature and further decrease to 150 Ω when the temperature rises to another 10°C.

The PTC and NTC resistors can perform switching operation at specific temperature. They are also used for measurements and temperature compensators.

VDR (Varistors) : The VDR (Voltage dependent resistor) resistance falls non-linearly with increasing voltage. For example, a VDR, may have 100 Ω resistance at 10 V, and it may decrease to 90 Ω at rise in 5V. By further increasing the voltage to another 5V, the resistance may fall to 50 Ω. The VDRS are used in voltage stabilisation, arc quenching and over voltage protection.

Light dependent resistor (LDR): The LDRs are also known as photo- conductors. In LDRs the resistance falls with increase in intensity of illumination. The phenomena is explained as the light energy frees some electron in the materials of the resistors, which are then available as extra conducting electrons. The LDR shall have exposed surface to sense the light. These are used for light barriers in operating relays. These are also used for measuring the intensity of light.

Marking codes for resistors

Commercially, the value of resistance and tolerance value are marked over the resistors by colour codes (or) letter and digital codes.

Resistance and tolerance value of colour coded resistors.

The colour codes for indicating the values to two significant figure and tolerances are given in Table 1 as per IS:8186.

Table 1

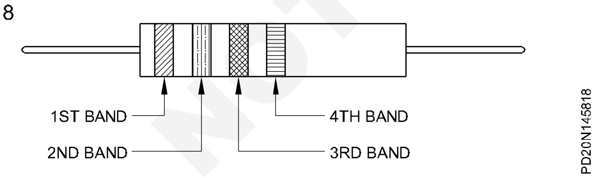
Values to two significant figures and tolerances corresponding to colours

Colour	**First Band/ Dot**	**Second Band/ Dot**	**Third Band/ Dot**	**Fourth Band/ Dot**
	First Figure	**Second Figure**	**Multiplier**	**Tolerance**
Silver	—	—	10^{-2}	± 10 %
Gold	—	—	10^{-1}	± 5 %
Black	—	0	1	—
Brown	1	1	10	± 1 %
Red	2	2	10^{2}	± 2 %
Orange	3	3	10^{3}	—
Yellow	4	4	10^{4}	—
Green	5	5	10^{5}	—
Blue	6	6	10^{6}	—
Violet	7	7	10^{7}	—
Grey	8	8	10^{8}	—
White	9	9	10^{9}	—
None	—	—	—	± 20 %

The two significant figures and tolerances colour coded resistors have 4 bands of colours coated on the body as in Fig 8.

The first band shall be the one nearest to one end of the component resistor.The second, third and four colourbands are shown in Fig 8.

Fig 8



The first two colour bands indicate the first two digits in the numeric value of resistance. The third colour band indicates the multiplier.The first two digits are multiplied by the multiplier to obtain the actual resistance value. The forth colour band indicates the tolerance in percentage.

Example

Resistance value : If the colour band on a resistor are in the order- Red, Violet, Orange and Gold, then the value of the resistor is 27,000 ohms with +5% tolerance.

First colour	**Second colour**	**Third colour**	**Fourth colour**
Red	Violet	Orange	Gold
2	7	1000(10^3)	±5%

Tolerance value: The fourth band (tolerance) indicates the resistance range within which is the actual value falls. In the above example, the tolerance is ±5%. ±5% of 27000 is 1350 ohms. Therefore, the value of the resistor is any value between 25650 ohms and 28350 ohms. The resistors with lower value of tolerance (precision) are costlier than normal value of resistors.

For less than ten ohms, the third band will be either golden or silver.

The colours are,

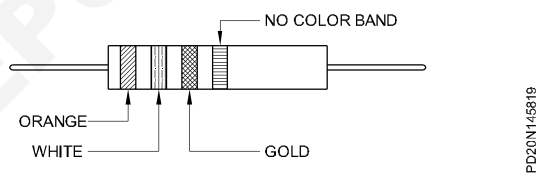
Gold -	10^{-1}	=	1/10 = 0.1
Silver -	10^{-2}	=	1/100 = 0.01

Example (Refer Fig 17)

Colour of Ist Band Orange	Colour of 2nd Band White	Colour of 3rd Band Gold
3	9	1/10

thus, the value of resistor is 39/10 or 3.9 ohms.

Fig 9



Large value resistances are expressed in kilo ohms and megohms. Letter 'k' stands for kilo and M stands for mega. One kilo equals 1000 (10^3) and one mega equals 1000000 (10^6). The resistance values are expressed as

1000 ohms	=	1 k
1800 ohms	=	1k 8
100 ohms	=	0.1 k
10000 ohms	=	0.1 M
1500000 ohms	=	1 M 5.

Preferred values for resistors: It is not possible to manufacture all values of resistors right from one ohm to a million ohms. So only a set of preferred values of resistors are generally made. Also in the manufacturing process, in which thousands of resistors are made in a day, it is not possible to adjust every ordinary resistor to an exact value. The term 'tolerance' denotes the acceptable deviation in the resistance value of a resistor. The usual specified tolerances are ±5%, ±10% and ±20% for the ordinary resistors. The precision resistors may have selected tolerances as close as ±0.1%. In each tolerance range, a set of preferred values are available refer Table 2.

Table 2

Preferred series of values for resistors with ordinary tolerances

E 24 Series Tolerance ±5 percent	E12 Series Tolerance ± 10 percent	E 6 Series Tolerance ±20 percent
1.0	1.0	1.0
1.1	—	—
1.2	1.2	—
1.3	—	—
1.5	1.5	1.5
1.6	—	—
1.8	1.8	—
2.0	—	—
2.2	2.2	2.2
2.4	—	—
2.7	2.7	—
3.0	—	—
3.3	3.3	3.3
3.6	—	—
3.9	3.9	—
4.3	—	—
4.7	4.7	4.7
5.1	—	—

Table 2 contd.

E 24 Series Tolerance ±5 percent	E12 Series Tolerance ± 10 percent	E 6 Series Tolerance ±20 percent
5.6	5.6	—
6.2	—	—
6.8	6.8	6.8
7.5	—	—
8.2	8.2	—
9.1	—	—

Letter and digit code for resistance values: In this system of coding, numbers and letter are used. Generally three or four, or five characters consisting of

1 Two figures and letters

2 Three figures and letter,

3 Four figures and letters are used as the case may be.

The letter R.K. and M. shall be used for multipliers of the resistance values expressed in ohms R = (10°) = 1, k $=10^3$ = 1000, M = 10^6 = 1 000000

For example (Fig 18)

0.1Ω is coded as R10 and 1200 Ω or 1.2k Ω is coded as 1.2 kΩ similarly 1500000 Ω or 1.5 M Ω is coded as 1 M 5.

For symmetrical tolerance in percentage the following letter shall be used for indicating tolerance of the resistance ±5% = J, ±10% = K, ±20% = M

For example (Refer Fig 18)

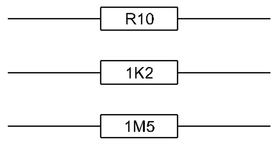
1 1.5 Ω ±10% 1 W is letter coded as K 1R51W

2 330 Ω ±20% 0.5 W is letter coded as M 330R 0.5W

3 2.7 K Ω ±5% 2W is letter coded as J 2K72W

4 1M Ω ±20% 1 W is letter coded as M 1M1W

Fig 10



LETTER CODING OF RESISTORS

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Semiconductor theory-Active and passive components

Objectives: At the end of this lesson you shall be able to
- **explain atom conductor, semiconductor, insulator and atomic structure**
- **state the function of N and P type semiconductor, PN junction, depletion region**
- **state the coding of semiconductor devices and its meaning**
- **explain active and passive components, symbols - uses.**

Atom

The very tiny fundamental unit of an element which is capable of independent existence is the atom. An atom of any element consists of a central core called Nucleus. A number of small particles called electrons move around the central core.

The nucleus contains protons and neutrons. A proton in the nucleus possess a positive electrical charge. An electron in an atom possess negative electrical charge. In normal state, the atom is electrically neutral, that is the number of electrons is equal to the number of protons in the nucleus.

For stability of materials (solids), the valence (outer most) shell of an atom should contain either 8 or more number of electrons, if it is to be complete.The above stability keeps the atoms and the molecules together in a solid state.

There are three important kinds of bonding amongst the atoms and the molecules of a solid. They are i) ionic ii) covalent and iii) metallic bonds.

Examples of solids under different bondings are,

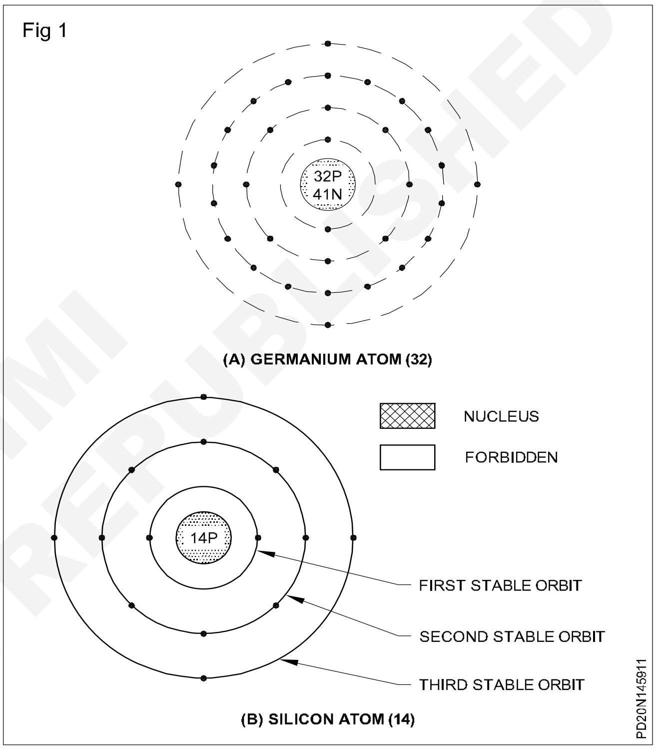
Ionic bond	:	sodium chloride
Covalent bond	:	silicon and germanium
Metallic bond	:	metals like copper

Difference between conductors insulators and semi conductors: We are familiar with conducting and insulating materials. Conducting materials are good conductors of electricity. Insulating materials are bad conductors of electricity. There is another group of materials called as semiconductors, such as germanium and silicon. These are neither good conductors nor good insulators.

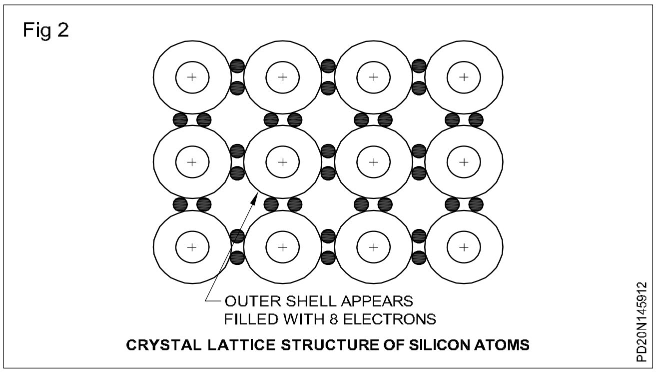
The conductors on valence electrons are always free. In an insulator the valence electrons are always bound. Whereas in semi conductors the valence electrons are normally bound but can be set free by supplying a small amount of energy. Several electronic devices are made using semi conductor materials.

Semi conductors - Atomic structure: Germanium (Ge) and silicon (Si) are examples of semi conductors. Fig 1a shows a germanium atom. In the centre is a nucleus with 32 protons. 32 revolving electrons are distributed themselves in different orbits. There are 2 electrons in the first orbit, 8 electrons in the second orbit, and 18 electrons in the third orbit. The fourth orbit is the outer or valence orbit which contains 4 electrons.

Fig 1b shows a silicon atom. It has 14 protons in the nucleus and 14 electrons in 3 orbits. There are 2 electrons in the first orbit and 8 in the second orbit. The remaining 4 electrons are in the outer or valence orbit.



In semiconductor materials, the atoms are arranged in an orderly pattern called a crystal lattice structure. If a pure silicon crystal is examined we find that the four electrons in the outer (valence) shell of an atom is shared by the neighbouring atoms as in Fig 2.

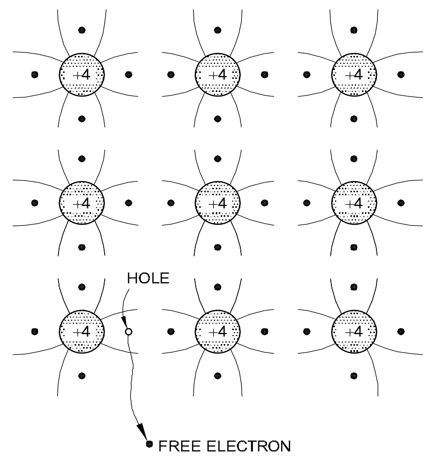


The union of atoms sharing the valence electrons is called a **covalent band**.That means a valence electron being shared by two adjacent atoms. Each atom appears to have a full outer shell of eight electrons.

Types of semiconductors : A pure semiconductor is called an intrinsic semiconductor. For example, a silicon crystal is an intrinsic semiconductor because every atom in the crystal is a silicon atom. One way to increase conductivity in a semiconductor is by **'doping'**. This means adding impurity atoms to an intrinsic semiconductor. The doped semi-conductor is known as an extrinsic semiconductor.

The residual heat at room temperature (300K) is sufficient to make a valence electron of an intrinsic semiconductor to move away from the covalent bond and then the covalent bond is broken, and the electron becomes a free electron to move in the crystal. This is shown in Fig 3.

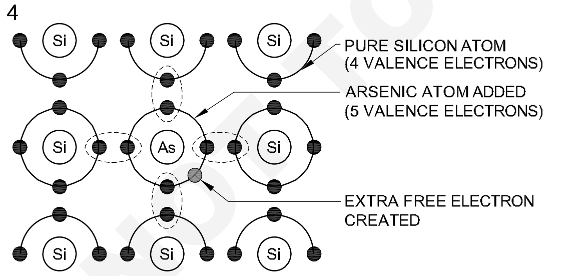
Fig 3



When an electron breaks a covalent bond and moves away, a vacancy is created in the broken covalent bond. This vacancy is called a 'hole'. A hole has a positive charge. When a free electron is liberated, a hole is created.

N - type semiconductor : A semiconductor with excess of electrons is called N-type. To obtain excess free electrons the element doped with the semiconductor material is arsenic, or antimony or phosphorus. Each of these atoms has five electrons in its outer orbit. (Fig 4)

Fig 4



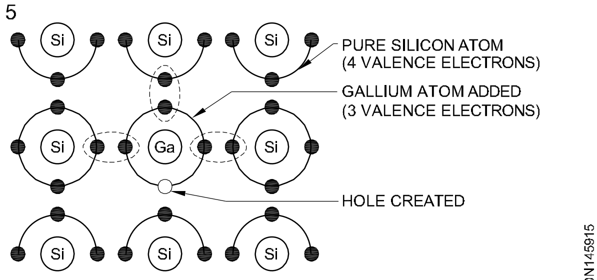
FORMATION OF 'N' TYPE SEMICONDUCTOR

Because the outer orbits of the atoms can hold eight electrons, no hole is available for the fifth electron in the arsenic atoms to move into. It, therefore, becomes a free electron. The number of such free electrons is controlled by the amount of arsenic added to the crystals.

In N-type, the free electrons are called the **majority** carriers, and the holes **minority** carriers.

P-type semiconductor : To obtain more holes, a pure silicon crystal is doped with elements such as aluminum or boron or gallium. The atoms of each of these elements have three electrons only in their outer orbit. Adding gallium to pure silicon crystals allows the atoms of the two elements to share seven electrons. (Fig 5)

Fig 5

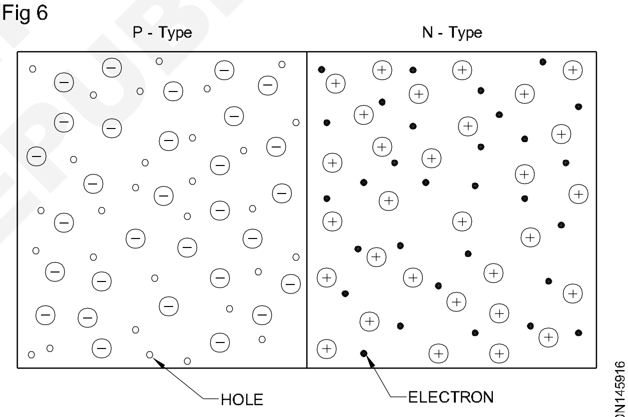


FORMATION OF 'P' TYPE SEMICONDUCTOR

A hole is created in the place of the eighth electron. Now that the number of holes exceeds the number of free electrons the substance becomes 'P' type material. The holes in P-type are the **majority** carriers, and the free electrons are the minority carriers.

PN Junction : A PN junction is formed by combining P and N type materials. The surface where they meet is called the PN junction. A PN junction is illustrated in Fig 6.

Fig 6



P – N JUNCTION

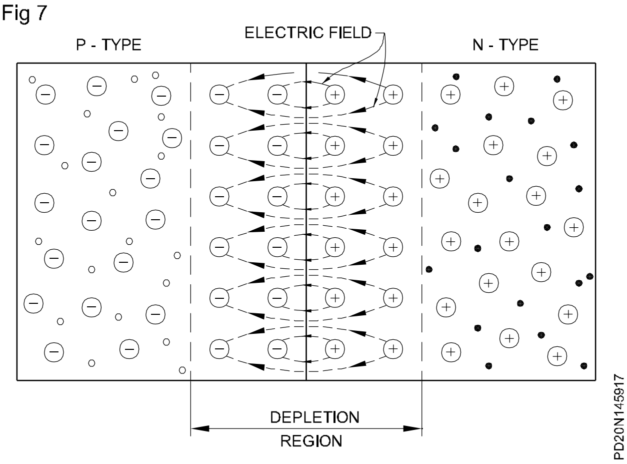
The free electrons in the N-regions diffuse across the junctions into the P-region. The free electrons lose energy and recombine with the holes in the P-regions. This recombination eliminates a free electron and a hole. When the electron moved from the N-region and diffused across the junction, it leaves the atom to be a positive ion.

The positive ion is not balanced by a negative charge in the N-region. The hole is eliminated in the P-region by recombination. The elimination of the hole and its positive charge leaves the atom to be a negative ion in the P-region.

The ions in the crystal structure are fixed and cannot move. Thus, a layer of fixed charges is formed on the two sides of the junctions. This is shown in Fig 7.

There is a layer of positively charged ions on the N-side and on the P-side of the junction there is a layer of negatively charged ions. An electric field is created across the junction between the oppositely charged ions. This is called a junction field. The junction field is also known as 'barrier'. The distance between the sides of the barrier is the 'width' of the barrier.

Fig 7



Depletion region : The carrier in the vicinity of the junction are involved in forming the junction. Once the junction field is established, no carriers can move through the junction. Hence the junction field is called 'depletion region' or 'space charge region'. This layer is called the depletion layer, because there are neither free electrons nor holes present. This depletion region prevents further movement of electrons from the N-material to the P-material and thus an equilibrium is reached.

The intensity of the field is known as 'barrier height' or 'potential' hill'. The internal voltage set up due to positive and negative ions at the junction is called barrier potential. If any more electrons have to go over from the N-side to P-side, they have to over come this barrier potential. This means, only when the electrons on the N-side are supplied with energy to overcome the barrier potential they can go over to the P-side.

In order to cancel the barrier potential and the electrons to cross over a potential difference of 0.7 V is required for a silicon diode and 0.3 V for a germanium diode. The barrier voltage is more for silicon because its lower atomic number allows more stability in the covalent bonds. The barrier potential decreases at higher temperatures.

Old system : Some earlier semiconductor diodes and transistors have type numbers, consisting of two or three letters followed by group of one, two or three figures. The first letter is always 'O', indicating a semi-conductor device.

The second (and third) letter(s) indicate the general class of the device.

A – diode or rectifier

AP– photo-diode

AZ– voltage regulator diode

C – transistor

CP– phototransistor

The group of figures in a serial number indicating a particular design or development.

Present system : This system consists of two letters followed by a serial number. The serial number may consists of three figures of one letter and two figures depending on the main application of the device.

The first letter indicates the semiconductor material used.

A Germanium

B Silicon

C Compound materials such as gallium arsenide

R Compound materials such as cadmium sulphide

The second letter indicates the general function of the device.

A detection diode, high speed diode, mixer diode

B variable capacitance diode

C transistor for I.F. applications (not power types)

D power transistor for A.F. applications (not power types)

E tunnel diode

F transistor for A.F. applications (not power types)

G multiple of dissimilar devices, miscellaneous devices

L power transistor for a.f. applications

N photo-coupler

P radiation sensitive device such as photo-diode, photo-transistor, photo-conducive cell, or radiation detector diode

Q radiation generating device such as light-emitting diode

R controlling and switching devices (e.g. thyristor) having a specified breakdown characteristic (not power types)

S transistor for switching applications (not power types)

T controlling and switching power device (e.g. thyristor) having a specified breakdown characteristic.

U power transistor for switching applications

X multiplier diode such as varactor or step recovery diode

Y rectifier diode, booster diode, efficiency diode

Z voltage reference or voltage regulator diode, transient suppressor diode.

The remainder of the type number is a serial number indicating a particular design or development, and is in one of the following two groups.

a Devices intended primarily for use in consumer applications (radio and television receivers, audio-amplifiers, tape recorders, domestic appliances, etc.) The **serial number** consists of three figures.

b Devices intended mainly for applications other than (a) e.g. industrial, professional and transmitting equipments.

The serial number consists of one letter (Z,Y,X,W etc) followed by two numbers (digits)

The International System follows letters 1N, 2N, 3N etc followed by four numbers.

1N indicates single junction

2N indicates two junction

3N indicates three junctions.

The number indicates internationally agreed manufacturer's code e.g. 1N 4007, 2N 3055, 3N 2000.

Again, manufacturers use their own codes for semiconductor devices. Manufacturers in Japan use 2SA, 2SB, 2SC, 2SD etc. followed by a group of numbers e.g. 2SC 1061, 2SA 934, 2SB 77. Indian manufacturers have their own codes too.

Passive and active electronic components

Introduction: The Components used in electronic circuits can broadly grouped under two headings.

– passive components

– active components

Passive components: Components like resistors, capacitors, and inductors used in electronic circuit are called as passive components. These components by themselves are not capable of amplifying or processing an electrical signal. However these components are equally important in electronic circuit as that of active components, without the aid of passive components, a transistor (active components) cannot be made to amplify electrical signal.

Circuits formed with passive components obey the electrical circuits laws such as ohm's law, Kirchoff's Laws etc.,

Resistors: The components whose purpose to introduce resistance in the circuit is called as resistors. Other details of resistors are dealt in earlier lessons.

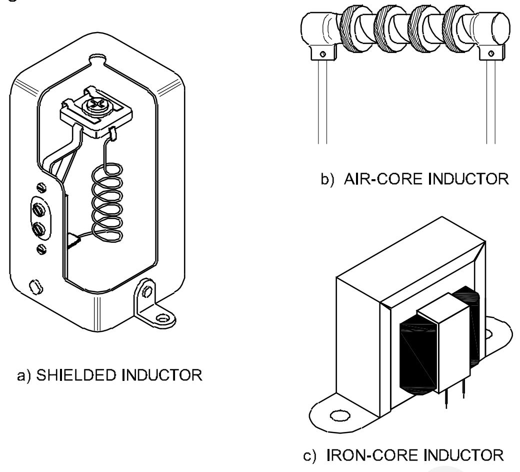
Capacitor: The components whose purpose to introduce capacitance in the circuit is called as capacitor. The unit of capacitance is 'FARAD'. Commercially capacitors are available in Microfarad (μF), Nanofarad (nF) and Picofarads (pF).

The colour coding of capacitors and resistors are same. Where as, in the case of fixed capacitors, the colour coded unit shall be in Picofarads.

For letter coding, incase of capacitor, the letter 'p', 'n', 'μ' shall be used as multipliers. Where p = 10^{-12}, n= 10^{-9} and μ = 10^{-6} farads, and letter code for tolerance on capacitor is the same as in resistor.

Inductor: The ability of the conductor to induce voltage in itself, when the current changes in it is called as self inductance (or) simply inductance. A coil introduced in a circuit to have inductance is called as inductor. Different type of inductors are shown in Fig 8. The unit of inductance is "Henry". Commercially a coil may have inductance in Millihenry (10^{-3}H), or in Microhenry (10^{-6}H).

Fig 8



TYPES OF INDUCTORS

While specifying the inductance the following factors to be considered

- nominal value of inductance in Henry / Millihenry / Microhenry.
- tolerance in percentage (±5/10/20%)
- type of winding like single layer, double layer, multilayer and pie (p) etc.
- type of core like air core, iron core, ferrite core
- type of application like audio frequency (AF), Radio frequency (RF) coupling coil, filter coil etc.,

In an electronic circuit some time, it is also required to vary the inductance.

The inductance of a coil can be varied by:-

- providing tapped inductive coil, as in Fig 9 or
- adjusting the core of a coil as in Fig 10.

However, all inductor coils have inherent resistance due to the resistance of the winding wire in the coil. Further the maximum current that can be safely carried by an inductor depends upon the size of the winding wire used.

Active components

In electronic circuit, the components, other than passive are known as active components. Namely, transistors, diodes, SCRs Vacuum tubes etc.,

Active components : In electronic circuits, components other than resistors, capacitors and inductors are also used. Namely, transistors, diodes, vacuum tubes, SCRs, diacs, zener-diode (Fig 11) etc. The application of electrical circuit laws (Ohm's law etc.) in the circuit containing the above components will not give correct results. i.e. these components do not obey. Ohm's law, Kirchoff's law etc. These components are called active components.

The different active components and the method of representing them by symbols in the circuit diagram are given below (Fig 11)

The different types of diodes (Fig 12) used for specific purposes are represented by the symbols given.

Fig 9

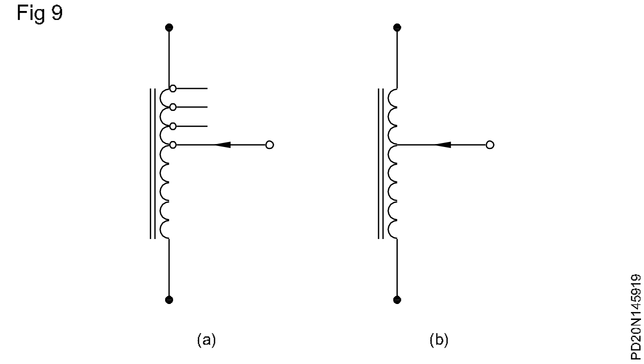


Fig 10

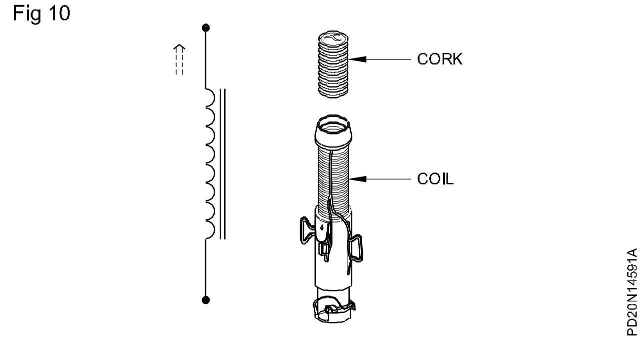


Fig 11

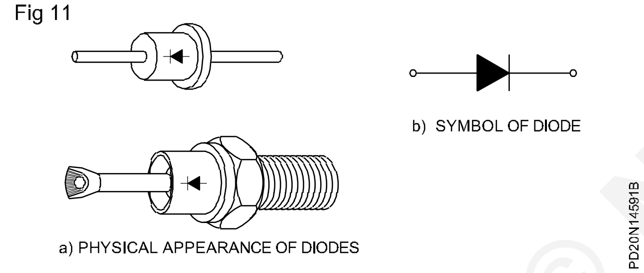
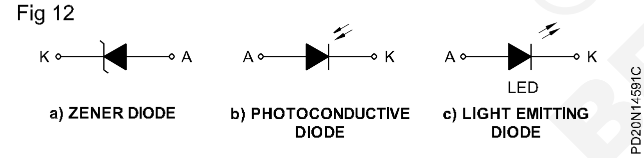
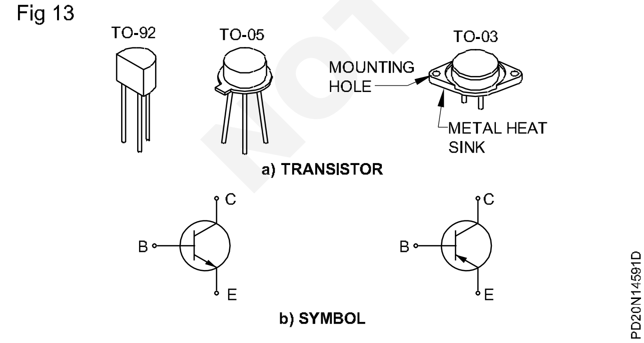


Fig 12



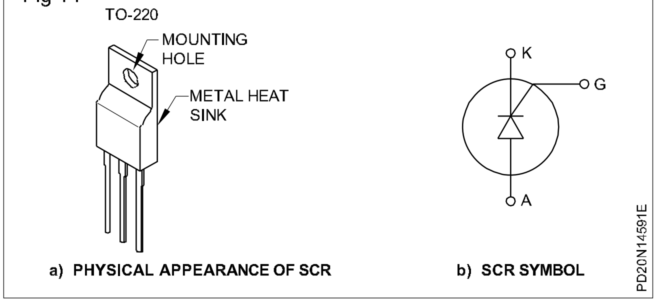
Transistor : Figure 13a shows the physical appearance of transistors. There are two symbols to represent a transistor. (Fig 13b). The selection of a symbol is based on either the NPN or the PNP type of transistor.

Fig 13



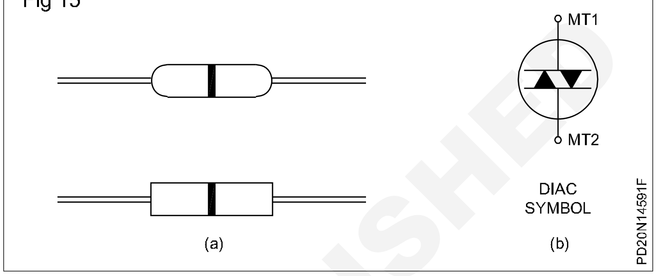
SCR (Silicon controlled rectifier) : Figure 14a shows the physical appearance of one type of SCR and the symbol is shown in Fig 14b. SCRs are also called thyristors and used as switching devices.

Fig 14



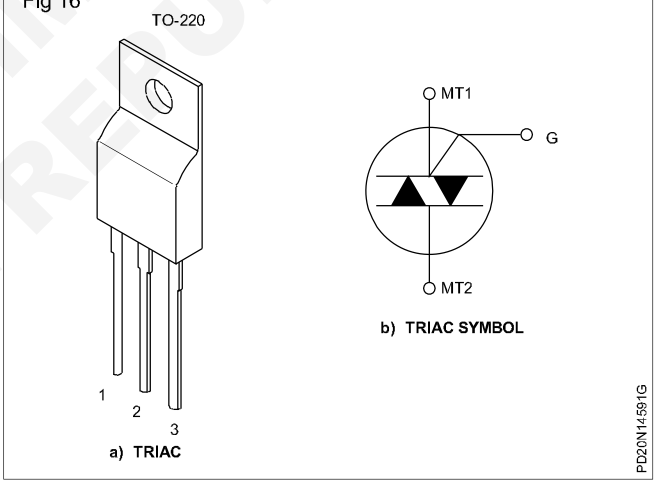
Diac : A diac (Fig 15a) is a two-lead device like a diode. It is a bidirectional switching device. Its symbol is shown in Fig 15b.

Fig 15



Triac : A triac is also a semiconductor device with three leads like two SCRs in parallel. The triac can control the circuit in either direction. (Fig 16)

Fig 16



Bridge rectifier or diode bridge : It is a single package of four semiconductor diodes connected in bridge circuit. The input AC and the output DC leads are marked and terminated as shown in the Figure 17.

UJT (Uni-junction transistor) : It has two doped regions with three leads and has one emitter and two bases (Fig 18).

FET (Field effect transistor) : Fig 19a give a pictorial view of the component, and the related symbol to represent the field effect transistor is shown in Fig 19b. The selection of the symbol is based on whether the FET is a 'N' channel or a 'P' channel one.

In the active components few basic components discussed have and many more advanced components associated with modern circuits are in use.

Fig 17

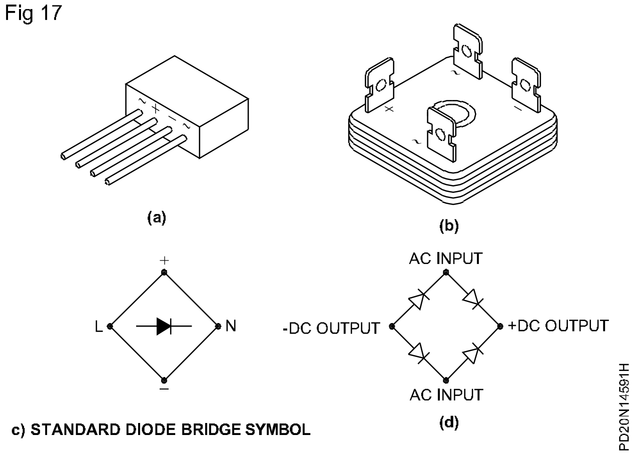


Fig 18

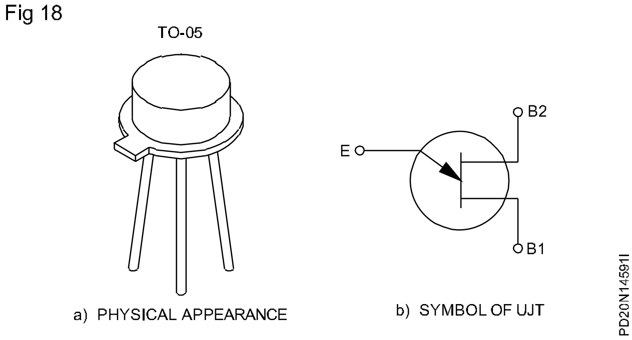
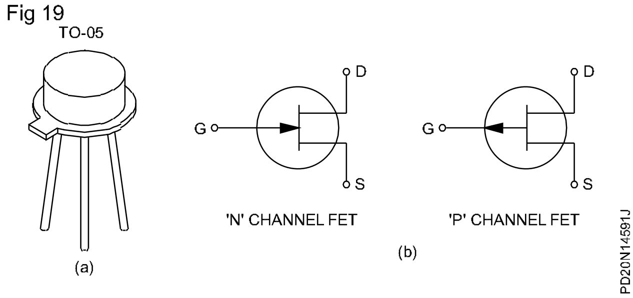


Fig 19



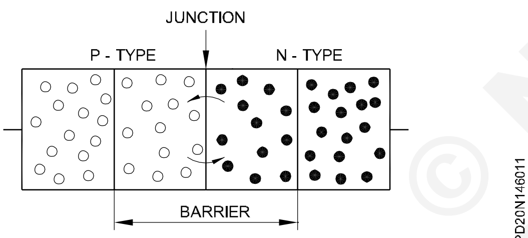
PN Junction - semi conductor diodes

Objectives: At the end of this lesson you shall be able to
- **explain diffusion in PN junction and barrier potential**
- **explain forward and reverse biasing of PN junction and semi conductor diodes and its VI characteristics**
- **state the applications specifications and classification of diodes**
- **state the different industry standards for diode numbering and finding equivalents of diode**
- **state the method of testing diode and identifying the polarity**
- **state special diodes and their functions and PIV.**

PN junction: A diode is made by combining P and N materials. The surface at which these materials meet is the PN junction.

Diffusion occurs when P and N materials are joined together.(Fig 1) some electrons in the N material, near the junction, are attracted to the holes in the P material, thus leaving holes in the N material. The diffusion of electrical charges produces a potential difference in a small area near the junction (Fig 2).As a result, the material will conduct in one direction but not in the opposite direction. For this reason, the area in which this emf exists is called a barrier.

Fig 1



The internal barrier potential (V_b) : Although it is an internal contact potential that cannot be measured directly, the effect can be overcome by 0.3V for a **Ge** junction or 0.7 V for **Si**. The barrier voltage is more for **Si** because its lower atomic number allows more stability in the covalent bonds as already stated.

The PN junction, with the depletion zone magnified, shows the iron that has +ve and -ve charges produce the internal contact potential V_b at the barrier. (Fig 2)

A PN device is knows as a diode. The diode and its symbol are in Fig 3. This type of construction permits the current to flow in one direction but not in the opposite direction.

Biasing the PN junction

Forward Bias : A forward-biased PN junction is in Fig 4 The positive terminal is connected to the P-side and the negative terminal of the DC supply is connected to the N-side of the junction.

A current will flow through the diode as in the Fig 4. The positive terminal for the battery attracts electrons from P material, leaving an excess of holes. Because electrons are drifting away from the junction, the excess holes tend to accumulate near the junction. At the same instant, electrons from the negative terminal of the battery are attracted to the less negative N material of the diode. This action overcomes the barrier at the junction and allows the electrons to move into the excess holes of the P material, the result is a continuous flow of electrons in one direction. The voltage required to move the charge carries in forward bias conduction called the barrier voltage.

Fig 2

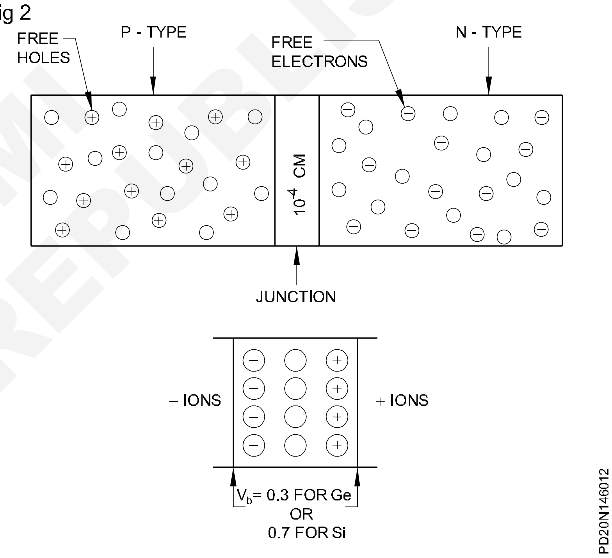
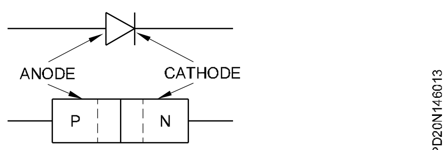


Fig 3



Reverse Bias: If the polarities of the DC supply are as shown in Fig 5, the PN junction is said to be reverse-biased. That is, the P side is connected to the negative and the N-side is connected to the positive terminals of the supply. Fig 5 shows the battery connection reversed (reverse bias). At the same instant, a shift in electrons in the P material causes the positive holes to appear further away from the junction near the end for the diode, which is connected to the negative terminal of the battery. This action produces a wider barrier at the PN junction through which the electrons cannot flow. (A very small current leakage may however occur).

Fig 4

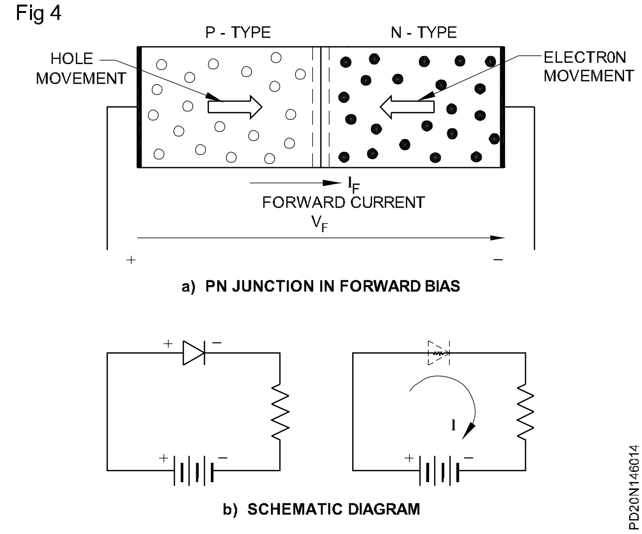
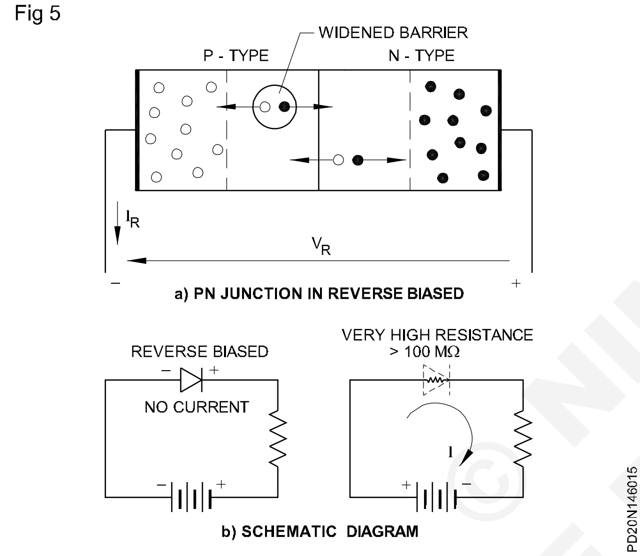
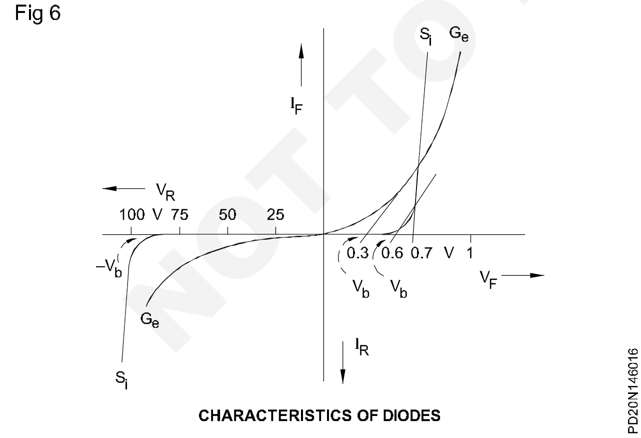


Fig 5



V-I characteristic of PN junction : The static current voltage characteristic is in Fig 6.

Fig 6



The current in the forward direction increases rapidly upon reaching the forward voltage V_b which is known as the barrier potential or the junction potential and the barrier potential for germanium is 0.3 V and for silicon it is 0.7 V.

The behaviour of the PN junction is limited by the maximum forward current, as too much of current may destroy a diode due to the excess heat generation.

The current in the reverse direction of the junction is very small. Upon reaching —V_b in the reverse direction, the reverse current suddenly increases. —V_b in the reverse direction where the current starts increasing is called the knee potential or breakdown voltage. Normally the diode should not be operated in this region. The knee voltage depends on the type of diode which varies from 3V to 20 kV or more.

Application of diodes : Semi conductor diodes are used for various applications. Some of the major areas of application are listed below.

- Modulation and demodulation in communication receivers.
- Switching high speed digital circuits
- Low power and high power rectification
- As surge protectors in EM relay and other circuits.
- For clipping, clamping wave-forms.

For different applications, diodes of different current carrying capacity, different PIV capacity and so on are required. Therefore, manufacturers make diodes to cater to varied applications with different specifications. Before using a diode for a particular application, it is a must to find out whether the voltage, current, and temperature characteristics of the given diode match the requirement or not.

Important specifications of a diodes

The material : The diode is made-of dopped semi-conductor material. This could be Silicon or Germanium or Selenium.This is important because the cut-in voltage depends upon the material the diode is made-of. For example, in Ge diodes the cut-in voltage is around 0.3V, whereas in Si diodes the cut-in voltage is around 0.7V.

Maximum safe reverse voltage : Denoted as V_R or V_r that can be applied across the diode. This is known as peak-inverse-voltage or PIV. If a higher reverse voltage than the rated PIV is applied across the diode, it will become defective permanently.

Maximum average forward current : I_f or I_F that a diode can allow to flow through it without getting damaged.

Forward voltage drop : V_F or V_f that appears across the diode when the maximum average current, I_f flows through it continuously

Maximum reverse current : I_{vr} that flows through the diode when the maximum reverse voltage, PIV is applied.

Maximum forward surge current : I_s that can flow through the diode for a defined short period of time.

The maximum junction temperature: The temperature upto which the diode junction can withstand without mal functioning or getting damaged.

Manufacturer's code of Diodes : The diodes are printed with a type number. When this type number is referred to in the manufacturer's manual, the detailed specifications for a particular type, number of the diode, can be obtained.

To bring standardization for the diodes and other components manufactured by different manufacturers. The Manufacturer and Standards Associations have set certain International Standards for the benefit of users of the components. The principal industry standard numbering systems are dealt with here.

1 **The JEDEC type code:** The EIA in USA maintains a register of 1N, 2N, types familiarly known as JEDEC types, which have world wide acceptance.

1N is used as a prefix for semiconductors with one junction. For example all 1N components refer to diodes because diodes have one junction. Similarly, prefix 2N is used with components with two junctions and so on.

2 **The PRO-ELECTION type code :** The Association International pro-electron in Europe maintains a register of Pro-electron type which have wide acceptance in Europe.

Components in the Pro-electron system have,

- two letter and numeral code for consumer devices (Example, BY127 and so on)
- three letter and numeral code for industrial devices. (Example, ACY17 and so on).

The first letter in the pro-electron type code indicates the type of semiconductor material used in making the device. Example, device numbers starting with A are made of germanium. Refer to diode data book for further details and examples.

The second and third letter indicate the applications of the component. Example, in the type code BY127, the second letter Y indicates that it is a rectifier diode.

The numeral after the second or third letter is the code number of its detailed voltage, current and temperature specification.

3 **The JIS type code:** In Japan, the JIS, (Japanese Industrial Standards) code is used. This system of component numbering is almost universal. In this system, all component numbers start with 2S, followed by a letter and several numbers. Example. 2SB364.

The letters after the S has the following significance:

A = pnp hf

B = pnp if

C = npn hf

D = npn if

Some components will have a type number which does not match with any of the above said International Standards. Then, these type numbers are particularly known to the individual manufacturer. These codes are generally referred to as manufacturer's house code. However, these type numbers may conform to one or more of the International Standards. Almost all standard diode data books lists popular manufacturers house codes.

Diode equivalent: There are several occasions, especially while servicing electronic circuits, it may not be possible to get a replacement for a diode of a particular type number. In such cases one can obtain a diode having specification closest to the one to be replaced. Such diodes are referred to as equivalents.

Example: In a circuit, diode 1N 4007 is found to be defective, and if 1N4007 is not available in stock, then instead of 1N4007, BY 127 can be used as it is the equivalent for 1N4007.

Some data books give these lists of equivalents.

Classification of Diode

1 Based on their current carrying capacity/power handling capacity, diodes can be classified as

- **low power diode**

  It can handle power of the order of several milliwatts only

- **medium power diode**

  It can handle power of the order of several watts only

- **high power diode**

  It can handle power of the order of several 100's of watts.

2 Based on their principal application, diodes can be classified as,

- **Signal diode**

  Low power diodes are used in communication circuits such as radio receivers etc. for signal detection and mixing

- **Switching diode**

  Low power diodes are used in switching circuits such as digital electronics etc. for fast switching ON/OFF of circuits

- **Rectifier diode**

  Medium to high power is used in power supplies for electronic circuits for converting AC to DC voltage.

3. Based on the manufacturing techniques used, diodes can be classified as,

- **point contact diode**

  A metal needle is connected with pressure on to a small germanium (Ge) or silicon (Si)

- **Junction diode**

  They are made by alloying or growling or diffusing P and N materials on a semiconductor substrate.

Types of diode packaging : The type of packaging given to diodes is mainly based on the current carrying capacity of the diode. Low power diodes have either glass or plastic packaging. Medium power diodes have either plastic or metal can packaging. High power diodes will invariably have either metal can or ceramic packaging. High power diodes are generally of stud-mounting type.

Testing diodes using ohmmeter: A simple ohmmeter can be used to quickly test the condition of diodes. In this testing method, the resistance of the diode in forward and reverse bias condition is checked to confirm its condition.

Recall that there will be a battery inside an ohmmeter or a multimeter in the resistance range. This battery voltage comes in series with the leads of the meter terminals as in Fig 7.In Fig 7 the lead A is positive, lead B negative.

> **If the polarity of the meter leads are not known at first, the polarity of the meter leads can be determined by using a voltmeter across the ohm meter terminals.**

If the positive lead of the ohmmeter, lead A in the Fig 7 is connected to the anode of a diode, and the negative (lead B) to the cathode, the diode will be forward-biased. Current will flow, and the meter will indicate low resistance.

On the other hand, if the meter leads are reversed, the diode will be reverse-biased. Very little current will flow because a good diode will have very high resistance when reverse biased, and the meter will indicate a very high resistance.

While doing the above test, if a diode shows a very low resistance in both the forward and reverse biased conditions, then, the diode under test must have got damaged or more specifically shorted. On the other hand, a diode is said to be open if the meter shows very high resistance both in the forward and reverse biased conditions.

Polarity marking on the diodes: The cathode end of a diode is usually marked by a circular band or by a dot or by plus (+) sign. In some diodes the symbol of the diode, which itself indicates the polarities, is printed on the body of the diode.

Special diodes: All diodes are basically PN junction diodes and are made according to the application. There are many special purpose diodes are in use in which zener diodes widely used for voltage regulation.

Zener diode: This diode specially designed for voltage regulation. A wide range of voltage regulated zener diodes are available.

It is a PN junction diode doped heavily for regulation purpose. It has a normal VI characteristic when it is forward biased. But the characteristic are changed abruptly when it is connected in reverse bias.

In the reverse bias condition a leakage current in the order of Microamps will flow. When the reverse voltage reaches to a particular designed voltage a sudden breakdown known as avalanche breakdown happens.

When a heavy current flows at constant voltage, the voltage continue to remain constant. Further increase in voltage, the current suddenly increases. Fig 8 shows the reverse characterises of zener diode.

Fig 7

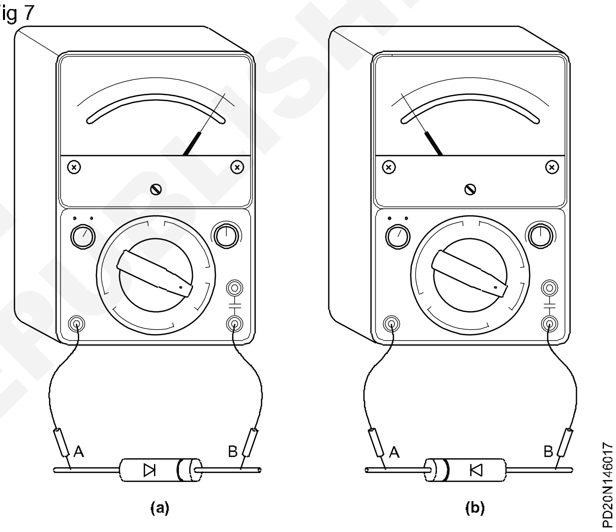
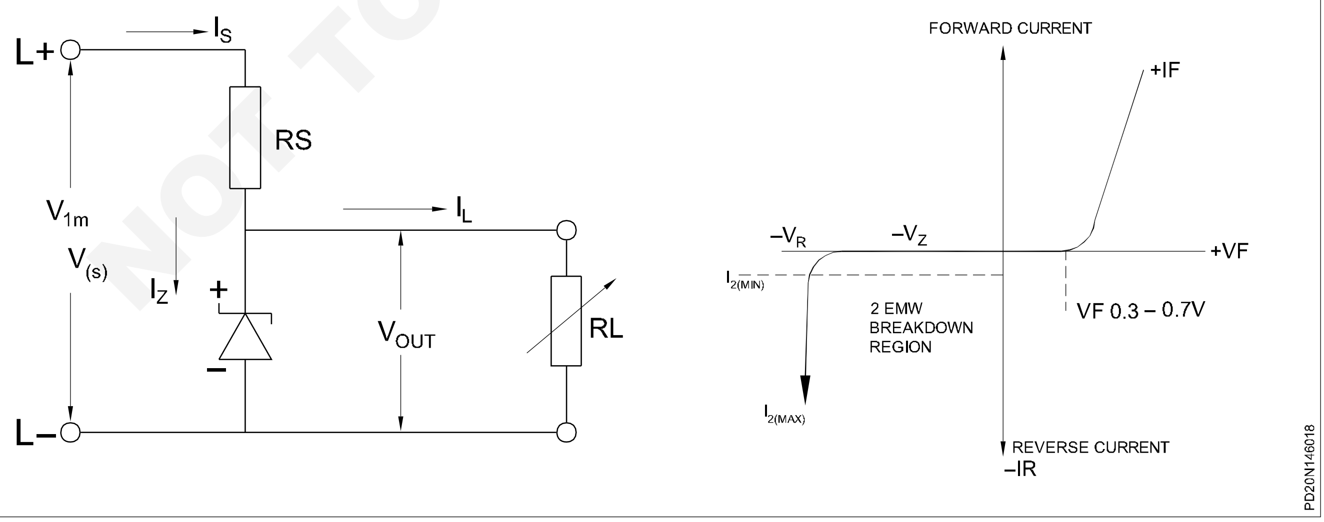
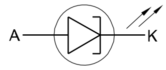
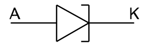
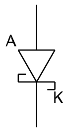
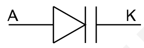
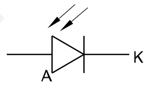
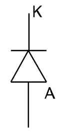
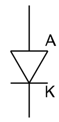


Fig 8



Few more special diodes listed below in Table 1

Sl.No	Name	Purpose	Symbol
1	LED	Light emitting diode - exhibits light in conduction	
2	TUNEL or ESAKI	Un effected by change in temperature	
3	SCHOTTKY	Fast switching	
4	VARICAP	Varactor -Variable capacitance diode or tuning diode	
5	SCHOKLEY	Constant current diode	
6	PHOTO DIODE	Light dependent diode	
7	IMPATT DIODE	Heavily doped PN layers	
8	PIN DIODE	Low capacitance switching	

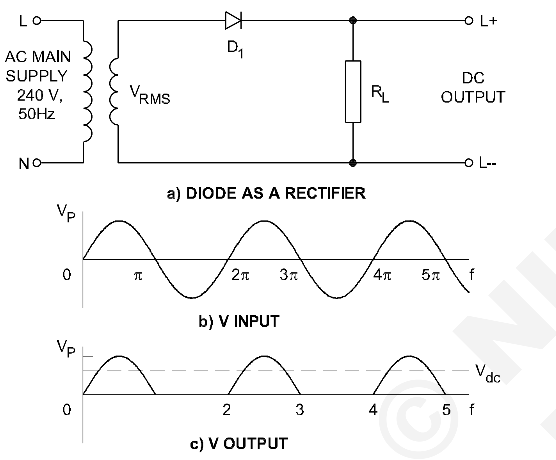
Rectifiers

Objectives: At the end of this lesson you shall be able to
- **state the purpose of rectifier in power supply circuit**
- **explain the working of half-wave, full-wave and bridge rectifier circuit**
- **state the need of filter circuit to rectifier circuits**
- **state the different types filter circuit for rectifiers and their working.**

Most of the electronic equipment, both entertainment and professional, need DC voltage for operation. The power supply converts AC supply voltage into DC. Diodes are used as rectifier in a power supply circuit.

Half wave rectifier: This simplest form of AC to DC converter is by using one diode such an AC to DC converter is known as half-wave rectifier as in Fig 1.

Fig 1



A diode D_1 and a load resistance R_L in series are connected across the secondary of a step down transformer (Fig 1(a). The transformer steps up or steps down the supply voltage as needed. Further the transformer isolates the power line and reduces the risk of electrical shock. During the positive half-cycle of the input line frequency, (Fig 1b) the diode anode is made positive with respect to the cathode. The diode D_1 conducts because it is forward-biased. Current flows from the positive end of the supply through diode D_1 and R_L to the negative terminal of the input. During this period of time, a voltage is developed across R_L. The polarity of the voltage is as indicated in Fig 1C.

During the negative half cycle of AC input line frequency, the diode is reverse-biased. Practically no current flows through the diode and the load R_L and there is no voltage output.

DC output: The voltage drop across the forward biased diode is low, because the resistance of the forward-biased diode is very low. Ge diode drops 0.3V and Si diode drops 0.7V. Ignoring the small voltage drop across the diode. We can find the relationship between AC input and DC output voltage.

The AC input wave-form is shown in Fig 1b.

$V_{rms} = 0.707\ V_p$

$$V_p = \frac{V_{rms}}{0.707}$$

In Fig 1C, the DC output is shown. The diode produces only half cycle of the Ac input. The average value of this half wave is the DC output voltage.

$$V_{dc} = 0.318\ V_p$$

$$= 0.318\ x\ \frac{V_{rms}}{0.707}$$

$$= 0.45\ V_{rms}$$

For example if the input AC voltage is 24 volts the output DC of the half wave rectifier will be V_{dc} = 0.45 x 24= 10.8 V

The DC load current is $I_{dc} = \frac{V_{dc}}{R_L}$

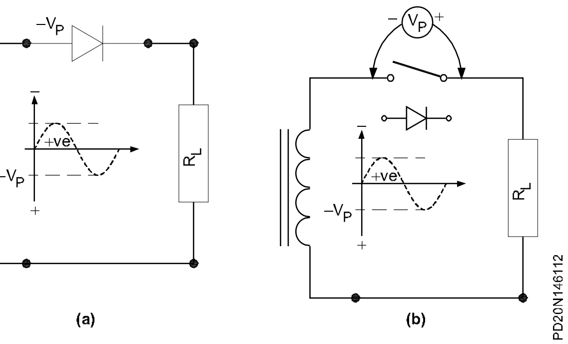
Ripple frequency: From Fig 1 it is evident that the frequency of the rectified pulsating DC is same as the frequency of the input AC signal. This is true for all half-wave rectifiers.

Peak inverse voltage: Fig 1(a) shows the half-wave rectifier at the instant the secondary voltage is at its maximum negative peak.

In this condition, since the diode is reverse biased, it behaves as an open switch as in Fig 2b. Since the diode is reverse biased, there is no voltage across the load R_L. Therefore, from Kirchhoff's Voltage law, all the secondary voltage appears across the diode as shown in Fig 2a. This is the maximum reverse voltage that appears across the diode in the reverse biased condition. This voltage is called the peak reverse voltage or more commonly as the peak inverse voltage (PIV). Therefore, in a half-wave rectifier the peak inverse voltage across the diode is equal to the -ve peak value of the secondary voltage $V_{s(peak)}$. Since the -ve peak voltage and +ve peak voltage in a sinusoidal wave is same in magnitude, the peak inverse voltage (PIV) across the diode in a halfwave rectifier can be taken as a $V_{s(peak)}$.

In the example considered earlier, the PIV across the diode will be,

Fig 2



$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 33.9 = 34 \text{ volts}$$

To avoid break down of the diode used, the PIV appearing across the diode of the designed HW rectifier must be less than the PIV rating of the diode. For instance, in the above example to avoid break down of the diode, the PIV rating of the diode should be greater than 34 volts.

However this condition changes when a filter capacitor is used in the output DC circuit.

Full wave rectifier (FW): A full wave rectifier circuit is in Fig 3. The secondary winding of the transformer is centre-tapped. The secondary voltage is divided equally into two halves, one end of the load R_L is connected to the centre tap and the other end of R_L to the diodes.

It is seen that two half-wave rectifiers are conducting on alternate half cycles of the input Ac.

During the positive half cycle of the secondary voltage, diode D_1 is forward-biased and diode D_2 is reverse-biased. (Fig 3b) The current flows through the load resistor R_L, diode D_1 and the upper half of the secondary winding.

During the negative half cycle of secondary voltage, diode D_2 is forward-biased and diode D_1 is reverse-biased. Therefore, current flows through the load resistor RL diode D_2 and the lower half of the secondary winding. (Fig 3c)

The load current is in the same direction during both the half-cycles of the AC input. The output of the full-wave rectifier is shown in Fig 3d.

DC output : Since a full wave rectifier is nothing but a combination of two half-wave rectifiers, the average or DC value of a full wave rectifier is naturally twice the output of a half wave rectifier driven by the same secondary voltage.

From Fig 3 it i s evident that the average of DC value of a full wave rectified output is

$V_{dc} = 0.318\ V_{s(peak)} + 0.318\ V_{s(peak)}$

$V_{dc} = 0.636\ V_{s(peak)}$

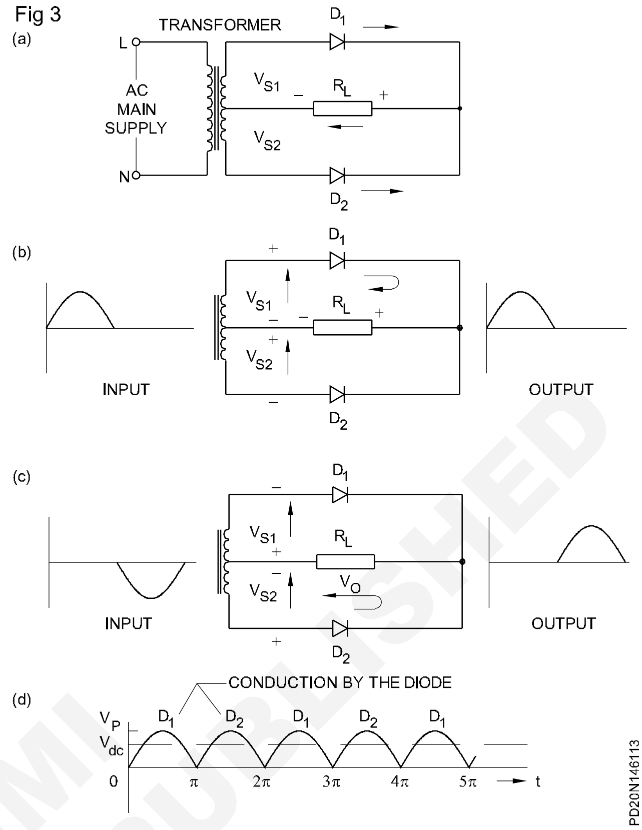
where, $V_{s(peak)}$ is the equal peak voltage between the centre-tap and any one end A or B of the transformer secondary.

In terms of $V_{s(rms)}$ V_{dc} of full wave rectifier is given by,

$Vs_{(rms)} = 0.707\ V_{s(peak)}$

$$\text{Therefore, } V_{dc} = 0.636 = \frac{V_{s\,(rms)}}{0.707} = 0.9\ V_{s\,(rms)}$$

Fig 3



Example

Suppose the secondary voltage of the transformer is 24-0-24V(rms), the Dc output voltage of a full wave rectifier using this transformer will be,

For a two diode full wave rectifier

$V_{dc} = 0.9\ V_{s(rms)}$

Therefore, in the given example

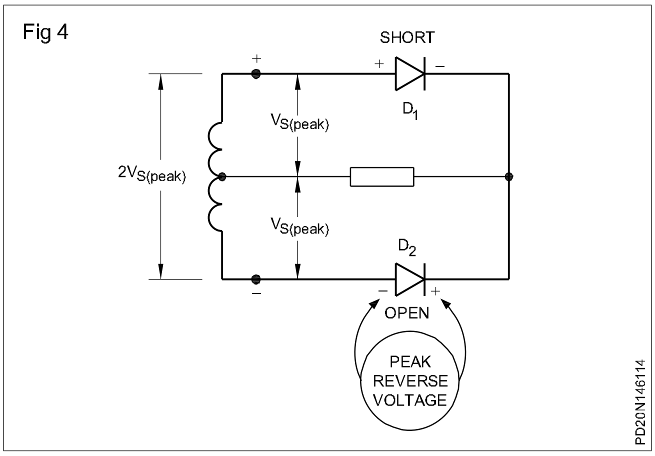
$V_{dc} = 0.9 \times V_{s(rms)} = 0.9 \times 24 = 21.6$ volts

Ripple frequency in a full wave rectifier: From Fig 3c it can be seen that two cycles of output occur for each input cycle of AC voltage. This is because, the full wave rectifier has inverted the negative half cycle of the input voltage. As a result, the output of a full wave rectifier has frequency double the input AC frequency. If mains AC supply is used as input to a full wave rectifier, the mains frequency is 50 Hz, the output frequency of the pulsating DC will be 100 Hz.

Note: This increased ripple frequency has certain advantages when the pulsating DC is smoothed. This will be dealt with in further lesson.

Peak inverse voltage: Fig 4 shows the full wave rectifier at the instant the secondary voltage reaches its maximum positive value.

Applying Kirchhoff's law around the outside loop, we get, $2V_{s(peak)}$ - Reverse voltage(PIV)



across D_2 + Forward voltage across D_1 = 0

Neglecting the small forward voltage across D_1 we have, $2V_{s(peak)}$ = PIV across D_2 + 0 = 0

or PIV across D_2 = $2V_{s(peak)}$

From the above it can be seen that each diode in a fullwave rectifier must have PIV rating greater than the peak value of the full secondary voltage. $2V_{s(peak)}$

In the example considered earlier, the PIV of diodes should be 2 $V_{s(peak)}$.

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} \quad = \quad 2\,V_{s(peak)} = \frac{2 \times V_{s(rms)}}{0.707}$$

$$= \frac{2 \times 24}{0.707} = 68 \text{ volts (approx.)}$$

Current rating of diodes in a full wave rectifier : If the load, R_L connected in the fullwave rectifier is, say 10Ω the DC current through it will be,

$$I_{dc} = \frac{V_{dc}}{10\,\Omega}$$

In the example considered above, V_{dc} = 21.6 volts

Therefore, $$I_{dc} = \frac{21.6}{10} = 2.16 \text{ amps.}$$

It is interesting to note this current I_{dc} is shared by the two diodes D_1 and D_2. This is because each diode conducts only for one half cycle. Therefore, the DC current through each diode is half the total DC load current I_{dc}. Hence, the maximum current through each diode with 10Ω load will be 2.16/2 = 1.08 amps. From this it follows that the current rating (If(max)) of each diode need only be half the maximum/rated load current.

NOTE: In a halfwave rectifier, since there is only one diode, the current rating of the diode used should be the maximum current through the load unlike in the case of a full wave rectifier in which the current rating of the diodes used is only half the maximum current through the load.

Example: In a two diode full wave rectifier, with a load current requirement of 1.8 amps, what should be the current ratings of the diodes used?

Since it is a two diode full wave rectifier, the current rating of each diode should be = 1/2 the total load current.

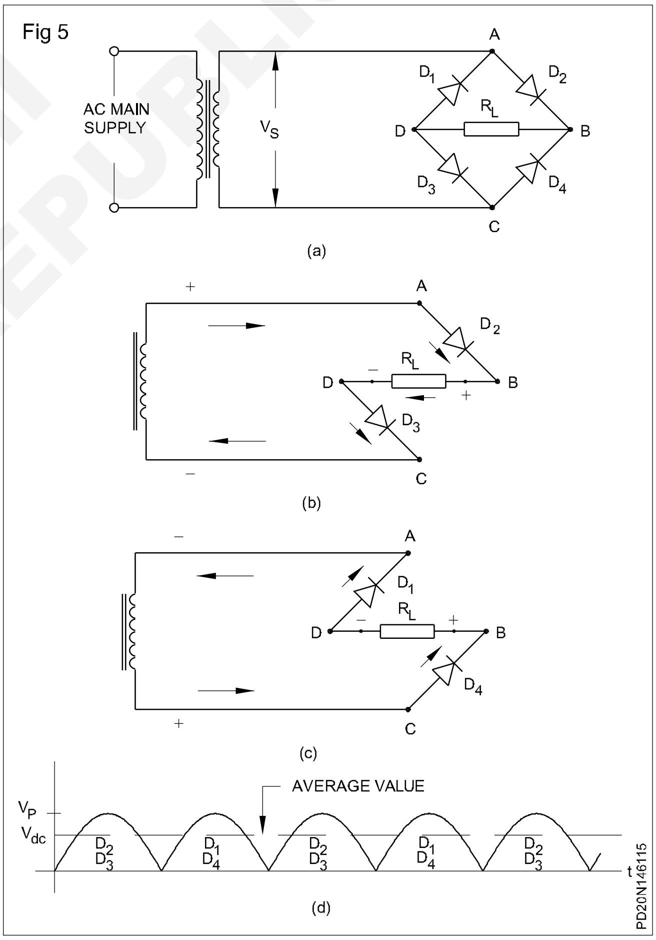
Therefore I_f(max) of diodes should be = 1.8 amps/2 = 0.9 amps.

It is fine if a diode of 1 amp current rating is used for this rectifier circuit.

Disadvantages of TWO DIODE full wave rectifier : The full wave rectifier using two diodes and centre tap transformer has the following disadvantages

- A centre-tapped transformer that produces equal voltages on each half of the secondary winding is difficult to manufacturer and, hence, expensive.
- Centre-tapped transformers are generally bulkier than ordinary transformers, and, hence, occupy larger space.
- In a two diode full wave rectifier, only half of the secondary voltage is made use at a time although it works in both +ve and -ve half cycles.

Bridge rectifier : It is a full-wave rectifier. The circuit is in Fig 5a. In the bridge rectifier four diodes are used. There is no centre tap on the secondary of the transformer.



During the positive half of the secondary voltage, diodes D_2 and D_3 are forward-biased. Hence current flows through diode D_2 load resistance R_L and D_3 to the other end of the secondary. This is illustrated in Fig 5b. During the negative half of the secondary voltage, diodes D_1 and D_4 are conducting . The current flows through diode D_4, resistor R_L and diode D_1 to the other end of the secondary. This is illustrated in Fig 5c.

In both cases the current flows through the load resistor in the same direction. Hence, a fluctuating DC is developed across the load resistor RL. This is shown in Fig 5d.

DC output: Fig 6 shows the input AC and the output pulsating DC wave-form of a bridge rectifier.

This wave-form is similar to that of the full wave rectifier using a centre-tap transformer. Hence, the average DC value of the output is,

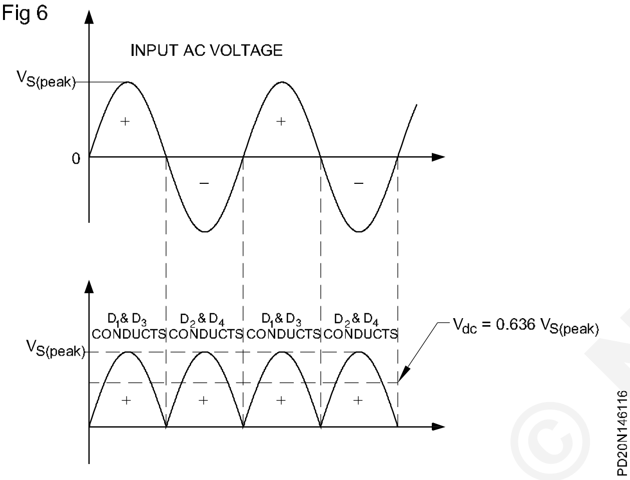
V_{dc} = 0,636 $V_{s(peak)}$

or V_{dc} = 0.9 $V_{s(rms)}$

where, Vs(rms) is the full secondary AC rms voltage.

> **NOTE: In a two -diode full wave rectifier $V_{s(rms)}$ refers to only half for the total secondary voltage whereas in a bridge rectifier $V_{s(rms)}$ refers to full secondary voltage.**

Fig 6



Example: In Fig 5, if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, the rectified DC voltage V_{dc} across the load R_L will be,

From equation ....2, V_{dc} for a bridge rectifier is given by, V_{dc} = 0.9 $V_{s(rms)}$

In the given example, $V_{s(rms)}$ = 24 volts

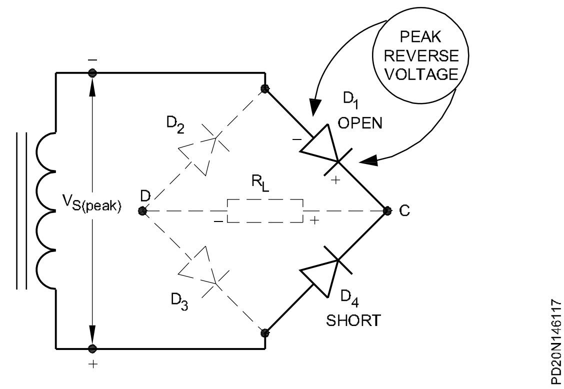
Therefore, V_{dc} = 0.9 x 24 = 21.6 volts

> **NOTE: Using the same transformer, a two-diode full wave rectifier would have given only 10.8 volts which is half of that of bridge rectifier output.**

Ripple frequency - Bridge rectifier: The pulsating DC output of a bridge is similar to the two diode full wave. Hence as in a two diode fullwave rectifier, the output ripple frequency of the bridge rectifier is also twice the input AC frequency.

Peak inverse voltage - Bridge rectifier: Fig 7 shows a bridge rectifier at the instant the secondary voltage has reached its maximum value.

Fig 7



Diode D_4 is ideally short (as it is conducting) and D_1 is ideally open. summing the voltages around the outside loop and applying Kirchhoff's law,

$V_{s(peak)}$ - PIV across D_1 + 0 = 0

or PIV across D_1 = $V_{s(peak)}$

Therefore, the peak inverse voltage across D_1 is equal to the peak secondary voltage $V_{s(peak)}$

In a similar way, the peak inverse voltage across each diode will be equal to the peak secondary voltage $V_{s(peak)}$ of the transformer secondary. Hence the PIV ratings of the diodes used should be greater than $V_{s(peak)}$

Example

In Fig 7 if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, find the minimum PIV of diodes used. In a bridge rectifier PIV across the diodes is same and is equal to $V_{s(peak)}$

Therefore, in the given example,

$$PIV = V_{sd(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 34 \text{ volts}$$

Current rating of diodes in bridge rectifiers : As in the case of a two diode fullwave rectifier even in a bridge rectifier is in Fig 5, diode pairs D_1, D_3 and D_2 D_4 carry half the total load current1. This is because each diode pair is conducting only during one half of the AC input cycle.

The only disadvantage of bridge rectifiers, D_1, D_3 and D_2, D_4 is that, this circuit uses four diodes for full wave rectification instead of two as in two-diode fullwave rectifier. But this disadvantage is compensated by the simple transformer requirement of the bridge rectifier and higher DC output level. Hence, bridge rectifiers are the most popular AC to DC rectifiers for most applications.

Encapsulated bridge rectifiers are available as a single pack with two terminals for AC input and two terminals for DC output.

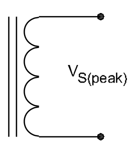
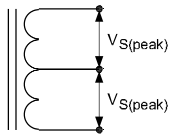
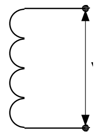
The following table provides data for a normally used diode having the current rating of one ampere.

Maximum ratings

Rating	Symbol	Type Number							Unit
		IN 4001	IN 4002	IN 4003	IN 4004	IN 4005	IN 4006	IN 4007	
Peak repetitive reverse voltage Working peak reverse voltage DC blocking voltage	$V_{RM(rep)}$ $V_{RM(wkg)}$ V_R	50	100	200	400	600	800	1000	Volts
Non-repetitive peak reverse voltage (half wave, single phase, 50 Hz peak)	$V_{RM\ (nonrep)}$	75	150	300	600	900	1200	1500	Volts
RMS reverse voltage	Vr	35	70	140	280	420	560	700	Volts
Average rectified forward current (Single phase, resistive load, 50Hz, T_A = 75°C)	Io			1.0					Amp
Non-repetitive (Half sine wave t=10m sec)	IFM			30					
Maximum thermal resistance junction temperature to ambient (lead length = 25 mm)	TJA			85					
Maximum Operating and storage junction temperature range	T_jT_{stg}			-65 to 175					

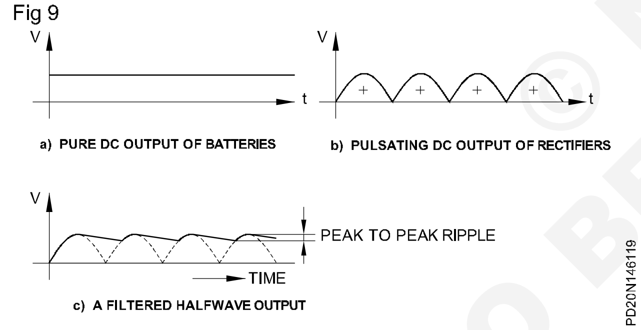
Other diode specifications can be obtained from the data book).

A comparison of half-wave, fullwave and bridge rectifier is given below in a tabular form

	Half wave	Full wave	Bridge
Number of diodes required	1	2	4
Transformers peak output voltage	Fig 8 		
DC output voltage in terms of $V_{s(peak)}$	0.318 $Y_{s(peak)}$	0.636V $V_{s(peak)}$	0.636V $V_{s(peak)}$
DC output voltage in terms of $V_{s(rms)}$	0.45 $V_{s(rms)}$	0.9 $V_{s(rms)}$	0.9$V_{s(rms)}$
Diode current rating	$I_{L(max)}$	0.5 $I_{L(max)}$	0.5$I_{L(max)}$
Peak inverse voltage	$V_{s(peak)}$	2$V_{s(peak)}$	$V_{s(peak)}$
Ripple frequency	f_{input}	2f_{input}	2f_{finput}

Filter circuits : Alternating current is rectified to provide a steady DC voltage similar to the output of a battery as shown in Fig 9a. But the output of rectifiers in a pulsating DC as in Fig 9b.

Fig 9



Pulsating DC voltages cannot be used in most of the electronic circuits. For example a buzzing sound will be obtained from a radio if these pulsations are not removed in the output of the rectifiers. The circuits used to filter off or reduce the pulsation in the DC output of rectifiers are known as smoothing circuits or popularly as Ripple filters.

Ripple : The small voltage fluctuations in the output of a filter like those shown in figure 9c are called Ripple.

Filter circuit components : Filter circuits are normally combinations of capacitors, inductors and resistors.

Types of filter circuits : The different filter circuits in use are

1 Capacitor input filter.

2 RC filter

3 Series inductor filter

4 Choke input LC filter

5 π filter.

1 Capacitor filter : A capacitor filter is the most simplest and cheapest filter. Here a large value capacitor C is connected across the load resistor RL as in Fig 10a. The capacitance offers a low reactance path to the AC components of current and offers very high resistance to DC. So all the DC current passes through the load.

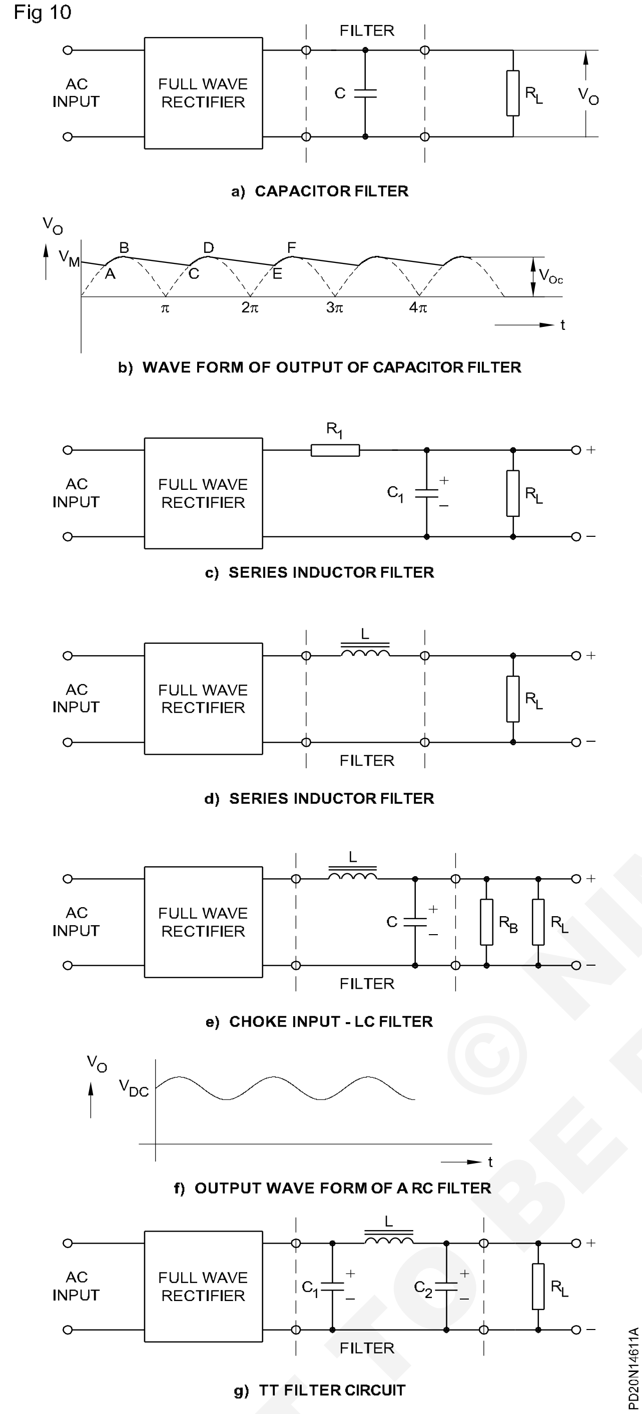
Working : When the rectifier output voltage is increasing the capacitor charges to the peak voltage Vm. After reaching the positive peak the rectifier output voltage tries to fall. Observe the wave form in Fig 10b. At point 'B' the capacitor has +V_m volts across it. Since the source voltage becomes slightly less than Vm, the capacitor will try to send current back through the diode, which reverse biases the diode.

The diode disconnects the source from load. The capacitor starts to discharge through the load. Thus the voltage across load will not fall to zero. The capacitor continues to discharge until the source voltage becomes more than the capacitor voltage at point C. The diode again starts conducting and the capacitor is again charged to peak value V_m. During the charging period for the capacitor the rectifier supplies the charging current I_c through capacitor as well as the load current I_L. Thus the current is maintained through the load always.

The rate at which the capacitor discharges between points B and C in Fig 10b depends upon the time constant R_LC. longer this time constant is, the steadier is the output voltage.

Calculation of Ripple : While designing a filter circuit the following methods can be used to calculate theoretically the ripple voltage in the output of the filter circuit.

Fig 10



Method 1

Knowing the required load current, I_L, for a given value of frequency f and capacitance C, the peak-to-peak ripple voltage can be found using the formula,

$$V_{rip(p-p)} = \frac{I_L}{F_r C} \quad ....(2)$$

Where

$V_{r(p-p)}$ = peak-to-peak ripple voltage in volts

I_L = required Dc load current, in Amps

F_r = ripple frequency, in Hz

C = capacitance in Farads

Fixing the permissible $V_{r(p-p)}$ and knowing f and I_L the required value for C can also be found using this formula

Method 2

Another method of expressing the ripple in the output DC is by ripple factor r defined as,

where,

$$\text{Ripple factor, r} = \frac{V_{r(rms)}}{V_{dc}}$$

r = ripple factor (dimension less)

$V_{r\,(rms)}$ = rms value for ripple voltages.

V_{dc} is the measured dc voltage at the output.

2 RC filter

A simple RC filter circuit is in Fig 10c. It consists of a resistor R_1 and capacitor C_1 connected as shown . The resistor R_1 help the filtering provided by the capacitor by lengthening the discharge time of the capacitor.

3 Series inductor filter

The figure 10d shows a series inductor filter circuit. An inductor is a device which has the fundamental property of opposing any change in current flowing through it. This property is used in the series inductor filter.

Working : Whenever the current through an inductor tends to change, a back emf is induced in the inductor which prevents the current from changing its value. The operation of a series inductor filter depends upon the current through it. Therefore this filter can be used together with a full wave rectifier only. further an increase in load current result in reduced ripple.

4 Choke-input LC filter

A choke input filter consists of an inductor L in series and a capacitor C in shunt with load as shown in Figure 10e.

Working : An LC filter combines the features of both the series inductor filter and shunt capacitor filter. The choke (iron-core inductor) allows the DC component to pass through easily because it offers no resistance to DC. While the capacitor allows AC ripples to pass through but blocks DC. As a result all the DC current passes through the load resistor R_L. The output wave form of a LC filter is an shown in Figure 10f.

Bleeder resistor : An inductor functions better when large steady current flows. For optimum functioning of choke filter a bleeder resistance R_B, which by passes the fluctuating current is included in the circuit as shown in Fig 10e.

5 PI-Filter (π filter)

This circuit is shown in Fig 10g. It is also called as a capacitor input filter. This circuit uses one inductor and two electrolytic capacitors. It is called capacitor-input filter because C_1 is the first filtering component. It is also called PI filter because the circuit looks like π (Greek letter)

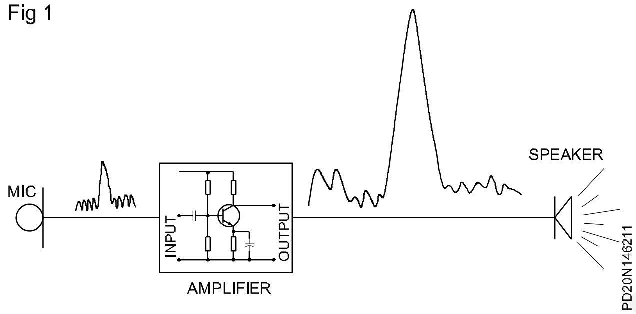
Working : The rectifier output first goes to C, which alternately charge and discharges as in the case of a capacitor filter. The capacitor C_2 also provides a similar filtering action. The inductor opposes the changes in both the output of C_2 and in the current drawn by the load. Also the LC filters are capable of removing the voltage spikes at the input.

Transistors

Objectives: At the end of this lesson you shall be able to
- **explain the construction of bipolar transistors**
- **explain the classification and working of PNP and NPN transistors**
- **state the important packages and type number systems of transistor**
- **explain the methods of testing transistor.**

Introduction: Transistor is an active device which can be compared to the heart of modern electronics. It accepts small electrical signal either in the form of current or voltage at the input and then amplifies (increase the amplitude) and provides a large signal at the output as in Fig 1. Transistors are used in almost all electronic gadgets such as radio, TV, tape recorder, computer etc.,

Fig 1



Before the transistors were invented (1947), certain devices are used known as vaccum tubes or valves which were used in amplifiers.

Compared with the present day transistors the vacuum tubes were big in size, consumed more power, generated lot of unwanted heat and were fragile. Hence vaccum tubes became obsolete as soon as transistors came to market.

Transistors were invented by walter H. Brazil and John Barlow of Bell Telephone Laboratories on 23rd Dec. 1947. Compared to vaccum tubes transistors have several advantages. Some important advantages are listed below.

- Very small in size
- Light in weight
- Minimum power loss in the form of heat
- Low operating voltage
- Rugged in construction
- Long life and cheap.

To satisfy the requirements of different applications, several types of transistors in different types of packaging are available. As in diodes, depending upon the characteristics, transistors are given a type number such as BC 107, 2N 6004 etc., The characteristics data corresponding to these type numbers are given in Transistor data books.

Transistor are available as bi polar, field effect and unijunction etc.,

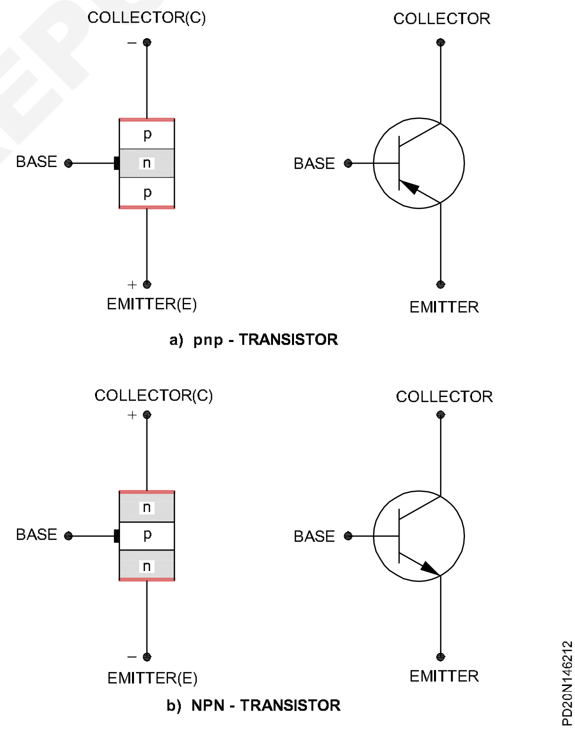
A bipolar junction transistor uses two opposite polarity of doped semiconductor i.e. 'N' type and 'P' type.

A field-effect transistor uses electrostatic field of charged carriers for its working.

An unijunction transistor uses a single junction of 'P' and 'N' type semiconductor.

Construction of bipolar junction transistors : The bipolar junction transistor is a three-element device (emitter, base, collector) made up of silicon or germanium materials by various methods like point contact, grown junction, alloy junction, diffusion junction and epitaxial. The construction of the transistor and the symbols, NPN and PNP, are shown in Fig 2.

Fig 2



A transistor is represented with the symbol shown. The arrow at the emitter shows the current flow through the transistor.

In most of the transistors, the collector region is made physically larger than the emitter region since it is required to dissipate more heat. The base is very lightly doped and is very thin. The emitter is heavily doped. The doping of the collector is more than that of the base but less than of the emitter.

Classification of transistors

1 Based on the semiconductor used

- Germanium transistors
- Silicon transistors

Like in diodes, transistors can be made, using any one of the above two important semiconductors. However, most of the transistors are made using silicon. this is because, silicon transistors work better over a wide temperature range (higher thermal stability) compared to germanium transistor.

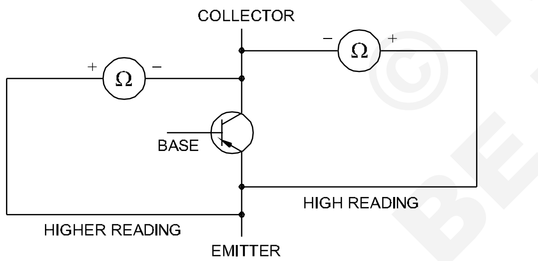
Method of finding the semi conductor used in Transistor

Transistor data books give information about the semi conductor used in any particular transistor.

In the absence of data, still a quick check can be made with an ohmmeter to determine whether a transistor is made from silicon or germanium. In the test of a PNP transistor in Fig 3 first connect the ohmmeter negative lead to the collector and the positive lead to the emitter. With this hook-up a high resistance reading from the emitter to the collector will be shown.

Then reverse the ohmmeter lead connections, and the resistance reading will go even higher. If it is possible to read the ohms on the meter scale, it is germanium transistor. If the reading is in the megohms-to-infinity range, it is a silicon transistor.

Fig 3



OHMMETER TEST RESULTS PROVE WHETHER THE PNP TRANSISTOR UNDER TEST IS MADE FROM GERMANIUM OR SILICON

2 Based on the way the P and N junctions are organised as in Fig 4

- NPN transistor
- PNP transistor

Both NPN and PNP transistors are equally useful in electronic circuits. However, NPN transistors are preferred for the reason that NPN has higher switching speed compared to PNP.

Operation of NPN transistor : During the normal operation of the transistor for amplifications the emitter base junction must be forward-biased, and the base collector junction must be reverse-biased, as in Fig 5.

If V_{EB} is greater than the barrier potential (0.3 V for germanium and 0.7 V for silicon), the electrons in the emitter are repelled by the negative polarity of V_{EB} and sent to the base. After filling a few holes in the base, these electrons can flow in either of the two directions. A few of the electrons are attracted to the positive terminal of V_{EB}, producing base current I_B. Many electrons in the base and collector are attracted by the high position potential of V_{CB}, producing collector current I_c. Emitter current I_E is equal to base and collector currents.

$I_E = I_B + I_c$

Fig 4

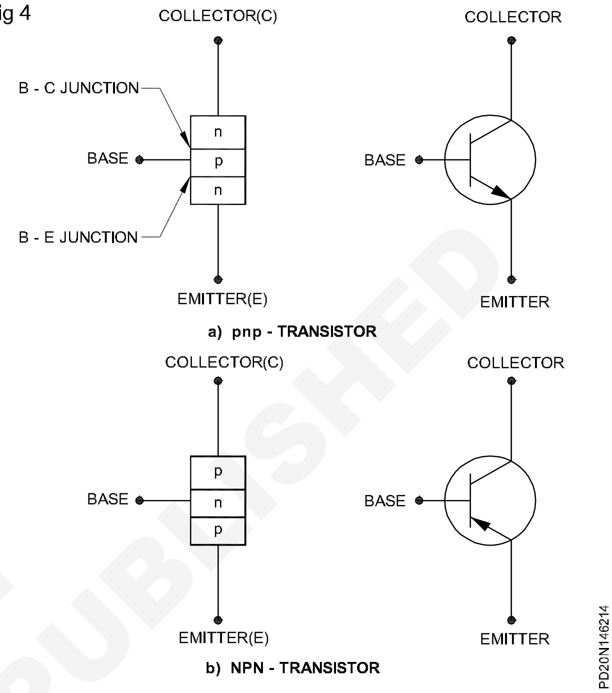
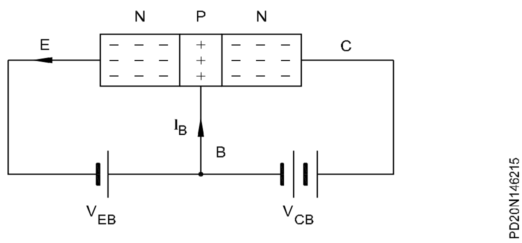


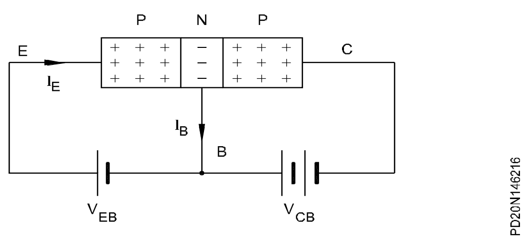
Fig 5



Working of PNP transistor: For proper operation of a PNP transistors as amplifier the base emitter junction must be forward-biased and the collector-base junction must be reverse-biased as in Fig 6.

Holes which are the majority carries are injected from the emitter into the base region. By the reverse biasing of the base-collection junction, the collector region is made negative with respect to the base, and hence holes, which carry a positive charge, penetrate into to base and flow across the collector junction and flow into the external applied voltage.

Fig 6



Method of identifying PNP and NPN transistors : Whether a transistor is PNP or NPN can be found with the help of transistor data book.

In the absence of data the following procedure may be adopted to identify the type of transistor whether it is PNP or NPN.

PNP identification : To identify the type of transistor first, make sure which is the positive lead and which is the negative lead from the ohmmeter. If necessary, take of the back for the instrument and check the polarity of the battery against the lead connections (positive to positive, negative to negative).

To test the transistor for its type:

1 Hook the positive lead from the ohmmeter to the base of the transistor. Fig 7

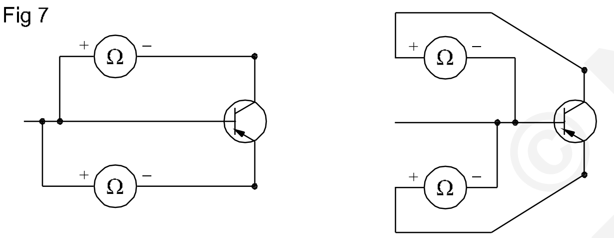
2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

3 If both readings shows high resistance, hook the negative ohmmeter lead to the base of the transistor. (Fig 7)

4 Connect the positive lead from the ohmmeter first to one transistor lead, then to he other.

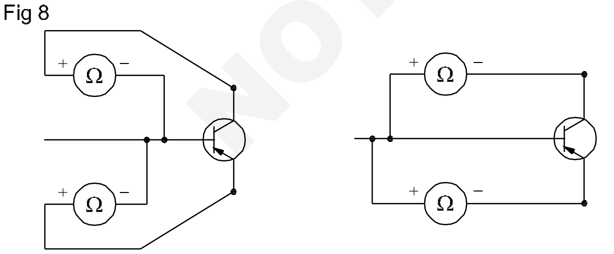
5 If both readings show low resistance, then it is a PNP transistor.

Fig 7



NPN identification : Suppose the ohmmeter tests show high resistance with the negative ohmmeter lead connected to the base of the transistor and the other lead is switched from transistor lead to transistor lead. See Fig 8 for reference.

Fig 8



Continue testing as follows:

1 Reverse the ohmmeter leads, connecting the positive lead to the base of the transistor.

2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

3 If the readings show low resistance, then it is a NPN transistor.

3 Based on the power handling capacity of transistors, they are classified as

1 Low power transistors less than 2 watts

2 Medium power transistors is 2 to 10 watts

3 High power transistors more than 10 watts

Low power transistors, also known as small signal amplifiers, are generally used at the first stage of amplification in which the strength of the signal to be amplified is low. For example to amplify signals from a microphone, tape head, transducers etc.,

Medium power and high power transistors, also known as large signal amplifiers are used for achieving medium to high power amplification. For example, signals to be given to loudspeakers etc. High power transistors are usually mounted on metal chassis or on a physically large piece of metal known as heat sink. The function of heat sink is to, take away the heat from the transistor and pass it to the surrounding air.

Transistor data books give information about the power handling capacity of different transistor.

4 Based on the frequency of application

- Low frequency transistor (Audio Frequency of A/F transistors)
- High frequency transistor (Radio frequency of R/F transistors)

Amplification required for signals of low or audio range of frequencies in Tape recorders, PA systems etc., make use of A/F transistors. Amplifications required for signals of high and very high frequencies as, in radio receivers, television receivers etc., use R/F transistors.

Transistors data books give information for any particular transistor as to whether it is a AF of RF transistor.

5 Based on the manufacturing method

- Grown junction
- Alloy junction
- Planar contact
- Epitaxial
- Mesa

The aim of each manufacturing process is to yield transistors most suitable for a particular type of application.

Transistor data books generally do not give information about the adopted manufacturing process of transistor. However, the relevant details can be obtained from the transistor manufacturer.

6 Based on the type of final packaging

- Metal

- Plastic
- Ceramic

Metal packaged transistors are generally used in medium and high power amplifications. Plastic packaging is generally used for low power amplification. Some plastic packages come with a metal heat sink. Such transistors are used for medium power amplification. Ceramic packaging is used for special purpose very high frequency applications, for higher temperature stability etc.,

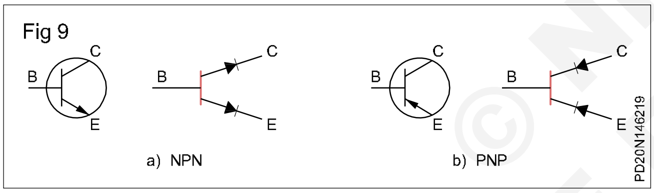
Some examples of packaging type codes used with transistors are, TO-3, TO-92- SOT-25 and so on.

Transistor data books give information about the type of packaging and its case outline.

Three lead devices such as transistors, SCRs, triacs etc., are cased in packages numbered as TO (transistor outline) or SOT (semi-conductor outline for transistors) followed by a number. A number of packages after designs are rarely used by circuit designers and have become obsolete.

Testing of transistor : A transistor can be tested for all specifications shown in the data book. But verification of almost all specifications, except a few requires an elaborate step up and can damage the transistor permanently.

The condition of a transistor with two diodes connected back to back will be as shown in Fig 9(a) & (b)



An ohmmeter can be used to check the junction either for an open circuit or a short circuit. The short is indicated by R practically zero ohms. A very high R of many megohms, in the direction of infinite ohms, means an open circuit. Power must be off in the circuit for ohmmeter readings. Preferably, the device is out of the circuit to eliminate any parallel paths that can affect the resistance readings for a transistor, low resistance from base to emitter or base to collector indicate forward bias and when the ohm-meter/ multimeter leads are transferred the resistance should be very high indicate reverse bias.

Probable possibilities are

1 When the ratio of reverse to forward R is very high, the junction is good.

2 When both the forward and reverse R are very low, close to zero, the junction is short-circuited.

3 When both the forward and reverse R are very high, close to infinity, the junction is open.

4 When both junctions are good transistor is good.

5 For a transistor without terminal details, base can be identified easily by identifying between collector and emitter terminal.

Normally for any power transistor, collector is connected to the metallic part/case to dissipate excess heat generated.

6 With a high voltage multimeter (MOTWANE multimeter with 9 V cell in Ω x 100 range), emitter base junction shows some reverse resistance due to zener action which should be treated as high resistance for all purpose.

A germanium transistor has very low forward resistance for each of junction and a high resistance in the reverse direction, while a silicon transistor has moderate forward resistance and infinity reverse resistance.

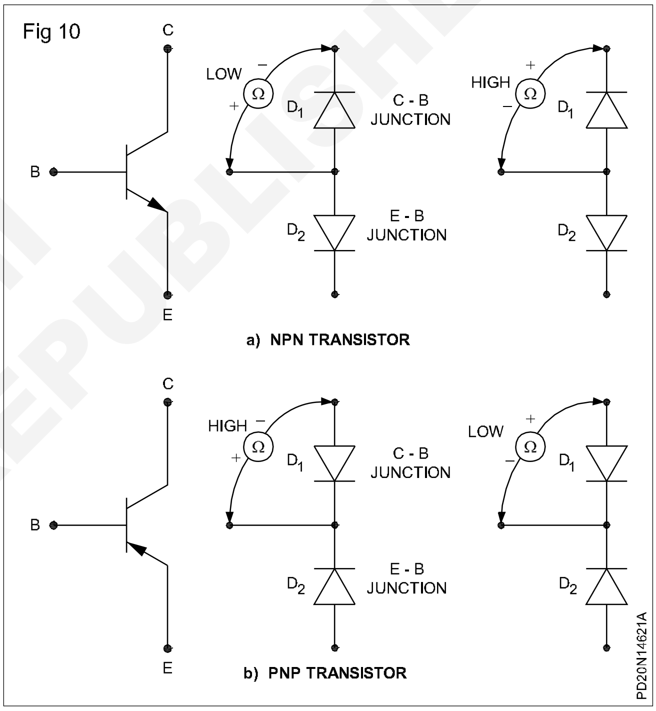


Fig 10a shows a NPN transistor and Fig 10b shows a PNP transistor. The imaginary diodes1 and 2 can be tested as similar to testing any diode. When a diode is tested, if the ohmmeter shows high resistance in one direction and low resistance in another direction, then the diode corresponding to that diode junction can be regarded as GOOD. One important point to note in a transistor is that, both the diodes of the transistor should be GOOD to declare the transistor as GOOD.

When testing, a transistor using ohmmeter, it is suggested to use the middle ohmmeter range (Rx 100) because, ohmmeters in low range can produce excessive current and ohmmeters in high range can produce excessive voltage which may be sufficient to damage small signal transistors.

Transistor biasing and characteristics

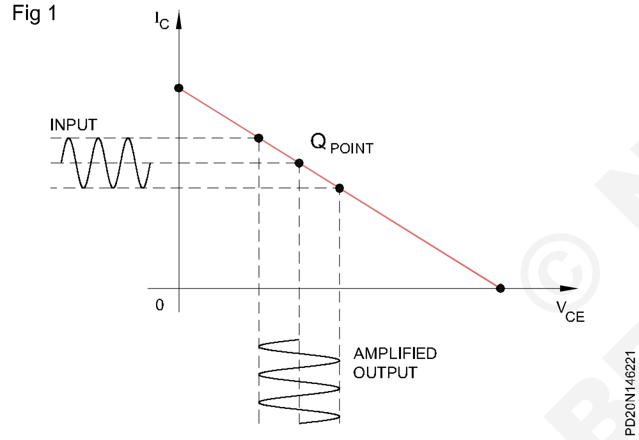
Objectives: At the end of this lesson you shall be able to
- **state the need and type of transistors biasing**
- **state the reason for shifting Q point due to temperature and β_{dc} changes**
- **state the necessity and importance of transistor characteristics**
- **state the importance of DC load line and meaning of Q point in transistors characteristics.**

Need of biasing of transistor

Before any one rides a motor cycle or drives a car, he has to start the engine and keep the engine running. In simple terms biasing transistors is similar to keeping the transistor started before making the real use of it. Once the transistor is started, like the engine of a car, it can be made to amplify, like covering the distance by driving the car.

Before an AC signal is fed to a transistor, it is necessary to set up an operating point or the quiescent(Q) point of operation. Generally this Q point is set at the middle of the DC load line. Once the Q point is set, then the incoming AC signals can produce fluctuations above and below this Q point as in Fig 1.

Fig 1



For the normal operation of a transistor amplifier circuit, it is essential that there should be

a) a forward bias on the emitter-base junction and

b) reverse-bias on the collector-base junction

In addition, the amount of bias required is important for establishing the Q point which is dictated by the mode of operation desired.

If the transistor is not biased correctly, it would

1) work inefficiently and

2) produce distortion in the output signal.

It is desirable, that once selected, the Q point should remain stable i.e. should not shift its position due to temperature rise which cause variation in β (V_{BE}) or leakage currents.

Further the amplitude variations in current and voltage of the input signal must not drive the transistor either into saturation of cut off.

Stable Q point: A set Q point of a transistor amplifier may shift due to increased temperature and transistor β value changes. Therefore, the objective of good biasing is to limit this shifting of the Q point or to achieve a stable Q point.

The Q point is nothing but a point in the output characteristic of the transistor. This point corresponds to a particular value of I_B, I_C and V_{CE}. Further , the collector current I_C depends both on I_B and β of the transistor. If I_B changes, I_c also changes, and hence, the Q point changes. If β changes, again I_C changes, and hence, the Q point gets shifted.

Shifting of Q point due to temperature: Remember that a transistor is a temperature sensitive device. Any increase in the junction temperature results in leakage current. this increased leakage current in turn increases the temperature and the effect is cumulative. This chain reaction is called thermal run away. If this thermal run away is not stopped, it may result in the complete destruction of the transistor due to excessive heat. In transistors, due to this increased leakage current, the base current increases, and hence, the Q point gets shifted. This change in the set Q point affects the performance of the amplifier resulting in distortion.

Shifting of Q point due to β_{dc} changes: Practically two transistors of the same type number may have different value of β. this is due to the manufacturing process of transistors. Hence, when a transistor is replaced or changed, due to different β of the replaced transistor, the Q point again gets shifted.

Therefore, a stable biasing is one which does not shift the Q-point even if temperature varies and/or the β of the transistor changes.

Different methods for transistor biasing: There are several ways to bias a transistor for linear operation. This means, there are several ways of setting up a Q point near the middle of the dc load line.

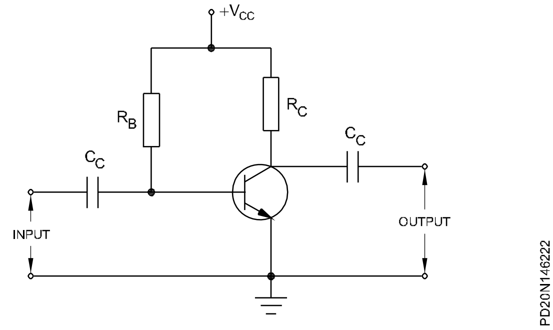
The methods used for providing a bias for transistors are 1 fixed bias or base bias

2 self-bias or emitter bias or emitter feed back bias

3 voltage divider bias

Fixed bias or base bias: The circuit in Fig 2 provides a fixed bias by means of the power source V_{cc} and the base resistor R_B

Fig 2



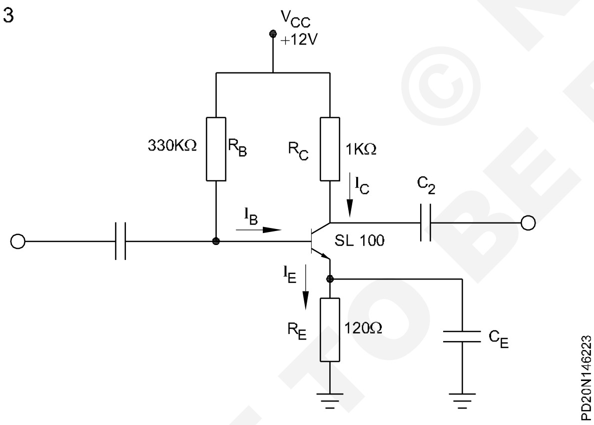
Self-bias arrangements are not practicable for small values of current because the DC Q point changes due to

- poor Beta sensitivity
- bias voltages and current do not remain constant during transistor operation due to temperature variation.

Hence, in a base-biased transistor, it is impossible to set up a stable Q point. Therefore, base biasing of transistors is not generally done in linear amplifier circuits. However, base biasing is commonly used in digital circuits (discussed in further lessons) where transistor are used as a switch and not as a linear amplifier.

2 SELF BIAS or EMITTER BIAS or emitter feedback bias: Fig 3 shows a emitter-biased transistor. This type of biasing compensates for the variations in temperature and keeps the Q point fairly stable.

Fig 3



Let the temperature rise-causing rise in I_c and consequently rise in I_c. Then the current in R_E increases. The increased current in R_E increases the DC voltage drop across R_E, reduces the net emitter to the base bias, and the base current, and hence reduces the collector current. Thus the presence of the self-biasing resistor R_E reduces the increase in Ic and improves the operating point stability.

However if β_{dc} increases, the collector current increase. This inturn increases the voltage at the emitter. This increased emitter voltage decreases the voltage across the base-emitter junction and therefore, the base current reduces. This reduced base current results in less collector current, which partially offsets the increase in I_c due to increase β_{dc}.

Emitter bias is also referred to as emitter feedback bias. This is because an output quantity, i.e., the collector current, produces a change in an input quantity i.e., the base current. The term feedback means a portion of the output is given back to the input. In emitter bias, the emitter resistor is the feedback element because it is common to both the output and input circuits.

Referring Fig 3, if we go for further analysis of the circuit we find if we add the voltages around the collector loop, we get,

$I_C R_C + V_{CE} + I_E R_E - V_{CC} = 0$ ...... (1)

Since I_E approximately equals I_c (as I_B is comparatively very small), equation ..(1) can be arranged as,

$$I_C = \frac{V_{CC} - V_{CE}}{R_C + R_E} \quad ....(2)$$

If we add voltages around the base loop, we get,

$I_B R_B + V_{BE} + I_E R_E - V_{CC} = 0$ ...(3)

Since $I_E = I_c$ and $I_B = I_c / \beta_{dc}$, we can rewrite the equation as,

$$I_C = \frac{V_{CC} - V_{BE}}{R_B + R_D/\beta_{dc}} \quad ....(4)$$

From equation...(4), the presence of term β indicates that I_c is dependent on β. The intention f emitter-feedback bias to swamp out the effect β_{dc}. This is possible when R_E is made much larger than R_B/β_{dc}. However, in practical circuits R_E cannot be made very large because, large value of R_E takes the transistor out of the linear operating region. Due to this problem, the emitter-feedback bias is almost as sensitive to changes in β_{dc} as in the base-bias. Therefore, emitter-feedback bias is also not a preferred form of transistor bias and should be avoided.

In emitter-bias, the saturation current will be,

$$I_{C(sat)} = \frac{V_{CC} - V_{CE\,(sat)}}{R_E + R_C} \quad ....(1)$$

When the transistor is saturated, the value of V_{CE} will be between 0.2 to 0.3V. Hence can be neglected for all practical purposes.

In Fig 3, the saturation current is,

Note:

$$I_{C(sat)} = \frac{12V}{1000\Omega + 120\Omega} = 10.71\,mA$$

$V_{CE(sat)}$ of 0.2 volts is neglected.

When β_{dc} = 100, equation...(4) gives,

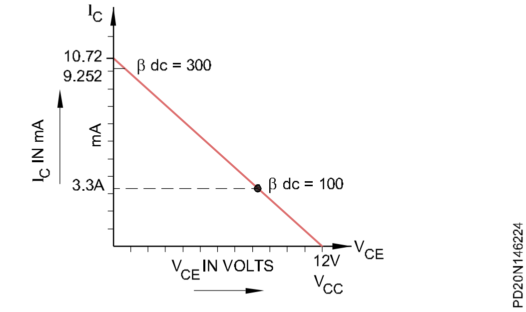
$$I_C = \frac{12V - 0.7V}{120\Omega + 330\,K\Omega/100} = 3.3mA$$

When β_{dc} = 300, the same equation...(4) gives,

$$I_C = \frac{12V - 0.7V}{120\Omega + 330\,K\Omega/300} = 9.262mA$$

Fig 4 summarizes the calculations by showing the DC load line and the two Q points. As can be seen, a 3:1 change in β_{dc} produces almost a 3:1 change in the collector current. This change is unacceptable as a stable-biased state.

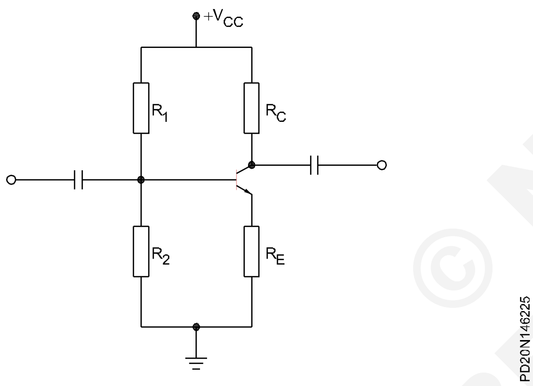
Fig 4



TIP: For linear operation of the transistor, the base resistor RB should be greater than βR_c. A base resistance of less than $\beta_{dc}R_c$ produces saturation in an emitter feedback-biased circuit.

3 **VOLTAGE-DIVIDER bias: Collector to base bias**: Fig 5 shows a typical voltage-divider bias. This type of biasing is also called the universal bias because, this is the most widely used type of biasing in linear circuits.

Fig 5



This type of biasing is known as voltage divider bias because of the voltage divider formed by resistors R_1 and R_2. The voltage drop across R_2 should be such that it forward biases the emitter diode.

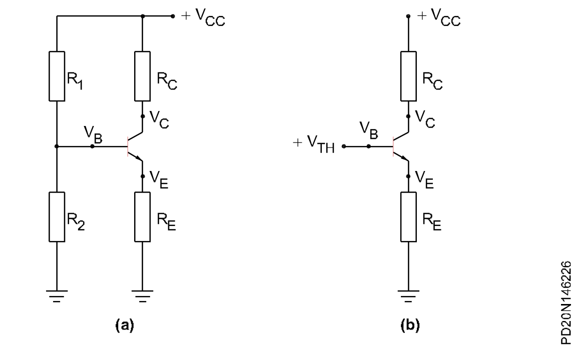
Emitter current in voltage divider bias : Assume that the base lead is open as shown in Fig 6b. Looking back at the unloaded voltage divider,

$$V_{TH} = \frac{R_2}{R_1 + R_2} = V_{CC}.$$

NOTE: V_{TH} is known as the Thevenin's voltage. Refer reference books for Thevinin's theorem.

Now assume that, the base lead is connected back to the voltage divider as in Fig 6a. then, voltage V_{TH} drives the base of the transistor. In other words, the circuit simplifies to Fig 6a and the transistor acts like the controlled current source.

Fig 6



Because the emitter is boot-strapped to the base,

$$I_E = \frac{V_{TH} - V_{BE}}{R_E}$$

The collector current I_c will be approximately equal to I_E.

Notice that β_{dc} does not appear in the formula for emitter current. This means that the circuit is not dependent on variations in β_{dc}. This means that the divider-biased transistor has a stable Q point.

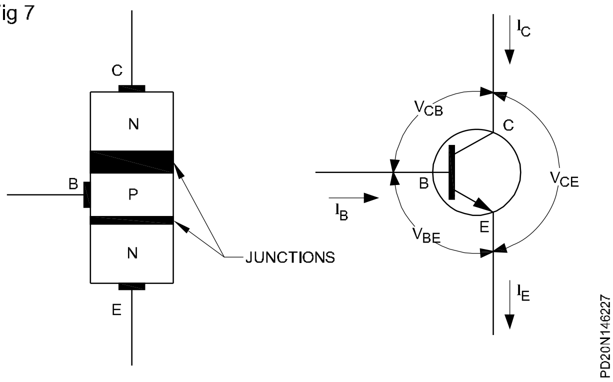
Because of the stable Q point, voltage-divider bias is the most preferred form of bias in linear transistor circuits. Hence, divider bias is used almost universally.

Transistor characteristics

In a transistor there are two PN junctions followed by three voltage parameters V_{BE}, V_{BC}, V_{CE} and three current parameters I_B, I_C, I_E is in Fig 7.

Any change in any one parameter causes changes in all the other parameters. Hence it is not very easy to correlate the effect of one parameter with the others. To have a clear understanding of their relationship a minimum of two characteristics graphs should be plotted for any transistor. They are,

Fig 7



– Input characteristics

– Output characteristics

For simplicity in understanding, consider a common-emitter amplifiers circuit (Fig 8). The two characteristics graphs are in Fig 9 and Fig 10.

The graph at Fig 9 shows the relationship between the input voltage V_{BE} and input current I_B for different values of V_{CE}

Fig 8

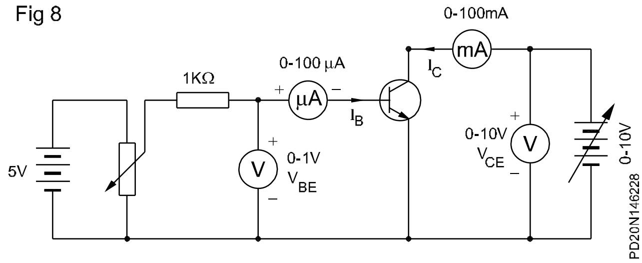
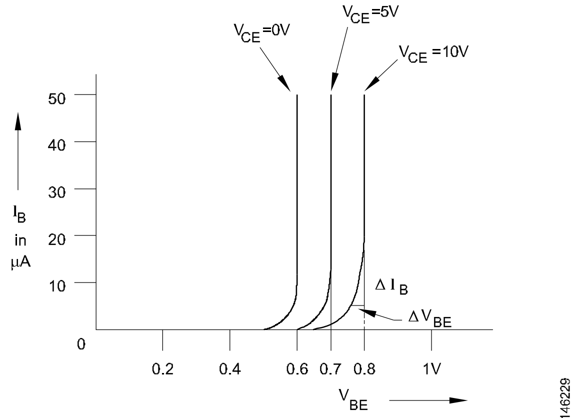


Fig 9



INPUT CHARACTERISTICS OF A COMMON EMITTER AMPLIFIER

To find the input characteristics from the circuit as in Fig 8 keep V_{CE} = 0 constant; increase V_{BE} at regular steps of 0.1V and note the value of I_B at each step. Repeat the above procedure for different value of V_{CE} say V_{CE} = 5V and 10V.

Input characteristic curves can be obtained by plotting I_B on the Y axis against V_{BE} on the X axis. A typical input characteristic is in Fig 9.

The reason for deviation of the characteristic curve for V_{CE}, 5V and 10V from V_{CE} 0 volt is, at higher values of V_{CE} the collector gathers a few more electrons flowing through the emitter. This reduces the base current. Hence the curve with higher V_{CE} has slightly less base current for a given V_{BE}. This phenomenon is known as early effect.

However for the practical purposes the difference in gap is so small it can be regarded as negligible.

The CE input characteristic curves resemble the forward characteristic of a PN diode. The input resistance can be calculated by using the formula.

$$R_{in} = \frac{V_{BE}}{I_B} = \frac{0.72 - 0.7}{20\ \mu A - 10\ \mu A} = \frac{0.02}{10\ \mu A} = 2k\Omega$$

(μ = micro)

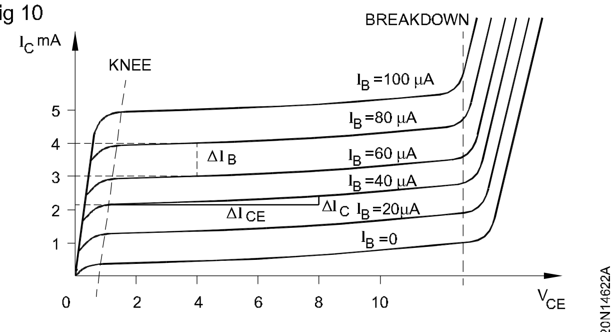
The voltage gain can be calculated by using the formula:

$$V_{gain} = \frac{V_{CE}}{I_{BE}} = \frac{10\ V - 5\ V}{0.15\ \mu A - 0.65\ \mu A} = \frac{5\ V}{0.1\ \mu A} = 50$$

Output CE characteristics: To find the output characteristics, keep I_B=0 micro-amp constant, increase V_{CE} in regular steps of 1V and note the value of I_B at each step. Repeat the above procedure for I_B = 20 micro-amp, 40 micro-amp and 60 micro–amp.

Output characteristics curves can be obtained by plotting I_c on the Y axis against V_{CE} on the X axis. A typical output characteristics curve is shown in Fig 10.

Fig 10



OUTPUT CHARACTERISTICS

It is seen that as V_{CE} increases from zero, I_c rapidly increases to a near saturation level for a fixed value of I_B. As shown, a small amount of collector current flows even when I_B= 0. It is called leakage current I_{CEO}. Since the main collector current is zero, the transistor is said to be cut-off.

For simplicity in understanding consider on the output characteristic curve where I_B = 40 μA.

The output resistance can be calculated by the formula

$$R_0 = \frac{V_{CE}}{I_C} = \frac{8 - 2}{2.15\ mA - 2m\ A} = \frac{6}{0.15m\ A} = 40\ k\ ohms.$$

Current gain can be calculated by the formula

$$\text{Beta } \beta = \frac{I_C}{I_B} = \frac{4mA - 3\ mA}{80\ \mu A - 60\ \mu A} = \frac{1mA}{20\ \mu A} = 50$$

In the common base configuration, the current gain can be calculated by the formula:

$$\text{Alpha } \alpha = \frac{I_C}{I_E} = \frac{\beta}{1+\beta} = \frac{50}{1+50} = 0.98$$

Analysis of common emitter output characteristics

Active region : In the active region the collector junction is reverse-biased and the emitter junction is forward-biased. In the active region, the collector current is Beta times greater than the base current. Thus, a small input current I_B produces a large output current I_c.

Saturation regions : In the saturated region, the emitter and collector junctions are forward-biased. When the transistor is operated in the saturated region, it acts as a closed switch having V_{CE} = 0 and I_c maximum.

Behaviour of Ic for different values of V_{CE} is explained below:

- When V_{CE} is 0, the collector-base diode is not reverse-biased. Therefore, the collector current is negligibly small and this continues upto knee point.
- For V_{CE} between 0.7V and 1V, say up to knee point voltage the collector diode gets reverse-biased. Once reverse biased, the collector gather all the electrons that reach its depletion layer. Hence the collector current rises sharply and then becomes almost constant.

- Above the knee voltage and below the break down voltage, the collector current does not rise steeply or the current is almost constant even if the value of V_{CE} is increased. Thus the transistor works like a controlled constant current source in this region.
- Assuming that the transistor has a β_{dc} of approximately 50, the collector current is approximately 100 times the base current as in Fig 4 (1mA is 50 times 20 μA).
- If V_{CE} is further increased, beyond the break down level, $V_{CE(max)}$, the collector-base diode breaks down and normal transistor action is lost. The transistor no longer acts like a current. As the collector-base gets ruptured, the junction is shorted and hence current increases rapidly above the breakdown point as in Fig 10.

Cut off region : In the cut off region, the emitter and collector junctions are reverse-biased. When the transistor is operated in the cut off region, it acts as an open switch, having $V_{CE} = V_{cc}$ and $I_c = 0$

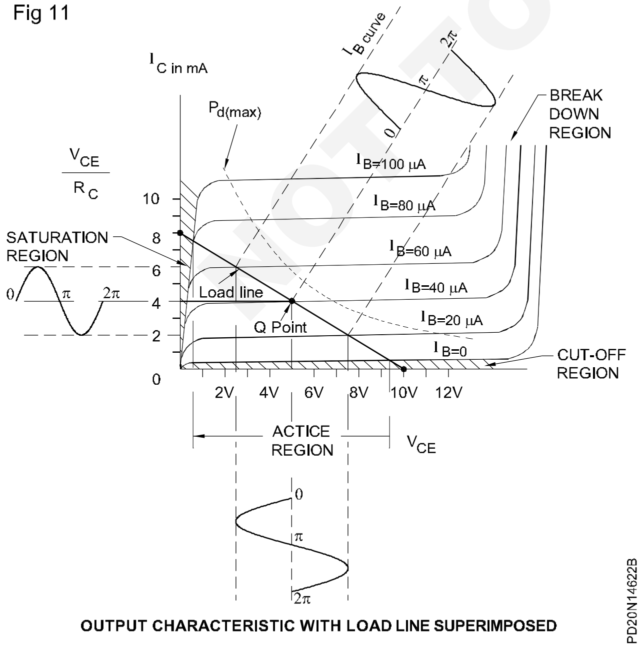
Break down region : When the collector voltage is too large, the collector diode breaks down by a rapid increase of collector current. Usually, a designer should avoid operation in the breakdown region because the excessive power dissipation may destroy the transistor.

For instance, a 2N3904 has a collector break down voltage of 40V. For normal operation, therefore, V_{CE} should be less than 40V.

Maximum power dissipation region : The maximum power dissipation ($P_{o\ max}$), defined as the product of maximum collector current $I_{c\ max}$ and maximum collector emitter voltage $V_{CE\ max}$, restricts the operation to an area on the output characteristic bounded by a hyperbola.

To understand the function of the transistor at active, cut off, saturation regions and breakdown regions, refer to Fig 11.

Fig 11



The collector curves are very important because, from these curves the following important information required while designing an amplifier circuit using a particular type of transistor can be obtained;

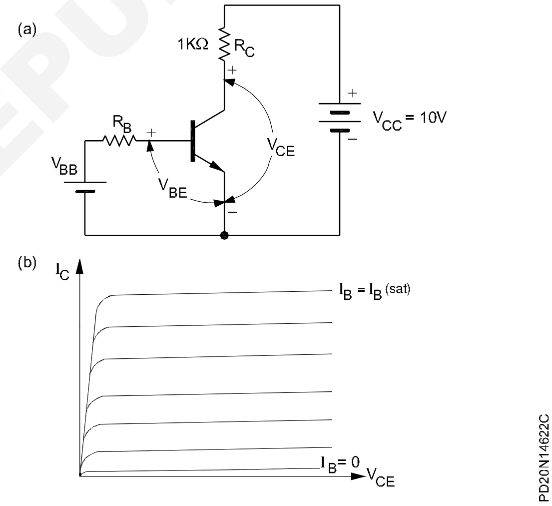
- DC current gain ß of the transistor at different set DC values of I_B and V_{CE}
- Maximum value of V_{CE} that can be applied for a set value of I_B and I_c.
- Maximum value of I_c that can be made to flow for a set value of I_B

Operation point : The position of the operating point on the DC load line determines the maximum signal that we can get from the circuit before clipping occurs. The operating point or quiescent point is a point on the DC load line which represents the values of I_c and V_{CE} that exist in a transistor circuit when no input signal is applied. The best position for this point is midway between cut-off and saturation point where $V_{CE} = 1/2\ V_{cc}$.

DC load lines of transistors : To have a further insight into how a transistor works and in what region of the collector characteristics does it work better can be seen using DC load lines.

Consider a forward biased transistor as in Fig 12a. Fig 12b shows the collector characteristics of the transistor used.

Fig 12



In the circuit at Fig 12a, consider the following two situations,

– Maximum collector current, $I_{c(max)}$

– Minimum collector current, I_c

For situation (1) assume that V_{CE} is zero or collector is at short. In that case, the collector current is limited only by the collector resistor R_c.

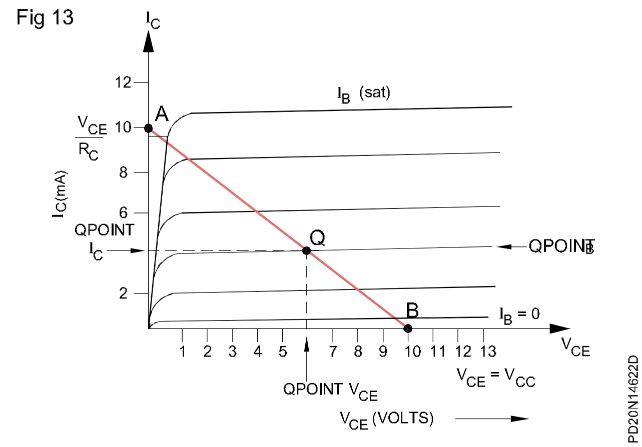
Therefore

$$I_C = \frac{V_{CC}}{R_C} \text{ at } I_{CE} = 0$$

Under such a condition for the circuit at Fig 12a I_c will be equal to 10V/kΩ = 10mA

Mark this I_c=10mA point along V_{CE}=0 on the collector characteristics of the transistor as shown in Fig 13 at point A.

Fig 13



For situation (2), assume that V_{CE} is maximum or collector emitter is open. In that case, the collector current is zero.

Therefore,

$V_{CE} = V_{cc}$ In the circuit at 6a, $V_{CE} = V_{CC}$ = 10V

Mark this point of I_C = 0 and V_{CE} = 10 V on the collector characteristics of the transistor as in Fig 13 at point B.

Connect the two marked points A and B through a straight line as shown in Fig 13. This line is called the load line.

The point at which the load line intersects the I_B = 0 is known as the cut off point. At cut off, I_B = 0; hence emitter diode is out of forward bias and the transistor action is lost.

The point at which the load line intersects $I_B = I_B$(sat) is called the saturation point. At this point the base current is maximum and the collector current is also maximum. At saturation, the collector diode comes out of the reverse bias, and hence, the normal transistor action is lost.

For a transistor to work in a normal way, i.e. as a controlled current source, it must not be made to work either in the cut off or in saturation. Therefore the ideal point would be somewhere in the middle of these extreme points on the load line. This middle point is known as Quiescent point or Q-point as in Fig 13. knowing the Q point we can fix up the value of resistors RC and RB of the circuit.

Transistor as a switch, series voltage regulator and amplifiers

Objectives: At the end of this lesson you shall be able to
- **explain the function of the transistor at cut-off and saturation condition**
- **explain the operation of a transistor as a switch and its application**
- **state the working of series voltage regulator using transistor**
- **state the classification of amplifiers.**

The function of a transistor at cut-off condition: The transistor is operated at cut–off condition when the emitter and collector junctions are both reverse-biased.

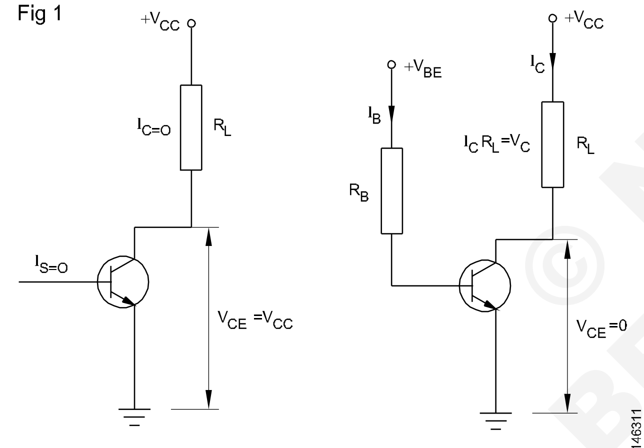
Consider the circuit in Fig 1.

$V_{CE} = V_{CC} - (I_C \times R_L)$ ..... (1)

Since, $I_B = 0$ and $I_c = 0$ $V_{CE} = V_{CC}$

The transistor is said to be cutoff for the simple reason that it does not conduct any current as in Fig 1a.This corresponds to a switch in an open state. Therefore, a transistor at cut off is said to be at open state.

Fig 1



a) TRANSISTOR AT CUT OFF CONDITION   b) TRANSISTOR AT SATURATED CONDITION

The function of a transistor at saturated condition : The transistor is operated at saturated condition when both the emitter and the collector junctions are forward biased.

In Fig 1b, if the value of R_B and R_L are such that V_{CE} tends to zero, then the transistor is said to be saturated. Putting $V_{CE} = 0$ in the equation (1) we get

$V_{CE} = 0 = V_{cc} - I_c R_L$ or $I_c = V_{cc} - R_L$

It should be noted that a transistor, when saturated, acts as closed switch of negligible resistance.

It is obvious that under saturation conditions,

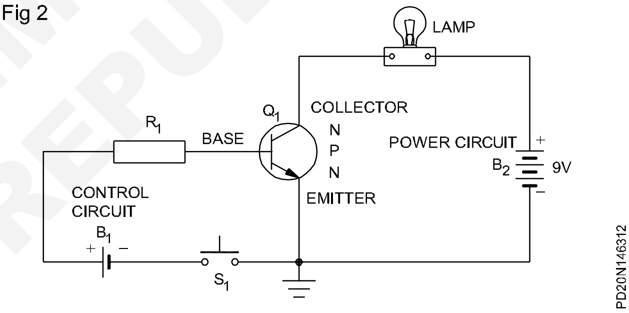
- the whole of V_{cc} drops across R_L
- the collector current has maximum possible value called $I_{C(SAT)}$

The operation of transistor as switch: The switching action for Q_1 in Fig 2 illustrates how the output current can be controlled at the input. Note the following important operating characteristics.

- The transistor is normally off, without any output current unless forward voltage is applied in the base-emitter circuit.
- The forward voltage controlling the base current determines the amount of output current.

In Fig 2 the control circuit of the input determines the base current. For the power circuit, the output is the collector current. An NPN transistor is used for Q_1. This type requires positive V_{BE} forward voltage. The emitter is common to both (a) the control circuit at the input and (b) the power output circuit.

Fig 2



The base emitter junction of Q_1, in Fig 2 can be forward biased by the battery B_1. Switch S_1 must be closed to apply the forward voltage. Reverse voltage for the collector of Q_1 is supplied by B_2.The reverse polarity means that the N collector is more positive than the base. With switch S_1 open, no current flows in the base-emitter (or control) circuit.

The reason is that the forward voltage is not applied. Therefore, the resistance from the emitter to the collector of the transistor is very high. No current flows in the power circuit, and the lamp does not light.

Next, assume that switch S_1 is closed. This causes a small current to flow in the control circuit. R_1 is a current limiting resistor for the base circuit. Therefore, the resistance from the emitter to the collector of the transistor drops. Consequently, a large current flows in the power circuit, causing the lamp to light.

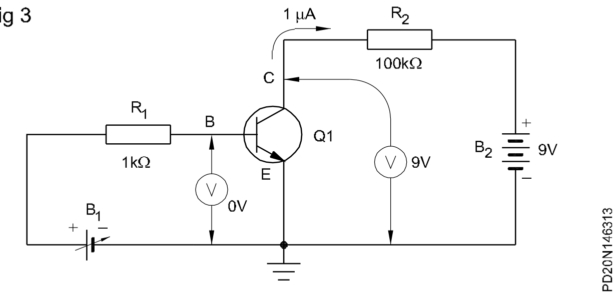
Finally, the opening of the switch S_1 in the control circuit cause the lamp in the power circuit to go out. This is because the resistance from the emitter(E) to the collector (C) of Q_1 has again increased to near infinity.

In summary, a small current in the control circuit causes a large current to flow in the power circuit. With no current in the control circuit, the transistor acts like an open switch. With some current in the control circuit, the transistor acts like a closed switch.

Operation of transistor switching circuit : The schematic circuit in Fig 3 shows the measured voltages and collector current I_c in the 'transistor off' circuit. Note that only a tiny leakage current of 1micro amp flows from the emitter to the collector. The resistance from E to C is calculated as

$$R = \frac{V}{I} = \frac{9\ V}{0.000001\ A} = 9 \text{ megohm}$$

Fig 3

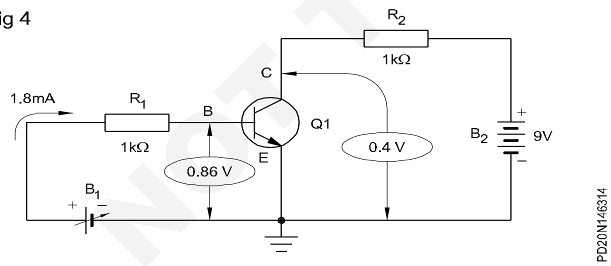


The transistor has a resistance of 9 Megohm, which is like the open or off condition of a switch.

The schematic in Fig 4, shows the measured voltages and currents in the 'transistor on' circuit. First, the voltage from the emitter to the base has been increased by adjusting B_1. The forward-biased voltage of 0,86V at the emitter-base junction of the transistor causes 1.8 mA to flow in the control circuit. This current in turn causes the resistance of the transistor from E to C to drop. The effect is that a large current of 85mA flows from the collector of the transistor. The resistance from E to C in Fig 4 is calculated as

$$R = \frac{V}{I} = \frac{0.4\ V}{0.085A} = 4.7 \text{ ohm}$$

Fig 4



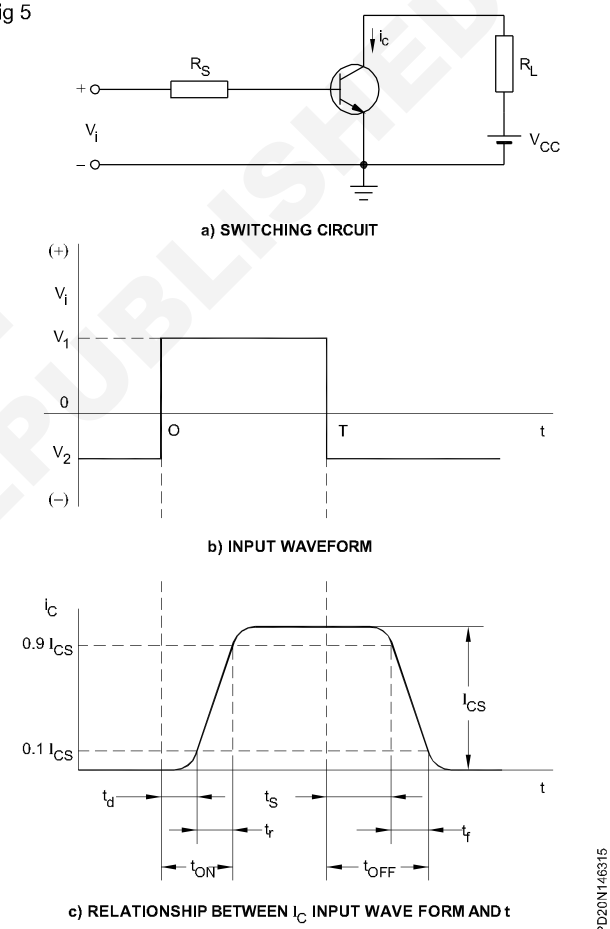
The resistance of the transistor from E to C has dropped from its previous high value of 9 megohm to a low value of 4.7 ohm. As a result, the transistor is acting like a closed switch.

The transistor in Fig 3 is said to be at cut off position. It has reached its maximum resistance from E to C and has cut off the current. The very tiny current still flowing is due to minority current carriers in the transistor, which is the leakage current.

The transistor in Fig 4 is said to be at saturation. It has reached its minimum resistance from E to C, which produces the maximum collector current. When used as a switch, the transistor is driven to cut off or to saturation by the base current caused by the emitter-base voltage.

Transistor switching times : Now let us pay attention to the behaviour of the transistor as it makes a transition from one state to the other. Consider the transistor circuit in Fig 5a, driven by the pulse wave-form in Fig 5b. This wave-form makes transitions between the voltage levels V_2 and V_1. At V_2 the transistor is at cut off, and at V_1 is applied between the base and the emitter through a resistor R_1 which may be included explicitly in the circuit or may represent the output impedance of the source in the wave-form Fig 5b.

Fig 5



The response of the collector current I_c to the input wave-form, together with its time relationship to that waveform, is in Fig 5c. The current does not immediately respond to the input signal. Instead, there is a delay, and the time that elapses during this delay, together with the time required for the current to rise to 10 percent of its maximum (saturation) value $I_{CS} = V_{cc}/R_L$, is called the delay time t_d. The current waveform has a nonzero rise time tr which is the time required for the current to rise from 10 to 90 percent of I_{CS}. The total turn-on time t_{ON} is the sum of the delay and rise time,

$$t_{ON} = t_d + t_r$$

When the input signal returns to its initial state at t = T (Fig 5b), the current again fails to respond immediately.

The interval which elapses between the transition of the input waveform and the time when i_c has dropped to 90 percent of ICS is called the storage time t_s. The storage interval is followed by the fall time tt, which is the time required for i_c to fall from 90 to 10 percent of I_{CS}. The turn off time to t_{OFF} is defined as the sum of the storage and fall times,

$$t_{OFF} = t_s + t_F$$

The application of transistor switch: The transistor switch is used

- as an electronic ON and OFF switch
- in the stable, mono-stable and bi-stable or filp-flop multi-vibrator circuits
- in the counter and pulse generator circuit
- in the clipping circuits
- as a sweep starting switch in the cathode ray oscilloscope equipment
- as a relay, but unlike the mechanical relay, the transistor has no moving mechanical parts.

Classification of the Switching Transistor: Transistor switches are used very often as they are small and are of light weight, and they consume low power. The important specifications of a switching transistor are the numerical values of delay time, rise time, storage time and fall time. For the TEXAS INSTRUMENTS n-p-n silicon transistor 2N3830, under specified conditions can be as low as t_d = 10 nsec, t_r = 50 nsec, t_s = 40 nsec and t_f = 30 nsec.

Series voltage regulator

Voltage regulated power supply using zener diode is the simplest form of voltage regulator. But, zener voltage regulators have two main disadvantages:

1 When the load current requirement is higher, say of the order of a few amperes, the zener regulator requires a very high wattage zener diode capable of handling high current.

2 In a zener regulator, the load resistor sees an output impedance of approximately the zener impedance, R_Z which ranges from a few ohms to a few tens of ohms (typically 5Ω to 25Ω). This is a considerably high output impedance because the output impedance of a ideal power supply should be zero ohms.

These two disadvantages of zener regulators are overcome in a simple series regulator shown in Fig 6.

The simple series regulator is in Fig 6a, redrawn in Fig 6b is nothing but a zener regulator followed by an emitter follower. A circuit like this can hold the load voltage almost constant, thus working as a voltage regulator.

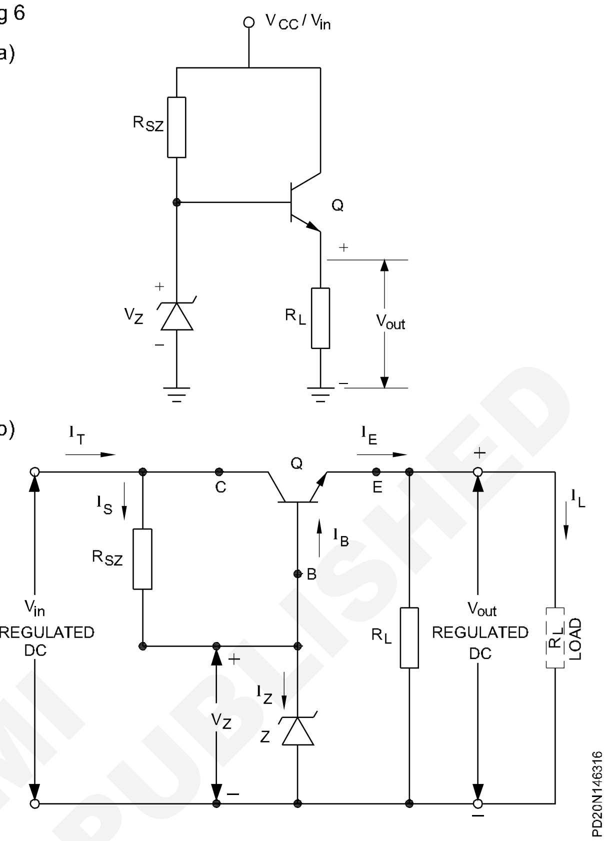
The advantages of this circuit are listed below;

1 Less load on the zener diode

Current through R_Z is the sum of current just required to keep the zener fired and the small base current I_B.

$$I_B = \frac{\text{emitter current}}{\beta_{dc} \text{ of transistor}} = \frac{I_E}{\beta_{dc}} = \frac{I_L}{\beta_{dc}}$$

Fig 6



Since the base current is very much smaller than the emitter current or the load current, a very small wattage zener diode itself is sufficient.

For instance for a load of say 1 amp, if the β_{dc} of the transistor is 100, then the zener diode need to handle only,

$$I_Z = I_{Z(min)} + \frac{I_L}{\beta_{dc}} = I_{Z(min)} + \frac{1\,Amp}{100}$$

Since $I_{Z(min)}$ will generally be in the range of 5 to 10mA, I_Z = 10mA + 10mA = 20mA.

2 Lower output impedance

If the zener resistance, R_Z is say 7Ω, then, in a zener regulator discussed in unit 9, the output impedance of the power supply will be approximately equal to R_Z = 7Ω.

Fig 7 shows the output equivalent circuit of the series regulator at Fig 6. As in Fig 7, the output impedance of the power supply will be,

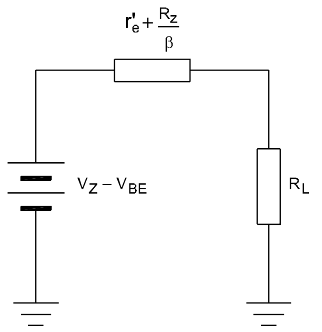
$$Z_{out} = r'e + \frac{R_Z}{\beta}$$

Since I_E is very large (load current), r^l_e will be comparatively small, hence the term r^l_e can be neglected. Therefore, in Fig 6 the output impedance will be,

$$Z_{out} \cong \frac{R_Z}{\beta} = \frac{7}{100} = 0.07\Omega$$

This low output impedance of 0.07Ω is close to the ideal output impedance of zero required for a power supply.

Fig 7



r'_e = AC RESISTANCE OF TRANSISTOR

R_Z = INTERNAL RESISTANCE OF ZENER

β = CURRENT GAIN OF TRANSISTOR

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Working of a simple series regulator

In Fig 6b, the current through R_{SZ} should be atleast equal to zener breakdown current, plus, base current for the transistor Q.

The voltage across the zener, V_Z drives the base of the emitter follower. Therefore, the DC output voltage is bootstrapped to within one V_{BE} drop of the zener voltage. The regulated dc output voltage will be,

$V_{out} = V_Z - V_{BE}$ ....[1]

The collector - emitter voltage across the transistor will be the difference in the voltage between the input and output.

$V_{CE} = V_{in} - V_{out}$

If the input voltage V_{in} increases, the output voltage V_{out} remains constant due to the bootstrapped zener voltage. Therefore, the drop across the collector-emitter, V_{CE} of the transistor increases compensating the rise in the input voltage V_i.

For example, in the series regulator shown in Fig 6, if V_{in} is 15 V and V_{out} is 12 volts, then, V_{CE} will be,

$V_{CE} = V_{in} - V_{out} = 15\text{-}12 = 3$ V.

If V_{in} increases to say 20 V, then V_{CE} increases to 20-12=8 V, thus keeping the output voltage unaltered at 12 volts. Since the collector and emitter of the transistor in Fig 6 is in series with the input and output terminals, this type of regulators are known as series voltage regulators.

Because the transistor is in series, all the load current must pass through the transistor. Hence the transistor is referred to as the pass transistor.

Because of the fact, that all the load current must flow through the pass transistor and that the value of V_{CE} increases when V_{in} increases, the wattage rating of the pass transistor should be high enough to handle the dissipation.

For instance, while supplying a load current of 300 mA, with V_{in} at 20 V and V_{out} at 12V, V_{CE} will be 8 V. Therefore, the dissipation at the transistor will be,

$P_D = V_{CE} \times I_L = 8 \times 300$ mA = 2400 mw = 2.4 watts

To accommodate this, the wattage rating of the chosen pass transistor should be greater than 2.4 watts.

TIP: Allow at least 20% higher rating. For the example above, choose a transistor of rating 2.4 + 0.48 watts= 3 watts.

Because there will be quite a high dissipation depending on load current requirement, medium to high power transistors are used as pass transistors.

Temperature effect on output voltage

When temperature increases, V_{BE} decreases. Therefore, V_{out} decreases by the change of current in V_{BE}.

Data sheets of transistors usually give information about how much V_{BE} changes with temperature.

For all practical purposes, an approximate of 2 mV decreases in V_{BE} for each degree rise in temperature. For instance when the temperature of the transistor rises from 25°C (room temperature) to 75°C (due to power dissipation at the transistor), V_{BE} decreases approximately 100 mV. Hence, the output will increases by 100 mV. This is relatively small, and hence, can be neglected.

Temperature also has an effect on the voltage across the zener. Any increase or decrease in the voltage across the zener is reflected at the output. Hence, while choosing the zener, it is equally important to know the temperature coefficient of the zener, specially when the power supply is connected to higher loads of the order of a few amperes.

Classifications of amplifiers : An amplifier is an electronic circuit which is used to amplify or increase the level of weak input signals into very high output signals. Transistors are used as amplifiers in most circuits. In addition, resistors, capacitors and a biasing battery are required to form complete amplifier circuits.

Almost all electronic systems work with amplifiers. We are able to hear the news or other programmes on our radio, simply because the amplifier in the radio amplifiers the weak signals received by its antenna.

Classification of amplifiers: Linear amplifiers are classified according to their mode of operation, i.e. the way they operate according to a predetermined set of values. Various amplifier descriptions are based on the following factors.

1 Based on the transistor configuration
   a common emitter (CE) amplifier
   b common collector (CC) amplifier
   c common Base (CB) amplifier
2 Based on the output
   a voltage amplifier
   b current amplifier
   c power amplifier
3 Based on the input
   a small signal amplifier
   b large signal amplifier

4 Based on the coupling

  a RC coupled amplifier

  b transformer coupled amplifier

  c impedance coupled amplifier

  d direct coupled amplifier

5 Based on the frequency response

  a audio frequency (AF) amplifier

  b intermediate frequency (IF) amplifier

  c radio frequency (RF) amplifier

  d VHF and UHF amplifiers

6 Based on the feedback

  a current series feedback amplifier

  b current parallel feedback amplifier

  c voltage series feedback amplifier

  d voltage parallel feedback amplifier

7 Based on the biasing conditions

  a Class A power amplifier

  b Class B power amplifier

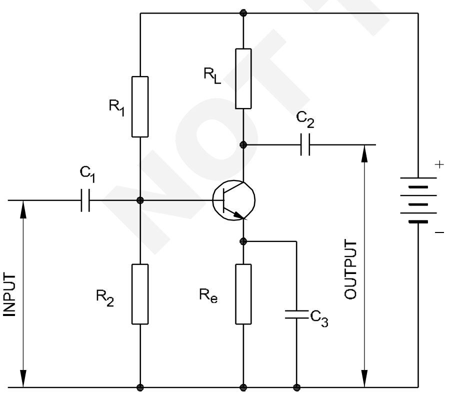
  c Class AB power amplifier

  d Class C power amplifier

Of the above mentioned, serial numbers one and two are explained at this state. Some of the amplifiers dealt in this book for detailed study the students can refer to any standard books for the remaining portions depending on their special interest.

Common-emitter amplifier: This type of circuit is by far the most frequently used. It has the greatest power gain, substantial current and voltage gains, and is specially advantageous in multistage application when a high gain is a primary requirement. A common-emitter amplifier stage with biasing from a single D.C supply battery is in Figure 8.

Fig 8



RESISTORS	CAPACITORS
R_1=22kΩ	C_1=10 μF
R_2=5kΩ	C_2=10 μF
R_L=3.3kΩ	C_3=200 μF
R_e=0.5kΩ	

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The A.C. signal is applied between the base and the emitter and the output is taken from the collector. For the transistor to operate, the emitter base junction must be forward-biased, the resistors R_1 and R_2 setting the base voltage so that the emitter is forward-biased. The collector current flows through the load resistors R_L and R_e and the voltage developed by R_L at the collector is the output.

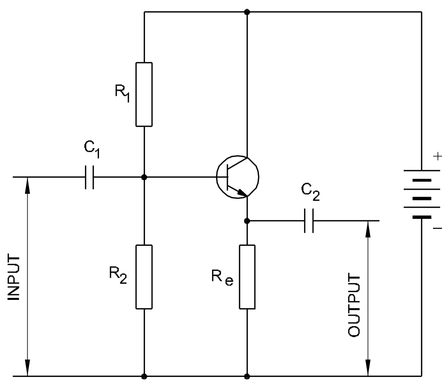
The voltage gain of a transistor is largely determined by the value of this particular resistor since the voltage developed across it due to change in the collector current is far greater than that developed across the base resistor from the input signal.

Resistor R_e is included to minimise the effect of temperature changes in the collector current. To prevent R_e from reducing the signal gain by current feedback, a capacitor C_3 may be included in parallel with R_e.

The capacitors C_1 and C_2 are provided to prevent (block) the flow of direct current so that the D.C. bias conditions are in no ways affected by the signal circuit. In this way, the D.C. conditions at one stage are prevented from affecting the following stage, so that only D.C. signals are passed from one stage to the next one.

Common-collector amplifier : In this configuration, the collector is the common point for the input and output circuits, the input signal being applied between the base and collector and taken off between the emitter and collector, Fig 9. The notable feature is the large input impedance virtually equal to that of the parallel circuit of R_1 and R_2. The output resistance is, however, low and, hence it follows that the voltage gain is low, but a high current amplification can be obtained.

Fig 9



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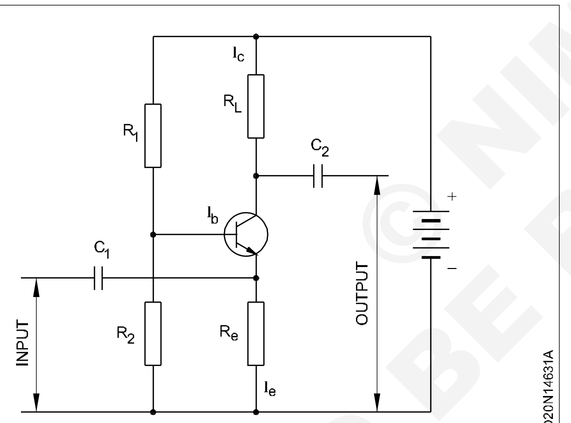
The functions of the capacitors C_1 and C_2 are the same as for the common-emitter stage, as the potential networks R_1 and R_2 which provide forward bias for the emitter-base junction. The main advantage of the common-collector circuit is the readiness with which it may be directly coupled to any point in a circuit regardless of voltage.

The circuit is often called the emitter-follower because the emitter voltage tends to follow the input voltage, the difference between the two being only the AC voltage across the base-emitter junction of the transistor which is quite small. Hence the output gain is less than 1.The current gain 50 to 500 is, however, high, being approximately equal to that of the common-emitter circuit. The output resistance is very low (less than 100 ohms) since the emitter-to-collector resistance is low and there is not resistance in the collector circuit.

The external resistance of the collector circuit, that is, the impedance presented by the transistor to the load is, however, very high (300 KΩ) and hence the emitter follower, circuit, transforms a very high input impedance into a low output impedance; it is in fact an impedance transformer. Hence its main application is as a buffer, i.e. an impedance matching device in which it can be connected between a high impedance source and a low impedance load without excessive loss of power due to mismatching or not suitable.

Common-base amplifier: In this circuit the base is the common terminal between the emitter terminal and the collector terminal. The emitter current I_c is the input current and the collector current I_c is the output current. (Fig 10) Since $I_e = I_b + I_c$ and since in this circuit Ie is greater than I_c, by the value of I_b, the current gain I_c/I_e will always be slightly less than one. Therefore, there can be no current gain in a common-base circuit. However, because of the low impedance of the forward-biased emitter-base junction and the high impedance of the reverse-biased collector-base junction a sizable voltage gain is obtained.

Fig 10



For instance, if we assume that input resistance of 200Ω, a load resistance of 50K and a current gain of 0.98, the voltage gain is 0.98 x 50k/200 = 245

The common-base circuit is not suitable for multi-stage amplification because its current and power gain are low when compared with the common-emitter. Also its low input impedance shunts the load resistance of any previous stage, thereby reducing the output voltage from that stage causing a corresponding fall in overall gain.

However, its ability to operate at high frequencies makes it useful in v.h.f. amplifiers. At such frequencies this circuit is more stable than the common-emitter amplifiers because of the very small capacitance linking input and output circuits (the emitter-collector capacitance).

Voltage amplifier: An amplifier is a circuit that incorporates one or more transistors and is designed to increase an alternating signal applied to the input terminals. It is called a voltage amplifier. If the size or magnitude of the output voltage is considerably greater than the input voltage, it is called the voltage gain of the amplifier.

The main function of a voltage amplifier is to produce a given gain with the minimum of distortion, i.e. the output voltages should have the same wave-form as the input wave-form, but should of course be much higher in magnitude. Examples for the voltage amplifier are the common base and the common emitter amplifiers.

Current amplifier: The function of the current amplifier is when the current injected in the base, load can influence to much greater current to flow in the emitter-collector circuit.

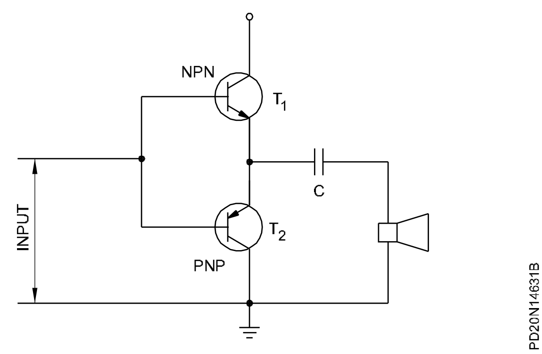
The remarkable result is that, if the base current is increased by a certain proportion, the base current in the collector current gives rise to a corresponding, but much larger changes in the collector current. We have achieved current amplification. The ratio of the output current to the input current is called the current gain of the amplifier.

An example for the current amplifier is the common-emitter, common-collector amplifier. The current gain of common-emitter amplifier is 50 to 300 and that of the common-collector amplifier is 50 to 500.

Power amplifier : Power amplifiers are used to drive the output mechanism, e.g. a loudspeaker, a pair of earphones, a moving coil meter or some other type of indicating device. The main function of a power amplifier is to deliver a good deal of undistorted power into the output device or load circuit. Examples for the power amplifiers are class A, class B, class AB and class C.

Fig 11 shows the complementary symmetry Class B push-pull power amplifier circuit. In a complementary pair of power amplifiers, one of them is an NPN type and the other a PNP type. With no input signal, neither transistor conducts and the output is zero. When the input signal is positive going, the NPN transistor T_1 conducts and the PNP transistor T_2 is cut off. When the signal is negative going, T_1 is tuned of while T_2 conductors. The maximum efficiency of this circuit is about 78%.

Fig 11



Function generator and cathode ray oscilloscope (CRO)

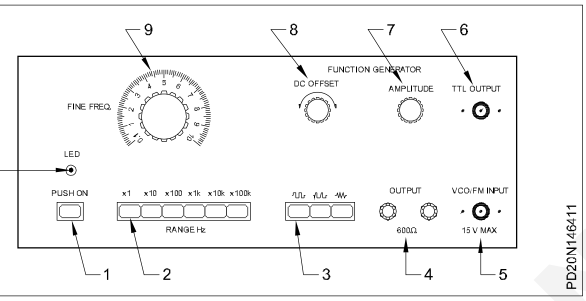
Objectives: At the end of this lesson you shall be able to
- **explain the use and control of function and AF (audio frequency) generator**
- **explain the function of CRO with block diagram**
- **state the functions of various controls in CRO**
- **state the use of CRO in electronic circuits.**

Introduction: A function generator is an equipment capable of providing sine, square and triangular wave outputs at different frequencies and amplitude. It has a maximum of 20 volts peak to peak single amplitude. A function generator finds applications in frequency modulations, tone control, Audio electronic, other laboratory and research work.

Panel controls and features of function generator

The front panel controls of function generator. (Fig 1)

Fig 1



1 **Power ON-OFF switch:** To turn on the function generator this button should be depressed. To turn off the same button should be pressed to release.

2 **Range selectors:** The range selection is of decade frequency type. The output frequency is given by the product of range selected and frequency dial indication. For example if the 10 K range button in depressed and frequency dial is at 2, then the output frequency is 20 KHz.

3 **Function selectors:** These selectors select the desired output waveform. (square, sine or Triangle)

4 **Output jack:** The wave forms selected by the function switches are available at this jack.

5 **VCO input jack:** An external voltage (not exceeding ± 20V peak) input will vary the output frequency. The change in frequency is directly proportional to the input voltages.

6 **TTL JACK:** A TTL (Transistor, Transistor logic) square wave is available at this jack. This output is independent of the Amplitude.

7 **Amplitude control:** This controls the amplitudes of the output signal.

8 **Offset control:** This controls the DC offset of the output.

9 **Fine frequency dial:** The output frequency of the wave forms is given by the product of the setting of this dial and the range selected.

Operating information: The function generator is powered by 240V. AC mains. When the power ON switch is depressed the LED will glow.

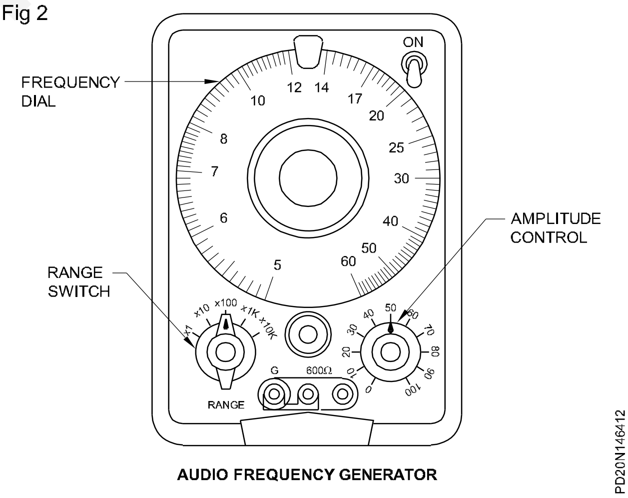
The desired frequency is set by depressing the frequency range switch an positioning the fine frequency dial.

The desired wave from is selected by depressing the appropriate function button from sine, square or triangle.

The amplitude of the selected output signal is adjusted by Amplitude control knob. A variation of the display amplitude from 0-20 V peak is possible. The TTL output is not affected by the amplitude control.

Audio Frequency (AF) Generator (Fig 2): Audio frequency generators produce sine wave signals from 20 Hz to 20 kHZ. Certain type of AF generators produce sine wave upto 100 kHZ. In addition to sine wave there may be provision to produce square waves too.

Fig 2



These generators contain a variable amplitude control which changes the signal amplitude from 10 mv to 20V. With the help of this generator the audio amplifier stages in radio, TV recorders and audio amplifier could be tested.

While the frequency range switch selects the desired frequency range switch selects the desired frequency range, the frequency dial is used to select the frequency within the desired range.

Cathode ray oscilloscope (CRO)

Introduction: The oscilloscope is an electronic measuring device which provides a visual presentation of any wave form applied to the input terminals. Cathode ray tube (CRT) like a television tube provides the visual display of the signal applied as a wave form on the front screen. An electron beam is deflected as it sweeps across the tube face, leaving a display of the input signal.

An oscilloscope usually consists of:

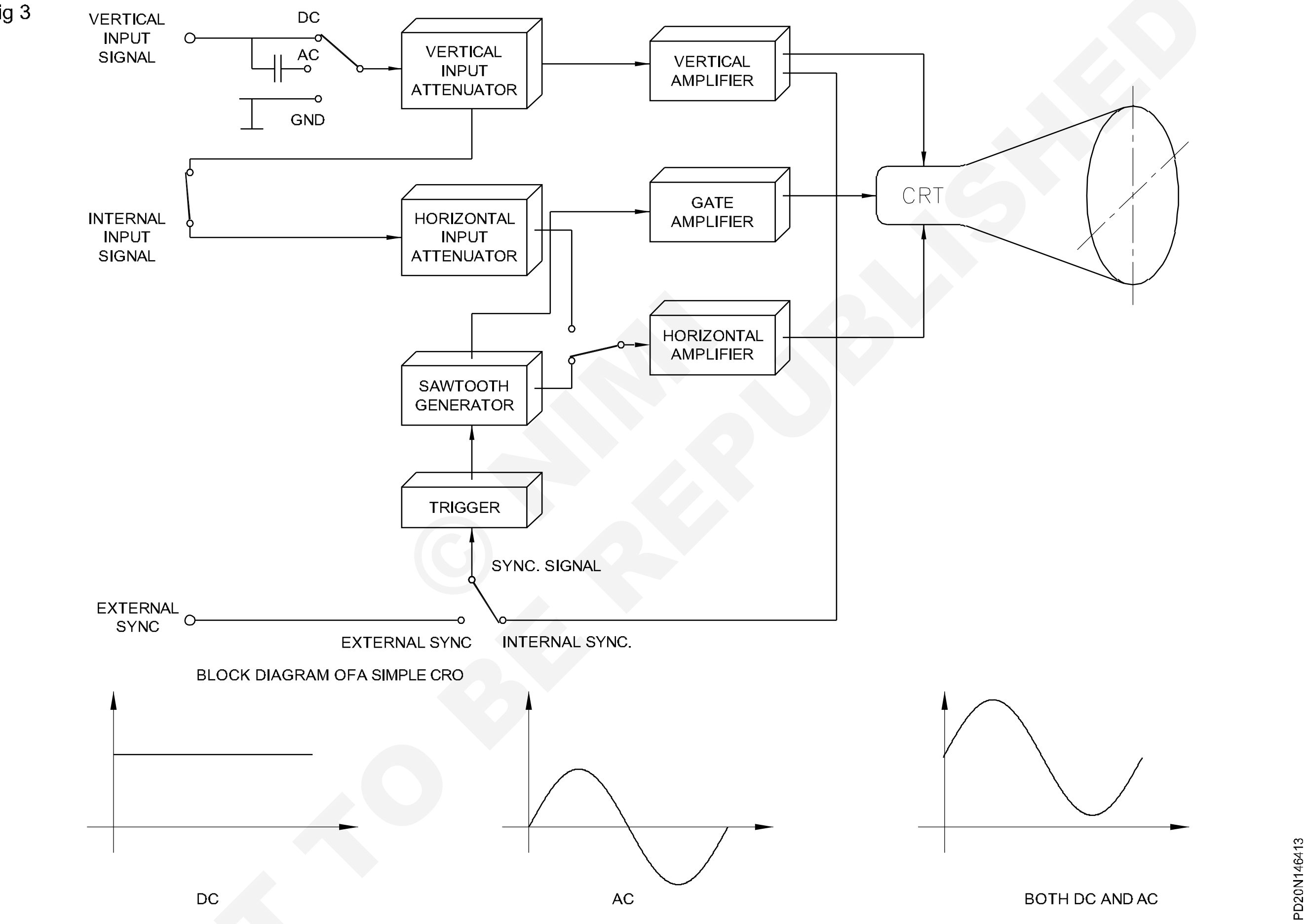
- Attenuator
- amplifiers
- saw-tooth generator
- gate amplifiers or Z-amplifier
- Trigger
- CRT (cathode ray tube)
- power supply

The block diagram of a simple cathode ray oscilloscope is shown in Fig 3.

Attenuator : The input signal should be attenuated to a suitable magnitude before it is applied to the amplifier. The attenuators are employed at the input of both vertical and horizontal amplifiers.

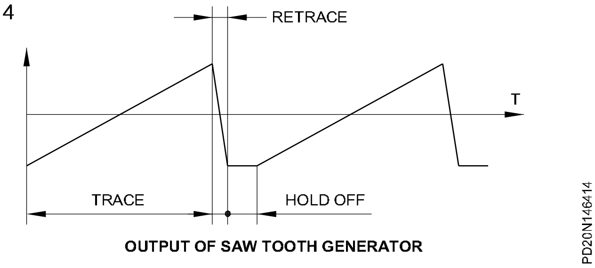
Amplifier : The amplifiers of an oscilloscope consist of a vertical amplifier and a horizontal amplifier. The vertical amplifiers amplify the vertical input signal before it is applied to the Y-plates. The horizontal amplifier amplifies the signal, before it is connected to the X-plates.

Fig 3



Saw-tooth generator: The measuring signal of any shape is connected to the Y-input(plates) and then it appears on the screen. The signal on X-plates should be such that the image on the screen is similar to that on the Y-plates. Hence a saw-tooth signal is required to be connected to the X-plates which makes the image on the screen like the signal connected at the vertical plate. The saw-tooth signal is called the time base signal, and is produced by the saw-tooth generator. The shape of the saw-tooth signal is shown in Fig 4. The time-base signal consists of trace, retrace and hold off period.

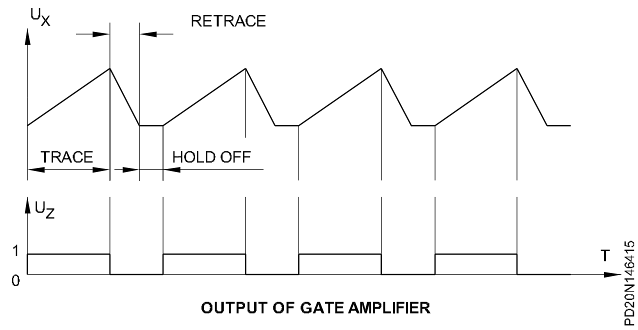
Fig 4



Gate amplifier or Z-amplifier: It is desirable that the image seen on the screen of the CRT must be continuous, that is, the electron beam is desired to appear only in the trace period of the time-base signal. The retrace period of the electron beam must not be visible on the screen. Therefore, the gate amplifier is required to control the electron beam in order that it appears only in the trace period.

The signal from the gate amplifier is a square wave and is related to the time-base signal. This is illustrated in Fig 5.

Fig 5



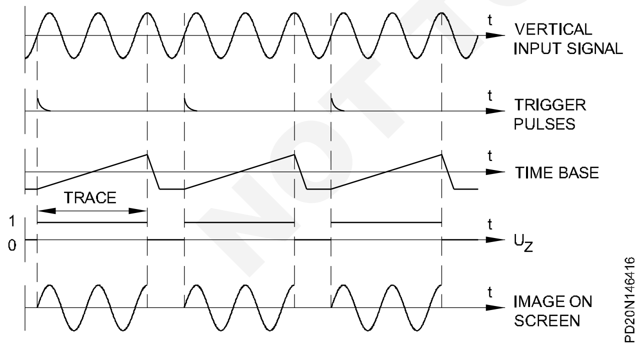
Trigger (Gate amplifier output) : As mentioned earlier, the measuring signal-wave form is connected to Y-input, which appears on the screen. In order to make the wave-form stationary on the screen, it is required that the starting point of the time base signal has to be fixed related to the signal connected to the Y-input. This is known s 'synchronization'. The functional stage which performs synchronization is the trigger.

The trigger will produce a pulse or impulse for triggering the time-base. Every time the time-base is triggered, one saw-tooth wave-form is produced.

There are three forms of triggering in an oscilloscope.

Internal triggering : The signal which is supplied to the trigger is the internal signal of the CRO produced by using the signal from the vertical input signal. The sequence of signal processing is shown in Fig 6.

Fig 6



External triggering : The signal which is supplied to the trigger is the external signal, produced by using the signal from the external, sync.

Line triggering : The signal which is supplied to the trigger is the signal from the power supply of CRO. (Not shown in the block diagram)

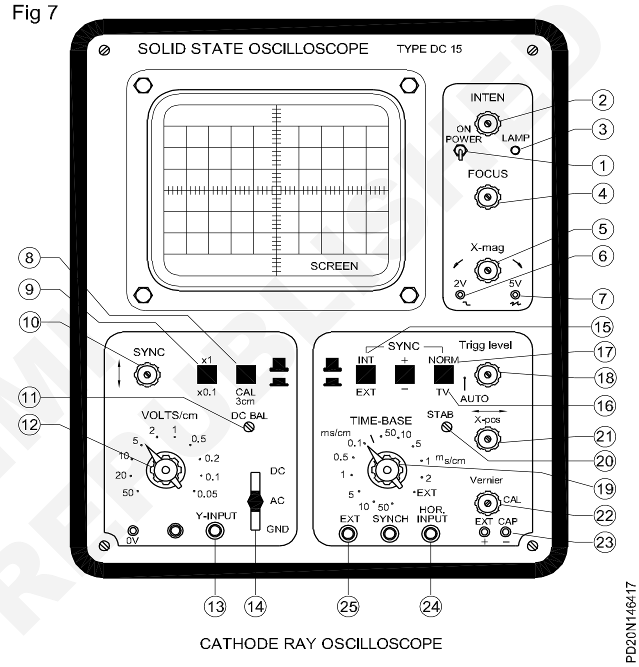
Switches are provided to select the form of triggers as required. In a CRO, suitable timing can be selected that causes the image on the screen to be stationary.

CRO (The Cathode ray tube): The constructional features are explained later in this text.

Power supply: Low voltage and high voltage DC supplies which are required for the oscilloscope function are produced by rectifier filters and switch mode power supply circuits.

Controls and their functions in a CRO: The operating controls on the front panel of a general purpose oscilloscope is shown in Fig 7. The names of the controls and their functions are listed below.

Fig 7



General

Power-on (1): It is toggle switch meant for switching on power. In the ON position, power is supplied to the instrument and the neon lamp (3) glows.

Intensity (2): It controls the trace intensity from zero to maximum.

It controls the sharpness of the trace. A slight readjustment of this control may be necessary after changing the intensity of the trace.

X-Magnification (5): It expands length of the time-based from 1 to 5 times continuously, and makes the maximum time-base to 40ns/cm.

Square wave (6): This provides a square wave of 2 V (p-p) amplitude to enable the user of the scope to check the Y-calibration of the scope.

Saw-tooth wave (7): This provides a saw-tooth, wave-form output coincident to the sweep-speed switch with an output of 5V (p-p). The load resistance should not be less than 10 k ohms.

Vertical section

Y (10) : This control enables the movement of the display along the y-axis.

Y (13) : It connects the input signal to the vertical amplifier through the AC-DC-GND coupling switch (14)

AC-DC-GND coupling switch (14): It selects coupling to the vertical amplifier, in DC mode, it directly couples the signal to the input; in AC mode, it couples the signal to the input through a 0.1 MF, 400-V capacitor. In GND position, the input to the attenuator (12) is grounded, whereas the Y-input is isolated.

Volts/cm (Attenuator) (12): It is a 10-position attenuator switch. It adjusts the sensitivity of the vertical amplifier from 50 m V/cm to 50 V/cm in 1,2,5,10 sequence. The attenuator accuracy is ±3%.

x1 or x 0.1 switch (9)

When switched in x 0.1 or position, it magnifies the basic sensitivity to 5 m V/cm from 50 m V/ cm

CAL switch (8): When pressed, a DC signal of 15 m V or 150 m V is applied to a vertical amplifier depending upon the position of x1-x0.1 switch (9) position.

DC bal (11): It is a preset control on the panel. It is adjusted for no movement of the trace when either x1 -x0.1 switch (9) is pressed, or the position of AC-DC-GND coupling switch (14) is changed.

X-Position (21): This control enables the movement of display along the X-axis.

Trigger level (18): It selects the mode of triggering. In AUTO position, the time-base line is displayed in the absence of the input signal. When the input signal is present, the display is automatically triggered. The span of the control enables the trigger point to be manually selected.

Time-base (19): This sector switch selects sweep speeds from 50 ms/cm to 0.2Ms/cm in 11 steps. The position marked EXT is used when an external signal to be applied to the horizontal input (24)

Vernier (22): This control is a fine adjustment associated with the time-based sweep-selector switch (19). It extends the range of sweep by a factor of 5. It should be turned fully clockwise to the CAL position for calibrated sweep speeds.

Sync. selector (15, 16, 17): The INT/EXT switch (15) selects internal or external trigger signal. The +ve or -ve switch (16) selects whether the wave-form is to be triggered on +ve or -ve step. NORM/TV switch (17) permits normal or TV (line frequency) frame.

Stab (20): It is a preset control on the panel. It should be adjusted so that you just get the base line in the AUTO position of the trigger level control (18). In any other position of the trigger level control, you should not get the base line.

Ext. Cap (23): This pair of connectors enables the time-base range to be extended beyond 50 ms/cm by connecting a capacitor at these connectors.

Hor. input (24): In connects the external signal to the horizontal amplifier.

Ext. sync. (25): It connects the external signal to the trigger circuit for synchronization.

Application of CRO

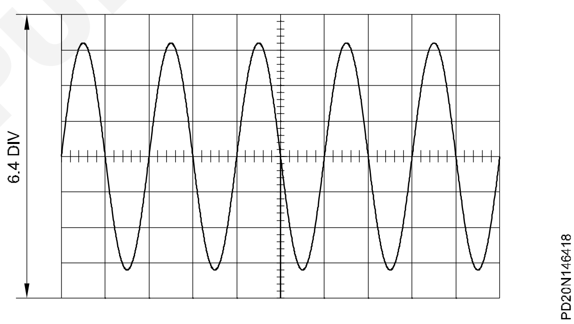
AC voltage measurement: The screen of the cathode ray oscilloscope usually has a plastic gratitude overlay, marked in centimeter divisions. The vertical amplitude of any wave form indicates peak-to-peak voltage.

To measure unknown AC voltages the main supply AC should be isolated through a isolation transformer and the attenuator is set to 50 V/ div. The AC-DC switch is set to AC position (out). Voltage to be measured is connected to the input and common terminal. Set the time base switch to display several cycles of the wave form. Adjust the V/div switch to get a wave form at a convenient height such that the positive and negative peaks appears with-in the screen.

Measure the vertical amplitude (no. of divisions peak-to-peak) of the voltage on the screen. Now multiply the amplitude by the volts/div setting to find the peak-to-peak voltage value.

Example : Assume a vertical deflection of 6.4 divisions as in Fig 8 and a volt/div setting of 5 volts.

Fig 8



Peak-to-peak voltage	= 6.4 x 5 = 32 V	
therefore peak voltage	= 16 V	
therefore RMS voltage	= 16 x 0.707	= 11.31 V

$$\text{or RMS voltage} = \frac{\text{Peak to peak voltage}}{2.83} = \frac{V_{PP}}{2 \times \sqrt{2}}$$

$$= \frac{32}{2 \times \sqrt{2}} = 11.31\text{v}$$

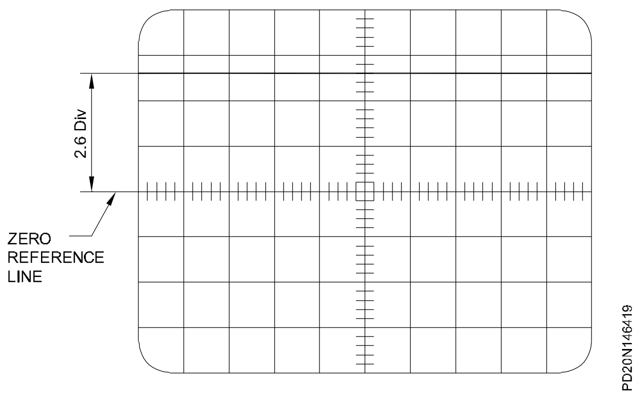
DC voltage measurement : The input selector switch is set to DC position. Adjust the Y shift position to get the trace at the centre of the screen. This line represents zero DC volts. Connect the +ve of the DC voltage to be measured to input terminal and the -ve to the common terminal. Now the horizontal line will move up. (Down for reverse polarity) the volts/div switch is set as required.

Now measure the vertical distance in divisions form the zero reference line.

The DC voltage can be found by multiplying the vertical distance (division) with VOLT/DIV setting.

An example is worked out with reference to Fig 9

Fig 9 DC VOLTAGE MEASUREMENT



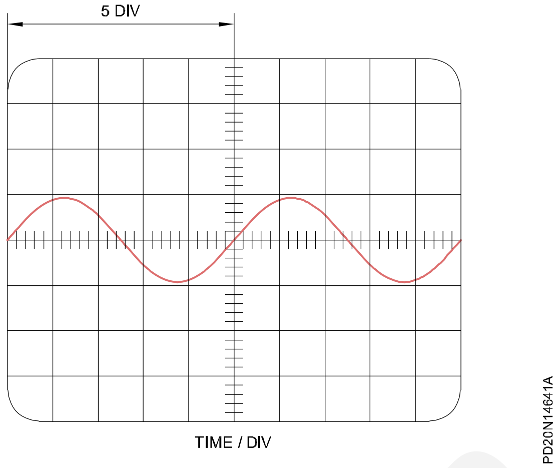
Assume a vertical deflection of 2.6 division and a Volts/ Div setting of 20 V.

DC voltage = 2.6 x 20 = 52V.

Measurement of time and frequency : The wave-form to be measured is connected to the V input. The volts/ Div switch is set to display a suitable vertical amplitude of the wave-form. The Time/Div switch is set to display approximately two cycles of the wave-form to be measured. Adjust the Y-SHIFT control to move the trace so that the measurement points are on the horizontal centre line. The X-SHIFT control is adjusted to move the start of the measurement points to a convenient reference line.

The distance (divisions) between the points of one cycle is measured as in Fig 10.

Fig 10 PERIOD AND FREQENCY MEASUREMENT



The product of the divisions of one cycle and the setting of time/div switch gives the period of one cycle.

The frequency can be determined by the formula

$$\text{Frequency} = \frac{1}{\text{Time period}}$$

where frequency is in hertz and time in seconds.

Example

Time = Div x time base setting

= 5 x 0.2 ms

= 1 ms

$$\text{therefore frequency} = \frac{1}{T} = \frac{1}{1 \times 10^{-3}} = 1000\text{ Hz}$$

Frequency = 1 kHz.

Printed circuit boards (PCB)

Objectives : At the end of this lesson you shall be able to
- **state the types of etchants used for etching and preparation of etchant solution**
- **state the reasons for agitating the etchant solution while etching**
- **list the important points while drilling holes on PCBs**
- **list the advantages of marking component positions on PCBs.**

Introduction

Printed circuit board in which the connecting wires are replaced by a thin conducting path called copper or silver foil which is moulded in one side of the insulated board. The insulating board is generally made up of phonetic, paper or fibre glass or epoxy.

The moulded conducting path generally known as tracks size depend on the power of the circuit. The width of tracks are varied few millimeters to less than one millimeter depend on the circuit.

The thin tracks less than one millimeter made up with silver tracks where IC circuits and micro controller circuits are to be made. Several process moulded to make PCB and it is explained below.

Etching

Once the required portions on the copper foil side of the laminate is painted/masked and dried, the next step is to remove the copper present in the unmasked portions of the laminate. This process is known as etching.

Only after etching the unwanted areas of the copper foil, the metal side of the laminate gets the actual shape of the circuit connection required.

Etching is done using any one of the following chemicals;

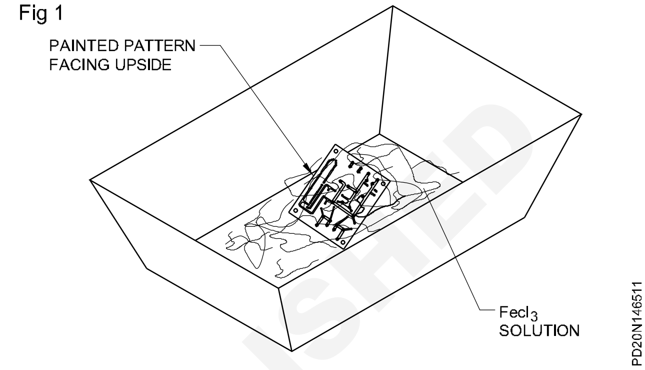
- Alkaline ammonia
- Sulpuric-hydrogen peroxide
- Ferric chloride
- Cupric chloride

The most popular amongst beginners and economical way of etching, is the manual etching process. This is done generally using a solution of ferric chloride. Ferric chloride is available in liquid, powder and crystal forms.

While preparing the etching solution, concentrated ferric chloride solution/powder is mixed with lukewarm water(27°F) and stirred well using a glass rod. This forms a diluted acid ($FeCl_3$) solution.

The ratio of ferric chloride and water decides the rate of etching. The typical ratio is, 100mg of concentrated ferric chloride powder/liquid for one litre of water. This $Fecl_3$ is prepared in a plastic tray of suitable size such that the painted laminate to be etched can be fully immersed as shown in Fig 1.

Fig 1

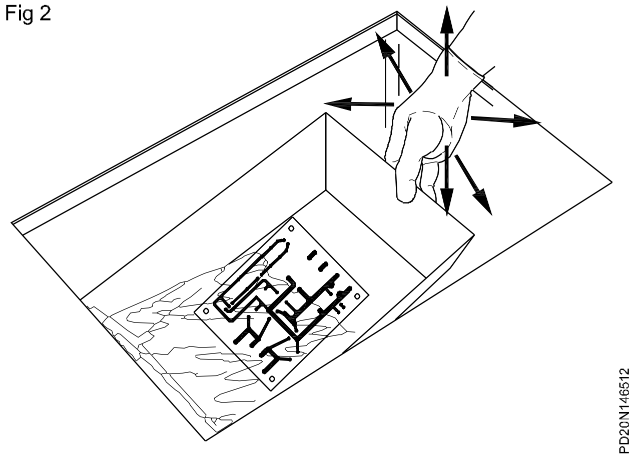


Since ferric chloride is an acid solution, although diluted, it is harmful to the skin. Hence, rubber gloves are to be used while working with this solution.

The painted laminate to be etched is slid into the $Fecl_3$ solution of required quantity, with the painted surface of the laminate facing the top as in Fig 1, such that, as the process of etching progresses, the extent of etching is visible.

To ensure speedy and uniform etching, the etchant solution is agitated lightly by shaking and tilting the tray as shown in Fig 2. Too much of agitation of the solution should be avoided, as this may peel off the ends of the painted tracks and remove those portions which were not intended to be etched.

Fig 2



Power electronic devices - UJT and FET

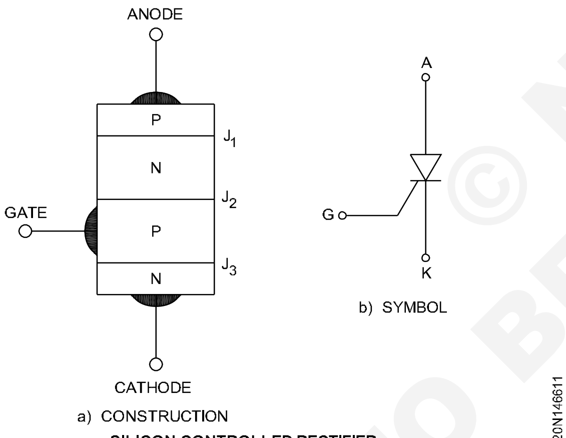
Objectives: At the end of this lesson you shall be able to
- **state the construction and working characteristics of SCR and its testing**
- **state the use of UJT for triggering gate circuits**
- **explain the function of DIAC and TRIC**
- **state the FET principle working, biasing, applications**
- **state the JFET principle, biasing, application as an amplifiers.**

Introduction

Thyristors are four layer device which can be switched 'ON' or 'OFF' electronically to control relatively large amounts of current for motors and other electrical equipment. The Silicon Controlled Rectifier (SCR) and the Triac are examples of Thyristor. Almost all electronic controls used in modern industries consist of electronic circuits with Thyristors.

Construction of SCR: The cross-sectional view of a typical SCR and the symbol are shown in Fig 1. Basically, the SCR consists of a four-layer pellet of P and N type semiconductor materials. Silicon is used as the intrinsic semiconductor to which the proper impurities are added.

Fig 1



SILICON CONTROLLED RECTIFIER

Working of SCR: The SCR is a four-layer device with three terminals, namely, the anode, the cathode, and the gate. When the anode is made positive with respect to the cathode (Fig 1), junction J_2 is reverse-biased and only the leakage current will flow through the device.

The SCR is then said to be in the forward blocking state or off-state. When the anode-to-cathode voltage is increased, the reverse-biased junction J_2 will break down due to the large voltage gradient across the depletion layers. This is the avalanche breakdown. Since the other junctions J_1 and J_3 are forward-biased, there will be free carrier movement across all the three junctions, resulting in a large anode-to-cathode forward current I_F. The voltage drop V_F across the device will be the ohmic drop in the four layers, and the device is then said to be in the conduction state or on-state.

In the ON-state, the current is limited by the external impedance. If the anode-to cathode voltage is now reduced, since the original depletion layer and the reverse-biased junction J_2 no longer exist due to the free movement of the carriers, the device will continue to stay ON. When the forward current falls below the level of the holding current I_h, the depletion region will begin to develop around J_2 due to the reduced number of carriers, and the device will go to the blocking state. Similarly, when the SCR is switched on, the resulting forward current has to be more than the latching current I_L.

This is necessary for maintaining the required amount of carrier flow across the junctions; otherwise, the device will return to the blocking state as soon as the anode-to-cathode voltage is reduced. The holding current is usually lower than, but very close to the latching current; its magnitude is in the order of a few milliampere(mA). When the cathode is made positive with respect to the anode, junctions J_1 and J_3 are reverse-biased, and a small reverse leakage current will flow through the SCR. This is the reverse blocking state of the device.

When the SCR is reversed biased the device will behave in the same manner as two diodes connected in series with the reverse voltage applied across them. The inner two regions of the SCR will be lightly doped as compared to the outer layers.

Hence, the thickness of the J_2 depletion layer during the forward-bias condition will be greater than the total thickness of the two depletion layers at J_1 and J_3 when the device is reverse-biased. Therefore, the forward break-over voltage V_{BO} will be generally higher than the reverse break-over voltage V_{BR}.

SCR has two stable and reversible operating states. The change over from off-state to on-state, called turn-on, is achieved by increasing the forward voltage beyond V_{BO}. There reverse transition, termed turn-off, is made by reducing the forward current below I_h. A more convenient and useful method of turning on the device employs the gate drive.

Characteristics of SCR

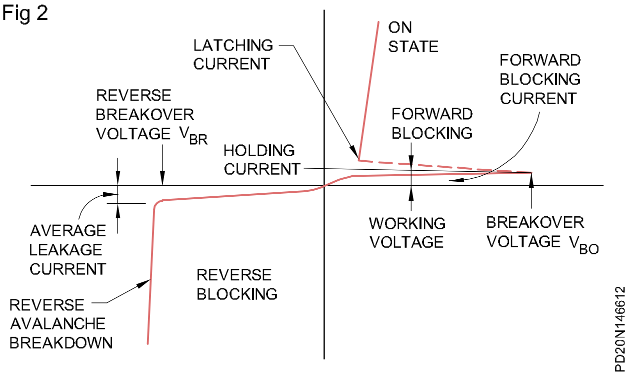
SCR voltage current characteristic: Fig 2 shows the voltage current characteristic of an SCR whose gate is not connected(open). When the anode-cathode circuit is reverse biased a very small current in micro ampere called reverse blocking current flows through the SCR.

When the reverse break over voltage reaches a value equivalent to peak reverse voltage V_{BR}, the SCR conducts due to reverse avalanche breakdown and the current increases sharply into ampere.

In most of the cases the SCR gets damaged in this mode. The behaviour of the SCR at reverse bias mode is shown by VI characteristic of Fig 2.

When the SCR is forward biased, there is small forward leakage current (as in Fig 2) called forward blocking current which remains small, until the forward breakdown voltage V_{BO} is reached. This is the forward avalanche region.

Fig 2



At that point current increases suddenly to higher conduction level. At this point the anode to cathode resistance of the SCR becomes very small and the SCR acts like a closed switch. The voltage across the SCR drops to about 1.4V. Hence we can say that in forward bias mode when the applied voltage is less than B_{FO} the SCR behaves as open switch and when the applied voltage exceeds B_{FO} the SCR behaves as closed switch. The current through SCR is limited by the external load resistance.

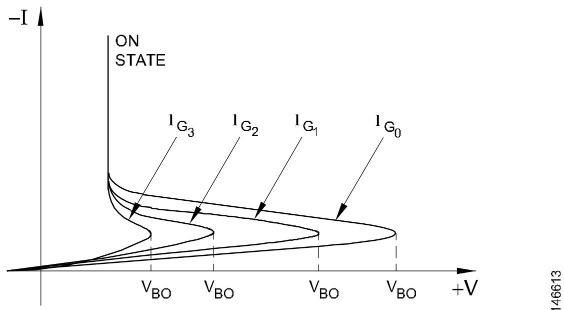
Holding and latching currents: The holding current is the +I value necessary in the anode circuit to keep the SCR in conduction while it is ON. The latching current is +I value needed to switch the SCR anode circuit ON from the OFF condition. This I (current) is typically about three times more than the holding current. When the SCR is switched into conduction, the gate voltage must be on long enough for the anode current to reach the value for latching.

Triggering of SCR: SCR can be switched into conduction either by increasing the forward voltage beyond V_{BO} or by applying a positive gate signal when the device is forward-biased. Of these two methods, the latter, called the gate-control method, is used as it is more efficient and easy to implement for power control.

Gate-current control: Injecting gate current into the SCR lower the break over voltage, as shown in Fig 3. Here I_{GO} is for zero gate current. This situation is the same as that shown in Fig 2, but the other examples in Fig 3 are for increasing gate current. Note that, as gate current is increased, the break over voltage is reduced.

When there is enough gate current, the break over voltage becomes lower than the operating voltage or the forward blocking voltage of the SCR. That is how the SCR is used. The injection of gate current lower the break over voltage to a value below that of the applied voltage, thereby turning the SCR on.

Fig 3



EFFECT OF GATE CURRENT IN LOWERING THE BREAKOVER VOLTAGE OF AN SCR

Note that the 'ON' state is the same for all different values of gate current in Fig 3. The gate current triggers the SCR 'on'; but when the SCR conducts the amount of forward current is determined by the anode circuit impedance.

Applications: The following are the major applications of SCR

- Power control
- Over voltage protection
- Time delay circuit
- Soft start circuit
- Logic and digital circuits
- Pulse circuits references
- Phase control in AC power control
- full-wave control circuit
- Speed control of motors
- Regulated DC power supplies
- DC motor control

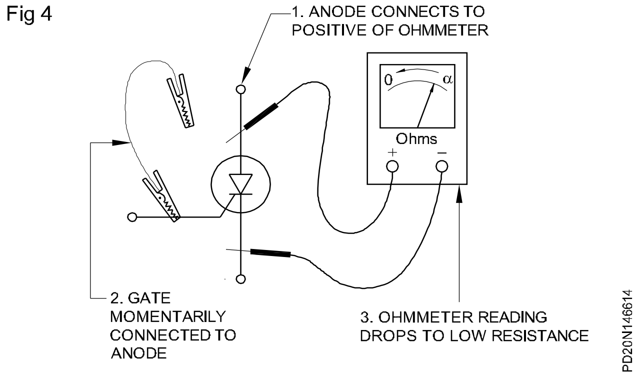
Testing of SCR by multimeter

SCR can be tested in the multimeter in the following sequence.

Set the multimeter to a low range. Adjust to zero and infinity with the adjustment knob. Connect the SCR as shown in Fig 4. The meter will not indicate any reading. Even the test prods are interchanged because of the junctions. The multimeter shows infinite resistance. Connect the SCR as in Fig 4. When the gate is touched momentarily with the anode prods, the meter reads low resistance between 30 and 40 ohm. When the gate is removed, the meter still continues to read the same value of 30 and 40 ohm.

This means that the SCR is in good working condition. If the meter does not show any reading, the SCR is faulty. When the gate is given a small forward bias, the gate switching the SCR and the internal resistance of the junction is low, so the current can flow easily from the cathode to the anode. Once the SCR is conducted, even if the gate's forward bias is removed, the SCR anode-to-cathode current will flow through the meter, and the multimeter will continue to read a low resistance, ie 30 to 40ohm.

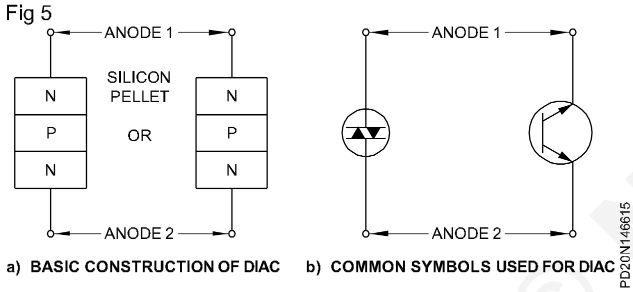
Fig 4



The DIAC and TRIAC

Like UJTs, DIAC is a semi-conductor device used extensively as a trigger device for triacs and thyristors gate circuit. In its most elementary form, DIAC is a three layer device as in Fig 5 without gate terminal.

Fig 5



a) BASIC CONSTRUCTION OF DIAC b) COMMON SYMBOLS USED FOR DIAC

As can be seen from Fig 5, DIAC is a three layer, two terminal semi-conductor device capable of conducting current in both directions.

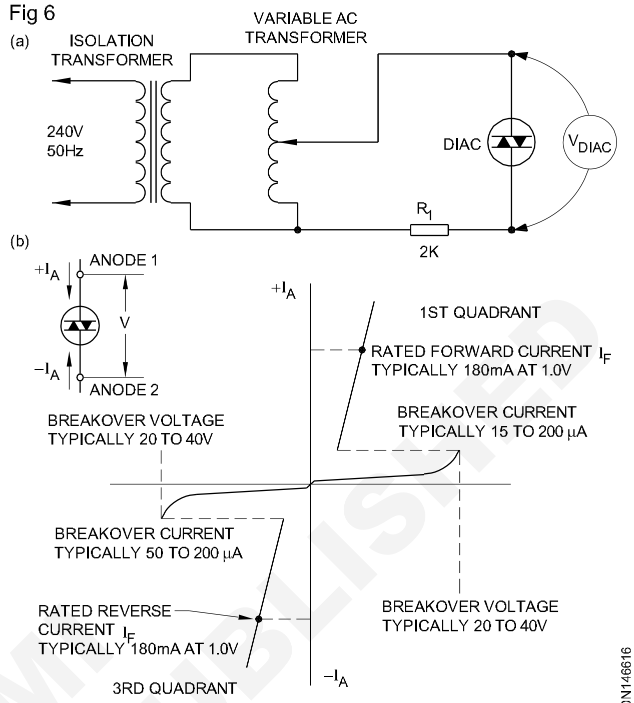
DIACs resembles an NPN or PNP bipolar transistor with no base connection. Unlike bipolar transistor, the diac possess uniform construction. This means, N-type and P-type doping is essentially the same at both junctions. As in Fig 5, diac may be constructed as either an NPN or PNP structure.

Fig 6a shows the experimental setup for testing the diac. The isolation transformer is used to isolate the circuit from the supply mains. The variable transformer is used to apply the variable voltage to diac under test. The characteristic curve of a typical diac is shown in Fig 6b.

As shown in the experimental setup at Fig 6a, when a small voltage of either polarity is applied across a DIAC, the current flow is very small as can be seen from its characteristics in the first and the third quadrants. If the applied voltage is steadily increased, the current will remain at a low value until the applied voltage reaches a value known as the breakover voltage of the DIAC as in Fig 6b.

Once this point is reached the diac current increases rapidly and the diac voltage falls to a low value. At this point, the diac exhibits negative resistance characteristics (current conduction increases while the voltage across the device decreases). The diac will continue to conduct current as long as the current is greater than the holding current of the device.

Fig 6



CHARACTERISTIC OF DIAC

A diac acts in a similar manner to two zener diodes that are connected in reverse parallel and it therefore it is able to rectify AC voltage during both half cycles. The symbol used for DIAC is in Fig 5b.

Application of DIAC: DIAC can be used to trigger triac or SCR at specified voltage levels.

DIAC testing: DIACs are similar to two diodes connected back to back and break down in either direction once the applied voltage reaches the breakdown voltage of the diode. While testing a diac using a ohmmeter, it should show high resistance (infinite resistance) when checked in either direction. The quick test only confirms that the DIAC is not shorted; however this quick test is worth carrying out before using the Diac in a circuit.

TRIAC

TRIAC is a three terminal gated semi-conductor device for controlling AC in either direction. The term TRIAC stands for TRIODE AC semi-conductor. TRIAC is very similar to that of two SCR connected in reverse parallel. A Triac is able to conduct a large current in both directions, being trigged ON in one direction or the other by a gate pulse of the appropriate polarity.

UJT and its applications of triggering circuits

UJTs are employed in a wide variety of circuits involving electronic switching and voltage or current sensing applications. These include

– triggers for thyristors

– as oscillators

– as pulse and sawtooth generators

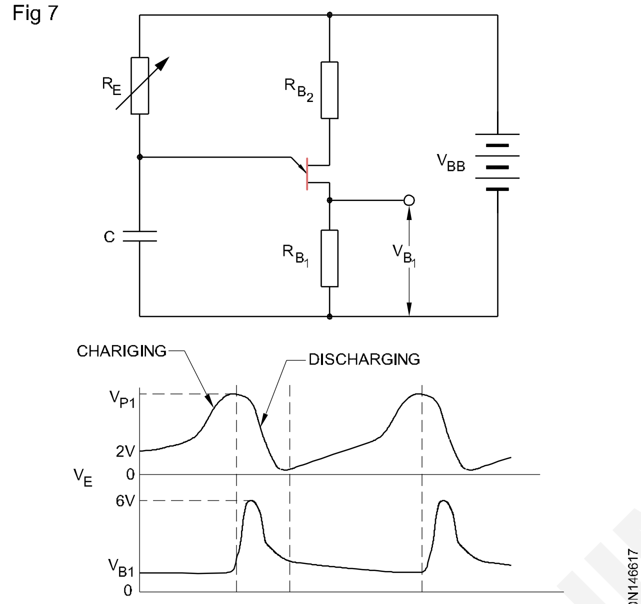
– timing circuits

– regulated power supplies

– bistable circuits and so on.

Let us analyse the waveform generated across the capacitor and R_1 with respect to the relaxation oscillator or free running oscillator as in Fig 7.

Fig 7



UJT AS RELAXATION OSCILLATOR

The negative - resistance portion of the UJT characteristic is used in the circuit shown in Fig 7 to develop a relaxation oscillator.

The wave form developed across the capacitor is shown in Fig 7 as V_E, whereas the waveform produced across the resistor R_{B1} is shown as a pulse V_{B1}.

The frequency of oscillation

$$f = \frac{1}{R_E C}$$

Where R_E is the value of variable resistor in ohms and C is the value of the capacitor in farad.

By varying the value of R_E, the frequency of the oscillator can be varied. Although such an oscillator using a DC supply voltage could be used to trigger a SCR, there would be trouble in synchronizing the pulses with the cycles of alternating current. Fig 8 shows a stable triggering circuit for an SCR in which the firing angle can be varied from 0° to 180°.

The low output impedance of the UJT (39 ohms) is ideal for driving the SCR, which has a relatively low input impedance from gate to cathode.

Resistor R_D is used as a dropping resistor to restrict the peak voltage across the UJT to within its specifications.

By varying the variable resistor R_E the oscillator frequency can be varied thereby the frequency of trigger pulses which are used to trigger the SCR. Time used for delay in switching the SCR could be measured through a stop watch from the time of switching on.

Basic construction of a Triac, its symbol and a typical Triac is shown in Fig 9a, 9b and 9c. As can be noticed in Fig 9, the electrodes of a Triac are labelled as,

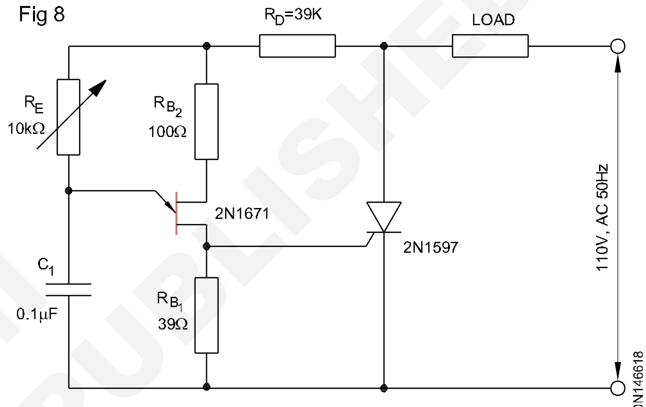
– Main terminal-1 (MT_1)

– Main terminal-2 (MT_2) and

– Gate (G)

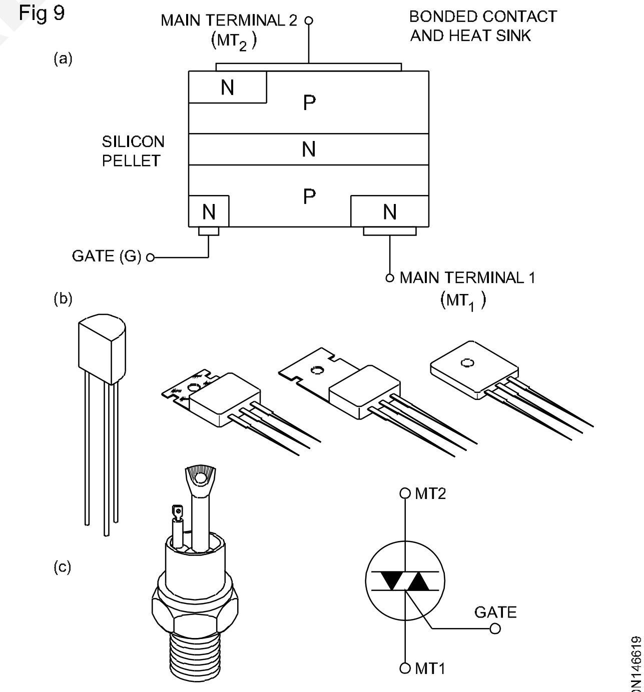
The terminals are so labelled because, this device operated in both directions and hence the terms anode and cathode does not apply.

Fig 8



UJT RELAXATION OSCILLATOR USED FOR TRIGGERING THE SCR

Fig 9



CONSTRUCTION AND SYMBOL OF TRIAC

TRIAC triggering : Triac can be triggered/turned-ON by,

1 applying a gate current,

2 applying a voltage exceeding the avalanche breakdown voltage V_{BO}

3 allowing the MT_1 - MT_2 applied voltage to increase at a rate in excess of the maximum dv/dt figure.

Methods 2 and 3 above are not employed in normal Triac operation but they may be considered as limiting factors in circuit design. Hence, in all further discussion it is restricted to triggering the Triac via the gate. Since Triac is a bidirectional device, it can be triggered into conduction by a negative or a positive gate signal. Triacs potentials are considered with respect to main terminal - 1 (MT_1). This gives the following possible operating situations or modes;

– MT_2 +ve with respect to MT_1 - Gate signal +ve (1st quadrant +)

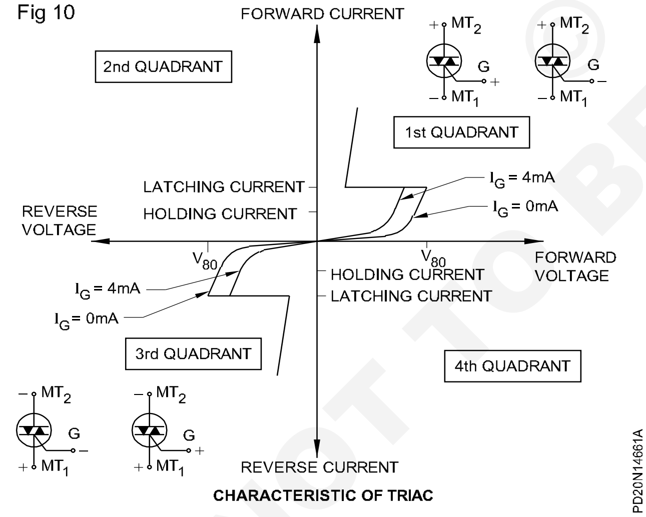
– MT_2 +ve with respect to MT_1 - Gate signal –ve (1st quadrant –)

– MT_2 –ve with respect of MT_1 - Gate signal +ve +(3rd quadrant +)

– MT_2 –ve with respect to MT_1 - Gate signal –ve (3rd quadrant –)

Unfortunately, Triac is not equally sensitive in all the above said modes. It is least sensitive in 3rd quadrant mode (MT_2 negative with respect of MT_1 and triggered by a +ve gate signal) so this mode is very rarely used in practice. When a Triac is ON the current flowing between MT_1 and MT_2 is known as principal current. The TRIAC will remain ON as long as the current flowing through it is larger than the holding current as in the static characteristics of a Triac in Fig 10.

Fig 10



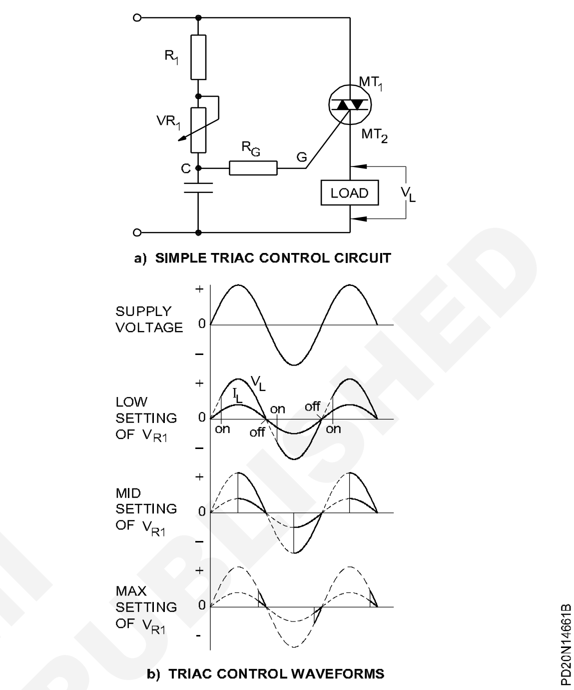
CHARACTERISTIC OF TRIAC

From the Triac static characteristics. When MT_2 is positive with respect to MT_1, the (Fig 6) Triac operates in the first quadrant of its static characteristics, if it is not triggered, the small forward current increases slowly with increase in voltage until the breakdown voltage V_{BO} is reached and then the current increases rapidly. The device can be, and usually is, turned 'ON' at a smaller forward current by injecting a suitable gate current and the characteristics shows the effect of increasing the gate current from zero to 4mA.

The gate current must be maintained until the main current is atleast equal to the latching current. When terminal MT_1 is positive with respect to MT_2 the Triac operates in the third quadrant and the current flows in the opposite direction.

Full wave control using a TRIAC: Fig 11a shows a Triac used for controlling the current flowing in an AC circuit. Fig 11b shows the wave forms with different settings of POT V_{R1}.

Fig 11



Note: In Triac the terms forward and reverse do not arise since it is bidirectional.

Quick testing TRIAC: A quick test can be carried out on triac using an ohmmeter. If the readings taken are comparable to the one shown in table below, the Triac can be considered as satisfactory and can be used in circuit;

Meter polarities +	Resistance
MT_2	MT_1 > 1M
MT_1	MT_2 > 1M
MT_2	G > 1M
G	MT_2 > 1M
MT_1	G > 300Ω
G	MT_1 > 300Ω

Field-effect transistor (FET)

The main difference between a Bi-polar transistor and a field effect transistor is that,

Bi-polar transistor is a current controlled device

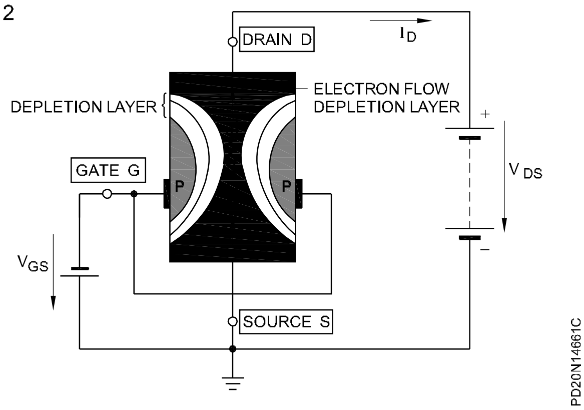
In simple terms, this means that the main current in a bi-polar transistor (collector current) is controlled by the base current.

Filed effect transistor is a voltage controlled device

This means that the voltage at the gate(similar to base of a bi-polar transistor) controls the main current.

In addition to the above, in a bi-polar trasistor (NPN or PNP), the main current always flows through N-doped and P-doped semiconductor materials. Whereas, in a Field effect transistor the main current flows either only through the N-doped semiconductor or only through the P-doped semiconductor as in Fig 12.

Fig 12



If the main current flow is only through the N-doped material, then such a FET is referred as a N-channel or N-type FET. The current through the N-doped material in the N-type FET is only by electrons.

If the main current flow is only through the P-doped material, then such a FET is referred as a P-channel or P-type FET. The current through the P-doped material in the P-type FET is only by Holes.

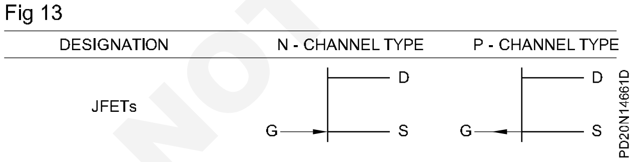
Unlike in bipolar transistors in which the main current is both by electrons and holes, in contrast in FETs depending on the type(P or N type) the main current is either by electrons or by holes and never both. For this reason FETs are also known as Unipolar transistors or Unipolar device.

There are a wide variety of FETs. In this lesson one of the fundamental types called as Junction Field Effect Trasistor (JFET) is discussed.

Junction Field effect Transistor(JFET)

It is a three terminal device and looks similar to a bi-polar transistor. The standard circuit symbols of N-channel and P-channel type FETs are shown in Fig 13.

Fig 13



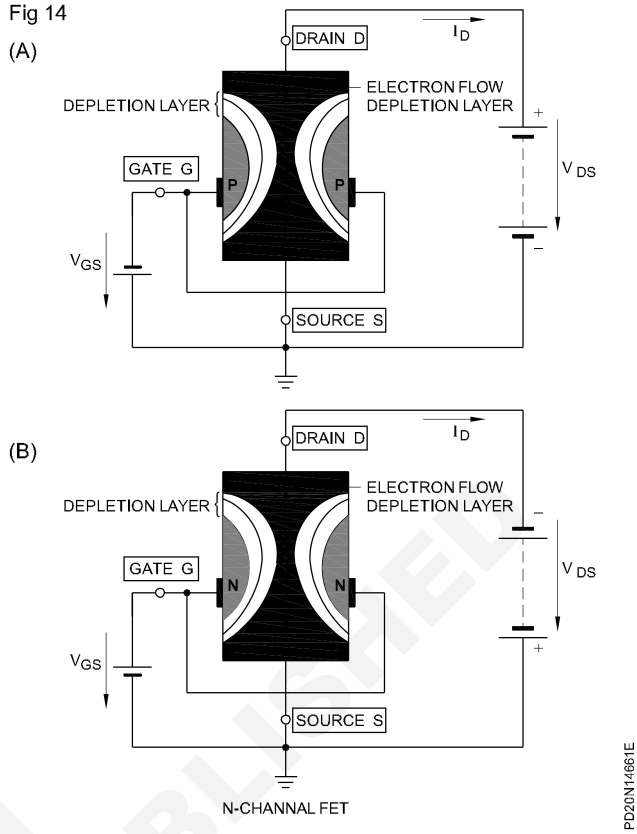
The internal diagram of a N-channel FET is shown in Fig 14.

FET notation listed below are essential and worth memorizing,

1 **Source terminal:** It is the terminal through which majority carriers enter the bar(N or P bar depending upon the type of FET).

2 **Drain terminal:** It is the terminal through which majority carriers come out of the bar.

Fig 14



3 **Gate terminal:** These are two internally connected heavily doped regions which form two P-N junctions.

4 **Channel:** It is the space between the two gates through which majority carriers pass from source to drain when FET is working(on).

Working of FET

Similar to Biploar transistors, the working point of adjustment and stabilization are also required for FETs.

Biasing a JFET

– Gates are always reverse biased. Therefore the gate current I_G is practically zero.

– The source terminal is always connected to that end of the supply which provides the necessary charge carriers. For instance, in an N-channel JFET source terminal S is connected to the negative of the DC power supply. And, the posive of the DC power supply is connected to the drain terminal of the JFET.

Whereas in a P channel JFET, Source is connected to the positive end of the power supply and the drain is connected to the negative end of the power supply for the drain to get the holes from the P-channel where the holes are the charge carriers.

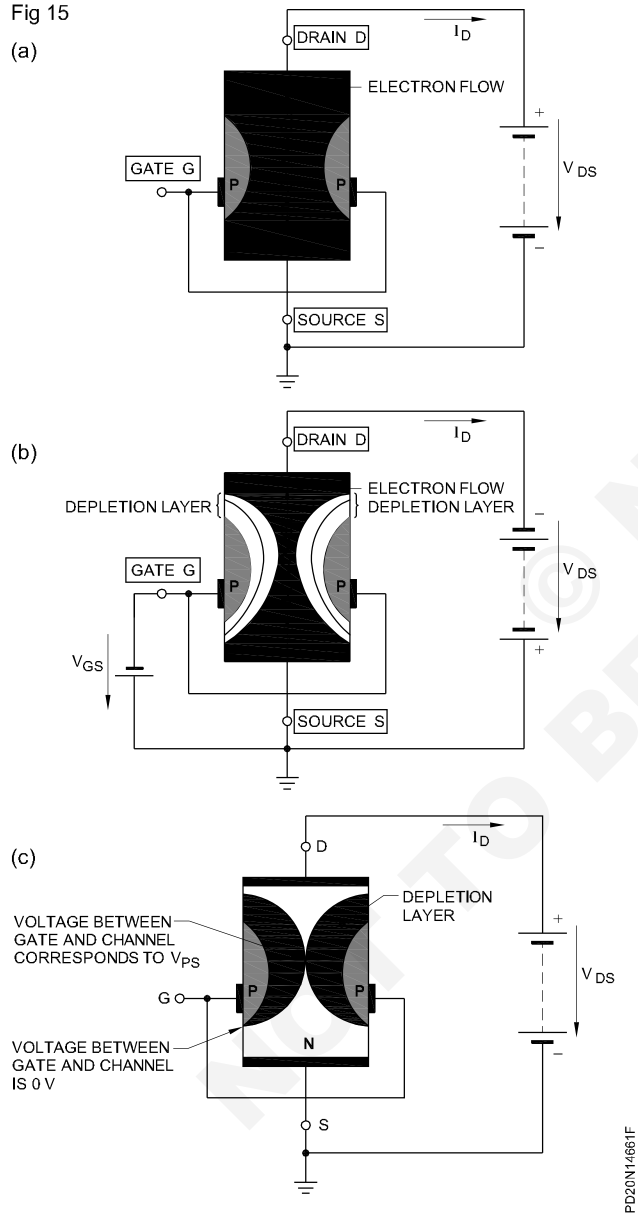
Let us now consider an N channel JFET, the drain is made positive with respect to source by voltage V_{DS} as shown in Fig 15a. When gate to source voltage V_{GS} is zero, there is no control voltage and maximum electron current flows from source(S) - through the channel - to the drain(D). This electron current from source to drain is referred to as Drain current, I_D.

When gate is reverse biased with a negative voltage(V_{GS} negative) as shown in Fig 15b, the static field established at the gate causes depletion region to occur in the channel as shown in Fig 15b.

This depletion region decreases the width of the channel causing the drain current to decrease.

If V_{GS} is made more and more negative, the channel width decreases further resulting in further decrease in drain current. When the negative gate voltage is sufficiently high, the two depletion layers meet and block the channel cutting off the flow of drain current as in Fig 15c. This voltage at which this effect occurs is referred to as the Pinch off voltage, V_P.

Fig 15



Thus, by varying the reverse bias voltage between gate and source($-V_{GS}$), the drain current can be varied between maximum current (with $-V_{GS}$=0) and zero current(with $-V_{GS}$=pinch off voltage). So, JFET can be referred as a voltage controlled devices.

P channel JFET operates in the same way as explined above except that bias voltages are reversed and the majority carrier of channel are holes.

Important specifications of typial JFETs

	BF245B	BFW10
Polarity of the device (N-type/P-type)	Nj	Nj
Maximum drain-source voltage, V_{DS}	30 V	30 V
Maximum gate-source voltage, V_{GS}	30 V	30 V
Maximum drain current, I_D	25 mA	20 mA
Maximum forward gate current, I_G	10 mA	10 mA
Pinch-off Voltage (at I_D=0), V_P		8 V
Maximum power dissipation, P_{max}	300 mW	300mW
Package type	TO92	TO72
Pin Diagram (Refer 6605 data manual)	fig W141e	fig W158b
The term Nj in the specification indicates that it is a N-type junction FET.		

As discussed earlier FETs also need a proper biasing arrangement for it to work. Like transistors, FETs can also be connected in different configuration. Fig 16 gives a summary and comparision of basic FET configurations.

Advantages of FET

1 Since they are voltage controlled amplifier this makes their input impedence very high

2 They have a low noise output. This makes them useful as preamplifiers where the noise must be very low because of high gain in the following stages.

3 They have better linearity

4 they have low interelectrode capacity.

Typical applications of JFET

One very important characteristic of JFET is its very high input impedence of the order of 10^9 ohms. This characteristic of FET, has made it very popular at the input stage of a majority of electroinc circuits.

As discrete components FETS are mainly used in,

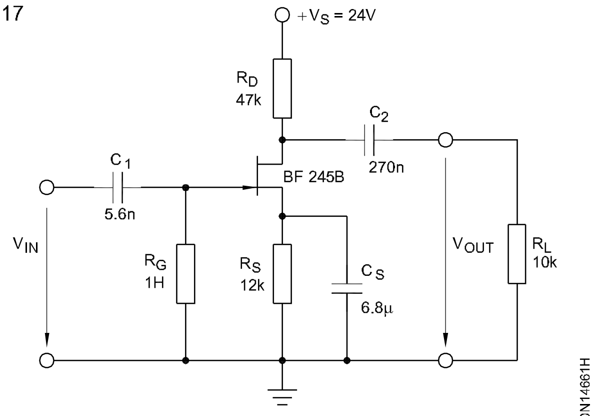
- DC voltage amplifiers
- AC voltage amplifiers(input stage amplifers in HF and LF ranges)
- Constant current sources

- Integtated circuits of both analog and especially in Digital technology.

1 FET AC voltage amplifier

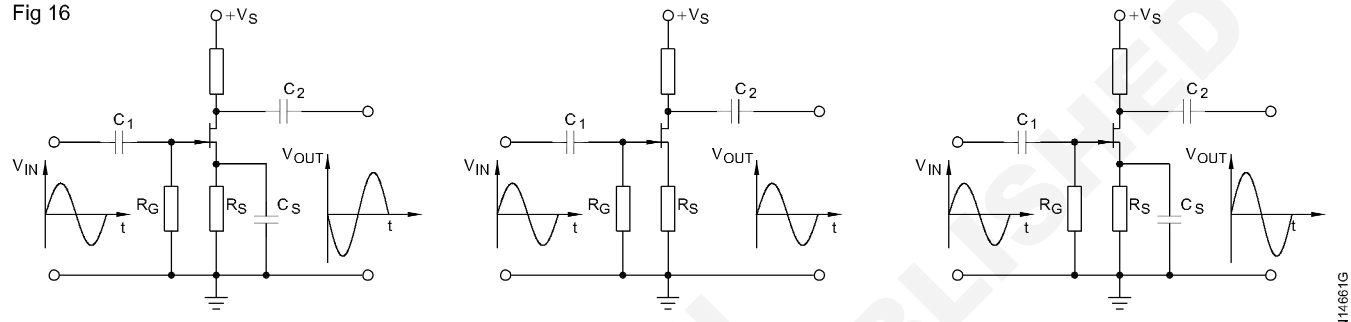
In the circuit at Fig 17, the amplification is determined by the design. it can be varied within certain limits of the drain resistance and the source resistance are made variable. Potentiometer can be connected in series for this purpose.

Fig 17



CIRCUIT DIAGRAM OF THE CALCULATED A.C VOLTAGE AMPLIFIER

Fig 16



COMMON - SOURCE CONFIGURATION | COMMON - DRAIN CONFIGURATION | COMMON - GATE CONFIGURATION

Power supplies-troubleshooting

Objectives: At the end of this lesson you shall be able to
- **list the initial activities involved in troubleshooting**
- **list the three general steps involved in troubleshooting**
- **list and explain the two popular methods of troubleshooting**
- **list the possible defects in a power supply**
- **state the meaning and use of Problem Trees (PT) and service flow diagram (SFD).**

Introduction

Troubleshooting in any equipment or in a circuit involves the following activities:

– To identify the exact nature of the problem.

– To identify the section causing the problem.

– To isolate and arrive at the exact cause(s).

– To confirm the causes by necessary tests.

– To replace the problem-causing parts.

– To re-test and confirm the satisfactory working.

The following are the general steps involved in troubleshooting.

i Physical and sensory tests

– Look for the most common physical faults, such as broken wires, cracked circuit boards, dry solders and burnt out components.

– Smell for hot or burning components.

– Feel with the fingers for unduly hot components.

ii Symptom diagnosis

Learn the operation of the system to be repaired with the help of its block diagram and its input and output specifications.

Observe the symptoms produced by the defective system, and determine which section or function would produce the symptoms.

iii Testing and replacing defective components

When the probable defective section has been diagnosed, check the probable components in that section of the circuit that are most likely to go defective in the order given below:

Components should be checked in the order given below because that is the order in which they fall in most cases.

– **Active high power components:** For example, components such as transistors, ICs, and diodes. High power devices are physically large in size and are used for handling the high power, generally in output circuits.

– **Active low power components:** These are the same as in (a) but are physically small and can handle smaller amounts of power.

– **High voltage/power passive components:** Such components are resistors, capacitors, transformers, coils, etc. which handle large amounts of voltage/ power. They are found in power supplies and output circuits.

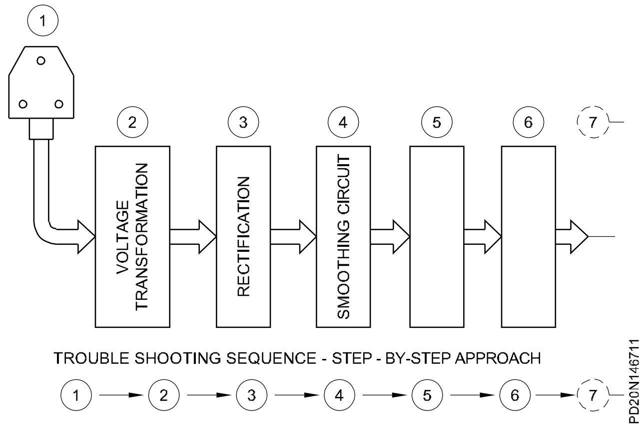
– **Low power passive components:** These are the same as in (c) but are physically smaller and handle comparatively less power and are low in value (ohm, microfarad, microhenry, etc.)

> **Note: This procedure may not turn out to be true always. Hence, do not attempt to replace common sense and meter measurements with the procedure.**

While troubleshooting any electronic system, two main methods are generally adopted. They are:

Step-by-step method of troubleshooting: This approach is preferred by the beginners. In this approach, the problem causing part or section is identified by testing the parts or sections from the beginning to the end as shown in Fig 1.

Fig 1



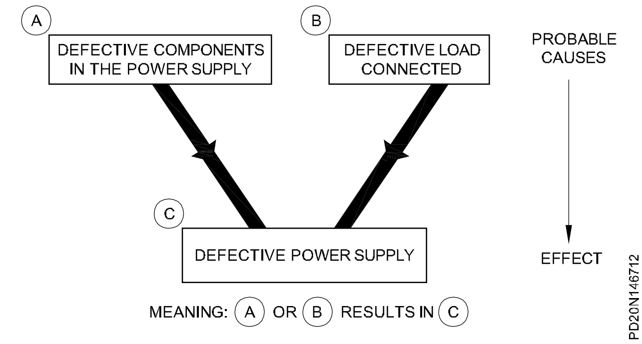
Although this approach may take more time, this is the most suited approach for the beginners.

Shortcut or logical approach method of troubleshooting: This method is used by the experienced servicing people. In this method, the problem causing part or section is identified from the nature of the problem symptom. Divide and conquer procedure is adopted to arrive at the exact cause. This method takes less time comparatively.

Troubleshooting power supplies: All electronic systems can be broken down into blocks, generally based on their function. Fig 1 shows the various blocks of a simple power supply. Each block has a particular function to perform.

Before carrying out the troubleshooting of power supplies, the first thing to be done is to isolate the load connected to the power supply. This is because the connected load itself may be the cause of the problem as shown in the problem tree (PT) in Fig 2.

Fig 2



Once it is confirmed that the power supply has the same defect even with the load disconnected, you can follow either the step-by-step approach or the logical approach to troubleshoot the power supply.

Step-by-step approach to troubleshoot power supply: In the step-by-step approach of troubleshooting, the various blocks of the power supply is in Fig 1 and the components of the blocks are checked one by one, starting with block 1 and in steps as given below.

Step 1: Confirm the presence and satisfactory level of the mains supply from which the power supply is powered.

Step 2: Switch the power ON and test and note down the exact nature of the problem. Although the nature of the problem has been already told, it is essential to confirm the exact nature of the problem. This is because, in a real life situation, the customer may not be a technical person to inform the exact nature of the problem.

Step 3: Carry out physical and sensory tests.

Step 4: Trace the circuit to identify any wrong polarity connections.

Step 5: Remove the power cord of the power supply from the mains and test the power cord.

Step 6: Test the transformer.

Step 7: Test the diode(s) of the rectifier section.

Step 8: Test the capacitor(s) of the filter section.

Step 9: Test the bleeder resistor, surge resistor and other resistors, if any.

Step 10: Test the output indicator lamps/LEDs.

After completing all the above steps, from the defective components identified, analyze the root cause for the problem and confirm that the cause will not reoccur if the identified components are replaced.

Step 11: Replace the identified defective component(s).

Step 12: Switch the power ON and test the power supply, first without load, and then connecting it to the load.

Logical approach to troubleshoot power supply: In this approach steps 1 to 4 of the step-by-step approach are the same. The next step is to refer to the Logical Service Flow Diagram (SFD) for the identified problem and proceed with the troubleshooting as directed in the SFD.

SFDs are very good tools in troubleshooting as they take into account, the divide and conquer technique, thus reducing the overall time taken to troubleshoot the defect in the power supply.

The possible types of defects that can occur in a simple power supply consisting of a bridge rectifier and capacitance input filter are listed below alongwith their SFD numbers.

Possible defects in a power supply using bridge rectifier and filter capacitor

i No output voltage

This defect in the power supply may be due to one or more component of the circuit. Problem Tree-1 (PT-1) given at the end of this lesson for the causes of the problem.

This PT shows the cause-effect relationship of the defective components with the problem. The cause is given at the top and the effect at the bottom for the only reason that it is a normal tendency to read a page from the top to the bottom.

PT-1 shows two problem trees. The first in Chart 1, indicated as Level-1 is a simple tree which gives the level-1 causes of the problem. Level-2 is an extension of the same problem tree, which gives one more level of the causes for the causes given in the simple tree at level-1.

Hints to Instructor: Instructor to discuss PT-1 and ensure that trainees clearly understand the need and meaning of PTs.

Chart 2 at the end of this lesson, shows the sequence to be adopted while servicing a defective power supply. The Service Flow Sequence - 1(SFS-1) at Chart 2 is self-explanatory. However the following tips make it easy to go through the SFS.

– The flow is from top to bottom.

– Rectangular blocks indicate work to be done or action to be taken.

– Follow the path of the arrow.

– Diamond blocks indicate a decision to be taken after conducting a test or making a measurement. If the answer to the question in the diamond block is YES, follow the path of YES and continue. If the answer is NO, follow the path of NO and continue.

– Rounded rectangular ;block indicates the end of the job.

ii Low output voltage/increased ripple in output

Here, note that two defects are combined. The reason being, that these two defects generally occur simultaneously. If the output voltage is low, the cause(s) for this also results in increased ripple and vice versa. Of course with one exception that, if the mains level itself is low or if the secondary voltage of the transformer itself is low due to shorted windings, a low output voltage is not associated with increased ripple. The cause for this defect are given in problem tree PT-2 in Chart 3. Chart 4 shows, the service flow diagram (SFS-2) for servicing the defect.

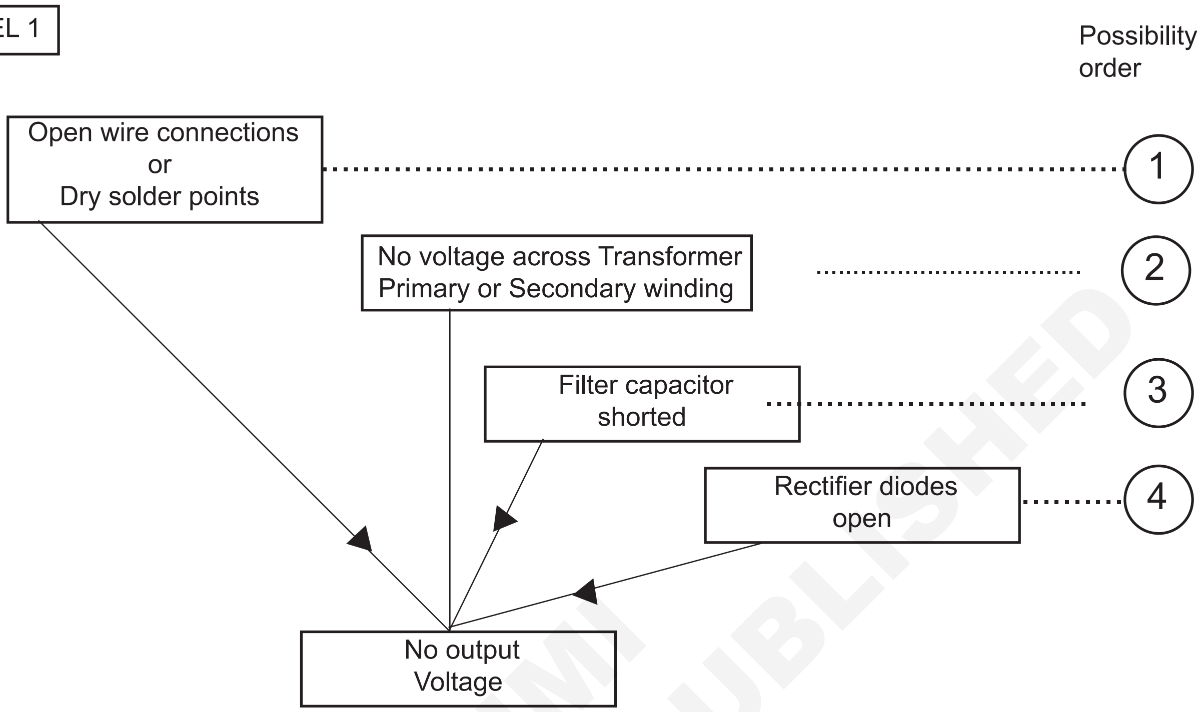
NOTE: The SFSs and PTs for a fullwave rectifier with a capacitance filter is almost similar to that of a bridge rectifier. However, it is suggested that the trainees shall make SFSs and PTs for a fullwave rectifier power supply on their own for practice and better understanding of the method.

Problem Tree - PT1

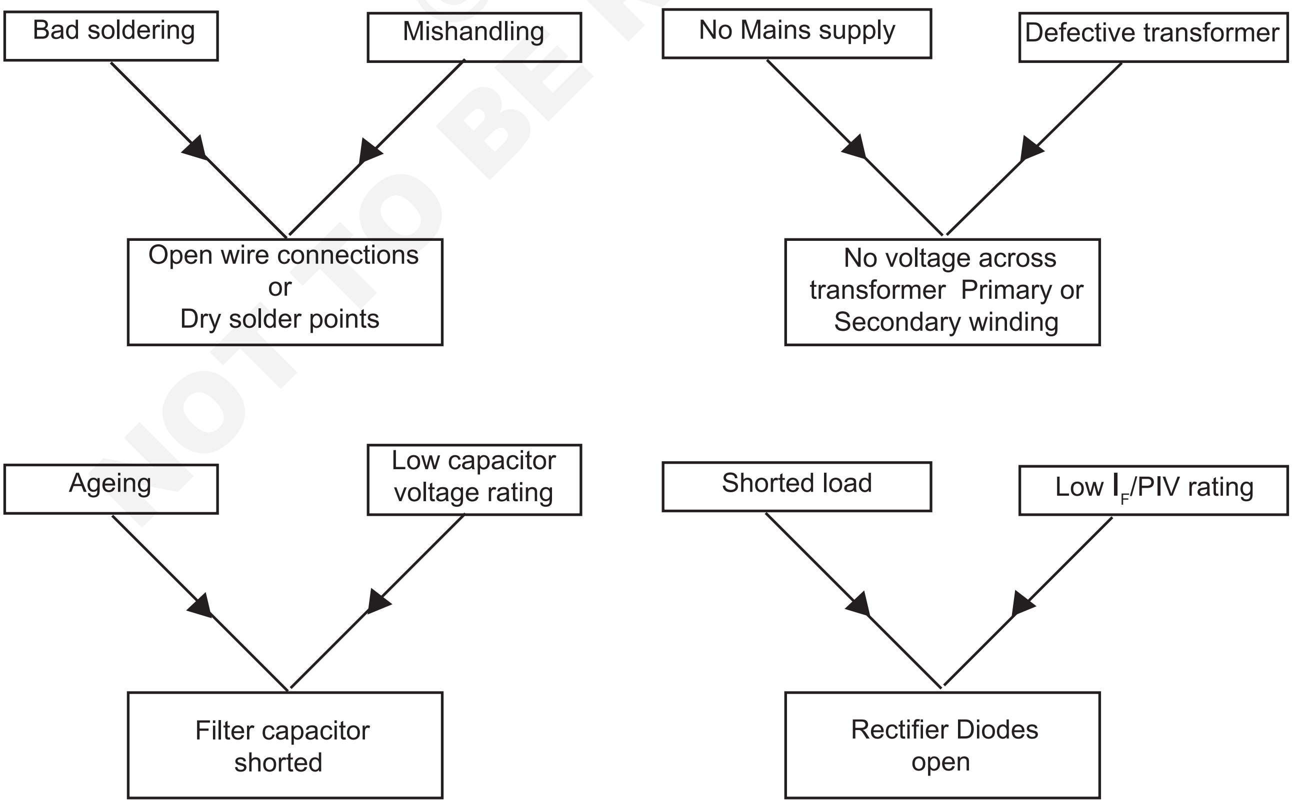
NATURE OF DEFECT : No Output voltage

TYPE OF SYSTEM : Bridge rectifier with capacitor filter

LEVEL 1

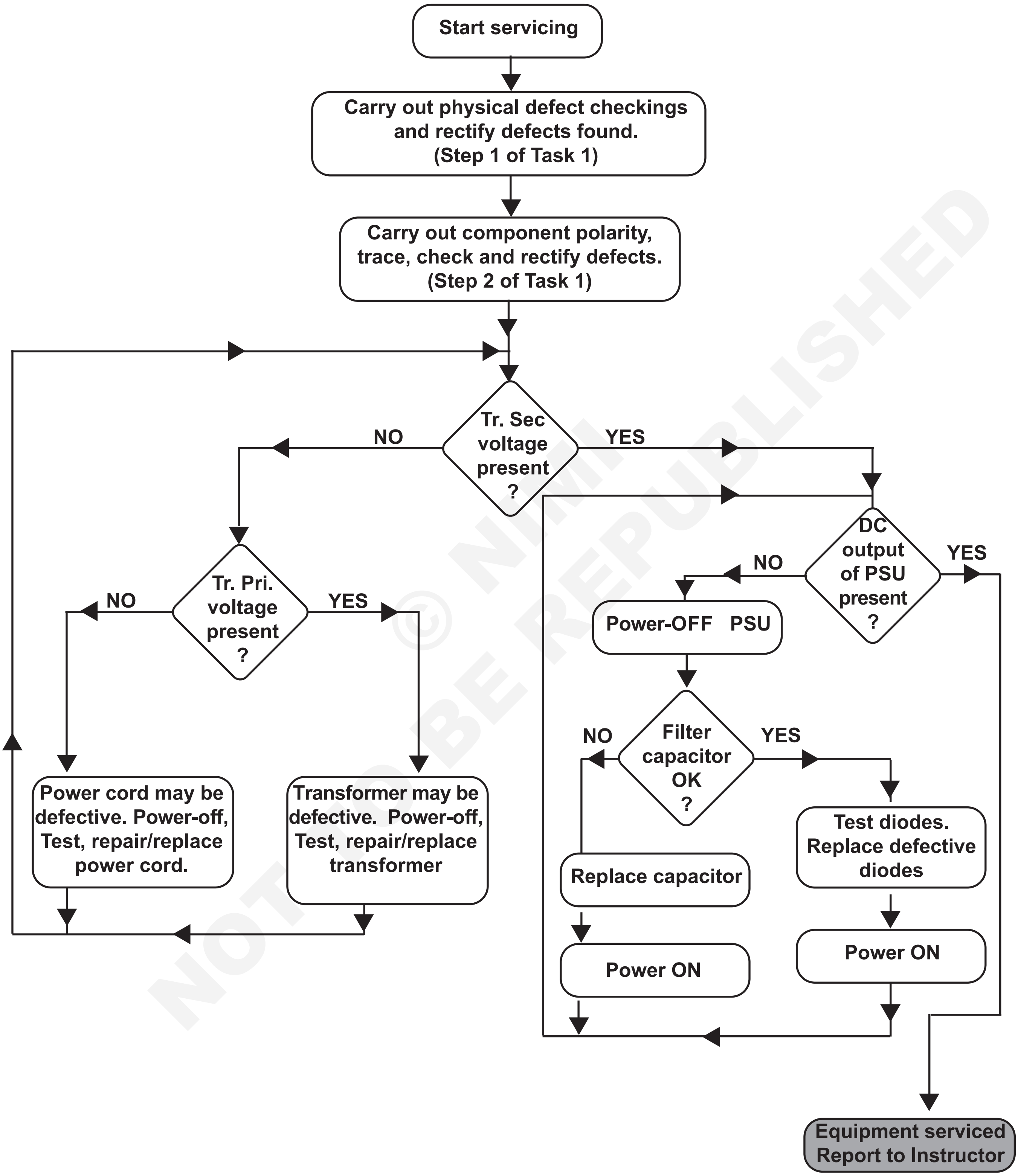


LEVEL 2



Service flow sequence (SFS-2)

NATURE OF DEFECT : **Defective power supply with NO OUTPUT VOLTAGE**

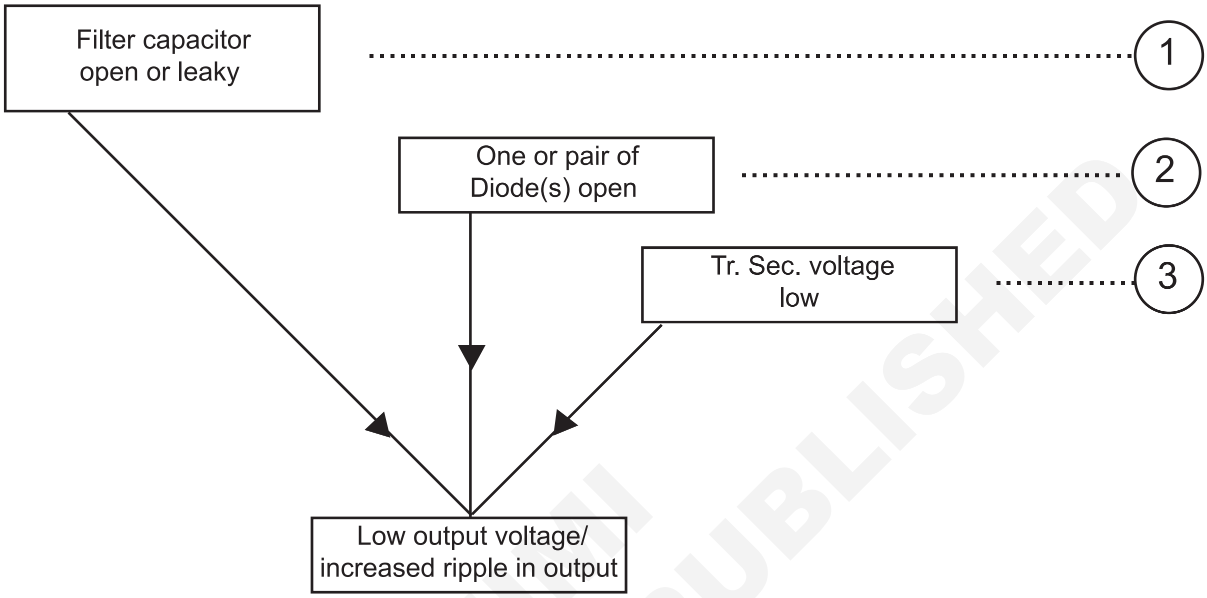


Problem Tree - PT2

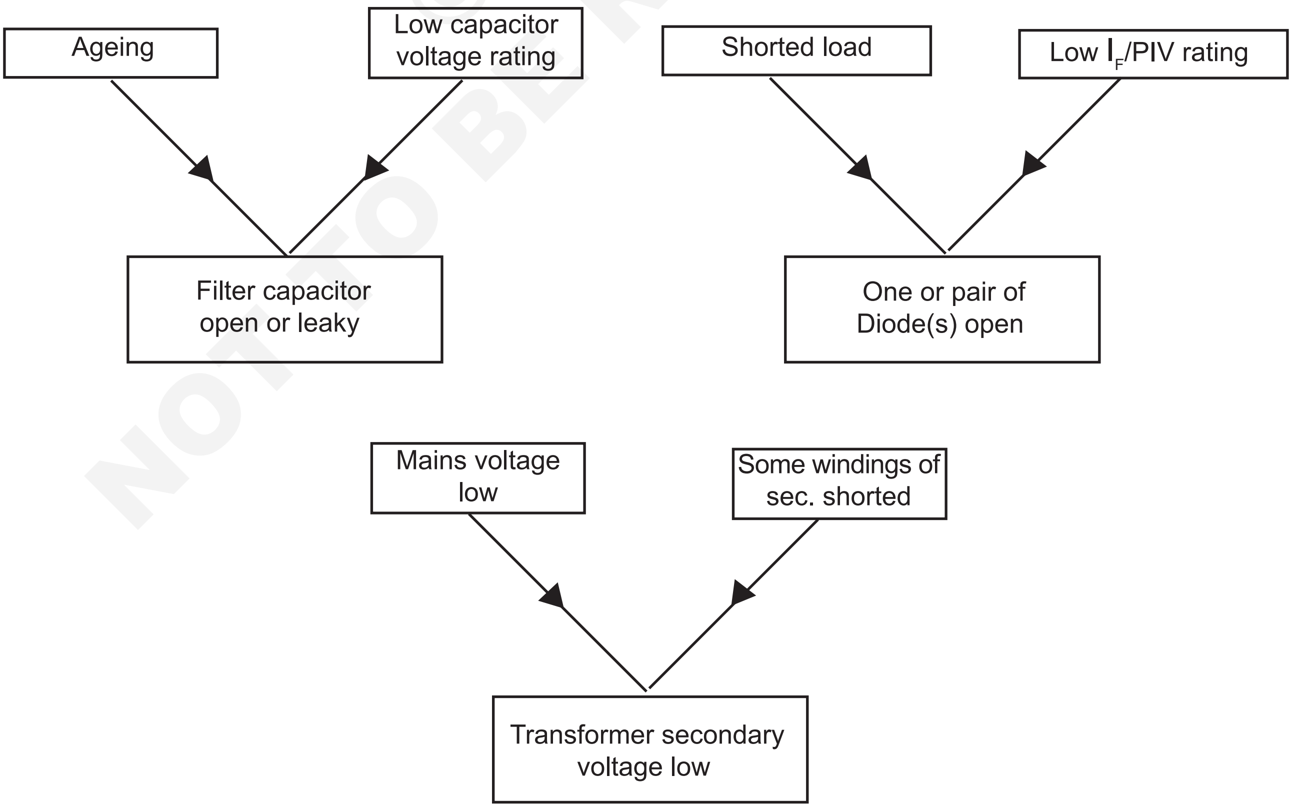
NATURE OF DEFECT : Low Output DC/Increased ripple

TYPE OF SYSTEM : Bridge rectifier with capacitor filter

LEVEL 1



LEVEL 2



Power control circuit using SCR,DIAC,TRIAC & IGBT

Objectives : At the end of this lesson you shall be able to
- **explain the construction and working of SCR,DIAC,TRIAC & IGBT**
- **explain power control circuits using SCR**
- **explain power control circuit using DIAC & TRIAC**
- **explain the construction and using of IGBT.**

Introduction to power electronics devices

Industrial electronics is concerned primarily with electronics applied to industries such as industrial equipments, controls and processes. An important application of electronics in industries is in controlling of machinery.

In communication electronics, domestic & entertainment electronics, generally, the electronic devices operate with currents in the order of Microamper to Milliamper. For industrial applications, most frequently, devices are required to handle currents in the range of ampere to several thousands of ampere. This, therefore calls for high power electronic devices. One such high power electronic device frequently used in industrial electronic application is the SCR,TRIAC,IGBT and DIAC for associate triggering circuits.

This devices can be used to run, dc motors from an ac power source, control power tool speed,also to control motor speeds of small appliances like, mixers and food blenders, illumination control, temperature control and so on.

Silicon Controlled Rectifier (SCR)

Before Silicon controlled rectifiers were invented(1956), a glass tube device called Thyratron was used for high power applications. Silicon Controlled Rectifier (SCR) is the first device of the thyristor family. The term thyristor is coined from the expression Thyratron-transistor.SCR is a semiconductor device. SCR does the function of controlled rectification. Unlike a rectifier diode, SCR has an additional terminal called the gate which controls the rectification(gated silicon rectifier).

The basic principle application of SCRs is to control the amount of power delivered to a load(motor, lamp, etc.,).A rectifier diode will have one PN junction. SCRs on the other hand will have two PN junctions (P-N-P-N layers). Fig 1 shows the electrical symbol, basic construction and a typical SCR packages.

Basic operation of SCR

When a gate direct current is applied to the gate terminal, forward current conduction commences in the SCR(latched into conduction). When the gate current is removed, the forward current through the SCR **does not cut-off**. This means, once the SCR is latched into conduction, the gate loses control over the conduction. The current through the SCR can be turned off only by reducing the current through it(load current) below a critical value called the **Holding current**.

Fig 1

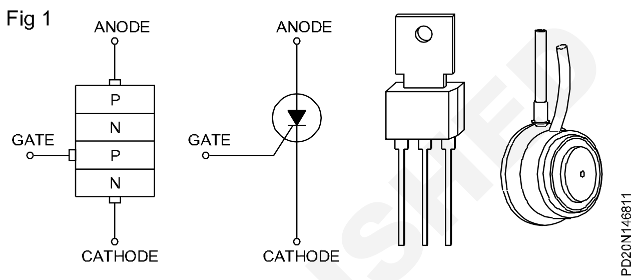


Fig 2 shows how an SCR can be gated into conduction or turned off.

In Fig 2a, with switched S1 open the SCR is in OFF state and no current is flowing through the load.

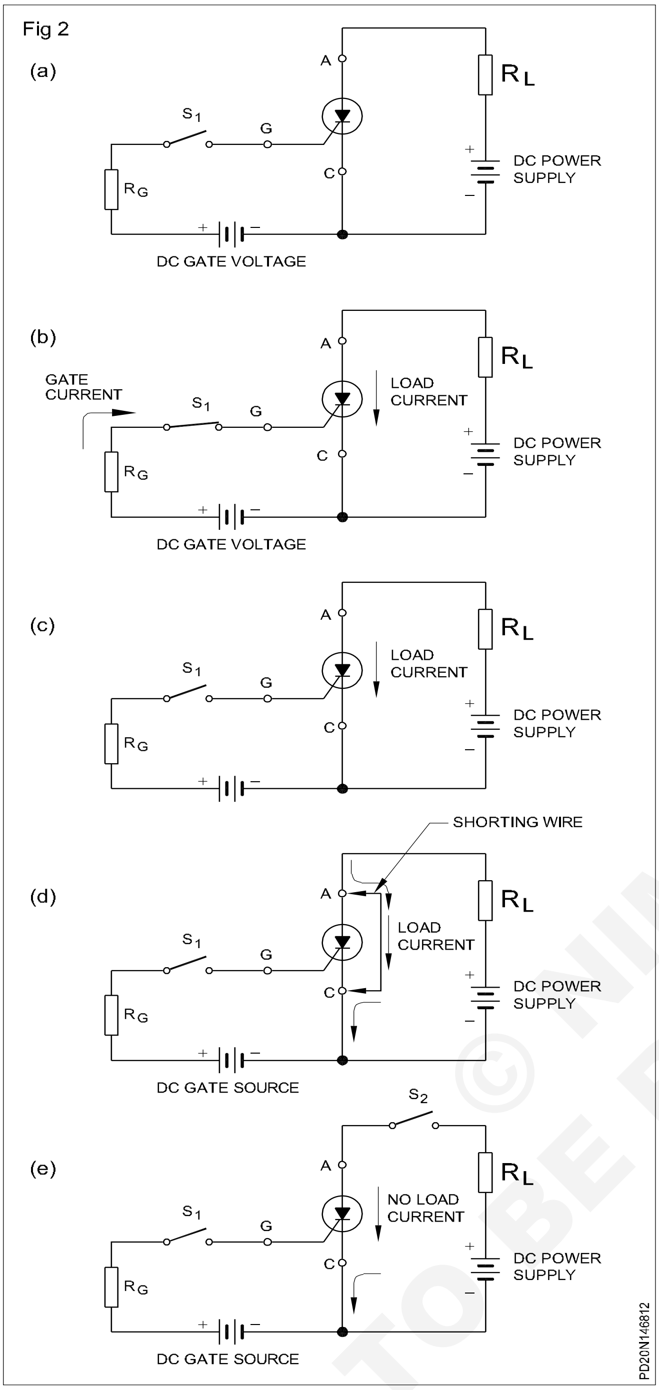
In Fig 2b, when S_1 is closed, a small gate current(around 1/1000 or less compared to load current) turns-ON (fires) the SCR. A heavy load current starts flowing through the SCR and load R_L.

In Fig 2c, when S_1 is opened, gate current becomes zero. This will have no effect on the current through the SCR and the heavy load current continues to flow through the SCR in the DC gate supply.

In Fig 2d, if a shorting wire is placed across the anode and the cathode terminals, the current though the SCR gets by-passed and all the current starts flowing through the shorted wire instead through the SCR. This means the current through the SCR is reduced below the rated holding current(minimum current required through SCR to keep it latched). This turns-OFF the SCR. Even when the shorting wire is removed the SCR remains to be in OFF state.

Fig 2e shows an alternative method of turning-OFF the SCR. In this instead of shorting the anode and cathode terminals of the SCR, the load current is cut-off by opening the Switch S_2. This reduced current through the SCR below the holding current and thus turns- OFF the SCR. Once the SCR is turned_OFF, the SCR does not turn-ON even if the switch S_2 is closed. To make the SCR fire again, with the switch S_2 closed, the gate current should be made to flow by closing the switch S_1.

Since the SCR does not conduct in the reverse direction, the anode of the SCR should always be positive with respect to cathode for conduction.



Important features of SCR,

- A very small gate current will control the switching OFF a large load current.

SCR operation with AC supply

Operation of SCR with AC circuit is similar to SCR operation . Fig 3 illustrates working of SCR in AC control circuits.

The SCR gate circuit consists of resistor R_1, potentiometer R_2 and silicon diode D_1. Resistors R_1 and R_2 act as a variable voltage divider. By adjusting the value of R_2 the gate current I_G can be suitably modified. Diode D_1 prevents negative voltage being applied to the gate when the ac supply is in the negative half cycle.

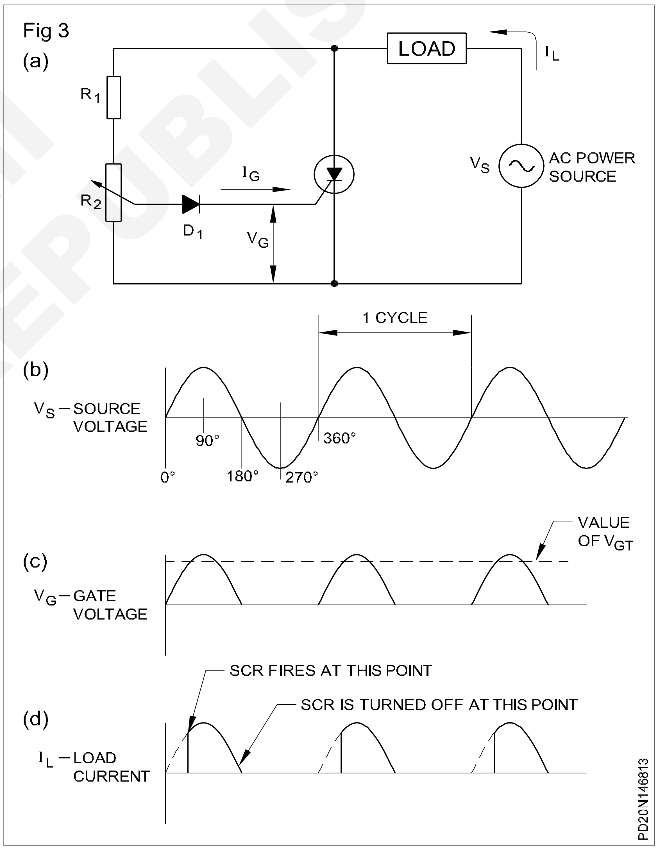
[X] During the +ve half cycle of the AC power source, as the positive half cycle voltage increases, the gate current I_G increases. When I_G reaches the trigger level, SCR fires and allows current I_L to flow through the load.

From this point onwards the SCR impedance is low and current I_L continues to flow throughout the +ve half cycle even though the gate current reduces below the trigger value(recall: once SCR is fired it continues to conduct even if the gate trigger is decreased or removed).

[Y] At the end of the +ve half cycle of AC power source, the +ve voltage drops to zero and SCR ceases to conduct(recall: one method of turning off SCR is to reduce the current through the SCR to below the holding current. This can be done by either opening the load circuit or reducing the supply to zero). Thus the SCR remains in off state throughout the negative half cycle.

Cycle [X] and [Y] repeats and current through the load flows in pulses as in Fig 3d.

Fig 3b,3c shows the voltage wave forms of source and gate voltage.



If the value of R_2 is varied, the point at which SCR triggers also varies changing the firing point shown in Fig 3d. In the circuit shown in Fig 3a, the firing of SCR can be adjusted any where between almost 180 degrees(maximum) to 90 degrees(minimum).

This simple AC control circuit shown in Fig 3a using SCR can be used to control the current through the load during the +ve half cycle of AC. During the -ve half cycle the SCR remains turned off. Thus, SCR can be used as an excellent switching device in AC control circuits.

> **The circuit in Fig 3 is useful only in limited applications such as temperature control of soldering iron etc.,**

Power control using SCR

- DC Motor speed control
- AC Motor speed control
- Regulated DC power supplies
- Power control
- Circuit breakers
- Time delay circuits
- Soft start circuits
- Pulse, logic and digital circuits and so on.

Speed control of DC motors: In this Related Theory information only brief outline of power circuits is discussed. Due variation of motor load currents, inductance effect in winding, the practical circuit should be modified to suit the requirement. DC motors consists of field winding and armature winding. The speed of DC motors can be varied by two methods,

1 controlling the field current

2 controlling the armature voltage

The first method is used for controlling the motor speed above the rated speed of the motor. The second method is used for controlling the motor speed below the rated speed of the motor.

Speed control of DC shunt motor by controlling the armature voltage: This is the most popular method of controlling the speed of DC shunt motors. Fig 4a illustrates the speed control of a DC shunt motor with separate field excitation. The DC supply to the field winding is given from a full wave bridge rectifier. The DC supply to the armature is given using a 'symmetrical half controlled bridge rectifier'. By controlling the SCRs 1 and 2, the DC voltage to the armature can be varied by varying the motor speed. The principle of operation of the circuit at Fig 4a can be understood by examining the current and voltage wave forms shown in Fig 4b. SCR-1 and 2 are fired in half cycles.

During the positive ;half cycle, SCR_1 and D_3 will conduct. The SCR firing angle is set to desired angle as in Fig 4b. Hence the reduced applied armature voltage is shown shaded (Fig 4b). This applied voltage to the armature can be varied by changing the firing angle using a suitable phase control circuit thus controlling the motor speed. A similar operation will take place during the negative half cycle as in Fig 4b when SCR_2 and D_1 conduct.

> **There are few more details to be known specially while designing and setting the firing angles. For details refer reference books of SCR.**

Fig 5a shows another simple circuit for speed control of DC motors. The speed control is based on controlled full wave rectified supply to the armature through an SCR.

Fig 4

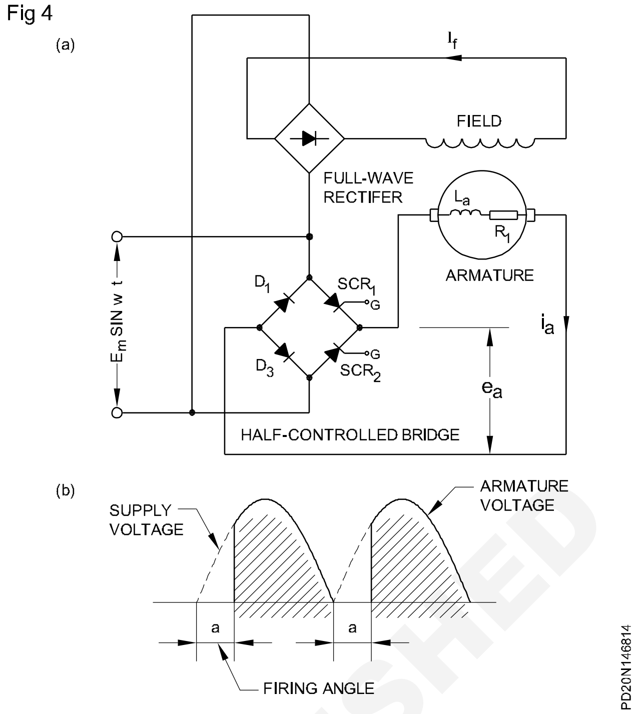
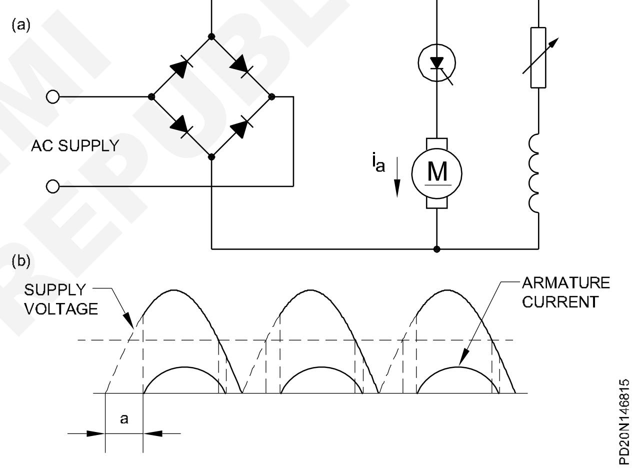


Fig 5



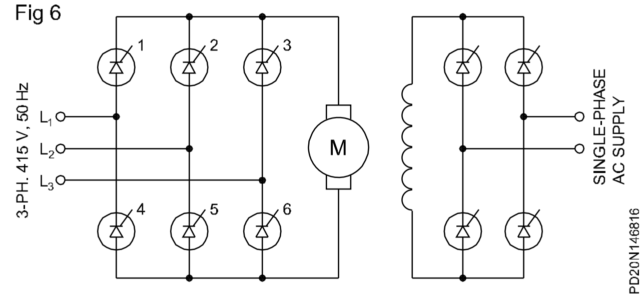
This control circuit is applicable only to shunt or separately excited motors. The voltage and current wave forms are given in Fig 5b. Please note that DC series motor cannot be controlled by this circuit. For reasons refer reference books on motor control circuits.

Fig 6 shows a speed controller by armature control method for a separately excited 415volts DC motor.

Other DC motor's speed control circuits are discussed in further lessons after learning a few more components that go along with SCR in motor speed control.

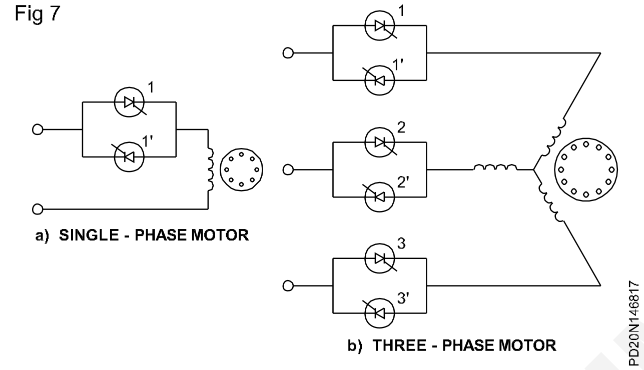
Speed control of AC motors: Phase control can be very conveniently used for speed control of AC motors also. This is achieved by applying a variable voltage to the motor whose speed is to be controlled. As the speed of the synchronous motors does not change when the input voltage is varied, this method is useful only for commutator or induction motors.

Fig 6



For AC motors, full wave phase control circuits are required. Fig 7 shows a schematic arrangement for speed control of single phase and three phase induction motors. When the firing angle of SCR are varied the RMS input voltage to the motor can be changed thus changing the speed of the motor.

Fig 7



Power circuit using TRIAC and DIAC

TRIAC or SCR for speed control of AC motors: Compared to SCR, Triac is most popular and works satisfactorily for lamp dimmer circuits and speed control of universal motors. Although both SCR and TRIAC can be used to phase control and vary the current through the lamp or motor, TRIAC being a full wave device, symmetrically controls the phase of both half cycles of the applied AC.

The resultant full wave current format then produces smooth lamp or motor operation that can be attained from the half wave rectification using SCRs. This is particularly noticeable during low/dim light requirement or low speed for motors.

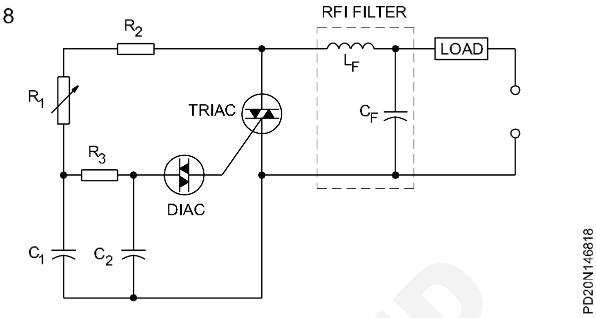
The circuit at Fig 8 shows a TRIAC phase control circuit for controlling the brightness of the lamp or speed of universal motors.

The load shown in circuit at Fig 8 is a general load rather than a motor symbol because, this circuit can also be used for light dimmers and for the control of heaters.

This circuit features a double time constant phase-shift network. This reduces hysteresis in firing of the triac, thereby making the manual adjustment of dimmer operation or control off speed more repeatable.

The DIAC used as trigger device, adds to the reliability of the circuit. The elemental low-pass filter comprising L_F and C_F attenuates much of the radio-frequency interference (RFI) that gets generated and tries to get into the power line. This high frequency RF1 energy is generated by the extremely rapid turn-on time of the TRIAC. Which should be eliminated to avoid radio interference due to higher frequency content of the rectified wave form Otherwise, the frequency may interfere with reception at nearby places or in the main line circuit elsewhere.

Fig 8



Lamp dimmers: Lamp dimmer is a circuit which controls as AC power supplied to an incandescent lamp thereby controlling the intensity of light emitted by the lamp from almost zero to full brilliance.

Conventional and soft-start dimming of incandescent lights: Advantage of semi-conductor based light dimmers over the auto transformer connected light dimmers

Old technology light dimmers used high wattage rheostats adjustable auto-transformers or saturable reactors, which were large, expensive generated considerable heat and power loss. Present day semi-conductor light dimmers have overcome these difficiencies and have therefore become very popular for many applications.

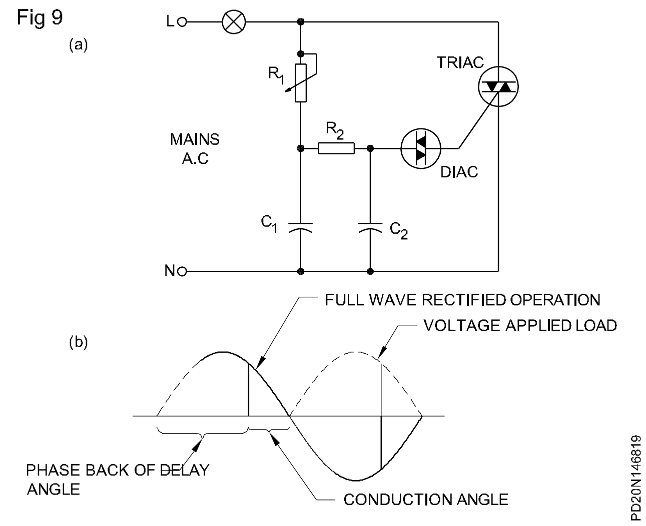
Modern semi-conductor dimmers are inexpensive, reliable, small generate little heat, and are easy to control remotely. These properties have not only permitted semi-conductor dimmers to supersede older types in theatres and auditoriums with excellent results, but have made dimmers practical for built-in home lighting, table and floor lamps, projection equipment and other uses.

Semi-conductor based light dimmers: Two light dimmers for incandescent light bulbs are discussed below. Both these dimmer circuits control light intensity by adjusting the angle of conduction of a triac connected in series with the bulb. The first dimmer uses a very simple circuit that is ideal for highly compact applications requiring minimum cost. The second dimmer features soft starting for low in rush current and consequent long lamp life. Soft start lamp dimmers are especially useful with expensive lights with short lives, such as projection lamps and photo-graphic bulbs.

Simple light dimmer: The circuit shown in Fig 9 is a wide range light dimmer using very few parts. The circuit can be operated using any mains supply source (240V, 50Hz) by choosing appropriate value of circuit components. The circuit can control upto 1000watts of power to incandescent bulbs.

The power to the bulbs is varied by controlling the conduction angle of Triac. Many circuits can be used for phase control, but the single Triac circuit used is the simplest and is therefore chosen for this particular application.

Fig 9



The control circuit for this Triac must function as shown in Fig 9b. The control circuit must create a delay between the time voltage is applied to the circuit and the time it is applied to the load. The Triac is triggered after this delay and conducts current through the load for the remaining part of each alteration. This circuit can control the conduction angle from 0° to about 170° and provides better than 97% of full power control.

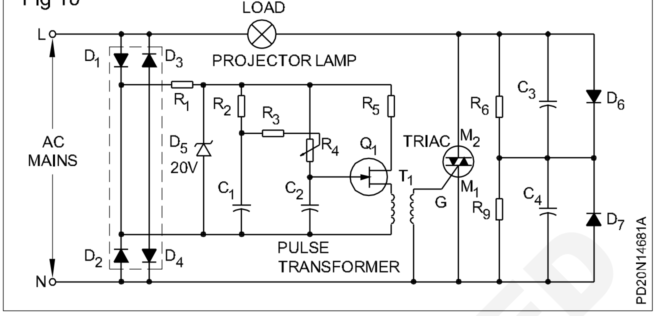
Light dimmer with soft-start option: The circuit at Fig 10 is a light dimmer with soft start option. Soft starting is desirable because of the very low resistance of a cold lamp filament compared to its hot resistance. At the time of initial switching ON, the low resistance of the lamp causes very high inrush currents which leads to short filament/lamp life. Lamp failures caused by high inrush currents is eliminated by the soft start feature, which applies current to the bulb slowly enough to eliminate high surges.

Operation of the circuit at Fig 10 begins when voltage is applied to the diode bridge consisting of D_1 through D_4. The bridge rectifies the input and applies a DC voltage to resistor R_1 and zener diode D_5. The zener provides a constant voltage of 20volts to unijunction transistor Q_1, except at the end of each alternation when the line voltage drops to zero. Initially the voltage across capacitor C_1 is zero and capacitor C_2 cannot charge to trigger Q_1. C_1 will begin to charge, but because the voltage is low, C_2 will have adequate voltage to trigger Q_1 only near the end of the half cycle. Although the lamp resistance is low at this time, the voltage applied to the lamp is low and the inrush current is small. Then the voltage on C_1 rises, allowing C_2 to trigger Q_1 earlier in the cycle.

At the same time the lamp is being heated by slowly increasing applied voltage and by the time the peak voltage applied to the lamp has its maximum value, the bulb has been heated sufficiently so that the peak inrush current is kept to a reasonable value.

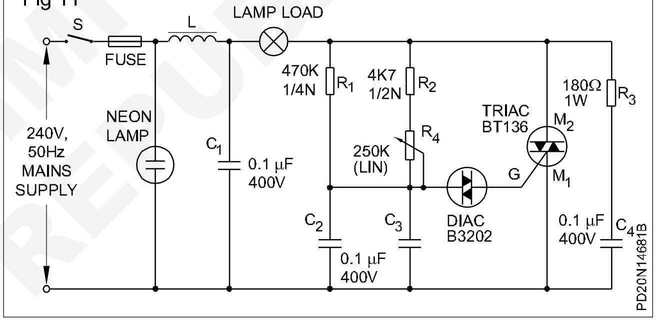
Resistor R_4 controls the charging rate of C_2 and provides the means to dim the lamp. Power to the load can be adjusted manually by varying the resistance of R_4. T1 is a pulse transformer. In addition to supplying the trigger to Triac, this transformer isolates the high current load circuit from the low power triggering circuit (gate isolation methods for Triac is discussed in further paragraphs).

Fig 10



A simple lamp dimmer cum Universal motor speed controller: In the lamp dimmer cum universal speed controller circuit is in Fig 11, a Triac is used as control device. Phase control technique is used to control conduction angle of the triac which inturn control the power fed to the lamp.

Fig 11



A lamp L is connected in series with AC mains supply to the Triac. The trigger pulses to Triac gate is given through Diac. The Diac is triggered at the same breakover voltage level (30V) during both positive and negative half cycles.

Potentiometer R_4 provides the facility for varying the intensity of light or speed of a universal motor.

Snubber circuit: One problem with the Triac control is the sudden application of reverse voltage across the triac immediately after it has stopped conduction. This is a serious problem when the load is a highly inductive as in motors. This reapplied voltage denoted by dv/dt can trigger-on (unwanted or false triggering) the device losing the phase control.

To avoid this false triggering, an R and C series network is placed across the circuit R_4 and C_4 as shown in Fig 11. This RC network slows down the rate of rise of voltage applied across the Triac. This RC circuit connected across the Triac circuit is called snubber circuit.

The inductance L and capacitor C_1 forms a low pass filter to substantially reduce the radio frequency interference (RF) generated by the rapid turn-on and turn-off the triac.

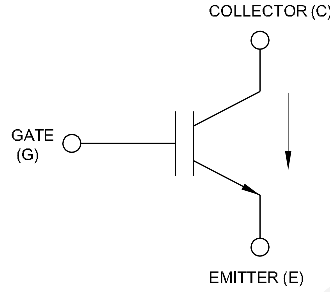
Fan speed regulator: The lamp dimmer circuit at Fig 11 can be used equally well as a fan speed regulator. The only change to be made is to connect a fan in place of the lamp shown in the circuit at Fig 11. The speed can be varied from almost zero to full speed by just rotating POT R_3.

IGBT (Insulated Gate Bipolar Transistor)

The insulated Gate Bipolar Transistor (IGBT) is the latest device is power electronics. It is obtained by combining the properties of BJT and MOSFET. We know that BJT has lower on - state losses for high values of collector current. But the drive requirement of BJT is little complicated. The drive of MOSFET is very simple (i.e only voltage is to be applied between gate and source). But MOSFET has high on - state losses.

The gate circuit of MOSFET and collector emitter circuits of BJT are combined together to form a new device. This device is called IGBT. Thus IGBT has advantages of both the BJT and MOSFETs. Fig 12 shows the symbol of IGBT. Observer that the symbol clearly indicates combination of MOSFET and BJT.

Fig 12



The IGBT has three terminals : Gate (G), collector (C) and emitter (E), Current flows from collector to emitter whenever a voltage between gate and emitter is applied. The IGBT is said to have turned 'ON'. When gate emitter voltage is removed, IGBT turns - off. Thus gate has full control over the conduction of IGBT. When the gate to emitter voltage is applied, very small (negligible) current flows. This is similar to the gate circuit of MOSFET. The on - state collector to emitter drop is very small like BJT.

Structure of IGBT

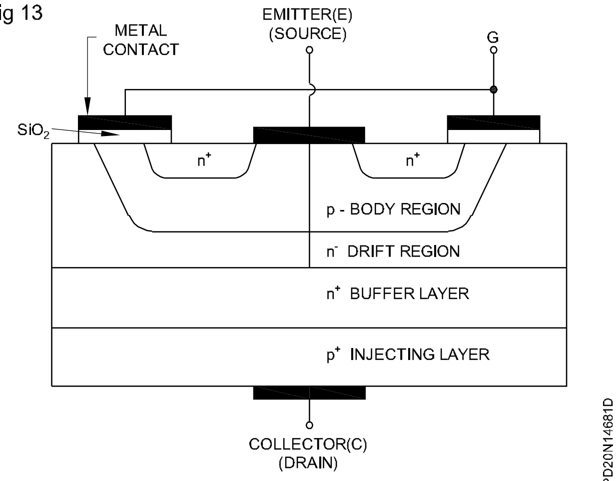
The structure of IGBT is similar to that of MOSFET. Fig 13 show the vertical cross section of IGBT . In this structure observe that there is additional P+ layer. This layer is collector (Drain) of IGBT.

This P+ injection layer is heavily doped. It has the doping intensity of 10^{19} per cm^3. The doping of other layer is similar to that of MOSFET. n+ layers have 10^{19} per cm^3. P-type body region has doping level of 10^{16} per cm^3. The n- drift region is lightly doped (10^{14} per cm^3).

Punch through IGBT

The n+ buffer layer is not necessary for the operation of IGBT. The IGBTs which have n+ buffer layer are called punch through IGBTs. Such IGBTs have asymmetric voltage blocking capabilities. Punch through IGBTs have faster turn-off times. Hence they are used for inverter and chopper circuits.

Fig 13



Non - punch through IGBT

The IGBTs without n+ buffer layer are called non-punch through IGBTs. These IGBTs have symmetric voltage blocking capabilities. These IGBTs are used for rectifier type applications.

Operation of IGBT

When $V_{GS} > V_{GS}$(threshold), then the channel of electrons is formed beneath the gate as in Fig 14. These electrons attract holes from p+ layer. Hence, holes are injected from p+ layer into n- drift region. Thus hole / electron current starts flowing from collector to emitter. When holes enter p-type body region, they attract more electrons from n+ layer. This action is exactly similar to MOSFET.

Fig 15 shows the structure of IGBT showing how internal MOSFETs and transistors are formed. The MOSFET is formed with input gate, emitter as source and n- drift region as drain. The two transistors T_1 and T_2 are formed as in Fig 15. The holes injected by the P+ injecting layer go to the n- drift region. This n- drift region is base of T_1 and collector of T_2. The holes in the n- drift region further go to the p - type body region, which is connected to the emitter. The electrons from n+ region (which is emitter) pass through the transistor T_2 and further in the n- drift region. Thus holes and electrons are injected in large amounts in n- drift region. This reduces the resistance of the n- drift region. This is called conductivity modulation of n- drift region. Note that such conductivity modulation does not exist in MOSFET. The connection of T_1 and T_2 is such that large amount of hole/electrons are injected in n- drift region.

The action of T_1 and T_2 is like SCR which is regenerative. The gate serves as trigger for T_1 through internally formed MOSFET. Fig 16 shows the equivalent circuit. In this figure observe that when gate is applied ($V_{GS} > V_{GS}$(th)), the internal equivalent MOSFET turns ON. This gives base drive to T_1. Hence T_1 starts conducting. The collector of T_1 is base of T_2. Therefore T_2 also turns ON. The collector of T_2 is base of T_1. Thus the regenerative loop begins and large number of carriers are injected in n- drift region. This reduces the on- state loss of the IGBT just like BJT. This happens due to conductivity modulation of n- drift region.

Fig 14

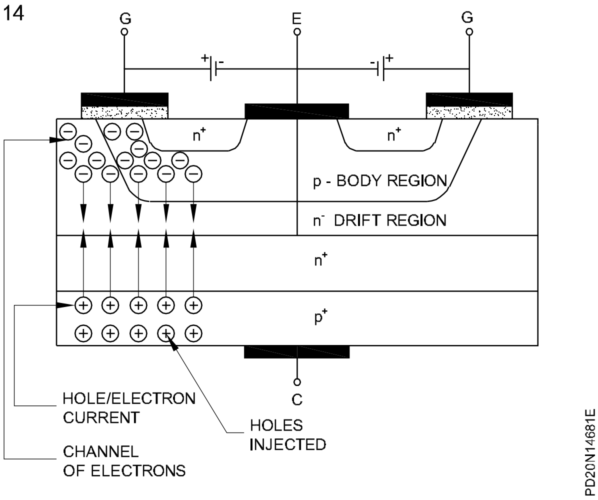


Fig 15

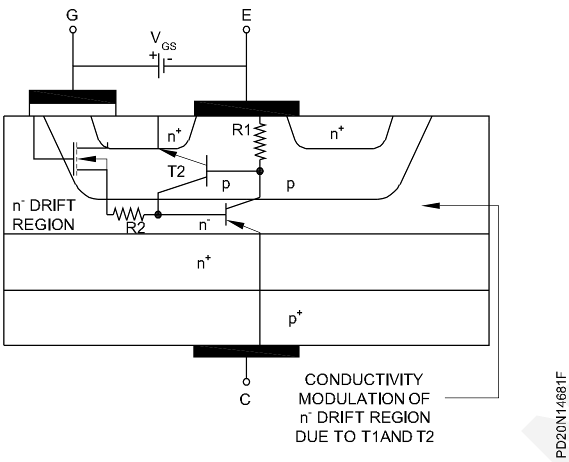
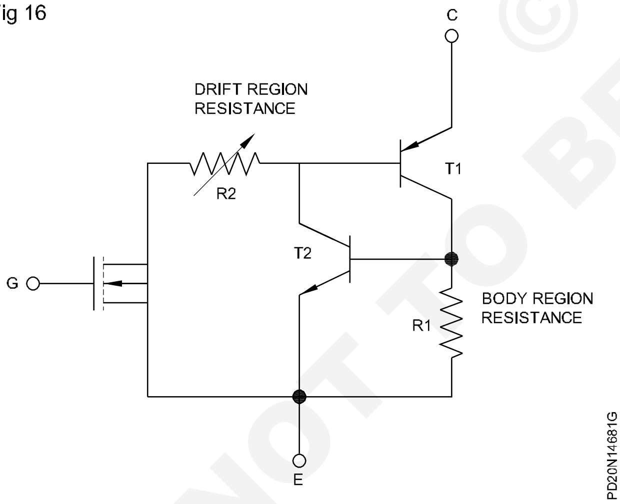


Fig 16

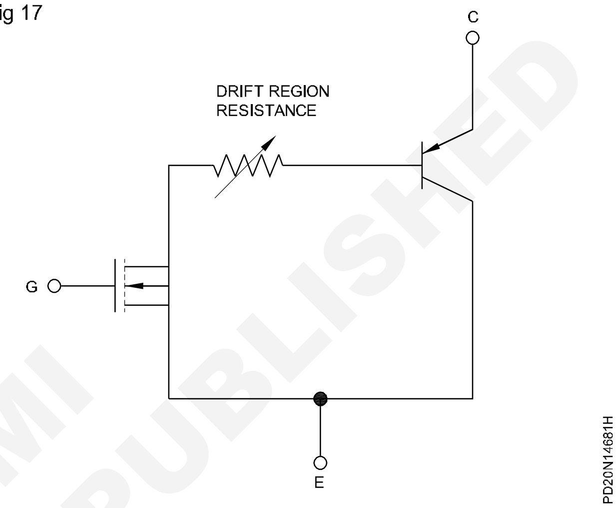


When the gate drive is removed, the IGBT should turn-OFF. When gate is removed, the induced channel will be vanished and internal equivalent MOSFET will turn-OFF. Hence T_1 will turn -OFF if T_2 turns-OFF T_2 will turn - OFF if the p- type body region resistance R_1 is very very small.

Under such situation, its base and emitter will be virtually shorted. Hence T_2 turns - OFF. Therefore T_1 will also turn - OFF. Hence structure of IGBT is organizes such that body region resistance (R_1) is very very small.

If R_1 is very very small, than T_2 will never conduct and the equivalent circuit of IGBT will be as in Fig 17. IGBTs are thus different than MOSFETs because of conduction of current from collector to emitter. For MOSFETs, on state losses are high since resistance of drift region remains same. But in IGBTs, resistance of drift region reduces when gate drive is applied. This resistance reduces because of P+ injecting region. Hence, on state loss of IGBT is very small.

Fig 17



Merits, Demerits and Applications of IGBT

Merits of IGBT

1 Voltage controlled device. Hence drive circuit is very simple.

2 On - state losses are reduced.

3 Switching frequencies are higher than thyristors.

4 No commutation circuits are required.

5 Gate have full control over the operation of IGBT

6 IGBTs have approximately flat temperature coefficient.

Demerits of IGBT

1 IGBTs have static charge problems.

2 IGBTs are costlier than BJTs and MOSFETs.

Applications of IGBTs

1 AC motor drives, i.e. inverters.

2 DC to DC power supplies, i.e choppers

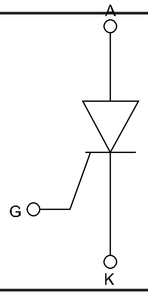
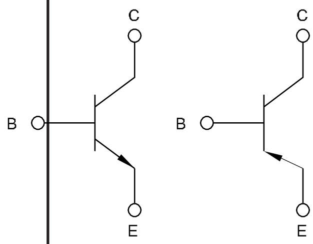
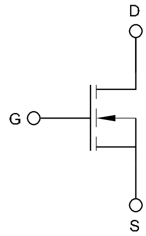
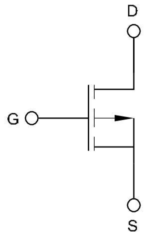
3 UPS systems.

4 Harmonic compensators.

Comparison of Power Devices

The power devices can be compared on the basis of switching frequency, gate drive circuit, power handling capacity etc. Table 1 shows the comparison of SCR, BJT, MOSFET and IGBT.

Table 1

S.No.	Parameter	SCR	BJT	MOSFET	IGBT
1	Symbol				
2	Triggered i.e latching or linear	Triggered or latching device	Linear trigger	Linear trigger	Linear trigger
3	Type of carriers in device	Majority carrier device	Bipolar device	Majority carrier device	Majority carrier device
4	Control of gate or base	Gate has no control once turned on	Base has full control control	Gate has full control	Gate has full control
5	On-state drop	< 2 Volts	< 2 Volts	< 4-6 Volts	< 3.3 Volts
6	Switching frequency	500 Hz	10 kHz	up to 100 kHz	20 kHz
7	Gate drive	Current	Current	Voltage	Voltage
8	Snubber	Unpolarized	Polarized	Not essential	Not essential
9	Temperature coefficient	Negative	Negative	Positive	Approximately flat, but positive at high current
10	Voltage and current ratings	10 kV/4kA	2 kV/4kA	1 kV/50 A	1.5 kV/400 A
11	Voltage blocking capability	Symmetric and	Asymmetric	Asymmetric	Asymmetric
12	Application	AC to DC converters, AC voltage controllers, electronic circuit breakers	DC to AC converters, induction motor drives, UPS, SMPS, Choppers	DC choppers, low powers, UPS, SMPS, brushless DC motor drives	DC to AC converters, AC motor drivers, UPS choppers, SMPS etc,.

Integrated circuit voltage regulators

Objectives: At the end of this lesson you shall be able to
- **explain integrated circuit**
- **state the classification of integrated circuit**
- **state the types of IC voltage regulators**
- **design voltage regulator for a required output voltage**
- **modify fixed voltage regulator to variable output regulator, circuit.**

IC introduction

Integrated circuit

Electronic circuits invariably consist of a number of discrete components connected to each other in a specific way. For instance, the series regulator circuit discussed in earlier lessons, consists of transistors, zener diodes, resistors and so on, connected in a defined way for it to function as a regulator. If all these components instead of building on a board, if they are built on a single wafer of a semiconductor crystal, then, the physical size of the circuit becomes very small. although small, this will do the same job as that of the circuit wired using discrete components. Such miniaturised electronic circuits produced within and upon a single crystal, usually silicon, are known as Integrated circuits or ICs. Integrated circuits (ICs) can consists of thousands of active components like transistor, diodes and passive components like resistors and capacitors in some specific order such that they function in a defined way, say as voltage regulators or amplifiers or oscillators and so on.

Classification of Integrated circuits: Integrated circuits may be classified in several ways. However the most popular classifications is as follows:

1 Based on its type of circuitry

   i Analog ICs - Example: amplifier ICs, voltage regulator ICs etc.

   ii Digital ICs - Example: Digital gates, flip-flops, address etc.

2 Based on the number of transistors built into IC

   i Small scale integration (SSI) - consists of 1 to 10 transistors.

   ii Medium scale integration (MSI) - consists of 10 to 100 transistors.

   iii Large scale integration (LSI) - 100 to 1000 transistors.

   ivVery large scale integration (VLSI) - 1000 and above.

3 Based on the type of transistors used

   i Bipolar - carries both electron and hole current.

   ii Metal oxide semiconductor (MOS) - electron or hole current.

   iii Complementary metal oxide semiconductor (CMOS) - electron or hole current.

> **Note: The terms MOS and CMOS are another type of transistor and the trainees are requested to refer any standard electronic book for further reference.**

ICs are available in different packages and shapes. The usual packages are:

– dual in the packages DIP

– single in line package SIP and

– metal can packages.

ICs handling power more than IW are provided with heat sinks.

Advantages of integrated circuits over discrete circuit (Refer Table 1)

Table 1

Integrated circuits	Discrete circuits
Advantages	
1 All in a single chip	All are separate discrete components
2 Requires less space due to smaller size	Requires more space
3 Cheaper due to mass manufacture	Costlier due to individual components
4 More reliable due to specific construction	Less reliable
5 Easy for servicing and repairs	Difficult for servicing and repairs
Disadvantages	
1 ICs are manufactured for specific applications having specific circuits	Discrete devices can be used for any circuit
2 If any part of IC is defective, the entire IC is to be replaced	Only particular defective component requires replacement

When the advantages are considered, the disadvantages of IC are negligible. They are widely used for different applications such as voltage regulators, audio amplifiers, TV circuits, computers, industrial amplifiers etc. ICs are available in different pin configurations in different outlines suitable for different circuits.

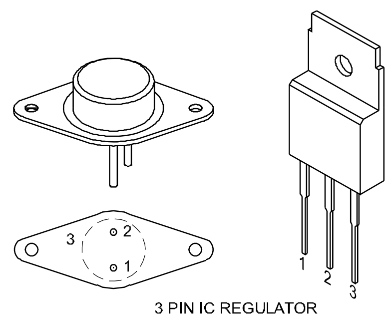
Integrated circuit (IC) voltage regulators: The series voltage regulators discussed in earlier lessons are available in the form of integrated circuits (ICs). They are known as voltage regulator ICs.

There are two types of voltage regulator ICs. They are,

- Fixed output voltage regulator ICs
- Adjustable output voltage regulator ICs.

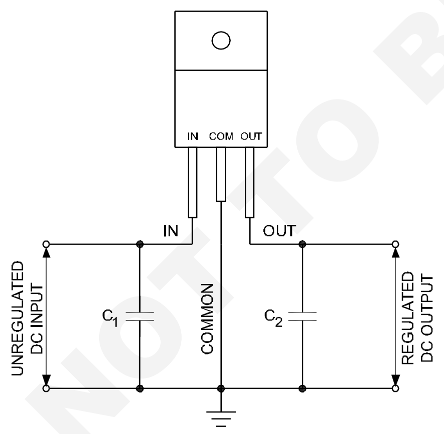
Fixed output voltage regulator ICs: The latest generation of fixed output voltage regulator ICs have only three pins as in Fig 1. They are designed to provide either positive or negative regulated DC output voltage.

Fig 1



These ICs consist of all those components and even more in the small packages in Fig 1. These ICs, when used as voltage regulators, do not need extra components other than two small value capacitors as in Fig 2.

Fig 2



The reason behind using capacitor C_1 is when the voltage regulator IC is more than a few inches from the filter capacitors of the unregulated power supply, the lead inductance may produce oscillations within the IC. Capacitor C_1 prevents setting up of such oscillations. Typical value of bypass capacitor C_1 range from 0.220µF to 1µF. It is important to note that C_1 should be connected as close to the IC as possible.

The capacitor C_2 is used to improve the transient response of the regulated output voltage. C_2 bypasses these transients produced during the ON/OFF time. Typical values of C_2 range from 0.1µF to 10µF.

Fixed voltage three terminal regulators are available from different IC manufacturers for different output voltages (such as 5V, 9v, 12V, 24V) with maximum load current rating ranging from 100mA to more than three amps.

The most popular three terminal IC regulators are,

1 LMXXX-X series

Example: LM320-5, LM320-24 etc.

2 78XX and 79XX series

Example: 7805, 7812, 7912 etc.

A list of popular three terminal regulators is given in IC data book.

Specifications of three terminal IC regulators: For simplicity in understanding, let us consider the specification of a three terminal IC µA7812. The table 2 given below lists the specifications of µA7812.

Table 2

Parameter	Min.	Type.	Max.	Units
Output voltage	11.5	12	12.5	V
Output regulation		4	120	mV
Short-circuit output current			350	mA
Drop out voltage			2.0	V
Ripple rejection	55	71		dB
Peak output current		2.2		A

Output voltage: This specification indicates the regulated DC output voltage that can be obtained from the IC. As can be seen from the sample specification table given above, the manufacturer specifies minimum, typical and maximum output voltage. While using this IC take the typical value as this value corresponds to the output voltage at IC under normal input and load conditions.

Output regulation: This indicates the amount by which the output voltage may vary at rated maximum load condition. For example, in µA7812 IC, the output voltage may vary by 4mV from its rated 12V DC when the rated typical load current is 2.2A.

Short circuit output current: This indicates the shorted current I_{SC}, if the output gets shorted. In µA 7812 the output current is limited to 350mA when the output terminals are shorted.

These regulators also canbe used fold back current limiting.

Drop out voltage: For instance, in µA7812 in which the output voltage is +12V, the input unregulated DC voltage to the regulator must be higher than the output voltage.

The specification drop out voltage indicates, the minimum positive different between the input and output voltages for the IC to operate as a regulator. For example, in, µA7812 the unregulated input voltage should be atleast 2 volts more than the regulated DC output of 12V. This means for µA7812 the input must be atleast 14V.

The difference between the voltage across the input and output of the IC should also not to be very high as this causes unwanted dissipation. As a thumb rule, the input voltage to the regulator shall be restricted to a maximum of twice the output voltage of the regulator. For example, for µA7812, the unregulated input voltage should be more than 14V, but less than 24V.

– Ripple rejection

  This indicates the ratio of ripple rejection between the output to input, expressed in decibels,

– Peak output current

This indicates the highest output or load current that can be drawn. Above this rated maximum current the safety of the IC is not guaranteed.

Identification of output voltage and rated maximum load current from IC type number

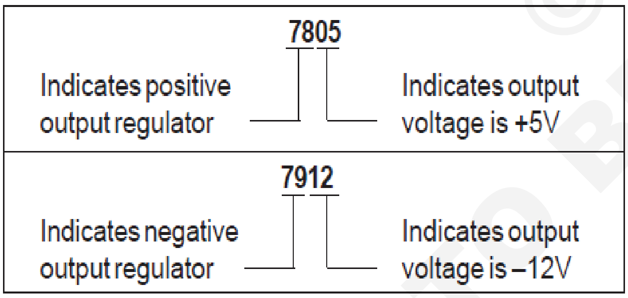
– 78XX and 79XX series are 3 Terminal voltage regulators.

– All 78XX series are positive output voltage regulators

– All 79XX series are negative output voltage regulators

The term XX indicates the rated output regulated voltage.

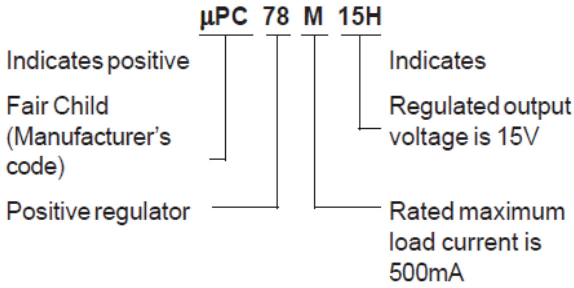
Example



It is important to note that, different manufacturers of 78 XX/ 79XX series such as Fair Child (MA/Mpc), Motorola, Signetics (SS) adopt slightly different coding schemes to indicate the rated maximum current of the three pin regulated. ICs. One such scheme is given below.

78LXX	-	L indicates rated maximum load current as 100mA.
78MXX	-	M indicates rated a maximum load current as 500mA
78XX	-	Absence of an alphabet between 78 and XX indicates that the rated maximum load current is 1A.
78SXX	-	S indicates rated maximum load current is 2amp.

Example

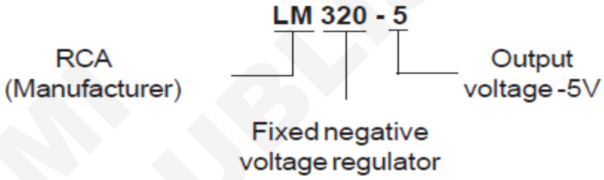


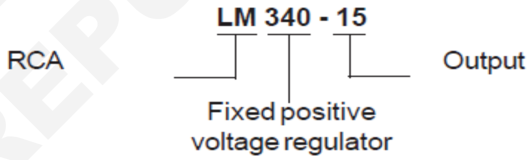
LM 3XX series of 3 terminal voltage regulators: In LM series of three terminal regulators, to find the specifications, it is suggested to refer to its data manual. However, the following tips will help in identifying whether the IC is a fixed positive or fixed negative regulator.

LM320-X and LM320-XX → Fixed –ve voltage regulators.

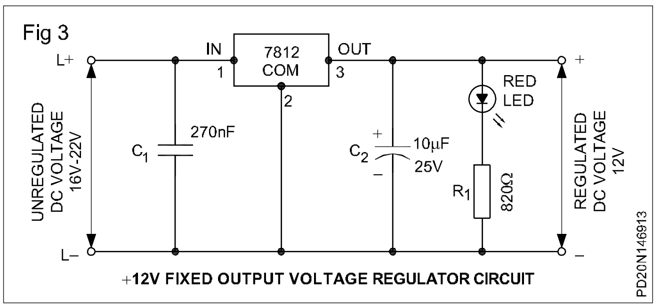
LM340-X or LM340-XX → Fixed +ve voltage regulators.

Examples



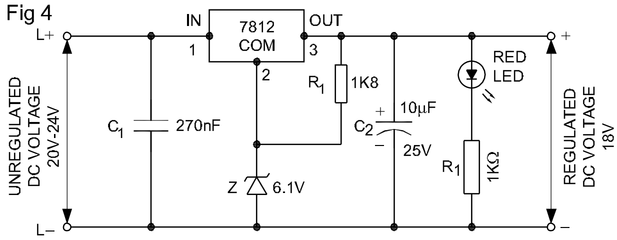


Practical 78XX and 79XX voltage regulator: Fig 3 shows the circuit connections of a 12V, 1A regulated power supply using 7812.



The output voltage of a 3-terminal regulator IC is with reference to the IC's common terminal (COM). When the COM terminal is grounded, the output voltage of the regulator will be the specified output voltage of the IC as in Fig 3. But the output voltage of the IC can be increased above the specified value by rising the voltage at the COM terminal as in Fig 4. Because of 6.1V zener, the output voltage of the IC can be increased above the specified value by raising the voltage at the COM terminals as in Fig 4. Because of 6.1V zener, the output voltage will be 6.1V + 12V = 18.1V or approximately 18V as in Fig 4.

Fig 4



+18V FIXED OUTPUT VOLTAGE REGULATOR CIRCUIT

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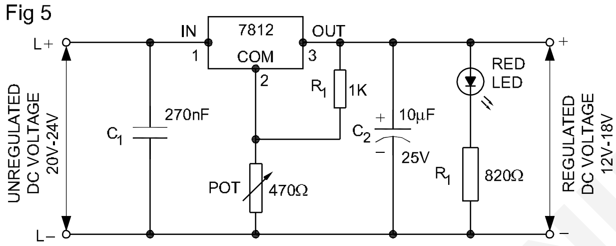
When the COM terminal of the IC is grounded as in Fig 2, the quiescent current flowing from the COM terminal to ground in 78 series is around 8µA. This current decreases as the load current increases. When a zener is connected at COM terminal as in Fig 4, to ensure that the zener is always in the reverse ON condition, resistor R_1 is used. If R_1 = 1.8K, I_z will be 7mA which is sufficient to keep the zener ON always.

Fig 5 shows a variable output voltage regulator. The variable reference voltage at COM terminal is obtained using a POT.

Fig 5



VARIABLE OUTPUT VOLTAGE REGULATOR CIRCUIT

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Four-terminal regulators: These are adjustable output voltage regulators and are also available as +ve and -ve regulators. These ICs have internal reference voltages and are protected internally for thermal overload, short circuit etc. Table 1 provides important specifications for most common ICs.

Fig 6 to 8 shows the common ICs used as voltage regulators with their terminal marking and Fig 9 to 11 shows the circuit configuration.

Fig 6

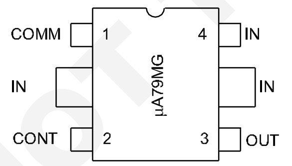

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Fig 7

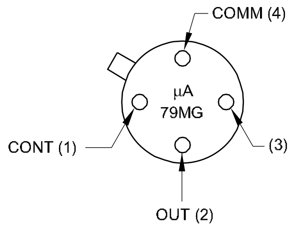

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Fig 8

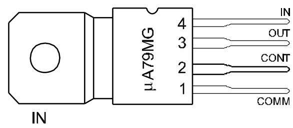

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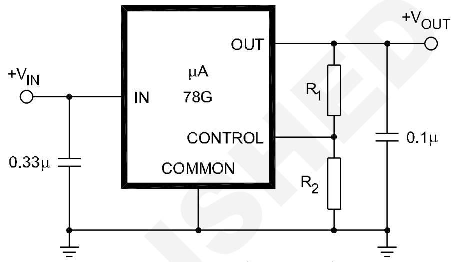
Fig 9

BASIC POSITIVE REGULATOR



$V_{OUT} = V_{CONT}\left(\frac{R_1 + R_2}{2}\right)$

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Fig 10

POSITIVE 5 TO 30V ADJUSTABLE REGULATOR

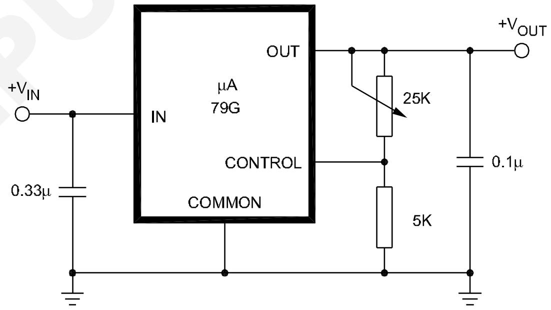

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Fig 11

–30V To –2.2V ADJUSTABLE REGULATOR

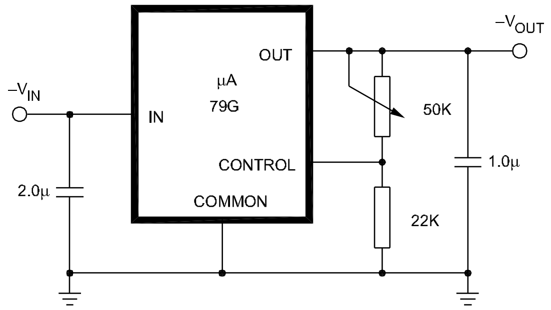

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Table 3

Specifications of a 4-terminal voltage regulator

Sl. No.	IC	MA 78G	MA78MG	MA79G	MA79MG
1	Input voltage range	7.5V to 40V	7.5V to 40V	–7V to –40V	–7V to –40V
2	Output voltage range	5V to 30V	5V to 30V	–2.23V to –30V	–2.23V to –30V
3	Line regulation	← better than 1% for all →			
4	Load regulation	← better than 1% for all →			
5	Drop out voltage	3V	3V	2.5V	2.5V
6	Peak output current	2.2A	800mA	2.2A	–800mA
7	Control pin current	5μA	5μA	2 μA	2μA
8	Short circuit current	750mA	300mA	250mA	100mA
9	Internal reference voltage	5V	5V	2.23V	2.23V
10	Ripple reflection {When the $[(V_{IN}) - (V_{OUT})] > 10$ V}	← better than 1000 →			

Binary numbers, logic gates and combinational circuits

Objectives : At the end this lesson you shall be able to
- **explain the digital electronics principle and positional notation and weightage**
- **explain decimal to binary conversion, binary odometer**
- **explain hexadecimal number system**
- **convert decimal to hexa, hexa to decimal and BCD system**
- **explain logic gates principle - NOT, OR and AND gates with truth table**
- **explain combinational gates - NAND, NOR with truth table and logic pulser.**

Introduction

When we hear the word 'number' immediately we recall the decimal digits 0,1,2....9 and their combinations. Digital circuits do not process decimal numbers. Instead, they work with binary numbers which use the digits '0' and '1' only. The binary number system and digital codes are fundamental to digital electronics. But people do not like working with binary numbers because they are very long when representing larger decimal quantities. Therefore digital codes like octal, hexadecimal and binary coded decimal are widely used to compress long strings of binary numbers.

Binary number systems consists of 1s and 0s. Hence this number system is well suited for adopting it to the digital electronics.

The decimal number system is the most commonly used number system in the world. It uses 10 different characters to show the values of numbers. Because this number system uses 10 different characters it is called base-10 system. The base of a number system tells you how many different characters are used. The mathematical term for the base of a number system is radix.

The 10 characters used in the decimal number systems are 0,1,2,3,4,5,6,7,8,9.

Positional notation and weightage

A decimal integer value can be expressed in units, tens, hundreds, thousands and so on. For example decimal number 1967 can be written as 1967 = 1000 + 900 + 60 + 7. In powers of 10, this becomes.

10^3	10^2	10^1	10^0	
				$1 \times 10^3 = 1000$
				$9 \times 10^2 = 900$
				$6 \times 10^1 = 60$
1	9	6	7	$7 \times 10^0 = 7$
				1967

i.e. $[1967]_{10} = 1(10^3) + 9(10^2) + 6(10^1) + 7(10^0)$

This decimal number system is an example of positional notation. Each digit position has a weightage. The positional weightage for each digit varies in the sequence $10^0, 10^1, 10^2, 10^3$ etc starting from the least significant digit.

The sum of the digits multiplied by their weightage gives the total amount being represented as shown above.

In a similar way, binary number can be written in terms of weightage.

To get the decimal equivalent, then the positional weightage should be written as follows.

$$[1010]_2 = 1(2^3) + 0(2^2) + 1(2^1) + 0(2^0)$$
$$= 8 + 0 + 2 + 0$$
$$[1010]_2 = [10]_{10}$$

Any binary number can be converted into decimal number by the above said positional weightage method.

Decimal to Binary conversion

Divide the given decimal number by 2 as shown below and note down the remainder till you get the quotient - zero.

Example

Divisor	Quotient	Remainder	
	0		
2	1	1	⟶ MSB
2	2	0	
2	4	0	
2	8	0	
2	17	1	
2	34	0	⟶ LSB

The remainder generated by each division form the binary number. The first remainder becomes the LSB and the last remainder becomes the MSB of binary number.

Therefore, $[34]_{10} = [100010]_2$

Counting binary number

To understand how to count with binary numbers, let us see how an odometer (KM indicator of a car) counts with decimal numbers,

The odometer of a new car starts with the reading 0000.

After traveling 1KM , reading becomes 0001.

Successive KM produces 0002, 0003 and so on upto 0009

At the end of 10th KM , the units wheel turns back from 9 to 0, a tab on this wheel forces the tens wheel to advance by 1. That is why the number changed from 0009 to 0010.

That is, the units wheel is reset to 0 and sent a carry to the tens wheel. Let us call this familiar action as reset and carry. The other wheels of odometer also reset and carry. For instance, after covering 999KM , the odometer shows 0999.

After the next KM , the unit wheel resets and carries, the tens wheel resets and carries, the hundreds wheel resets and carries and the thousands wheel advances by 1 to get the reading 01000.

Binary odometer

Visualize a binary odometer, a device whose wheels have only two digits 0 and 1. When each wheel turns, it displays 0 then 1 and then back to 0 and the cycle repeats. A four digit binary odometer starts with 0000.

After 1km, it indicates - 0001.

The next km forces the units wheel to reset and sends carry. So the number changes to 0010.

The third km results in 0011.

After 4km, the units wheel resets and sends carry, the second wheel resets and sends carry and the third wheel advances by 1. Hence it indicates 0100.

Table below shows all the binary numbers from 0000 to 1111 equivalent to decimal 0 to 15.

Decimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Addition of binary numbers

Sum	Carry
0 + 0 = 0	0
1 + 0 = 1	0
0 + 1 = 1	0
1 + 1 = 0	1 (one plus one is equal to zero with carry one)

Ex: 1Ex: 2

```
   1 0          1 + 1 + 1 =  1
 + 1 1                      + 1   (One plus one
plus                                one is equal to
one                                 with carry one)
                             10
                            + 1
 -----                      ----
  1 0 1                      11
```

Hexadecimal number system: In hexadecimal system there are 16 characters. They are 0,1,2,3,4,5,6,7,8,9, A,B,C,D,E,F where A=10, B=11, C=12, D=13, E=14, F=15 in decimal. In this system, the base is 16. This system is mainly used to develop programmes for computers.

For Example

$[23]_{16} = [35]_{10}$; $16^1 \times 2 + 16^0 \times 3 = 32 + 3 = 35$;

$[2C]_{16} = [44]_{10}$;$16^1 \times 2 + 16^0 \times 12 = 32 + 12 = 44$;

Decimal to hexadecimal conversions

The conversion of decimal to hexadecimal is similar to binary conversion. Only difference is that divide the decimal number successively by 16, and note down the remainder.

```
        0
   16 | 1      1   ⟶ MSB
   16 | 27     11 or B
   16 | 432    0   ⟶ LSB
```

$[432]_{10} = [1B0]_{16}$

Hexadecimal to Decimal

This conversion can be done by putting it into the positional notation.

Ex: $223A_{16} = 2 \times 16^3 + 2 \times 16^2 + 3 \times 16^1 + A \times 16^0$

$= 2 \times 4096 + 2 \times 256 + 3 \times 16 + 10 \times 1$

$= 8192 + 512 + 48 + 10$

$= 8762_{10}$

BCD (Binary Coded Decimal)

Binary Coded Decimal (BCD) is a way to express each of the decimal digits with a binary code, since there are only ten code groups in the BCD system, it is very easy to convert between decimal and BCD. Because decimal system is used for read and write, BCD code provides an excellent interface to binary systems. Examples of such interfaces are keypad inputs and digital readouts.

8421 code

The 8421 code is a type of binary coded decimal (BCD), binary coded decimal means that each decimal digit, 0 through 9 is represented by a binary code of four bits. The designation 8421 indicates the binary weights of the four bits (2^3, 2^2, 2^1, 2^0). The ease of conversion between 8421 code numbers and the familiar decimal numbers is the main advantage of this code. All you have to remember are the ten binary combinations that represents the ten decimal digits as shown in the Table.

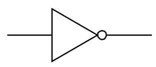
Decimal digit	0	1	2	3	4
BCD	0000	0001	0010	0011	0100
Decimal digit	5	6	7	8	9
BCD	0101	0110	0111	1000	1001

The 8421 code is the pre-dominant BCD code, and when we refer to BCD, we always mean the 8421 code unless otherwise stated.

Inverters (NOT Gate)

An inverter is a gate with only one input signal and one output signal. The output state is always the opposite of the input state. Logic symbol is shown in Fig 1.

Fig 1



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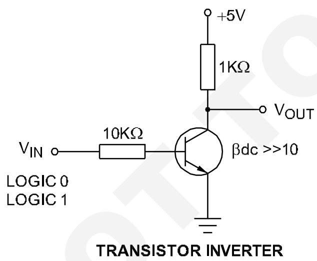
Transistor inverter

The Fig 2 shows the transistor inverter circuit. The circuit is a common emitter amplifier which works in saturation or in cut off region depending upon the input voltage. When V_{in} is in low level, say less than the transistor cut in voltage 0.6V in silicon type, the transistor goes to cut off condition and the collector current is zero. Therefore, V_{out} = +5V which is taken as high logic level. On the other hand, when V_{in} is in high level, the transistor saturates and V_{out} = V_{sat} = 0.3V i.e low level.

Fig 2



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The table summarizes the operation

V_{in}	V_{out}
Low(0)	High(1)
High(1)	Low(0)

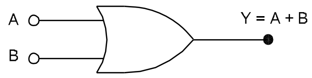
The logic expression for the inverter is as follows: Let the input variable be 'A' and the output variable be Y, then the output Y = $\overline{A}$.

OR and AND gate circuits

OR Gate

The output of an OR will be in 1 state if one or more of the inputs is in 1 state. Only when all the inputs are in 0-state, the output will go to 0-state. Fig 3 shows the schematic Symbol of an OR Gate :

Fig 3



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The boolean expression for OR gate is Y=A+B.

The equation is to be read as Y equals A ORed B. Two-input truth table given below is equivalent to the definition of the OR operation.

Truth table for OR gate

A	B	Y=A + B
0	0	0
1	0	1
0	1	1
1	1	1

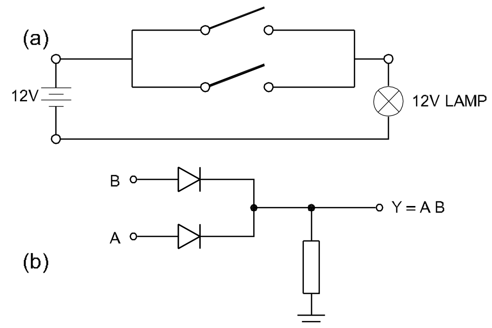
Electrical equivalent circuit

The Fig 4a shows the electrical equivalent circuit of an OR gate. It is evident that if any one of the switch is closed, there will be output.

2 in-put OR gate using diode

The Fig 4b shows one way to build a 2-input OR gate, using diodes. The inputs are labeled as A and B, while the output is Y.

Fig 4



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Assume logic 0 = 0V (low)

logic 1 = +5V (high)

Since this is a 2 input OR gate, there are only four possible cases,

Case 1: A is low and B is low. With both the input voltage low, both the diodes are not conducting. Therefore the output Y is in low level.

Case 2: A is low and B is high, The high B input voltage (+5V) forward biases the lower diode, producing an output voltage that is ideally +5V (actually +4.3V taking the diode voltage drop 0.7V into consideration). That is, the output is in high level. During this condition, the diode connected to input A is under reverse bias or OFF condition.

Case 3: A is high and B is low, the condition is similar to case 2. Input A diode is ON and Input B diode is OFF and Y is in high level.

Case 4: A is high, B is high. With both the inputs at +5V, both diodes are forward biased, since the input voltages are in parallel, the output voltage is +5V ideally [+4.3V to a second approximation]. That is, the output Y-is in high level.

OR gates are available in the IC form. IC7432 is a T.T.L OR gate IC having 4 OR gates inside it.

Simple application of OR gate

Intrusion detection

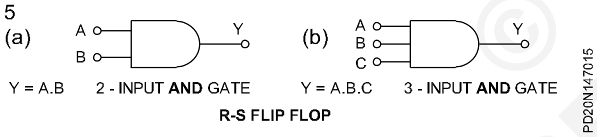
Simplified portion of an intrusion detection and alarm system is two windows and a door. The sensors are magnetic switches that produce a high(1) output when windows and doors are opened and a low(0) output when closed. As long as the windows and the door are secured, the switches are closed and all three of the OR gate inputs are in low(0). When one of the windows or the door is opened, a high(1) output is produced on that input of the OR gate and the gate output goes high. It then activities an alarm circuit to warn of the intrusion.

AND gates

The AND gate has two or more inputs but only one output. All input signals must be held high to get a high output. Even if one of the inputs is low, the output becomes low.

AND gate symbols for 2 input and 3 input gates are shown in Fig 5a and 5b.

Fig 5



Truth table

Two input AND gate

A	B	Y=AB
0	0	0
0	1	0
1	0	0
1	1	1

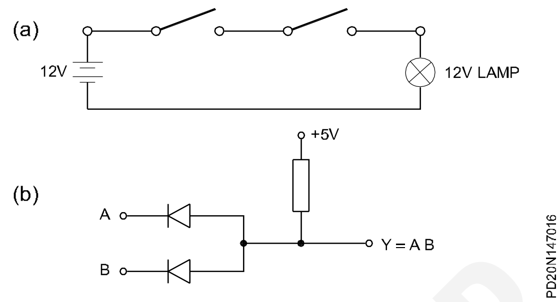
Three input AND GATE

A	B	C	Y=ABC
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Electrical equivalent circuit of an AND gate

The output is available only when both the switches are closed. IC7408 is a T.T.L quad AND gate IC. (Refer data book for pin diagram). The electrical equivalent of AND gate and AND gate using diodes are shown in Fig 6a and 6b.

Fig 6

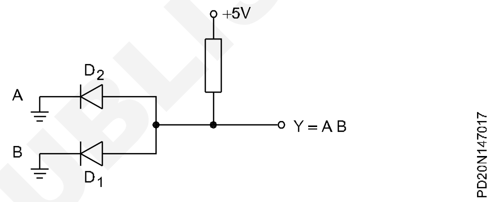


Two input AND gate using diode

I condition

A=0, B=0, Y=0 as in Fig 7.

Fig 7

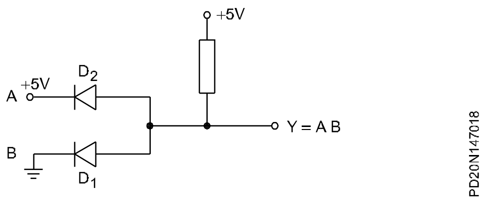


During the above condition I/P A and B are connected to ground to make logic low inputs. During this condition, both the diodes conduct, and pulls the O/P Y to logic-0.

II condition

A=0, B=1, Y=0 as in Fig 8.

Fig 8

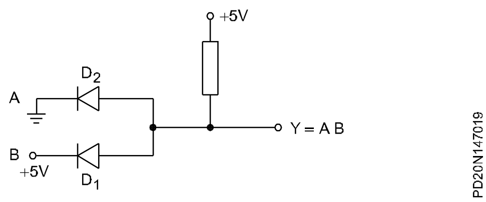


In the II condition shown in the figure above, diode D_1 is connected logic-0 input and diode D_2 is connected to +5V [Logic high]. Diode D_1 is in forward bias and conducts. Diode D_2 is having equal potential (+5V) at anode and cathode. So potential difference between anode and cathode is 0. Hence diode D2 does not conduct. The output Y is pulled down to logic zero, since D_1 is conducting.

III condition

A=1, B=0, Y=0 as in Fig 9.

Fig 9

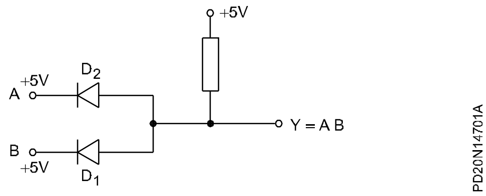


The III condition is similar to the II condition. D_2 is forward biased. D_1 is reverse biased. Hence output Y is pulled to logic-0.

IV condition

A=1, B=1, Y=1 as in Fig 10.

Fig 10



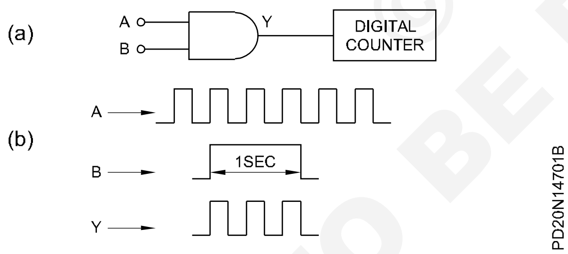
In this condition both the diodes are reverse biased. So both the diodes act as open circuit. Therefore output y is +5V i.e y is in logic-1 condition.

AND gate as an Enable/Inhibit device

A common application of the AND gate is to enable (i.e to allow) the passage of a signal (pulse waveform) from one point to another at certain times and to inhibit (prevent) the passage at other times.

In Fig 11a AND gate controls the passage of a signal (waveform A) to a digital counter. The purpose of this circuit is to measure the frequency of waveform 'A'. The enable pulse has a width of precisely 1 second. When the enable pulse applied at B is high, waveform A passes through the gate to the counter, and when the enabled pulse is low, the signal is prevented (inhibited) from passing through. Refer Fig 11b for the waveforms of the above process.

Fig 11



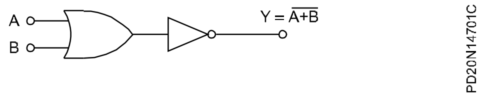
During the 1 second interval of the enabled pulse, a certain number of pulses in waveform A pass through the AND gate to the counter. The number of pulses counted by the counter is equal to the frequency of the waveform A. For example, if 1000 pulses pass through the gate in the 1 second interval of the enabled pulse, there are 1000 pulses/sec. That is, frequency is 1000Hz.

Combinational gate circuits - NOR and NAND

NOR Gate

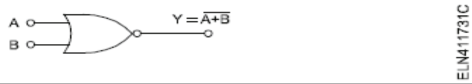
In Fig 12a the output y of the circuit equals to the complement of A OR B, because the circuit is an OR gate followed by a NOT gate. To obtain high output [Logic-1], both the inputs should be tied to low input [Logic-0]. For the rest of the other three possibilities, output will be zero, the combination of this OR and NOT gate is called as NOR gate.

Fig 12(a)



Symbol (Fig 12b) :

Fig 12(b)



We can define a NOR gate as follows:

The output of a NOR gate is 0, even if one of the inputs is in logic-1. Only when both the inputs are in logic-0, the output is in logic-1.

Truth table

A	B	A + B
0	0	1
0	1	0
1	0	0
1	1	0

IC7402 is a T.T.L NOR gate IC. It contains 4 NOR gates. For pin details, refer data book.

NAND gate

An AND gate followed by a NOT gate forms the NAND gate as in Fig 13a. In this gate to get a low output (logic=0), all the inputs must be in high state and to get high output state, any one of the inputs or both inputs must be in low state.

Fig 13

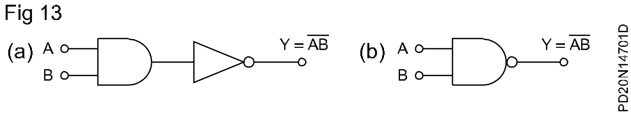


Fig 13b is the standard symbol for a NAND gate. The inverter triangle has been deleted and the bubble is moved to the AND-gate output.

Truth table for NAND gate

A	B	$Y = \overline{AB}$
0	0	1
0	1	1
1	0	1
1	1	0

Pulsed operation

Output waveform Y is low only for the time intervals when both inputs A and B are high as shown in the timing diagram Fig 14.

Logic pulser

Fig 15 shows the circuit diagram of logic pulser, the circuit essentially consists of NAND gates connected debouncer circuit and its output is Double inverted. The LED indicates, pulses ON or OFF status.

When switch S_1 is not pressed, (OFF position) B input of NAND gate No.2 is grounded, hence its output $\overline{Y}$ is forced to go logic HIGH. This HIGH output is feedback to NAND gate 1, A input of NAND gate 1 is also held HIGH through R_1 resistor (820Ω) and thus the output of NAND gate-1 'Y' is at low. This logic low output keeps LED in OFF condition and this logic low is again double inverted at the logic pulser tip through NAND gate 3 and 4 to get logic low level at pulser tip.

When S_1 is pressed to ON, A input of NAND gate is forced to go logic-low. Hence the output of this NAND gate is forced to go logic-HIGH. Therefore the 'Y' output is at logic-1, so LED glows and a logic-HIGH appears at probe tip. Also note that with HIGH at Y output, the inputs of NAND gate 2 are also at logic-HIGH and the output of NAND gate-2 is forced to go low. As long as switch S_1 is at ON position the probe tip is HIGH. When it is released it springs back to OFF position, and the output returns to a logic-LOW condition.

Fig 14

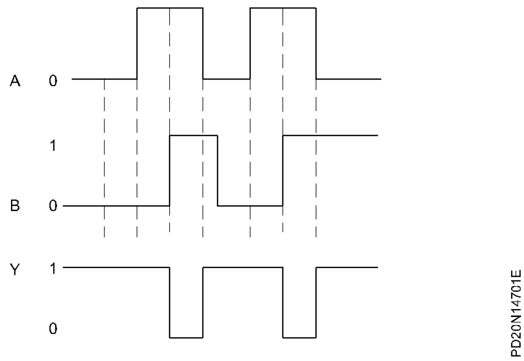
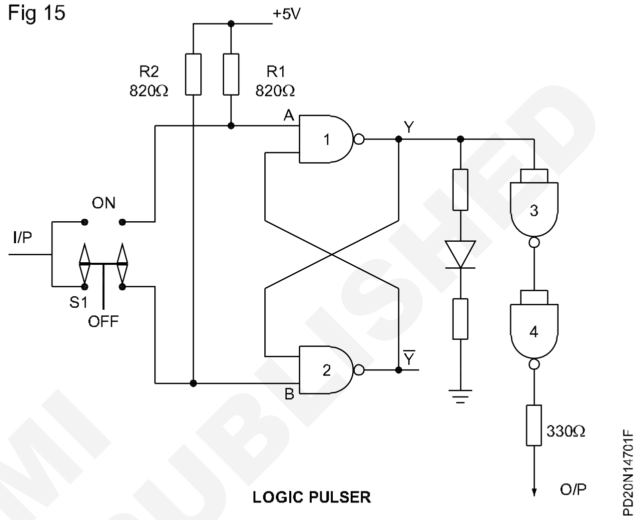


Fig 15

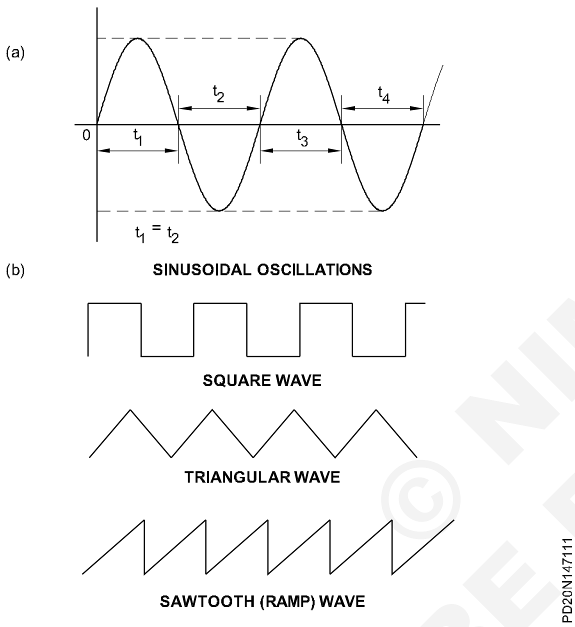


Wave shapes - oscillators and multivibrators

Objectives: At the end of this lesson you shall be able to
- **state the working principle and gain of oscillator**
- **explain the RC phase-shift oscillator and frequency calculation**
- **state the features, gain and frequency of Hartley, colpitts and crystal oscillators**
- **state the working principle and frequency calculation of bistable and monostable multivibrator using CRO.**

Oscillator: An oscillator is a circuit for producing voltages that vary in a regular fashion with respect to time. The output wave forms of oscillators are repeated exactly in equal successive intervals of time as in Fig 1a and Fig 1b.

Fig 1



The output wave-form of an oscillator may be sinusoidal as in Fig 1a. Such oscillators are known as sine wave oscillators or harmonic oscillators.

The output of oscillators may be square, triangular or saw-tooth wave forms as in Fig 1b. Such oscillators are known as non-sinusoidal oscillators or relaxation oscillators.

It was discussed earlier that positive feedback results in converting an amplifier into an oscillator. To provide positive feedback the feedback signal should be inphase with the input signal such that it adds up with the input signal.

In practice, an oscillator will have no input AC signal at all, but it still generates AC signal. An oscillator will have only a DC supply. The oscillator circuit, makes use of the noise generated in resistors at the switching on time of dc supply and sustains the oscillations.

To build an oscillator, the following are essential;

- An amplifier
- A circuit which provides positive feedback from output to input.

The gain of an amplifier with feedback is given by,

$$A_{vf} = \frac{A_V}{1 - kA_V}$$

kA_v is known as the loop gain of the amplifier. In the case of the amplifiers when the sign associated with kA_v is negative, the denominator has value more than 1. And, hence the value of Avt will always be less than A_v (negative feedback). But, if the value of kA_v is made larger, such that, it approaches unity, and, if the sign associated with kA_v is negative then the value of the denominator decreases to less than 1, and hence, A_{vf} will be larger than A_v.

In case of oscillators, if the loop gain kA_v is made positive, i.e. by feeding back signal which is in-phase with the input signal, then there will be an output signal even though there is no external input signal. In other words, an amplifier is modified to be an oscillator by positive feedback such that it supplies its own input signal.

Example

An amplifier has a voltage gain of 40 without feedback. Determine the voltage gains when positive feedback of the following amounts is applied.

i) k = 0.01

ii) k = 0.02

iii) k = 0.025

Solution

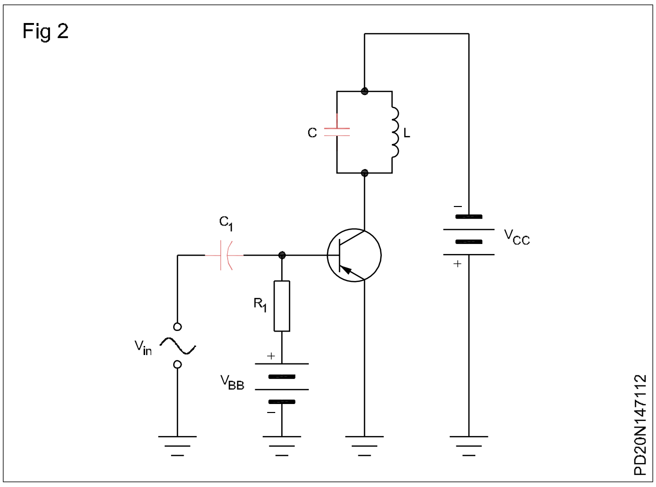
i) $$A_{vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.01 \times 40} = \frac{40}{0.6} = 66.7$$

ii) $$A_{vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.02 \times 40} = \frac{40}{0.2} = 200$$

In (iii) the gain of the amplifier become infinite when the loop gain kA_v = +1. This is known as the critical value of the loop gain kA_v. It is important to note that the output voltage cannot be infinite. Instead the amplifier will start working as an oscillator without the need of any separate input. If the feedback path contains a frequency selective network, the requirement of $kA_v = 1$ can be met at only one particular frequency, such that, the output of the oscillator will be a sinusoidal signal of a particular frequency. Such oscillators are known as sine wave oscillators.

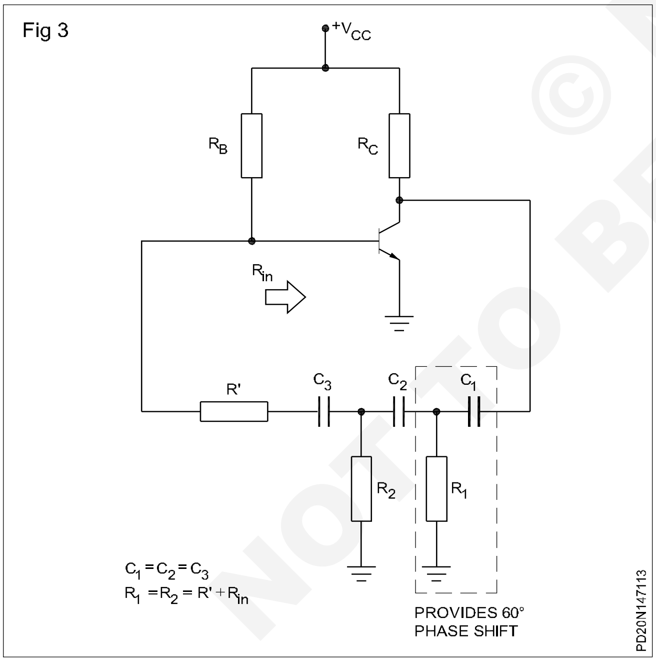
One of the simplest form of sine wave oscillators is the phase shift oscillator. Fig 2 shows the principle behind an RC phase shift oscillator.

Fig 2



The feedback network shown in Fig 3 consists of resistors and capacitors which provide the required phase shift of 180°. Due to the presence of capacitors in the feedback network, the feedback network can be so designed to provides the required phase shift of exactly 180° at a particular frequency f given by,

Fig 3



$$f = \frac{1}{2\pi RC\sqrt{6}}$$

The other condition to be satisfied oscillations to occur is that the loop gain KA_v should be equal to unity. To satisfy this condition, using classical network analysis, it can be found that, the value of K should be, k =1/29. Therefore, the voltage gain of the amplifier A_v stage must be greater than $1/k$ or greater than 29 so that kA_v becomes equal to 1.

Transistor RC phase shift oscillator: Fig 3 shows a single transistor phase shift oscillator using resistors and capacitors in a feedback network.

There are three sections of R and C in the feedback network. Each RC section provides a 60° phase shift at a specific frequency, resulting in a 180° phase shift as required for positive feedback. This satisfies one of the two required conditions for oscillations.

In Fig 3, the feedback signals coupled through a feedback resistor R^1 in series with the amplifier stage input Resistance R_{in}. resistor R^1 can be made variable for adjusting the oscillator frequency. For each of three sections of R_C phase shift network to produce 60° phase shift, it is necessary that $C_1 = C_2 = C_3$ and $R_1 = R_2 = R' + R_{in}$.

The other required condition for oscillation, i.e. loop gain kA_v to be unity is satisfied by the circuit at Fig 2, when β of the transistor used in the circuit is,

$$h_{fe} = \beta = 23 + 29\frac{R}{R_C} = + 4\frac{R_C}{R} \quad ......(2)$$

where, $R_1 = R_2 = R$

When β is atleast the value given by equation (2) or greater than, the circuit at Fig 2 it will oscillate.

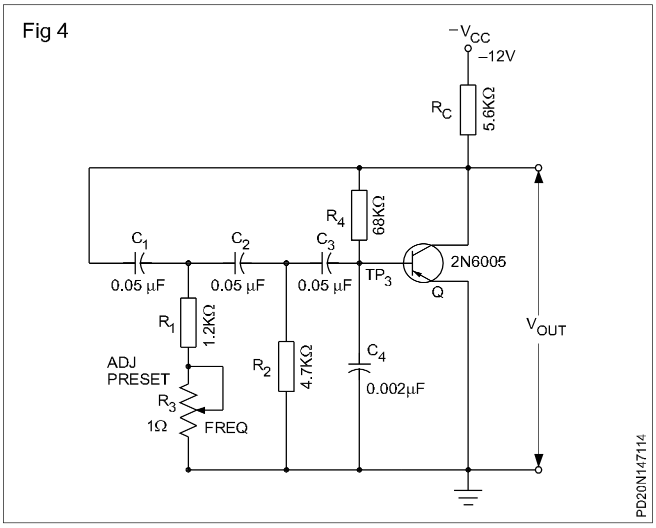
Practical transistor RC phase shift oscillator

Fig 4 shows a practical transistor RC phase shift oscillator which is similar to that shown in Fig 2.

In Fig 4 note that resistor R_3 (in Fig 2 it is denoted as R') used for frequency adjustments is connected in series with one of the resistors of the RC section. Resistor R_4 provides the necessary bias stabilisation for the transistor operation. Note that a small value capacitor C_4 is connected in parallel with the input. The purpose of C_4 is to bypass the unwanted high frequency oscillations to ground. The value of R_3 can be varied to adjust the frequency of oscillations. However, the variation that can be obtained by R_3 is limited.

For the circuit at Fig 3, the frequency of oscillation is given by,

Fig 4



$$f = \frac{1}{2\pi C\sqrt{6R_1^2 + 4R_1R_C}} \qquad ......(3)$$

where, $C = C_1 = C_2 = C_3$

The minimum value of hfe or β of the transistor used in the circuit at Fig 3 should be,

$$h_{fe} = \beta = 23 + 29\frac{R_1}{R_C} + 4\frac{R_C}{R1}$$

using the component values at Fig 3, the β of the transistor used should be a minimum of,

$$\beta = 23 + 29\frac{1.2K}{5.6K} + 4\frac{5.6K}{1.2K} = 47.89$$

The frequency of oscillations can be increased by decreasing the value of R or by decreasing the value of C.

In the practical circuit at Fig 3, collector feedback bias is employed to ensure that the transistor will never go to saturation. Other biasing techniques such as voltage divider bias can also be used for DC biasing of the transistor. Since the frequency of oscillations is decided only by the feedback phase shift network, biasing resistors will not have any effect of the frequency of oscillations. The important point to be noted is that the β of the transistor should be higher than the minimum β given in equation 2 to have sustained oscillations.

Hartley oscillator

Principle of sinusoidal or harmonic oscillations: Fig 5a shows an inductor and a capacitor connected in parallel as a parallel LC resonant circuit. A parallel LC circuit is also known as tuned circuit or tank circuit.

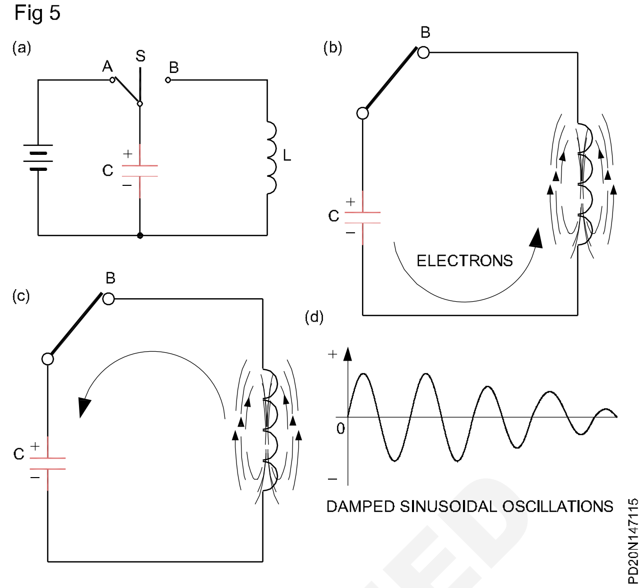
In Fig 5a, when switch S is put into position A, the capacitor gets charged with the bottom plate being negative and the top plate positive. This means, energy is stored in the capacitor in the form of an electric charge.

When switch S is put into position B, as in Fig 5b, the capacitor starts discharging through the inductor, creating an expanding magnetic field around L. Since the inductor has the property of opposing any sudden change in current through it, the current builds up slowly.

Once the capacitor gets fully discharged, the magnetic field around L begins to collapse. The collapsing magnetic field, induces a voltage (back-emf) in L. This back emf tends to maintain the electron flow through L in the same direction as when C was discharging. Hence, this back emf in the inductor starts charging the capacitor with opposite polarity as in Fig 5c. After the magnetic field has totally collapsed, C would have got charged in the opposite direction as in Fig 5c.

Sinusoidal wave form: However, owing to the resistance in a practical inductor and the losses in the capacitor due to resulting I^2R (heat loss) the amplified of the oscillation decreases gradually (damped) and ultimately the oscillations die down as in Fig 5d.

Fig 5



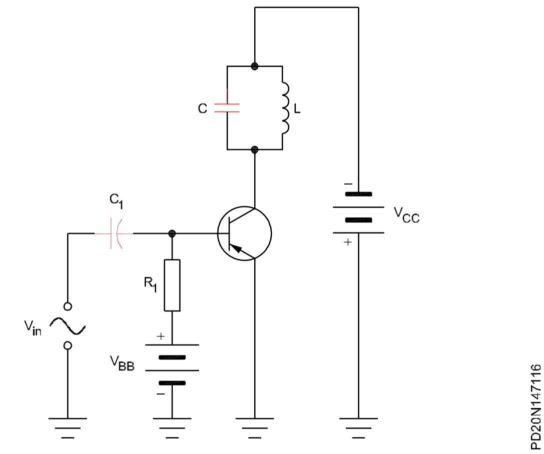
The frequency of oscillation produced by the resonant frequency is given by,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Overcoming losses in tank circuit for sustained oscillations: To avoid the damping of oscillations, when the energy fed into the circuit has been used up, it is necessary to supply more energy by charging the capacitor again. As shown in Fig 5a, by switching S between A and B at proper time, the oscillations can be maintained thus obtaining sinusoidal waveform of constant amplitude and frequency.

Another method of making the LC tank circuit to give undamped oscillations is, to connect the tank circuit in the output of an amplifier as in Fig 6.

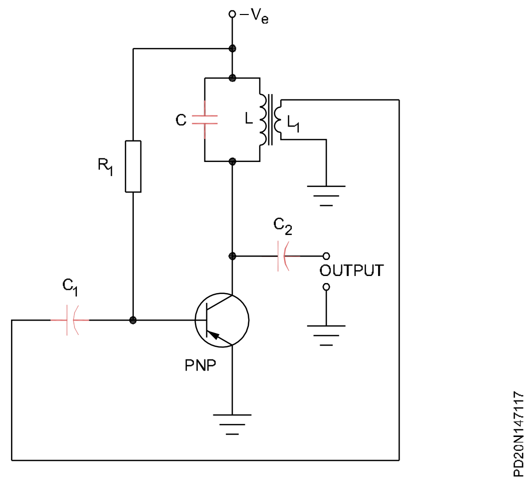
Fig 6



The amplifier is kept at cut-off by the dc supply V_{BB} which reverse-biases the base-emitter circuit. A sine wave is injected to the base circuit with such an amplitude that the collector current flows at the peak of the negative alterations of the input sine wave. This excites the LC circuit in the collector of the transistor and the tank keeps oscillating. If the input sine wave has the same frequency as the frequency of oscillations of the tank circuit, the oscillations in the LC tank is maintained.

Fig 7 shows a modified form of circuit at Fig 6. In Fig 5a transistor amplifier connected in such a way that it will cause undamped oscillations without requiring any external signal. Such a circuit is known as an oscillator.

Fig 7



The oscillator circuit at Fig 7 is known as tickler-coil oscillator. Here L1 is inductively coupled to L. When power is first switched ON to the circuit, current flows in the transistor. As the current flows through L, it induces a voltage in L1 which is coupled to the base of the transistor and is amplified.

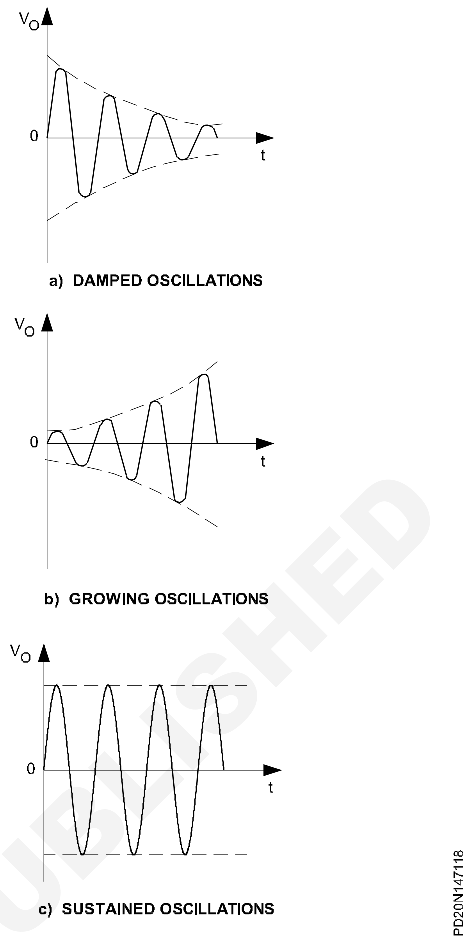
If the phase of the feedback voltage is adding, then there is an increase in the collector current. This action builds up a large current pulse which excites the LC tank into oscillations. The signal fed by L1 to the base of the transistor is a sine wave of the same frequency as that in the LC circuit and of proper phase to sustain the oscillations. The signal induced in the base thus eliminates the need for an external input to the oscillator and the LC tank will oscillate as long as the DC power to the circuit is ON.

The feedback given to the amplifier in Fig 7 in the proper phase so as to sustain (keep going) oscillations is referred to as positive feedback or regenerative feedback.

Barkhausen criterion: The mathematical analysis for an amplifier to oscillate on its own is given below:

- In the amplifier shown in Fig 7, assume that the gain of the amplifier is A and the feedback factors is β. If the product of $A\beta$ is less than 1 ($A\beta<1$), then the output signal will be a damped oscillations which will die down as is shown in Fig 8a.
- If $A\beta>1$, the output voltage builds up as shown in Fig 8b. Such oscillations are called growing oscillations.
- If $A\beta=1$, the output amplitude of oscillations remains constant as in Fig 8c.

Fig 8



When the feedback is positive (regenerative), the overall gain of the amplifier with feedback (A_f) is given by,

$$A_f = \frac{A}{1 - A\beta}$$

When $A\beta$ = 1, the denominator of the equation will be zero, and hence A_f = Infinity. The gain becoming infinity means, there is output without any input. i.e. the amplifier becomes an oscillator. This condition $A\beta$ = 1, is known as Barkhausen criterion for oscillations.

Summarizing, the basic requirements for an oscillator are;

- A stable DC power supply source
- An amplifier
- A regenerative (positive) feedback from output to input
- A LC tank circuit to determine the frequency of oscillations

Starting signal for oscillators: As discussed above an oscillator gives alternating output voltage without an input signal once the amplifier is given a regenerative feedback. But in a practical oscillator circuit, to start off oscillations, no starting input signal is provided. However, the starting signal of an oscillator is generated by the noise voltage while switching on the oscillator circuit. Such noise voltages are produced due to the random motion of electrons in resistors used in the circuit.

Noise voltage contains almost all the sinusoidal frequencies of small amplitude. However, it gets amplified and appears at the output terminals. The amplified noise now drives the feedback network, which is a resonant tank circuit. Because of this tuned tank circuit, the feedback voltage $A\beta$ is maximum at a particular frequency f_r, which will be the frequency of oscillations.

Further more, the phase shift required for positive feedback is correct at this frequency f_r only. Thus although the noise voltage contains several frequency components, the output of the oscillator will contain a single sinusoidal frequency f_r the resonant frequency of the tank circuit.

To summarize, the following are the requirements of an oscillator circuit to take-off with oscillations and have sustained oscillations,

- there must be positive feedback.
- Initially the loop gain product $A\beta$ must be >1.
- After the circuit starts oscillating, the loop gain product $A\beta$ must decrease to 1 and remain at 1.

Hartley oscillator: One of the simplest of sinusoidal oscillators is the Hartley oscillator shown in Figs 9a and 9b.

As in Fig 9a is a series fed Hartley oscillator. This circuit is similar to the tickler coil oscillator shown in Fig 7, but the tickler circuit coil L_1 is physically connected to L, and is hence a part of L (like an auto-transformer). This oscillator is called series-fed because, the high frequency oscillations generated and the DC paths are the same, just as they would be in a series circuit. Series fed Hartley oscillators are not preferred due to their poor stability of oscillations.

Fig 9b is parallel fed Hartley oscillator commonly used in radio receivers. Parallel fed Hartley oscillators are known for their high stability of oscillations.

The circuit at Fig 9b is actually an amplifier with positive (regenerative) feedback to have sustained oscillations. The capacitor C_2 and inductor L_2 form the path for RF current in the collector to ground circuit.

RF current through L_2 induces a voltage in L_1 in proper phase and amplitude to sustain oscillations.

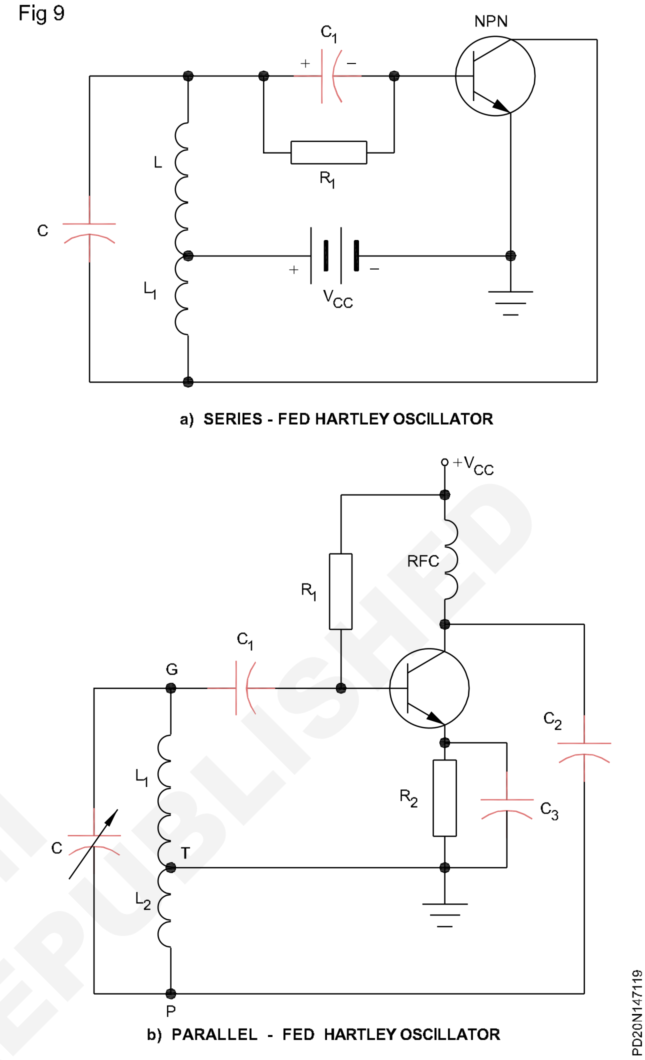
The position of the tap at the junction of L_1 and L_2 determines how much signal is fed back to the base circuit.

The capacitor C and the inductors $L_1 + L_2$ forms the resonant tank circuit of the oscillator which determines the frequency of oscillations. Capacitor C can be made variable capacitor for tuning the oscillator to different frequencies. C_1 and R_1 form the RC circuit which develops the bias voltage at the base.

The RF choke at the collector keeps the high frequency ac signal out of the V_{cc} supply. In cheaper oscillator circuits the RF choke is omitted and is replaced by a resistor.

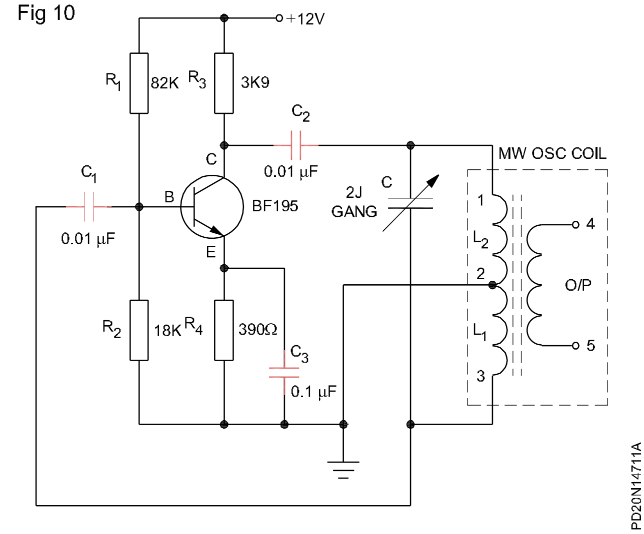
Resistor R_2 connected in the emitter provides DC stabilization. R_2 is by-passed by C_3 to prevent AC degeneration.

Fig 9



The Hartley oscillator coil has three connections. These are usually coded on the coil. If they are not, it is generally possible to identify them by a resistance check. The resistance between the taps T and P as in Fig 10, is small compared with the resistance between T and G., If the coil connections are not made properly, the oscillator will not work.

Fig 10



Checking oscillator frequency: The frequency of an oscillator can be computed if the values of L ($L = L_1 + L_2$) and C are known using the formula,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where, f is in hertz, L in henry, and C in farad.

The frequency of an oscillator may be measured in two ways,

- Using a direct read-out frequency meter also known as frequency counter which is most accurate, popular and easy to use.
- Using an oscilloscope with a calibrated time base to measure the period of the wave-form. From the measured period, 'T' frequency is calculated using the formula

$$f = \frac{1}{T}$$

where, f is the frequency in Hz and 'T' the time period in seconds.

A practical Hartley oscillator circuit using medium-wave oscillator coil as L is shown in Fig 10.

The advantage of using a medium wave oscillator coil for L is that the output can be taken out of the secondary winding (4 and 5) of the coil.

The transistor used is a silicon high frequency transistor (BF series) as the oscillator frequency is in the range of 1 MHz.

The divider biasing is provided to make the DC conditions such that the amplifier works as Class A. With the heavy feedback (large β), the large feedback signal drives the base of the transistor into saturation and cut-off. This large feedback signal produces negative DC clamping at the base, changing the operation from Class A to Class C. This negative clamping automatically adjusts the value of $A\beta$ to 1. If the feedback is too large, it may result in loss of some of the output voltage because of the stray power loses.

When you build an oscillator, you can adjust the amount of feedback to maximize the output voltage. The trick is to use enough feedback to start under all conditions (different transistors, temperature, voltage etc.), but not so much that you lose more output than necessary.

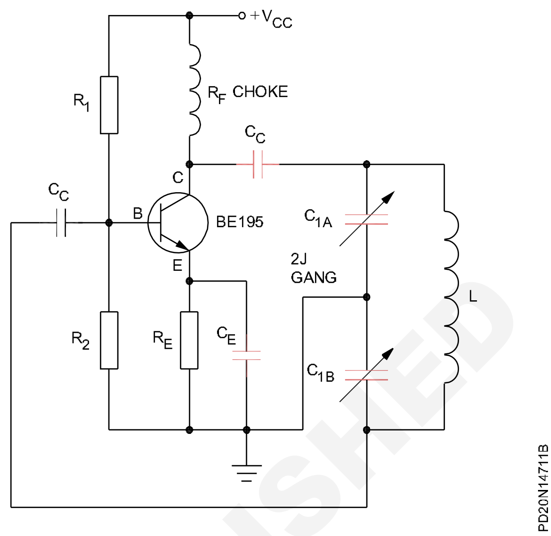
The frequency of oscillations of the oscillator circuit at Fig 10 can be varied by varying the position of the shaft of the gang of the gang capacitor (C_4).

Colpitt's oscillator: Colpitt's oscillator is another type of sinusoidal oscillator or harmonic oscillator which uses a tank circuit for oscillations. Colpitt's oscillators are very popular and are widely used in commercial signal generators and communication receivers.

A typical Colpitt's oscillator is in Fig 11 is similar to a Hartley oscillator. The only difference is that the Colpitt's oscillator uses a split capacitor for the tank instead of a split inductor used in Hartley oscillators.

The parallel-fed or shunt-fed Colpitt's oscillator is in Fig 11, uses the common emitter configuration. The capacitors C_{1A} & C_{1B} from the voltage divider used to provide the feedback signal. The voltage drop across C_{1B} determines the feedback voltage. All other components in this circuit have the same function as in the Hartley circuit.

Fig 11



The frequency of oscillations of the Colpitt's oscillator is given by,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where,

f is the frequency of oscillation in hertz,

L is the inductance of the coil in henry

C is the total capacitance in farad given by,

$$C = \frac{C_{1A} \times C_{1B}}{C_{1A} + C_{1B}}$$

The frequency of oscillations can be changed by using a miniature ganged capacitor for C_{1A} & C_{1B}.

By varying the shaft of the ganged capacitor, both the capacitances C_{1A} and C_{1B} get varied, and hence, the frequency of oscillations of the oscillator varies.

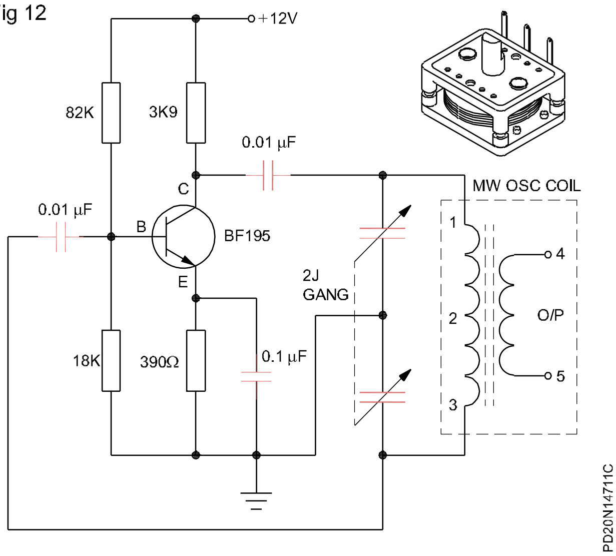
Colpitt's oscillators are generally used for generating frequencies above 1 MHz.

A practical Colpitts oscillator circuit using a ganged capacitor for C_{1A} and C_{1B} and a medium wave oscillator coil for L is in Fig 12.

Crystal oscillators: The LC oscillator circuits such as Hartley and Colpitts have the problem of frequency in-stability. The most important reason for the frequency drift in LC oscillators is, the change in value of capacitance and inductance of the tank circuit that occurs when temperature changes.

As the temperature increases or decreases, the values of L and C deviate causing the circuit to oscillate at a frequency different from the desired resonant frequency. Other reasons for frequency deviation are, the leads of transistor, inter electrode and wiring capacitances.

Fig 12

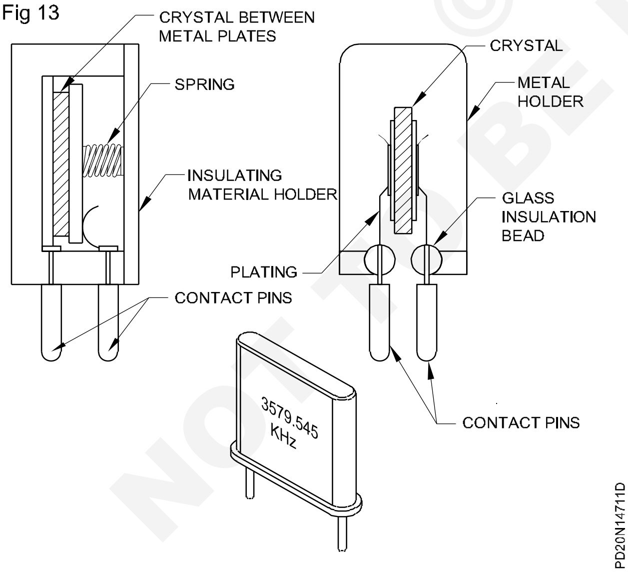


The problem of frequency drift can be largely overcome by using high Q coils and good quality capacitors. But, with ordinary inductors and capacitors, Q-values in excess of a few hundred is very difficult or impossible to achieve.

Large improvements in frequency stability can be achieved by using a quartz crystal in the place of the conventional tuned circuit. Such oscillator circuits are referred to as crystal controlled oscillators.

Piezo-electric effect: It was discovered that certain crystals such as quartz and Rochelle salt, exhibit a special property known as piezo-electric property. A quartz crystal looks like a piece of thin frosted glass usually cut into 1/4 to 1 inch squares as in Fig 13.

Fig 13



When such a crystal is held between two flat metal plates and pressed together, a small emf will be developed between the plates as if the crystal became a battery for an instant. When the plates are released, the crystal springs brings back to its original shape and an emf of opposite polarity is developed between the two plates. In this way, mechanical energy/force is converted to electrical energy by the crystal.

This property is made use of in the pick-ups for gramophone records. In a gramophone record, small mechanical vibrations are produced when the stylus tracks the groove on the gramophone plate. This vibrating force gives rise to corresponding voltages representing the recorded sound at the pick-up terminals.

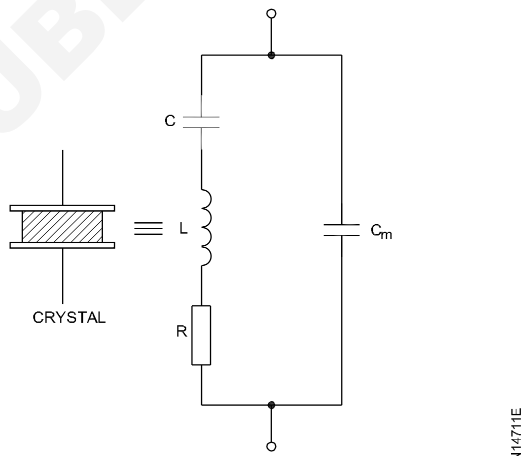
In addition to the above property of the crystal, when an emf is applied across the two plates of the crystal, the crystal will distort from its normal shape. If an opposite polarity emf is applied, the crystal will reverse its physical distorted shape. In this way, these crystals also convert electrical energy into mechanical energy.

The above two reciprocal actions of a crystal are known as piezo-electric effect. Such crystals are housed in crystal holders as in Fig 13.

Amongst several crystals having this piezo-electric property, the quartz crystal is most popular because, mechanical oscillations are started in this crystal it takes a long time for the oscillations to die away. Quartz crystals therefore, have a very high mechanical Q.

So far as the electrical properties are concerned, a quartz crystal is equivalent to the LC resonant circuit is in Fig 14.

Fig 14



AC EQUIVALENT CIRCUIT

The values of L,R,C and C_m depend upon the physical size of the crystal and how the crystal is cut from the original mass. Capacitance C_m represents the mounting capacitance. For using the crystal in electronic circuits, two conducting electrodes are placed onto its two faces. Connecting leads are then joined to these electrodes. When the leads are connected to a source of oscillating voltage, mechanical vibrations are set up within the crystal.

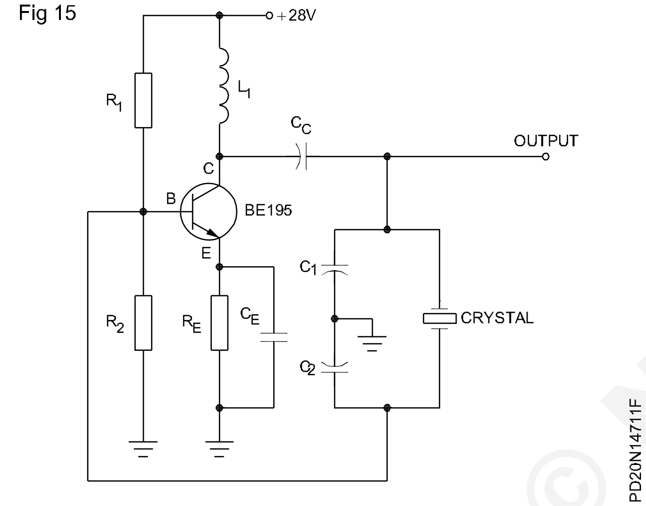
If the frequency of the oscillating voltage is close to a resonant frequency of the crystal, then the crystal forces the oscillating voltage to coincide with the oscillating frequency of the crystal. Hence, in an oscillator, by using the crystal in the place of an LC resonant circuit, the frequency of oscillation is determined almost entirely by the crystal. Q values in excess of 20,000 are easily obtained with readily available crystals resulting in highly stable oscillating frequency.

Hence, when accuracy and stability of the oscillation frequency are important, a quartz crystal oscillator is used instead of Hartley or Colpitt's oscillators. The frequency range of crystals is usually between 0.5 to 30 MHz.

Pierce crystal oscillator: The pierce crystal controlled oscillator is in Fig 15 is often used because it requires very few components and has good frequency stability.

The pierce crystal oscillator is similar to the Colpitts oscillator but for the inductance coil replaced by a crystal. Here the crystal across the collector and the base terminals of the transistor determines the oscillating frequency. As in a colpitts oscillator, capacitors C_1 and C_2 form a capacitive voltage divider for feedback. The ac voltage across C_2 provides the necessary positive feedback to the base.

Fig 15



In Fig 15, the crystal acts like an inductor that resonates with C_1 and C_2. In the base circuit, the R_1R_2 divider supplies forward bias voltage from the V_{CC}. Bias stabilization is provided by the R_EC_E combination in the emitter circuit.

In Fig 15, if the crystal resonant frequency is, say 3579.545 Hz, then the oscillator oscillates at the same frequency and gives a sinusoidal output of 3579.545 Hz.

Crystal oscillators are generally used in,

- mobile radio transmitters and receivers
- broadcast transmitters
- test equipments such as signal generators where exact frequency and very high frequency stability are of utmost importance. The frequency drift in crystal controlled oscillators will be less than 1 Hz per 10^6 Hz.

Multivibrator

It is a free running oscillator which gives repetitive pulse wave form output, and other types of multi-vibrators which are classified depending upon the manner in which the two stages of the multi-vibrator interchange their ON and OFF states. They are:

- **Mono-stable multivibrator** (having one stable state).
- **Bistable multivibrator** (having two stable states).

Mono-stable Multivibrator

Fig 16 shows a typical mono-stable multi-vibrator also known as **mono-shot** or **one-shot**.

A mono-shot has one stable state with one transistor conducting and the other off. This state can be changed only temporarily by giving an input pulse generally known as **trigger** pulse to the transistor which is off. But this changed state returns back to its original stable state after a period decided by the values of R and C.

Fig 16

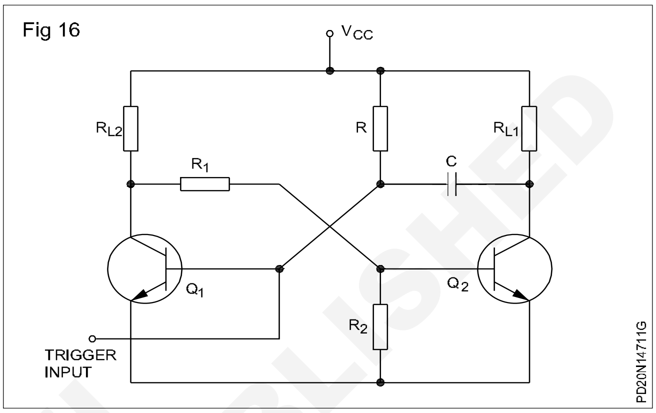
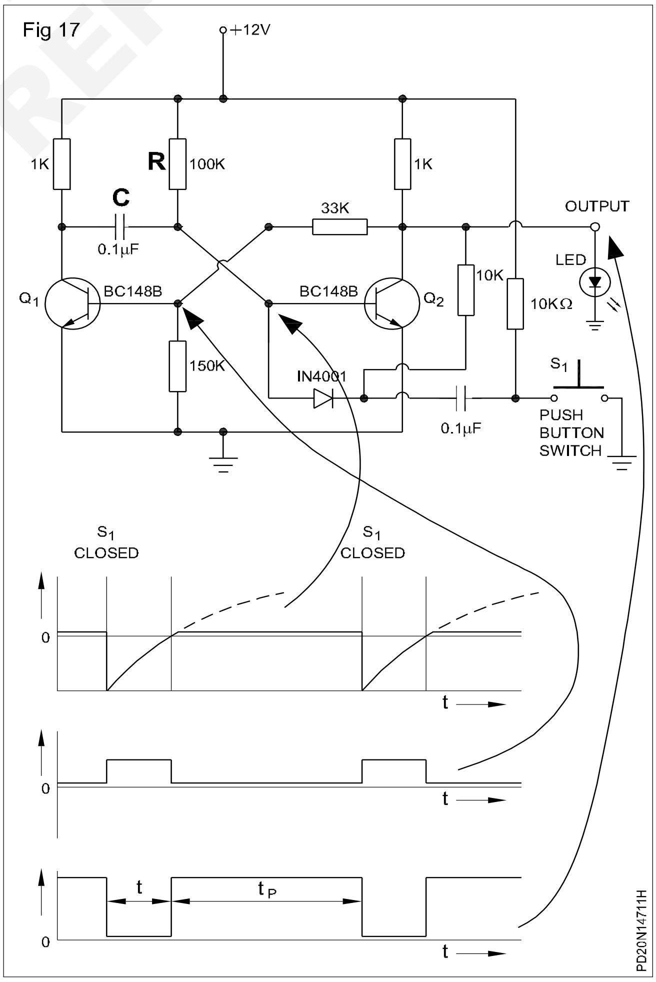


Fig 17 shows a practical mono-stable multi-vibrator with trigger input. Fig 17 also shows the wave-forms at different points of the circuit.

Fig 17



The period t for which Q_2 is kept off temporarily is given by,

$t = 0.69$ RC.

Mono-stable multi-vibrators are extensively used as timers in electronic timing control circuits.

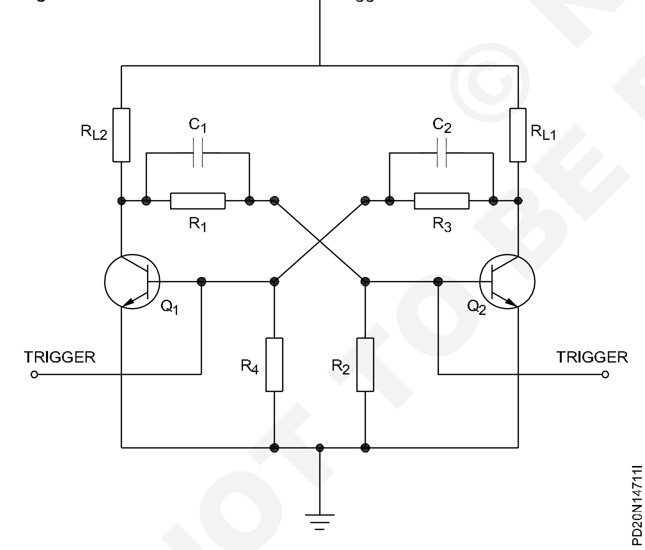
Bistable multivibrator

An astable multi-vibrator automatically switches from one state to other (ON-to-OFF or OFF-to-ON...). Whereas, a bistable multi-vibrator will change the state(ON to OFF or OFF to ON) when triggered and remain in the new state (ON or OFF). This means, a bistable multi-vibrator has two stable states. Fig 18 shows a typical bistable multi-vibrator circuit.

The circuit at Fig 18 is completely symmetrical. The potential dividers R_1, R_2 and R_3, R_4 form identical bias network at the base of transistors. Each transistor is biased from the collector of the other transistor. Due to the slightest difference in parameters of the transistor, when the circuit is switched ON, any one of the two transistors will turn-ON, and the other remain in OFF condition.

In the circuit at Fig 18, the two identical CE amplifier stages are so connected that the output of one is fed to the input of the other, through resistors R_1, R_3 and shunted by capacitors C_1, C_2. The purpose of the capacitor is nothing but to speed up the switching characteristic of the circuit to get distortion-less output wave-form. Capacitors C_1 & C_2 are also known as **commutating capacitors**.

Fig 18



A bistable multi-vibrator is also known as a **flip-flop**. The output terminals are generally identified as Q & $\overline{Q}$ (Q-bar) as in Fig 19.

When Q is in high state (also known as **Logic-1** state in digital electronics), $\overline{Q}$ (Q-bar) will be in low state (also known as **Logic-0** state), and vice versa. This circuit is known as a flip-flop circuit because, if one output flips(high/logic-1) the other output automatically flops(low/logic-0). A flip-flop can be switched from one state to the other by applying a suitable triggering input. Flip-flops are used as a basic **memory cell** in digital computers for storing information. Flip-flops are used in various forms in almost all digital system as counters, frequency dividers and so on.

Practical bistable multi-vibrators with unsymmetrical and symmetrical triggering arrangement are shown in Fig 20a and 20b.

Fig 19

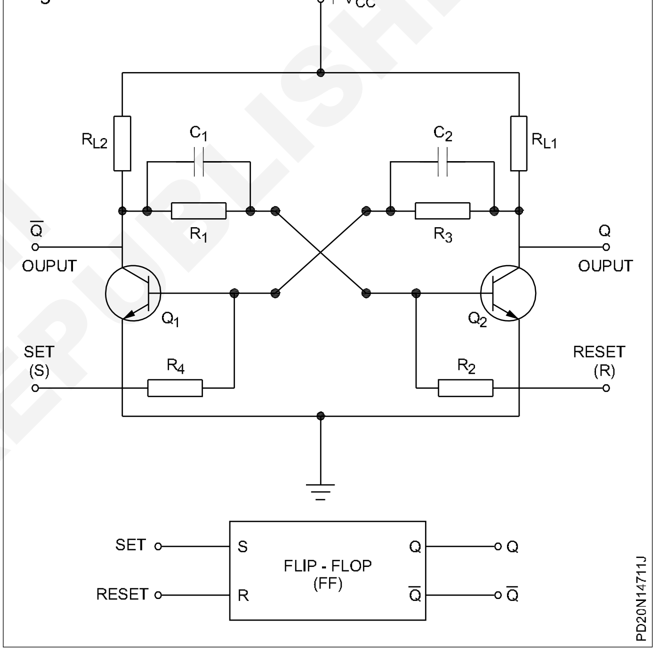
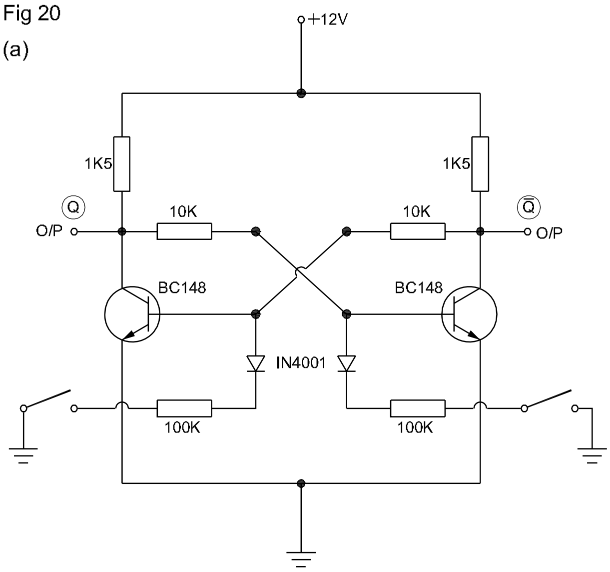


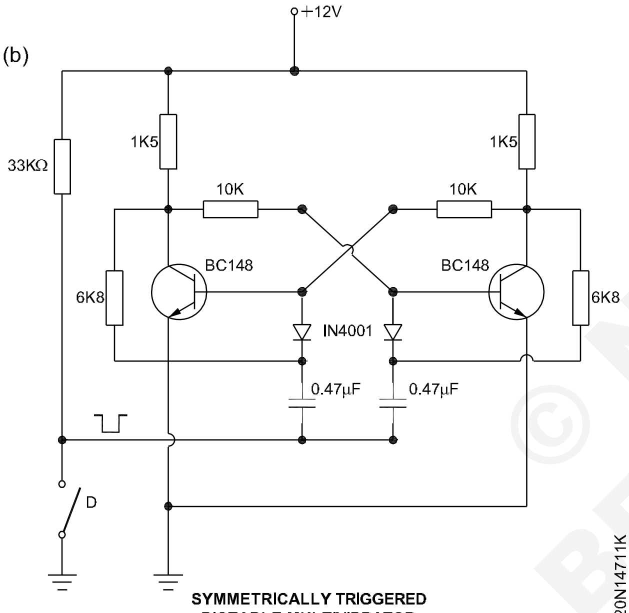
Fig 20

(a)



UNSYMMETRICALLY TRIGGERED
BISTABLE MULTIVIBRATOR

(b)



SYMMETRICALLY TRIGGERED
BISTABLE MULTIVIBRATOR

Electrician (Power distribution) - Cells and Batteries in Substation

Primary cells and secondary cells

Objectives: At the end of this lesson you shall be able to
- **state the chemical effect of electric current**
- **state the Laws of electrolysis**
- **state the basic principles of electroplating**
- **state the principle and construction of primary cells**
- **state the principle and construction of secondary cells (lead acid, nickel iron and nickel cadmium)**
- **compare the primary cells and secondary cells.**

Chemical effects of electric current

'There are some liquids in which a passage of electric current is accompanied by chemical changes.' This effect is known as chemical effect of electric current.

The applications of chemical effect of electric current may be observed in daily life; e.g., nickel or copper plating on metallic articles, production of E.M.F by a cell, etc. If two leads taken from the positive and negative terminals of a battery are immersed in a salted water, then the production of bubbles can be seen at the lead ends; it is all due to chemical effect of electric current.

Electrolysis

If an electric current is passed through different liquids or solutions in turn, then it is observed that the currrent passes through some of the solutions only and not through all of them. The liquid or a solution, through which an electric current can pass, is called a conductor-liquid such as ammonium chloride solution, silver nitrate solution etc.; and, through which an electric current can't pass, is called an insulator-liquid such as distilled water, alcohol, oil etc. If some salt or acid is mixed in the distilled water, then it becomes conductive.

Thus, 'the process of chemical changes due to the passage of an electric current through a liquid or a solution is called electrolysis.'

Electrolyte

'The liquid or solution which undergoes a chemical change in it on account of the passage of an electric current, is called an electrolyte'; e.g., salted water, acidic or a basic solution etc.

Electrodes (Anode and cathode)

'Two conductor plates are immersed in the liquid to form a passage of current through it, they are known as electrodes'. The electrode through which the current enters the liquid, is called a positive electrode or anode, while the other through which it leaves the liquid (electrolyte) is called a negative electrode or cathode.

Ions

During electrolysis, the molecules of the electrolyte split into their constituents whcih are called ions. When a p.d. is applied across the two electrodes, the positively charged ions (cat ions) move towards the cathode and the negatively charged ions (an ions) move towards the anode. On reaching at any electrode, an ion give up its charge and ceases to be an ion . The process of converting atoms into ions is called **Ionization.**

Electrochemical equivalent: The mass of a substance liberated or deposited during electrolysis by one coulomb of electricity is termed as electrochemical equivalent (ECE) of that substance.

The ECE of silver is 1.1182 milligram/coulomb.

Coulomb: The coulomb (C) is the unit of electric charge (Q) or the quantity of electricity.

The coulomb is the product of current in ampere and time in seconds.

Faraday's Law of Electrolysis

1. First law: The mass of the substance liberated or deposited at any electrode during electrolysis is propotional to the quantity of eletricity passed through the electrolyte. The mass of the substance liberated at any electrode will be more, if more current is passed or a current for more time is passed through the electrolyte.If the mass liberated is m then

$m \propto I$

$m \propto t$ -----(i)

$m \propto I \cdot t$ -----(ii)

$m = Z \cdot I \cdot t$

Where, I = current, amperes

t = time, seconds

m= mass of the substance liberated, grams

Z = constant

Here, the constant Z is known as electro-chemical equivalent (ECE).

2. Second Law - 'When the same quantity of electricity is passed through different electrolytes , then the quantites of elements liberated at the different electrodes are proportional to their electro-chemical equivalents.'

$\text{Mass} \propto \text{E.C.E}$

$M \propto Z$

Where Z = electro-chemical equivalent

According to Faraday's laws of electrolysis

$$m = Z . I . t$$

Where, m = mass of substance liberated in grams

z = Electro chemical equivalent of the substance in gram

I = Current in amperes

t = Time in seconds

Note. Mass deposited m = Volume x Density

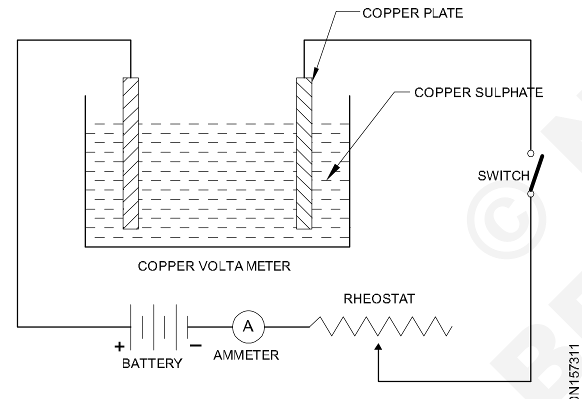
$$\text{Equivalent weight} = \frac{\text{Atomic weight}}{\text{Valency}}$$

$$\text{E.C.E. of nickel} = \frac{\text{Equivalent wt. of nickel}}{\text{Equivalent wt. of silver}} \times \text{E.C.E. of silver}$$

Verification of Faraday's laws

(1) Verification of first Law - For the verification of Faraday's first law, a copper sulphate solution is taken in a glass container (called a voltameter). Two copper plates are immersed in the solution. A battery, switch, ammeter and a rheostat are connected to the plates (Fig 1).

Fig 1



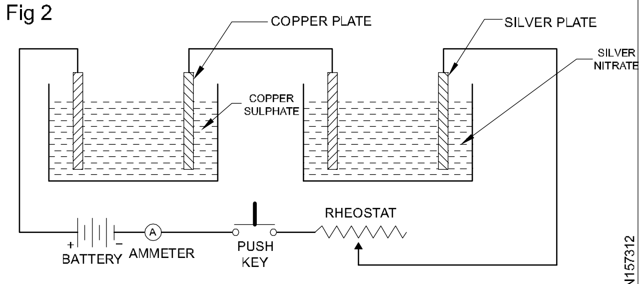
VERIFICATION OF FARADAY'S FIRST LAW

The negative elecrode is dried and weighed. After passing a definite amount of current (which can be adjusted by the rheostat) for a definite time, the cathode is weighed again, after being dried once again. Now, the mass of copper deposited at the cathode is equal to the weight of cathode after passing the current minus the weight of cathode before passing the current.

The above experiment is repeated for twice the time of the first measurement. It is observed that the mass of copper deposited is doubled. Similarly, if the current is doubled instead of the time, then also the mass of copper deposited is doubled. These three above observations verify that the mass of copper deposited at the cathode is proportional to the product of current and time.

(2) Verification of Second Law - For the verification of Faraday's second law, two voltameters are taken, i.e., copper and silver voltameters. The copper voltameter has a solution of copper sulphate and two copper electrodes whereas the silver voltameter has a solution of silver nitrate and two silver electrodes. Both voltameters are connected in series across a battery through a switch, ammeter and a rheostat (Fig 2).

Fig 2



VERIFICATION OF FARADAY'S SECOND LAW

Now a definite current is passed for a definite time through both the voltameters. If the mass of copper deposited at the copper cathode is m_1 and the mass of silver deposited at silver cathode is m_2 and their chemical equivalents are w_1 and w_2 respectively, then it is found that -

$$m_1 : m_2 = w_1 : w_2$$

or

$$\frac{m_1}{w_1} = \frac{m_2}{w_2} \text{ or } \frac{m_1}{m_2} = \frac{w_1}{w_2}$$

$$\frac{\text{the mass of copper deposited}}{\text{the mass of silver deposited}} = \frac{31.5}{108}$$

(Since the chemical equivalents of copper and silver are 31.5 and 108 respectively)

The relation $\frac{m_1}{m_2} = \frac{w_1}{w_2}$ verifies the second law.

Table for Elecro-Chemical Equivalents of Elements

Name of Element	Atomic Weight	Valency	Electro-Chemical Equivalent mg/c	Chemical equivalent g/c
Hydrogen	1.008	1	0.01045	1.008
Aluminium	27.1	3	0.0936	9.03
Copper	63.57	2	0.3293	31.78
Silver	107.88	1	1.118	107.88
Zinc	65.38	2	0.3387	32.69
Nickel	58.68	2	0.304	29.34
Chromium	52.0	3	0.18	17.33
Iron	55.85	2	0.2894	27.925
Lead	207.21	2	1.0738	103.6
Mercury	200.6	1	2.0791	200.6
Gold	197.0	1	2.0438	197

Note. (mg/c = milli-gram per coulomb)

Application of electrolysis

The principal applications of electrolysis are as follows:

1 Electroplating

2 Electro-refining of metals

3 Electrolytic capacitor

4 Electrotyping

5 Extraction of metals.

Electroplating

The process of depositing a metal on the surface of another metal by electrolysis is known as electroplating. Electroplating is widely used in giving an attractive appearance and finish to all types of products. In this process inferior metals are coated with costly metals (such as silver, nickel, gold, chromium, etc.) to give an attractive shiny appearance and rust-proof surface.

Conditions for electroplating

The following conditions must be fulfilled before electroplating an article.

(i) The article to be electroplated must have a chemically cleaned surface, i.e. it must not have any sort of dirt, rust and greasy surface.

(ii) The article to be plated should form a cathode.

(iii) The anode must be of the metal to be deposited for maintaining the concentration of the solution constantly during electrolysis.

(iv) The metal to be coated has to be in the solution of an electrolyte.

The electrolyte is contained in a wooden reinforced cement concrete tank which is known as a "vat". The anode as well as the article to be plated are hung through the conducting wires so as to dip in the solution. The value of the current is adjusted according to the metal deposited on the surface area of the article. The time required for electroplating can be calculated if we know the mass of the metal deposited and ECE with the formula

$$M = ZIt$$

Therefore, Time $t = \frac{M}{IZ}$

we know M = ZIt ------ (1)

$$I = \frac{M}{Zt} \text{ and } Z = \frac{M}{It} \text{ mg / Coulomb}$$

We know Volume = Area x Thickness ------(2)

$$\text{Area} = \frac{\text{Volume}}{\text{Thickness}} \text{ and}$$

$$\text{Thickness} = \frac{\text{Volume}}{\text{Area}}$$

Mass = Volume x Density ----- (3)

$$\text{Volume} = \frac{\text{Mass}}{\text{Density}} \text{ cc}$$

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \text{ gm /cc}$$

Example1: If 111.83 mg of silver is deposited on the cathode in 3 min 20 s, by a DC current of 0.5A, calculate the ECE of silver.

Solution:

t = 3 min 20 s = 200 s

M = 111.83 mg

From Faraday's law,

M = ZIt

$$Z = \frac{M}{It} = \frac{111.83}{0.5 \times 200}$$

= 1.1183 mg/ C

Example 2: It is required to be deposited copper on the both surfaces of an iron plate 200 cm^2 in area. What thickness of copper will be deposited if one ampere of current is passed through the solution for 1 1/2 hours. The density of copper is equal to 8.9 g/cc and E.C.E. of copper is 0.329 mg/C.

Solution:

$$Z - 0.329 \text{ mg/C} = \frac{0.329}{10^3} = 0.329 \times 10^{-3} \text{ g / C}$$

I = 1A

t = 90 x 60 = 5400 s

From Faraday's law,

M = ZIt

$0.329 \times 10^{-3} \times 1 \times 5400 = 1.7766$ g (i)

Suppose the thickness of copper deposited = T cm

Area = 200 cm^2

Density = 8.9 g/cc

Volume of copper deposited

= 2 x area x thickness

= 2 x 200 x T cc

Mass of copper deposited

= Volume x density

= 400 x T x 8.9 (ii)

Equating (i) and (ii);

400 x 8.9 x T = 1.7766

$$\text{or } T = \frac{1.7766}{400 \times 8.9} = 0.000499 \text{ cm} \quad \textbf{Ans.}$$

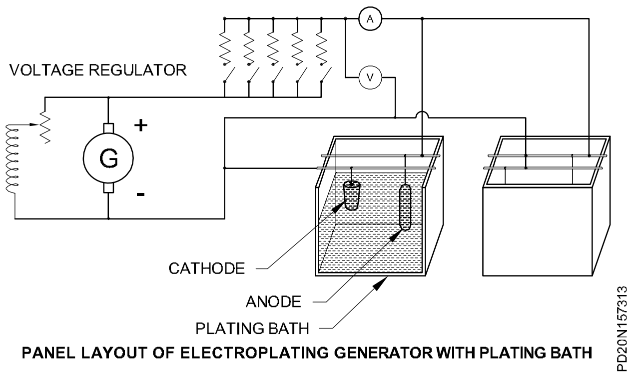
Current required for plating

Low pressure direct current (DC) supply is always used for electroplating purposes. The pressure used varies from 1 to 16 V depending upon the rate of plating and the nature of the electrolyte.

Dynamo for electroplating (Fig 3)

The shunt dynamo is generally used for electroplating. It delivers large current at low pressure and this requires a large commutator and brush gear. Such types of dynamos are run by either an AC or a DC motor or the petrol engine, etc and the current required for plating is controlled by the current regulator. The generated voltage of the dynamo is controlled by the voltage regulator (Fig 3).

Fig 3



PANEL LAYOUT OF ELECTROPLATING GENERATOR WITH PLATING BATH

Cathodic protection in Eletroplating

Cathodic protection (CP) is a technique used to control the corrossion of a metal surface by making it as the cathode of an electrochemical cell. A simple method of protection connects the metal to be protected to a more easily corroded sacrifical metal to act as the anode.

The sacrificial metal then corrodes instead of the protected metal. For the structures such as long pipe lines where passive galvanic cathodic protection is not adequate an external DC electrical power source is used to provide sufficicent current.

The CP system protects a wide range of metallic structures steel water, fuel pipe line, storage tanks water heaters, steel wire pipes, oil platform, oil well casing, wind farms etc. Another common application is in galvanised steel in which a sacrificial coating of zinc on steel parts protects them from rust. CP protection can in some cases prevents the stress corrossion cracking.

Type of cells

Cell: A cell is an electrochemical device consisting of two electrodes made of different materials and an electrolyte. The chemical reaction between the electrodes and the electrolyte produces a voltage.

Cells are classified as

- dry cells
- wet cells.

A dry cell is one that has a paste or gel electrolyte. With newer designs and manufacturing techniques, it is possible to completely (hermetically) seal a cell. With complete seals and chemical control of gas build-up, it is possible to use liquid electrolytes in dry cells. Today the term `dry cell' refers to a cell that can be operated in any position without electrolyte leakage.

Wet cells are cells that must be operated in an upright position. These cells have vents to allow the gases generated during charge or discharge to escape. The most common wet cell is the lead-acid cell.

Cells are further classified as primary and secondary cells.

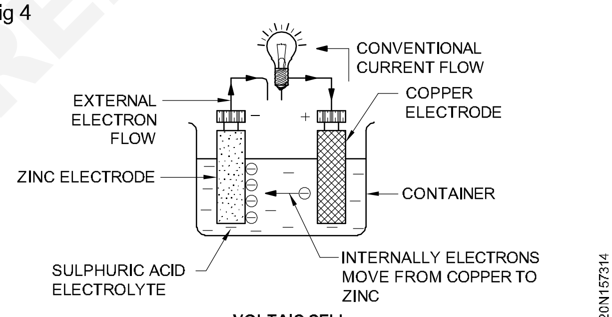
Primary cells: Primary cells are those cells that are not rechargeable. That is, the chemical reaction that occurs during discharge is not reversed. The chemicals used in the reactions are all converted when the cell is fully discharged. It must then be replaced by a new cell.

Types of primary cells:

- Voltaic cell
- Carbon-zinc cell (Leclanche cell and Dry cell)
- Alkaline cell
- Mercury cell
- Silver oxide cell
- Lithium cell

Simple voltaic cell: A voltaic cell uses copper and zinc as the two electrodes and sulphuric acid as the electrolyte. When they are placed together a chemical reaction occurs between the electrodes and the sulphuric acid. This reaction produces a negative charge on the zinc (surplus of electrons) and a positive charge on the copper (deficiency of electrons). If an external circuit is connected across the two electrodes, electrons will flow from the negative zinc electrode to the positive copper electrode (Fig 4).

Fig 4



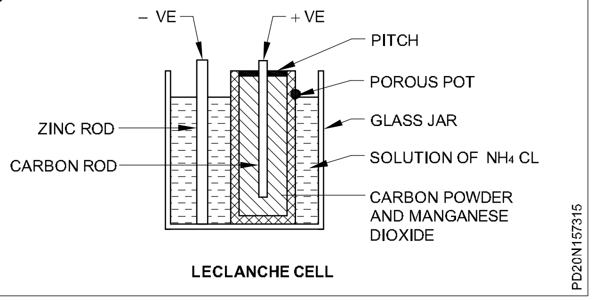
VOLTAIC CELL

The electric current will flow as long as the chemical action continues. In this type of cell the zinc electrode is eventually consumed as part of the chemical reaction.The voltaic cell is also known as a wet cell because it uses a liquid solution for the electrolyte.

Leclanche cell (Carbon-zinc cells) **:** The container of this cell is a glass jar. The jar contains a strong solution of ammonium chloride (NH_4Cl). This solution is an alkali and acts as the electrolyte. A porous pot is placed at the centre of the glass jar. This porous pot has in it a carbon rod surrounded by a mixture of manganese dioxide (MnO_2) and powdered carbon. The carbon rod forms the positive electrode of the cell and MnO_2 acts as the de-polarizer. A zinc rod is dipped in the solution in the jar and acts as the negative electrode (Fig 5).

Dry cell (Carbon-Zinc cell): The danger of spilling the liquid electrolyte from a Leclanche type of cell led to the invention of another class of cells called dry cells.

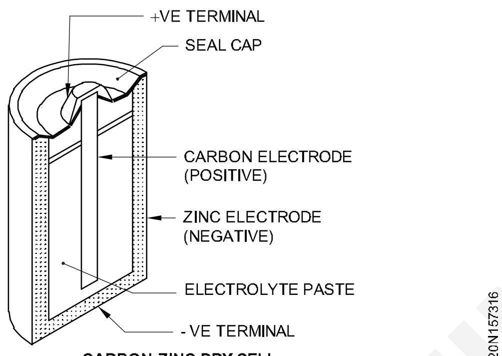
Fig 5



LECLANCHE CELL

The most common and least expensive type of a dry cell is the carbon-zinc type (Fig 6). This cell consists of a zinc container which acts as the negative electrode. In the centre is a carbon rod which is the positive electrode. The electrolyte takes the form of a moist paste made up of a solution containing ammonium chloride.

Fig 6



CARBON-ZINC DRY CELL

As with all primary cells, one of the electrodes becomes decomposed as part of the chemical reaction. In this cell the negative zinc container electrode is the one that is used up. As a result, cells left in equipment for long periods of time can rupture, spilling the electrolyte and causing damage to the neighbouring parts.

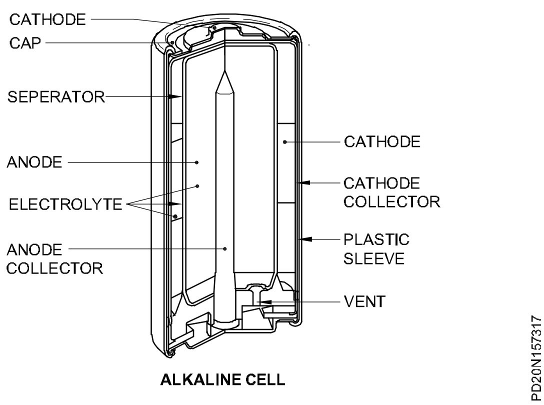
Carbon-zinc cells are produced in a range of common standard sizes. These include 1.5 V AA,C and D cells .(AA Pen type cell, `C' medium size and 'D' large/economy size).

Alkaline cells: Alkaline cells use a zinc container for the negative electrode and a cylinder of manganese di-oxide for the positive electrode (Fig 7). The electrolyte is made up of a solution of potassium hydroxide or an alkaline solution.

Alkaline cells are produced in the same standard sizes as carbon-zinc cells but are more expensive. They have the advantage of being able to supply large currents for a longer period of time. For example, a standard `D' type 1.5 V alkaline cell has a capacity of about 3.5 AH compared with about 2 AH for the carbon-zinc type. A second advantage is that the alkaline cell has a shelf life of about two and a half years as compared to about 6 to 12 months for the carbon-zinc type.

Mercury cells: Mercury cells are most often used in digital watches, calculators, hearing aids and other miniature electronic equipment. They are usually smaller and are shaped differently from the carbon-zinc type (Fig 8).

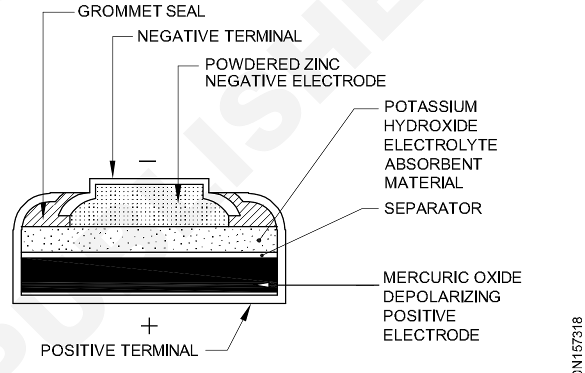
Fig 7



ALKALINE CELL

The electrolyte used in this cell is alkaline and the electrodes are of mercuric oxide (cathode) and zinc (anode).

Fig 8



MERCURY CELL

Silver oxide cells: Silver oxide cells are much like mercury cells. However, they provide a higher voltage (1.5 V) and they are made for light loads. The loads can be continuous, such as those encountered in hearing aids and electronic watches. Like the mercury cell, the silver oxide cell has good energy-to-weight and energy-to-volume ratios, poor low-termperature response, and flat output voltage characteristics.

The structures of the mercuric and silver oxide cells are very similar. The main difference is that the positive electrode of the silver cell is silver oxide instead of mercuric oxide. Fig 9 shows the cross-section of a silver oxide cell.

Lithium cells: The lithium cell is another type of primary cell (Fig 10). It is available in a variety of sizes and configurations. Depending on the chemicals used with lithium, the cell voltage is between 2.5 and 3.6 V. Note that this voltage is considerably higher than in other primary cells. Two of the advantages of lithium cells over other primary cells are:

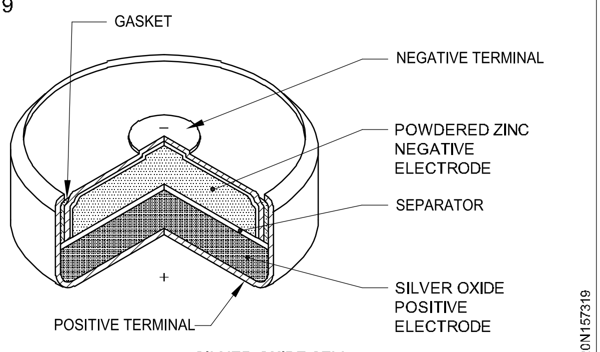
– longer shelf life - up to 10 years

– higher energy-to-weight ratios up to 350 WH/Kg.

Lithium cells operate at temperatures ranging from –50 to +75°C. They have a very constant output voltage during discharge.

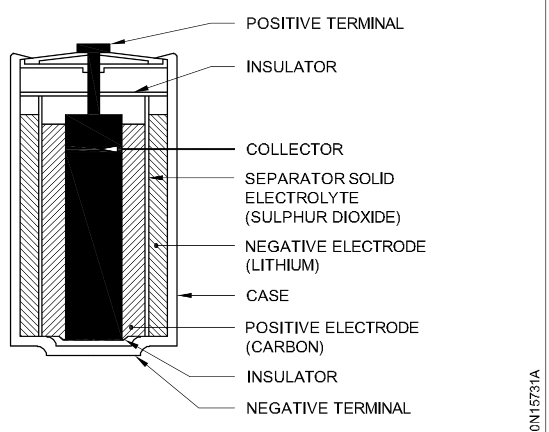
Uses: Primary cells are used in electronic products ranging from watches, smoke alarms, cardiac pacemakers, torches, hearing aids, transistor radios etc.

Fig 9



SILVER OXIDE CELL

Fig 10



LITHIUM CELL

Internal resistance: The output voltage from a cell varies as the load on the cell changes. Load on a cell refers to the amount of current drawn from the cell. As the load increases, the voltage output drops. The change in output voltage is caused by the internal resistance of the cell. Since materials from which the cell is made are not perfect conductors, they have resistance. Current flowing through the external circuit also flows through the internal resistance of the cell.

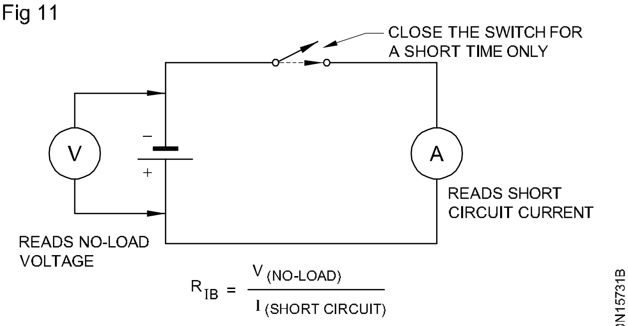
According to Ohm's law, a current flowing through a resistance (either external or internal) results in a voltage drop (V = IR) . Any voltage developed across the internal resistance is not available at the terminals of the cell.

The voltage at the terminals is the voltage produced due to the chemical reactions minus the voltage dropped across the internal resistance. The terminal voltage of a cell, therefore, depends on both the internal resistance of the cell and the amount of load current.

In some applications, the changes in cell terminal voltage are so small that they make no practical difference. In other applications, the changes are very noticeable. For example, when an automobile engine is started, the battery output voltage changes from about 12.6 to 8V.

Fig 11 shows the method of calculating the internal resistance of a cell . As a cell discharges, its internal resistance increases. Therefore its output voltage decreases for a given value of load current.

Fig 11



CALCULATING CELL INTERNAL RESISTANCE

Defects of a simple cell: With a simple voltaic cell, the strength of current gradually diminishes after some time. This defect is mainly due to two causes.

- Local action
- Polarisation

Local action: In a simple voltaic cell, bubbles of hydrogen are seen to evolve from the zinc plate even on open circuit. This effect is termed local action. This is due to the presence of impurities like carbon, iron, lead, etc. in the commercial zinc. This forms small local cells on the zinc plate and reduces the strength of current of the cell.

The local action is prevented by amalgamating the zinc plate with mercury. To do so, the zinc plate is immersed in dilute sulphuric acid for a short time, and afterwards, mercury is rubbed over its surface.

Polarisation: As current flows, bubbles of H_2 evolve at the copper plate on which they gradually form a thin layer. Due to this the current strength falls and finally stops altogether. This effect is called the polarization of the cell.

Polarisation can be prevented by using some chemicals which will oxidize the hydrogen to water before it can accumulate on the plate. The chemicals used to remove polarisation are called de-polarisers.

We learnt that most of the primary cell except rechargeable ones are usable once only. It does not supply current continuously. The secondary cells overcome this disadvantage.

Secondary cell: A cell that can be recharged by sending electric current in the reverse direction to that of a discharge mode is known as a secondary cell.

The secondary cell is also called a storage cell since after it is charged it stores the energy until it is used up or discharged.

In a secondary cell the charging and discharging processes are taking place according to Faraday's Laws of Electrolysis.

Types of secondary cells

– Lead acid cell

– Alkaline cell or nickel-iron cell

Comparison of primary cells				
	Carbon -Zinc	**Alkaline-Manganese**	**Mercury**	**Silver oxide**
Negative, Positive, Electrolyte	Zinc Carbon Ammonium Chloride	Zinc Manganese dioxide Potassium hydroxide or alkaline	Zinc Mercuric oxide Alkaline	Zinc Silver oxide Potassium hydroxide
Nominal voltage - volts Max. rated current - amperes	1.5 2-30	1.5 0.05-20	1.35 or 1.4 0.003-3	1.5 0.1
Energy output Watt-hrs Ampere-hours	 22 2.0	 35 3.5	 46 6.0	 50 8.0
Temperature range Storage ^{0}F Operating ^{0}F	 –40 to 120 20 to 130	 –40 to 120 –5 to 160	 –40 to 140 –5 to 160	 –40 to 140 –5 to 160
Shelf life in months at 68°F to 80% initial capacity Shape of discharge curve	 6 to 12 Sloping	 30 to 36 Sloping	 30 to 36 Flat	 30 to 36 Flat

Parts of Lead acid cell (Fig 12)

1 Container

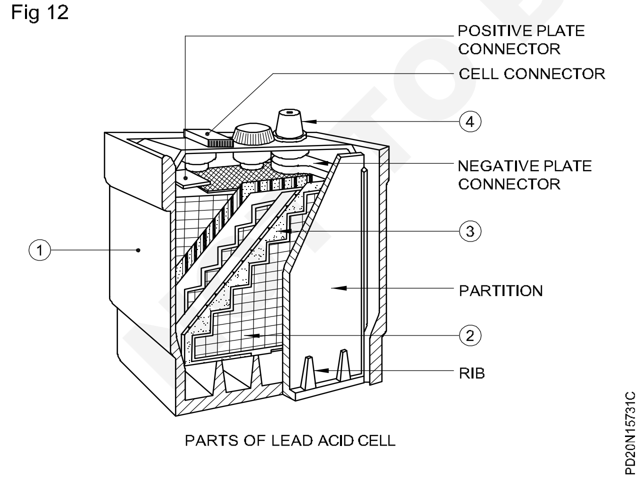
2 Plates

3 Separators

4 Post terminals

Container: The container is made of hard rubber, glass or celluloid to accommodate the active plates, separators and the electrolyte. The plates rest on ribs provided at the bottom of the container and the space between ribs is known as sediment chamber.

Fig 12



PARTS OF LEAD ACID CELL

Plates: Positive plates are of two types.

– Plante plate or formed plates

– Faure plate

Plante plates: These are prepared by the process of repeated charging and discharging. They are made of pure lead at the beginning which changes to lead peroxide after charge.

Faure plate: Pasted or Faure plates are made of rectangular lead grid into which the active material i.e. lead peroxide (Pb O_2) is filled in the form of a paste (Fig 13).

Negative plates are made of rectangular lead grid, and the active material is spongy lead (Pb) which is in the form of a paste (Fig 14).

Separators: These are made of thin sheets of chemically treated porous wood or rubber. They are used to avoid short in between the positive and negative plates (Fig 15).

Post terminal: A small pole extended upward from each group of welded plates from the plate connecter (Fig 16) forms the post terminal.

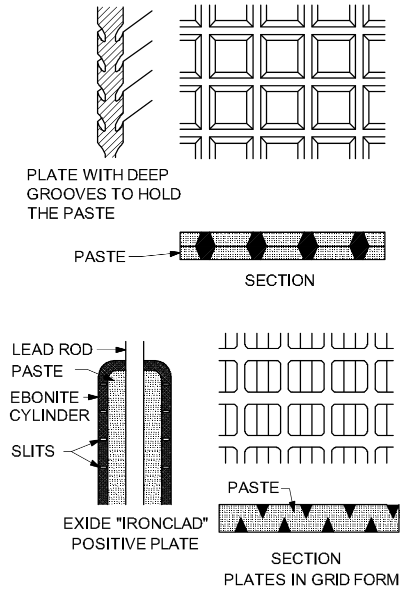
Electrolyte: The electrolyte used in a lead acid cell is dilute sulphuric acid (H_2SO_4). The specific gravity of the electrolyte is 1.24 to 1.28. It varies according to the manufacturer's specification.

Working principle

The secondary cell has no significant electrochemical energy at the start. The energy must first be charged into secondary cell. Then the cell retains the stored energy until it is used up. That is,both cell electrodes are basically lead sulphate(Pb SO_4).When the cell is charged, due to chemical reaction taking place in it, the lead sulphate eletctrode change to soft or sponge lead,(Pb - negative plate) and the other electrode changes to lead peroxided(Pb O_2 - positive plate).

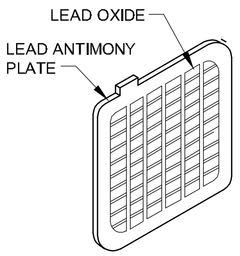
At the same time the electrolyte solution is strengthened and becomes strong sulphuric acid (H_2SO_4) (Fig 17).

Fig 13



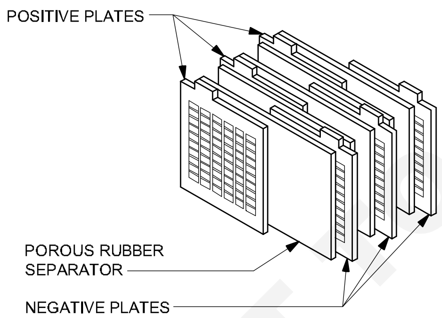
CONSTRUCTION OF PASTED-TYPE ACCUMULATOR PLATES

Fig 14



SINGLE LEAD PLATE

Fig 15



ARRANGEMENT OF PLATES AND SEPARATORS

Fig 16

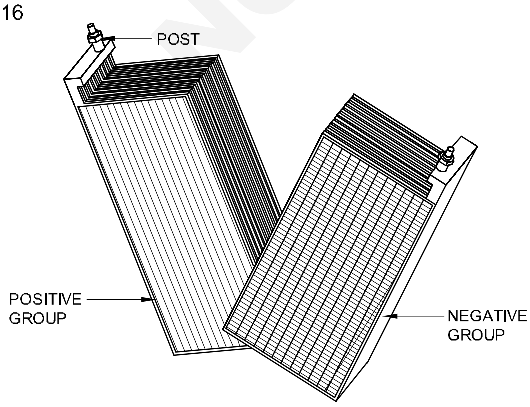
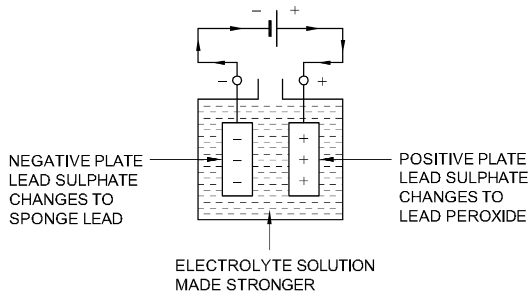


Fig 17



DURING CHARGING PROCESS

The general recommended specification of a storage cell(battery) is given below.

- Voltage/cell
- Ampere hour capacity
- No. of plates/cell
- Temperature
- Specific gravity of electrolyte
- No. of cells grouped

Voltage of a fully charged cell is 2.1 to 2.6V and the voltage falls to 1.8V after discharge.

Capacity: The unit of capacity of a storage cell is ampere-hour (AH). It is the product of the rated current of a cell/battery in amperes and the time in hours at which it can discharge that rated current,

Capacity = Current x Time - AH

The capacity of the cell depends on the following.

- Size of the plates
- No.of plates
- Active material used
- The strength of the electrolyte

Plates: There is always one more negative plate than the number of positive plates. That is, a negative plate at both ends of the cell gives not only more mechanical strength but also ensures that both sides of the positive plate are used. It also avoids buckling of positive plates. For example a nine plate cell is having four positive and five negative plates.

Temperature and specific gravity: The temperature of the electrolyte must be kept at 27°C and the specific gravity at 1.250 ± 0.010.

To correct the specific gravity reading to 27°C add 0.0007 to the observed hydrometer reading for each degree celsius above 27°C.

Excess temperature will cause more sulphation and buckling of the positive plate.

Defects

- Hard sulphation
- Buckling

- Partial short

Hard sulphation: Over discharging or the cell being left in a discharged condition for a long time cause sulphation on both electrodes and offers high internal resistance. The sulphation (hard) can be removed by recharging the cell for a longer period at a low rate called a trickle charge.

Buckling: The bending of electrodes due to overcharging and discharging, improper electrolyte and temperature is known as buckling.

Partial short: The sediments falling from the plates (electrodes) short- circuiting the positive and negative electrodes cause overheating of the particular cell during both charging and discharging periods. Such a cell may be replaced with a new one.

Efficiency: It is considered in two ways.

- Ampere-hour (AH) efficiency
- Watt-hour (WH) efficiency

$$\text{AH efficiency} = \frac{\text{Output in AH discharge}}{\text{Input in AH charge}}$$

The watt-hour efficiency is always less than the ampere-hour efficiency because the potential difference during discharge is less than that during charge.

Watt - hour efficiency

$$= \frac{\text{AH efficiency} \times \text{Average volts on discharge}}{\text{Average volts on charge}}$$

During discharge

positive plate

Lead peroxide	+	Hydrogen	+	Sulphuric Acid	$\rightarrow$	Lead sulphate	+	water
PbO_2	+	H_2	+	H_2SO_4	$\rightarrow$	$PbSO_4$	+	$2H_2O$

Negative plate

Pure lead	+	Sulphate	=	Lead sulphate
Pb	+	SO_4	=	$PbSO_4$

During charge

positive plate

Lead sulphate	+	Sulphate	+	Water	$\rightarrow$	Lead peroxide	+	Sulphuric acid
$PbSO_4$	+	SO_4	+	$2H_2O$	$\rightarrow$	PbO_2	+	$2H_2SO_4$

Negative plate

Lead sulphate	+	Hydrogen	$\rightarrow$	Lead	+	Sulphuric acid
$PbSO_4$	+	H_2	$\rightarrow$	Pb	+	H_2SO_4

Nickel iron and nickel cadmium cell

In construction there is no difference between the two cells except that the negative plate of the nickel iron cell is made of iron and in the nickel cadmium cell it is of cadmium.

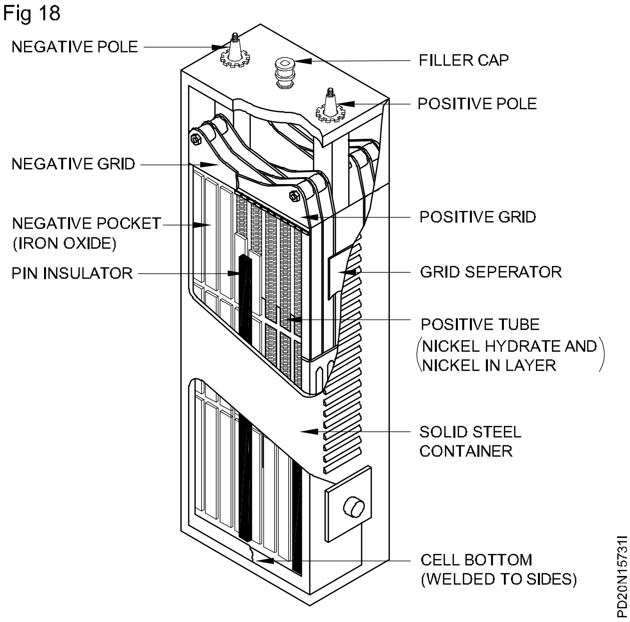
The nickel iron cell or Edison cell (Fig 18)

Parts

- Positive plate
- Negative plate
- Electrolyte
- Container
- Separators

The positive plate is made of Nickel hydroxide($Ni(OH)_4$) tubes and perforated steel ribbon wound spirally and held together by steel ribs, and the whole lot is nickel-plated.

Fig 18



The negative plate is made of a nickel steel strip with fine perforation.The electrolyte is 21% solution of potassium hydroxide (KOH) along with some quantity of lithium hydrate(LiOH).

The container is made of nickel-plated steel. The separators are made of hard rubber strips and held in the nickel-plated container.

Chemical changes: On discharge, potassium hydroxide (KOH) splits up into K and (OH)ions. i.e. into potassium and hydroxide ions. OH ions travel towards the negative and oxidise the iron. K ions go to the anode and reduce Ni $(OH)_1$ to Ni $(OH)_2$. During charging, the opposite reactions take place. The chemical changes during charging and discharging can be represented by a reversible equation.

It is seen from the equation that the electrolyte acts merely as a source for transfer of OH ions from one plate to another. It does not take part in any chemical change. As a result the density does not change to the same extent as in an ordinary lead acid cell. Thus, the density of the electrolyte remains almost the same during the action.

Charactereristics: The emf of the cell when fully charged is 1.4V, and it reaches to 1.2 on discharge. If the voltage falls below 1.15, the cell is fullly discharged.

- The mechanical strength of plates is good since they are made of steel.
- The cell is portable.
- The cell can withstand heavy charge and discharge currents, and does not deteriorate even if left discharged.
- Internal resistance is large, and so the efficiency is lower than that of a lead acid cell.
- With increase in the temperature, the e.m.f. increases slightly but the capacity increases appreciably, and with a decrease in the temperature, the capacity decreases.
- It is superior to a lead acid cell in mechanical strength, durability and robustness.

Moreover, as compared to lead-acid cells, the alkaline cells operate much better at low temperatures, do not emit obnoxious fumes, have very small self-discharge and their plates do not buckle or smell.

Shelf life: Batteries are also rated for shelf life in years. Even if a cell is not being used local action takes place within the cell at all times and will eventually render the cell useless. Shelf life is defined as the time in years a stored battery will produce at least 75% of its initial capacity.

Temperature:Batteries are most often rated for a specific output capacity at room temperature or 20°c. Operating them above and below this temperature will reduce their rated output. For example, the automobile battery output drops on cold days making it more difficult to turn the engine .

$$\underset{\text{Hydrated Ferrous}}{Ni(OH)_4} + \underset{\text{Potassium}}{KOH} + \underset{\text{Ferrous}}{Fe} \rightleftharpoons \underset{\text{Nickel}}{Ni(OH)_2} + KOH + Fe(OH)_2$$

Comparison : Lead-acid cell and Edison cell

SI.No.	Particulars	Lead-acid cell	Edison cell
1	Positive plate	PbO, lead peroxide	Nickel hydroxide $Ni(OH)_4$ or Nickel oxide (NiO_2)
2	Negative plate	Sponge lead	Iron
3	Electrolyte	Diluted H_2SO_4	KOH
4	Average emf	2.1 V/cell	1.2 V/cell
5	Internal resistance	Comparatively low	Comparatively higher resistance
6	Efficiency: Amp-hour Watt-hour	 90 - 95% 72 - 80%	 Nearly 80% About 60%
7	Cost	Comparatively less than alkaline cell	Almost twice that of Pb-acid cell (Easy maintenance)
8	Life	Gives nearly 1250 charges and discharges	Five years atleast
9	Strength	Needs much care and maintenance.Sulphation occurs often due to incomplete charge or discharge.	Robust, mechanically strong, can withstand vibration, light, unlimited rates of charge and discharge. Can be left discharged, free from corrosive liquids and fumes.

Advantages and disadvantages of nickel iron cell

(A) Advantages

(i) It can withstand heavy charge and discharge current and does not deteriorate.

(ii) It is robust in construction and thus it can be used even roughly.

(iii) It is light in weight and thus it is portable.

(iv) It can be left discharged for a long time.

(v) It can work on higher temperatures also.

(vi) It is used on higher temperatures also.

(vii) It is used in electric operated vehicles, switch-gear operations etc.

(B) Disadvantages

(i) Its EMF does not remain constant.

(ii) Its efficiency is lower than lead-acid cell.

(iii) It has a high internal resistance.

(iv) Its EMF is low in comparison to lead acid cell.

(v) If temperature is increased, its EMF will slightly reduce.

Comparison between primary and secondary cells

Primary Cell	Secondary Cell
1 It is an instant EMF producing device.	1 It is charged with electric supply first, then it produces EMF.
2 It cannot be recharged.	2 It can be recharged again and again.
3 It is light in weight.	3 It is heavy in weight.
4 It can supply a low current at a low voltage.	4 It can supply more current at comparatively more voltage.
5 It is cheap.	5 It is costly.
6 It has a short life.	6 It has a long life.
7 It transforms chemical energy into electrical energy.	7 In it, electrical energy produces certain actions in the chemicals and then chemical reactions reproduce electricity.

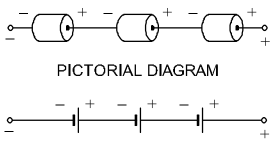
Grouping of cells

Objectives: At the end of this lesson you shall be able to
- **state the purpose of cells connected in series and parallel**
- **explain series connections, parallel connection and series-parallel connection of cells**
- **state the method of testing cells.**

Grouping of cells: Often an electric circuit requires a voltage or current that a single cell is not capable of supplying alone. In this case it is necessary to connect groups of cells in various series and parallel arrangements.

Series connections: Cells are connected in series by connecting the positive terminal of one cell to the negative terminal of the next cell (Fig 1).

Fig 1

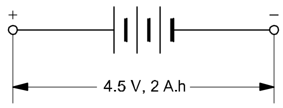


SERIES CONNECTION

Identical cells are connected in series to obtain a higher voltage than is available from a single cell. With this connection of cells, the output voltage is equal to the sum of the voltages of all the cells. However, the ampere hour (AH) rating remains equal to that of a single cell.

Example: Suppose three `D' flashlight cells are connected in series (Fig 2). Each cell has a rating of 1.5 V and 2 AH The voltage and ampere hour rating of this battery would be:

Fig 2



CIRCUIT SCHEMATIC

V Battery = V per cell x No.of cells
= (1.5V) (3)
= 4.5 V

AH Battery rating = AH rating of 1 cell
= 2 AH

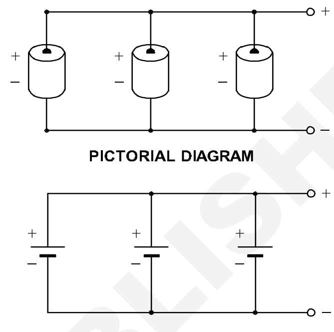
If, by mistake, one cell connection is reversed in a series group, its voltage will oppose that of the other cells. This will produce a lower than expected battery output voltage.

Example: Suppose that one of the three `D' flashlight cells of the previous example is connected in reverse, the output voltage then would be:

V Battery = (1.5V)+(1.5V) − (1.5V)
= (3.V) − (1.5V)
= 1.5V.

Parallel connection: Cells are connected in parallel by connecting all the positive terminals together and all the negative terminals together (Fig 3).

Fig 3



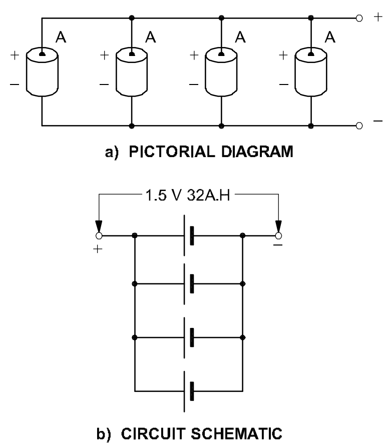
SCHEMATIC DIAGRAM
PARALLEL CONNECTION

Identical cells are connected in parallel to obtain a higher output current or ampere-hour rating. With this connection of cells, the output ampere hour rating is equal to the sum of the ampere hour ratings of all the cells. However, the output voltage remains the same as the voltage of a single cell.

Example: Suppose four cells are connected in parallel (Fig 4). Each cell has a rating of 1.5 V and 8 AH. The voltage and ampere-hour rating of this battery would be:

Fig 4

PARALLEL CONNECTION OF CELLS



b) CIRCUIT SCHEMATIC

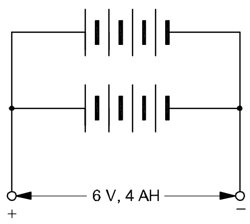
V Battery = V rating of 1 cell
= 1.5 V

AH Battery rating = AH rating per cell x no. of cells
= (8 AH) (4)
= 32 AH

If, by mistake, a cell connection is reversed in a parallel group, it will act as a short circuit. All cells will discharge their energy through this short circuit path. Maximum current will flow through the short circuit and the cells may be permanently damaged.

Series-parallel connection: Sometimes the requirements of a piece of equipment exceed both voltage and ampere hour rating of a single cell. In this case a series-parallel grouping of cells must be used (Fig 5).

Fig 5



SERIES-PARALLEL CONNECTION

The number of cells that must be connected in series to have voltage rating is calculated first and then the number of parallel rows of series connected cells is calculated for required ampere-hour rating.

Example: Suppose a battery operated circuit requires 6 V and a capacity of 4 AH (Fig 5). Cells rated at 1.5 V and 2 A H are available to do the job. The required arrangement of cells would then be:

$$\text{No. of cells in series} = \left(\frac{\text{V required}}{\text{V per cell}}\right)$$

$$= \frac{6\text{ V}}{1.5\text{ V}} = 4\text{ cells}$$

$$\text{No. of parallel rows} = \left(\frac{\text{AH required}}{\text{AH per cell}}\right)$$

$$= \frac{4\text{ AH}}{2\text{ AH}} = 2\text{ rows.}$$

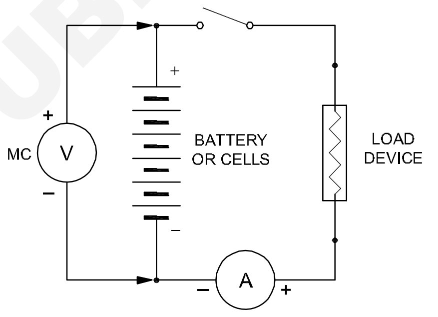
When connecting groups of cells or batteries in parallel, each group must be at the same voltage level. Paralleling two batteries of unequal voltage levels sets up a difference of potential energy between the two. As a result, the higher voltage battery will discharge its current into the other battery until both are at equal voltage value.

Testing primary cells or batteries: A visual inspection will tell you little about the useful life of a cell or battery unless it has deteriorated to the point where acid is spilling from the case.

A no-load voltage test of the cell of battery is another indication of cell or battery life. This test requires the cell or battery to deliver only a very small amount of current required to operate the voltmeter.

The best method that is used to check a cell or battery is an in-circuit test of the cell or battery voltage with the normal load connected to it (Fig 6). A substantial drop in cell or battery voltage, when normal load is applied, indicates a bad cell or battery.

Fig 6



TESTING A BATTERY UNDER LOAD

Battery charging method - Battery charger

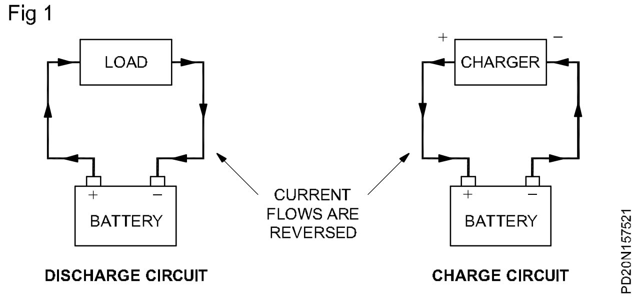
Objectives: At the end of this lesson you shall be able to
- **state the necessity of charging a battery**
- **describe the preparation of electolyte**
- **describe the use of a hydrometer and high rate discharge tester**
- **state the precautions to be followed while charging and discharging a battery**
- **describe the different types of charging methods of secondary cells**
- **explain the purpose, construction and working principle of battery charger.**

Necessity of charging: During discharge, due to chemical reaction, the active electrodes become smaller and the internal resistance becomes high causing a low output. To reverse the action, send a current (DC) through the battery or cell in the opposite direction to that of the discharge. This process is called charging. The charging can be done through a battery charger.

Battery chargers: When the chemical reaction in a rechargeable battery has ended, the battery is said to be discharged and can no longer produce the rated flow of electric current. This battery can be recharged, however, by passing direct current from an outside source to flow through it in a direction opposite to that in which it flowed out of the battery.

When charging a battery, the negative lead of the charger must connect to the negative lead of the battery and the positive lead of the charger to the positive lead of the battery (Fig 1). A reversal of these connections will produce a short circuit and may damage both the charger and the battery.

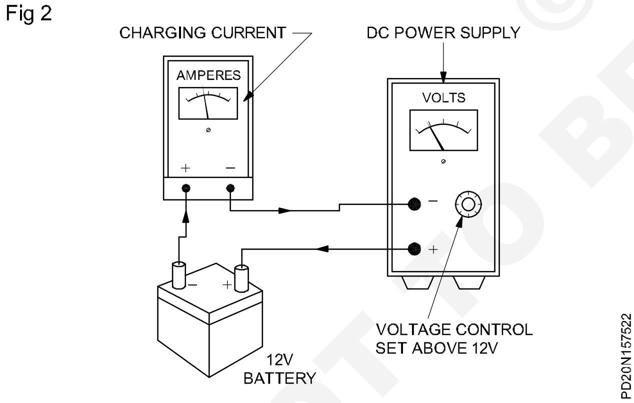
Fig 1



An automobile uses an automatic charging circuit as part of the car's electrical system, which is designed to recharge the battery as required and battery charging is also done using large commercial type battery chargers. Smaller type chargers are also available for use on the smaller nickel-cadmium cells. A simple variable-voltage DC power supply works well as a battery charger.

Charging current: When charging any battery, it is important to set the charging current to a value recommended by the manufacturer. This current is set by adjustment of the output voltage on the charger and read by an ammeter connected in series with the charger and battery (Fig 2). When the battery and charger are at the same voltage, no current flows. The charger voltage is set to a value higher than that of the battery to produce a current flow.

Fig 2



Before charging the battery or cell the following points are to be observed to ascertain the condition of the battery.

1 Specific gravity of the electrolyte

2 Voltage of each cell of the battery

3 Ampere hour capacity of each cell.

Preparation of Electrolyte

The electrolyte used in a cell is dilute sulphuric acid having a specific gravity between 1.21 and 1.3. The specific gravity of the acid available in the market is usually 1.835. Therefore, it is necessary to dilute the acid. Remember that for dilution, the acid is gently poured into distilled water and not the water into acid. In this way, the acid is diluted upto a specific gravity of 1.4 and stored. When, it is required to be filled up in the battery, then it is further diluted upto a specific gravity of 1.25.

Specific gravity

The ratio of the mass of a given volume of liquid to the mass of the same volume of the water at 4°C, is known as specific gravity of the liquid.

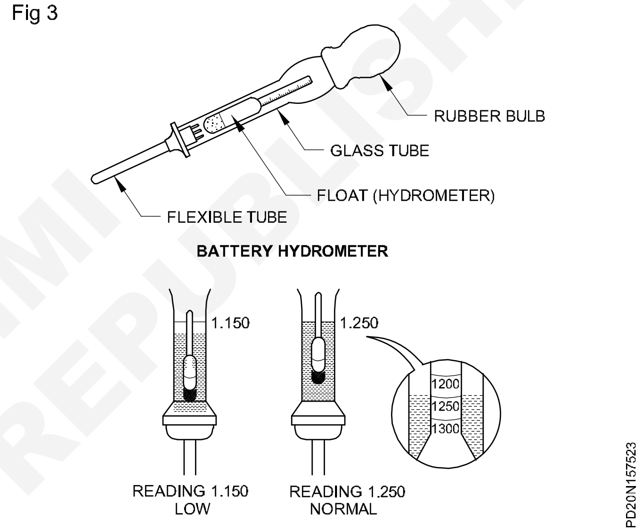
$$\text{Specific gravity} = \frac{\text{(mass of given volume of liquid)}}{\text{(Mass of the same volume of water at } 4^\circ\text{C)}}$$

It means that the specific gravity of a liquid is a measure of comparative weights of the same volume of liquid and water at 4°C.It has no unit.

Instrument for testing the condition of cells:

Hydrometer : The specific gravity of an electrolyte is measured with a hydrometer (Fig 3).

Fig 3



The main parts

- Rubber bulb
- Glass tube
- Float
- Flexible rubber tube

The charged condition of battery can be tested by means of a battery hydrometer. This instrument measures the relative density of the battery electrolyte. Since the strength of the electrolyte varies directly with the state of charge of each cell, you need only to find what specific gravity of sulphuric acid remains in each cell electrolyte to determine how much energy is available.

Cell condition	Hydrometer reading
Full charge	1.26
50% charge	1.20
Discharged	1.15

Voltage tests of lead-acid batteries, like primary cells, should be conducted under load. To make a simple light load voltage test of a car battery, check the value of the battery output voltage with and without the headlights on. A maximum load voltage test can be made by metering the battery voltage while operating the starting motor (Fig 4). In the case of a 12V battery, a drop of battery output voltage below 7V indicates the battery is defective or not fully charged.

High rate discharge tester: The internal condition of the cell is determined by this test. A low range (0-3V) voltmeter is shunted by a low resistance (Fig 5). The two terminal prods are pressed on to the terminals of a cell for testing. A fully charged cell which is in good condition reads in the range of full charge.

A sulphated old battery will show the discharge reading. The meter is having three colours red, yellow and green - red for fully discharged, yellow for half charge, green for fully charged condition of the cell respectively.

Fig 4

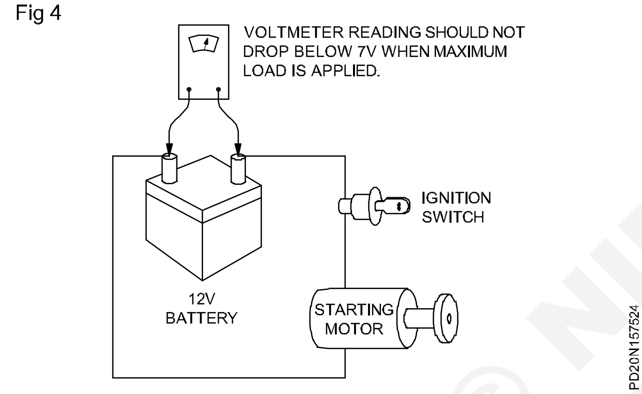
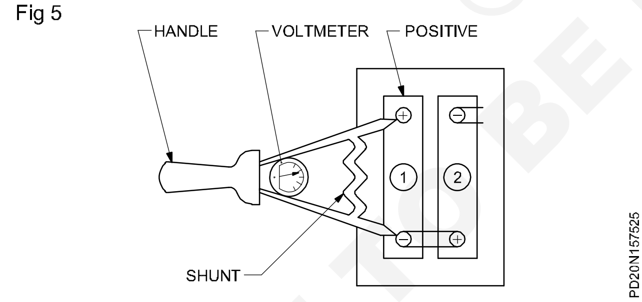


Fig 5



Voltage of each cell: The voltage of the cell is measured with a M C voltmeter. The fully charged cell will indicate 2.5 to 2.6V and a fully discharged cell will indicate 1.8V to 1.6V.

After determining the condition of the battery or cell, the charging rate, and the method of charging are to be decided. The battery should always be charged at the rates recommended by the manufacturer.

If you charge two or more batteries in series or in parallel, the potential difference between the terminals of the charging unit should not exceed the total voltage of all the batteries being charged in the case of series, and in the case of parallel the charging voltage should not exceed the voltage of a battery.

Safety precautions

Before putting the battery under charge, the following precautions are to be followed.

Topping up: If the level of the electrolyte on the surface of the plate is less than 10 to 15mm then distilled water should be added to the indicated level of the cell after removing the vent plugs.

Do not add tap water or well water for topping up.

During charge the vent plugs are to be kept open for the escape of gas produced freely.

Ventilation: The room where batteries are to be charged should be well ventilated.

Naked flame should not be brought near the battery or cell when it is under charge.

The terminal posts should be free from corrosion and they must be covered with petroleum jelly before and after charging.

Improper electrolytes must not be used for compensating the electrolyte after it is fully charged.

Boost charge: If a battery is in danger of becoming over-discharged during a working shift, you can give it a supplementary charge during a rest period. This boost charge is not a conventional method of charging the storage battery. It is not recommended as a standard procedure. It is generally a high rate charge of short duration, used only to ensure that the battery will last until the end of the shift.

Battery chargers

Primary batteries need to be replaced by new ones when they get exhausted. However in the recent past certain secondary cells like nickel cadmium cells which look similar to the primary cells could be recharged through low current plug-in cell chargers. On the other hand, primary cells like mercury cells should not be charged. Any attempt to charge them will make the cell to explode which will be dangerous.

Whereas in secondary or rechargeable batteries, supply power to a load till they discharge to a certain level. After this they are to be recharged with the help of battery chargers, and then they are ready for service again. Modern secondary batteries can withstand a large number of charge and discharge cycles under stipulated conditions.

Battery chargers: In general a charger is an electrical/ electronic device having provision for AC input and DC output. A battery charger is used to put energy into a cell. We know that the chemical reaction in a secondary battery is reversible. The reaction proceeds in one direction when the battery supplies power to a load. The direction of reaction is reversed during charging. This enables storage of electrical energy in the form of chemical energy inside the cell. This stored energy is again converted into electrical energy when the cell is used to supply power to a load.

A battery charger is a simple DC power supply that draws its power from the AC mains and supplies DC power at a voltage higher than that of the battery. Many chargers contain additional accessories to monitor and control the charging process. In general, a battery charger consists of the following four parts.

i) A transformer to step down the AC mains voltage to the desired AC voltage.

ii) A selector switch for voltage and current selection.

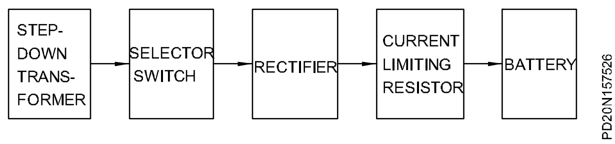
iii) A rectifier to convert AC into a uni-directional DC.

iv) A current limiting circuitry to prevent flow of excessive charging current into the battery under charge.

Construction: Fig 6 is a block diagram showing the different components that make a battery charger.

First of all, there is a step down transformer that transforms the high voltage of AC mains into a low AC voltage. The size of the transformer depends on the charging power required. Very small transformers are required for charging small Ni-Cd type batteries, while large size transformers are required to charge heavy duty automobile or emergency light batteries.

Fig 6



The transformers used for battery charging are generally provided with a number of tappings on their secondary side. In addition to stepping down the voltage, the transformer also serves another very important role. It isolates the charging circuit completely from the AC mains and thus completely eliminates the danger of electric shock from high voltage AC mains.

Most of the battery chargers are provided with two selector switches marked i) coarse and ii) fine indication.

The coarse selector switch is for the selection of output voltage according to the voltage of the battery to be charged, example 6V, 12V, 24V, 48V etc.

The fine selector switch is used for selecting either a low or a high rate charging current.

The rectifier converts the low voltage AC into uni-directional DC. There are 3 types of rectifiers which are normally used for a battery charger.

a) Tungsten rectifier

b) Metal rectifier

c) Junction diode rectifier.

Nowadays, almost all the battery chargers are provided with junction diode which are also called as 'Solid state rectifier units'.

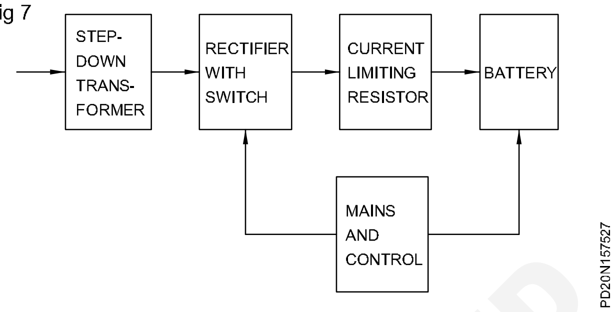
The rectifier unit used in a battery charger may be of half or full wave type. But in most cases full wave bridge rectifiers are used.

The size of diode depends upon the charging current requirements. A number of diode elements/metal rectifiers may be connected in series to withstand the operating voltage in the case of low voltage diodes/metal rectifier. Wherever junction diodes are used, suitable heat sinks are also provided along with the diode or bridge.

Fig 7 is a block diagram showing the different components that make a suitable battery charger for charging batteries in emergency lamp circuits.

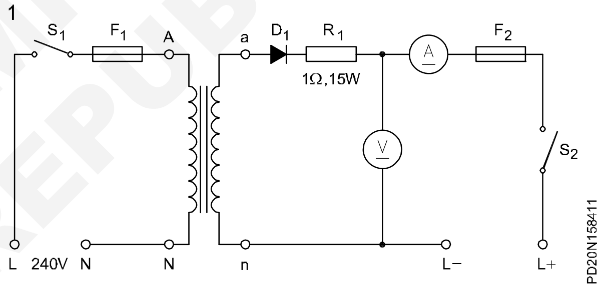
Working: A number of circuits are available for battery chargers. Anyhow only the 3 most commonly used circuits are explained here.

Fig 7



Circuit 1: The AC main supply to the primary of the stepdown transformer is protected by a fuse and controlled by a toggle switch Fig 11. Step-down secondary voltageis fed to the metal rectifier or diode and the output ispassed through a current limiting resistor, an ammeter (to measure the charging current), a fuse and a switch. A voltmeter is connected in the output circuit to measure the output voltage.

Fig 1



This type of circuit is protected only through fuses and needs constant attention during the entire period of battery charging. As the output voltage is fixed, only particular rated voltage batteries or a combination of them could be charged.

Circuit 2: In the case of commercial establishments where different voltage rating batteries are required to be charged, the secondary of the transformer has different tappings and the necessary output voltage could be selected through a selector switch (Fig 12).

Further the charging current could be varied through one or more selector switches where tappings are made for lower voltage ranges. A full wave rectifier with four power diodes are used to form the bridge.

Circuit 3: The circuit (Fig 13) contains an electronic circuit that continuously monitors the condition of the battery and then regulates the charging current accordingly. This circuit also terminates the charging process when it findsthat the battery has charged fully.

In many cases the charging process is not fully cut off but the charging rate is reduced to maintain a small charging current to maintain the battery in top condition.

This process is called '**trickle charging**'.

Fig 2

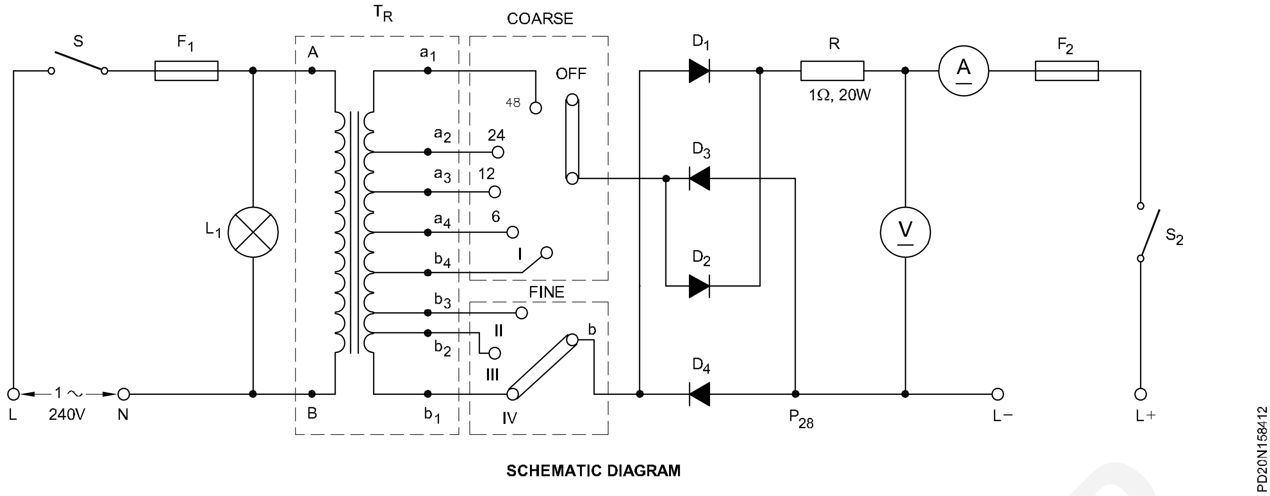


Fig 3

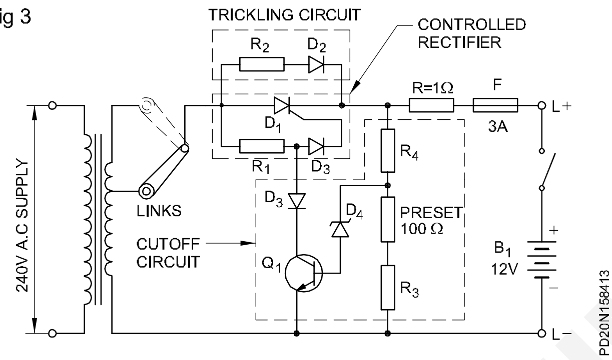
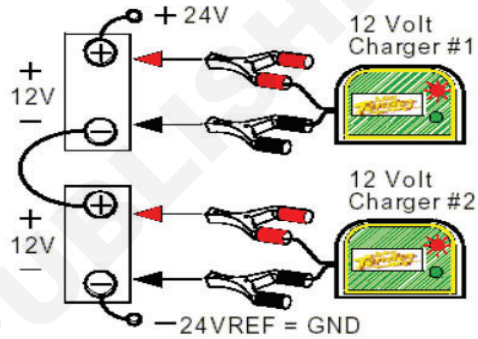


Fig 14



Two Battery and Two-Charger System

Fig 14 shows two 12 Volt batteries connected in series. The resulting battery pack voltage is 24 volts. As you can see, each battery is connected to a single 12-volt charger. This is probably the best way to ensure that each battery is completely recharged to its full capacity after each time that the battery pack is discharged. This eliminates most of the problems associated with cycling batteries connected in series strings.

End Cell (Cut-off) Cutting Voltage

The function of the cut-off voltage is to prevent the battery from entering the deep discharge stage. Usually, the low voltage cut-off (LVC) for a 12V battery is 10.5V. It means the battery will stop running the load when it comes down to 10.5 V.

C5 and C10 Charging Methods

When it comes to choosing a battery for an inverter, the decision between a c5 or c10 battery depends on your specific needs and requirements.

C5 and C10 refer to the battery's discharge rate, with c5 batteries designed to discharge over a 5-hour period, while c10 batteries discharge over a 10-hour period. C5 batteries tend to be more commonly used in applications that require higher power output, such as inverters for backup power or off-grid solar systems.

In general, c5 batteries are better suited for inverters because they are designed to deliver a higher amount of power over a shorter period. This means that they can provide the necessary surge capacity needed to start and run high-power loads such as refrigerators, air conditioners, and power tools.

However, c10 batteries can be a good option for smaller inverters that require less power output, such as those used for lighting or charging small electronics. They also tend to have a longer lifespan due to their slower discharge rate, which can make them a more cost-effective option over time.

Ultimately, the choice between a c5 or c10 battery for an inverter will depend on your specific power requirements and how you plan to use the system.

Alkaline Batteries

An alkaline battery is a type of primary battery where the electrolyte (most commonly potassium hydroxide) has a pH value above 7. Typically, these batteries derive energy from the reaction between zinc metal and manganese dioxide, nickel and cadmium, or nickel and hydrogen.

Compared with zinc-carbon batteries of the Leclanché cell or zinc chloride types, alkaline batteries have a higher energy density and longer shelf life, yet provide the same voltage.

The alkaline battery gets its name because it has an alkaline electrolyte of potassium hydroxide (KOH) instead of the acidic ammonium chloride (NH4Cl) or zinc chloride (ZnCl2) electrolyte of the zinc-carbon batteries. Other battery systems also use alkaline electrolytes, but they use different active materials for the electrodes.

What is an alkaline battery used for?

An alkaline battery is used in many different applications. They can be used to power tools such as drills, flashlights, and ratchets. They can also be used to power radios, toys, and other electrical products.

Is alkaline the same as lithium battery?

An alkaline battery is not the same as a lithium battery. There are several major differences. Lithium batteries, for example, can hold a charge for a longer time than alkaline batteries.

Are alkaline batteries toxic?

Alkaline batteries can be toxic if they are used in a manner that is inappropriate. They contain battery acid which can burn or cause other problems.

What chemicals are in alkaline batteries?

Alkaline batteries harness the energy produced from chemical reactions. Zinc metal and manganese oxide are the two reactants in alkaline batteries.

How do you know if batteries are alkaline?

Batteries are alkaline if they have a raised circular area on one end of the battery and a flat end, or at least an area that is mostly flat, on the other end.

Secondary batteries - types of charge, discharge and maintanance

Objectives : At the end of this lesson you shall be able to
- **state the applications of lead-acid batteries**
- **describe the construction of lead acid batteries**
- **explain types of secondary cells, their nominal cell voltage, capacity and applications**
- **explain the effect of temperature on AH capacity**
- **state the care and maintenance of lead acid batteries**
- **describe the hydrometer**
- **connect the cells in series, parallel and series-parallel.**

Secondary batteries

Secondary batteries are made of small units known as cells. The main difference between a primary and a secondary cell is that a secondary cell can be recharged. This is because the type of chemicals used in a secondary cell is such, the chemical reaction is reversible.

When a secondary cell is supplying current to a load, the cell is said to be *discharging*. This discharging current gradually neutralizes the separated positive and negative charges at the electrodes (Anode and Cathode).

On the other hand, when current is supplied to a cell, the charges get re-formed on the electrodes due to reverse chemical reaction. This action is known as *charging* the cell. For charging a cell, the charging current is supplied by an external DC voltage source, with the cell behaving as a load.

The process of discharging and recharging is called *cycling* of the cell. As long as the cell is in good condition the discharge and charge cycles can be repeated several hundred times.

Since a secondary cell can be recharged, in other words the charges restored, these cells are called *storage cells*.

The most common type of secondary cell is the *Lead-acid cell*. A battery consisting of a combination of such cells is called *Lead-acid battery*. Lead-acid batteries are commonly used in automobiles such as cars, buses and lorries etc.,

Lead-acid, wet type cells

Lead-acid secondary batteries made of lead-acid are used in almost every automobile, for starting the engine. These batteries supply load current of 100 to 400A to the starter motor of automobiles.

The nominal voltage of a lead-acid cell is 2.2 V. By connecting three or six cells in series, batteries of 6V or 12V is obtained.

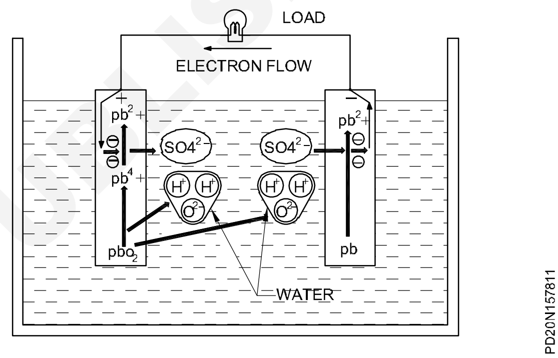
Principle of chemical action

A fully charged lead-acid cell has a lead peroxide (PbO_2) positive electrode, which will be reddish brown in colour and a gray spongy lead (Pb) as the negative electrode. These two electrodes are immersed in an electrolyte which is a diluted solution of sulphuric acid (27% sulphuric acid) having a specific gravity of 1.3. Such a cell produces an output of 2.2 V.

Discharging of lead-acid cells

The chemical action that takes place during the discharging of a lead-acid cell is shown in Fig 1.

Fig 1



During discharge, the lead (Pb) in both the electrodes react with sulphuric acid (H_2So_4) to displace hydrogen and form lead sulphate ($PbSo_4$). This lead sulphate, a whitish material, is somewhat insoluble and hence gets partially coated on both positive and negative plates. Since both plates approach the same material ($PbSo_4$) chemically, the potential difference between these plates begins to decrease. At the same time, the combining of oxygen in the lead peroxide (PbO_2) with the hydrogen atoms of the electrolyte forms water (H_2O) as shown in the equation given below,

$$Pb + PbO_2 + 2H_2So_4 \xrightarrow{\text{Discharge}} 2PbSo_4 + 2H_2O$$

It can be seen from the discharging equation that as the battery discharges (delivers energy to a load), the sulphuric acid solution becomes weaker (more and more diluted) with its specific gravity approaching 1.0.

The coating of whitish lead sulphate on the electrodes and the decrease in specific gravity of the electrolyte makes the voltage of the cell to drop off. Also, the internal resistance of the cell rises due to the sulphate coating on the plates.

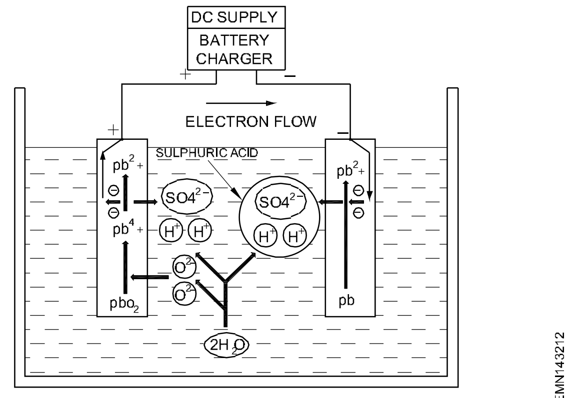
Charging of lead-acid cells

The chemical reaction that takes place during charging of a lead-acid cell is shown in Fig 2.

When a battery charger, having an output voltage (2.5V) which is slightly higher than the nominal voltage of the cell

(2.2V), is connected as shown in Fig 2, the direction of ionic flow gets reversed (refer to Fig 1 for the discharging direction). The electrical energy supplied by the charger causes the recombination of lead sulphate ($PbSo_4$) with hydrogen ions in the electrolyte. Therefore, the excess

Fig 2



water is removed from the electrolyte solution. As the electrolyte returns to its normal strength of sulphuric acid (27%) and the plates return to their original form of lead peroxide and spongy lead, the voltage across the electrodes returns to its nominal value of 2.2 V. The chemical action involved during charging can be represented by the following equation;

At the negative pole:

$PbSO_4$ + 2 electrons $\longrightarrow$ Pb + SO_4

At the positive pole:

$PbSO_4$ - 2 electrons + $2H_2O$ $\longrightarrow$ PbO_2 + So_4^{2-} - $4H^+$

As the above reactions take place simultaneously, the equation can be written as,

$2PbSO_4 + 2H_2O$ + Electrical energy $\longrightarrow 2H_2So_4$ + Pb + PbO_2.

It should be noted that, to charge a lead-acid battery of 12 V (2.2 V x 6 cells), the output voltage of the battery charger used for charging should be between 14.1 V to 15 V, and, its current rating not larger than 30 A. Charging batteries at excessively higher currents can cause boiling of the electrolyte. This reduces the liquid level in the battery and causes buckling and crumbling of the electrodes, thus reducing the life of the cells and hence the battery.

The lead sulphate ($PbSO_4$) which gets coated on the +ve and -ve plates tends to harden into an insoluble salt over a period of time. Hence, it is recommended to fully recharge a battery even if it is not used for quite some time.

Construction of lead-acid batteries

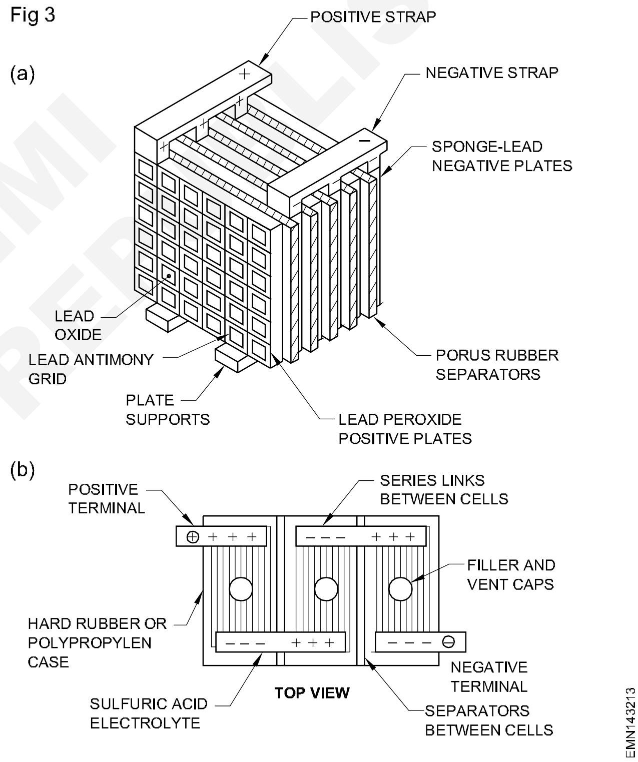
Fig 3 shows the principle behind the construction of commercial lead acid batteries.

Although in Figs 1 and 2, the lead-acid cell electrodes were shown as single plates, in a practical cell, it will not be the case. To increase the surface area and current capacity, a number of positive and negative plates are interleaved and separated by porous rubber sheets as shown in Fig 3a. All the positive plates are electrically connected, and all the negative plates are electrically connected. These parallel connections yield a higher current capacity of the cell with an overall cell output voltage of 2.2V. Several such cells can be connected in series to obtain the required battery voltage. For example, Fig 3b shows three such cells connected in series to produce a 6 volts Lead acid battery.

In lead-acid batteries, since hydrogen gas is produced during recharging, vents (holes) are provided on the battery compartment to let hydrogen and water vapour escape into free air. The vents also help in adding distilled water to the cells to compensate the water evaporated from the electrolyte.

For further details on the construction and manufacturing techniques of lead acid batteries refer reference books listed at the end of this unit.

Fig 3



Current rating of Lead acid batteries

The current rating of a lead acid battery is usually given in ampere-hour (AH) units, based on an 8 hour discharge period. In other words, batteries are rated in terms of how much discharge current they can supply for a specified period of time (often 8 hours). During this time, the cell's output voltage must not drop below 1.7 volts. Typical Ah values of automobile batteries range from 60 Ah to 300 Ah.

For example, A 60-AH battery, used in smaller automobiles, can supply a load current of 60/8 or 7.5 amperes for 8 hours without the cell voltages dropping below 1.7 volts. However this battery can supply less current for longer time (5 amps for 12 hours) or more current for a shorter time (60 amps for 1 hour).

Effect of temperature on AH capacity of Lead-acid batteries

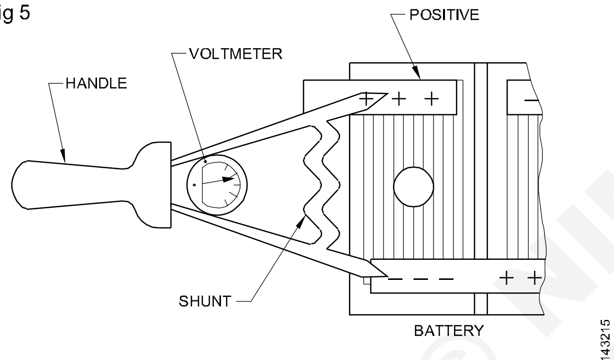
As in the case of primary cells, the capacity of a lead-acid cells also decreases significantly with temperature. These cells lose approximately 0.75% of its rated ampere-hour (Ah) capacity for every 1°F decrease is temperature. At 0°F (–18°C), its capacity is only 60% of the value at 60°F (15.6°C). In cold weather, therefore, it is very important to have an automobile battery always fully charged. In addition, at very cold temperature, the electrolyte freezes more easily as it is diluted by water in the discharged condition.

Keep the batteries always fully charged especially in cold weather conditions.

Instrument for testing condition of cells - High rate discharge tester

The internal condition of a lead-acid battery cell is determined by this test. A low range (0-3V) voltmeter is shunted by a low resistance as shown in Fig 5.

Fig 5



HIGH - RATE DISCHARGE TESTER

The two terminal prods are pressed on to the terminals of a cell for testing. For fully charged cell the meter pointer points in the range of *full charge* on the meter scale. A sulphated old cell will show the discharge reading. The meter is having three colours red, yellow and green; red for fully discharged, yellow for half charged and green for fully charged condition of the cell respectively.

Topping up of lead-acid battery cells

In normal working condition of a lead-acid battery, the level of the electrolyte solution should be such that all the plates of the cells are fully immersed. If the level of the electrolyte is found to be less, then distilled water should be added to the indicated level of the cell through the vent plugs. This process of maintaining the level of electrolyte in lead-acid battery cell is called topping up.

Do not add tap water or well water for topping up. This will reduce cell life.

When a lead acid battery is being charged, the vent plugs are to be kept open for the gas produced to escape freely into air.

In case of lead-acid batteries used as back-up DC supply in un-interrupted power supplies (UPS), since charging and discharging of batteries is a continuous process, the vent plugs of the batteries will have several holes made on it for the gases produced during charging.

Un-interrupted power supplies are used in Hospitals, Computers etc., where the power failure may prove very costly.

Care and routine maintenance of lead-acid batteries

- DO NOT use battery if it is discharged beyond the minimum value of 1.7V per cell.
- DO NOT leave a discharged battery in that condition for a long time. Even if not in use, keep the battery always fully charged.
- Always maintain the level of the electrolyte 10 to 15 mm above the top of the plates by adding suitable quantity of distilled water (NOT tap water).
- DO NOT add sulphuric acid to maintain specific gravity.
- Keep the vent openings in the filling plug always open to prevent build-up of high pressure due to the gases formed. At least the vent plug should have holes made in it.
- Wash off the acid and corrosion on the battery top using moist cloth, baking soda and water.
- Clean the battery terminals and metal supports up to the bare metal and apply vaseline or petroleum jelly over its surface.
- DO NOT test a discharged battery using a 'High rate discharge tester'.

Some applications of lead-acid batteries

Lead-acid storage battery is the most common type found in commercial market. Lead-acid batteries find a great variety and range of applications. Some common applications are listed below;

- In petrol run motor vehicles like scooters, cars etc.
- In small domestic and industrial private generating plants and in mines.
- Battery run locomotives.
- In emergency lamps for small capacity lighting.
- In uninterrupted power supplies (UPS) for providing reserve supply in the event of mains failure.

Although wet electrolyte lead-acid secondary cells are the most common type, there are other types of secondary cells which find application in certain fields due to their special features. A brief on other types of secondary batteries is given below;

Maintenance free lead-acid batteries

Recent advances in lead-acid cells have resulted in low maintenance and maintenance free batteries. In normal lead-acid batteries, the battery plates contain antimony (4%), as the plates are made of lead antimony. It has been found that the amount of *gassing* i.e. production of hydrogen while charging a cell can be reduced by lowering the amount of antimony in the lead plates. By reducing the antimony in plates to 2%, low maintenance cells can be made. These cells require very little addition of water because very little water is *boiled-off* during charging.

Totally maintenance free cells use antimony-free plates allowing complete sealing of battery, since no vents are necessary because gas does not build-up at all. Once sealed, no electrolyte can evaporate from the cell. However in some batteries, a small vent is provided to relieve the pressure arising from altitude changes.

One such maintenance free lead-acid cell is the *Gelled-Electrolyte Lead-acid Cell*. This cell enjoys all the advantages of a wet lead-acid cell but avoids the problems due to liquid electrolyte as it uses a gelled electrolyte. These cells use lead-calcium grids. These cells are completely sealed and can be mounted in any position. A one-way relief valve is provided to release excess pressure if the cell's internal pressure rises too high during charging, and it automatically recloses.

Gelled-electrolyte lead acid batteries are available from 2 V to 12 V with capacities ranging from 0.9 to 20Ah, based on a 20 hour discharge rate. The maximum current for these batteries ranges from 40 to 200 A. These batteries are used in domestic emergency lamps, portable television sets, portable tools and a variety of industrial applications.

Nickel-cadmium (NiCd) cell

Next to lead-acid, these cells are popular because of their ability to deliver high current and can get recycled many times. Also, the cell can be stored for a long time, even when discharged, without any damage. The NiCd cell is available in both sealed and non-sealed designs, but the sealed construction is more common. Nominal output voltage of a nickle-cadmium cell is 1.25 V per cell.

The chemical equation for the NiCd cell can be written as

$$2Ni(OH)_3 + Cd \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftarrows}} 2Ni(OH)_2 + Cd(OH)_2.$$

The electrolyte is potassium hydroxide (KOH), but it does not appear in the chemical equation. The reason is that the function of this electrolyte is just to act as a conductor for the transfer of hydroxyl (OH) ions. Therefore, unlike the lead-acid cell, the specific gravity of the electrolyte in the NiCd cell does not change with the state of charge.

The NiCd cell is a true storage cell with a reversible chemical reaction of recharging that can be cycled up to 1000 times. Maximum charging current is equal to the 10-h discharge rate. It should be noted that a new NiCd battery may need charging before use.

Applications include portable power tools, alarm systems, and portable radio or television equipment.

Nickel-iron or Edison cell

This cell was once used extensively in industrial truck and railway applications. However, it has been replaced almost entirely by the lead-acid battery. New methods of construction for less weight, though making this cell a possible alternative in some applications.

The Edison cell has a positive plate of nickel oxide, a negative plate of iron, and an electrolyte of potassium hydroxide in water with a small amount of lithium hydroxide added. The chemical reaction is reversible for recharging. The nominal output is 1.2 V per cell.

Nickel-zinc cell

This type has been used in limited railway applications. There has been renewed interest in it for use in electric cars, because of its high energy density. However, one drawback is its limited cycle life for recharging. The nominal output is 1.6 V per cell.

Alkaline - manganese secondary cells

Alkaline - manganese secondary batteries are maintenance free, hermetically sealed, and will operate in any position. Individual cells use electrodes of zinc and manganese dioxide with an alkaline electrolyte of potassium hydroxide. Each cell has a nominal voltage of 1.5 V. Alkaline-manganese batteries are available in rated Ah capacity of 1 to 4 Ah. The internal resistance of these batteries is appreciably higher than NiCd batteries. Therefore, alkaline manganese batteries are not suitable for large current supplies.

Alkaline manganese batteries have been designed for electronic and electrical appliances where initial cost and low operating cost are of paramount interest. The total number of times the alkaline manganese secondary batteries can be recharged is much less than that of NiCd batteries, but the initial cost is lower.

Charging alkaline manganese batteries is different from that of NiCd batteries. According to the manufacturer's data, the charging should be done at constant current but at a constant voltage. Another difference, when compared with other secondary batteries is that, the alkaline manganese batteries must not be discharged too much; otherwise, the chemical process can be no longer reversed which means they cannot be recharged. It is recommended by the manufacturer not to discharge the cells below 1 volt.

Zinc-chlorine (hydrate) cell

This cell has been under development for use in electric vehicles. It is sometimes considered as a zinc-chloride cell. This type has high energy density with a good cycle life. Nominal output is 2.1 V per cell.

Lithium-iron sulphide cell

This cell is under development for commercial energy applications. Nominal output is 1.6 V per cell. The normal operating temperature is 800 to 900°F which is high compared with the normal operating temperature of the more popular types of cells.

Sodium-sulphur Cell

This is another type of cell being developed for electric vehicle applications. It has the potential of long life at low cost with high efficiency. The cell is designed to operate at temperatures between 550 and 650°F. Its most interesting feature is the use of a ceramic electrolyte.

Lead-acid secondary batteries made of lead-acid are used in almost every automobile, for starting the engine. These batteries supply load current of 100 to 400A to the starter motor of automobiles.

The nominal voltage of a lead-acid cell is 2.2 V. By connecting three or six cells in series, batteries of 6V or 12V is obtained.

Plastic Cells

A recent development in battery technology is the rechargeable plastic cell made from a conductive polymer, which is a combination of organic chemical compounds. These cells could have ten times the power of the lead-acid type with one-tenth the weight and the one-third the volume. In addition, the plastic cell does not require maintenance. One significant application could be for electric vehicles.

A plastic cell consists of an electrolyte between two polymer electrodes. The operation is similar to that of a capacitor. During charge, electrons are transferred from the positive electrode to the negative electrode by a dc source. On discharge, the stored electrons are driven through the external circuit to provide current in the load.

Application of maintenance free Gelled Electrolyte Lead-acid batteries

Since Gelled electrolyte lead-acid batteries are maintenance free and can be placed in any position, these batteries are extensively used in almost all types of portable equipments. The most common application of Gel-batteries can be found in *emergency lamps*. Emergency lamps are nothing but stand-by light sources, used in the event of main's failure. The type of lamp used could be a miniature tube light or a simple filament lamp. Emergency lamps which use miniature tube lights need a special circuit known as *inverter*. The function of the inverter circuit is to convert a low DC voltage into a high AC voltage.

Recharging lead-acid batteries

Recall that lead-acid batteries are rechargeable. Once the cell voltages of a lead-acid battery falls below 1.8 V, the battery needs recharging. This discharged state of battery can be found by measuring the specific gravity of the electrolyte (1.150) or by measuring the voltage across the cells of the battery.

To charge a lead-acid battery, an equipment known as Battery charger is used. A battery charger is nothing but a DC voltage source which can supply the necessary voltage and charging current to the battery.

There are two main methods of charging batteries. They are;

1 Constant current battery charging

2 Constant voltage battery charging.

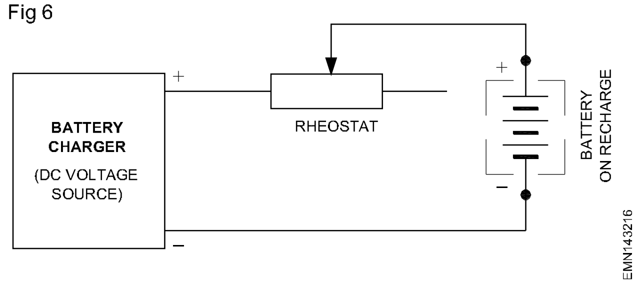
1) Constant current battery charging

In this method of charging batteries, the charging current supplied to the battery is kept at a prescribed (by the battery manufacturer) constant value. The amount of this constant current varies depending upon the Ah capacity of the battery. The value of constant charging current should not be excessive as this would cause excessive gassing. Excessive value current rises the cell temperature above the safe limit (generally 40°C) which will reduce the life of the battery.

Fig 6 shows a very simple method of constant current charging system.

In constant current charging, the output DC voltage of the charger will be generally twice the nominal voltage of the

Fig 6



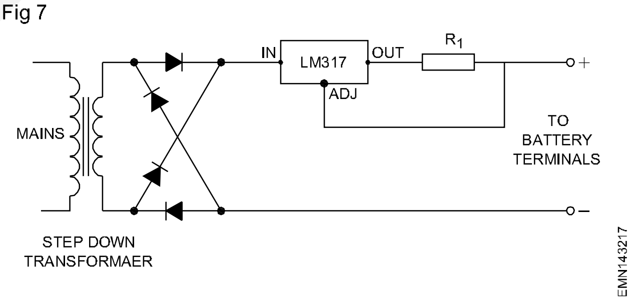
battery to be charged. But, the charging current is controlled by varying the rheostat connected in series with the battery. For example, to charge a 12 V battery, the DC voltage source can be 24 V, but the charging current will be kept controlled say, 1 ampere with the help of the rheostat.

With the introduction of voltage regulator integrated circuits like LM317, it has become very simple and less expensive to make constant current battery chargers. Fig 7 shows a simple constant current battery charger using LM317. This charger can be used for any type of battery charging as long as the charging current is less than 1.5 Amperes.

Current can be set at any value between 10 mA and 1.5 A in the circuit at Fig 7. To have higher currents, suitable external power transistors can be used. In Fig 7, the input voltage to the regulator IC (LM317) should be 1.5 times the battery voltage (to be charged) plus 3 V. LM317 used in Fig 7 is immune to output shorts or reverse battery connections. Hence, the charger will always be safe.

The disadvantage of constant current battery charging is that it takes comparatively long time to fully charge the battery. But, the charge efficiency, which is defined as, is

Fig 7



$$\text{Charge efficiency} = \frac{\text{Charge stored by the battery}}{\text{Charge supplied to the battery}}$$

high compared to constant voltage battery charging.

2) Constant voltage battery charging

In this method, the voltage applied across the battery terminals is kept constant, but no control is imposed on the charging current. Therefore, the battery draws large charging current in the beginning and as the cells gets charged, the charging current decreases to a small value.

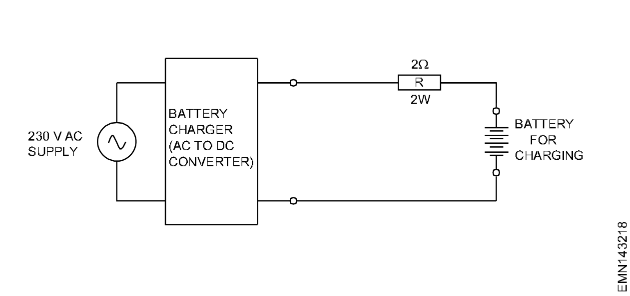
In this method, the time required for charging is reduced to half compared to the constant current charging. But, the charge efficiency gets reduced by approximately 10%.

In constant voltage charging, the voltage applied to the cells for charging should be fixed at about 2.3 to 2.5 volt per cell and not more. For instance, for a 12 volts car battery, the DC voltage output of the charger should be between 14 V to 15 V.

Simple constant voltage battery charging shown in Fig.8. Generally for converting AC into DC. Rectifier circuits are used. For pricision operation, Thyristor based rectifiers also used.

Resistor R is used to limit the initial charging surge current from becoming excessively high. This is because excessive current may damage the diode and transformer of the battery charger unit.

Fig 8



TRICKLE Charging

Whenever a storage battery is used as an emergency reserve, as in the case of un-interrupted power supply (UPS), it is necessary to keep the batteries fully charged and ready for use at any time if the mains supply fails.

A fully charged battery, which is not connected to any load is expected to maintain its terminal voltage. But, due to internal leakage in the battery and other open circuit losses, the battery voltage slowly falls even in idle or open circuit condition. Therefore, to keep it in fully charged condition, the battery should be supplied with a charging current which is small and just sufficient to compensate the idle condition or open circuit losses. This small current charging is known as Trickle charging. Trickle charging keeps the battery always fully charged and in ready to use condition, so that, the battery can be fully made use of in emergency conditions.

Float charging

In this method, the charger and the battery are always connected in parallel for supplying current to the load. The charger provided current for the load and the current necessary to keep the battery fully charged. The battery here is an auxilliary source of dc power.

Note that an automobile battery is in a floating-charge circuit. Ther battery charger is an AC generator or alternator with rectifier diodes driven by a belt from the engine. When the car is started, the battery supplies the cranking power. Once the engine is running, the alternator charges the battery.

What is load testing a battery?

Load testing a battery with an adjustable carbon pile battery tester is one way to check the condition of the plates inside a battery. A load tester applies a calibrated load and displays how the battery responds. The load, which is set to half the battery's cold cranking amp (CCA) rating, is applied for 15 seconds.

If the battery has a CCA rating, you can apply a load equal to the rating for 15 seconds. The voltage should stabilize above 9.6 volts while on load. To apply a more determined test, you may apply a load equal to 100% of the rated CCA or 5 to 6 times the 20-hour rate for 30 seconds.

The purpose of Load Testing is three-fold: To determine the capacity of the battery. To determine if the battery is capable of supporting the connected load for the specified time.""Once a battery shows signs of degradation or reaches 85% of its services life the recommendation is to Load Test annually.

Ni-Cad Battery Capacity Load Testing Procedure

A Set up the load and the necessary instrumentation to maintain and""rate record the determined discharge

B Disconnect the charging source, turn on load, start the timing and continue to maintain the selected discharge rate

C Read and record the individual cell voltages and the system voltage. The readings should be taken while the load is applied at the beginning and at the completion of the test and at specified intervals. As the test nears its end it will be necessary to take readings more frequently to monitor cells that are approaching low voltage limits.

D Maintain the discharge rate, and record the elapsed time at the point when the system voltage decreases to a value equal to the minimum average voltage per cell (e.g. 1.10 Volts) times the number of cells per""string If the battery does not pass, additional data will be beneficial for evaluation or for determining corrective action. If possible,""the testing should be continued to the original test time or a lower final voltage to acquire this information. Nickel-cadmium cells are not damaged as a result of cell reversal, so no provisions are required for bypassing weak cells. Reversing the polarity of NiCad cells should not be a basis for terminating a discharge test before the over all terminal voltage is reached.

E If one or more cells are approaching reversal of their polarity (0.5 Volts or less), and the test is at 90-95% of the expected""completion time, continue the test until the specified terminal voltage is reached.

F If earlier in the test one or more cells are approaching reversal of their polarity, the test may be continued so as to determine the capacity of the remainder of the battery. Bypassing of cells is not recommended. Because the reversed cell(s) will be making a negative contribution to the overall battery voltage, adjust the minimum terminal voltage to compensate. The new minimum terminal voltage will be the minimum cell voltage multiplied by the numbe of non-reversed cells, plus the negative voltage of the reversed cell(s). For example, a 95 cell battery is being tested to a terminal voltage of 105 Vdc (1.10 Vpc). During the discharge, two weak cells go into reversal and stabilize at -0.30 Volts.The new minimum terminal voltage is 93 cells x 1.10 Vpc-(2×0.3)=101.7 Vdc.

G At the conclusion of the test, determine the battery capacity according to the Time Adjusted Method for Calculating System.

Installation, care and maintenance of batteries

Objectives: At the end of this lesson you shall be able to
- **list out the guidelines for installation of batteries**
- **state the guidelines for care and maintenance of batteries**
- **state the precaution to be followed while charging and discharging of battery.**

Guidlines for installation of batteries

The following guide lines to be followed during installation of batteries at residential building

- Location of battery installed should be free from heat sources and flame.
- Battery connection cables should be as short as possible to prevent excessive voltage drop.
- Before connecting the battery the positive and negative poles must be carefully checked to ensure correct installation.
- Authorised and trained person must only be allowed for installation.
- If the batteries to be installed in the accessories like remote controls first open the battery cover, insert the batteries correctly into +ve and -ve ends then close the battery cover and press it to close.
- Do not expose the batteries to heat (or) flame.
- Manufacturer's instruction must be followed when installing the batteries.
- Follow the local, state and National electricity code.
- When installing a battery bank always be careful, since shock hazard may be present.
- Always use protecting/insulating equipment such as gloves, shoes and eye protectors, wrenches and other insulated tools.
- Use proper lifting techniques when working with large batteries.
- Never lift batteries by its terminals.
- Do not allow tools (or) unconnected cables to rest on the top of batteries.
- Never use power tools that may develop more torques while making the batteries terminal connections.
- Do not use chemical cleaner on batteries,they may cause irreversible damage.
- Do not remove vent plugs and Do not add distilled water to the sealed maintanence free (SMF) batteries.
- Ensure that test equipment leads are clean, in good condition and connected with sufficient length to prevent accident.
- Ensure that all monitoring systems are operationable.
- Ensure that battery area and cabinet is properly ventilated.
- Never install batteries in an airtight enclosure.

Care and maintenance of batteries

The lead acid batteries must be operated under the right conditions if they are to function properly. Regular maintenance is necessary in order to maintain proper conditions and thus prolong the life of the battery.

The battery should not be discharged beyond the minimum value of voltage say, 1.75 V for 2V battery.

The battery should not be kept under a discharged condition for a long time.

The level of the electrolyte should always be kept to a minimum of 10 to 15 mm above the plates by adding distilled water only.

The battery should never be charged and discharged at a higher rate which weakens the plate structure. It should be done as per the manufacturer's instructions.

The battery should be recharged as early as possible after discharge.

A discharged battery should never be tested with a high rate discharge tester.

The high rate discharge tester should be used only on charged batteries and for less than ten seconds.

The specific gravity of the electrolyte should be checked regularly before and after a battery is put on charge.

The battery charging room should always be well ventilated for the gases to escape freely.

The battery terminals must be free from corrosion. The terminals must always be kept clean and petroleum jelly should be applied on them.

The spilling of the electrolyte over the battery causes corrosion and it should be cleaned with soda water or ammonia water.

If the battery has not been used for a long period then the battery should be put on a trickle charge.

The vent plugs should be kept open while charging, for free liberation of gases.

Avoid overcharging and discharging at a high rate. This causes the plates to bend from their position and buckle.

Maintenance -free batteries do not require maintenance of electrolytes like traditional common batteries. Maintenance-free batteries are permanently sealed. Alloy use for making electrodes of maintenance-free batteries is different from the common batteries.

Maintenance -free batteries, now in use in place of common batteries as they do not need refilling of eletrolytes regular intervals. Common batteries have removable caps while Maintenance -free batteries have fixed caps.

In common batteries, elctrodes are made of lead-acid batteries. They are rechargeable batteries.

Grids of maintenance-free batteries are made up of calcium-containing lead alloy. The calcium content in alloy varied in the range of 0.6% to 0.1% however the tin content is about 0.1- 0.8%. These are non-rechargeableb batteries. Electrodes made of calcium-containing lead alloy.

Aqueous solvents are used as a medium in Maintenance -free batteries. Electrodes of Maintenance -free batteries are made up of calcium-containing lead alloy and non- platinum electrodes.

The main difference between common bartteries and Maintenance -free batteries is the alloy used for making electrodes.

In common batteries, the negative plate is made up of lead and the positive plate is made up of lead oxide.

Precautions

Make sure that, while charging, the positive terminal of the charger is connected to the positive terminal of the battery, and the negative terminal of the charger to the negative terminal of the battery. Otherwise, connecting it incorrectly causes very high current which can seriously damage both the battery and the charging unit.

Make sure the cell temperature during charge does not exceed the limit specified (43°C) as per the manufacturer's instruction.

A fully charged battery stored at 100°F (38°C) will loose almost all its charge in 90 days. The same battery stored at 60°F(15°C) will loose a little of its charge in the same period of 90 days. High temperature decreases the charging rate and shortens the life.

The rate of charging at the end of the period called finish rate is most important. It must not exceed the value recommended by the manufacturer.

During recharging, the lead acid battery produces flammable gases. An accidental spark can ignite these gases, causing an explosion inside the battery. Such an explosion can break the battery case and throw acid on the people and equipment in the area.

Do not top up the cell with improper water such as tap water, well water, mineral water or acids which will cause hard sulphation and increase the internal resistance.

Avoid improper cleaning agents for terminal posts and metal parts of the battery like emery or sandpaper. Use only the recommended cleaning agents such as baking soda water(warm), ammonia water, and wipe with cotton cloth or with an old brush.

Always wear safety glasses when working with lead acid cells and batteries. If acid does come in contact with clothing or with the skin, immediately flush with clean water. Then wash with soap and water except for eyes. Wash your hands in soap and water after handling batteries.

Solar cells

Objectives: At the end of this lesson you shall be able to
- **state the necessity of tapping natural resources for energy**
- **state about the solar cell /photo voltaic cell**
- **explain the basic principle, construction and characteristics of the solar cell**
- **calculate the required series, parallel group of solar cell for given power requirement.**

Heat energy

Heat energy is the most sought energy for human being to cook the food as well as to keep warm in cold climate. However the use of wood as the fuel for fire, has ended up in deforestation and resulted in drought.

Search of fuel led the man to use coal and then oil. However these commodities are fast dwindling and after few hundred years both may completely vanish from earth. As such it is essential that human race should find alternative source of energy from nature.

Hence the use of natural resources like heat from sun thought by several scientists and one of the solutions to the energy crisis is the invention of solar cells.

Solar cell / Photovoltaic cell

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon.It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels.

Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. They are used as a photo-detector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.

The operation of a photovoltaic (PV) cell requires 3 basic attributes:

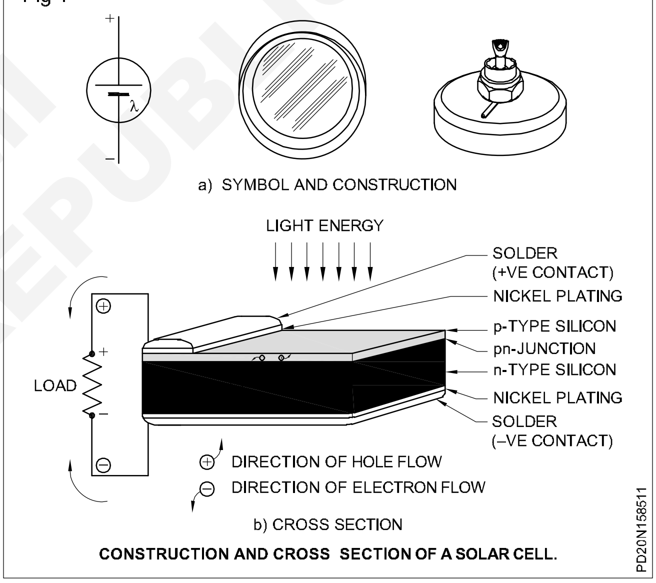
- The absorption of light, generating electron-hole pairs extraction.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

The solar cells is essentially a large photo diode designed to operate as photo voltaic device and to give as much output power as possible. When these cells are under the influence of light rays from sun, they give out about 100 mw/cm^2 power.

Fig 1 shows the construction, symbol and cross section of a typical power solar cell. The top surface consist of a extremely thin layer of P-type material through which light can penetrate to the junction.

The nickel plated ring around the P-type material is the positive output terminal, and the bottom plating is the negative output terminal. Commercially produced solar cells will be available in flat strip form for efficient coverage of available surface areas.

Fig 1



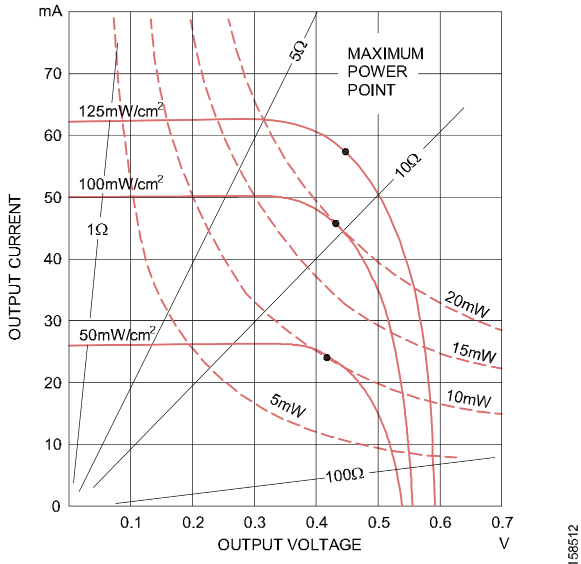
CONSTRUCTION AND CROSS SECTION OF A SOLAR CELL.

According to different manufacturing standards, the output power varies from 50mw/cm^2 to 125mw/cm^2 (Fig 2). The graph shows the characteristic of a solar cell which gives 100mw/cm^2. Considering the characteristic curve it is apparent that the cell will deliver an output current of 50mA when the output terminals are short circuited then the output voltage will be zero.

On the other hand open circuited voltage of the cell will be 0.55mv but the output current is zero. Therefore again the output power is zero. For maximum output power the device must be operated at the knee of the characteristic. In solar cells the output power decreases at high temperature.

Typical output characteristics of power photocell for use as a solar energy converter is shown in Fig 2.

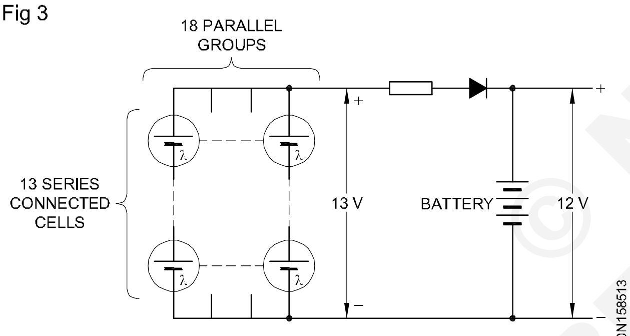
Fig 2



OUTPUT CHARACTERISTICS OF POWER PHOTOCELL FOR USE AS A SOLAR ENERGY CONVERTER

Array of solar cells is connected as a battery charger (Fig 3). Several cells must be connected in series to produce the required output voltage, and number of parallel groups to be provided as per the required output current.

Fig 3



ARRAY OF SOLAR CELLS CONNECTED AS A BATTERY CHARGER

Example

A village welfare club is having a black and white TV which operates at 24V taking a current of 3amp for four hours. Normally an array of solar cells are used for charging the 24V batteries and the light source from sun available to energise the cells for about 10hours a day.

Calculate the total number of solar cells of 125mw/cm^2 required and the series - parallel grouping of cells.

Solution

As per the graph (Fig 2) the solar cells (energy converters) should be operated at approximately 0.45V and 57mA. Assuming the charging voltage should be 10% higher than the battery voltage of 24V the solar cells should supply 26.4 volt for charging the battery circuit.

Number of series connected cells

$$= \frac{\text{Output voltage}}{\text{Cell voltage}} = \frac{26.4\text{V}}{0.45\text{V}}$$

$$= 58.5 = \text{say } 59 \text{ cells}$$

The charge taken by the batteries after every day of TV programme willbe be 3 amp x 4hours = 12 ampere hours. This should be supplied by the solar cells in 10 hours. Hence the ampere requirement.

$$= \frac{\text{Ampere hours}}{\text{hours}} = \frac{12}{10}$$

$$= 1.2 \text{ amp}$$

total number of groups of cells in parallel

$$= \frac{\text{output current}}{\text{cell current}} = \frac{1.2 \text{ amp}}{57 \text{ mA}}$$

= say 21 cells.

The total number of cells required

= Number of cells in series x Number of parallel groups

= **59 x 21 = 1239 cells.**

B.I.S. Symbols used for Power accessories

Objectives: At the end of this lesson you shall be able to
- **interpret the various BIS symbols used in electrical wiring diagrams**

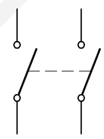
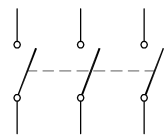
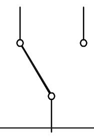
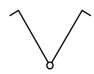
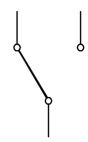
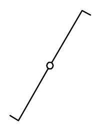
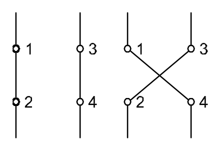
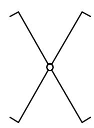
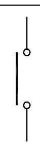
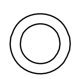
In electrotechnical engineering the symbols are used in layouts and wiring circuits to represent the electrical parts or the function of the circuit.

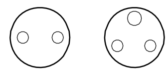
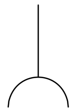
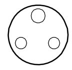
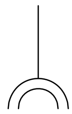
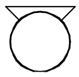
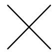
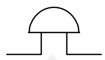
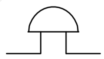
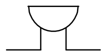
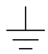
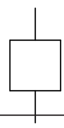
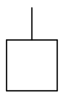
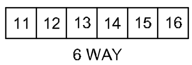
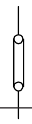
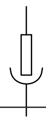
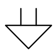
Since the drawing of the actual device is very laborious and would be drawn by each person differently, standardised symbols are used. With the help of the symbols, an electric circuit can be represented easily and can be described precisely as well.

The symbol represents only the function of a part irrespective of the structure and form.

Depending on the purpose of an application, different wiring schemes are used. For example, current flow diagram representation, plans of installation etc. the symbols of various plans of installation (layout) and the current flow diagrams (circuit diagram) differ from one another. A few examples of standard symbols recommen7ded by B.I.S. 2032 (different parts) used for wiring are given here.

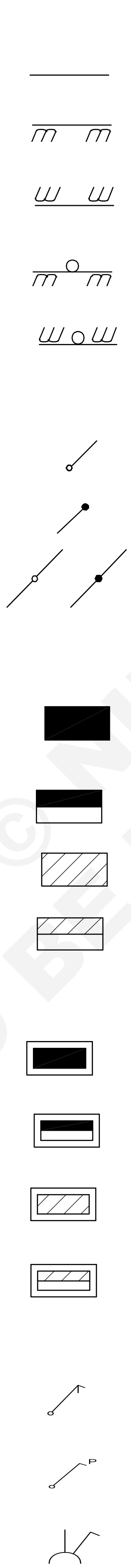
B.I.S. SYMBOLS FOR WIRING SCHEMES

Sl.No.	Description	Symbols used in the circuit diagram	Symbols used in layout
1	One-way switch, single pole		
2	One-way switch, two poles		
3	One-way switch, three poles		
4	Multi-position switch single pole		
5	Two-way switch		
6	Intermediate switch		
7	Push-button or bell-push		

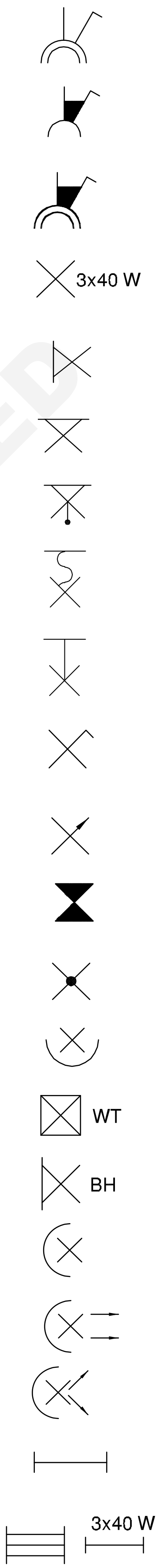
Sl.No.	Description	Symbols used in the circuit diagram	Symbols used in layout
8	Socket outlets, 6A		
9	Socket outlets, 16A		
10	Lamp or outlet for lamp		
11	Fuse		
12	Bell		
13	Buzzer		
14	Earth point		
15	Circuit breaker		
16	Terminal strip		N.A
17	Link (closed)		N.A
18	Plug and socket (male and female)		N.A
19	Ceiling rose		N.A
	N.A: Not applicable		

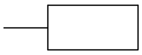
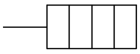
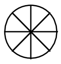
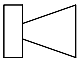
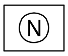
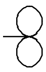
The B.I.S. Symbols used in the wiring is given here.

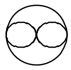
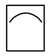
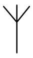
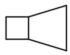
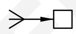
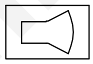
ITEMS	SYMBOLS
I Wiring	
1 General wiring	
2 Wiring on the surface	
3 Wiring under the surface	
4 Wiring in conduit	
a Conduit on the surface	
b Conduit concealed	
The type of conduit may be indicated, if necessary.	
5 Wiring going upwards	
6 Wiring going downwards	
7 Wiring passing vertically through a room	
II Fuse-boards	
1 Lighting circuit fuse-boards	
a Main fuse-board without switches	
b Main fuse-board with switches	
c Distribution fuse-board without switches	
d Distribution fuse-board with switches	
2 Power circuit fuse-boards	
a Main fuse-board without switches	
b Main fuse-board with switches	
c Distribution fuse-board without switches	
d Distribution fuse-board with switches	
III Switches and switch outlets	
1 Single pole pull-switch	
2 Pendent switch	P
IV Socket outlets	
1 Combined switch and socket outlet, 6A	



ITEMS	SYMBOLS
2 Combined switch and socket outlet, 16A	
3 Interlocking switch and socket outlet, 6A	
4 Interlocking switch and socket outlet 16A	
V Lamps	
1 Group of three 40 W lamps	3x40 W
2 Lamp, mounted on a wall or light bracket	
3 Lamp, mounted on ceiling	
4 Counterweight lamp fixture	
5 Chain lamp fixture	
6 Pendent lamp fixture	
7 Lamp fixture with built-in switch	
8 Lamp fed from variable voltage supply	
9 Emergency lamp	
10 Panic lamp	
11 Bulk-head lamp	
12 Watertight light fitting	WT
13 Batten lamp-holder (Mounted on the wall)	BH
14 Projector	
15 Spotlight	
16 Floodlight	
17 Fluorescent lamp	
18 Group of three 40W fluorescent lamps	3x40 W



ITEMS	SYMBOLS
VI Electrical appliances	
1 General If necessary, use designation to specify.	
2 Heater	
VII Bells, buzzers and sirens	
1 Siren	
2 Horn or hooter	
3 Indicator (at `N' insert number of ways)	
VIII Fans	
1 Ceiling fan	
2 Bracket fan	

ITEMS	SYMBOLS
3 Exhaust fan	
4 Fan regulator	
IX Telecommunication apparatus	
1 Aerial	
2 Loudspeaker	
3 Radio receiving set	
4 Television receiving set	

Power wiring accessories

Objectives: At the end of this lesson you shall be able to
- **classify, specify, identify and state the uses of the accessories employed in domestic wiring**
- **state the IE rules related to safety and electric supply.**

Electrical accessories: An electrical domestic accessory is a basic part used in wiring either for protection and adjustment or for the control of the electrical circuits or for a combination of these functions.

Rating of accessories: The standard current ratings of the accessories are 6, 16 and 32 amps. The voltage rating is 240V AC as per B.I.S. 1293-1988.

Mounting of accessories: The accessories are designed to mount either on the surface or concealed (flush type).

Surface mounting type: Accessories are provided with a seating so that when mounted they project wholly above the surface on which they are mounted.

Flush-mounting type: These accessories are designed to mount behind or incorporated with a switch plate, the back of the plate being flush with the surface of the wall or switch box.

The electrical accessories used in wiring installation, are classified according to their uses.

- Controlling accessories
- Holding accessories
- Safety accessories
- Outlet accessories
- General accessories

Controlling accessories: The accessories which are used to control the circuits or an electrical point like switches are called `controlling accessories'. All the switches are specified in accordance with their function, place of use, type of mounting, current capacity and working voltage. For example - S.P.T. (Single pole tumbler) flush-mounted switch 6 amps 240 volts.

Types of switches according to their function and place of use

1 Single pole, one-way switch

2 Single pole, two-way switch

3 Intermediate switch

4 Bell-push or push-button switch

5 Pull or ceiling switch

6 Double pole switch (DP switches)

7 Iron clad double pole, (ICDP) switch.

8 Iron clad triple - pole (ICTP) switch.

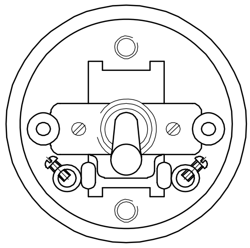
Of the above 1,2,3,4 and 6 may be either surface mounting type or flush-mounting type.

Single pole, one-way switch: This is a two terminal device, capable of making and breaking a single circuit only. A knob is provided to make or break the circuit

(Fig 1). It is used for controlling light or fan or 6 amps socket.

Single pole, two-way switch: This is a three terminal device capable of making or breaking two connections from a single position (Fig 2). These switches are used in staircase lighting where one lamp is controlled from two different places. Though four terminals could be seen, two

Fig 1



6 AMP SINGLE-WAY SURFACE MOUNTING SWITCH (COVER REMOVED)

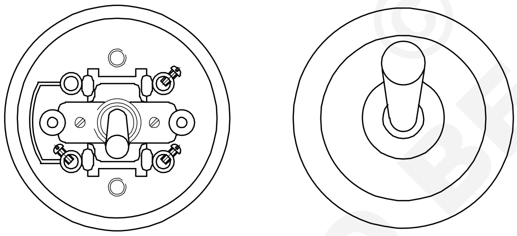
PD20N168621

are short circuited and only three terminals are available for connection.

However, both single way and two-way switches with their cover look alike (Fig 2b) but can be differentiated by looking at the bottom. Single way switches will have two terminal posts whereas two-way switches will have four terminal posts.

Intermediate switch: This is a four-terminal device capable of making or breaking two connections from two positions (Fig 3). This switch is used along with 2 way switches to control a lamp from three or more positions.

Fig 2



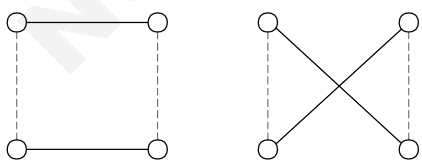
(a) 6 AMP 2-WAY SURFACE MOUNTING SWITCH (COVER REMOVED)

(b) A 2-WAY SWITCH WITH A METAL CAP

PD20N168622

Bell-push or push-button switch: This is a two-terminal device having a spring-loaded button. When pushed it `makes' the circuit temporarily and attains `break' position when released.

Fig 3



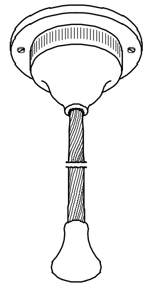
INTERMEDIATE SWITCH CONNECTIONS

PD20N168623

Pull or ceiling switch (Pendent switch): This switch is normally a two-terminal device functioning as a one-way switch to make or break a circuit (Fig 4).

This switch is mounted on ceilings. As the user could operate the switch from a distance through the insulated cord, this could be used safely for operating water heaters in bathrooms or fan or lights in bedrooms.

Fig 4



PULL SWITCH

PD20N168624

Double pole switch (DP switch): This is a switch with two poles, the two poles being mechanically coupled together. It is operated with a knob. It is also provided with a fuse and a neutral link. These switches are used as main switches to control main or branch circuits in domestic installation.

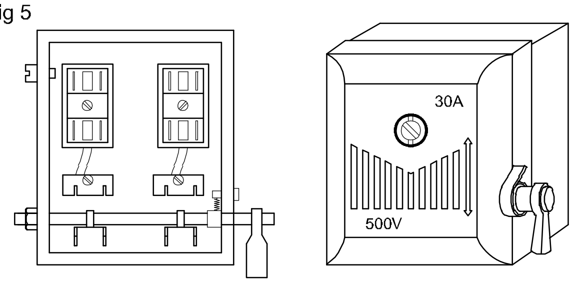
Iron - Clad Double pole (ICDP) main switch : This switch is also referred to as DPIC switch and is mainly used for single phase domestic installations, to control the main supply. It controls phase and neutral of the supply simultaneously (Fig 5).

This switch consists of two fuse-carriers. The one in the phase circuit is wired with the fuse and the other in neutral is linked with a brass plate or thick copper wire. These switches should be earthed properly to safeguard the user. The current rating of the switch varies from 16 amps to 200 amperes.

Specification of these switches should have:

– current rating
– voltage rating
– type of enclosure (sheet steel or cast iron).

Fig 5



DPIC MAIN SWITCH

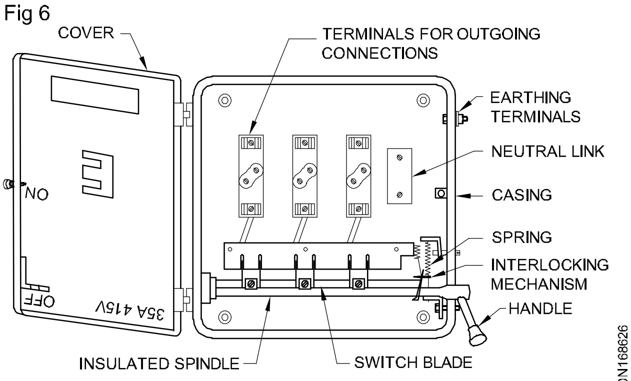
PD20N168625

Iron - Clad Triple pole (ICTP) main switch: This is also referred to as TPIC switch and is used in large domestic installation and also in 3-phase power circuits, the switch consists of 3 fuse carriers, one for each phase. Neutral connection is also possible as some switches are provided with a neutral link inside the casing (Fig 6).

These switches need to be earthed through an earth terminal or screw provided in the outer casing.

The current rating of the switch varies from 16 to 400 amps. Specification of these switches should have

Fig 6



FUSED ICTP `N' SWITCH

– current rating
– voltage rating
– type of enclosure (sheet steel or cast iron)
– whether with neutral link or otherwise
– rewirable type fuse carriers or HRC type fuse carriers.

Holding accessories

Lamp-holders : A lamp-holder is used to hold a lamp. Earlier, brass holders were most commonly used but nowadays these have been replaced by bakelite holders. These may contain solid or hollow spring contact terminals. Four types of lamp-holders are mainly available.

– Bayonet cap lamp-holders
– Screw type holders
– Edison screw type lamp-holders
– Goliath Edison screw type lamp-holders

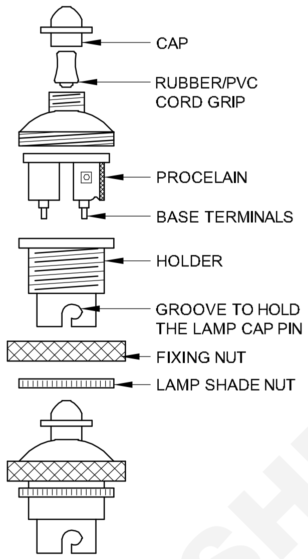
According to the Bureau of Indian Standard, 732, clause 5.8, all incandescent lamps, unless hung at a height of 2.5m (8ft), shall be provided with standard bayonet holders for lamps up to and including 200 watts. For lamp powers above 200 W and up to 300 watts Edison screw holders are to be used and for above 300 watts Goliath screw holders are to be used.

Bayonet cap (BC) lamp-holders: In this type, the bulb is fitted into the slot, and is held in position by means of two pins in the lamp cap. It has solid or hollow spring contact terminals, and the supply mains through the switch are connected to these contacts. In BC types there are two grooves on the circular construction of all types of holders.

The groove and the contact terminals are at right angle to each other. In this type of holders, the lamp is inserted, forced in, turned slightly and then left in position. These holders can be classified further as explained below.

Pendent lamp-holders: This holder (Fig 7) is used in places where the lamps are required in a hanging position. These holders are made of either brass or bakelite. An exploded view of this holder shows the parts of the holder. These holders are used along with ceiling roses for suspending the lamps from the ceiling.

Fig 7

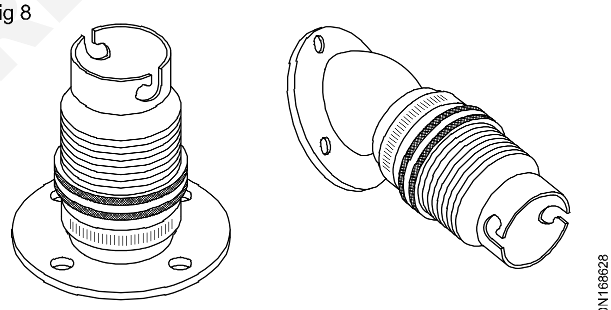


EXPLODED VIEW OF PENDENT HOLDER

Batten lamp-holders: The straight batten holder (Fig 8a) is used on a flat surface on the round block, wooden board etc. These holders are made of either brass or bakelite.

Angle holders: The angle bottom holder, (Fig 8b) is to hold the lamp in a particular angle. These are made of either brass or bakelite. These are used for advertising boards, window display, kitchens etc.

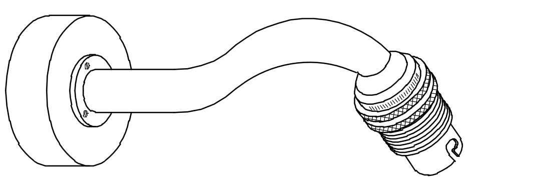
Fig 8



(a) BRASS BATTEN HOLDER (b) ANGLE HOLDER

Bracket holders: This holder (Fig 9) is used with a bracket. These are made of brass and are used to give direct light to a particular place. Brass bracket holders need to be earthed as per BIS recommendations.

Fig 9

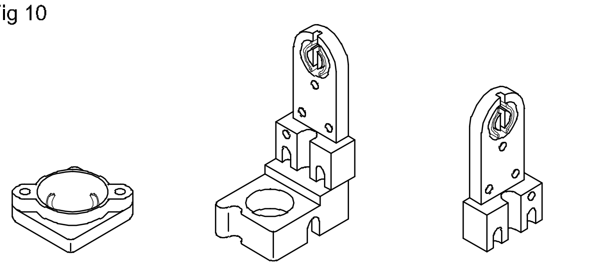


BRACKET HOLDERS

These are fixed on the bracket by the internal threading of the cap.

Tube light or fluorescent lamp-holders and starter-holders: Generally the fluorescent lamp-holders are of a bi-pin type (Fig 10).

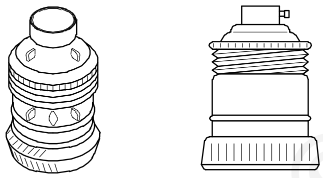
Fig 10



Edison screw-type lamp-holders: In this type, the holder is provided with inner screw threads and the lamp is fitted in it by screwing. It has a centre contact which is connected to the live wire and the screwed cap is connected to the neutral wire.

For lamps with wattage above 200W and not exceeding 300W, Edison screw-type holders are used. Edison screw (ES) lamp holders have spring-loaded central contact to ensure good contact (Fig 11).

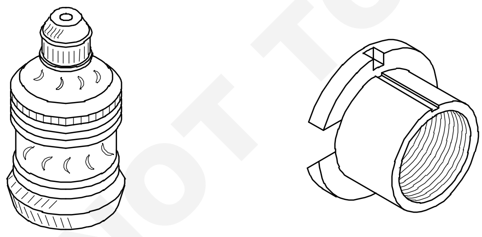
Fig 11



EDISON SCREW TYPE HOLDER

Goliath Edison screw (GES) type holders (Fig 12)**:** The cover of this type of holder is made of porcelain. Such holders are used in studios, headlights, floodlights, focussing lights etc.

Fig 12

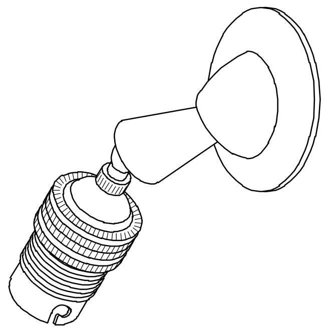


GOLIATH EDISON SCREW LAMP HOLDER

These holders are used for more than 300W lamps.

Swivel lamp-holders: The swivel lamp-holder is designed for wide angle directional lighting which is used for the lighting of shop windows, showcases, etc. It consists of a ball and socket joint fitted between a back plate and the lamp-holders. It is available in bayonet cap type, small bayonet cap type and Edison screw type. All these type of holders are also available for wall fixing patterns or ceiling pattern (Fig 13).

Fig 13



ANGLE SWIVEL LAMP-HOLDER

Specification of a lamp-holder: While specifying the lamp-holders, the type of material used for construction, type of gripping, type of mounting, working current and voltages should also be specified.

Safety accessories: A fuse is a safety accessory. It is connected in series with the circuit and protects the electrical apparatus and equipment from damage, when excess current flows.

The kit-kat type fuse is commonly used in domestic installation.

Types of fuses

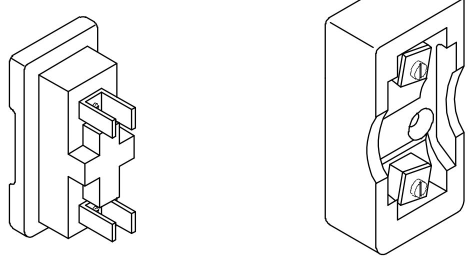
– Kit-kat type (Rewirable fuse)

– Iron-clad fuse cut out

Kit -kat type fuse: This fuse consists of a porcelain base having two fixed contacts, for connecting the incoming and outgoing cables.

The line and load wires are connected in the base terminals and the carrier is provided with a fuse (Fig 14). The base is fixed but the carrier is removable.

Fig 14

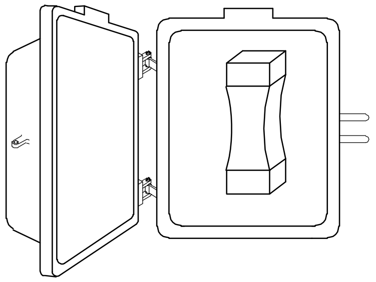


KIT-KAT FUSE

Iron-clad fuse cut outs (Fig 15): These are kit-kat fuses in an iron cover. The iron cover has facility to be closed and sealed with a lead seal. This is used at the incoming side of the power supply and sealed by the supply authorities to ensure the line is not loaded beyond a certain prescribed current capacity.

Outlet accessories: These accessories are used to take the supply for the portable appliances like table fans, TV, electric irons etc.

Fig 15



IRON CLAD CUT - OUT

Socket outlet current rating: The standard ratings shall be 6,16 and 32 amperes and 240 volts. The following types are normally used for domestic purposes. They have to be specified according to the mounting type, number of pins, current capacity and voltage.

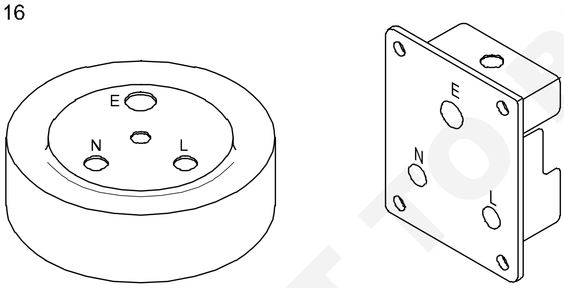
Two-pin socket: This socket is rated as 6A, 250V, having only two pins without earth connection. These are suitable only for double insulated appliances (having PVC or insulated body).

Two-pin plug top: It is used for taking the supply from the socket. It has got two pins of the same size.

Three-pin socket: This type of socket is suitable for light and power circuits. These sockets are rated as 6A, 250V or 16A, 250V, and are available as surface-mounting type and flush type (Fig 16). There are three terminals marked as Line (L) Neutral (N) and Earth (E). The line terminal is always on the right hand side, the neutral terminal on the left hand side, and the top is the earth terminal which is larger in diameter. In all the cases, the earth wire must be connected to the earth terminal of the socket.

Three-pin plug top : It is used for taking the supply from

Fig 16



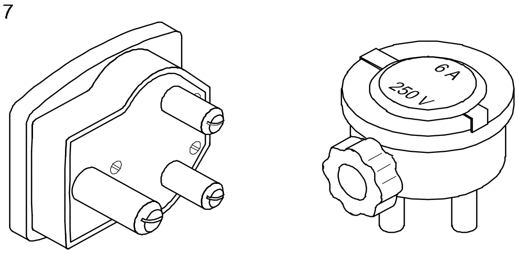
3-PIN 16 AMP SOCKET WITH TOP COVER FLUSH TYPE SOCKET

the socket. It has three pins. Two are similar in size and the third one is bigger and longer which is for earth (Fig 17). These are also rated as 6A,250V or 16A, 250V. These are made of bakelite, PVC materials.

A socket which is controlled by a switch, is also available. Multi-pin sockets are also available which are suitable for 2 pins and 3 pins having 5 holes in one unit. Further multi-pin sockets for 3 pin of 6 amps and 16 amps are also available having 6 holes in one unit.

General accessories : Some accessories are used for general and special purposes such as:

Fig 17



THREE-PIN PLUG TOP

– appliance connectors (or) iron connectors

– adapters

– ceiling roses

  a) two-plate

  b) three-plate

– connectors

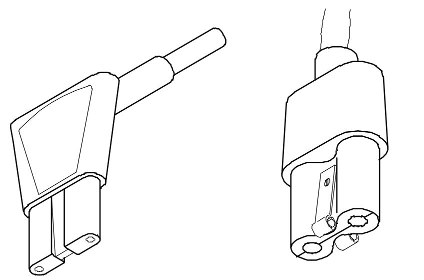
– distribution board

– neutral links.

Appliance connectors or iron connectors : These are used as female connectors to supply current to electric kettles, electric iron, hotplate, heaters etc. It is made of bakelite or porcelain. The wires are connected with two brass terminals and the earth connection is provided with a twin nickel spring. The cable entry has a rubber protection tybe. These are rated as 16A, 250V (Fig 18).

Adaptor (Fig 19)**:** They are used for taking supply from a lamp holder for small appliances. They are made out of bakelite. They are available in ratings up to 6 A 250 V.

Fig 18



FLAT CONNECTOR WITH SIDE ENTRY IRON CONNECTOR DIRECT ENTRY

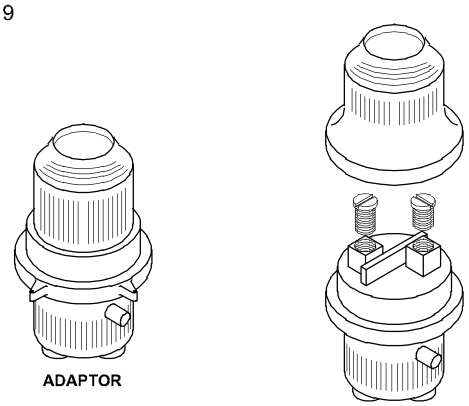
Adaptors with multiple plugs are also available for taking supply to a number of appliances from a single point.

These adaptors should not be used in bathrooms or other damp places.

Ceiling roses: Ceiling roses are used to provide tapping points from the wiring for supplying power to fans, pendent-holders, tube lights etc. Normally flexible wires are used for tapping from the ceiling roses.

Ceiling roses have two parts, base and cover, both made of bakelite. The cover has a hole in the centre for the connecting wires to be taken out. There are threadings on the internal sides so that the cover may be fixed or

Fig 19

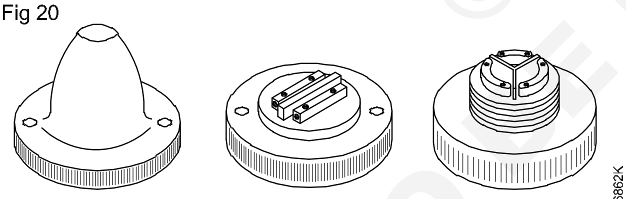


tightened with the base. The base has terminals and holes for fixing on the block etc. and for wires to connect with the supply. Two types of ceiling roses are in use.

Two-plate ceiling rose (Fig 20 a & b)**:** This is made of bakelite and it has 2 terminals (phase & neutral) which are separated from each other by a bakelite bridge. Each of the terminal plates is provided with a metallic sleeve and a binding screw on one side through which the circuit wire from the back via the mounting block enters them. The other side of the terminal plate is provided with a washer and screw to tap wire connection. The two-plate ceiling rose is used for 6A, 250V current capacity. It is not used in circuits whose voltage exceeds 250V.

Three-plate ceiling rose: This type of ceiling rose has 3 terminals which are separated from each other by a bakelite bridge. It can be used for two purposes. (Fig 20 a & c)

Fig 20



– Bunch light control

– To provide tapping for phase wire (Fig 21).

These ceiling roses are available in the rating of 6A, 250V. The covered 2 plate and 3 plate ceiling roses will look alike but could be identified by seeing the rear side.

Connectors (Fig 22): Connectors are used to extend the length of the wire without joining. They are made of porcelain, bakelite or PVC based material. There is a brass sleeve with threading for small screws to tighten the wire in the sleeves. These are available in single way, two-way, three-way, six-way, 12-way types. These are rated according to the current and voltage capacity - 6A 250V, 16A 250V, 32A 250V, 16A 500V, 32A 500V etc.

Distribution board (Fig 23): These are used where the total load is high and is to be divided into a number of circuits. These are used where the load is more than 800W.

Fig 21

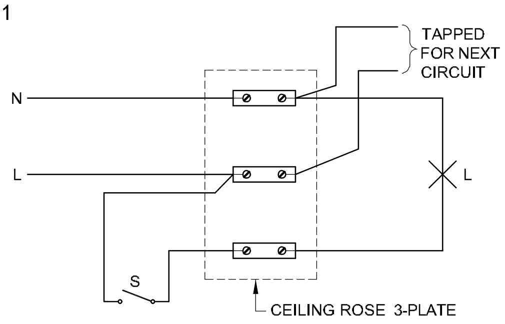


Fig 22

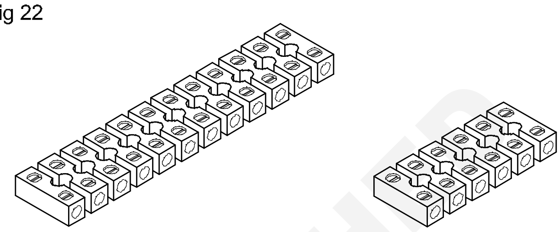
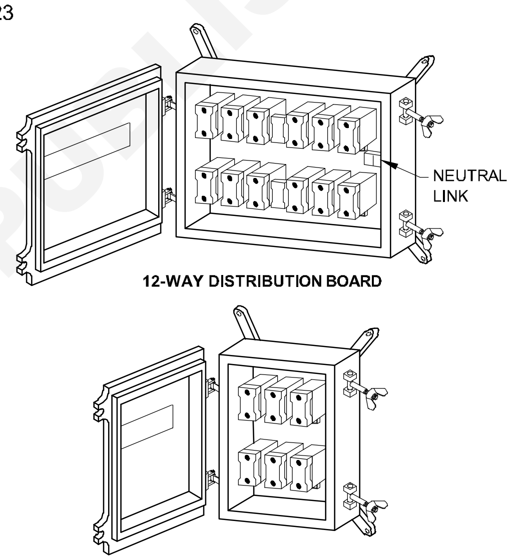


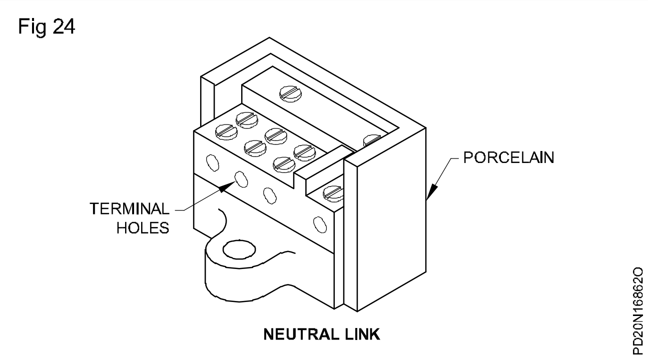
Fig 23



The number of fuses in the board is according to the number of circuits, and a neutral link is also provided so that the neutral wire can be taken for different circuits. All these branch fuses are enclosed in a metal box. These boards are available as two-way, three-way, 4,6,12-way types.

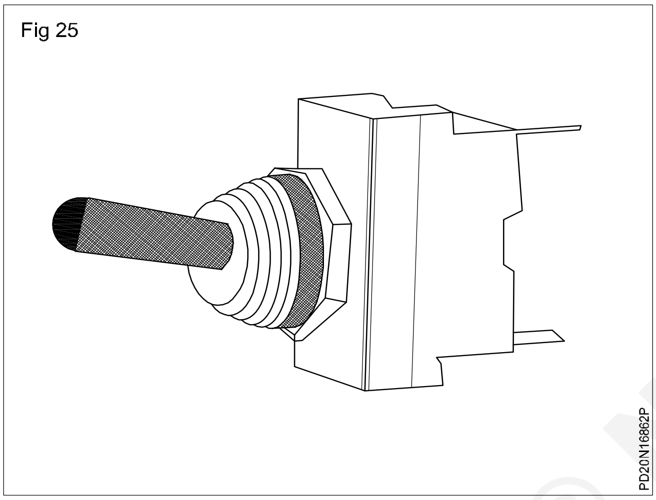
Neutral link: In a three-phase system of wiring installations, the phases are controlled through switches, and the neutral is tapped through a link called neutral link. The neutral link consists of a terminal for incoming current and a multi-way outgoing circuit. The metal terminals are mounted on high grade vitreous porcelain base (Fig 24). The ratings are 16A, 32A, 63A, 100A neutral link.

The accessories' rating shall be 240V and 6 or 16 amps from the year 1991, instead of 250V and 5 or 15 amps as per BIS 1293-1988.



Toggle switches (Fig 25)

It is an electric switch operated by means of a projecting lever that can be moved upward and downward and is also called as snap switches .



The toggle switches are generally specified based on

- Number of poles (single / double/ triple etc.)
- Number of throws (single / double/ double with center OFF etc.)
- Current rating (3,6,10,16,20 & 25A)
- Voltage rating (125V & 250V , AC)
- Size (8,10,12,15mm etc.)
- Knob type (Brass/ plastic and oval/ round/flat etc.)

Modular switches

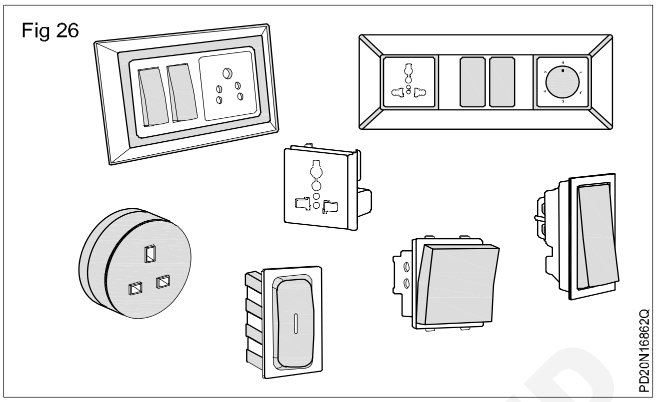
The latest version of modular switch of different sizes and colours along with sockets combined and switches with indicators are available in market (Fig 26).

Indian Electricity Rules - Safety Requirements

The IE rules 1956 was made under sections 37 of Indian Electricity Act 1910. Now it is redefined after the enactment of the Electricity Act 2003. The Central Electricity Authority (measures relating to safety and electric supply) Regulation (CEAR) 2010 which came into effect from 20th September 2010, in place of Indian Electricity Rules 1956.

SAFETY RULES: Among safety rules, the following are important and indeed requires attention. Every rule in the Indian Electricity Rules 1956 is related either directly or indirectly to safety.

Rule 32: Switches shall be on the live conductor. No cutout, link or switch other than gang switch shall be inserted in the neutral conductor. Code of Practice of wiring shall be followed while marking the conductors.



Rule 50: Energy shall not be supplied, transformed,converted or used unless the following provisions are observed. A suitable linked switch or circuit breaker is erected at the secondary side of the transformer. Every circuit is protected by a suitable cut-out. Supply to each motor or group of motors is controlled by a linked switch or circuit breaker. Adequate precautions are taken to ensure that no live parts are exposed.

Special provisions in respect of high and extra high voltage installations

Rule 63: Approval of Inspector is necessary before energising any high voltage installations.

Rule 65: The installation must be subjected to the prescribed testing before energizing.

Rule 66: Conductors shall be enclosed in a metallic covering and suitable circuit breakers shall be provided to protect the equipment from overloading.

Rule 68: Incase of outdoor type of sub-station a metallic fencing of not less than 1.8 m height shall be erected around the transformer.

Provisions in terms of OH line

Rule 77: Clearance of lowest conductor above ground across street.

- Low and Medium Voltage lines - 5.8 m.
- High voltage Lines - 6.1 m.
- Clearance of lowest conductor above ground along a street. Low and Medium Voltage lines - 5.5 m.
- High voltage lines - 5.8 m.
- Clearance of lowest conductor above ground other than along or across the street. Low, Medium and High Voltage lines upto 11 KV if bare - 4.6m .
- Low, Medium and High upto and including 11KV, if insulated - 4.0m.
- High Voltage above 11 KV - 5.2 m.

Rule 79: Clearance of low and medium voltage lines from building,

- Vertical Clearance - 2.5 m.
- Horizontal clearance - 1.2 m.

Rule 80: Clearance from building of high and extra high voltage. Vertical Clearance High Voltage upto 33KV - 3.7m.

- Extra High Voltage above 33KV - 3.7 m, plus 0.3 m for every 33KV part there of.
- Clearance from building of high and extra high voltage - Pitched Roof . Vertical Clearance upto 11KV - 1.2m.
- Above 11KV upto 33KV - 2.2 m.
- Above 33KV - 2m. plus 0.3m for every 33KV part there of.

Rule 85: Maximum interval between supports. It shall not exceed 65 m except by prior approval of inspector.

Indian electricity rules regarding to internal wiring:

1 The minimum size of conductor used in domestic wiring must not be of size less than 1/1.12mm in copper or 1/1.40mm (1.5mm) in aluminium wire.

2 For flexible wires the minimum size is 14/0.193mm.

3 The height at which meter board, Main switch board are to be fitted 1.5 meters from ground level.

4 The casing will be run at a height of 3.0 meters from the ground level.

5 The light brackets should be fixed at a height of 2 to 2.5 meters from ground level.

6 The maximum number of points in a sub circuit is 10.

7 The maximum load in a sub circuit is 800W.

I.E. Rules regarding - Voltage drop concept:

1 **I.E. Rule 48:** The insulation resistance between the wiring of an installation and earth should be of such a value that the leakage current may not exceed 1/50000 the part or 0.02 percent of the F.L. current.

2 The permissible voltage drop in a lighting circuit is 2% of the supply voltage plus one volt.

3 The maximum permissible voltage drop in a power industrial circuit should not be more than 5% of the declared supply voltage.

4 The insulation resistance of any wiring installation should not be less than 1MΩ .

5 The earth resistance should not exceed the value of one ohm.

I.E. Rules regarding to power wiring:

1 In a power sub circuit the load is normally restricted to 3000 watts and number of outlets to two in each sub circuit.

2 All equipment used in power wiring shall be iron clad construction and wiring shall be of the armoured cable or conduit type.

3 The length of flexible conduit used for connections between the terminal boxes of motors and starters, switches and motors shall not exceed 1.25 meters

4 Every motor, regardless of its size shall be provided with a switch fuse placed near it.

5 The minimum cross-sectional area of conductor, that can be used for power mining of 1.25 mm for copper conductor cables and 1.50 mm for Aluminium conductor cables (refer ISI recommendations). Hence VIR or PVC cables of size lower than 3/0.915 mm copper or 1/1.80 mm Aluminium can not be used for motor wiring.

Circuit Breaker (CB) - Miniature Circuit Breaker (MCB)- Moulded Case Circuit Breaker (MCCB)

Objectives: At the end of this lesson you shall be able to
- **explain the types, working principle and parts of a miniature circuit breaker.**
- **state the advantages and disadvantages of MCB**
- **explain the working of combination circuit breaker (ELCB + MCB)**
- **state the categories and applications of MCBs**
- **state the application, advantage and disadvantage of MCCBs.**

Circuit Breaker

A circuit breaker is a mechanical switching device capable of making, carrying and breaking the currents under normal condition and breaking the currents under abnormal conditions like a short circuit.

Miniature circuit breaker (MCB)

A miniature circuit breaker is a compact mechanical device for making and breaking a circuit both in normal condition and in abnormal conditions such as those of over current and short circuit.

Types of MCB's

MCBs are manufactured with three different principles of operation namely

a Thermal Magnetic

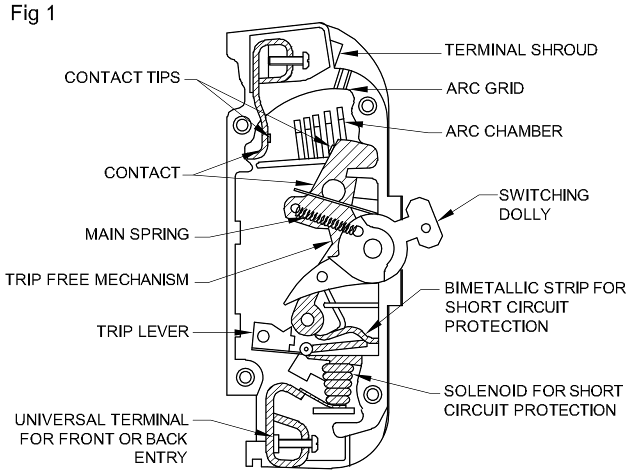
b Magnetic hydraulic and

c Assisted bimetallic

Thermal magnetic MCB

The switching mechanism is housed in a moulded housing with phenolic moulded high mechanically strong switching dolly. This type of MCB is also provided with bimetallic overload release (Fig 1).

Fig 1



NOTE: THE HATCHED PORTION SHOWS THE PATH OF CURRENT FROM TOP TERMINAL TO BOTTOM

THERMAL MAGNETIC TYPE MCB

PD20N168631

The electric current gets through two contact tips one each on moving and fixed contact of silver graphite.

An arcing chamber incorporating de-ionising arc chutes for control and quick suppression of the arc is provided in the gap between two contacts. It has a ribbed opening closed by metal grid which allows ventilation and escape of gases.

For protection against over-load and short circuit, MCB's have thermal magnetic release unit. The overload is taken care of by bimetallic strip, short circuit currents and over loads of more than 100% are taken care by solenoid.

Working

The bimetallic strip when flexing due to temperature rise caused by increasing normal rated current beyond 130% rotates a trip lever carrying an armature to which it is to brought into field of a solenoid. The solenoid is designed to attract the armature to full position at about 700% overload or instantaneous short circuit current.

For initial portion of current wise (130% to 400%) tripping of circuit breaker is due to thermal action, between 400 to 700% tripping is due to combined thermal and magnetic action and beyond 700% due to fully magnetic action.

Magnetic hydraulic MCB

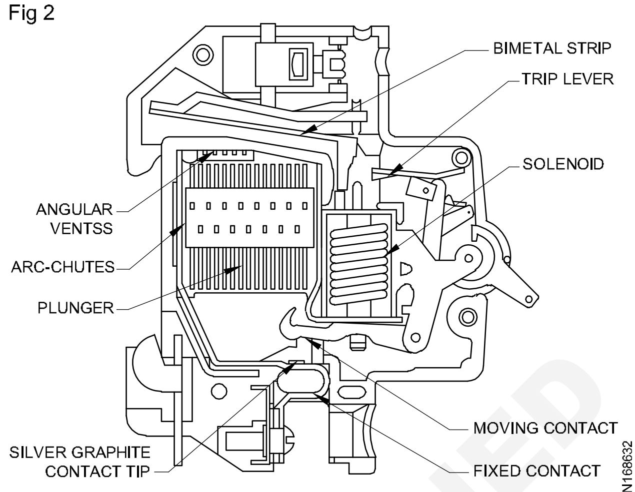
Magnetic hydraulic circuit breaker operates on the principle of a solenoid and hydraulically damped plunger.

Construction and working

A movable ferrous plunger is held against a non-ferrous tube containing polysiloxane liquid which have flat temperature viscosity characteristic in temperature range of 20 to 60°C. The solenoid is a series coil in the circuit of MCB. As the plunger moves towards a pole piece, the reluctance of magnetic path.

Containing the armature is cumulatively reduced leading to some magneto motive force producing a progressively increasing flux. The armature is then attracted causing the mechanism to trip and open the controls on overload or short circuit (Fig 2). Instantaneous tripping occurs on very large currents 7 to 8 times the full load current. The construction of magnetic hydraulic tripping mechanism is in Fig 2.

Fig 2



MAGNETIC HYDRAULIC MCB

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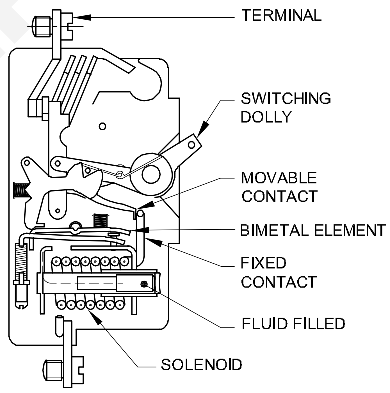
Assisted Bimetal Tripping MCB (Fig 3)

In the assisted bimetal form of construction, the time delay characteristic is provided by a thermally operated bimetal element which may be either directly or indirectly heated. Instantaneous tripping in short circuit condition is achieved by arranging a powerful magnetic pull to deflect the bimetal (Fig 4).

Fig 3



ASSISTED BIMETAL TRIPPING MCB

PD20N168633

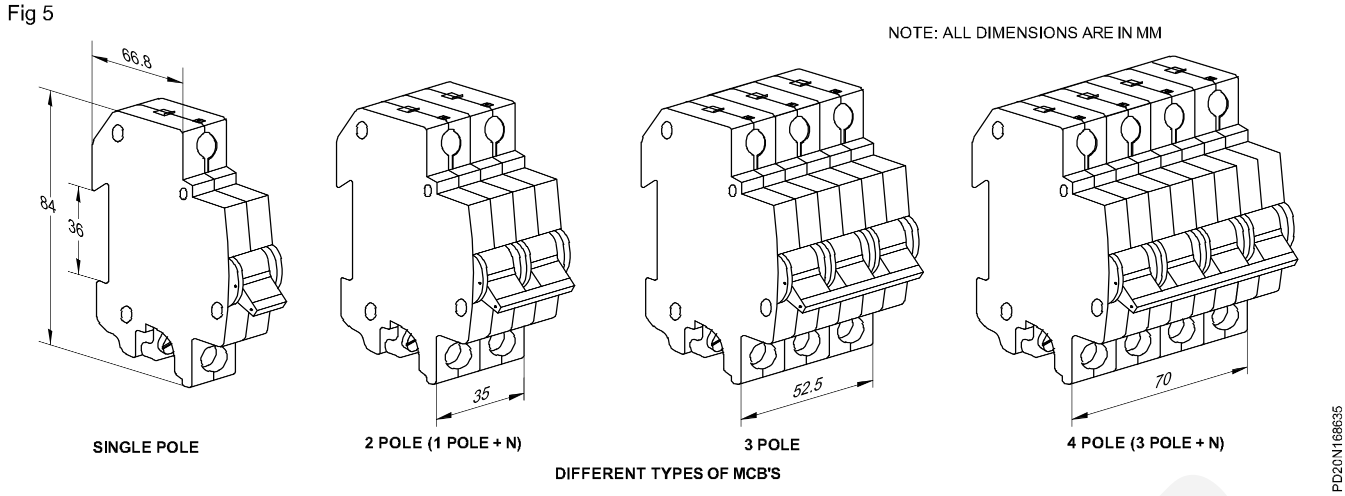
This method utilises the magnetic field which is produced when a current flows through the conductor. By locating the bimetal near to a substantial section of ferrous material, the magnetic field associated with current flowing in the bimetal will cause a sideways pull to be applied to the bimetal element, attracting the bimetal towards the ferrous material.

This sideways pull is arranged to coincide in direction with the normal direction of movement of the bimetal, which is powerful enough to deflect the bimetal (in heavy over load or short circuit condition) sufficiently to trip the breaker.

Design and rating of MCBs

MCBs are normally rated for 25°C ambient temperature and are available in the following various combination of poles and current ratings (Fig 5).

Fig 5



Sl.No.	No. of poles	Current
1	Single pole MCB	0.5 to 60A
2	Double pole MCB (ie. 2 MCBs with common trip bar)	5 to 60A
3	Triple pole MCB	5 to 60A
4	Four pole MCB	5 to 60A

Isolators

An isolator is a switch. These cannot be used for automatic tripping. Isolators are not meant for either closing or breaking the circuit on load or short circuit. Isolators have the same physical dimensions of MCBs and are available in the following configurations and ratings.

No. of poles	Current rating
Single pole	30, 60, and 100A
Single pole with Neutral	30, 60, and 100A
Triple pole	60, and 100A
Four pole	60 and 100A

ELCB + MCB combination circuit breaker

Now a days some manufacturers have introduced an ELCB + MCB combination circuit breaker which can be used instead of using separate MCB and ELCB (earth leakage circuit breaker). This combination not only allows reduction in costs, but also ensures

- over current
- short circuit
- earth leakage
- earth fault.

Earth leakage circuit breakers are now generally called Residual Current circuit breakers (RCCB).

The rated load currents of the RCCB + MCB combination are 6A, 10A, 16A, 20A, 25A, 32A and 35A. The bimetal trip is so adjusted that no tripping will occur upto 1.3 times the rated current.

Categories of MCBs

Certain manufacturers like Indo Kopp manufacture the MCBs in three different categories namely 'L' series, 'G' series, and 'DC' series.

'L' series MCBs

'L' series MCBs are designed to protect circuits with resistive loads. They are ideal for protection of equipment like Geysers, ovens and general lighting systems.

'G' series MCBs

'G' series MCBs are designed to protect circuits with inductive loads. G series MCBs are suitable for protection of motors, air conditioners, hand tools, halogen lamps etc.,

'DC' series MCBs

'DC' series MCBs are suitable for voltage upto 220V DC and have a breaking capacity up to 6kA.

The tripping characteristics are similar to 'L' an 'G' series. They find extensive application in DC controls, locomotives, diesel generator sets etc.,

Advantages of MCB

1 Tripping characteristic setting can be done during manufacture and it cannot be altered.

2 They will trip for a sustained overload but not for transient overload.

3 Faulty circuit is easily identified.

4 Supply can be quickly restored.

5 Tamper proof.

6 Multiple units are available.

Disadvantages

1 Expensive.

2 More mechanically moving parts.

3 They require regular testing to ensure satisfactory operation.

4 Their characteristics are affected by the ambient temperature.

Application of (RCCB + MCB) combination circuit breakers

1 All residential premises can have incoming protection after energy meter instead of fixing fuse and main switch.

2 All domestic equipments like water heaters, washing machines, electric iron, pump sets etc.,

3 All construction and outdoor electrical equipments such as lifts, hosts, vibrators, polishing machines etc.,

4 All industrial distribution and equipments

5 All agriculture pump sets.

6 Operation theatres and electrically operated medical equipment such as X-ray machines.

7 All neon sign installations

8 All low and medium voltage electrical distributions.

Technical specification of MCBs

Related voltage	240/ 415V AC 50Hz
	Up to 220V DC
Current rating	0.5, 1, 1.6, 2, 2.5, 3, 4, 5, 6, 7.5,
	10, 16, 20, 25, 32, 35, 40 and 63A.
No. of poles	1,2,3
Types	‘L’ ‘G’ and ‘DC’ series
Breaking capacity	UP to 9kA
Mechanical life	1,00, 000 operations
Electrical life	50,000 operations
Overload capacity	15% over load
Housing	Glass fiber reinforced polyester
Fixing	Snap fixing on 35 mm DIN channel
Types of terminals	25mm² box type terminal at the
	incoming and outgoing.

Definition of Breaking capacity of MCB

The short circuit breaking capacity of the circuit breaker is the current more than the prospective fault current at the point of installation of circuit breaker. Prospective fault current is the maximum fault current which may have to be interrupted by the circuit breaker.

Moulded Case Circuit Breakers (MCCB)

Moulded case circuit breakers are similar to thermo magnetic type MCBs except that these are available in higher ratings of 100 to 800amp at 500V 3-phase.

In MCCB, thermal and magnetic releases are adjustable. A shunt release is also incorporated for remote tripping and interlocking at MCCB. MCCBs are provided with under voltages release. There are two types of MCCB.

1 Thermal magnetic type.

2 Fully magnetic type (Fig 6).

Advantages of MCCB

1 MCCBs occupy much less space in comparison to fuse switch units.

2 MCCBs provide equal amount of protection against high faults as switch gears having HRC fuses.

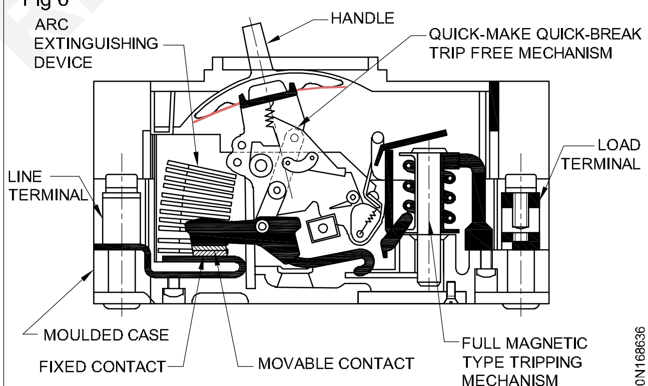
Disadvantages

1 MCCBs are much costlier.

2 Leak proof situation required.

3 Sensitivity to insulation resistance low.

Fig 6



FULLY MAGNETIC TYPE M.C.C.B

ELCB - types - working principle - specification

Objectives : At the end of this exercise you shall be able to
- **explain the working principle, different types and construction of an earth leakage circuit breaker (ELCB)**
- **explain the technical specifications of ELCB’s.**

Introduction

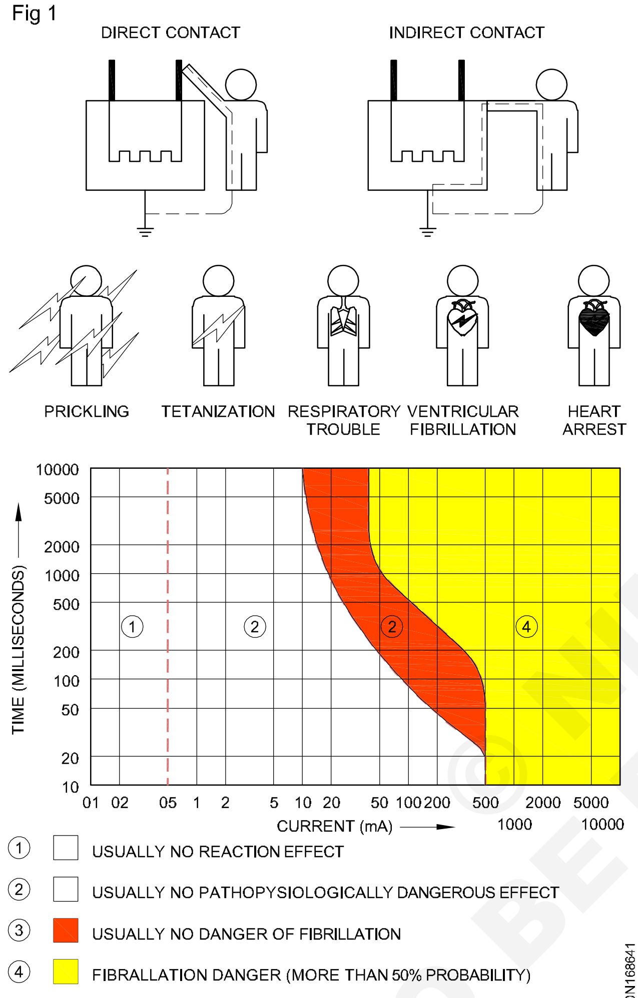
The sensation of electric shock is caused by the flow of electric current through the human body to earth. When a person comes in contact with electrically live objects like water heaters, washing machines electric iron etc., the extent of damages caused by this current depends on its magnitude and duration.

This kind of current is called the leakage current which comes in milli-amps. These leakage current being very small in magnitude, hence undetected by the fuses/MCBs are the major cause for the fires due to electricity.

The leakage current to earth also results in the wastage of energy and excessive billing for electricity not actually used.

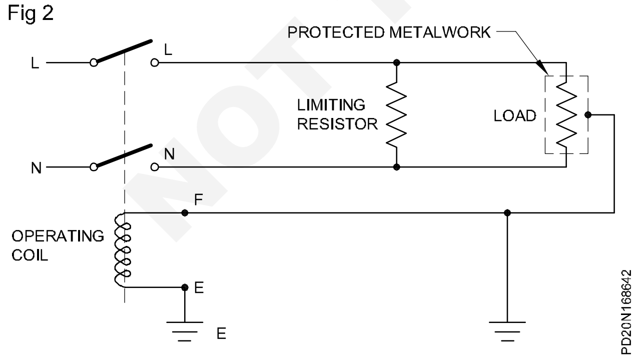
Residual current operated circuit breakers are internationally accepted means of providing maximum protection from electric shocks and fires caused due to earth leakage current and also prevents the waste of electrical energy. These residual current circuit breakers (RCCB) are popularly called as Earth leakage circuit breakers (ELCB). The effect of electric current on human body in various levels represented in graph (Fig 1).

Fig 1



EFFECT OF ELECTRIC CURRENT ON HUMAN BODY

Fig 2



Basically ELCBs are of two types namely voltage operated ELCBs and the current operated ELCBs.

Voltage operated ELCB

This device is used for making and breaking a circuit. It automatically trips or breaks the circuit when the potential difference between the protected metal work of the installation and the general mass of earth exceeds 24V. This voltage signal will cause the relay to operate (Fig 2).

Voltage operated ELCBs are meant to be used where it is not practicable to meet the requirements of IEE wiring regulation by direct earthing or where additional protection is desirable.

Current operated ELCB

This device is used for making and breaking a circuit and for breaking a circuit automatically when the vector sum of current in all conductors differs from zero by a predetermined amount. Current operated ELCBs are much more reliable in operation, easier to install and maintain.

Construction of current operated ELCB

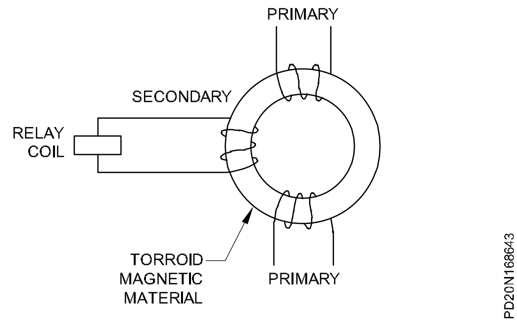
It consists of a Torroid ring made of high permeability magnetic material. It has two primary windings each carrying the current flowing through phase and neutral of the installation. The secondary winding is connected to a highly sensitive electro - magnetic trip relay which operates the trip mechanism.

Working principle

The residual current device (RCD) is a circuit breaker which continuously compares the current in the phase with that in the neutral. The difference between the two is called as the residual current which is flowing to earth.

The purpose of the residual current device is to monitor the residual current and to switch off the circuit if it rises from a preset level (Fig 3).

Fig 3



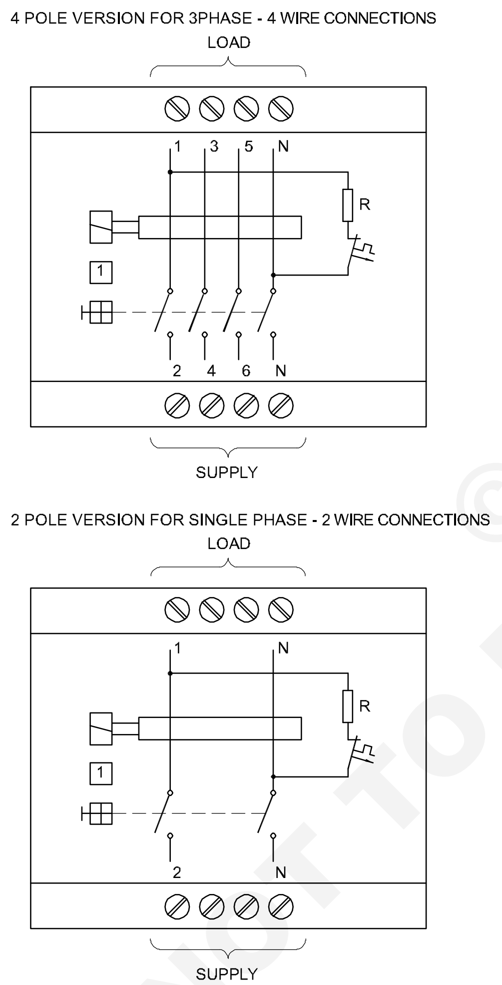
The main contacts are closed against the pressure of a spring which, provides the energy to open them when the device trips. Phase and neutral current pass through identical coils wound in opposing direction on a magnetic circuit, so that each coil will provide equal but opposing numbers of ampere turns when there is no residual current. The opposing ampere turns will cancel and no magnetic flux will be set up in the magnetic circuit.

In a healthy circuit the sum of the current in phases is equal to the current in the neutral and vector sum of all the current is equal to zero. If there is any insulation fault in the circuit then leakage current flows to earth. This residual current passes to the circuit through the phase coil but returns through the earth path and avoids the neutral coil, which will therefore carry less current.

So the phase ampere turns exceeds neutral ampere turns and an alternating magnetic flux results in the core. The flux links with the secondary coil wound on the same magnetic circuit inducing an emf into it. The value of this emf depends on the residual current, so it drives a current to the tripping system which depends on the difference between them and neutral current.

When tripping current reaches a predetermined level the circuit breaker trips and open the main contacts and thus interrupts the circuit. A 3 - phase 4 wire electric system can also be protected by providing a 4 pole RCCB (Fig 4).

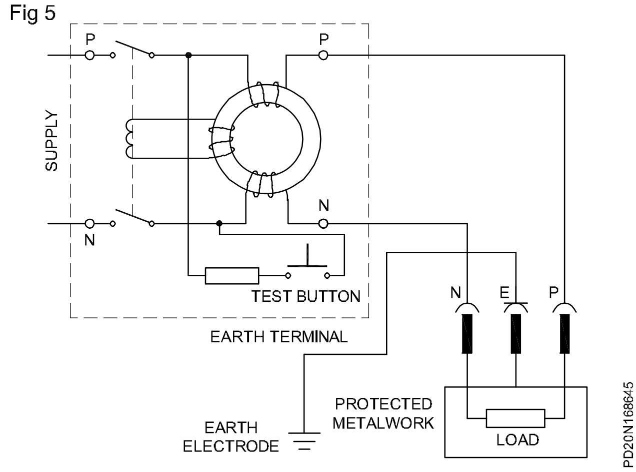
Fig 4



Test Switch

A test switch is a requirement as per BS842 (Fig 5). It is used to test the functioning of ELCB. When the test button is pressed it circulates additional current through neutral coil which is determined by the value of current limiting resistor R. As a result there exists a difference in current flowing through phase and neutral coils and hence the ELCB trips OFF.

Fig 5



Technical specification

The current ratings of ELCB are 25A, 40A and 63A.

No. of poles - 2 and 4

Nominal voltage - 240/415V 50Hz.

Sensitivities: ELCBs are designed to trip at leakage currents of 30mA, 100mA, and 300mA.

Electrical life: More then 10,000 operations.

Mechanical life:

20000 to 100000 operations.

Tripping time - < 30ms.

Time delayed RCCB

There are cases, where more than one RCCB is used in an installation, for example a complete installation may be protected by an RCCB rated at 100mA, while a socket intended for equipment may be protected by 30mA device.

Discrimination of the two devices then becomes important. For example an earth fault occurs in the equipment giving an earth fault current of 250mA. Since the fault current is higher, than the operating current of both devices, both will trip.

It does not follow, that the device with smaller operating current will trip first. This is a lack of discrimination between the two devices. To ensure proper discrimination, the device with a larger operating current, has a deliberate time delay built into its operation. It is called time-delayed RCCB. Images of 2 pole and 4 pole ELCB are given below (Fig 6).

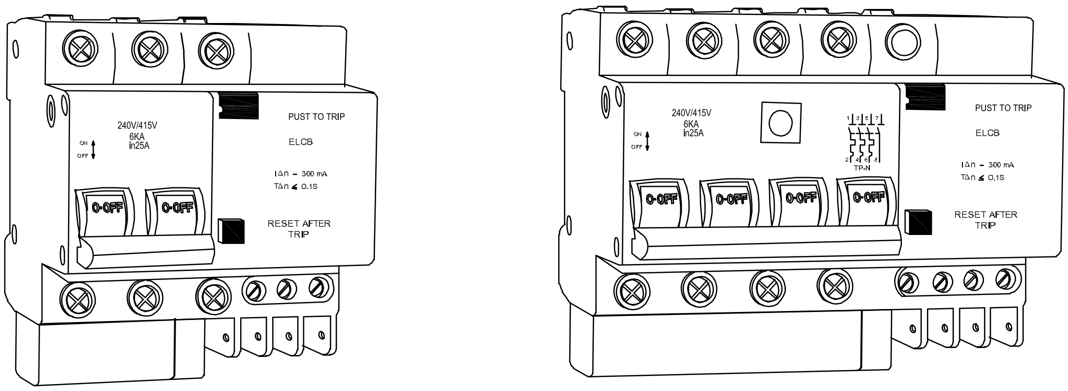
Earth fault loop impedance

Earth wire from an equipment to the earth electrode is called earth loop. Earth fault loop impedance (Z_E) is the impedance of the fault current path. It must be low enough to ensure that the productive devices like ELCB will operate within the specified time.

In any case, the multiplication value of earth fault loop impedance in Ohms and the rated tripping current (I_t)in ampere of ELCB should not exceed 50V .

$Z_E \times I_t < 50V.$

Fig 6



a) 2 POLE ELCB b) 4 POLE ELCB

Fuses

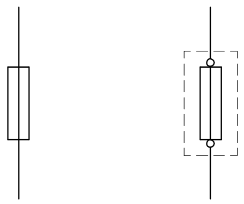
Objectives: At the end of this lesson you shall be able to
- **explain the purpose of the fuse in a circuit**
- **classify the different types of fuses and their uses.**

Purpose of fuses: A fuse is a safety device used for the purpose of protecting a circuit against excess current. In the event of excessive current, the fuse element melts and opens up the circuit thereby protecting it from damage.

Symbols: These are the graphical symbols used to illustrate an electrical fuse in electro-technical diagrams.

- General symbols of a fuse (Fig 1a)
- Fuse with terminals and protective housing (Fig 1b)

Fig 1



(a) (b)

Placement of fuses: In electrical installations, the fuses are always connected into the live wires (Fig 2) and never into the neutral N or the protective earth line PE.

Terminology

Fuse element: The part of the fuse which is designed to melt and open up a circuit.

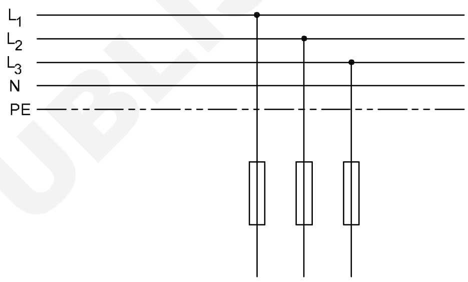
Fuse-carrier: The removable portion for carrying the fuse element.

Fuse base: The fixed part of the fuse provided with terminals for connection to the circuit which is suitable for the reception of the fuse- carrier.

Current rating: Safe maximum current that can pass continuously without overheating.

Fusing current: The current at which the fuse element melts.

Fig 2



Cut-off factor: Time (period) taken by a fuse to interrupt the circuit in the event of a fault.

Fusing factor: Ratio between minimum fusing current and current rating.

$$\text{Fusing factor} = \frac{\text{Minimum fusing current}}{\text{Rated current}}$$

The fusing factor for a re-wirable fuse varies between 1.4 to 1.7 and may go up to 2.0, but for a HRC fuse it is 1.1

However, a fuse selected for over-current protection should not have a fusing factor of more than 1.4.

Types of fuses used in domestic wiring:

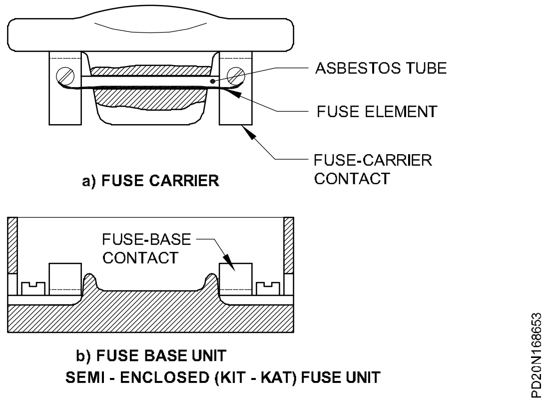
- Re-wirable type (up to 200A)
- Cartridge type (up to 1250A)

Rewirable type fuse (Fig 3): The fuse element in this type of fuse consists of a wire which may be replaced when necessary. These fuses are simple in construction and the initial cost as well as the renewal cost is very low.

The fuse elements used in this type are tinned copper wire, lead and tin alloy or aluminium wire (Table 1).

The fuse element will melt after approximately 2 minutes when carrying a current equal to twice the current rating. However, the cut-off time factor varies in rewirable fuses due to:

Fig 3



- the construction of the carrier (design of fuse-carrier/ base)
- the manner in which the fuse wire has been fitted
- the length of time the fuse was in service
- ambient temperature
- the amount of current etc.

Small fuse wires in parallel in a carrier to carry a large current should be avoided, as far as possible. The actual rating becomes less than the sum of the ratings of the individual strands. A paralleling factor of 0.7 to 0.8 is used to multiply the sum of the rating of individual strands to get the actual current rating.

Example: 35 SWG - copper wire has a fuse rating of 5 amps, and 3 strands in parallel together will a have current rating equal to 5x3x0.8=12 amps when 0.8 is taken as the paralleling factor.

Disadvantages of rewirable type fuse:

- Deterioration of the fuse element by oxidation due to heating.
- Lack of discrimination.
- Effected by the fluctuation of the ambient temperature.
- Premature failure due to deterioration under normal load.
- Low speed operation (poor cut - OFF factor).
- External flash or arc on blowing.
- Poor rupturing capacity (under short-circuit condition).
- Wrong rating possible by human error.

Rewirable-type fuses up to 16A rated current should not be used in locations where short circuit level exceeds 2 KA, (I.S. 2086-963).

Cartridge fuses: Cartridge fuses are developed to overcome the disadvantages of the rewirable fuses. As cartridge fuse elements are enclosed in an air tight chamber, deterioration does not take place. Further the rating of a cartridge fuse could be accurately determined from its marking. However, the cost of replacement of cartridge fuses is more than that of rewirable fuses.

Table 1

Current rating for	Approximate fusing current Amp	Tinned copper wire		Aluminium wire dia. in mm
		S.W.G.	Diameter in mm	
1.5	3	40	.12192	--
2.5	4	39	.13208	–
3.0	5	38	.1524	.195
4.0	6	37	.17272	–
5.0	8	35	.21336	–
5.5	9	34	.23368	–
6.0	10	33	.254	.307
7.0	11	32	.27432	–
8.0	12	31	.29464	–
8.5	13	30	.31496	–
9.5	15	–	—	.400
10.0	16	29	.34544	–
12.0	18	28	.37592	–
13.0	20	–	—	.475
13.5	25	–	—	.560
14.0	28	26	.4572	–
15.0	30	25	.508	.630
17.0	33	24	.5588	–
18.0	35	–	—	.710
20.0	38	23	.6096	--
21.0	40	–	—	–
22.0	45	–	—	.750
24.0	48	22	.7112	.850
25.0	50	–	—	.90
29.0	58	21	.8128	–
30.0	60	–	—	1.00
34.0	70	20	.9144	1.22
37.5	80	–	—	1.25
38.0	81	19	1.016	--
40.0	90	–	—	1.32
43.0	98	–	1.1176	–
43.5	100	–	—	1.40
45.0	106	18	1.2192	–
55.0	120	–	—	1.60
62.0	130	–	—	1.70
65.0	135	17	1.4224	–
66.0	140	–	—	1.80
69.0	150	–	—	1.85
73.0	166	16	1.6256	–
75.0	175	–	---	2.06
78.0	197	15	1.8288	–
80.0	200	–	—	2.24
102.0	230	14	2.032	–

Cartridge fuses can be grouped as those with a:

- low rupturing capacity (Say rupturing capacity up to 50 KA.)
- high rupturing capacity. (Say rupturing capacity above 80 KA.)

Rupturing capacity is the ability of a fuse to open the faulty circuit without much arcing or damage to itself. For domestic installations, low rupturing capacity fuses are used whereas for power installations, high rupturing capacity (HRC) fuses are used.

Low rupturing capacity cartridge fuses can be further divided into:

- Ferrule-contact cartridge fuses (Fig 4).
- diazed screw-type cartridge fuses (Fig 5).

Ferrule-contact cartridge fuses: This type, is used for protecting electrical and electronic circuits. These are available in 25, 50, 100, 200, 250, 500 milliamperes, and also in 1,2,5,6,10,16 & 32 amperes capacity.

Normally the current rating is written on one side of the cap, and while replacing, the same capacity fuse should be used. Its body is made of glass and the fuse wire is connected between two metallic caps.

This fuse can be plugged into the fuse socket (Fig 4a) or it can be fitted into a fuse base with a screw, type fuse- holder (Fig 4b).

Diazed screw-type cartridge fuses: This type of fuse is commonly used in domestic and industrial electrical installations . It consists of the following parts Fig 5.

- Screw cap or fuse cartridge-holder(1)
- Fuse cartridge(2)
- Fitting screw or contact screw(3)
- Protective plastic or ceramic ring(4)
- Fuse base or fuse socket(5)

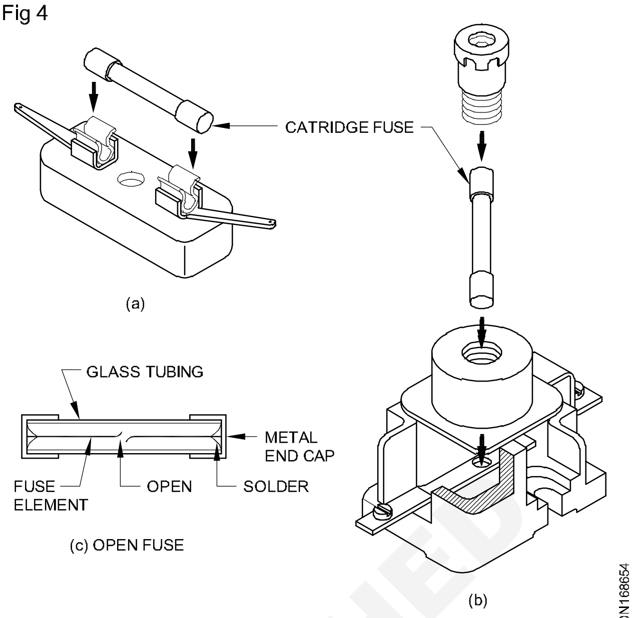
Fuse cartridges are available for rated electric currents of: 2-4-6-10-16-20-25-32-50 and 63 amperes. To prevent the insertion of a fuse cartridge having a larger current rating than intended, the foot contacts of the fuse cartridges have different diameters for each rated current(the smaller the current the smaller the diameter of the foot contact). As there is also a separate fitting screw for each type of cartridge, it is not possible to insert, let's say, a 32 amp. fuse cartridge into the fitting screw of a 25 amp fuse cartridge.

The fuse cartridges has ceramic body of the cartridge with its foot and head contacts. The two contacts are linked by a fuse wire which is embedded in sand. Each cartridge has a break indicator which will be ejected from the cartridge if the fuse wire is burnt out (Fig 6).

The parts of this fuse cartridge are

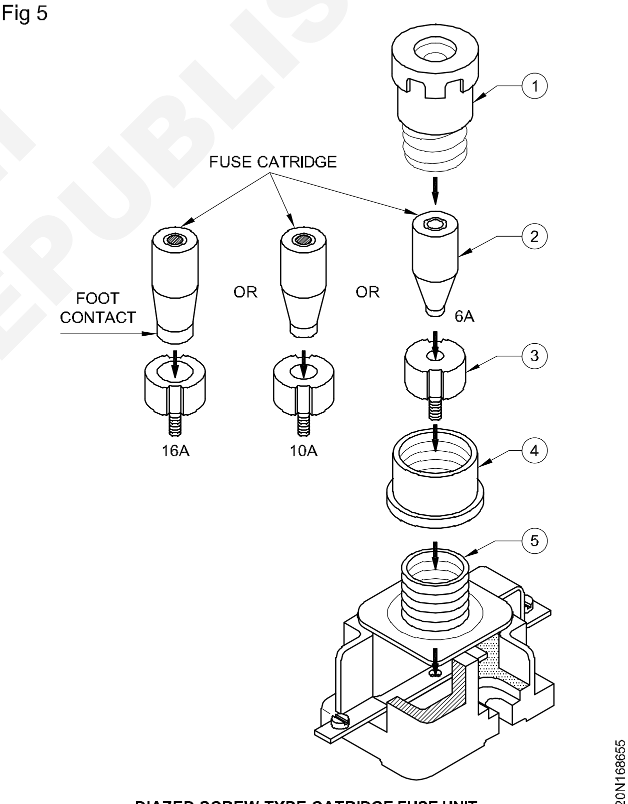
- head contact (1)
- break indicator (2)
- fuse wire (3)

Fig 4



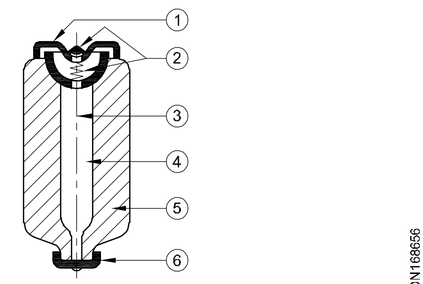
FERRULE - CONTACT CATRIDGE FUSE UNIT

Fig 5



DIAZED SCREW TYPE CATRIDGE FUSE UNIT

Fig 6

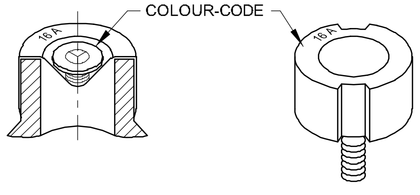


FUSE CATRIDGE

- sand filling(4)
- ceramic fuse body (5)
- foot contact (6).

For easy identification of the fuse cartridges and the corresponding fitting screws, they are marked with various colours at the places (Fig 7). For each current rating, a different colour is used.

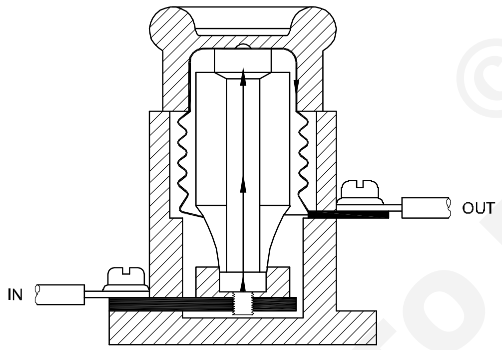
Fig 7



Pink	- 2 amperes	Blue	- 20 amperes
Brown	- 4 amperes	Yellow	- 25 amperes
Green	- 6 amperes	Black	- 32 amperes
Red	- 10 amperes	White	- 50 amperes
Grey	- 16 amperes	Copper	- 63 amperes

The flow of the electric current through the fuse base and the fuse is as shown in Fig 8. In order to prevent the accidental touching of a live line, the electrical supply must be connected to the terminal which is connected to the fixing screw at the bottom of the base.

Fig 8



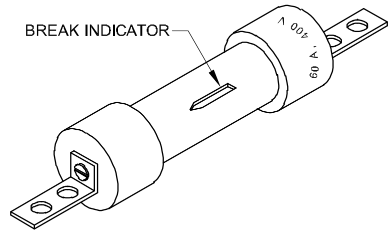
Diazed type fuses are available in two categories, a)quick-response type and b) delayed-action type. The quick-response type is used for heating circuits and normal loads whereas the delayed- action type is used for motor circuits and highly inductive circuits.

High rupturing capacity (HRC) fuses (Fig 9): They are cylindrical in shape and are made of a ceramic body filled in with a chemically treated filling powder or silica to quench the arcing quickly without any fire hazard.

Normally a silver alloy is used as the fusing element and when it melts due to the excessive current, it combines with the surrounded sand/powder, and forms small globules without making an arc, spark or gas. HRC fuses can open a short-circuited circuit within 0.013 second. It has an indicator to show the fuse has blown. The rupturing capacity of the fuse could be calculated from the following formula.

$$\text{Rupturing capacityin MVA} = \frac{\text{Fault current in amperes} \times \text{Circuit voltage}}{10^6}$$

Fig 9



As HRC fuses are capable of opening circuits having very high faulty currents, these are preferred in high power circuits even though the replacement cost is high.

Comparison between HRC & Rewirable fuses

Factor	Rewirable	HRC fuse
Rupturing capacity	Not recommended for currents exceeding 200 A or for more than 600V or where there is a possibility of S.C. fault of more than 5 MVA.	Normal types cater to fault loads up to 2500 KVA. For certain appli-tions, fuses up to 50 MVA are obtainable.
Rupturing speed(Cut-off factor)	Rating and cut-off are not absolutely reliable.	Very rapid. Usually AC supply current is cut off within the first half cycle.
Discrimi-nation	Poor.	Accurate.
Safety in operation	Risk of flash-over under heavy fault condition.	No external flame.
Deterio-ration	Oxidation and conse-quent scaling causes reduction in the cross-sectional area, thus increasing resistance, and leading to over-heating and premature rupturing.	No oxidation. The element is completely sealed.
Fusing factor	Copper wire upto 20A -1.7. Over 20A- 2.0.	As low as 1.1.

Relays - types - symbols

Objectives: At the end of this lesson you shall be able to
- **define a relay and classify the relays**
- **classify relays according to the operating force and function**
- **state the common codes used for specifying contacts and poles**
- **specify a relay**
- **explain the function of the shading coil in an AC relay**
- **state the causes of the failure of the relay**
- **identify the symbols used in relay as per I.S.2032 (Part XXVII).**

Relay: A relay is a device which opens or closes an auxiliary circuit under predetermined conditions in the main circuit.

Relays are extensively used in electronics, electrical engineering and many other fields.

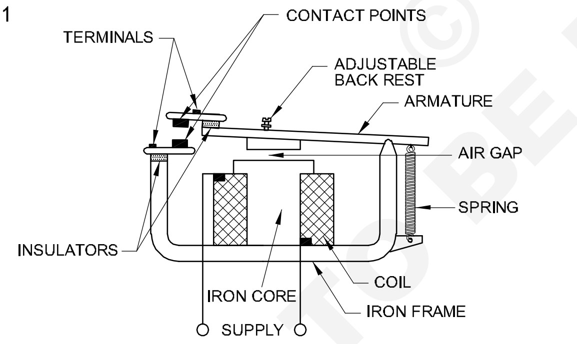
There are relays that are sensitive to conditions of voltage, current, temperature, frequency or some combination of these conditions.

Relays are also classified according to their main operating force as stated under.

- Electromagnetic relays
- Thermal relays

Electromagnetic relay: A relay switch assembly is a combination of movable and fixed low-resistance contacts that open or close a circuit. The fixed contacts are mounted on springs or brackets, which have some flexibility. The movable contacts are mounted on a spring or a hinged arm that is moved by the electromagnet in the relay (Fig 1).

Fig 1



ELECTRO MAGNETIC RELAY

The other types of relays coming under this group are as follows.

Current sensing relay: A current sensing relay functions whenever the current in the coil reaches an upper limit. The difference between the current specified for pick up (must operate) and non-pick up (must not operate) is usually closely controlled. The difference in current may also be closely controlled for drop out (must release) and non-drop out (must not release).

Under-current relay: Under-current relay is an alarm or protective relay. It is specifically designed to operate when the current falls below a predetermined value.

Voltage sensing relay: A voltage sensing relay is used where a condition of under-voltage or over-voltage may cause a damage to the equipment. For example, these types of relays are used in voltage stabilizers. Either a proportional AC voltage derived from a transformer or a proportional DC derived from a transformer and rectifier used for this purpose.

Latching relays

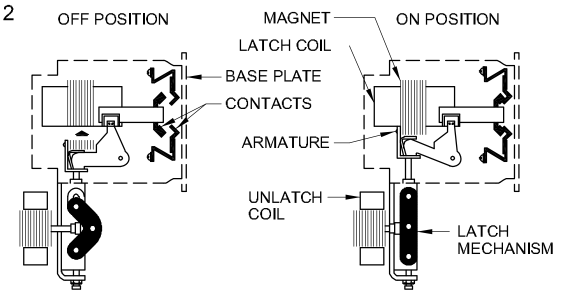
Latching relays are capable of maintaining their contacts in the last assumed position without the maintained current in the coil. These relays hold their contacts in position after power is cut off.

There are two basic kinds of latching relays called mechanical reset and electrical reset.

Mechanical re-set relays: Mechanical re-set relays have a coil, an armature mechanism, and a mechanical latching device that locks the armature in the operated position after the coil has been de-energised. Manual tripping of the locking mechanism, re-sets the relay.

Electrical reset relays: An electrical re-set relay (Fig 2) has the same operating mechanism, but it includes a second coil and armature to trip the latching mechanism. This system allows remote re-setting of the relays to their original position.

Fig 2



LATCH RELAY ELECTRICAL RE-SET TYPE

Reed relays

Reed relays physically look different than other kinds of relays. They consist of essentially magnetically actuated reed switches, with actuating solenoids or coils.

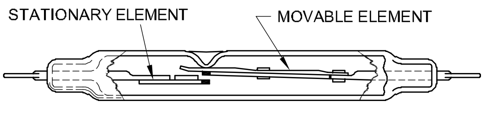
In the reed relay, freedom from contamination and the limited number of moving parts, avoid many disadvantages of the conventional electromechanical relays. In addition to the above, the contact resistance is kept to minimum due to the fact the contact points are made either with gold or rhodium. Further, these relays need very low power to operate and can handle a 250 watt solenoid load on their contacts.

There are three types of reed relays namely

- dry-reed relay
- ferreed relay
- mercury wetted contact relay

Dry reed relay: Two opposing reeds are sealed in to a narrow glass tube (Fig 3). The reeds overlap at their free ends. At the contact area, they are usually plated with gold or rhodium to produce a low contact resistance. They may have multipole multicontact designs.

Fig 3

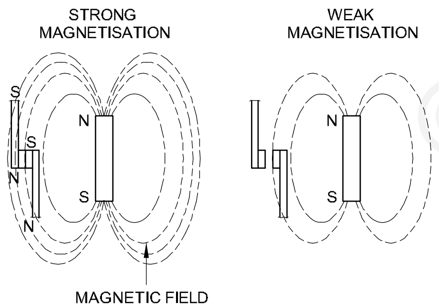


DRY REED RELAY

Ferreed relay: The word ferreed denotes a reed relay in which the dry-reed switch is contained with one or more magnetic members. The magnetisation can be changed by current pulses in associated coils.

In the magnetised state the magnetic members supply a field strong enough to close the contacts. In the other magnetised state, the field is too weak to hold the contacts closed (Fig 4). An operating pulse through the coil produces the first state. A release pulse produces the second state. The contacts can break or make within 5 micro-seconds duration.

Fig 4

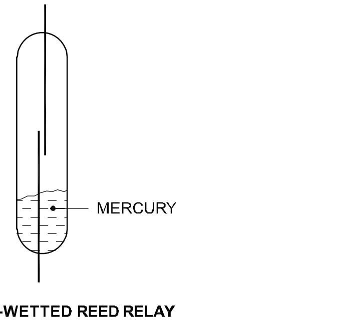


Mercury wetted contact relay: This relay consists of a glass enclosed reed with its base immersed in a pool of mercury (Fig 5) . When the coil surrounding the capsule is activated, mercury makes the contact between fixed and movable contacts.

Impulse relay: The impulse relay (Fig 6) is a special single-coil relay. It has an armature-driven mechanism that alternatively assumes one of two positions as the coil is pulsed. This mechanism moves the contact from one position to the other and back again as electrical pulses are received. The relay can operate on AC or DC power.

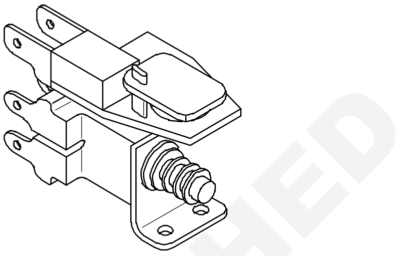
Clapper-type armature relay: The simplest contact arrangement used in armature relays is the break-make or transfer-contact combination. A clapper-type armature, (Fig 7) opens or closes the contacts. A movable contact is attached directly to the armature by means of a flexible strip of metal. When the electromagnet operates, the armature moves this contact, opening and closing the two sets of contacts.

Fig 5



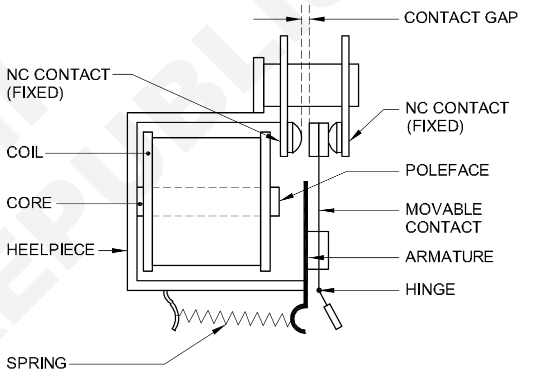
MERCURY-WETTED REED RELAY

Fig 6



IMPULSE RELAY

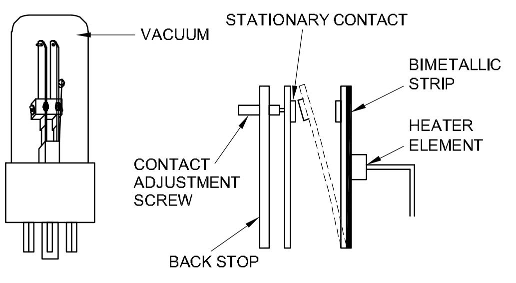
Fig 7



Thermal relay: A thermal relay (Fig 8) is one that operates by changes in temperature. Most of the bimetallic relays where the bimetallic element changes its shape, in response to changes in temperature comes under this group.

It takes time for the heating element to reach the necessary temperature and more time to raise the temperature of the bimetallic element. Therefore, thermal relays are often used as time-delay relays.

Fig 8



Poles and contacts: Relays may operate single or as multi-poles and may open or close specified contacts. In writing specifications certain abbreviations as stated below are commonly used.

SP - Single pole

SB - Single break

ST - Single throw

DB - Double break

DP - Double pole

DM - Double make

DT - Double throw

NO - Normally open

3P - Three pole

NC - Normally closed

4P - Four pole

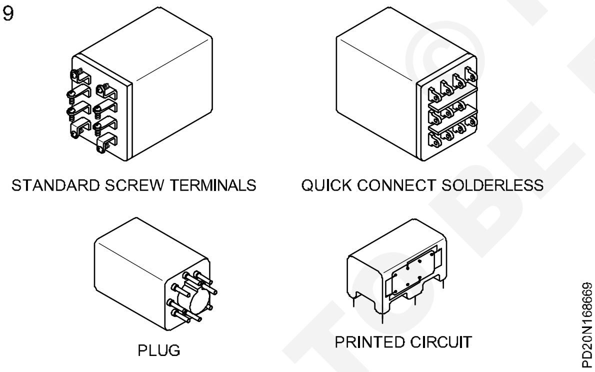
For example a 4PDT has a four-pole, double throw contact arrangement.

NO indicates the contacts are open in the unoperated position of the relay and they are called as normally open (NO) contacts.

NC indicates the contacts are closed in the unoperated position of the relay and they are called normally closed (NC) contacts.

Enclosures and mounts: Relays are normally enclosed in plastic or metal caps to protect the operating parts against dust and environment. Relays can be mounted to the circuit direct by plug-in system, PCB mounting or may be wired separately using screws terminals (Fig 9).

Fig 9



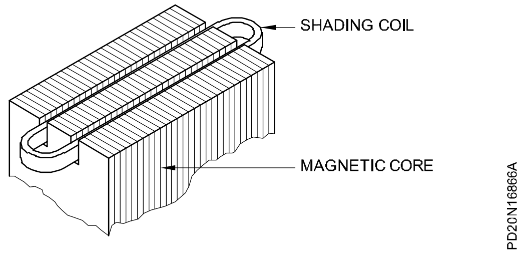
AC relay: In an AC relay magnet, the magnetic field continually changes direction. With a 50 Hz supply the magnetic field passes through zero 100 times per second. At the time of zero field, the armature starts to release. Although the field quickly builds up in the reverse direction, a noisy chatter can result.

To eliminate chatter, a shading coil (Fig 10) is placed near the tip of the magnet pole face. This shading coil establishes a magnetic field that lags the main magnetic field slightly and aids in keeping the magnet sealed when the main field passes through zero.

An AC relay should not be used in DC supply.

The AC relay when connected to DC supply, will draw more current in the absence of inductive reactance and result in burning out the coil.

Fig 10



Causes of relay failures: Relay failures are usually caused by the gradual deterioration of the parts. This deterioration can be electrical, mechanical or chemical in nature.

The environmental shirks that contribute to physical breakdown include large temperature changes, shock, vibration and voltage or current changes. Therefore, it is important that these factors are taken into consideration to ensure reliable performance of relays.

In general, when a relay fails, look for the following.

1 Improper control voltage.

2 Dirt, grease or gum on contacts or moving parts.

3 Excessive heating of parts: discolouration or charred insulation on coil or base.

4 Bending of moving parts.

5 Corrosion or deposits on metal parts.

6 Excessive wear on moving parts.

7 Loose connections.

8 Improper spring tension.

9 Improper control pressure.

10 Improper functioning of the time delay device.

While specifying relays the following particulars are necessary.

Type of operating voltage

AC or DC

Sequence of operation ______________________

Operating voltage ______________________ volts

Current rating ______________________ amps

Coil resistance ______________________ ohms

Number of contacts __________ NO __________ NC

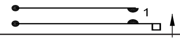
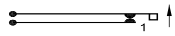
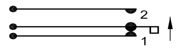
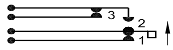
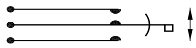
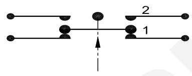
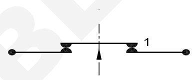
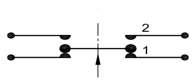
Number of poles ______________________

Type of mount ______________________

Type of enclosure ______________________

Table 1 given below lists some of the relay contact combinations.

Table 1

Design	Sequence	Symbol
1 SPST-NO	Make 1	
2 SPST-NC	Break 1	
3 SPDT	Break1 before make 2	
4 SPDT	Make 1 before break 2	
5 SPDT (B-M-B)	Break 1 before make 2 before break 3	
6 SPDT-NO	Center OFF	
7 SPDT-NC-NO (DB-DM)	Double break 1 double make 2	
8 SPST-NO (DM)	Double make 1	
9 SPST-NC (DB)	Double break 1	
10 SPDT-NC (DB-DM)	Double break 1 double make 2	

NE code Mounting accessories - specification of wooden boards and blocks

Objectives: At the end of this lesson you shall be able to
- **state the National Electrical Code of Practice with respect to mounting accessories and boards**
- **specify the wooden round blocks and boards for mounting electrical accessories.**

Recommendations of the National Electrical Code for mounting the accessories on the boards

When electrical accessories are to be mounted on the boards, the following National Electrical Code recommendations should be adopted.

- All ceiling roses, brackets, pendents and accessories shall be mounted on substantial wooden blocks, having a depth of not less than 4 cm.
- Where teak or hardwood boards are used for mounting switches, regulators etc., these boards shall be well varnished with pure shellac on all sides (both inside and outside), irrespective of being painted, to match the surroundings. The size of such boards shall depend on the number of accessories that could be conveniently and neatly arranged.
- No mounting of accessories shall be done within 2.5 cm of any edge of the panel of the board, and no hole other than the holes by means of which the panel is fixed shall be drilled closer than 1.3 cm from any edge of the panel.
- A switchboard shall not be installed with its bottom within 1.25 m above the floor unless the switchboard is enclosed in a box with locking arrangement.
- If the switchboards are recessed in the wall, the front shall be fitted with a hinged panel of teakwood or other suitable material, such as bakelite, or fitted with an unbreakable glass door in teakwood frame.
- Open type switchboards shall not be placed in the vicinity of storage batteries or exposed to chemical fumes.
- Switchboards shall not be erected above gas stoves or sinks, or within 2.5 m of any washing unit in the washing room.
- Unnecessary crossing of connections should be avoided between apparatus and terminals, within the board.
- In a hinged type board, the incoming and outgoing cables shall be fixed at one or more points according to the number of cables on the back of the board, leaving suitable space in between the cables, which shall also,

if possible, be fixed at the corresponding points on the switchboard panel. The cables between these points shall be of such length as to allow the switchboard panel to swing through an angle of not less than 90°.

Specification of commercially available boards, round blocks for mounting electrical accessories

The boards which are used for wiring installation are available in different sizes, made up of teak wood, P.V.C. or metal. When selecting the boards, the following points are to be considered.

Size of the board: The number and type of accessories to be mounted on the board decide the size of the board. After selecting the accessories to be mounted on the board, the layout may be formed on a cardboard template, and then the size of the board may be determined.

System of wiring: This decides whether boards should be placed on the surface of the wall or flush-mounted. Accordingly, a single or hinged board could be selected. However, depending upon the system like batten or metal conduit or PVC conduit, the board may be made of wood, metal or PVC respectively.

Place of wiring : This is another deciding factor to choose the material of the board. For indoors we may use board of any material depending upon the system of wiring.

Specification for blocks and boards

While specifying the boards for wiring installation, the following particulars shall be given.

- Material of the board - wood, PVC or metal.
- Size - length, breadth and height in mm.
- Thickness of the material in mm.
- Single or double (double-hinged or non-hinged type).
- Additional information like type of finish on wooden boards, colour of PVC or metal boards, surface or flush mounting etc.

T.W. round blocks: For specifying the round blocks, its overall diameter and thickness have to be given. Single and double (with base block) round blocks are available. Nowadays, P.V.C. blocks are also in use. The following sizes are available commercially. The first dimension denotes the overall diameter, and the second dimension denotes the thickness of the block.

Round blocks - single	Round blocks - double
75 mm x 25 mm	75 mm x 35 mm
75 mm x 40 mm	75 mm x 40 mm
90 mm x 25 mm	90 mm x 35 mm
90 mm x 40 mm	100 mm x 35 mm
100 mm x 25 mm	100 mm x 40 mm
100 mm x 40 mm	

Instead of round blocks, square blocks are also available. For certain special purposes hexagonal shape blocks are also used. According to the code of practice, the minimum thickness of round blocks should be 40 mm.

T.W. boards

For fixing two or more accessories on one board or for fixing accessories like fan regulators, D.P. switches etc. T.W. boards are used. Generally, the following sizes of boards are available commercially, in teak wood, PVC or metal.

The minimum thickness of non-hinged boards should be 40 mm whereas for hinged boards the thickness varies from 65 to 80 mm.

Specification: Metric System

Length Breadth	Length Breadth
100 mm x 100 mm	300 mm x 250 mm
150 mm x 100 mm	380 mm x 450 mm
150 mm x 150 mm	450 mm x 250 mm
200 mm x 150 mm	450 mm x 300 mm
200 mm x 200 mm	600 mm x 300 mm
250 mm x 200 mm	600 mm x 300 mm
300 mm x 200 mm	750 mm x 600 mm

Through and pilot holes - wood-machine screw specifications

Objectives: At the end of this lesson you shall be able to
- **determine the size of through holes, with respect to the cable size and the number of cables**
- **state the method of making pilot holes using a bradawl or gimlet or by undersized drills**
- **specify wood screws and machine screws.**

Determining the through hole size according to the cable size and number of cables

While drilling holes in the boards for cable entry, the overall diameter of the cable has to be known. The overall dia. of the cable may vary according to the type of insulation used, and also from one manufacturer to another. Further the size depends upon the voltage grading. Hence the best practice is to take a piece of the cable, measure the overall size and select a suitable drill so that the cable enters the hole freely. When the number of cables to be inserted is more than one, the drill size may be selected accordingly.

The overall dia. and the overall sizes of the cables are indicated in Table 1.

Example: Referring to Table 1 it is found that for a 2.5 sq.mm. size conductor of the cable, the diameter of the cable (including insulation) is 4.6 mm. Hence, the hole size

TABLE 1
Sizes of conductors

Conductor of cables		Approximate overall dia . of cables	
Normal area in mm^2	Number and dia of wire in mm	250V grade in mm	660 V grade in mm
1.5	1/1.40	4.20	5.40
2.5	1/1.80	4.60	6.00
4.0	1/2.24	5.25	6.80
6.0	1/2.24	6.00	7.35
10.0	1/3.55	7.10	8.10
16.0	7/1.70	8.85	9.65
25.0	7/2.24	10.80	11.50
35.0	7/2.50	11.75	12.25
50.0	7/3.00	13.40	13.90
70.0	19/2.24	---	16.70
95.0	19/2.50	---	19.10

can be determined as 5 mm dia. and the drill required is of 5 mm dia.

The method of making pilot holes in wood using bradawl and gimlet

Pilot holes should always be made in the wood, when using wood screw for fixings so that the screw can be driven securely into the wood without damaging the wood, and is fixed with less effort.

First, position the accessories to be fitted on the board according to the layout and also to meet the aesthetic requirements. Open the cover and identify the placeswhere the pilot holes are to be made. The usual practice is to identify the cable entry 'through holes' and the screw fixing 'pilot holes' with different distinct markings.

Use a bradawl for making the pilot holes in softwood. If a gimlet is chosen, it should not be bigger than the wood screw proposed to be fitted. Pilot holes can be made in softwoods for screws up to size 6. For larger sized screws and for harder woods, pilot holes can be made best by a gimlet, or a second choice is by drilling undersized holes.

Select the correct size of drill for pilot holes: Drill sizes should be about 2 mm smaller in diameter than the diameter of the screw shank.

Drill hole to correct depth: In softwoods - hole depth equals 1/2 screw length.

In hardwoods - hole depth equals screw length.

For secure fixings it is important not to drill holes too deep.

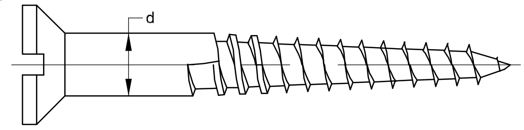
Wood screws: These screws have a single spiral of thread running from the point, clockwise for about two thirds of the length. The unthreaded part is called the shank, and gives the 'screw number' (Designation number).

Types of wood screws

Wood screws are classified with respect to the shape of the heads. Accordingly 3 types of wood screws are used for wiring installation.

Slotted countersunk head wood screws (Fig 1): This type of screws is used for general wood work for fitting miscellaneous hardware.

Fig 1



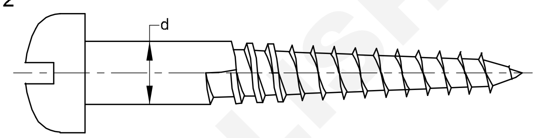
SLOTTED COUNTERSUNK HEAD WOOD SCREW

PD20N168671

In electrical wiring for fixing wooden blocks, boards, battens and electrical accessories, countersunk holes should be used. The screw shall be driven until the head is flush with the work or slightly below surface.

Slotted round head wood screws (Fig 2): This type of wood screws is used for surface work, for installing electrical fittings and accessories where fitting holes are not countersunk.

Fig 2

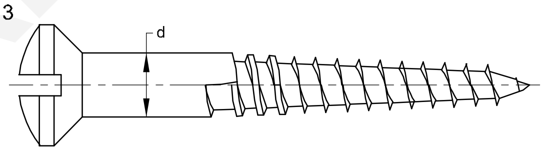


SLOTTED ROUND HEAD WOOD SCREW

PD20N168672

Slotted raised countersunk head wood screws (Fig 3): Raised countersunk wood screws are used for fixing decorative electrical fittings. Even for fixing flush type electrical accessories on T.W. board or box, raised countersunk wood screws are used.

Fig 3



SLOTTED RAISED COUNTERSUNK HEAD WOOD SCREW

PD20N168673

Of the three types of screws listed above, countersunk (flat head) screws are commonly used for electrical wiring installations.

Designation of wood screws: Wood screws shall be designated by the screw number, length, type of head and material. Table 2 gives the designation number, shank diameter available and length for slotted countersunk wood screws.

Example 1: A slotted countersunk head wood screw of shank 4.17 mm dia. length 20 mm, made of steel shall be designated as

Wood screw No. 8 x 20 countersunk steel (or)

Wood screw No. 8 x 20 I.S. 6760 steel.

The preferred length and screw number of countersunk wood screws are given in Table 2.

Example 2: A slotted round head wood screw of shank, 3.45 mm dia. length 30 mm, made of steel shall be designated as

Wood screw No.6 x 30 round head steel or

Wood screw No.6 x 30 I.S. 6739 steel.

Example 3: A slotted raised countersunk head wood screw of 2.08 mm dia. length 12 mm, made of steel shall be designated as

Wood screw No.2 x 12 raised countersunk steel, or

Wood screw No.2 x 12 I.S. 6736 steel.

Selection of the correct type, size and length of screws: Note the surface finish on the fixture at the fixing point, where a recess is provided. Select a countersunk screw; if not, select a round head screw.

Check the size of the hole in the fixture, then select a screw with a screw shank diameter equal to the hole size.

Decide on the length of the screw from the thickness of the fixture, and the thickness of the wood that the fixture is to be fixed in.

Screwing methods

In softwood: Locate the fixture and screw over the hole and tighten the screw.

In hardwood: Locate the screw in the hole and drive the screw for atleast 5 turns. Withdraw the screw, then locate the fixture and screw over the hole and tighten the screw. When the fixture has more than one fixing hole prepare the uppermost hole, and allow the fixture to hang from its fixing screw while the other fixing screws are located and then tightened.

Precautions to be adopted while fixing wood screws

- Before fixing the wood screws, the tip of the screws must be coated with rust-preventing material such as soap, wax etc.

Screws should never be hammered.

- Use a proper screwdriver which fits as closely as possible in the slots of the screws.
- Do not use a high-leverage screwdriver for fixing small screws.
- Pilot holes should be made, before fixing the wood screws.

Advantages of screws over nails

Screws provide for a more secure fixing than is possible with nails, and have the further advantage that they may be loosened or tightened as required. Screws can be made from rust-proof and corrosion-resistant materials, like brass, stainless steel, aluminium alloy, bronze etc.

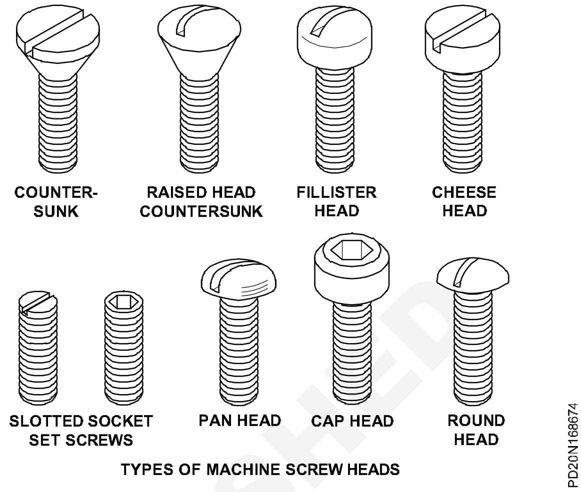
Machine screws: Machine screws are used for securing component and assembly work.

These screws should normally be screwed into tapped holes or used with nuts.

Types of machine screw head

Machine screws are mainly classified with respect to the shape of heads.The different types of screw heads in general use is given below (Fig 4).

Fig 4



TYPES OF MACHINE SCREW HEADS

Application: The cheese head type of screws is used for general assembly work.

Flush fitting screws are used when there is little clearance between assemblies or where protruding heads are not desirable.

The semi-flush type is used mainly for panel assembly or where a pleasing appearance is required.

Types of threads

Various types of thread screws are available.

Metric threaded screws: These screws are normally specified with alphabet `M'. M4, where `4' denotes the diameter of the screw in mm, and M denotes the type of thread in metric. Hence `M4 x 20' is a machine screw of metric thread having 4 mm dia. and 20 mm length.

BA (British Association) threaded screws: These screws are specified with the letters `BA'.

Unified national threaded screws (UNF): These screws are specified as `UNF' i.e. `Unified National Fine' or `UNC' i.e. `Unified National Coarse'.

Self-tapping screws: These are also called `Thread forming tapping screws'. They are specified in screw size and number, similar to the wood screws.

Specification: While specifying a machine screw, it is essential to mention the head type, screw length and the thread type.

Table 2

Screw No.	Nominal diameter of un- threaded shank in mm.	Preferred length in mm															
		8	10	12	15	20	25	30	35	40	45	50	55	60	65	70	75
0	1.52	✓	✓	✓													
1	1.78	✓	✓	✓													
2	2.08	✓	✓	✓													
3	2.39	✓	✓	✓													
4	2.74			✓	✓	✓	✓										
5	3.10			✓	✓	✓	✓	✓									
6	3.45			✓	✓	✓	✓	✓	✓	✓							
7	3.81			✓	✓	✓	✓	✓	✓	✓							
8	4.17			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
9	4.52				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
10	4.88				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Types of wiring : Domestic and Industrial - selection of cable size

Objectives: At the end of this lesson you shall be able to
- **state the types wiring used in domestic installations**
- **state the use of cord grip and underwriter's knot.**

Introduction

The type of wiring to be adopted is dependent on various factors viz. location durability, safety, appearance, cost and consumer's budget etc.

Types of wiring

The following are the types of internal wiring used in domestic installations.

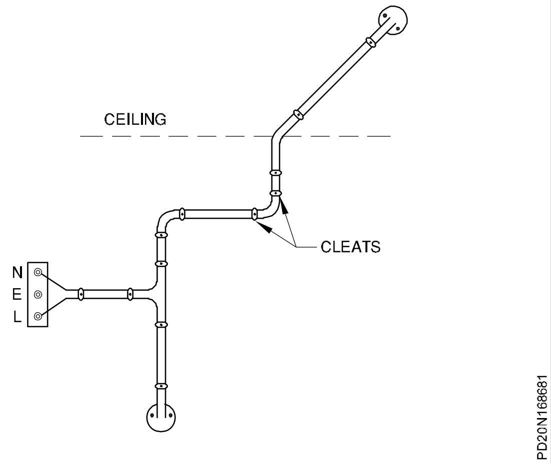
- Cleat wiring (for temporary wiring only)
- CTS/TRS (batten) wiring
- Metal/PVC conduit wiring, either on surface or concealed in the wall.
- PVC casing & capping wiring

Cleat wiring

This system uses insulated cables supported in porcelain cleats (Fig 1).

Cleat wiring is recommended only for temporary installations. These cleats are made in pairs having bottom and top halves (Fig 2). Bottom half is grooved to receive the wire and the top half is for cable grip.

Fig 1

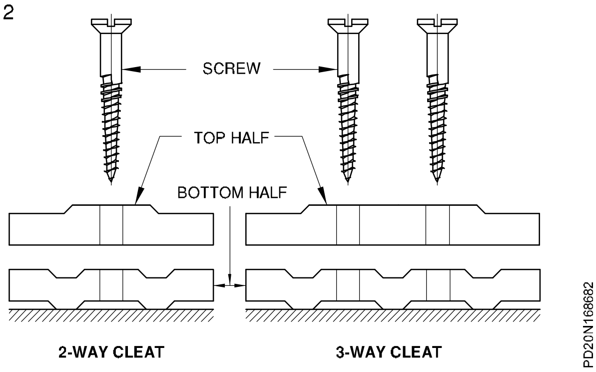


Initially the bottom and top cleats are fixed on the wall loosely according to the layout. Then the cable is drawn through the cleat grooves, and it is tensioned by pulling and the cleats are tightened by the screw.

The cleats are of three types, having one, two or three grooves, so as to receive one, two or three wires.

Cleat wiring is one of the cheapest wirings considering the initial cost and labour, and is most suitable for temporary

Fig 2



wiring. This wiring can be quickly installed, easily inspected and altered. When not required this wiring could be dismantled without damage to the cables, cleats and accessories. This type of wiring may be done by semi-skilled persons.

Cord grip and underwriter's knot

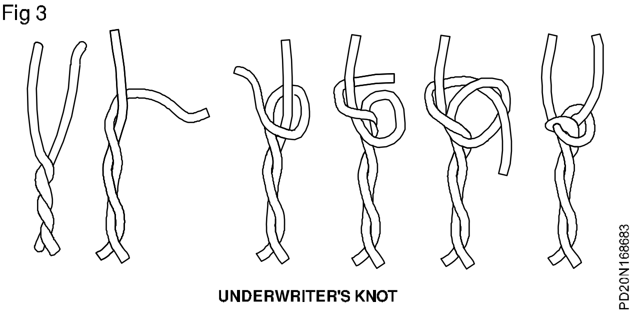
When a lamp or lamp with its shade is hung from the ceiling, the flexible cable connected to the lamp-holder is subjected to mechanical stress due to the weight of the lamp-shade and the lamp.

If the stress is not removed, the cable connection may come out of the terminals and result in shock hazards. To relieve the strain from the terminals of pendants, lamp-holders and ceiling roses, a cord grip or an underwriter's knot is used. A cord grip or underwriter's knot is also used in pull switches and other portable appliance connectors.

Underwriter's knot (Fig 3)

A knot is made on twin-twisted or twin-core flexible cable inside the accessories' cap cover.

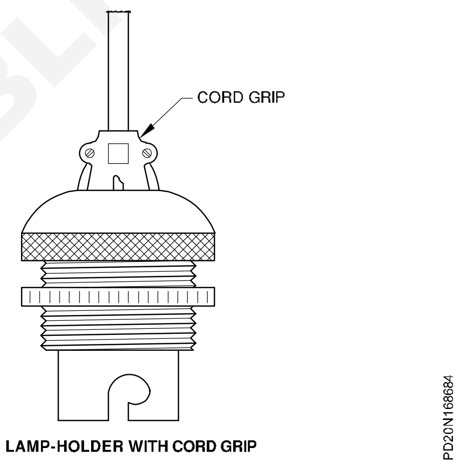
Fig 3



Cord grip (Fig 4)

In some of the electrical accessories like lamp-holders, appliance connectors, plug pin tops etc. a cord grip arrangement is provided. These are an effective means of relieving the terminals from strain due to pulling or twisting of the cord.

Fig 4



Types of Power wiring

Objectives: At the end of this lesson you shall be able to
- **explain the types of electrical wiring and their application**
- **state the advantages and disadvantages of each types.**

Many wiring systems are developed to meet the safety requirements, economy of cost, easy maintenance and trouble shooting. A particular system can be chosen according to technical requirements but the system needs to be approved by the local electricity authorities. The following are the fundamental requirements for any wiring system. They are:

i For safety, switches should control the live phase wire. The second terminal of the switch called as half wire should be connected to the appliance or socket through the wire. The neutral can be connected directly to the appliance, socket or lamp. This enables the workman to rectify the defects of the particular lamp or appliance by switching off the particular circuit only and the main supply need not be switched 'off'.

ii For safety, fuses should be placed in the live/phase wire only. The lamp should not get supply when the fuse is blown.

iii To supply the rated voltage, parallel connections should be given to all lamps and appliances.

Types of wiring system: There are three types of wiring systems used for tapping supply from mains to the different branches. They are as follows.

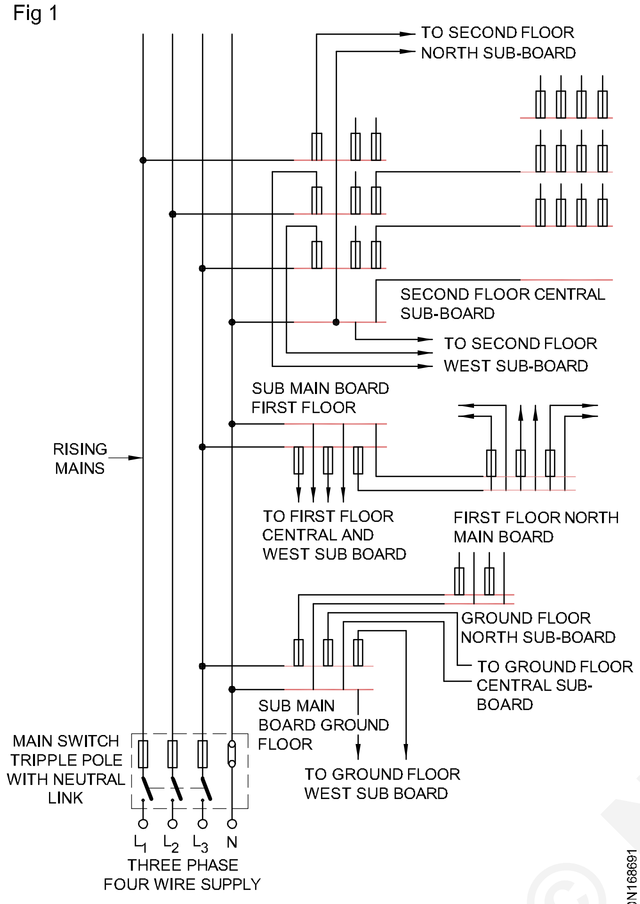
1 Tree system

2 Ring main system

3 Distribution board system

Tree system: In this system, copper or aluminium strips in the form of bus bars are used to connect the main supply to the raising mains (Fig1). This system is suitable for multi-story buildings and the bus bar trunking space is provided in the building at a convenient location and at load centres for the purpose of economy.

Fig 1



WIRING OF BUILDING BY TREE SYSTEM

At each floor the running main is connected to the sub-main board through proper cable terminations. If there are more than one flat in each floor the individual main switches for the flat get their supply from the sub-main board through a distribution network which may include an energy meter for each flat.

However the system adopted within the flat will be the distribution board system.

Advantages

1 The length of the cables required for installation will become less. Hence, the cost is less.

2 This system is suitable for high rise buildings.

Disadvantages

1 The voltage across the appliances which are at the farthest end of the tree system may be less when compared to the one connected to the nearest end if the bus bars size is not of sufficient size.

2 As fuses are located at different places, fault location becomes troublesome.

3 When aluminium bus bars are used for economic considerations, the tappings can become loose and interrupt power supply.

Ring main system: This system consists of two pairs of cables of size 4 or 6sq.mm which run through the rooms and are brought back to the main or sub-board (Fig 2 and 3). Tappings are taken for sockets or ceiling roses from the pair of cables through fuses and controlling switches. There may be saving of copper used because the current can be fed from both sides. As this system requires special sockets or plugs with fuses it becomes costly; and hence rarely used in India.

As per IEE regulations one ring circuit has to be there for every 100 sq metres of the floor area or part thereof. The number of power plugs fed from branch lines (spurs) should not exceed two and the total current should not exceed 30 amps. Protection for individual power plug can be provided by having built-in-fuses with the individual power plugs or by having MCB type switch and socket arrangement.

Distribution board system: This is the most commonly used system. This system enables the appliances connected to the system to have the same voltage. The main switch is connected to the distribution board through suitable cables. The distribution board has a number of fuses depending upon the number of circuits required in the installation, and the phase and neutral cable of each phase are taken from the distribution board (Fig 4).

As each circuit can have power up to 800 watt, the phase wire which is taken from the circuit fuse of the distribution board is looped to the other light switches or fan switches of the same circuit by any one of the following ways.

Fig 2

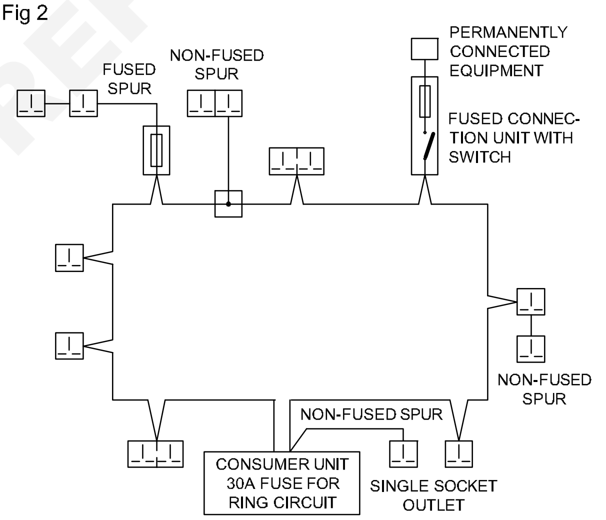


Fig 4

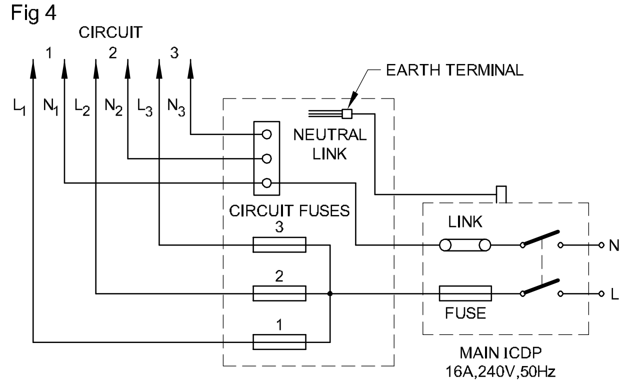
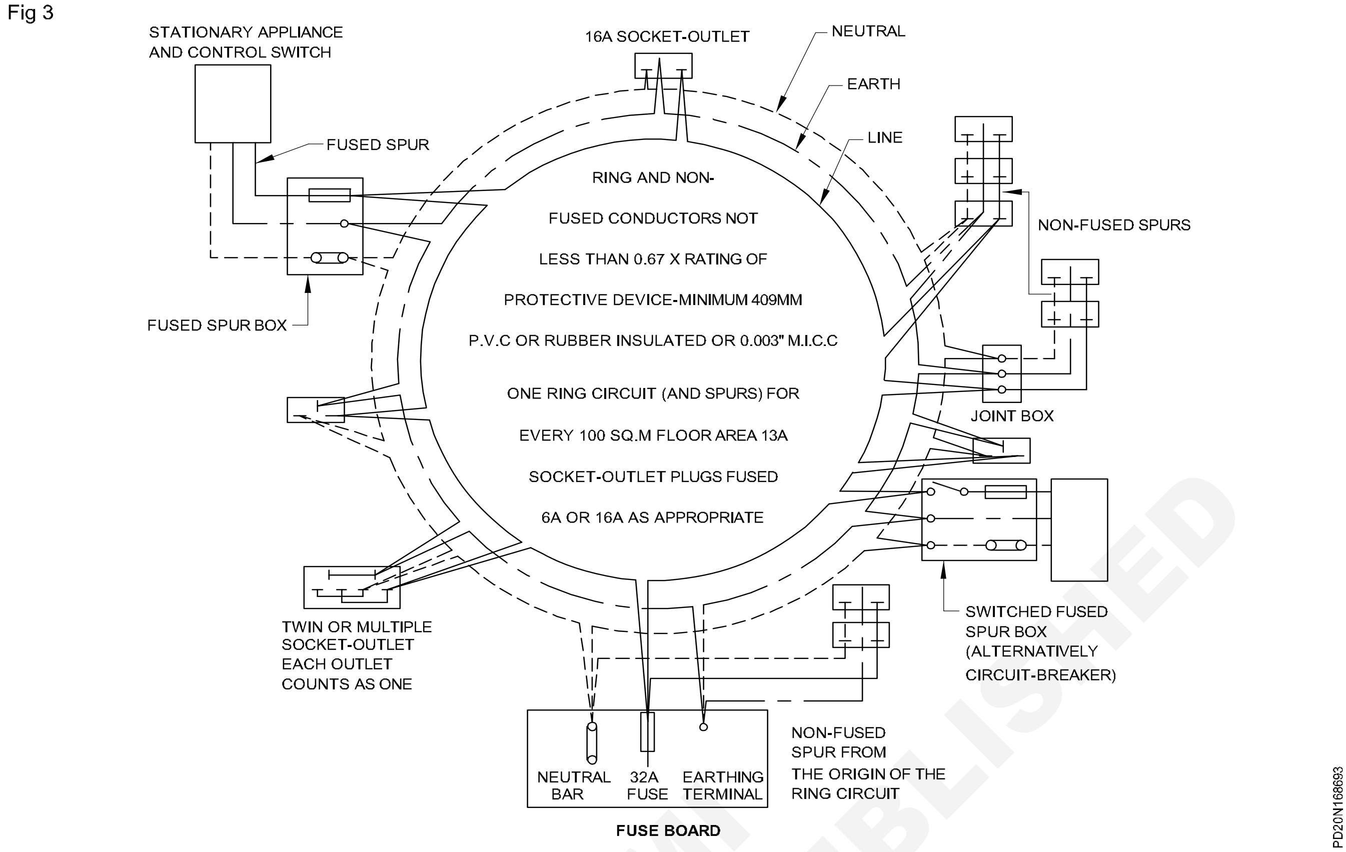


Fig 3



No joint is allowed in the cable route except in switches, ceiling roses and joint boxes.

a Looping out from switch and ceiling rose: Fig 5 shows the simple looping in method which is commonly employed. The phase wire which is connected to the terminals of the switch is looped out to the next switch and so on, whereas the neutral wires are looped together from ceiling roses (Fig 5). Cable consumed in this system is very high.

b Looping out from switch: This system employs special switches having two terminals and one connector (Fig 6). Both the phase and neutral cables are taken to the switch for looping the cables. As these accessories are not commonly manufactured in India such a system is not used.

c Looping out from 3-plate Ceiling roses: In this type of system, three terminal ceiling roses need to be used (Fig 7). As this system uses less cables when compared to (a), this system is in use in some parts of India.

d Looping out with junction box: In this system a pair of conductors from the distribution board is brought to the junction box and tappings are taken to switches, two plate ceiling roses as well as other points from the junction box are shown in Fig 8. This method may be economical for lodges where a row of rooms are constructed on either side of a common corridor.

Fig 5

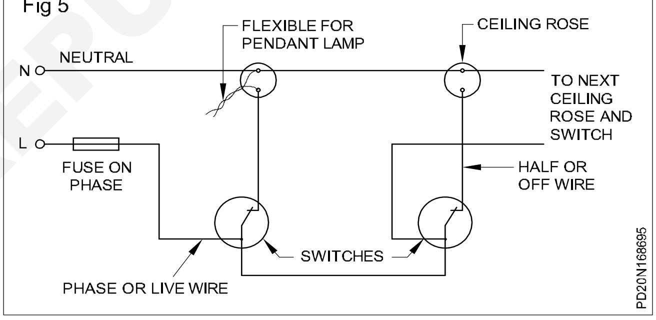
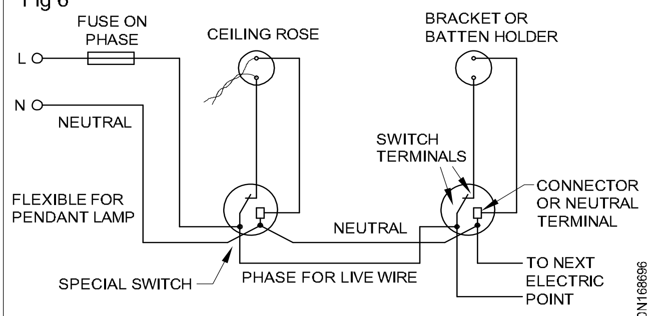


Fig 6



WIRING WITH TWO TERMINALS AND ONE CONNECTOR SWITCH

Distribution board system

Advantages:

1 All loads are connected across the same voltage

2 Fault location is easy.

Disadvantages:

1 Requires skilled labour

2 Costlier than other systems.

Fig 7

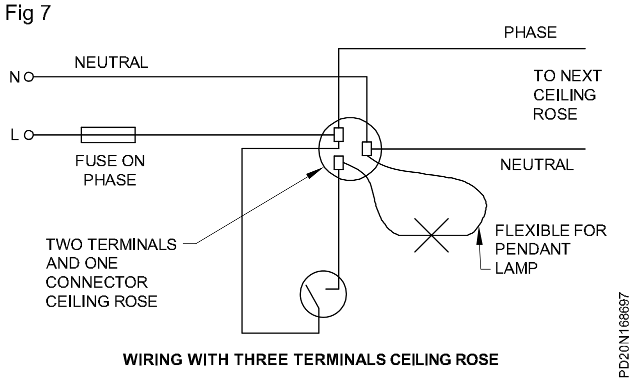
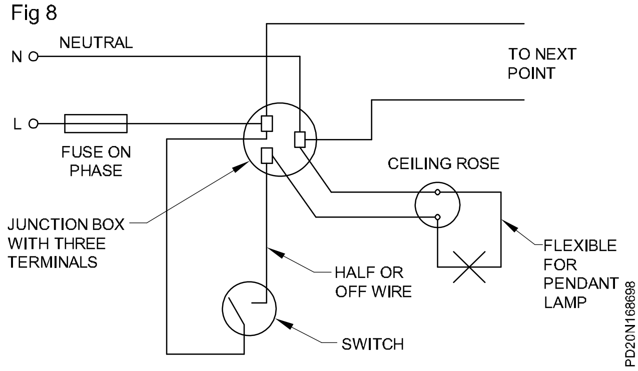


Fig 8



Comparison of different types of wiring at a glance is given in the following table.

Different types of wiring at a glance

Sl. No.	Particulars	Casing & Capping	Batten wiring		Conduit wiring	
		PVC (Poly Vinyl Chloride)	TRS (Tough Rubber Sheathed)	LCC (Lead Covered Cable)	Metal	PVC
1	Material	PVC casing and capping PVC wires wooden gutties screws, blocks and boards.	T.W.Batten TRS/CTS wires gutties, screws, nails, clips, board & blocks.	Batten lead covered wire gutties, screw clips, board and blocks.	Metal conduit pipe, saddles hooks, wooden gutties, bend and socket and other accessories screws, block and board.	PVC conduit pipe, saddles, hooks, wooden gutties, bend and socket and other accessories screws block and board.
2	Cost	Fairly cheap	Cheap	Expensive	Expensive	Cheap
3	Life	Fairly long	Long	Long	Very long	Long
4	Mechanical Protection	Fair	Fair	Good	Very good	Good
5	Protection	Bad	Fair	Fair	Very good	Bad
6	Safety	Fair	Good	Good	Very good	Fair
7	Labour	Skilled	Skilled	Skilled	Highly skilled	Skilled
8	Extension and removal	Easy	Easy	Difficult	Not so easy and costly.	Easy
9	Time	Fairly short	Short	Fairly long	Very much longer	Fairly long
10	General reliability	Good	Fairly good	Fairly good	Very good	Good
11	Appearance	Good	Good	Good	Very good	Very good
12	Nature of application	Office only for Computer wiring.	Domestic & Office building	Domestic & Office building	Workshop	Domestic

Types of domestic wiring

Objectives: At the end of this lesson you shall be able to
- **explain the layout, installation plan, circuit -diagram, wiring diagram and state their uses**
- **state the B.I.S. regulation pertaining to wiring installation.**

In electrical wiring work, the electrician is supplied with a layout of wiring installation and an installation plan initially.

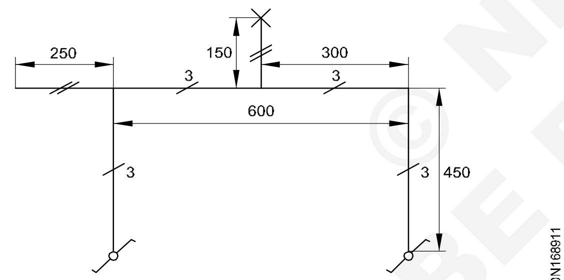
On the basis of the layout and installation plan, the electrician should draw the circuit and wiring diagrams before the commencement of work for systematic execution of the work.

The terms used in wiring installation drawings are explained here.

Layout diagram: Some customers give their requirements in writing. But a few can give them in the form of a layout diagram to the electrician. In the case of a written requirement, the electrician will prepare a layout diagram and then get the approval of the consumer.

The layout diagram (Fig 1) is a simplified version of the wiring diagram. Its purpose is to inform the reader quickly and exactly, what the circuit is designed for without giving any information on the circuit itself.

Fig 1



LAYOUT

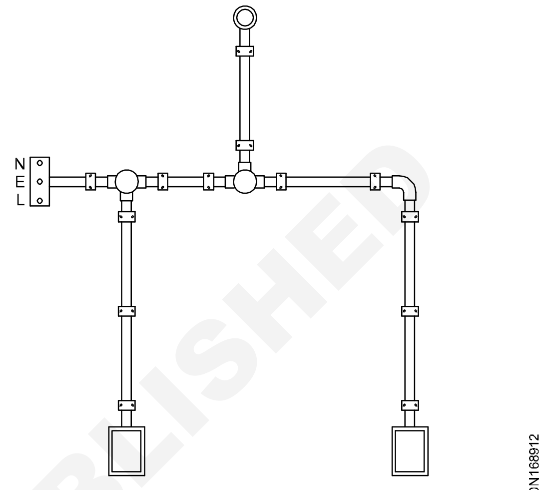
This type of layout diagram is used for preparing architectural diagrams, plans, etc. of a building.

In a layout diagram, it is necessary to indicate with symbols details like whether the wiring is on the surface or concealed, and the run `up' or `down', the number of wires in run, dimensions, and accessories with appropriate I.S. symbols.

Normally the layout plan is drawn and then the wiring diagram. After completion of the wiring diagram, the number of cables to be run in each cable run and the size of conduit or batten are estimated. With the help of the distance marking in the layout plan, the estimation of cables, could be made.

Installation plan (Fig 2): This plan shows the physical position of accessories in an installation, and also gives the final appearance of the installation. It may not be possible to draw the installation plan for the entire layout diagram. But it can be restricted to a small part of the installation to highlight the type of conduit, accessories, spacing of gutties, clamps etc.

Fig 2

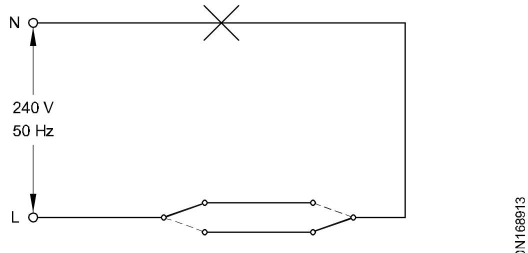


INSTALLATION PLAN

Circuit diagram (Fig 3): This shows the schematic connections of the circuit for a specific task in the simplest form, incorporating the graphical symbols.

The purpose of a circuit diagram is to explain the function of the various accessories in the circuit. Fig 3 is an example of a circuit diagram for controlling a lamp from two different places.

Fig 3

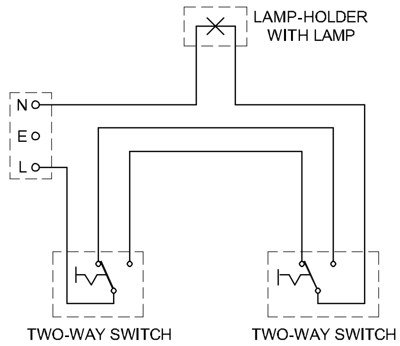


SCHEMATIC (CIRCUIT) DIAGRAM

Wiring diagram (Fig 4): This is the diagram in which the position of the components in the diagram bears a resemblance to their actual physical position.

The wiring diagram may not have distance marking. Use of the wiring diagram along with the layout diagram enables the technician in the initial stages of the planning to specify/estimate the required type, size and length of the cables, and also to decide on the vertical, horizontal and ceiling runs of the cable. The wiring diagram is of great use to test and rectify faults in the installation during maintenance work. Fig 4 also shows the wiring plan for controlling a lamp from two different places with their actual locations.

Fig 4



WIRING DIAGRAM

For his own good and to facilitate quick location of faults at a later stage, the customer should insist on the electrician giving him a copy of the wiring diagram soon after the completion of wiring. The electrician should make it a point to do so.

B.I.S. Regulations and the N .E. code pertaining to wiring installations

The wiring installation shall generally be carried out in conformity with the requirements of the Indian Electricity Act 1910, as updated from time to time and the Indian Electricity Rules 1956, framed thereunder, and also the relevant regulations of the electric supply authority of the concerned area (State Government).

To govern the installation of electrical wirings in buildings, with particular reference to safety and good engineering practice, the Indian Standard is published.

The following are some of the extracts of B.I.S. (Bureau of Indian Standards) regulations pertaining to wiring installations. All the B.I.S. regulations are recommended by the National Electrical Code (NEC).

B.I.S. regulations pertaining to wiring installations

Wiring: Any one of the following types of wiring may be used in a residential building.

- Tough rubber-sheathed or PVC-sheathed or batten wiring.
- Metal-sheathed wiring system
- Conduit wiring system:
  a rigid steel conduit wiring
  b rigid non-metallic conduit wiring
- Wood casing wiring

Fittings and accessories: All fittings, accessories and appliances used in wiring installations shall conform to Indian Standards. (I.S. mark)

The system should provide easy access to fittings for maintenance and repair, and for any possible modification to the system. Modifications to the system shall be done only by licensed electrical contractors, licensed under the Indian Electricity Rules.

Sub-circuits - different types: The sub-circuits may be divided into the following two groups:

- Light and fan sub-circuit
- Power sub-circuit.

After the main switch, the supply shall be brought to a distribution board. Separate distribution boards shall be used for light and power circuits.

Light and fan sub-circuits: Lights and fans may be wired on a common circuit. Each sub-circuit shall have not more than a total of ten points of lights, fans and 6A socket-outlets. The load on each sub-circuit shall be restricted to 800 watts. If a separate circuit is installed for fans, the number of fans in that circuit shall not exceed ten.

Power sub-circuits: The load on each power sub-circuit should normally be restricted to 3000 watts. In no case shall there be more than two outlets on each sub-circuit.

If the load on any power sub-circuit exceeds 3000 watts, the wiring for that sub-circuit shall be done in consultation with the supply authority.

A switch shall be provided adjacent to the normal entrance to any area for controlling the general lighting in that area. The switches should be fixed on a usable wall space and should not be obstructed by a door or window in its fully open position. They may be installed at any height up to 1.3m above the floor level.

Two-way switching is recommended for halls and staircases.

Switches and bell pushes should preferably be self-illuminating where they are often operated in dark.

Deep, dark cupboards and larders may be fitted with a lighting outlet, preferably with a door switch.

The light fittings in kitchens should be so placed that all working surfaces are well illuminated and no shadow falls on them when in normal use.

In living and dining rooms, if a cover or valance is provided, a lighting outlet should be provided, and it should have a separate switch.

In bedrooms it is recommended that some lighting be controlled from the bed location.

For bathrooms, it is recommended to use ceiling lighting with the switch located outside the bathroom. Alternatively an insulated cord-operated switch may be used. However, if the light switch is installed inside the bathroom, it should be out of reach of a person in a bath-tub or under the shower. Touching a switch with wet hand is highly dangerous.

It is recommended that lighting facilities be provided for lighting of all steps, walkways, driveways, porch, carport, terrace, etc, with switches for each provided inside the house at a convenient place. If the switches are installed outdoors, they should be weatherproof.

Waterproof lighting fittings should be used for outdoor lighting.

Socket-outlets: All plugs and socket-outlets shall be of 3-pin type, the appropriate pin of the socket being connected permanently to the earthing system.

An adequate number of socket-outlets shall be placed suitably in all rooms so as to avoid the use of long lengths of flexible cords.

Only 3-pin, 6A socket-outlets shall be used in all light and fan sub-circuits. 3 pin, 16A socket-outlets shall be controlled by individual switches which shall be located immediately adjacent to it. For 6A socket-outlets, if installed at a height of 130 cm above the floor level, in situations where a socket-outlet is accessible to children, it is recommended to use shuttered or interlocked socket-outlets.

In case an appliance requiring the use of a socket-outlet of a rating higher than 16A is to be used, it should be connected through a double-pole switch of appropriate rating.

Socket outlets shall not be located centrally behind the appliances with which they are used. Socket-outlets shall be installed either 25 or 130 cm above the floor as desired.

It is recommended that 3-pin, 6A socket-outlets may be provided near the shelves, bookcases, clock positions, probable bed positions etc.

Depending on the size of the kitchen, one or two 3-pin, 16A socket-outlets shall be provided to plug in hot plates and other appliances. Dining rooms, bedrooms, living rooms, and study rooms, if required, shall each be provided with atleast one 3-pin, 16A socket outlet.

No socket-outlet shall be provided in the bathroom at a height less than 130 cm.

A recommended schedule of socket-outlets is given below.

Location	6A Outlets	16A Outlets
Bedroom	2 to 3 Nos.	1 No.
Living room	2 to 3 Nos.	2 Nos.
Kitchen	1 No	2 Nos.
Dining room	2 Nos	1 No.
Garage	1 No	1 No.
Refrigerator	-	1 No.
Air-conditioners	-	1 No.
Verandah	1 No.	1 No.
Bathroom	1 No.	1 No.

Multi-plug adaptors for connecting more than one appliance to one socket outlet should not be used.

Fans: Ceiling fans shall be wired to ceiling roses or to special connector boxes. All ceiling fans shall be provided with a switch besides its regulator.

Fans shall be suspended from hooks or shackles with insulators between the hooks or shackles and also with insulators between the hooks and suspension rods.

Unless otherwise specified, all ceiling fans shall be hung not less than 2.75 m above the floor.

Flexible cords: Flexible cords shall be used only for the following purposes.

- For pendents
- For wiring of fixtures
- For connection of transportable and hand-held appliances

Flexible cords shall not be used in the following cases.

- As a substitute for the fixed wiring.
- Where cables may have to run into holes through the ceiling, walls, floors, windows, etc.
- For concealed wiring.
- If attached permanently to the walls, ceilings, etc.

Mounting levels of the accessories and cables as recommended in B.I.S. and N.E.C.

Height of main and branch distribution boards should be not more than 2m from the floor level. A front clearance of 1 m should also be provided.

All the lighting fittings shall be at a height of not less than 2.25 m from the floor.

A switch shall be installed at any height 1.3 m above the floor level.

Socket-outlets shall be installed either 0.25 or 1.3 m above the floor as desired.

The clearance between the bottom point of the ceiling fan and the floor shall be not less than 2.4 m. The minimum clearance between the ceiling and the plane of the blades of the fan shall not be less than 300 mm.

The cables shall be run at any desired height from the ground level, and while passing through the floors in the case of wood casing and capping and T.R.S. wiring, it shall be carried in heavy gauge conduit 1.5 m above floor level.

References

I.S. 732-1963

I.S. 4648-1968

N.E. Code

Method of marking the layout for wiring

Objective: At the end of this lesson you shall be able to
- **list the tools required for layout marking and state the method of marking the layout for wiring.**

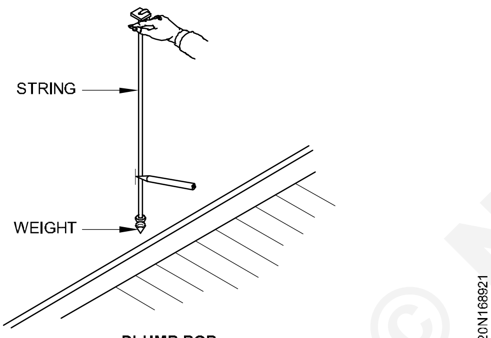
When installing electrical wiring in a building, it is necessary to mark the layout on the ceiling and walls to indicate the position of the various fittings and appliances to be installed and the routing of the cable runs.

To assist in the marking of the layout on the walls and ceilings, the following tools are used.

- Plumb bob or plummet
- Spirit-level
- Water-level

Plumb bob: A plumb bob consists of a block and a weight attached to each other by a string through their centres. When the plumb bob is placed on the wall, the weight is made to hang vertically through the string and the plumb line (string) indicates the true vertical (Fig 1).

Fig 1

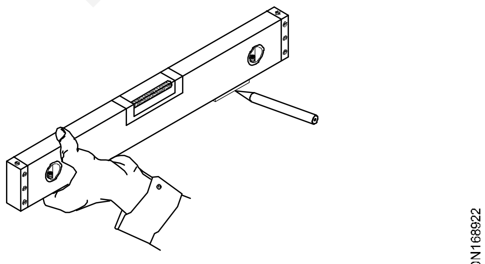


PLUMB BOB

Spirit-level: This consists of a level tube set in a straight edge. When the air bubble in the level tube locates centrally between the markings on the tube, the surface on which the straight edge is kept, it is deemed to be in a horizontal position. Spirit-levels are usually available in sizes from 150 mm to 1 m long (Fig 2).

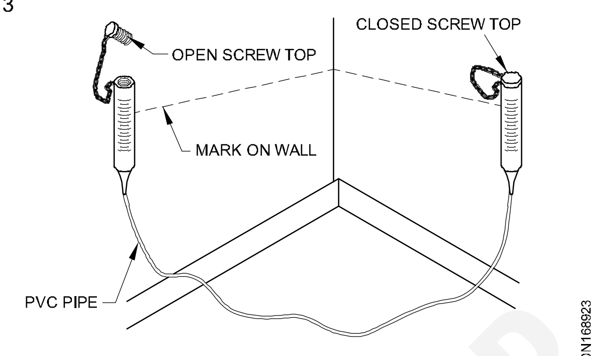
Water-level: A water-level consists of two calibrated glass tubes which are connected together by a flexible rubber tube. The tube is filled with water until the level is halfway up in both the glass tubes. The glass tubes shall be sealed when not in use. Instead of glass tubes on either side of a non-transparent tube, we can use an ordinary transparent PVC tube as water level(Fig 3) .

Fig 2



USE OF SPIRIT LEVEL

Fig 3



WATER LEVEL

Marking of layout: For marking of layout on walls and ceilings of an installation, chalking lines are used. Fine chalk powder is dusted on to a twine thread. When the twine thread dusted with chalk powder is held taut against a wall and `plucked', it marks the wall with a fine line of chalk dust.

Marking of true vertical runs: For marking the vertical lines, a `plumb bob' also known as plumb line, is generally used. A `plumb line' is used in the following manner.

Determine the position of the vertical line to be marked.

Hold the string(line) between the finger and the thumb at an appropriate distance from the weight to correspond with the height of the vertical line position marked.

Suspend the weight just clear of the floor or other obstructions, such as skirting boards, and rest the thumb against the wall and hold it steady until the string and the plumb bob are at rest, just clear of the wall's surface, at the location required as in Fig 1.

Make two pencil or chalk marks on the wall atleast 1 metre apart to correspond with the line of the string.

Draw a line joining the two marks using a straight edge and extend the lines as necessary.

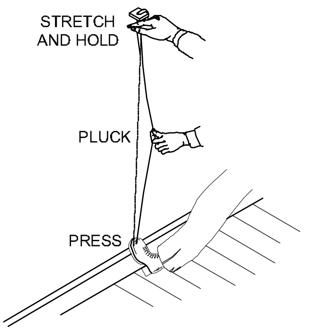
For marking chalking twine (string) lines, stretch out the chalking twine, pull out a sufficient length for the height of the line required.

Hold the lower end with one foot and pull the string taut, adjusting the foot and hand as necessary until the line is directly over the two pencil marks on the wall. (Instead of holding the string with your foot, another person may be asked to assist.)

Use the free hand to lift the tautly held string about 20-30 mm away from the wall and release it. The string springs back to deposit a line of chalk dust on the surface of the wall (Fig 4).

A chalking line is usually used to mark long lines.

Fig 4



MARKING VERTICAL LINES

Marking `true' horizontal runs: The horizontal run is marked either by using a spirit-level or a water-level. Generally for electrical works, a spirit-level is used.

Mark the horizontal lines as outlined below.

Determine where you want the horizontal line to be drawn, using dimensions from the drawings and measuring off the fixed features such as the floor or ceiling. Make a single mark on the wall at the required height.

Hold the spirit-level with both hands and line it up with the mark on the wall.

Check the position of the air bubble in relation to the markings on the tube. Adjust the spirit-level until the bubble comes to rest exactly in the centre of the two markings.

Finally hold the level in position with one hand, and with the free hand draw a pencil line along the straight end of the level (Fig 2).

Use the straight edge of the level and line it up with the line already made and extend the pencil mark to the left and right of the original line.

Where long lines are required, repeat the above steps in the desired direction of the wall.

Measuring of horizontal and vertical runs: Horizontal lines can also be drawn by measuring off from a common base. For drawing horizontal lines on the walls, the common base could either be the floor, top of the skirting board or ceiling surface, provided the floor or the ceiling is reasonably level and even.

This method of measuring is used in many situations where installations are made parallel to existing features such as door frames, and skirting boards.

Marking cable runs on the ceiling: For marking on the ceiling, choose two adjoining walls which are at right angles to each other. Taking these walls as the base, take the measurement of the cable run route centres.

Keep the chalk-powdered string on the marking jointly by holding the edges of the string with the help of assistants and pull the strings hard to make the chalk marking on the ceiling.

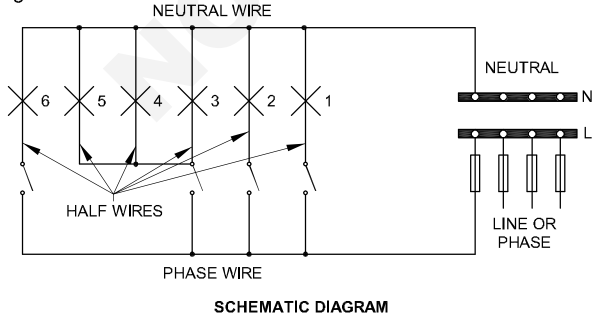
Methods of connections in domestic wiring installations

Objectives: At the end of this lesson you shall be able to
- **explain the looping-back (loop-in) method**
- **explain the joint-box method**.

Introduction

The circuit diagram of a sub-circuit of six lamps, three controlled separately by one-way switches, and three controlled as a group by a one-way switch (Fig 1). If the circuit were wired exactly as in the circuit diagram, a large number of joints would be necessary which are to be done in joint boxes only resulting in an increase in cost and labour. Two methods are adopted to execute the wiring economically. They are 1) the looping-back method and 2) the joint-box method.

Fig 1



SCHEMATIC DIAGRAM

Looping-back (loop-in) method

In this method, no separate joints are used. Instead twisted joints are used at the terminals of the accessories themselves. (In switches and ceiling roses)

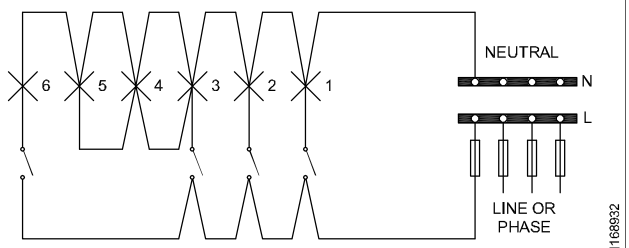
Where the looping-back system of wiring is specified, the wiring shall be done without any junction or connector boxes on their line.

In domestic wiring installation, the looping-back system should be preferred.

The loop-back system can be adopted with two variations.

Loop-in method using 2-plate ceiling roses and switches: Fig 2 shows the schematic diagram of the circuit (Fig 1) as wired by the looping-in system. No separate joints are required in joint boxes. Twisted joints in the terminals of the two-plate ceiling roses and of the switches are, however, required. The schematic diagram (Fig 2) is not practicable and cannot be acceptable in any of the wiring systems like conduit, wooden batten or casing and capping system as it is generally necessary to run the cables close together in the same conduit, batten or casing.

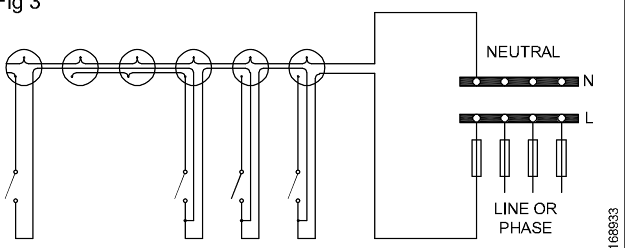
Fig 2



SCHEMATIC DIAGRAM OF LOOP-IN METHOD

Fig 3 shows the same circuit suitable for practical work.

Fig 3



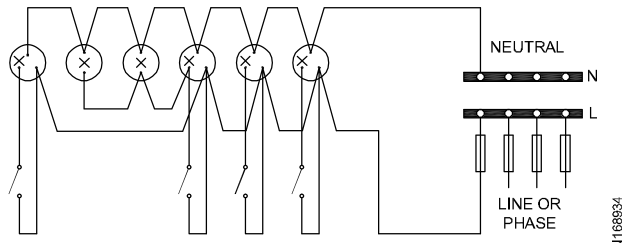
PRACTICAL WAY OF LOOP-IN METHOD

Loop-in method by 3-plate ceiling rose: We can also use 3-plate ceiling roses (Fig 4). Considerable cable length could be saved by using the third terminal of the ceiling rose as a looping-in terminal for the switch drop, so that two cables only are required from the ceiling rose to the switch.

Joint-box method

In the joint-box method, wherever tapping has to be taken from the cable, joints are made. All joints in cable conductors shall be made by means of porcelain connectors or connector-boxes, and housed in suitable joint-boxes.

Fig 4

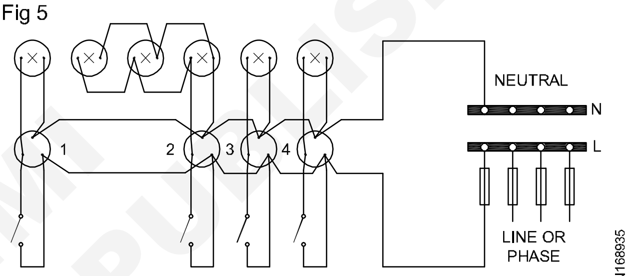


PRACTICAL WAY OF LOOP-IN METHOD

In any wiring system no bare or twist joints shall be made at intermittent points in the cable run of the main circuit or sub-circuit. If joining is unavoidable, such joints shall be made through proper cut outs or drawn through proper junction-boxes open for easy inspection.

The joint-box method of wiring system a pair of cables from the switches and ceiling roses will terminate in the junction box. The junction-box is kept in between the light points and switches for economy in the cable length (Fig 5).

Fig 5



1,2,3 AND 4 JOINT BOXES

Selection of the type and size of cable for a given wiring installation

Objectives: At the end of this lesson you will be able to
- **state the factors to be considered for selecting the cable for a circuit**
- **apply the factors and select the cable.**

In order to determine the type and size of the cable for a given circuit, the following points should be taken into account.

- Suitability of the type of cable for the location of the circuit and the type of wiring.
- Size of the cable depending upon the current carrying capacity of the cable.
- Size of the cable depending upon the length of the wiring and permissible voltage drop in the cable.
- Minimum size of the cable based on the economy.

Location of the circuit and the type of wiring decide the type of cable.

It is necessary to consider whether the installation is for industry or domestic use and whether the atmosphere is damp or corrosive. Accordingly the type of cable has to be chosen.

Further the type of wiring determines the type of cable suitable for the installations.

The current carrying capacity of the cable decides the size of the cable.

In this, the first step is to find out the current expected to flow in the circuit when the total connected load is fully switched on. This current is the maximum current that would flow through the circuit in case all the loads are working at the same time. But this is not the case in actual situations.

Diversity factor

In the case of lighting installation all the lamps in a domestic installation may not be switched 'on' at the same time. Hence, it is assumed only two thirds of the lights (say 66%) only will be 'on' at a given time. This introduces a factor called 'diversity factor'.

When the connected load is multiplied by the diversity factor you get a load value which can be said as normal working load. Use of this diversity factor enables the technician to use a lesser size cable than the one calculated, based on the connected load. The suggested diversity factor according to IEE rules is given in Table 2.

Based on the working load the current in each circuit is to be calculated and the size of the cable suitable to carry the current has to be chosen from Tables 3, 4 and 5.

Voltage drop in the cable

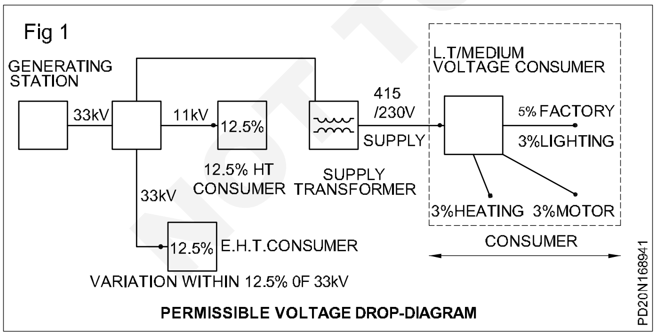
In any current carrying conductor, voltage drop takes place due to its internal resistance. This voltage drop in a premises as per BIS 732 should not be more than 3 percent of the standard supply voltage when measured between the consumer supply point and any point of the installation when the conductors are carrying the maximum current under the normal conditions of service.

Tables 3 and 4 for aluminium cable and 5 for copper cable give the relation between voltage drop and length of the cable run for various cables. In case the voltage drop found in the cable exceeds the stipulated limit of 3% voltage drop, the technician has to choose the next bigger sized cable to maintain the voltage drop within limits.

If the cable size is increased to avoid voltage drop in the circuit, the rating of the cable shall be the current which the circuit is designed to carry. In each circuit or sub-circuit the fuse shall be selected to match the load or the cable rating whichever is minimum, to ensure the desired protection (BIS 732).

Declared voltage of supply to consumer

On the other hand according to IE Rule No.54, the voltage at the point of commencement of supply at the consumer should not vary from the declared voltage by more than 5 percent in the case of low or medium voltage or by more than 12 percent in the case of high or extra high voltage (Fig 1).



At this stage it is better to remember that when current flows through a conductor, the resistance offered by the conductor produces heat. The increase in heat is proportional to the cable resistance which in turn depends upon the cross-sectional area of the cable. Since overheating damages the insulation, the conductor size must be adequate to prevent this from occurring.

While choosing the cable size, voltage drop is a more severe limitation than any other criterion. Hence, it is advisable to select the cable size only after ascertaining the permissible voltage drop. Excessive voltage drop impairs the performance of heating appliances, lights and the electric motors.

Calculation of voltage drop

In DC and single phase AC two-wire circuits

Voltage drop = Current x Total resistance of cables

= 2 IR

where I is the current and

R is the resistance of one conductor only

Wherever voltage drop is given as 1 volt drop per metre run of cable, we have to assume that both (lead and return) cables are taken into account and the cable carries its rated current. In such cases the voltage drop for X metre length of cable for a current of Y amps is calculated as given.

$$\left\{\begin{matrix}\text{Voltage}\\ \text{drop}\end{matrix}\right\} = \frac{\left\{\begin{matrix}\text{Length of}\\ \text{the cable}\end{matrix}\right\} \text{x} \left\{\begin{matrix}\text{Actual current}\\ \text{of the load}\end{matrix}\right\}}{\left\{\begin{matrix}\text{Metre length of}\\ \text{the cable per one}\\ \text{volt drop}\end{matrix}\right\} \text{x} \left\{\begin{matrix}\text{Rated current}\\ \text{of the cable}\end{matrix}\right\}}$$

$$= \frac{XY}{\left\{\begin{matrix}\text{Metre length of}\\ \text{the cable per one}\\ \text{volt drop}\end{matrix}\right\} \text{x} \left\{\begin{matrix}\text{Rated current}\\ \text{of the cable}\end{matrix}\right\}}$$

3-phase circuits

$$\text{Voltage drop} = 1.73 \text{ x } I\,R = \sqrt{3}\,IR$$

where I is the line current

R is the resistance of one core only.

The above points could be explained through the following set of examples.

Example 1

A guest house installation has the following loads connected to the three phase 415 V supply with neutral. Select a proper size of cable for this installation.

Lighting - 3 circuits of tungsten lighting total 2860 watts

Power from 3 x 30A ring circuits to 16A socket outlets for

1 x 7 KW Water heater (Instant)

2 x 3 KW Immersion heater (Thermostatically controlled)

Cooking appliances: 1 x 3 KW cooker

1 x 10.7 KW cooker

Current demand in amperes in each of the circuit is calculated by referring the Table 1. Calculation of current taking account into the diversity factor from Table 2.

Assuming the declared voltage as 240 volts and the length of the longest run in a circuit as 50 metres

Permissible voltage drop at the rate of 3%

$$= \frac{3 \times 240}{100} = 7.2 \text{ Volts}$$

Referring to Table 3, if the size of the conductor selected is 35.0 sq.mm which can carry 69 amps, the voltage drop at 69 amperes rating will be 1 volt for every 7.2 metres cable run.

For 50 metres cable run the voltage drop at 69 amps current rating = 50 / 7.2 volts.

Voltage drop for 65 amps

$$= \frac{50 \times 65}{7.2 \times 69} = 6.54 \text{ Volts}$$

Table 1

Sl. No	Demand description	Current Demand (Ampere)	Diversity Factor (Table 2)	Current allowing for Diversity (Ampere)
1	Lighting	11.9	75%	9.00
2	Power i ii iii	30 30 30	100% 80% 60%	30 24 } 72.00 18
3	Water heaters (inst)	29.2	100%	29.2
4	Water heaters (thermo)	25.00	100%	25.00
5	Cooker i ii	12.5 44.5	80% 100%	10.00 44.5
Total current		= 213.1		189.7

Total current demand (allowing diversity) = 189.7 amps
Load spread over 3 phases = 189.7/3 = 63.23 amps, say 65 amps per phase.

As the actual voltage drop in the circuit, that is 6.54 volts, is well within the permissible value, of 7.2 volts, the cable selected is suitable for the installation.

Example 2

A three-phase 3-wire connection is to be given to a premises in which an electric motor of 50 H.P. is to be installed. 40 metres of cable run from the main switch is required for this purpose. Determine the size of the 3-core cable to be used, if the available voltage is 400 V 50 Hz (Assuming PF is 0.8).

$$\{\text{Current drawn by the motor}\} = \frac{50 \times 746}{\sqrt{3} \times 400 \times 0.8} = 67.3$$

As a 3-core cable is used, referring to Table 4 it will be seen that 35 sq.mm. (7/2.5) PVC cable will be in a position to carry the motor current safely.

$$\left\{ \begin{matrix} \text{The Permissible} \\ \text{Voltage drop} \end{matrix} \right\} = \frac{400 \times 3}{100} = 12 \text{ Volts}$$

But as per Table 4, the selected cable will have 1 volt drop for every 7.1 m cable run.

Hence, for 40 metres the voltage drop is = 40 / 7.1 volts = 5.63 volts.

Referring to Table 4 we have voltage drop at 69 amps = 5.63 volts.

Hence the voltage drop at 67.3 amp is

$$= \frac{40 \times 67.3}{7.1 \times 69} = 5.49 \text{ Volts}$$

As the drop is within permissible limits, of 12V ,the 3-core PVC cable size 35 sq.mm (7/2.5) is suitable.

TABLE 2

Allowances for diversity

	Purpose of final circuit fed from conductors or switchgear to which diversity applies	**Individual household installations, including individual dwellings of a block**	**Small shops, stores, offices and business premises.**	**Small hotels, boarding houses**
1	Lighting	66% of total current demand	90% of total current demand	75% of total current demand
2	Heating and power (but see 3 to 8 below)	100% of total current demand up to 10 amperes + 50% of any current demand in excess of 10 amperes.	100% FLC of largest appliance + 75% FLC of remaining appliances.	100% of FLC of largest appliance + 80% FLC of 2nd largest appliance + 60% FLC of remaining appliances
3	Cooking appliances	10 amperes = 30% FLC of connected cooking appliances in excess of 10 amperes + 5 amperes if socket outlet incorporated in unit.	100% FLC of largest appliance + 80% FLC of 2nd largest appliance + 60% FLC of remaining appliances	100% FLC of largest appliance + 80% FLC of 2nd largest appliance + 60% FLC of remaining appliances
4	Motors (other than lift motors which are subject to special consideration)	100% FLC of largest motor + 80% FLC of 2nd largest motor + 60% FLC of remaining motors.		100% FLC of largest motor + 50% FLC of remaining motors.
5	Water heaters (instantaneous type)*	100% FLC of largest appliance + 100% FLC of 2nd largest appliance + 25% FLC of remaining appliances.	100% FLC of largest appliance +100% FLC of 2nd largest appliance + 25% FLC of remaining appliances	100% FLC of largest appliance + 100% FLC of 2nd largest + 25% FLC of remaining appliances.
6	Water heaters (thermostatically controlled)	No diversity allowable.		
7	Floor warming installations	No diversity allowable.		
8	Thermal storage space heating installations	No diversity allowable.		
9	Standard arrangements of final circuits in accordance with Appendix 5	100% of current demand of largest circuit + 40% of current demand of every other circuit.	100% of current demand of largest circuit + 50% of current demand of every other circuit.	
10	Socket outlets other than those included in 9 above	100% of current demand of largest point of utilisation + 40% of current demand of every other point of utilisation.	100% of current demand of largest point of utilisation + 75% of current demand of every other point of utilisation.	100% of current demand of largest point of utilisation + 75% of current demand of every point in main rooms (dining rooms etc.) + 40% of current demand of every other point of utilisation.

* **For the purpose of this table an instantaneous water heater is deemed to be a water heater of any loading which heats water only while the tap is turned on and, therefore, uses electricity intermittently.**

It is important to ensure that the distribution boards are of sufficient rating to take the total load connected to them without the application of any diversity.

Table 3

Current ratings and voltage drop for vulcanised rubber PVC or polythene insulated or tough rubber PVC lead sheathed, single core, aluminium wires or cables

Size of conductor		2 cable DC or single phase AC		3 or 4 cables balance 3 phase		4 cables DC	
Nominal area sq.mm	No. and diameter of wire in metres	Current rating in amperes	Approx. length of run for 1 volt drop in metres	Current rating in amperes	Approx. length of run for 1 volt drop/ metre	Current rating in amperes	Approx. length of run for 1 volt drop in metres
1.5	1/1.40	10	2.3	9	2.9	9	2.5
2.5	1/1.80	15	2.5	12	3.6	11	3.4
4.0	1/2.24	20	2.9	17	3.9	15	4.1
6.0	1/2.80	27	3.4	24	4.3	21	4.3
10.0	1/3.55	34	4.3	31	5.4	27	5.4
16.0	7/1.70	43	5.4	38	7.0	35	6.8
25.0	7/2.24	59	6.8	54	8.5	48	8.5
35.0	7/2.50	69	7.2	62	9.3	55	9.0
50.0	7/3.0 19/1.80	91	7.9	82	10.1	69	10.0

TABLE 4

Current ratings and voltage drop for vulcanised rubber, PVC or polythene insulated or tough rubber, PVC lead sheathed, twin, three or four cores aluminium wires or cables

Nominal area sq. mm.	No. and diameter of wire in metres	Current rating in amperes	Approx.length of run for 1 voltage drop/ metre	Current rating in amperes	Approx. length of run for 1 volt drop in metres
1.5	1/1.40	10	2.3	7	3.7
2.5	1/1.80	15	2.5	11	1.9
4.0	1/2.24	20	2.9	14	4.8
6.0	1/2.80	27	3.4	19	5.5
10.0	1/3.55	34	4.2	24	6.8
16.0	7/1.70	43	5.3	30	8.7
25.0	7/2.24	59	6.6	42	10.8
35.0	7/2.50	69	7.1	48	11.7
50.0	7/3.00 19/1.80	91	7.7	62	13.1
70.0	19/2.24	118	8.8	82	14.7
95.0	19/2.50	135	9.5	94	15.7
120.0	37/2.06	162	10.3	114	16.8

TABLE 5

Wattage loading of small VR Insulated copper conductor cables

Maximum permissible loading in watts at unity power factor for two single core cables in one conduit based on IEE current ratings subject to voltage drop

Cable Size			Current rating	Circuit Voltage		Approximate voltage drop per 10 metres run with current in Col 4.
mm	inch	approx. area in mm	amp	230V watts	250 V watts	volts
1	2	3	4	5	6	7
1/1.11	1/.044	1	5	1150	1250	1.97
3/0.74	3/.029	1.2	10	2300	2500	3.09
3/0.91	3/.036	2	15	3450	3750	2.98
7/0.74	7/.029	3	20	4600	5000	2.64
7/0.91	7/.036	4.5	28	6440	7000	2.37
7/1.11	7/.044	6.75	36	8280	9000	2.04
7/1.32	7/.052	9.5	43	9890	10750	1.75
7/1.62	7/.064	15	53	12190	13250	1.42
19/1.11	19/.044	18	62	14260	15500	1.30
19/1.32	19/.052	25	74	17020	18500	1.11
19/1.62	19/.064	38.75	97	22310	24250	0.96

Metal conduit pipe - methods of cutting, threading and bending

Objectives: At the end of this lesson you shall be able to
- **state the methods of cutting a metal conduit pipe**
- **state the purpose and process of threading and list out the precautions of conduit pipes**
- **list the different accessories used in conduit installation**
- **state the purpose and methods of bending the conduit pipes and list out the precautions.**

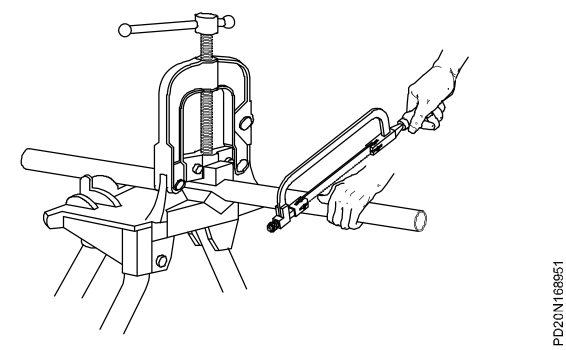
Cutting: Rigid and intermediate conduits may be cut with a hacksaw (Fig 1) or a pipe cutter (Fig 2). With either method, the conduit must be locked in a pipe vice before making the cut. Fix the conduit in the vice so that the vice grips the conduit 50 or 75 mm from the point where the cut has to be made. This prevents the grip of the pipe vice from damaging the surface of the conduit that must be threaded.

If a hacksaw is used, use 24 teeth per 25 mm blade. Be sure to install the blade so that the cut is made on the forward stroke.

After cutting (Figs 1 and 2) the inside edge of the conduit must be smoothed with a half round file (Fig 3) or a pipe reamer mounted in a brace.

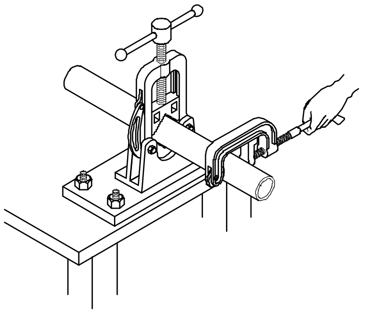
Be particularly careful while cutting the conduit with a pipe cutting tool. This tool tends to leave a sharp ridge on the inner edge of the cut. Be sure this ridge is removed and the conduit is smooth before installing a coupling or any fitting, to avoid damage to the insulation of conductors.

Fig 1



Purpose of threading: When short lengths of conduits are to be used for switch or lamp drops, the cut end of the pipe needs to be threaded to enable fixing of the conduit to accessories. Threads on conduit pipes in all cases shall be

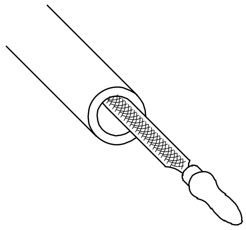
Fig 2



CUTTING A PIPE USING A PIPE CUTTER

between 11 mm to 27 mm long, sufficient to accommodate pipes to the full-threaded portion of couplers or accessories.

Fig 3



DEBURRING PROCESS

Threading: Conduit is threaded by using dies and a die stock. Apply cutting oil to the end of the conduit before starting to cut threads. Cutting the threads longer than necessary will leave the exposed threads subject to corrosion.

Do not use any lubricant which is an electrical insulator, as this may increase the resistance of the conduit assembly and affect its use as the circuit protective earthing conductor.

Precautions to be observed while threading conduit pipes

1 Chamfer the end of the conduit to be threaded. Make the depth of the chamfer equal to the pitch of the thread (1.5 mm for conduit).

2 Apply a lubricant frequently while threading the conduit pipe. It helps the die to cut more easily and the die to stay sharp.

3 Check whether stock is at right angles to the pipe axis.

4 Reverse turnings of the die stock are necessary to break off cut chips and to clear the cutting edges of the die.

5 Use only a brush to remove the metal burrs from the die. Do not use your hand.

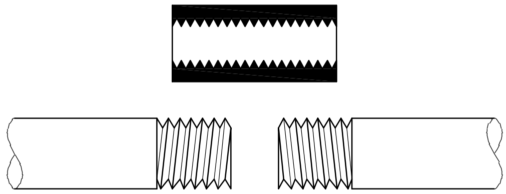
Conduit accessories

Conduit coupling: As conduits are commercially available in specific lengths only, it has become necessary to join two or more lengths to obtain the required runs. Joining of conduits is done by means of couplers.

There are two types of couplers used for rigid metal conduits as explained below.

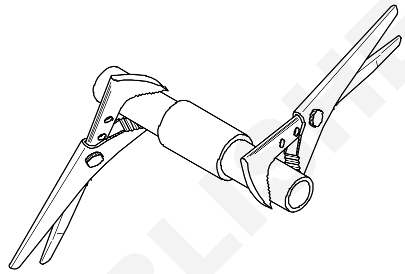
Screwed couplers: They are also called running couplers and are made of cast iron, having female threads inside (Fig 4). The conduits to be joined should be threaded to a length sufficiently long to fit half way into the coupling such that no threaded portion is visible outside (Fig 5) to avoid corrosion.

Fig 4



CONDUIT COUPLER ASSEMBLY

Fig 5

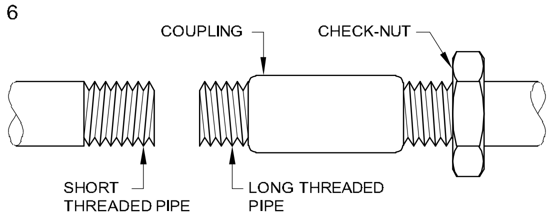


FIXING A CONDUIT COUPLER

This type of running couplers makes the joint mechanically weaker and electrically non-continuous. Hence the second type of coupler uses a check (jam) nut along with the running coupler which is a much better choice than the running coupler.

Check-nut and running coupler: For using this coupler, one of the conduits should have longer threads to accommodate fully the coupler, and the other conduit should have threads to a length equal to half the length of the coupler (Fig 6).

Fig 6



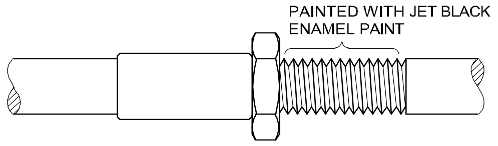
COUPLER AND CHECK-NUT ASSEMBLY

First the check-nut and then the coupler should be screwed inside the long threaded conduit. Then the short threaded conduit is butted with the long threaded conduit and the coupler is screwed on the short threaded conduit tightly. Then the check-nut is screwed and tightened along the coupler (Fig 7).

The exposed threaded portion of the long threaded conduit is painted with jet black enamel paint to prevent rust.

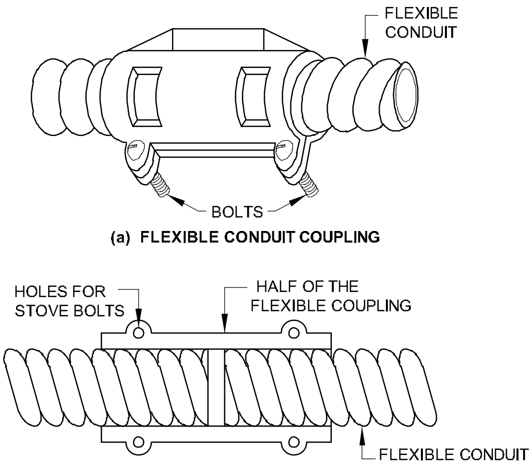
Coupling for flexible conduits: For flexible conduits, split couplings are used (Fig 8).

Fig 7



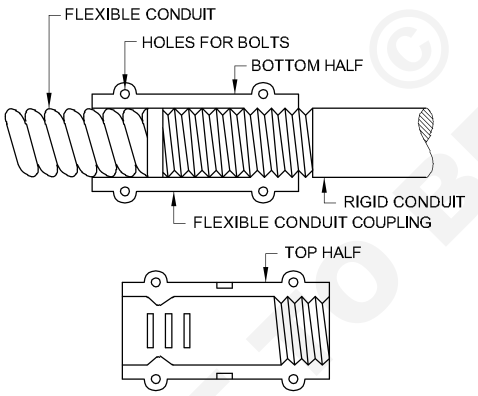
COUPLE AND CHECK-NUT ASSEMBLY.

Fig 8



Special type of split couplings (Fig 9) is to be used when the flexible conduit is to be connected to a rigid conduit at places where high flexibility is required. This coupling has threading on one side with the other side made suitable to grip the flexible conduit.

Fig 9



DUEL CONDUIT COUPLING

Metal conduit boxes: Termination of rigid conduits is done at metal conduit boxes of either cast iron or sheet metal. Various shapes and sizes of boxes are commercially available in the market. Junction boxes of round, square, rectangular and hexagonal shapes are manufactured for one-way, 2-way, 3-way and 4-way outlets.

These outlets may be straight, angular or tangential as required for the situation. When ordering, the specification should contain the material with which the box is to be made, the size of the conduit to be fitted, the number of ways, shape and the position of outlets.

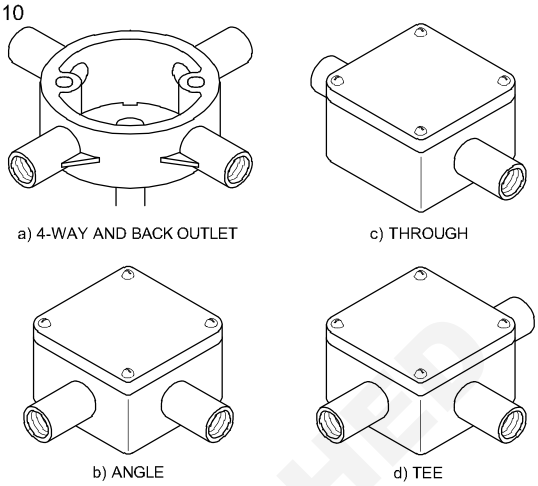
Example: Cast iron 20 mm, 3-way, round tee.

Fig 10 shows some of the popular types of outlet boxes. Cast iron 20 mm, 3-way, round tee.

Fig 11 shows various types of circular (round) boxes in a single line diagram.

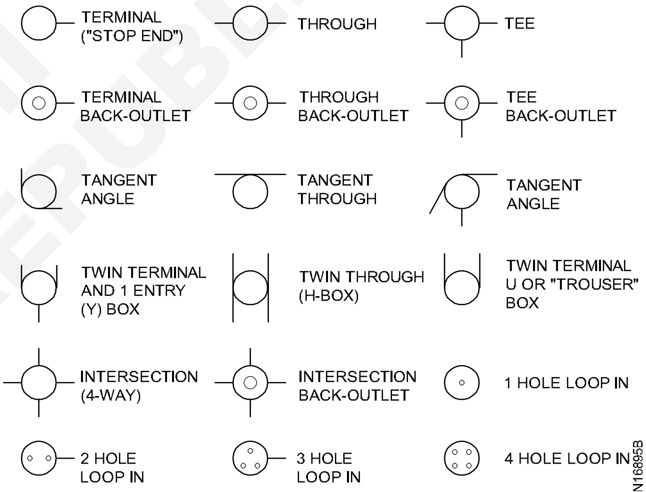
Fig 12 shows typical ceiling boxes, and Fig 13 shows wall boxes whereas Fig 14 shows switch boxes.

Fig 10



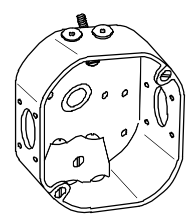
CONDUIT OUTLET BOXES

Fig 11



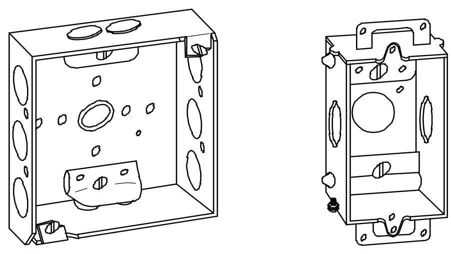
SMALL CIRCULAR BOXES

Fig 12



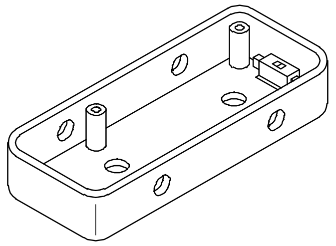
CEILING BOX FOR CONDUIT WIRING

Fig 13



WALL BOXES FOR CONDUIT WIRING

Fig 14



SWITCH BOXES FOR CONDUIT WIRING

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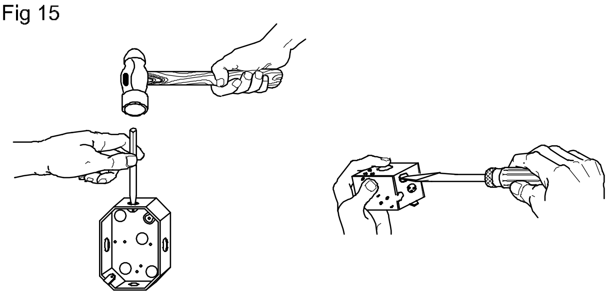
The ceiling, wall and switch boxes are normally provided with knock-out openings which can be removed when required by using punches or chisels with a stroke from a hammer. In some cases the knock-out openings could be made by the pry out-method with a screwdriver (Fig 15).

Fig 15



(a) KNOCK OUT PUNCH METHOD (b) PRY OUT METHOD

METHOD OF REMOVING THE KNOCK OUTS

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After removing the knock-outs, the conduit is to be fitted in the opening by any one of the methods shown in Fig 16.

However, when brass bushes are not used in the terminating end of the conduits, it is necessary to use PVC bushes at the conduit ends to facilitate easy drawing of the cables and to avoid damage to the cable insulation.

Lock nuts: Hexagonal lock nuts are used at the conduit terminations (Fig 17) to make the terminations mechanically strong and electrically continuous. Remember that the paint at the box entries should be scraped out, before fitting the lock nut in position to facilitate electrical continuity.

Conduit bushings: These are made from brass or malleable iron or PVC and have a smooth large radius edge (Fig 18). This should be used at conduit terminations for dual purposes.

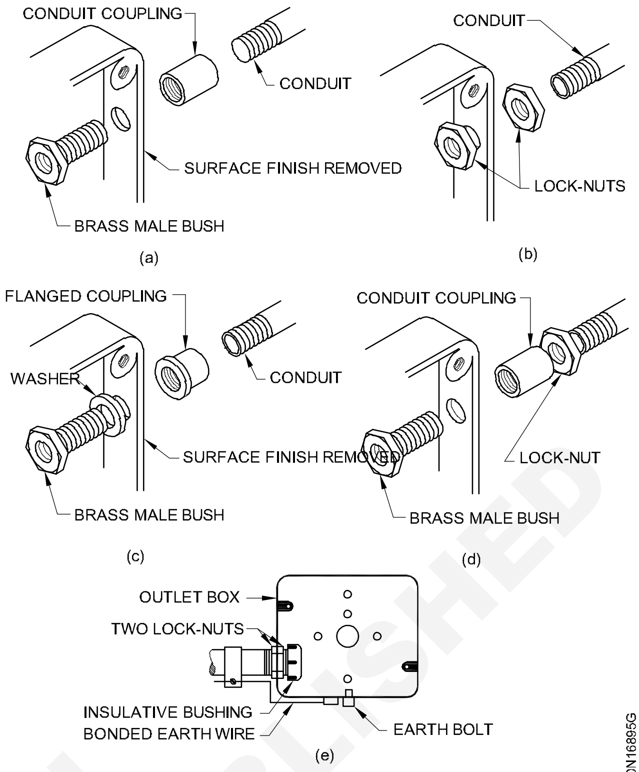
The first purpose is to protect the cable insulation from getting damaged during drawing of the cables, and the second purpose is to give a proper grip mechanically and make the conduit electrically continuous in the installation.

Conduit nipples (Fig 19) are provided in conduit termination along with couplers and they serve the same purpose as conduit bushes.

Conduit fittings like elbows, bends and Tees: All these fittings are available in two categories.

- Normal
- Inspection type

Fig 16



CONDUIT BOX ASSEMBLY

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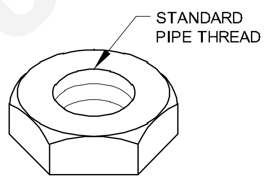
Fig 17



LOCK-NUT

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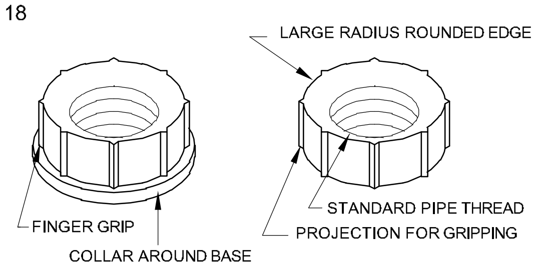
Fig 18



CONDUIT BUSHINGS

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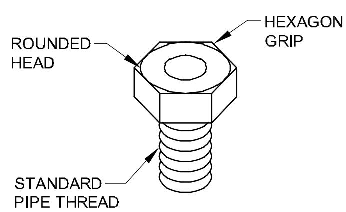
Fig 19



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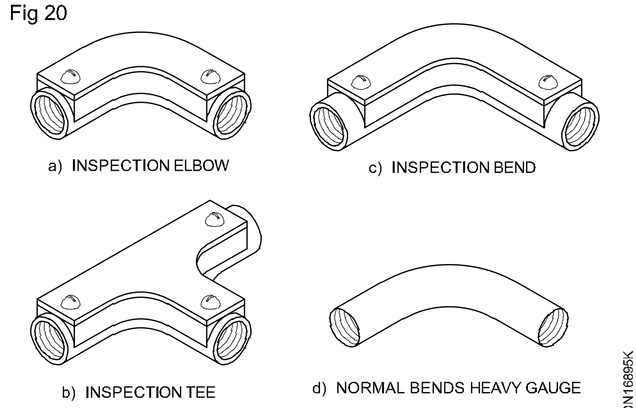
They are made from cast iron.

Elbows are suitable for short bends whereas bends are suitable for long bends. In general where a conduit runs between the wall and the ceiling, elbows are used.

Tees are used in switch-drops and diversions. Various types of these accessories (Fig 20).

Fig 20



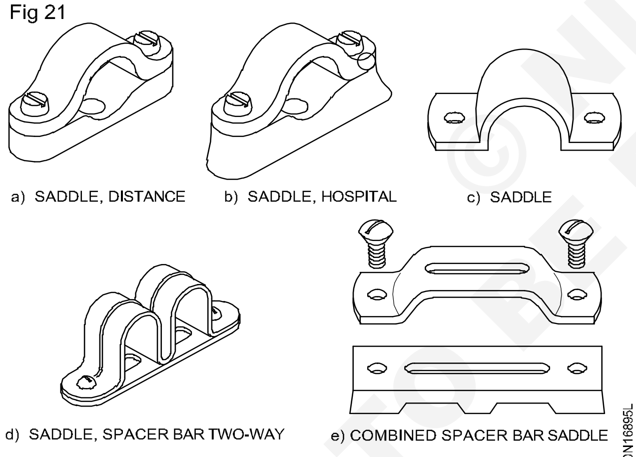
CONDUIT ACCESSORIES

Conduit saddles are used to fasten the conduit on the surface of the walls. These saddles could be used along with any one of the following bases. They are:

- spacers made from sheet metal
- distance piece made from wood or PVC
- hospital piece made from wood or PVC.

Various types of these base fittings along with the saddles are shown in Fig 21.

Fig 21



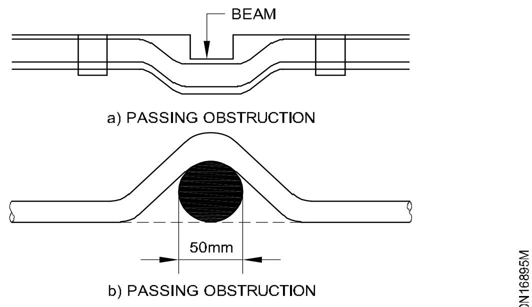
CONDUIT SADDLE ASSEMBLY

Conduit pipe bending: It is often necessary to set or bend the conduit to enable it to pass over an obstruction (Fig 22) or to turn a corner which is less or more than 90^0 (Fig 23). The bending may be a little offset to the line of conduit installation. This can be manipulated by proper bending as required.

The bending may be done by using a simple bending block or by a hickey or with the help of a bending machine. Further, in concealed conduit wiring, the B.I.S. recommends bending of conduit pipes in preference to the use of bends and elbows.

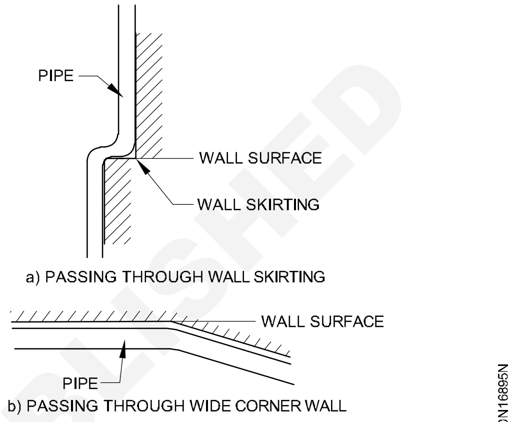
Using bending block for bending conduit: The bending block (Fig 24) is made preferably with teak wood or strong country wood, and should have holes suitable for the conduit to be bent. Edges are chamferred to avoid kinks in

Fig 22



OFFSETTING THE CONDUIT RUN

Fig 23

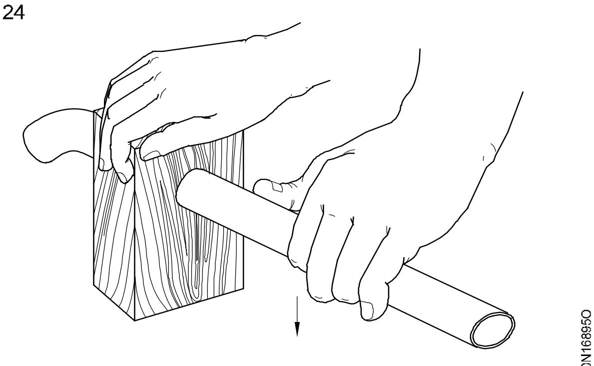


CONDUIT RUN THROUGH OFFSET WALL SURFACE

the bent portion of the conduit. Light gauge conduits need to be filled with sand and heated before bending to have smooth bends.

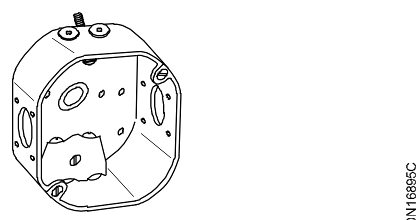
Using hickey for bending conduits: A hickey is a special bending tool (Fig 25) and is made of forged steel or alloy steel. A particular size of pipe requires that size of hickey. Bending of pipes could be performed cold or hot by using a hickey.

Fig 24



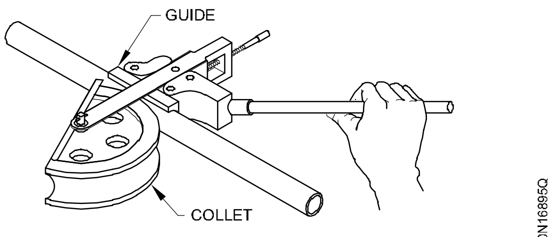
BENDING CONDUIT WITH THE BENDING BLOCK

Fig 12



CEILING BOX FOR CONDUIT WIRING

Fig 26



BENDING CONDUIT WITH THE BENDING MACHINE

Using bending machine for bending conduit: Various types of bending machines are available in the market. They can either be operated by hand (Fig 26) or by hydraulic pressure. For each size of conduit, the guide and collet need to be changed.

Precautions to be observed while bending

- The pipe used should be mechanically strong to withstand the pressure while bending.
- Poorly seam-welded pipes are not suitable for bending as they may split while bending.
- One of the easy methods of bending is to draw the bending curve on the floor and bend the pipe accordingly.
- When a wooden block is used for bending, chamfer both sides of the hole opening in the block.
- Ensure that the conduit does not twist while bending.
- Use a proper size of hickey according to the dia. of the pipe to be bent.
- While doing manual hot bending do not use wet sand as the steam generated during heating may cause an explosion.

Test board, Extension board and colour code of cables

Objectives: At the end of this lesson you shall be able to
- **explain the method of using a test board**
- **state the general colour codes used in cables.**

Test board: A test board is an electric switch board, used for conducting the following tests.

- **Continuity test** (Load connected in series with a lamp)

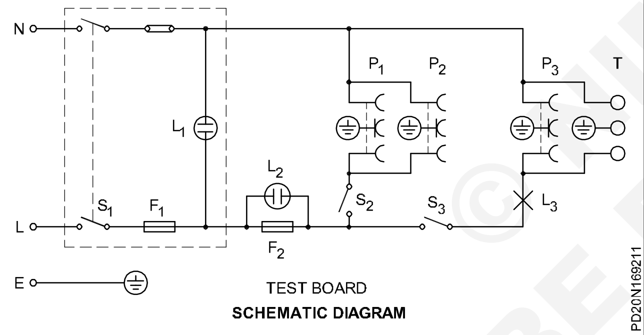
  Example: Testing of fan winding, condition of choke and tube light starter etc.

- **Direct test**

  Example : Testing electrical appliances of 1000 watts or lower rating for proper functioning.

Fig 1 source the schematic diagram of a test board with all the outlets and controls. Sockets P_1 and P_2 provide direct, single-phase supply whereas socket P_3 and terminal block T provide a single-phase supply in series with the lamp L_3.

Fig 1



Continuity test: While performing a continuity test, the appliance to be tested is connected to the socket P_3 or to the terminal T which are in series with the lamp L_3 and are controlled by switch S_3. Normally this test is conducted by the electrician to ascertain whether the appliance is open-circuited or short-circuited. A low wattage, appliance when connected, will make the lamp L_3 to burn dim, and a high wattage appliance will make the lamp to burn bright.

According to the brightness of the lamp, the behaviour of the appliance, as well as the wattage of the appliance and the lamp and the condition of the appliance could be judged. `No light' indicates either open circuit or high resistance in the appliance. In the same way, a choke coil and a starter of a tube light can be checked. (The flickering of the lamp L_3 with the starter indicates that the starter is good.)

Thus the testing board also works as a continuity tester.

Direct testing: By connecting the appliance direct to the socket P_1 or P_2, the performance of the appliance can be verified after repair.

Fuses: If the indicator lamp L_1 does not burn, it indicates no supply. On the other hand, in normal conditions, the indicator lamp L_2 will not burn, and it burns only when the fuse F_2 is open.

Thus the test board is a cheap and handy test set which is easy to use by an electrician to carry out his routine checks in the course of his work.

Colour identification of cables: The colour of the cables indicates their function. Table 1 gives the colour code and the alpha-numeric notation as recommended by N.E.Code.

The rules apply for marking conductors in equipment/ apparatus/installation.

TABLE 1

Alpha-numeric notation and colours

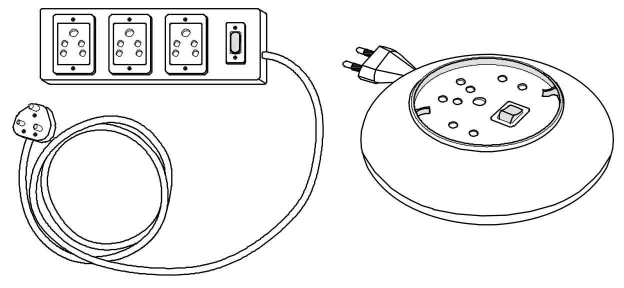
Designation of		Identification by	
		alpha	colour
Supply AC system	Phase 1	L1	Red
	Phase 2	L2	Yellow
	Phase 3	L3	Blue
	Neutral	N	Black
Apparatus AC system	Phase 1	U	Red
	Phase 2	V	Yellow
	Phase 3	W	Blue
	Neutral	N	Black
Supply DC system	Positive	L+	Red
	Negative	L-	Blue
	Mid-wire	M	Black
Supply AC system (Single phase)	Phase	L	Red
	Neutral	N	Black
Protective Earth conductor		PE	Green and yellow
Earth		E	Colour of the bare conductor.

Extension board (Fig 2)

Extension boards are used to operate portable electrical appliances/ machines. It is also used where more number of sockets are required at a time.

Extension boards are available in different shapes with PVC (or) plastic boxes provided with 2 core (or) 3 core cables and moulded plugs. Extension boards are available in 6A and 16A ratings.

Fig 2



Conduit wiring - types of conduits - non-metallic conduits (PVC)

Objectives: At the end of this lesson you shall be able to
- **distinguish between the different types of conduits used in wiring**
- **compare metal and PVC conduit wiring**
- **state the different types of accessories used in non-metallic conduits wiring.**

In general, conduit is defined as a tube or channel, which is the most commonly used in electrical installations. When cables are drawn through the conduit and terminated at the outlet or switch points, the system of wiring is called conduit wiring.

Types of conduits

There are four types of conduits used for wiring.

- Rigid steel conduits
- Rigid non-metallic conduits
- Flexible conduits
- Flexible non-metallic conduits.

Non-metallic conduits

These are made of fibres, asbestos, polyvinyl chloride (PVC), high density polyethylene (HDP) or poly vinyl (PV). Of the above, PVC conduits are popular owing to their high resistance to moisture and chemical atmosphere, high dielectric strength, low weight and low cost. These conduits may be buried in lime, concrete or plaster without harmful effects.

However, light gauge (lower than 1.5 mm wall thickness) PVC pipes are not as strong as metal conduits against mechanical impact. Special PVC pipes which are heavy gauge and high impact resistance are available in the market which can withstand heavy mechanical impact as the thickness of the pipe is more than 2 mm.

There are some PVC heavy gauge conduits having special base material made to withstand temperatures up to 85°C. These PVC conduits are available in 3 m length.

Flexible conduits

Apart from rigid conduits, flexible conduits are also used for protecting cable ends connected to a vibrating machine inter connection between switchgear and distribution boards. In the case of metal flexible conduits, steel strips are spirally wound to form a tube. However, these flexible conduits of any type cannot be relied on as the sole means of earthing due to the manufacturing method as well as material. Hence, earthing conductors should run either externally or internally to the flexible conduit to form the earth connection. Flexible conduit accessories should be of threaded type.

Variation in conduit wiring systems

There are two types of conduit wiring systems as stated below, for either metallic or non-metallic types.

- Surface conduit wiring system done on wall surfaces.
- Concealed (recessed) conduit wiring system done inside the concrete, plaster or wall.

Selection of the type of conduit

Metallic or PVC conduits are equally popular in electrical installations. Selection of the type of conduit depends upon the following criteria.

- Type of location, outdoor or indoor
- Type of atmosphere, dry or damp or explosive or corrosive
- Expected working temperature
- Exposure to physical damage due to mechanical impact
- Allowable weight of conduit runs
- Estimated cost.

A comparison between metal and PVC conduit wirings given in Table 1 will help in choosing the right type of conduit for a specific installation.

Special precautions with non- metallic conduits

1 If the conduits are liable to mechanical damages they should be adequately protected.

2 Non-metallic conduits shall not be used for the following applications.

- In concealed/inaccessible places of combustible construction where the ambient temperature exceeds 60°C.
- In places where the ambient temperature is less than 5°C.

- For suspension of fluorescent fittings and other fixtures
- In areas exposed to sunlight.

Table 1

Comparison between metal and PVC wirings

Metal conduit	PVC conduit
1 Provides good physical protection to cables.	Comparatively poor.
2 Weighs more for a given length.	Lighter.
3 Needs skill and time for installation.	Needs less skill and time.
4 Risk of electric shock due to leakage.	No risk as PVC is an insulator.
5 Good earth continuity available through the pipe itself.	Not possible. Separate earth wire required.
6 Can be used in gas-light and explosive-proof installations.	Not suitable.
7 Not resistant to corrosion, needs protective coating.	Resistant to corrosion.
8 Large ambient temperature range	Suitable for limited temperature range. At temperature above 60^0C, the conduit starts melting. At very low temperature the conduit cracks.
9 Fire resistant.	Non-fire-resistant.
10 More costly.	Less costly.

Non-metallic conduit accessories

Non-metallic conduit fittings and accessories shall be fabricated or moulded to the required shape. They shall be so designed and constructed so that they can be fitted with the corresponding conduit sizes without any adjustment, ensuring ready mechanical protection to the cables.

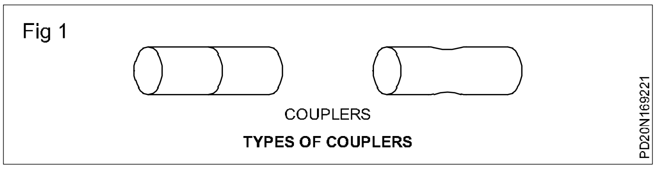
These fittings and accessories are used for conduit extension, and tappings or to assist pulling conductors. Rigid conduit accessories are normally of grip type only.

Inspection type, non-metallic fittings and accessories are permitted to be used only with surface mounting type wiring. Inspection fittings shall be so constructed that the screws used for fixing the cover do not deform the conduits or damage the insulation of the cables enclosed.

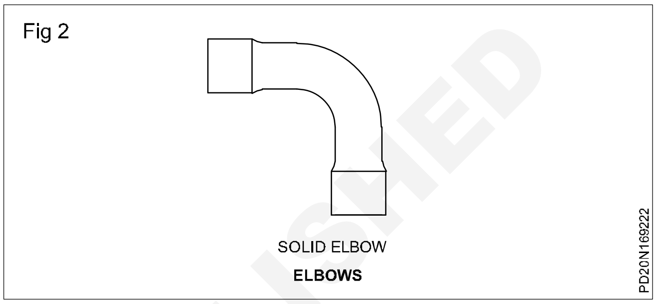
PVC fittings and accessories

Couplers (Fig 1)

Normally push type couplers are used and the conduit shall be pushed right through to the interior of the fittings. Inspection type couplers are used in straight conduit runs to assist in the inspection of the cables.

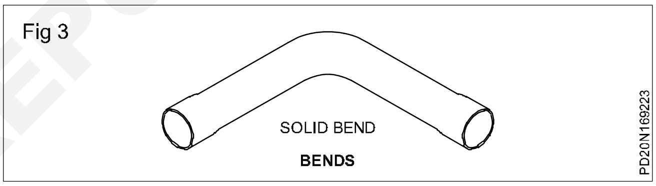


Elbow (Fig 2)



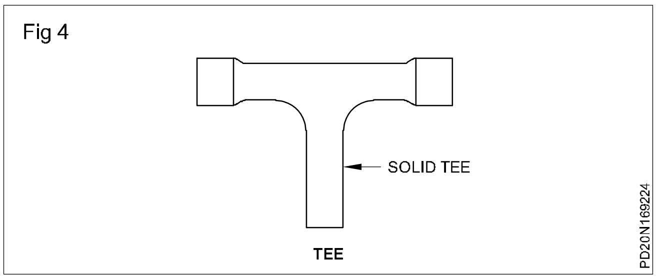
The axis of any elbow shall be a quadrant of a circle plus a straight portion of each end. Elbows are used at sharp ends of nearby walls or roof and wall.

Bends (Fig 3)



A bend gives a diversion of 90°C in the turn of a conduit, and a normal bend shall be a large sweep. Inspection type bends are used to assist in the inspection at the corners and for drawing cables.

Tees (Fig 4)



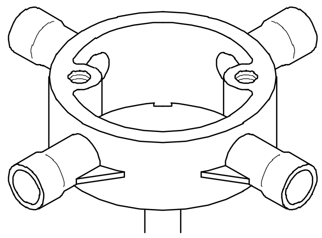
Tees are used to take diversion from the main line either to the switch points or the light points. It may be either an ordinary type or an inspection type. Inspection type tees are used to assist in the inspection in case there is a need.

Boxes

Circular boxes (Fig 5)

Small circular boxes shall be provided with two machine screws of a diameter not less than 2.8 mm for fixing the covers. Large circular boxes have four machine screws of

Fig 5



CIRCULAR BOXES

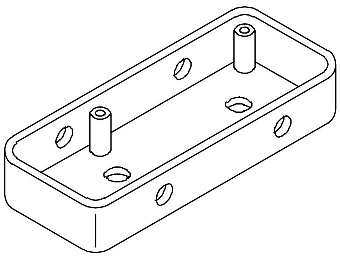
not less than 4 mm diameter having not less than 10mm threaded portion for fixing the cover.

They are available in a single-way, two-way, three-way and four-way as well as back outlet types which can be used as per necessity in wiring. The minimum depth of junction boxes used in roof slabs shall be 65 mm. The cover of the circular box shall be made of the same material as that of the the box, and have a minimum thickness of 1.6 mm.

Rectangular boxes (Fig 6)

These boxes shall be provided with two machine screws of a diameter not less than 2.8 mm for fixing the cover. They can be used as a junction box or switch box, for fixing flush type switches. These boxes shall be free from burrs, fins and internal roughness. The minimum thickness of the wall and base of the PVC box should be 2 mm and clear depth of 60 mm.

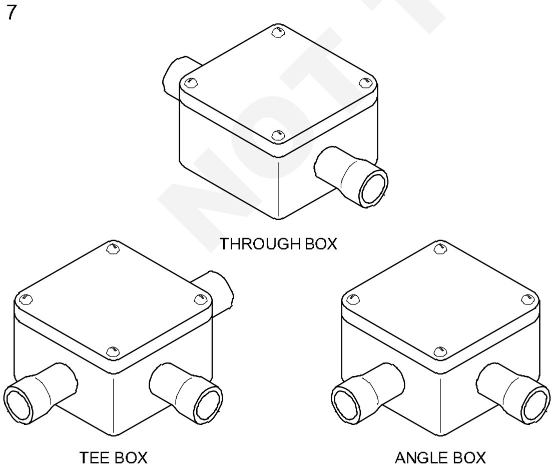
Fig 6



RECTANGULAR BOX

Apart from the above types, various other types are used as junction boxes (Fig 7).

Fig 7



TYPES OF BOXES (JUNCTION BOXES)

Method of cutting, joining and bending PVC conduit pipes

While doing the conduit wiring, it becomes essential, that the length has to be increased or decreased. Further the conduit is to be bent according to the required situation.

Cutting PVC conduit

A PVC conduit is easily cut by holding at the corner of a bench and using a hacksaw. Any roughness of cut and burrs should be removed with the aid of a knife blade/emery sheet, or sometimes by using a reamer. Before installing the PVC conduit pipe great care should be taken to remove the burrs inside the pipes to avoid damage to the cables during the cable drawing process.

Joining conduit with fittings

The most common jointing procedure uses a PVC solvent adhesive. Before applying the adhesive the inner surface of the accessory and the outer surface of the PVC pipe shall be cleaned with emery sheet to have a better grip. The adhesive should be applied to the receiving portion of the conduit fitting, and the conduit twisted into it to ensure a total coverage.

Generally, the joint is solid enough for use after two minutes although complete adhesion takes several hours. In order to ensure a sound joint, the tube and fittings must be clean and free from dust and oil.

Where expansion is likely and adjustments become necessary a mastic adhesive should be used. This is a flexible adhesive which makes a weatherproof joint, ideal for surface installations and in conditions of wide temperature variation. It is also advisable to use the mastic adhesive where there are straight runs on the surface exceeding 8 metres in length.

> **Conduit fittings should be best avoided, as far as possible, on outdoor systems.**

Bends in conduit

All bends in the non-metallic system shall be formed either by bending the pipes by proper heating or by inserting suitable accessories such as bends elbows or similar fittings. Solid type fittings shall be used for recessed wiring. Solid type/inspection type of fittings shall be used for surface conduit wiring.

The minimum bending radius of conduits shall be 7.5 cm. Care should be taken while bending the pipes to ensure that conduit pipes are not damaged or cracked and the internal diameter is not effectively reduced.

In recessed conduit wiring, conduit bending, other than at the ends, shall be made by bending the pipes to the required angle and clamping at short intervals. In the case of conduits laid in the roof slab, it can be clamped or tied to steel reinforcement bars with suitable metallic clamps.

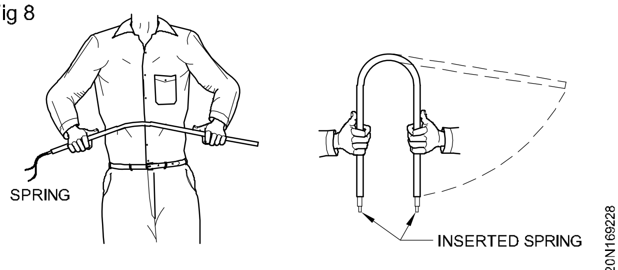
In the case of conduits recessed on walls, the chasis shall be made in the required shape and conduit fixed in the groove with suitable clamps. In the case of bending for surface conduit system, bending can be done either at cold state or by proper heating.

Cold bending PVC conduit pipes

PVC conduits not exceeding 25 mm diameter can be bent cold by using a spring. The bend is then made either with the hands or across the knee (Fig 8). In order to achieve the angle required the original bend should be made at twice the angle required and the tube allowed to return to the correct angle.

Under no circumstances should an attempt be made to force the bend back with the spring if it is twisted in an anticlockwise direction. This reduces the diameter of the spring, making it for easy withdrawal.

Fig 8



BENDING OF PVC PIPE BY HAND

Bending PVC conduit in cold weather

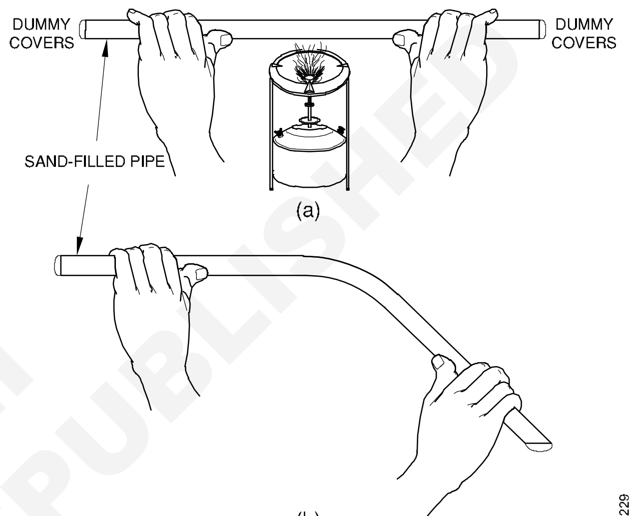
In cold weather it may become necessary to warm the conduit slightly at the point where the bend is required. One of the simplest ways to do this is to rub the conduit with the hand or a cloth. The PVC will retain the heat created long enough for the bend to be made. In order that the bend is maintained at the correct angle, the conduit should be saddled as quickly as possible.

Bending of conduit by heating

The piece of conduit to be bent is first cut and inspected for any sharp edges or burrs left out. In such cases it shall be made smooth by using suitable emery sheet. The conduit is then filled with river sand. The ends are sealed with suitable dummy covers. The portion where the bend is to be made shall be heated uniformly (Fig 9a) to a temperature below its melting point.

Then bend the required angle is made by holding both sides, with sufficient gap from the heated portion to avoid burning of hands, and applying uniform pressure (Fig 9b). Care shall be taken to avoid kinks on the conduits while bending.

Fig 9



HOT BENDING OF THE PVC PIPE

Selection of conduit sizes and general regulations

Objectives: At the end of this lesson you shall be able to

- **state the method of selection of a suitable size of conduit for a specific number and size of cables.**

In PVC conduit wiring the first step is to select the correct size of conduit. The conduit size is determined by the size of cables and the number of cables to be drawn in a particular section. This information can be obtained from the wiring layout and the wiring diagram.

Selection of conduit size

A non-metallic conduit pipe, used in wiring, should have a minimum size of 20 mm in diameter. Where a large number of conductors are to be drawn, the size of the diameter depends on the size of the conductor and the number of conductors. Table 1 gives details of the numbers and the sizes of conductors that can be drawn in each size of a non-metallic conduit.

Example

For selection of a PVC conduit

When 2.5 sq mm 650 V grade single core cables of six numbers are to be drawn in a single run, we can use 25 mm non-metallic conduit as per the table.

When 6 sq mm. 650 V single core 6 cables are to be drawn in a single pipe we can use 32 mm PVC pipe. The following are the maximum permissible number of 650/1100V volts grade single core cables that may be drawn into rigid non-metallic conduits (Table 1).

TABLE 1

Maximum number of PVC insulated 650 V/1100 V grade aluminium/copper conductor cable drawing through conduits conforming to IS: 694-1990.												
Nominal Cross- sectional area of condutor in sq.mm	**20 mm**		**25 mm**		**32 mm**		**38 mm**		**51 mm**		**70 mm**	
	S*	B*	S	B	S	B	S	B	S	B	S	B
1.50	5	4	10	8	18	12	–	–	–	–	–	–
2.50	5	3	8	6	12	10	–	–	–	–	–	–
4	3	2	6	5	10	8	–	–	–	–	–	–
6	2	–	5	4	8	7	–	–	–	–	–	–
10	2	–	4	3	6	5	8	6	–	–	–	–
16	–	–	2	2	3	3	6	5	10	7	12	8
25	–	–	–	–	3	2	5	3	8	6	9	7
35	–	–	–	–	–	–	3	2	6	5	8	6
50	–	–	–	–	–	–	–	–	5	3	6	5
70	–	–	–	–	–	–	–	–	4	3	5	4

- *** The above table shows the maximum capacity of conduits for a simultaneous drawing in of cables.**
- *** The columns headed 'S' apply to runs of conduits which have a distance not exceeding 4.25 m between draw in boxes and which do not deflect from the straight by an angle of more than 15 degrees. The columns headed 'B' apply to runs of conduit which deflect from the straight by an angle of more than 15 degrees.**
- *** Conduit sizes are the nominal external diameters.**

PVC Channel (casing and capping) wiring

Objectives: At the end of this lesson you shall be able to
- **state the use limitation and rules of channel wiring system**
- **select the channel size according to size and number of cables from the chart**
- **explain the method of fabricating neutral, bend, and junction in PVC channel .**

Introduction : Channel (Casing and Capping) wiring is a system of wiring in which PVC/metallic channels with covers are used for drawing wires. This system of wiring is suitable for indoor surface wiring works. This system is adopted to give a good appearance and for extension of existing wiring installation. PVC insulated cables are generally used for wiring in casing and capping system. This is otherwise called 'wireways'.

The channel and top cover shall be of the same material either PVC or anodised aluminium. The casing is square or rectangular in shape. The capping shall be slide in type with double grooving in the case of PVC wire ways. Plain type capping are used for metallic wireways.

The only disadvantage in a channel wiring is that it is inflammable and risk of fire.

Channel (casing & capping) wireways should not be used.

In residential buildings or such buildings were there is a risk of tampering where ambient temperature exceeds 60°C or less than 5°C in areas exposed to sunlight.

Dimensions : The sizes of channel, the maximum number of wires which can be drawn in each size are given in the table 1 below.

The thickness of channel should be 1.2mm ± 0.1mm.

TABLE 1

Nominal cross sectional area of conductor in sq.mm	10/15mm x 10mm size channel	20mm x 10mm size channel	25mm x 10mm size channel	30mm x 10mm size channel	40mm x 20mm size channel	50mm x 20mm size channel
	No. of wires	No. of wires	No. of wires	No. of wires	No. of wires	No. of wires
1.5	3	5	6	8	12	18
2.5	2	4	5	6	9	15
4	2	3	4	5	8	12
6	-	2	3	4	6	9
10	-	1	2	3	5	8
16	-	-	1	2	4	6
25	-	-	-	1	3	5
35	-	-	-	-	2	4
50	-	-	-	-	1	3
70	-	-	-	-	1	2

Precautions

1 Neutral (Negative) cables should be carried in top channel and phase (Positive) in the bottom channel.

2 Crossing of cables between phase (Positive) and neutral (Negative) should be avoided.

3 Porcelain or PVC pipe should be used for crossing the cables through the walls.

Installation of PVC channel : The channel should be fixed to wall/ceiling with flat headed screws and rawlplugs. These screws shall be fixed at an interval of 60cm. On either side of joints this distance shall not exceed 15cm from the end point. Channel under steel joints shall be fixed with MS clips of not less than 1.2mm (18SWG) thickness and width not less than 19mm.

Floor/Wall crossings : When conductor pass through floors/wall the same should be carried in a steel conduit/ PVC conduits properly bushed at both ends. The conduits shall be carried 20cm above floor level and 2.5cm below ceiling level and properly terminated into the channel.

Joints in PVC/Metal channel : As far as possible wireways in straight runs should be single piece. All joints shall be scarfed or cut diagonally in longitudinal section. The section ends shall be filed smoothly but joined without any gap. Care shall be taken to see that the joints in PVC cover does not overlap those channel.

Joints shall also be done using standard accessories like elbows, tees, 3 ways/4 ways junction box etc of high grade PVC/Aluminium alloy. In PVC channel separate channel cover for joint, elbows, tees, cross etc are available. These can be fixed after fixing the channel to give a good appearance. The radius of curvature of the cables inside a bend should be more than 6 times its over all diameter.

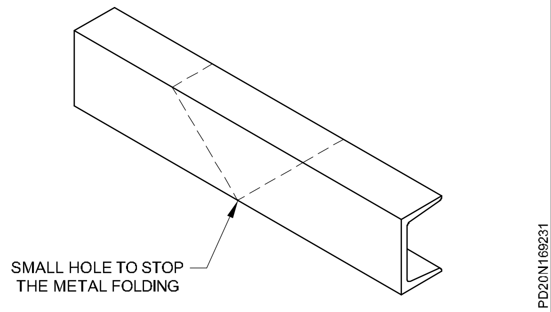
In the case of PVC channel, making joints is comparatively easy. Mark the joints by placing the two pieces in required angle. Identify the position to be cut and remove on each pieces. Cut through the lines and file the edges to get gapless joint.

Fabricating a right-angled vertical bend

1 Mark out the position of bend of all sides as shown in Fig 1. the width 'Y' must be made equal to the diagonal length 'Y' to be cut.

2 Drill small holes in corners at point of bend to stop channel folding (Fig 1).

Fig 1



3 Place wood blocks inside trunking for support. Cut sides of trunking (Fig 2).

4 Cut, file and break-off waste (Fig 3).

5 File all the edges smooth in order to bend to shape (Fig 4).

6 Make 'L' plates out of PVC scrap (Fig 5).

Fig 2

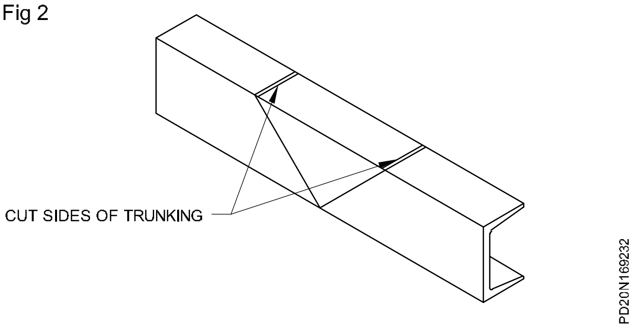


Fig 3

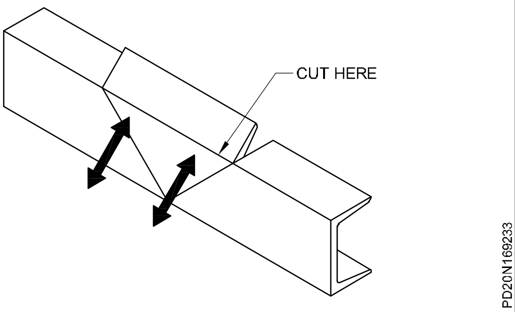


Fig 4

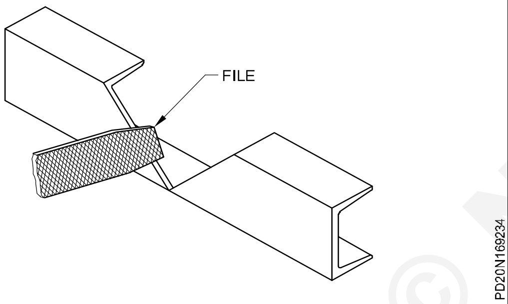
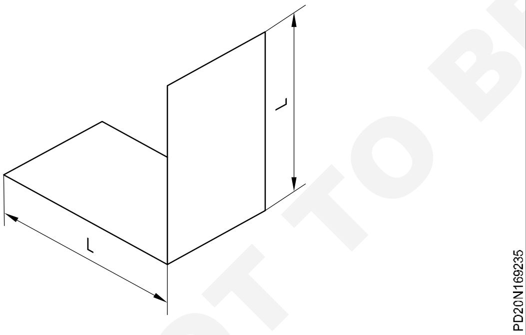
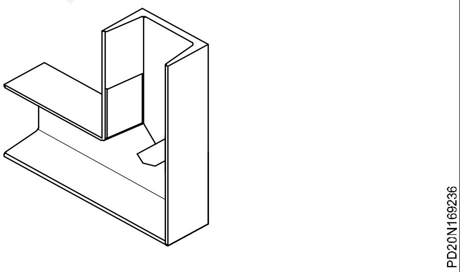


Fig 5



7 Make and secure assembly with 'L' plates and paste it with suitable adhesive (Fig 6).

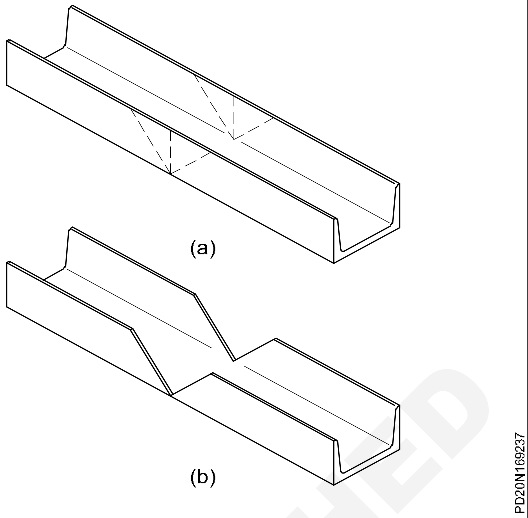
Fig 6



Fabricating 90° bend

1 Mark out the position of bend (Fig 7a & b).

Fig 7



2 Place wood blocks in trunking for support and make cuts with hacksaw.

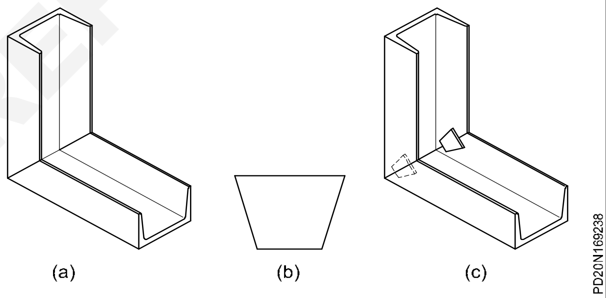
3 Remove sections and file smoothly.

4 Bend shape and adjust the fit as required (Fig 8a, b & c).

5 Make fish plates from PVC scrap (Fig 8b).

6 Make and secure the assembly with fish plate (Fig 8).

Fig 8



Fabricating a Tee junction

1 Mark out the position of tee using another piece of trunking to gauge width

2 Cut out the space for the tee (Fig 9a). Blocks of wood should be used to support section being cut.

3 In another piece cut away the section (Fig 9b) to form two legs (Fig 9c).

4 File edges smooth and remove burrs. Check fit and adjust as necessary.

5 Make, assemble and secure the Tee junction using suitable adhesive (Fig 10).

Fabricating a cross junction

1 Mark the position of first set (Fig 11a).

2 Place blocks of wood in trunking for support and make cuts with hacksaw.

3 Remove section of trunking and file the edges.

Fig 9

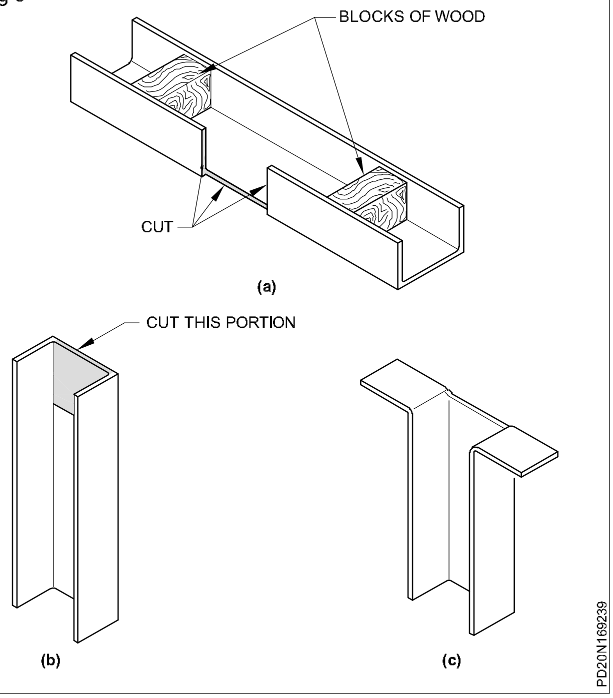
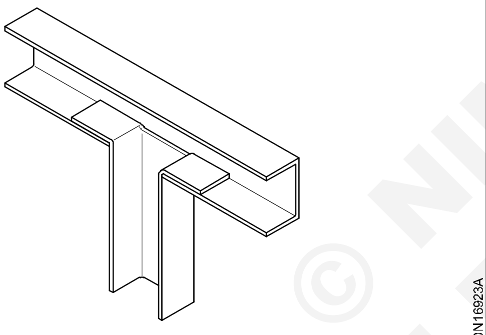
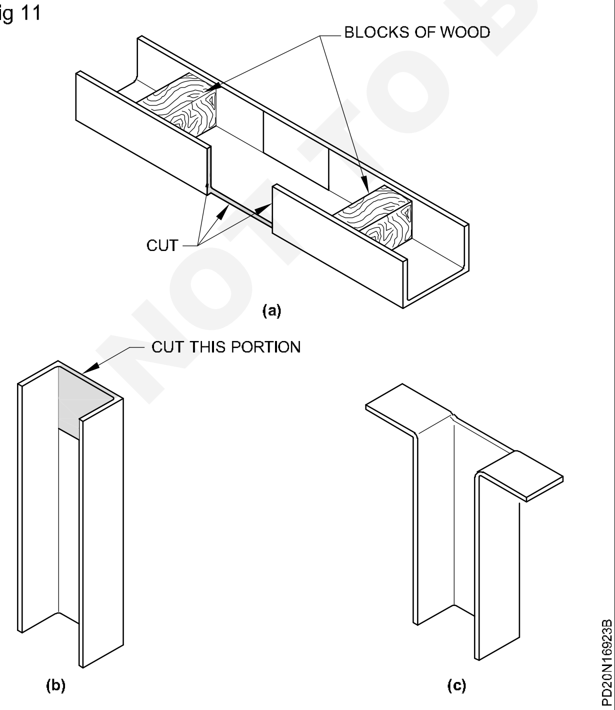


Fig 10



ASSEMBLEDTEE JUNCTION

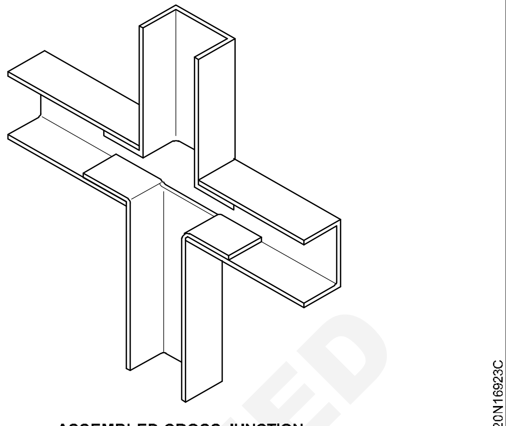
Fig 11



4 Take another two pieces and cut away the section (Fig 11b) to from two legs (11c).

5 Make, assemble and secure the cross junction using suitable adhesive (Fig 12).

Fig 12



ASSEMBLED CROSS JUNCTION

Installation of cables : Cables carrying the direct current or alternate current shall always be bunched seperately so that the outgoing and return cables are drawn in the same channel. Clamps shall be provided to hold the wires inside the channel at suitable intervals, so at the time of opening of the cover of channel, the wires do not fall out.

Attachment of cover : Cover should be attached to channel in individual sections after drawing all wires inside. No screws or nails shall be used for fixing PVC capping (cover) to the casing (channel). The capping (cover) should be slided in through the grooves. Metallic capping (cover) shall be fixed by using cadmium plated screws in a staggered manner with axial spacing not exceeding 30cm.

Earth continuity conductor : Earth continuity conductor shall be drawn inside the casing and capping (channel) for earthing of all metallic boxes of the installation as well as for connecting to earthpin of the socket.

In case of metallic casing and capping channel, there shall be a metallic link between adjacent casing with screw connections, and also connections from end channel (casing) to earth terminal of metallic boxes/outlets.

Power wiring

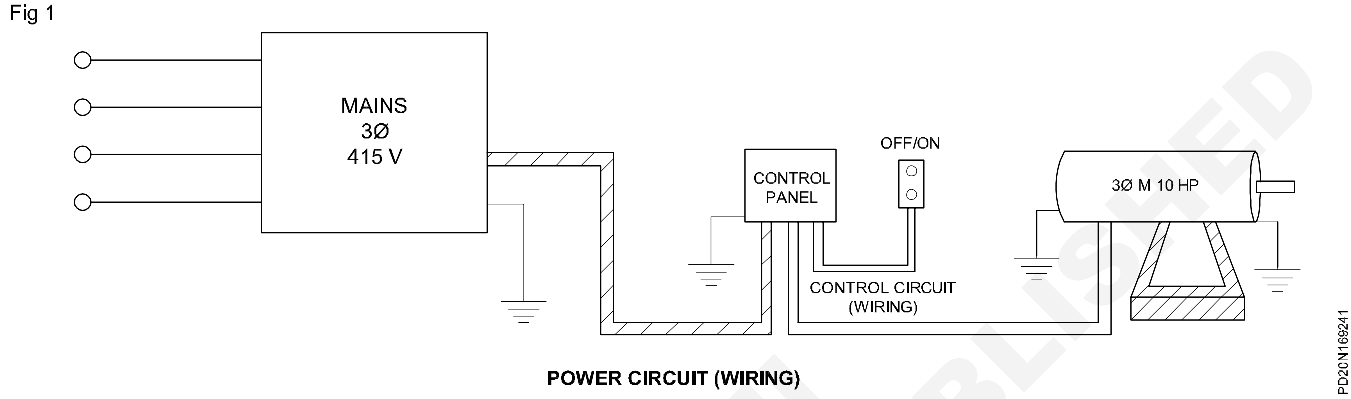
Objectives: At the end of this lesson you shall be able to
- **state the power, control, communication and entertainment wiring**
- **state the necessity of various wiring.**

A panel wiring diagram usually gives information about the relative position and arrangement of devices and terminals of the devices to help in installing or servicing the device.

Generally all the control panel / commercial / industrial wiring invariably consists of two sections viz control wiring and power wiring.

Fig 1 shows the typical layout diagram of a motor wiring. The control panel consisting of all the control and protective devices installed near to the power source and the load like, furnace, compressor etc, are installed away from the power source / panel boards.

Fig 1



Power wiring is a high current carrying circuit which is wired to connect / disconnect the load like motors/ furnace through the protective devices like OLR and fuses etc..

Power wiring has to be done as per the guideline and rules specified in IE rules. The cable size depends on the load current and it varies according to the load.

The power and control cable should not be run into single conduit. As the current radiation influences the control cable, a seperate conduit to be provided for control and power cables.

Control wiring

Control wiring is a circuit which is wired to communicate the commands and other information between control devices and lighting.

Control wiring enables the control circuit for various control purpose. In a motor control unit the control circuit is wired and kept near to motor. In other system such as fire alarm, fire detector etc. The control circuit is wired seperately with low current carrying condutors and drawn seperately for easy maintenance.

Fire alarm

The purpose of fire alarm system is to provide an immediate alarm in case of any fire and to prevent loss of life, also to secure the immediate attention of fire fighting staff.

Fire detectors

The three principal fire detection method involve sensing the heat, presence of flame or smoke. The third method identifies the pre - fire condition that is a flammable gas detector, which is techniclaly not a fire detector and its use is limited to places where flammable gases are likely to be present.

I Heat detector

The three basic operating principles for heat detection are:

a Fusion detector (melting of a metal)

b Thermal expansion detector

c Electrical sensing

II Smoke detectors

There are three types of smoke detectors namely

1 Ionisation detector

2 Light - scattering smoke detector

3 Obscuration smoke detector.

III Flammable gas detector

A flammable gas detector is designed to measure the amount of flammable gas in the atmosphere. The gas mixture is drawn over a catalytic surface where oxidation i.e. combustion takes place. The combustion causes a rise in temperature of the surface which is measured by a decrease in its electrical resistance. The instruments are calibrated by considering pentane or heptane as reference gas. The readings are displayed in terms of percentage of lower explosive limit.

Control panel for fire alarm system

The control panel is the heart of the system through which the fire alarm system is monitored and alarm is initiated if any indication/signal is conveyed to the panel.

The working of the fire alarm system should be checked once in a month regularly.

The features of the control panel are the power supply, battery charging unit and control card.

Communication wiring

It is type of wiring which is used to transmit the voice, data, images and video etc to the desired places.

Some of examples are

- Telephone wiring
- Internet / LAN network wiring
- Cable TV and other entertainment wiring
- Data and security services wiring
- Telex/ Fax machines wiring

Faster and more reliable than ordinary phone wiring, low-cost, high-tech copper wiring should serve every room in the modern home. Its is required to carry voice, data and other services from where they enter the house to every room, and from any one room to any other.

Necessity of communication wiring

Unshielded twisted pair (UTP) copper information wiring often called structured wiring is used today for offices, schools and factories to provide local area networks (LANs), which allow computers to talk to one another and to receive and send Internet and high-speed computer data outside the facility.

Educated homebuyers-and homebuilders realize it is better to use the most advanced wiring technology up front, when installation is economical.

It's better to anticipate the homeowner's future needs by wiring the house with a state-of-the-art system while it is being built, and at the same time equip yourself with a powerful marketing tool.

The phone wiring of the past, often referred to as quad wiring because it has four copper wires, is now obsolete. Cat 5 or higher speed wiring has four twisted wire pairs, or eight wires.

Copper UTP Wiring

Copper UTP wiring contains eight color-coded conductors (four twisted pairs of copper wires). It offers greatly increased bandwidth compared with old-fashioned quad wiring.

The cable is small (roughly 3/16 inch in diameter), inexpensive and easy to pull, although it must be handled with care.

Advantages

Modern copper UTP wiring offers the following advantages:

Diversity

The Internet and computer communications, as well as ordinary phone signals, can be carried throughout the home on modern, inexpensive, high-speed, UTP cables. (To service a large number of TV channels, it is recommended to also run high-quality coaxial cable, such as quad-shielded RG-6.)

More phone numbers

Several phone numbers can be made available throughout the house. Actually, voice service requires very little bandwidth, and the addition of separate numbers is almost trivial.

Bandwidth

Bandwidth correlates with speed, and these bandwidths are many orders of magnitude greater than the bandwidth required for a "modern" 56 kbps (kilobits per second) modem.

New Services

The Internet is now available at high speed to many homes, but homebuyers are not able to take full advantage of it, if their wiring is inadequate. One high-capacity technology now being offered by local phone companies is DSL (digital subscriber line). And cable modems are being offered by cable TV companies that bring in the Internet on the same coaxial cable carrying the TV signals.

Fig 1 is a simplified plan of a small, two-bedroom, single-story house. Note that all the wiring radiates from a single distribution device the star pattern and there are multiple outlets in each major room, including the kitchen and the porch.

Use 8-Pin Modular (RJ-45) Jacks (Fig 2)

These devices provide connection points for all eight of the wires contained in the four twisted pairs.

Fig 2 (below) shows a wall outlet with two such jacks.

All connecting devices, central distribution device, plugs on the ends of cables, outlets, etc.-should be rated for the cable used.

Finally, the finished installation should be thoroughly tested.

Video Cables

Although the industry is working toward an all-UTP solution for wiring residences, at this time it is prudent to also include conventional coaxial cable for video distribution, particularly cable TV. This is because it is difficult to predict whether many channels well over 100, for example-may become a reality in the near future, some channels of which will be the more bandwidth-consuming high-definition television (HDTV).

If coax is installed, quad-shielded RG-6 coax, with an all-copper center conductor, should be used for superior performance. (Copper-plated steel center conductors are also available, providing additional stiffness, but are unable to handle low-frequency currents used to power some devices.) A lesser grade, RG-59, should not be used.

Entertainment wiring

It is a type of wiring which is mainly used for entertainment or relaxation purpose.Example Home theatre wiring.

The nature and quality of wiring will not only determine the level of safety in home theatre room, but equally important, will have a noticeable impact on the video and sound quality of your system components.

Fig 1

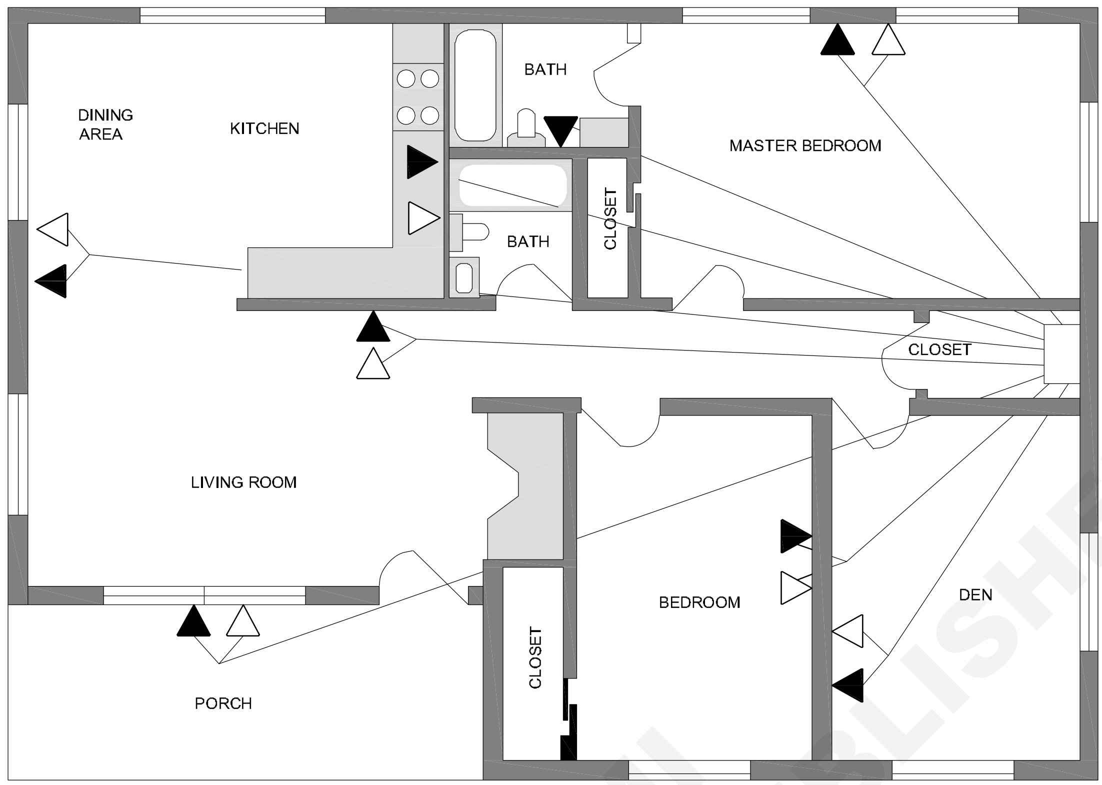
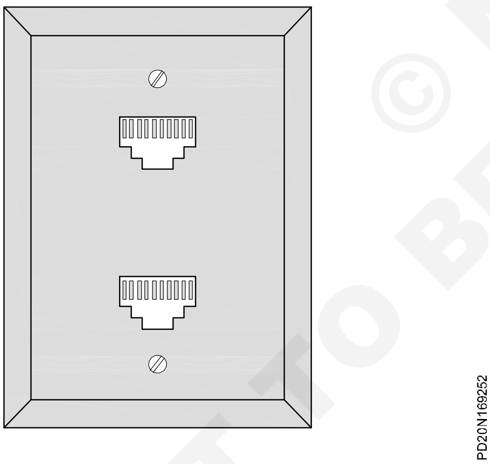


Fig 2



Home Theatre Wiring Basics: Safety, planning, budgeting

When it comes to home theatre wiring, the guiding principle is...

- Do it safe
- Do it once
- Do it right

Safety: This is a most important aspect in any installation. Do not save on the wiring by using sub-standard cables.

With in-wall installations, Specially certified wires (UL-rated CL3 wires) should be used that comply with national standards for resistance to fire, chemicals, abrasion, and temperature extremes.

Planning: Planning is the key to future proofing the installation while avoiding costly alterations later on.

AV (Audio Video) equipment and speaker placement the room lighting requirements, networking, possible future additions, etc. are to be taken care of these will determine the quantity and placement of the various audio/video points in the room as well as the electrical needs for home theatre installation.

Finally, when it comes to estimating the required cable lengths, do not just calculate the linear lengths to complete your cable runs; allow for at least 20% extra to cover for possible errors and slack for terminations.

Budgeting: The wiring requirements during planning stage will determine the budget necessary for your home theater wiring project.

Home Theatre Speaker Wiring

Many fail to realize that home theatre wiring can have a noticeable impact on speaker performance. The greatest speakers will not sound their best with the use of inappropriate speaker wires or an incorrect wiring installation. In particular, selecting the correct speaker wire thickness is essential for the best speaker performance.

At the same time, keep in mind that some speaker manufacturers use non-standard connectors with their speakers; in these circumstances, use of optional third-part speaker wire and connectors may not always be an option unless you take the extreme route of splice your wiring.

Speaker Wire Size

Selecting the correct thickness for your home theater wiring is important as it affects the speakers' performance; it will impact the speakers' ability to deliver the explosive effects in home theatre sound.

The thickness of a wire conductive copper part is identified by its Wire Gauge, normally expressed either in AWG (American Wire Gauge) or SWG (British Standard Wire Gauge)

Single Room Installation

The thicker wire will help bring out fine musical detail in quality music systems, as well as deliver the explosive effects of surround sound.

In those situations where long speaker wire runs cannot be avoided, thicker wire helps reduce the overall resistance, and therefore amplifier load - leading to lower operating temperatures. This will result in improved sound quality and long-term stability.

After setting up a modestly priced home-theatre-in-a-box package, do not go for the more expensive thicker wire unless you plan an upgrade sometime in the future; using of gauge 16 speaker wire should suffice in this case.

Multi-Room Wiring

In a multi-room installation, long home theatre wire runs are inevitable; The suggested wire gauge to use in home theatre wiring is given below:

Distance between speaker and amplifier	Speaker Wire Gauge
Less than 50 feet	16
50 to 100 feet	14
100 to 150 feet	12
more than 150 feet	10

The 'length factor' is not the only issue to consider when determining the wire gauge to use. The speaker impedance should also be taken into account.

Connection Basics

Speakers and amplifiers/receivers normally come equipped with one of two types of connectors - spring terminals or binding post connectors.

Each speaker connection have two such terminals marked (+) and (-) to help you distinguish the two leads. Maintaining correct polarity all along your home theater wiring is important. For this reason, speaker wire and terminals are normally color coded black for the -ve terminal and red for +ve side.

Spring terminals will only accept pin connectors or tinned base wire ends. Instead, binding posts accept many types of connection, including pin, banana plug or spade.

Guidelines for Home theatre wiring & installation

- Do not run home theatre cables in close proximity or parallel to other electrical lines, nor run your wiring around power supplies as these can lead to interference issues with both your audio and video system components.
- Avoid splicing wiring at all cost, as it leads to a lowering in performance. In addition, always use direct speaker wire runs straight from amplifier to each speaker. This is the normal way of wiring the sound in the home theatre but in the case of a multi-room audio installation, some may simply skip on this and splice the speaker cable along the way. Doing so, may not only lead to a detrimental effect but equally important, makes fault tracing even more difficult later should problems arise.
- Leave extra length at each end of the cable runs. And if home theatre wiring is part of a renovation project, it is also advisable to cover the extra cable lengths and termination/junction boxes. The plastering/painting process that follows can be really messy..

IE Regulation for main switch and distribution board

Objectives: At the end of this lesson you will be able to
- **state the I E regulations/ B I S recommendations/ NE Code of practice with regard to the main switch and distribution fuse box.**

Reception and distribution of main supply

There shall be a circuit breaker or a linked switch with fuse in each live conductor of the supply mains at the point of entry.

The neutral wire should not have any break in the form of switch or fuse unit. In the main switch, the neutral conductor should be marked clearly.

The main switchgear shall be located in a place where it is accessible and should be near to the terminating point of the service line.

Main switches and switchboards

Reference BIS 732-1963 and NE code.

All main switches shall be either of metal-clad enclosed pattern or of any insulated enclosed pattern which shall be fixed at close proximity to the point of entry of supply.

Location

Switchboards shall not be erected above gas stoves or sinks, or within 2.5 m of any washing unit in the washing rooms or laundries, or in bathrooms, lavatories, toilets, or kitchens.

In the case of switchboards unavoidably fixed in places likely to be exposed to atmospheric weather, the outer casing shall be weatherproof and shall be provided with glands or bushings or adapted to receive screwed conduit, according to the manner in which the cables are run.

Metal-clad switchgears shall preferably be mounted on any of the following types of boards.

Hinged type metal boards

These shall consist of a box made of sheet metal not less than 2 mm thick and shall be provided with a hinged cover to enable the board to swing open for examination of the wiring at the back.

The joints shall be welded. The board shall be securely fixed to the wall by means of rag bolts, plugs, or wooden gutties and shall be provided with a locking arrangement and an earthing stud. All wires passing through the metal board shall be bushed. Alternatively, hinged type metal boards shall be made of sheet covering mounted on channel or angle iron frames.

Such types of boards are particularly suitable for small switchboards for mounting metal-clad switchgears connected to supply at low voltages.

Fixed type metal boards

These shall consist of an angle or channel iron frame fixed on the wall or on the floor and supported on the wall at the top, if necessary. There shall be a clear distance of one metre in front of the switchboard.

Such types of boards are particularly suitable for large switchboards for mounting large number of switchgears or higher capacity metal-clad switchgear or both.

Teak wood boards

For small installations connected to a single phase 240 volts supply, teak wood boards may be used as main boards or sub-boards. These shall be of seasoned teak or other durable wood with solid back impregnated with varnish of approved quality with all joints dovetailed.

Thoroughly protected both inside and outside with good insulating varnish conforming to IS:347-1952 and of not less than 6.5 mm thickness, shall be provided at the back for attachment of incoming and outgoing cables. There shall be a clear distance of not less than 2.5 cm between the teak wood board and the cover,

Recessing of boards

Where so specified, the switchboards shall be recessed in the wall. The front shall be fitted with a hinged panel of teak wood or other suitable materials, such as Bakelite, or with unbreakable glass doors in teak wood frames with locking arrangement, the other surface of the doors being flush with the walls. Ample room shall be provided at the back for connection and at the front between the switchgear mountings.

Arrangement of apparatus

Equipment which is on the front of a switchboard shall be so arranged that inadvertent personal contact with live parts is unlikely during the manipulation of switches, changing of fuses or like operation.

No apparatus shall project beyond any edge of the panel. No fuse body shall be mounted into 2.5 cm of any edge of the panel and no hole other than the holes by means of which the panel is fixed shall be drilled closer than 1.3 cm from any edge of the panel.

In every case in which switches and fuses are fitted on the same pole, these fuses shall be so arranged that the fuses are not live when their respective switches are in the 'off' position.

No fuses other than the fuses in the instrument circuit shall be fixed on the back of or behind a switchboard panel or frame.

Marking of apparatus

Where a board is connected to a voltage higher than 250 volts, all the apparatus mounted on it shall be marked in the following colours to indicate the different poles or phases to which the apparatus or its different terminals may have been connected.

Alternating current

Three phases – red, yellow and blue.

Neutral – black.

Where three-phase, 4-wire wiring is done, the neutral shall be in one colour and the other three wires in another colour.

Where a board has more than one switch, each such switch shall be marked to indicate which section of the installation it controls. The main switch shall be marked as such and where there is more than one main switch in the building, each such switch shall be marked to indicate which section of the installation it controls.

Main and branch distribution boards

The main and branch distribution boards shall be of any type mentioned here.

The main distribution board shall be provided with a switch or circuit-breaker on each pole of each circuit, a fuse on the phase or live conductor and a link on the neutral or earthed conductor of each circuit. The switches shall always be linked.

Branch distribution boards shall be provided with a fuse on the live conductor of each circuit and the earthed neutral conductor shall be connected to a common link and be capable of being disconnected individually for testing purposes. One spare circuit of the same capacity shall be provided on each branch distribution board. Lights and fans may be wired on a common circuit. Such sub-circuit shall not have more than a total of ten points of lights, fans and socket outlets. The load of such circuit shall be restricted to **800 watts**. If a separate fan circuit is adopted, the number of fans in the circuit shall not exceed ten.

Power sub-circuits

The outlet shall be provided according to the load design for these circuits but in no case shall there be more than two outlets on each circuit. The load on each power sub-circuit should be restricted to **3000 watts.**

Installation of distribution boards

- The distribution fuse-boards shall be located as near as possible to the centre of the load they are intended to control.
- Distribution boards shall be fixed at a height not more than 2 metres from the floor level.
- These shall be fixed on suitable stanchion or wall and shall be accessible for replacement of fuses.
- These shall be of either metal-clad type or all-insulated type. But, if exposed to weather or damp situations, they shall be of weatherproof type and, if installed where exposed to explosive dust, vapour or gas, they shall be of flame proof type.
- Where there are two or more distribution fuse-boards in feeding low voltage circuits and fed from a supply at medium voltage, these distribution boards shall be:
  - fixed not less than 2 m apart; or
  - arranged so that it is not possible to open two at a time, namely, they are interlocked and the metal case is marked 'Danger 415 Volts'; or
  - installed in a room or enclosure accessible to only authorized persons.
- All distribution boards shall be marked 'Lighting' or 'Power' as the case may be and also marked with the voltage and number of phases of the supply. Each shall be provided with a circuit list giving details of each circuit with controls, the current rating and its size of fuse-element.

Wiring of distribution boards

In wiring branch distribution board, the total load of the consuming devices shall be divided, as far as possible evenly between branch circuits.

Cables shall be connected to a terminal only by soldered or welded or crimped lugs using suitable sleeve or lugs or ferrules unless the terminal is of such a form that it is possible to securely clamp them without cutting away cable strands.

Fuses

a A fuse carrier shall not be fitted with a fuse element of higher rating than that for which the carrier is designed.

b The current rating of a fuse shall not exceed the current rating of the smallest cable in the circuit protected by the fuse.

c Every fuse shall have in its own case or cover, or in an adjacent conspicuous position, an indelible indication of its appropriate current rating for the protection of the circuit which it controls.

Selection of size of conductor

The size of conductors of circuits shall be so selected that the drop in voltage from the consumer's terminals in a public supply (or from the bus-bars of the main switch-board controlling the various circuits in a private generation plant) to any point on the installation does not exceed 3 per cent of the voltage at the consumer's terminals.

In each circuit or sub-circuit the fuse shall be selected to match the cable rating to ensure the desired production.

All conductors shall be of copper or aluminium. The conductor for final sub-circuit for fan and light wiring shall have a nominal cross-sectional area of not less than 1.00 mm^2 copper and 1.50 mm^2 aluminium. The cross-sectional areas of conductors for power wiring shall be not less than 2.5 mm^2 copper, 4.00 mm^2 aluminium. The minimum cross-sectional area of conductors of flexible cords shall be 0.50 mm^2 copper.

Branch switches

Where the supply is derived from a three-wire or four-wire source and distribution is done on the two wire system, all the branch switches shall be placed in the outer or live conductor of the circuit and no single phase switch or fuse shall be inserted in the middle wire, earth or earthed neutral conductor of the circuit.

Passing through walls and floors

Where conductors pass through walls the conductor shall be carried either in a rigid steel conduit or a rigid non-metallic conduit or in a porcelain tube of such a size which permits easy drawing in. The end of the conduit shall be neatly bushed with porcelain, wood or other suitable material.This steel conduit shall be earthed andsecurely bushed.

Where a wall tube passes outside a building so as to be exposed to the weather, the outer end shall be bell mouthed and turned downwards and properly bushed on the open end.

Fixing to walls and ceilings

Plugs for ordinary walls or ceilings shall be of well seasoned teak or other suitable hardwood not less than 5 cm long and 2.5 cm square on the inner end and 2 cm square on the outer end. They shall be cemented into walls to within 6.5 cm of the surface, the remainder being finished according to the nature of the surface with plaster .

In the case of new buildings, wherever possible, teak wood plugs shall be fixed in the walls before they are plastered. To achieve neatness, plugging of walls or ceilings may be done by a suitable type of asbestos, metallic or fibre fixing plug.

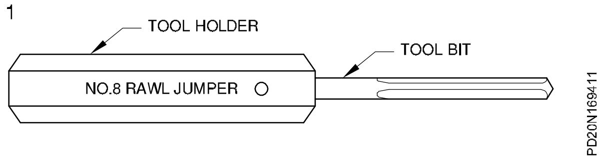
Energy meter board installation

Objectives: At the end of this lesson, you shall be able to
- **state the purpose and method of use of a rawl jumper**
- **state the type of filler materials used for rawl jumper holes**
- **state the shape and use of wooden gutties**
- **describe the method of preparing pipe jumpers**
- **state the precautions while making through holes in the wall.**

Purpose of Rawl jumper

The purpose of the rawl jumper is to make holes in the brick and concrete walls or ceiling for fixing the batten or round blocks. It consists of two parts. Tool bit and tool holder as shown in Fig 1. The tool bit is made of carbon steel whereas the holder is made of mild steel.

Fig 1

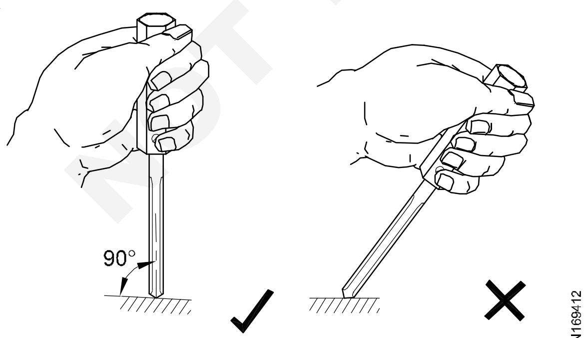


The tool bit is fluted to allow maximum debris clearance and ensure fast penetration. The shank of the tool bit is tapered to fit into the tool holder.

There are different sizes available. Numbers 8, 10, 12, and 14 are used in electrical work. As the number increases the size of the bit as well as the size of the holder decreases

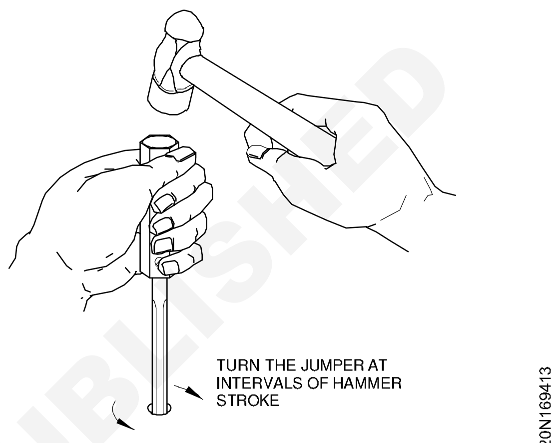
While making holes, the rawl jumper is held at right angles to the wall surface and hit by a hammer. The rawl jumper is turned clockwise and anticlockwise by 90^o between hits as shown in Fig 3 to enable removal of debris and to avoid breakage of the tool bit. Care should be taken to see that the mushroom is removed from the tool holder head after every use. (Fig 2)

Fig 2



RAWL BIT SHOULD BE KEPT AT RIGHT ANGLE TO THE WALL SURFACE

Fig 3



CORRECT METHOD OF USING RAWL JUMPER

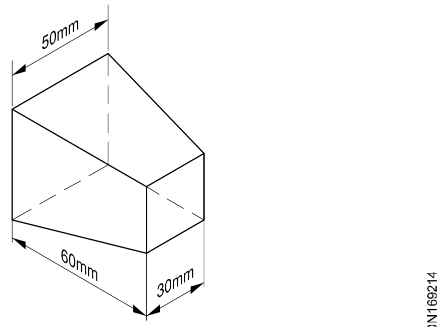
Types of filler materials

Saw dust, fibre, plastic, asbestos, and some times nylon plugs are inserted into the holes. The batten or round block etc are fixed by the screws penetrated into the plug which expands and grips the wall firmly.Rawl plugs are only suitable for rigid walls. But for non-rigid walls, wooden gutties are used.

Shape of the wooden guttie

A wooden guttie is made up of teak wood. The shape of the guttie : Normally, it is 50 mm sq. on one side and gradually tapered to 30 mm sq. at the other side. The length on the side will be 60 mm. The size of the guttie depends upon the load it has to carry. After fixing wooden gutties the cement requires atleast 24 hours of curing before screws could be used on them.(Fig 4)

Fig 4



WOODEN GUTTIES

Method of fixing

A recess hole of a size larger than the size of guttie is made in the wall with a cold chisel and hammer. Then water is sprinkled inside the hole and a small quantity of cement mortar is inserted into the hole. Then the larger area side of the guttie is inserted into the hole and positioned such that the smaller area side is flush with the wall. Fill the hole with cement mortar.

Allow it to set for a day. After 4 hours of fixing, water is sprinkled on the cemented area after every one hour duration for curing. After 24 hours of curing, fix the board or batten or round block with a screw driven into the guttie.

Pipe jumper

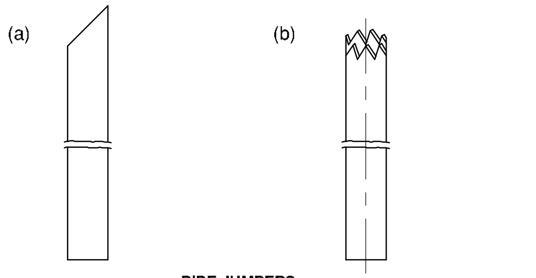
A pipe jumper is used along with a hammer to make through holes in walls during wiring. The diameter of the pipe jumper depends upon the diameter of the pipe to be accommodated in the wall and the length depends upon the wall thickness.

Preparing the pipe jumper

One method of making a pipe jumper is to use a GI pipe of suitable size and to have a slant cut by a hacksaw. (Fig 5 a).

The second method of preparing a pipe jumper is to cut the teeth on one end of the pipe Fig 5(b) in the form of a crown.

Fig 5



PIPE JUMPERS

While making through holes in the walls, the following precautions should be observed.

From time to time, between hammer blows, rotate as well as pull out the pipe jumper from the hole to remove the broken masonry pieces. This enables free movement of the pipe jumper.

Slow down the hammer strokes when the pipe jumper reaches nearer to the other end of the wall. Otherwise it causes larger sized plaster to fall down from the other side of the wall.

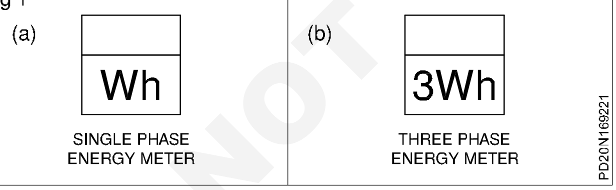
While making a hole on a wall in which concealed wiring exists, ascertain the lay out of the existing wiring on the wall and then make a hole. Otherwise switch off the mains to avoid electrocution.

NE code of practice and IE Rules for energy meter installation

Objectives: At the end of the lesson you shall be able to
- **interpret BIS symbols for single and 3-phase energy meters**
- **state the BIS recommendations pertaining to the mounting of the energy meters.**

The BIS symbols for energy meters are given in Figs 1a and 1b

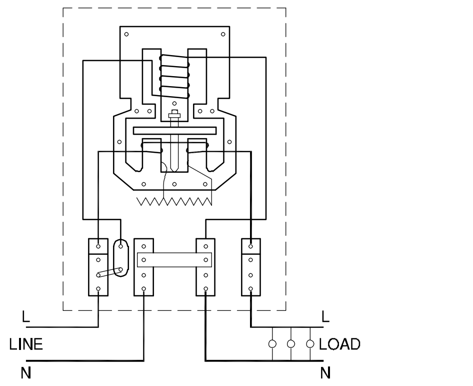
Fig 1



Internal circuit diagrams of single phase and three phase meters are Fig 2 and 3 respectively.

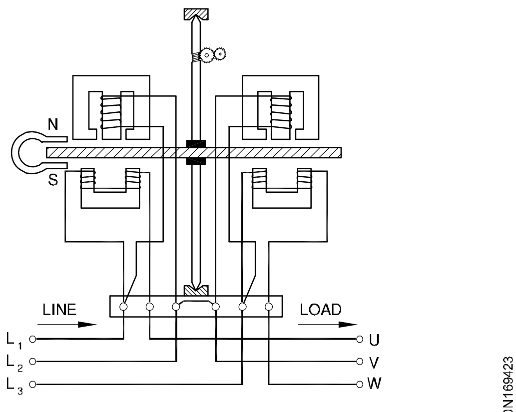
In earlier domestic installations the service mains were brought inside the consumer premises and first connected to the IC cutouts, then to the energy meter and to the consumer main switch (Fig 4a and 4b)

Fig 2



INTERNAL CONNECTION OF SINGLE PHASE ENERGY METER

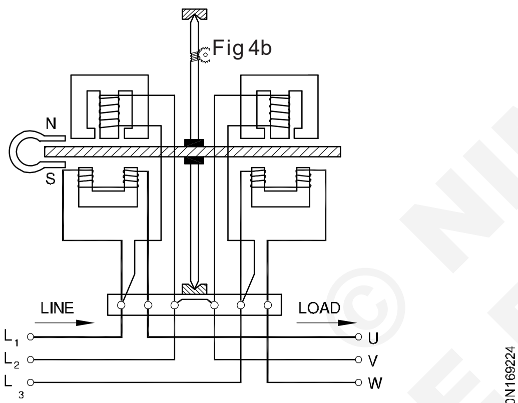
Fig 3



INTERNAL CONNECTIONS OF THREE PHASE ENERGY METER

However, to avoid pilferage of electricity, certain electricity boards insist that the service connections should first be connected to the energy meter, then to the I C cutout and then to the consumer main switch. In all the cases the neutral should be directly connected from the outgoing terminals of the energy meter to the consumer main switch. (Fig 4b)

Fig 4



INTERNAL CONNECTIONS OF THREE PHASE ENERGY METER

Precautions while installing energy meters

- Energy meters which are tested and approved by the local electricity board authorities only should be used.
- Energy meters should be used in vertical position only.
- Connections for incoming and outgoing supply should be made according to the manufacturer's instructions/ connection diagram which will be available on the inner side of the terminal plate of the energy meters.

NE code of practice and IE rules for energy meter installation

Energy meters shall be installed at such a place which is readily accessible to both the owner of the building and the authorised representatives of the supply authority.

It should be installed at a height where it is convenient to note the meter reading; it should preferably be not installed below 1 m from the ground. The energy meters should either be provided with a protective covering, enclosing them completely, except the glass window through which the readings are noted or should be mounted inside a completely enclosed panel provided with hinged or sliding doors with arrangement for locking it.

Any meter placed upon the consumer's premises shall be of appropriate capacity and shall be deemed to be correct if its limits of error do not exceed 3% above or below absolute accuracy at all loads in excess of one tenth of full loads and up to full load.

No meter shall register at no load.

General instructions

The body of the energy meter should be earthed to the general mass of earth using a proper size of earth continuity conductor depending upon the current capacity of the installation.

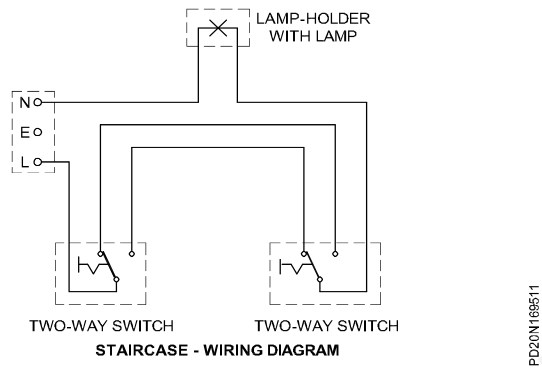
For multi-storeyed buildings which consist of a number of offices or commercial centres or flats occupying various areas, the electrical load for each of them is metered separately. In such cases, all the energy meters are located in a meter room which is normally situated on the ground floor.

Special wiring circuits - Tunnel, corridor, godown and hostel wiring

Objectives: At the end of this lesson you shall be able to
- **state the difference between godown, tunnel and corridor, bank/hostel wirings**
- **draw the tunnel lighting / corridor / bank / hostel circuits**
- **prepare the mode chart for the above circuits.**

Staircase wiring: In wiring one lamp controlled with one switch in a simple wiring circuit to begin with. However,one lamp controlled with two switches from two different places, known an staircase wiring in the very basic wiring. Fig 1 shows such a wiring where two double pole switches are used to control one lamp individually.

Fig 1



STAIRCASE - WIRING DIAGRAM

In the case of godown wiring we have seen that as you move inside the godown, you can switch on a lamp ahead of you while the light behind you is put off. The same process in the reverse order takes place while moving out of the godown.

But one light will not be sufficient to give enough illumination in the case of tunnels where darkness is more. Hence, the wiring circuit for a tunnel needs at least two lights to be 'ON' at a time while a person moves inside a tunnel and goes out.

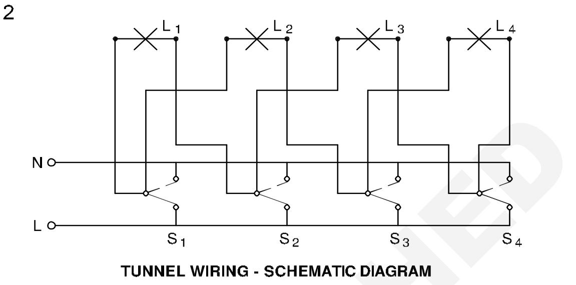
Whereas in the case of corridor wiring the corridor may have a number of rooms occupied by different persons. When one moves toward his room, he needs a forward light to do so. The moment he finds the room and opens it, he may not need the corridor light. Then there should be an arrangement to switch off the light left behind the forward moving person and at the same time there should be a provision to switch off the light in front of his room. Such an arrangement is incorporated in corridor wiring.

On the other hand in bank/jail/hostel, there may be a number of lights having individual controls. There should be a provision for the security staff/warden to switch ON all the lights where they are all OFF. Such a provision is incorporated in the bank / jail / hostel wiring.

Tunnel lighting circuit (Fig 2)

In tunnel wiring a person walking along the tunnel can successively light behind two lamps ahead and put off a lamp behind with one switch.

Fig 2



TUNNEL WIRING - SCHEMATIC DIAGRAM

All switches are two-way switches.

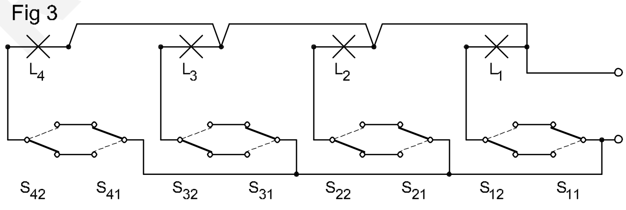
Caution: This circuit is not in accordance with IE rules as the phase and neutral come in the same switch. So care should be taken while connecting the wires.

The mode of operation of the switches and the consequent lighting position are shown below.

Mode chart for tunnel wiring

Corridor wiring (Fig 3)

Fig 3



SCHEMATIC DIAGRAM OF CORRIDOR WIRING

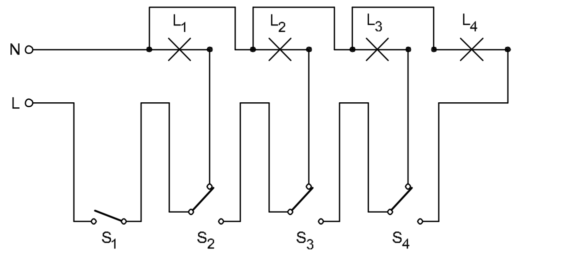
In this circuit, operating the first switch in one set makes the first light to switch on while operating the 2nd switch in the first set switches off the first light. This sequence goes on as explained in the mode chart.

Godown lighting circuit (Fig 4)

Let us consider a godown lighting circuit (Fig 4) having three lamps L_1, L_2, L_3 and L_4 which are to be controlled such that if one moves in a godown in either direction he can switch ON one light after the other in the forward direction while the lamp which was lighted earlier gets switched OFF. In an arrangement. S_1 is a one way switch, S_2, S_3 and S_4 are two-way switches.

While coming back from the godown when the person switches off the light 4, then the light 3 will be on and give light for his return movement. When he leaves the godown all the lights could be switched 'off' by operating switch S_1.

Fig 4



CIRCUIT DIAGRAM

The following chart gives the mode of operation of the switches and lights. Trainees are advised to make the return mode chart.

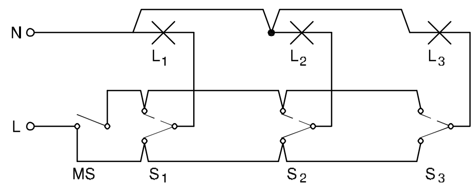
Mode chart for godown wiring

Switches				Lights			
S_1	S_2	S_3	S_4	L_1	L_2	L_3	L_4
ON	OFF	OFF	OFF	ON	-	-	-
ON	ON	OFF	OFF	-	ON	-	-
ON	ON	ON	OFF	-	-	ON	-
ON	ON	ON	ON	-	-	-	ON

Bank / jail / hostel wiring (Fig 5)

The master switch (MS) could be operated by the warden to make all the lights ON when they are all OFF.

Fig 5



SCHEMATIC DIAGRAM OF JAIL WIRING

Intermediate switch - specification and application in lighting circuit

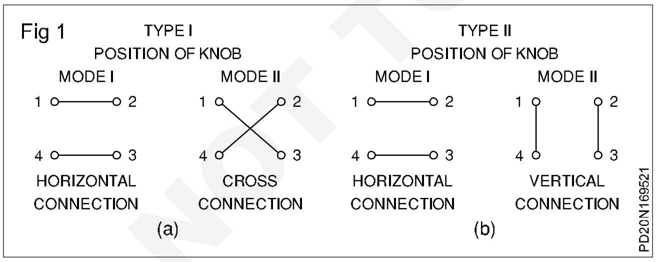
Objectives: At the end of this lesson you shall be able to
- **identify the features and specify an intermediate switch**
- **draw diagrams of a lighting circuit using intermediate switches.**

An intermediate switch is a special type of switch having four terminals for connection. This switch is commonly used to control a lamp or load from three or more positions as encountered in the lighting of staircases, corridors, bedrooms.

Specifications of an intermediate switch

These switches are available in the market with two possible change over types of connections Figs 1a and 1b.

Fig 1



Accordingly the specification should contain the following information.

- Type of mounting
- Voltage rating
- Current rating
- Type of connection

Example

Flush mounting intermediate switch 250 V 6 A horizontal and cross connection.

Circuit connections

For controlling a lamp from three locations, one intermediate switch and 2 two-way switches could be used (Fig 2). Knob positions of the switches and the conditions of the lamp are also given along with Figure 2 for easy understanding.

To control a lamp from three locations, three intermediate switches instead of a two two-way switches can also be used. (But, in practice, they are not used since it is very expensive).

Schematic diagrams (Figs 3 and 4) shows the method of controlling a lamp from three locations using three intermediate switches having horizontal and cross/ vertical connection respectively.

The schematic diagram (Fig 5) is for controlling one lamp from five locations using two two-way switches and three intermediate switches is given below.

In the schematic diagram (Fig 6) is for controlling one lamp from 3 positions with a master control as a security control switch. The lamp is controlled independently from three places by switches S_1, S_2 and S_3. When the master switch 'M' is 'ON' the lamp is permanently 'ON'and cannot be controlled by switches S_1, S_2 and S_3.

Fig 2

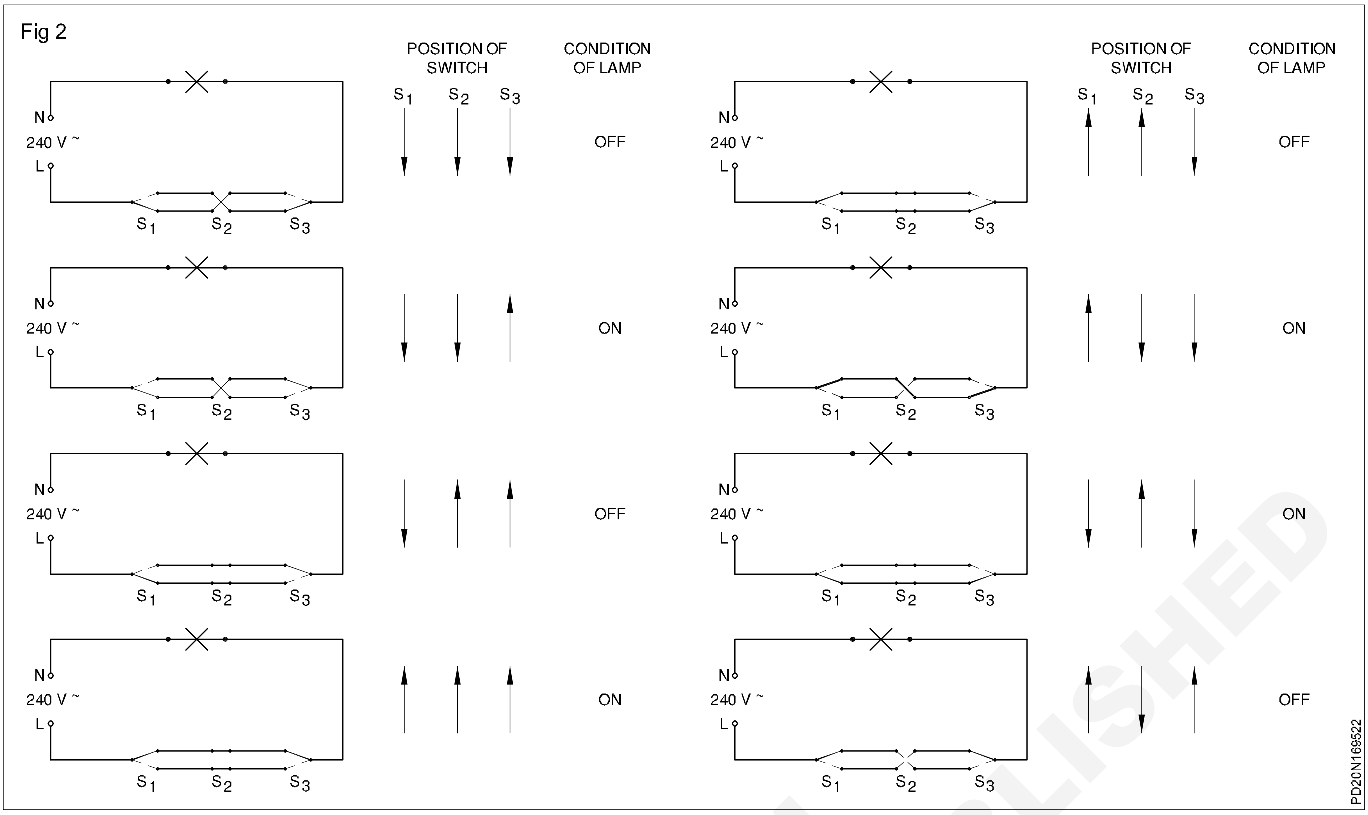


Fig 3

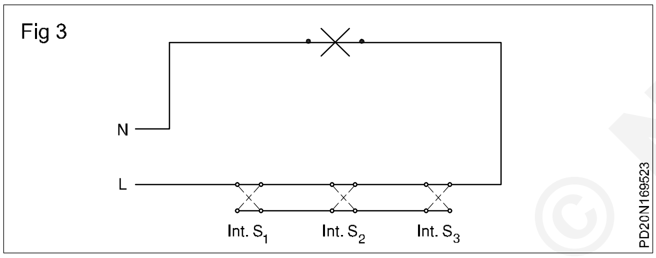


Fig 4

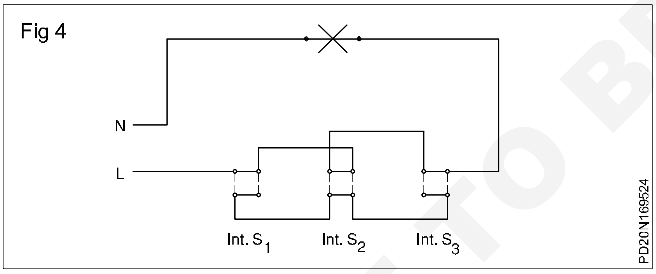


Fig 5

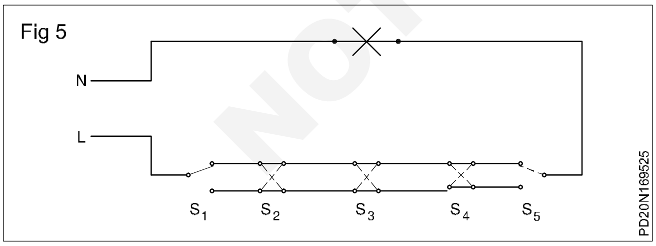
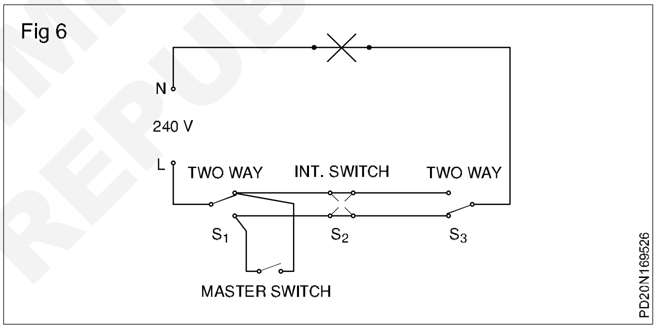
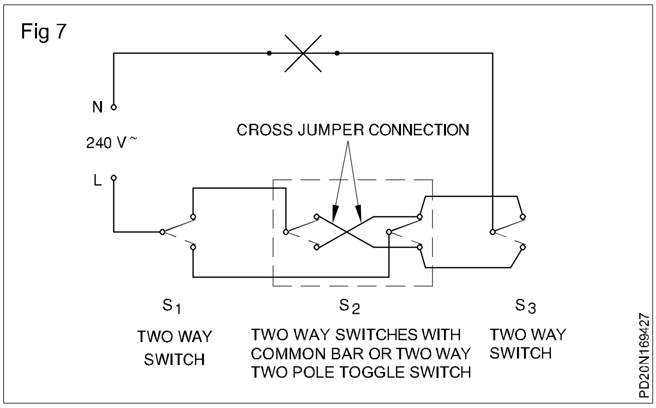


Fig 6



As intermediate switches are costly two numbers of two-way switches can be linked through a common bar and can be used as an intermediate switch (Fig 7). This circuit controls one lamp from 3 places.

Fig 7



Estimation and cost of material for wiring installation

Objectives: At the end of this lesson, you will be able to
- **state the points to be considered before taking up domestic wiring**
- **calculate the load(s) and select the number of sub(branch) circuits**
- **estimate the load in a circuit**
- **select proper cable size for branch main circuits and the supply system**
- **estimate and list out the accessories for given wiring installation.**

Points to be considered before taking up domestic wiring

The following points shall be noted particularly in respect of domestic dwellings.

Before starting the wiring installation, information should be exchanged between the owner of the building or architect and the local supply authority in respect of tariffs applicable, types of apparatus that may be connected under each tariff, requirement of space for installing meters, switches, service lines etc. and for the total load requirement of lights, fans and power.

While planning an installation, consideration should be given to the anticipated increase in the use of electricity for lighting, general purpose socket-outlet, kitchen, heating etc. Otherwise, the householder may be tempted to carry out extension of the installation himself or to rely upon the use of multiplug adaptors and long flexible cords, both of which are against the electric supply rules. Fundamentally safe installation may be rendered dangerous, if extended in this way.

Hence the National Electricity Code suggests the following schedule.

Number of points in branch circuits: The recommended yardstick for dwelling units for determining the number of points is given in Table 1.

Table 1

Number of points for dwelling units

Sl.No.	Description	Area of the main dwelling unit (m^2)				
		35	45	55	85	140
1	Light points	7	8	10	12	17
2	Ceiling fans (See NOTE below.)	2-2	3-2	4-3	5-4	7-5
3	5 A socket outlets	2	3	4	5	7
4	15 A socket outlets	–	1	2	3	4
5	Call bell (buzzer)	–	–	1	1	1

NOTE: **The figures in the table against Sl.No.2 indicate the recommended number of points and the number of fans. Example: For the main dwelling unit of 55m^2, 4 points with 3 fans are recommended.**

Number of socket outlets

The recommended schedule of socket outlets for the various sub-units of a domestic dwelling are given in Table 2.

Table 2

Description	Number of socket outlets	
	6A	16A
Bedroom	2 to 3	1
Living room	2 to 3	2
Kitchen	1	2
Dining room	2	1
Garage	1	1
For refrigerator	–	1
For air-conditioner	–	1 (for each)
Verandah	1 per 10 m^2	1
Bathroom	1	1

Note that the BIS has changed the ampere specification of socket and plugs as 6 amps and 16 amps,whereas the earlier BIS references is for 5 amps and 15 amps. Further the manufacturers are yet to change their product specification from 5 A/15 A to 6 A/16 A. Hence the trainees are advised to use the new reference with due care for old reference also.

Electrical installation in a new building should normally begin immediately on the completion of the main structural building work. For conduit wiring system, the work should start before finishing work like plastering has begun. For surface wiring system, however, work should begin before final finishing work like white washing, painting etc.

Usually, no installation work should start until the building is reasonably weatherproof, but where electric wiring is to be concealed within the structures, the necessary conduits and ducts should be positioned after the shuttering is in place and before the concrete is poured, provision being made to protect conduits from damage. For this purpose, sufficient coordination shall be ensured amongst the concerned parties.

Sub(branch) circuits

Stated below are some of the important points from the above information sheet.

Sub-circuits may be divided into two groups

a Light and fan sub-circuits.

b Power sub-circuit.

Separate distribution boards shall be provided for light and power.

Each circuit shall be provided with a fuse in the phase wire and the neutral conductor shall be connected to a common link with disconnecting arrangement for testing.

The load on the light and fan sub- circuits should be restricted to 800 watts or ten points considering each light, fan and 6 amps sockets as points.

A minimum of two lighting sub-circuits shall be provided in each house so that in case of fault in one sub-circuit, the whole house is not plunged in total darkness.

The load on power circuits should be restricted to 3000 watts having not more than two socket outlets.

Estimation of load requirements

Electrical installation in domestic dwellings is basically designed to cater to light and fan loads and for electrical appliances and gadgets. In estimating the current to be carried by any branch circuit, unless the actual values are known, these shall be calculated based on the following recommended ratings.

Item	Recommended rating (in watts)
Incandescent lamps	60
Ceiling fans	60
Table fans	60
6 A, 3-pin socket-outlet points	100
Fluorescent tubes	
Length 600 mm	25
1200 mm	50
1500 mm	90
Power socket outlets (16 A)	1000

Example

Estimate the cost of material for wiring PVC channel for an office room having 2 lamps 1 fan one 6A socket outlet.

To estimate the cost of material the electrician has to follow these steps:

Type of wiring to be decided- PVC channel (casing and capping - given).

Position of the electrical points/Loads has to be decided as per the requirment.

Layout of the office has to be prepared (Fig 1).

Total load to be calculated, In the given example

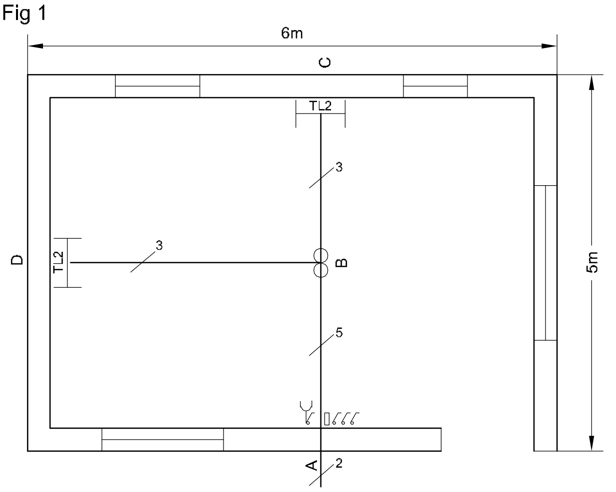
i) Tube 2nos x 50 W = 100 W

ii) Fan1no x 60 W = 60 W

iii) 6A socket 1 no = 100 W

260 W

Fig 1



LAYOUT DIAGRAM OF AN OFFICE ROOM

circuit/connection diagram for the room has to be developed.

Based on the layout and circuit diagram calculate the length of PVC channel required.

1) Length of PVC channel in Roof = 5 +3 = 8m

2) Vertical drops = 0.5 +0.5 +2.0 = 3.0m

Total = 8+ 3.0 = 11.0 m

3) Add 10% tolerance = 1.1 m

12.1 m

7 Calculate the length of wire and size of wire based on layout, circuit diagram and load. In the given example,the total load is 260W the current taken by the total load are

$$I = \frac{p}{v \times \cos\theta} = \frac{260}{240 \times 0.8} = 1.35A$$

Hence PVC copper flexible 1sqmm wire is enough to this circuit/room. However since this wiring come in the catagory of commercial wiring, for safe-side, we can choose 1.5sq mm PVC insulated copper flexible wire.

Assume vertical drop is 0.5 m for tube lights and 2m for switch board then the length of wire required is

From A to B and vertical drop = (2.5 +2)m x 5 = 22.5 m

From B to C and vertical drop = (2.5 +0.5) m x 3 = 9m

From B to D vertical drop = (3 +0.5)m x 3 =10.5m

total length = 22.5 + 9 +10.5 = 42m

add 10% telerance = 42 + 4.2 = 46 m

The maximum number of wire runs in a PVC channel is 5 hence 19 mm x 10mm PVC channel may be used.

List of electrical accessories required with complete specification has to be prepared. Also calculate the cost of materials as per the present market rate.

Sl No	Accessories	Length	unit price	price
1	PVC channel 19 mm x10mm	12m		
2	1.5 sq mm PVC insulated copper flexible 650V	46 m		
3	Flush type SPT switch 6 A 250 V	4 No		
4	Flush type socket 6 A 250V	1No		
5	Wooden switch board 250mm x 150mm	1No		
6	Tube light fitting complete set 250V 4 feet 40W	2No		
7	Ceiling fan 250V, 1200 mm sweep	1 No		
8	electrcial fan regulator 250V , 60W	1No		
9	Wood screws 15 x 4mm, 25 x 5mm, 30 x6mm	25 Nos each		
10	PVC insulation tape 19mm width 9m length	1No		
11	Ceiling rose 3 plate 250 V , 6 A	3No		
Total	Cost of the material required			

In the same way trainees can be instructed to calculate the cost of materials required to wire up the following wiring in the PVC conduit.

1) godown wiring

2) Corridor wiring

3) hostel wiring

4) Tunnel wiring

Estimation for 3 phase domestic and commercial wiring

Objectives: At the end of this lesson you shall be able to
- **state specific rules related to 3-phase wiring installations**
- **estimate the wiring by load calculation, load distribution, layout diagram, wiring diagram, selection of cables, selection of conduit, calculation of conduit length, cable length, accessories required and the cost of wiring.**

3-phase wiring installation : The following provisions must be maintained for electrical installation:

1 Separate and distinct circuits for lighting, fan, heating and power wiring shall be kept.

2 All the wiring conductors shall be run at a height of 2.5 metres along the wall or on ceiling.

3 Proper distribution of load should be done at the main distribution load and also at the branch distribution board.

4 The load should be arranged in such a way that it is balanced on all the phases in case of 3-phase 4 wire system or poly phase system.

5 Distribution boards should be located at convenient points, preferably at the load centre.

6 The third pin of all the wall sockets must be earthed with minimum size of earth conductor of GI 14SWG or Aluminium 1.4mm^2

7 All the metal boards must be double earthed for medium and high voltage installation.

8 The phase, neutral and earth wire shall be distinctly marked at the main and branch distributed loads as per Indian Electricity Rule 32 of 1956.

Estimation of wiring

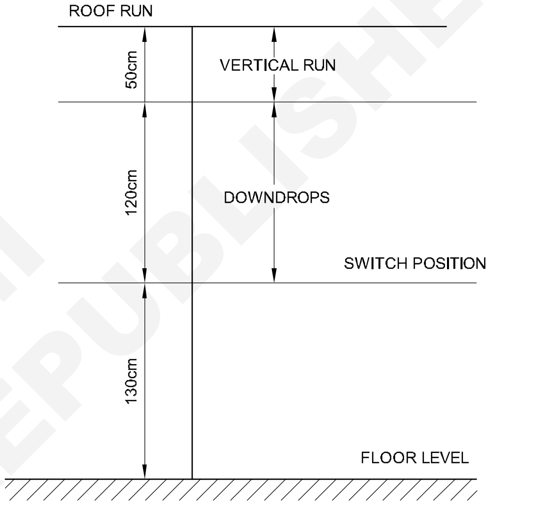
Fig 1 shows the vertical and down drops and switch position measurement from the ground level.

Study the consumer's requirement of light, fan and power points in each room (Fig 2).

Divide the load equally in 3-phases while doing so, as a requirement, the light and fan circuits of one room should be from the same phase.

In other words a single room should not get supply from two phases as this will pose a great danger to maintenance electrician and also separate line for individual phase is to be taken through the separate conduits. Clubbing of two or three phases through single conduit should be avoided.

Fig 1



VERTICAL RUN AND DOWN DROPS

Calculate the wattage of light, fan and power circuits in individual branch circuits of each phase. Then calculate the total connected load of the installation as well as current in each branch circuit.

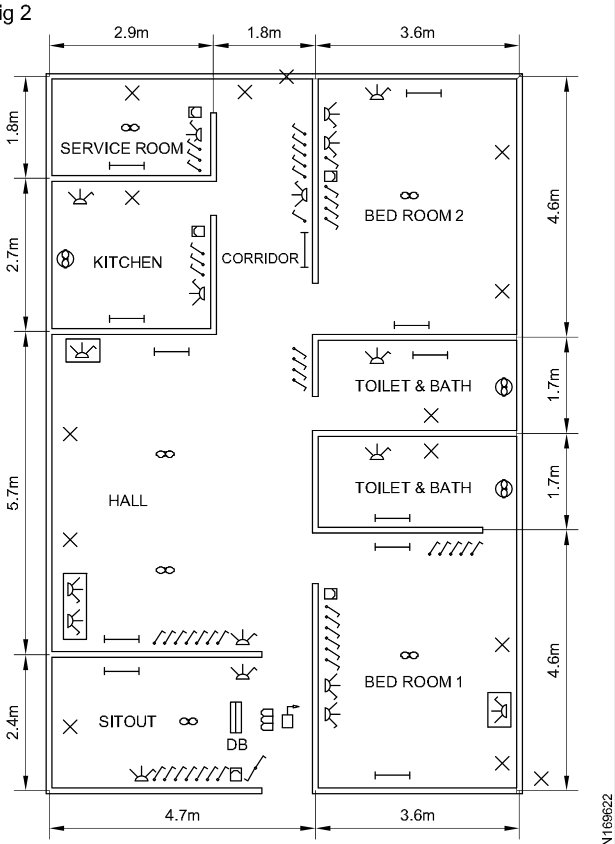
Refer to the position of accessories diagram and also the load division, then draw the layout diagram showing individual phase lines feeding to various rooms and exterior of the building. Fig 3 shows the layout diagram of phase L_1.

After finalizing the layout, the wiring diagram to be drawn.

Check the current capacity of each branch and select the size of the cable. After selecting the size of the cable and number of cables in each conduit run refer the PVC conduit table and select the size of the conduit (In the govt. installation CPWD has prescribed 19mm conduit as the minimum size to be used).

Required conduit length has to be calculated as per given method.

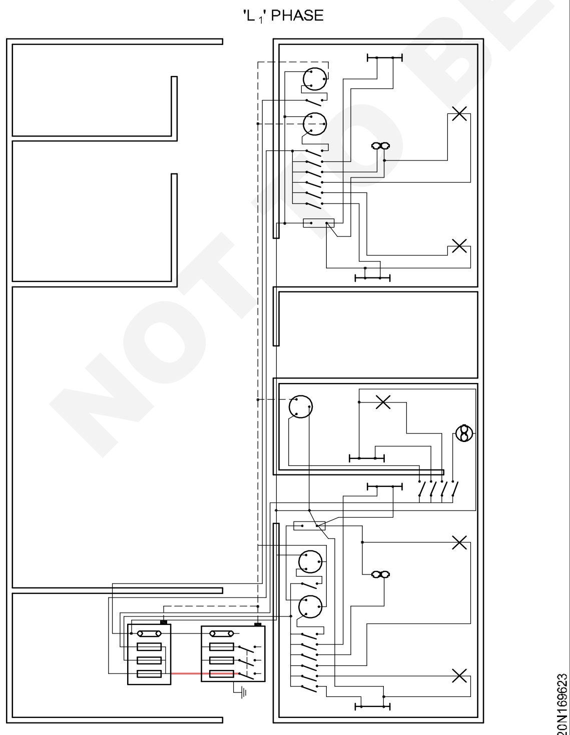
Fig 2



ACCESSORIES POSITION DIAGRAM

NE code recommends the horizontal run of cables should be at a height of 2.5m (250cm) and the height of switches from floor level should be 130cm. The example taken here for the roof height is 3m (300cm) from floor level. In all cases the dimension of the rooms should be available for estimating.

Fig 3



LAYOUT DIAGRAM OF PHASE L_1

Vertical run : As such all vertical runs can be calculated as under (Refer Fig 4) for L_2 phase.

Length of selected conduit =

Roof height - (down drop + switch height) x No. of vertical runs

= 3m - (1.20m + 1.30m) x No. of vertical heights
= (3m- 2.5m) x No. of vertical heights
= 0.5m x No. of vertical heights (Eqn. 1)

The value 0.5m will change if there is difference in roof height and height of horizontal run of conduit changes.

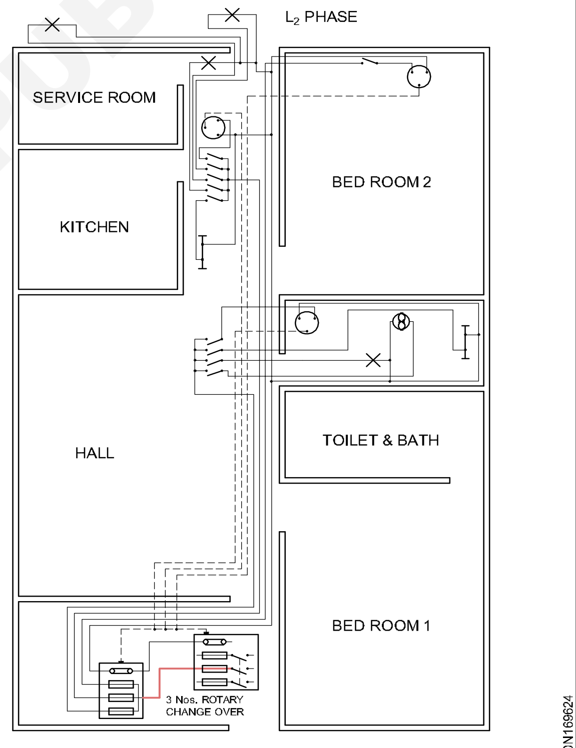
Length of conduit required for down drops

This could be calculated as under:

Length of selected conduit = Height of conduit in horizontal run - Switch position height x No. of down drops for switches

= (2.5m - 1.3m) x No. of down drops for switches
= 1.2m x No. of down drops to switches

Fig 4



LAYOUT DIAGRAM OF PHASE L_2

Length of conduit required for roof runs

This could be calculated as under

Length of selected conduit = Sum of the actual length of roof run taken in each case.

For each size the total requirement is to be calculated.

Length of conduit required for horizontal run

Length of selected conduit = sum of the actual length of horizontal run taken in each case.

Length of conduit required for the distance between main switch and DB is to be calculated. In most of the cases wall is thickness has to be taken into account.

Example

(Refer the layout and wiring diagram with respect to phase L_1) In all cases except for main switch and DB the cable used is 1/1.12 copper cable and maximum number of cable it can accommodate in 19mm conduit is 7 cables. Hence PVC conduit of 19mm is chosen.

1 Length of conduit required for vertical run

Length for vertical run = 0.5m x No. of vertical height

A careful study of layout indicates there are 8 vertical height runs

= 0.5m x 8 = 4m of 19mm PVC conduit

2 Length of conduit required for down drops

Length of down drops = 1.2m x No. of down drops

A careful study of layout indicates there are 9 down drops = 1.2m x 9 = 10.8m

3 Length of conduit required for roof runs

Length of conduit = 2.35m + 2.35m + 2.35m + 2.35m + 1.45m + 0.9m = 9.75m

4 Length of conduit required for horizontal runs

Length of conduit = 4.7m + 3.6m + 1m + 1m + 1.2m + 4.7m + 2.4m + 1.35m + 1.2m + 2m + 2.35m + 5.7m + 2.9m + 2.9m + 1.35m + 2.7m + 2.5m + 1.45m + 1.8m + 1.45m = 48.25m

5 Length of conduit required for main switch and DB

If individual phase line is to be drawn through 19mm PVC conduit will be sufficient on the other hand if all three phase cables to be drawn through single pipe, the requirement to be calculated separately.

Assuming individual phases will be drawn through individual conduits the 19mm PVC conduit will be sufficient to draw two cables of sizes upto 1/2.8 or 7/1.06 aluminium and copper cables respectively.

Length of conduit required for the distance between main switch and DB : Length of conduit = wall thickness + allowance for connection = 0.36m + 0.5m + 0.5m = 1.36m

Total length of PVC conduit 19mm for wiring phase L_1 as per layout and wiring diagram

= Vertical run + down drops + roof runs + horizontal runs + switch DB
= 4m + 10.8m + 9.75m + 48.25m + 1.36m = 74.16 m

Assuming 10% wastage, the total required length of 19mm PVC conduit will be 73.81m + 7.3m = 81.11m or say 80m

Calculation of length of cable required for wiring phase L_1: For calculating the length of cable accurately the layout and wiring diagrams should be referred. Selected cable in this case is 1 sq.mm copper cable.

Cable required = For outside runs ((L_1 + L_2 + L_3 + L_4) down drop + Horizontal run + switch board to outside wall (thickness of wall)
+ DB to switch board (DD + HR + DD)
+ Switch board to L_5 + (DD + HR)
+ L_5 to F_1 (VR + RR)
+ L_5 to L_6 L_7 (HR + HR)
+ DB to SB_2 (DD + HR + DD)
+ SB_2 to L_9 (DD + HR)
+ L_9 to F_2 (VR + RR)
+ SB_2 to S_3, S_4 (DD + HR + DD)
+ L_9 to L_{10} (HR)
+ L_{10} junction to F_3 (VR + RR)
+ L_{10} junction to L_{11} (HR)
+ S_3, S_4 to S_5 (DD + HR + DD)
+ From DB to S_6 (DD + HR +DD)
+ From S_6 to L_{12} (DD + HR)
+ L_{12} to F_5 (HR)
+ S_6 to F_4 (DD + HR + DD)
+ S_6 to L_{13} (DD + HR)
+ S_6 to S_8 (DD + HR + DD)
+ S_6 to S_7 (DD + HR + DD)
+ S_8 to F_6 (DD + RR)
+ F_6 to L_{15}
+ F_6 to L_{14}

=	+	(3.6m + 1m)2 + (4.7m + 1m)3	26.3m
	+	(0.36M+ 0.5m) x 5 + (1.2m + 3m + 1.2m)2	15.1m
	+	(1.2m + 3m + 1.2m)2	10.8m
	+	(1.2m + 4m + 1.2m)5	32.0m
	+	(0.5m + 2.35m)2	5.7m
	+	(1.2m + 2.35m)3 + 2.35m x 2	15.35m
	+	(1.2m + m2 + 1.2m)2	8.8m
	+	(1.2m + 4m + 2m)6	43.2m
	+	(0.5m + 2.35m)2	5.7m
	+	(1.2m + 1.5m)2	5.4m
	+	(1.2m + 4m + 2m + 1.2m)2	14.8m
	+	2m x 4	8.0m
	+	(0.5m + 2.35m)2	5.7m
	+	(2m + 2.5m)2	9.0m
	+	(1.2m + 5m + 1.2m)2	14.8m
	+	(1.2m + 4m + 5.7m + 2.9m + 2m + 1.2m)2	34.0m
	+	(1.2m + 1.4m + 1.5m)3	12.3m
	+	(1.5m + 1.35m)2	5.7m
	+	(1.35m x 3m) + (1.35m x 2m)	6.75m
	+	(1.35m + 1.45m + 1.2m)2	8.00m
	+	(1.2m + 1.4m + 0.9m + 1.2m)2	9.4m
	+	(1.2m + 1.45m + 1.2m)2	7.7m
	+	(1.2m + 1.45m)3	7.95m
	+	0.9m x 2m	1.8m
	+	0.9m x 2m	1.8m
			325.95m
		Add 10%	32.59m
		Say 360m of 1 sq.mm copper	358.54m

The length of the cable required for power circuit in phase L_1. The cable chosen is 4 sq.mm copper cable which can carry 24 amps

Total length of cable = (1.2m + 0.36m + 2.4m + 3.6m + 2.4m + 1.2m)2

= 11.16m x 2
= 22.32m

Add 10% for wastage = 2.2m

24.52m

Say 25m of 4 sq.mm copper cable is required.

In the same way for the circuits in L_2 and L_3 phases should be calculated. After the list of accessories for entire wiring is prepared the cost of the accessories could be obtained from any local electrical dealer.

Instructor is requested to discuss with the trainees about the mandays required to complete the job alongwith the cost of labour.

Total cost of wiring comprisis of following components.

Total cost of wiring = cost of the accessories
+ cost of cable
+ cost of conduit
+ cost of hardware items
+ labour cost

Estimation of cost for workshop wiring

Objectives: At the end of this lesson you shall be able to
- **calculate the full load current and size of cables**
- **estimate the cost for workshop wiring**
- **tabulate the material required.**

The trainees can be instructed to estimate the cost of materials for the workshop wiring. Some of the guidance are given below for the trainees and instructor referance.

A sample requirement is given below for trainee's reference

1 One 5HP, 415V 3 phase motor

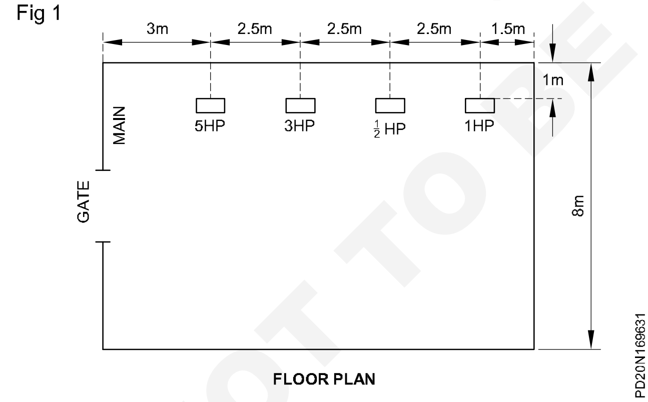
2 One 3HP, 415V 3 phase motor

3 One ½ HP, 240V 1 phase motor

4 One 1HP, 415V 3 phase motor

The motors are to be arranged in row (Fig 1).

Fig 1



The main switch, motor switch and starters are to be mounted at a height of not more than 1.5m from the ground level and the height of horizontal run from ground level will be 2.5 m.

Calculation for the size of cable:

Assuming the motor efficiency to be 85% and the power factor to be 0.8 for all the motors and the supply voltage is 400V.

$$\text{FL current of 5HP motor} = \frac{5 \times 735.5}{\sqrt{3} \times 400 \times 0.85 \times 0.8} = 7.8\text{A}$$

$$\text{FL current of 3HP motor} = \frac{3 \times 735.5}{\sqrt{3} \times 400 \times 0.85 \times 0.8} = 4.68\text{ A}$$

$$\text{FL current of ½ HP motor} = \frac{0.5 \times 735.5}{240 \times 0.85 \times 0.8} = 2.25\text{ A}$$

$$\text{FL current of 1HP motor} = \frac{1 \times 735.5}{\sqrt{3} \times 400 \times 0.85 \times 0.8} = 1.56\text{ A}$$

The main switch and the cable from meter to main switch should be capable of handling starting current of one motor of high rating plus full load current of the all other motors.

i.e, 15.6+4.68+2.35+1.56 = 24.19A

Assuming the starting current of each motor will be two times of their full load current Table 1 gives cable size of each motors to be installed for guidance.

Table - 1

Sl. No.	Motor	FL current I_L in Amp	Starting current $I_S = 2I_L$ in Amp	Recommended cable size
1	5HP motor	7.5	15.6	2.0mm² coppere conductor cable (17A) or 2.5mm² aluminium conductor cable (16A)

2	3HP motor	4.68	9.36	2.0mm^2 copper conductor cable (17A)
3	1/2 HP motor	2.25	4.5	1.0mm^2 copper conductor cable (11A) minimum recommended cable
4	1HP motor	1.56	3.12	1.0mm^2 copper conductor cable (11A) minimum recommended cable

The type and gauge of cable shall be selected by referring the table - 1

Some guidance are given bleow to select the suitable switches and distribution board for trainees reference.

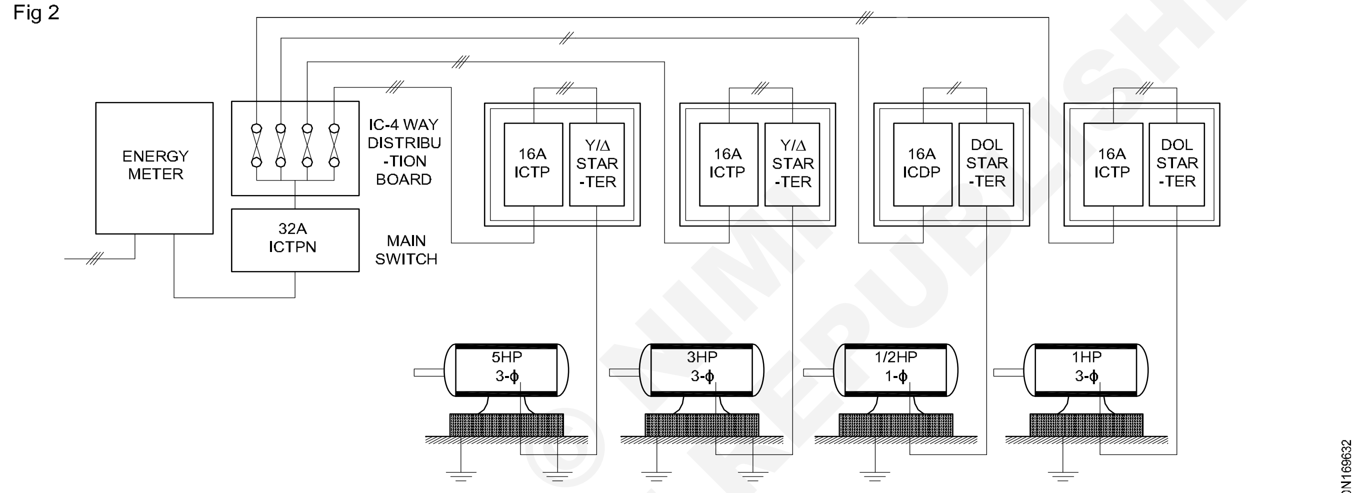
- A 32A, 415V ICTP switch with fuses can be used as main switch.
- 16A, 415V, ICTP switches with fuses can be used for 5HP, 3HP, & 1HP motors.
- 16A, 240V, ICDP switch with fuses can be used for ½ HP motor.
- 415V, 4 way, 16A per way IC distribution board with neutral link can be used for power distribution.

The single typical line diagram of power wirings (Fig.2)

Calculation for the sizes and length of conduit:

19mm heavy gauge conduit should be used for 3 cable runs and 24.4 mm heavy gauge conduits should be used for 6 cable runs.

Fig 2



SINGLE LINE DIAGRAM OF POWER WIRING IN WORKSHOP

- 19 mm heavy gauge conduit

Length from main board to 5HP motor starter = 1+1+3+1 = 6.0m

Length from main board to 3HP motor starter = 1+1+5.5+1 = 8.5m

Length from main board to ½ HP motor base = 1+1+8+1+1.5+1.5 = 14.0m

Length from main board to 1HP motor base = 1+1+10.5+1+1.5+1.5 = 16.5m

Total = 45.0 m

10% wastages = 4.5m

Total length = 49.5m, say 50.0m

- 25.4 mm heavy gauge conduit.

Length from meter to main switch = 0.75 m

Length from 5HP motor starter to 5HP motor base (1.5 +1.5) 3.0 m

Length from 3HP motor starter to motor base = 3.0 m

Total = 6.75 m

10% wastage = 0.67 m

Total = 7.42m, Say 8.0m

- 25.4 mm flexible conduit for 5HP & 3 HP motor (0.75+0.75) = 1.5, Say 2.0m
- 19mm flexible conduit for 1/2 HP & 1 HP motor (0.75+0.7) = 1.5, Say 2.0m

Calculation for the length of cables:

2.0mm^2 copper conductor from main board to 5HP motor terminals = 3(1+1+3+1) + 6(1.5+1.5+0.75) = 40.5m

15% wastages & end connections = 7.2 m

Total = 55.2m , Say = 56.0m

1.0mm^2 copper conductor from main board to 1/2 HP motor terminals = 2(1+1+8+1+1.5+1.5+0.75) = 29.5 m

15% wastages & end connections = 7.76m

Total = 59.51m, Say 60.0m

Trainees may be instructed to tabulate the list of materials.

Testing a domestic wiring installation - location of faults - Remedies

Objectives: At the end of this lesson you shall be able to
- **state the type of test to be carried out in wiring installations and explain the procedure of conducting them**
- **Determine the condition of installation and the method of improving the condition.**

General requirement of inspection and tests (Ref: B.I.S.732-(Part III) 1982.)

Before a completed installation or an addition to the existing installation is put into service, inspection and testing shall be carried out in accordance with the Indian Electricity Rules, 1956. In the event of defects being found, these shall be rectified as soon as practicable, and the installation re-tested.

Periodic inspection and testing shall be carried out in order to maintain the installation in a sound condition after putting it into service.

Items to be inspected in a lighting circuit

Lighting circuits: The lighting circuits shall be checked for ensuring the following.

- Wooden boxes and panels are avoided in factories for mounting the lighting boards and switch controls etc.
- Neutral links are provided in double pole switch-fuses which are used for lighting control, and no fuse is provided in the neutral.
- The plug points in the lighting circuit are all of 3-pin type, the third pin being suitably earthed.
- Tamper-proof interlocked switch sockets and plugs are used for locations easily accessible.
- Lighting wiring in the factory area is taken in enclosed conduits, and conduits are properly earthed, or alternatively, armoured cable wiring is used.
- A separate earth wire is run in the lighting installation to provide earthing for plug points, fixtures and equipment.
- Proper connectors and junction boxes are used wherever joints are to be made in conductors or when cross-over of conductors takes place.
- Cartridge fuse units are fitted with cartridge fuses only.
- Clear and permanent identification marks are painted in all distribution boards, switchboards, sub-main boards and switches as necessary.
- The polarity having been checked, all fuses and single pole switches are connected on the phase conductor only and wiring is correctly connected to the socket-outlets.
- The spare knock-outs provided in distribution boards and switch-fuses are blocked.
- The ends of the conduits enclosing the wiring leads are provided with ebonite or other suitable bushes.
- The fittings and fixtures used for outdoor use are all of weatherproof construction, and similarly, fixtures, fittings and switchgears used in the hazardous area are of flame-proof application.
- Proper terminal connectors are used for termination of wires (conductors and earth leads) and all strands are inserted in the terminals.
- Flat-ended screws are used for fixing conductors to the accessories.
- Use of flat washers backed up by spring washers for making end connections is desirable.
- The number of wires in a conduit conforms to the provisions of Part II of BIS 732.

Testing of installation: After inspection, the following tests shall be carried out, before an installation or an addition to the existing installation is put into service. Any testing of the electrical installation shall commence after obtaining a permit to work from the engineer in-charge and after ensuring the safety provisions.

1 Continuity or open circuit test
2 Polarity test
3 Earth and ground test
4 Insulation and leakage test:
   - between conductors
   - between conductors and earth.

Continuity or open circuit test: This test is carried out to check the continuity of cables in the individual sub-circuits. Before conducting this test, the main and all the distribution circuit fuses should be removed.

The phase and the neutral of the individual circuits should be identified from the distribution board and segregated.

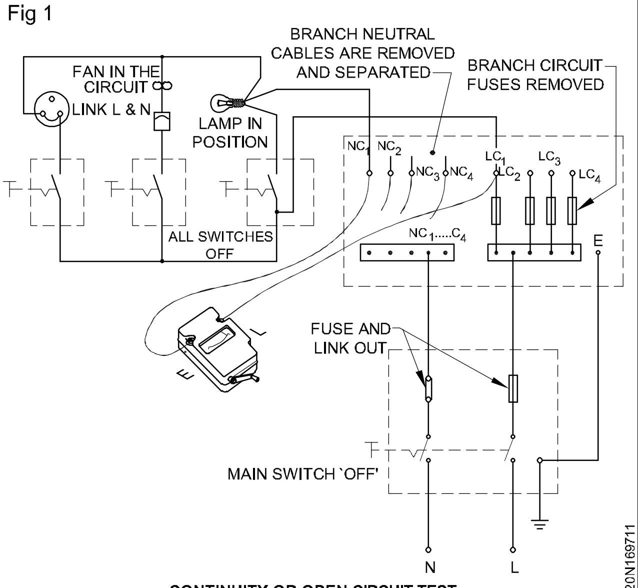
Place all bulbs in position, connect fans to respective ceiling roses, regulators and switches, short all socket outlets by linking the phase and neutral.

Connect the Megger terminals E and L to the individual circuit phase and neutral (Fig 1) and rotate the Megger.

By switching the switches ON and OFF one by one, the Megger should show zero reading and infinity alternatively. The two-way switches may have to be operated alternatively to ensure the correct test results.

If the Megger shows no continuity in the `ON' condition of the switch, then the particular circuit is deemed to be open. On the other hand, if the Megger shows continuity in both

Fig 1



CONTINUITY OR OPEN CIRCUIT TEST

the `ON' and `OFF' positions of the switch, this indicates short in the particular circuit.

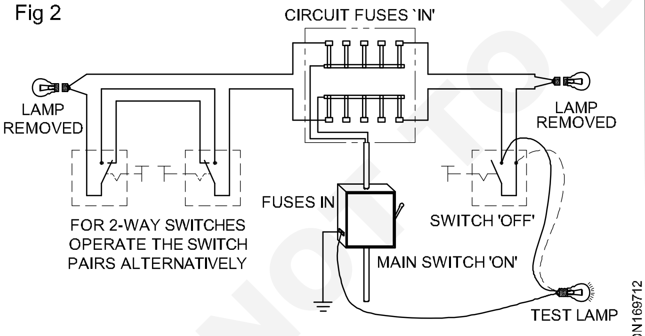
Remember to remove all the shorting links at socket points and to connect the phase to the fuse, and neutral to the link, before switching `ON' the supply.

Polarity test: This test is conducted to check whether switches are connected in phase/live cable or not.

For conducting this test, the lamps are removed from the lamp-holders, the fan regulators are kept in the `OFF' position and the fuses inserted in the main and distribution boards.

Remove the switch covers and switch `ON' the supply. Connect one end of the test lamp to the earth continuity conductor and the other end of the test lamp to the switch terminals alternatively (Fig 2).

Fig 2



POLARITY TEST

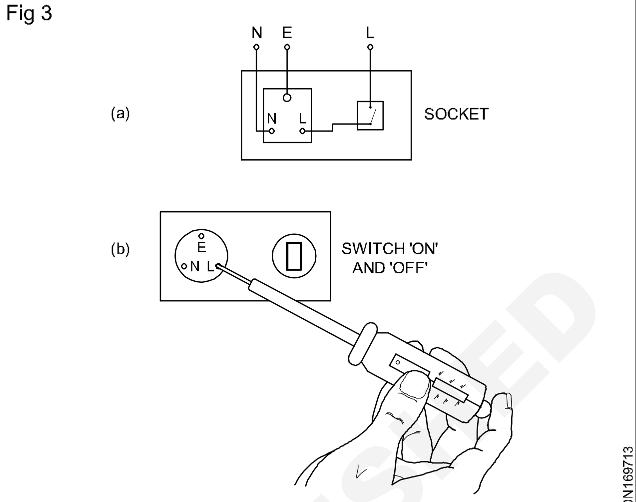
Lighting of the test lamp indicates that the phase or live cable is controlled by the switch.

A further polarity test should be done on the sockets to verify whether

- The phase wire is connected to the right side hole of the socket (Fig 3a).
- The switch controls the phase wire.

For this test, a neon tester could be inserted in the right side hole of the socket as shown in Fig 3b and the control switch is switched `ON'. Lighting of the neon tester when the switch is `ON' and no light when the switch is `OFF' indicate correct polarity. This test is a must, in all old or new wiring installations as a safety measure.

Fig 3



POLARITY TEST ON SOCKETS

Testing the effectiveness of earth connection: For checking the efficiency of earthing, the following tests are done.

- Testing the continuity of earth continuity conductor (ECC) and measuring its resistance.
- The earth resistance of the electrode shall be measured.

The value of earth electrode resistance should not exceed 5 ohms or to a value such that the protective devices in the circuit operate efficiently in case of earth faults in the circuit.

Insulation tests in wiring installation (BIS 732 (Part II) - 1982.)

The following tests shall be done:

1 The insulation resistance shall be measured by applying the test between the earth and the whole system of the conductor or any section thereof, with all the fuses in place and all the switches closed, and except in earthed concentric wiring, all lamps in position or both poles of installation, otherwise electrically connected together, a DC voltage of not less than twice the working voltage, provided that it does not exceed 500 volts for medium voltage circuits.

2 Where the supply is derived from a three-wire AC or DC or poly-phase system, the neutral pole of which is connected to earth either direct or through added resistance, the working voltage shall be deemed to be that which is maintained between the outer or phase conductor and the neutral.

3 The insulation resistance in megohms of an installation measured shall not be less than 50 divided by the number of points on the circuit, provided that the whole installation need not be required to have an insulation resistance greater than one megohm.

4 Control- rheostats, heating and power appliances and electric signs, may, if desired, be disconnected from the circuit during the test, but in that event the insulation resistance between the case or framework, and all the live parts of each rheostat, appliance and sign shall be not less than that specified in the relevant Indian Standard Specification, or where there is no such specification, shall be not less than half a megohm.

5 The insulation resistance shall also be measured between all conductors connected to one pole or phase conductor of the supply and all the conductors connected to the middle wire or to the middle wire or to the neutral on to the other pole of the phase conductors of the supply.

6 Such a test shall be made after removing all metallic connections between the two poles of the installation, and in these circumstances the insulation resistance between the conductors of the installation shall be not less than that specified.

On completion of an electrical installation (or an extension to an installation) a certificate shall be furnished by the contractor, countersigned by the certified supervisor under whose direct supervision the installation was carried out. This certificate shall be in the prescribed form as required by the local electric supply authority.

Insulation resistance between conductors and earth:

For this test, put `OFF' the main switch and remove the main fuse-carrier. All distribution fuses should be `IN'; the lamps should be in their holders and all switches for fans and lights should be in the `IN' position. Unplug all the appliances from the sockets, and short the phase and neutral of the sockets with a jumper wire.

Connect the phase and neutral cables at the outgoing terminals of the main switch together, and connect the lead of the Megger terminal to the shorted cables. (Fig 4) Connect the other lead of the Megger to the earth connection and rotate the Megger at its rated speed.

The reading thus obtained should not be lower than the lowest of the values obtained in these three methods.

Method 1 - **Standard value as per B.I.S.**

Standard value of insulation resistance

$$= \frac{50}{\text{No.of points in the circuit}} \text{Mega ohms}$$

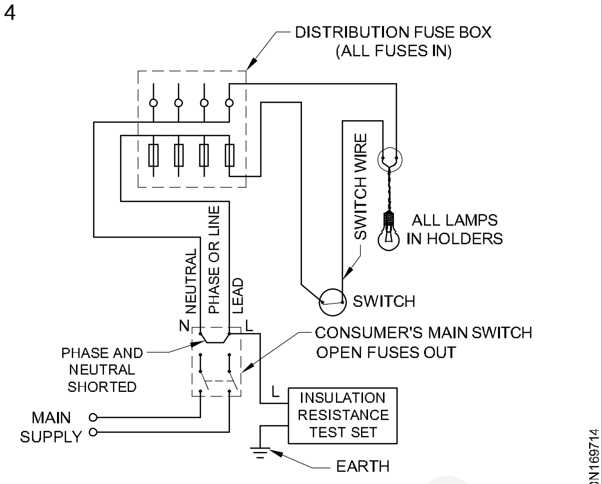
where the switch, the lamp-holder and the socket are taken as individual points.

In case, the wiring is done in PVC insulated cables, 50 should be replaced by 12.5.

Method 2 - **I.E. rules state that the leakage current in an installation should not exceed 1/5000th part of the full load current of the installation.**

Applying this, the value of insulation resistance

Fig 4



INSULATION RESISTANCE TEST BETWEEN CONDUCTORS AND EARTH

$$= \frac{\text{Supply voltage in volts}}{\text{Leakage current}} \text{ohms}$$

$$= \frac{\text{Supply voltage in volts x 5000}}{\text{Full load current of the insatallation}}$$

Where leakage current

$$= \text{Full load current of the installation x } \frac{1}{5000}$$

Hence the insulation resistance

$$= \frac{\text{Supply voltage in volts x 5000 x } 10^{-6}}{\text{Full load current of the installation}} \text{Megaohms}$$

Method 3 - **Thumb rule**

The measured insulation resistance of an installation should not be less than one megohm.

Insulation resistance between conductors: For this test, switch off the mains and remove the fuse-carriers.

Remove all lamps from their holders, disconnect all appliances and keep all switches in the ON position.

Keep all the distribution fuses in position.

Connect one test prod of the Megger to the phase cable and the other to the neutral (Fig 5).

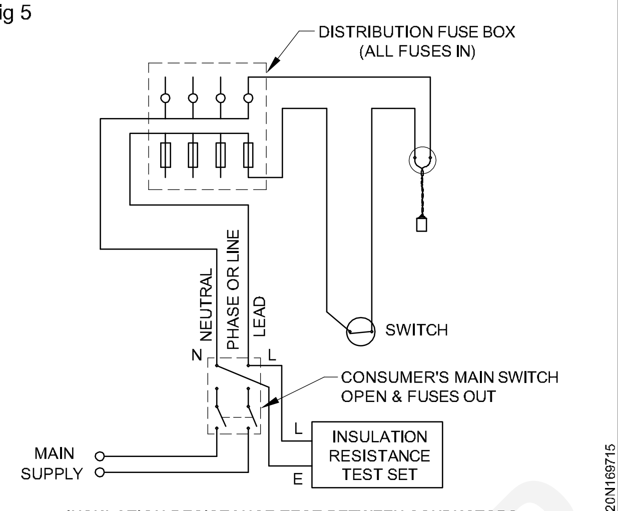
Rotate the Megger and measure the insulation resistance in megohms.

The reading in megohms should not be less than the lowest of the readings obtained in any one of the three methods, stated under `Insulation resistance between conductors and earth.

Inspection, testing and improving the condition of wiring installations

The table given below shows the test results, and the methods to improve the conditions of the wiring installations.

Fig 5



INSULATION RESISTANCE TEST BETWEEN CONDUCTORS

Test Results and Methods for Improving the conditions

S. No.	Test Conducted	Test results	Method of Improvement
1	Continuity or open circuit test	a) Zero reading b) Higher reading in terms of kiloohms or megohms	a) Ok. b) Operate each individual switch in the circuit.Where the reading jumps to a higher value, there will be an open circuit, either by fused bulbs or loose connections at the terminals or break in the wire. After identifying the subcircuit, check the continuity of cables in the smaller zones till the defect is detected and rectified. Where 2-way switches are encountered,operate the switches one by one to detect the fault.
2	Polarity test	a) Polarity was found wrong throughout the installation. b) Polarity found wrong in one or two sockets.	a) Switch off the mains. Remove the fuse-carrier.Interchange the output terminals at ICDP switch or at DB. b) See that the phase is connected to the right side terminal of the socket.
3	Effectiveness of earth connection	a) Discontinuity between earth electrode and one earth pin of the 3- pin socket. b) Indicates voltage drop between phase & the metallic body when tested by test lamp method.	a) Check up the connections and reconnect or replace the earth continuity conductor. b) The earth electrode resistance may be high. ECC may have high resistance. Prepare one more earth electrode and connect the electrodes in parallel. Remove rust and rectify loose connections in ECC connections at all earth terminals including the one at the earth electrode.
4	Insulation test between conductors and earth (or) between the phase and neutral	a) 1 megohm or above	a) Ok. Check the value of the insulation resistance by the formula Megohms = $\frac{50}{\text{No.of outlets}}$ For PVC wired installation replace 50 by 12.5. In case the measured value of insulation resistance is equal to or more than the calculated value, the insulation is OK.

S. No.	Test Conducted	Test results	Method of Improvement
		b) Less than 1 megohm	b) Otherwise locate the fault by sectionalising the zone and replacing the defective cable with a good one. If, however, the values obtained are not sufficiently high, withdraw all the fuses of the distribution fuse-board and test again. This test will include only that portion of the installation between the main switch and the distribution fuse-board. If the fault does not lie in this section,proceed to the distribution fuse-board, and test each branch circuit in turn till the faulty circuit or circuits are discovered.

Testing the industrial wiring installation for faults and their remedies - Flow chart

Objectives: At the end of this lesson you shall be able to
- **explain the different types of faults occur in the industrial**
- **trace and interpret the flow chart for locating the fault.**

Any fault can be found and rectified. It is necessary for the electrician to adopt a method or system based on a sound knowledge of circuitry and electrical theory on experience. The electrician detects to repair a faulty circuit in many ways like a doctor who makes his diagnosis or test using the correct instrument.

The investigation must always be based on an intelligent assessment of the fault and its probable causes, judged from its effects. In many instances, faults arise from installations or circuits. The following are some common installation defects which eventually lead to faults.

1 Fuse protection not matched to the current rating of cables to be protected. This is very often happening due to fitting the fuse-carries with a fuse element of maximum rating than the fuse unit in the protection system.

2 Indiscriminate bunching of too many cables with inadequate connections.

3 Insufficient protection provided for sheathed wiring (e.g.) to switch positions and on joints in roof voids.

4 Incorrect use of materials, not resistant to corrosion, in damp situation (e.g. enameled conduit and accessories)

5 Insufficient attention given to cleaning ends of conduit and/or . Omission of bushings .

6 Incorrect use of PVC insulated and/or sheathed cables and flexible cords instead of heat resistance type, for connections to immersion heating, thermal storage block heaters etc.,

7 Incorrect use of braided and twisted flexible cords for bathroom pendant fittings and similar situations subject to dampness or condensation.

8 Installation of cable of insufficient capacity to carry the starting current of motors, causing excessive voltage drops.

9 Incorrect rating of fuse-element to give protection to the cables connecting the motor.

Segregation of fault

Open circuit fault

Usually the effect of this fault is that the apparatus or lamp in the circuit will not operate. This fault can be located by using the continuity Tester. The fault is of a

a) break in a wire

b) very loose or disconnected terminal or joint connections

c) blown fuse

d) faulty switch contacts.

The fuse should always be checked first for fault finding. Their wirable type can be easily inspected. The cartridge type must be tested for continuity of the fuse element. If it is found not correct replace it. A broken wire or a disconnection will show high resistance in the kiloohm or Megohm ranges in continuity Tester. Before each wire in faulty circuit is tested in turn (live wire, switch-wire, and neutral) all mechanical connections should be inspected like plug, switch, lamp holders, junction box and appliance terminals etc). Make sure that the original connections are restored, once the fault has been found.

Earth Fault

An earth fault between earthed metal work and a live conductor will have the same effect as a direct short-circuit. For this situation the circuit fuse will blow off. To trace the fault, first isolate the live conductor from the neutral by removing all lamps etc.

Keeping all switches in ON position by using insulation resistance Tester, faults are traced. The reading obtained on the instrument will be in low ohms range. It is important to rectify any such fault found, other wise it may cause a shock and fire hazards.

Short circuit fault

Short circuit can occur as the result of damaged insulation, bare wire in junction boxes and fittings or loose terminals contact with a conductor of opposite polarity. The result of a short circuit is a blown fuse. The result will be over heating of the conductors and sparking or arcing at the point of contact. Open all switches, lamps and appliances from the faulty circuit and carry out an insulation resistance test between the live and neutral conductors.

If reading is obtained is satisfactory, close each circuit switch in turn until the fault is located.

High-value series resistance fault

This type of fault is most difficult to trace; it occurs in joint or terminator where it has become loose. Due to this effect the lights will be 'dim or motor will run very slow thereby heating up'. In new wiring wrong connection in a junction box resulting in two or more lamps being connected in series.

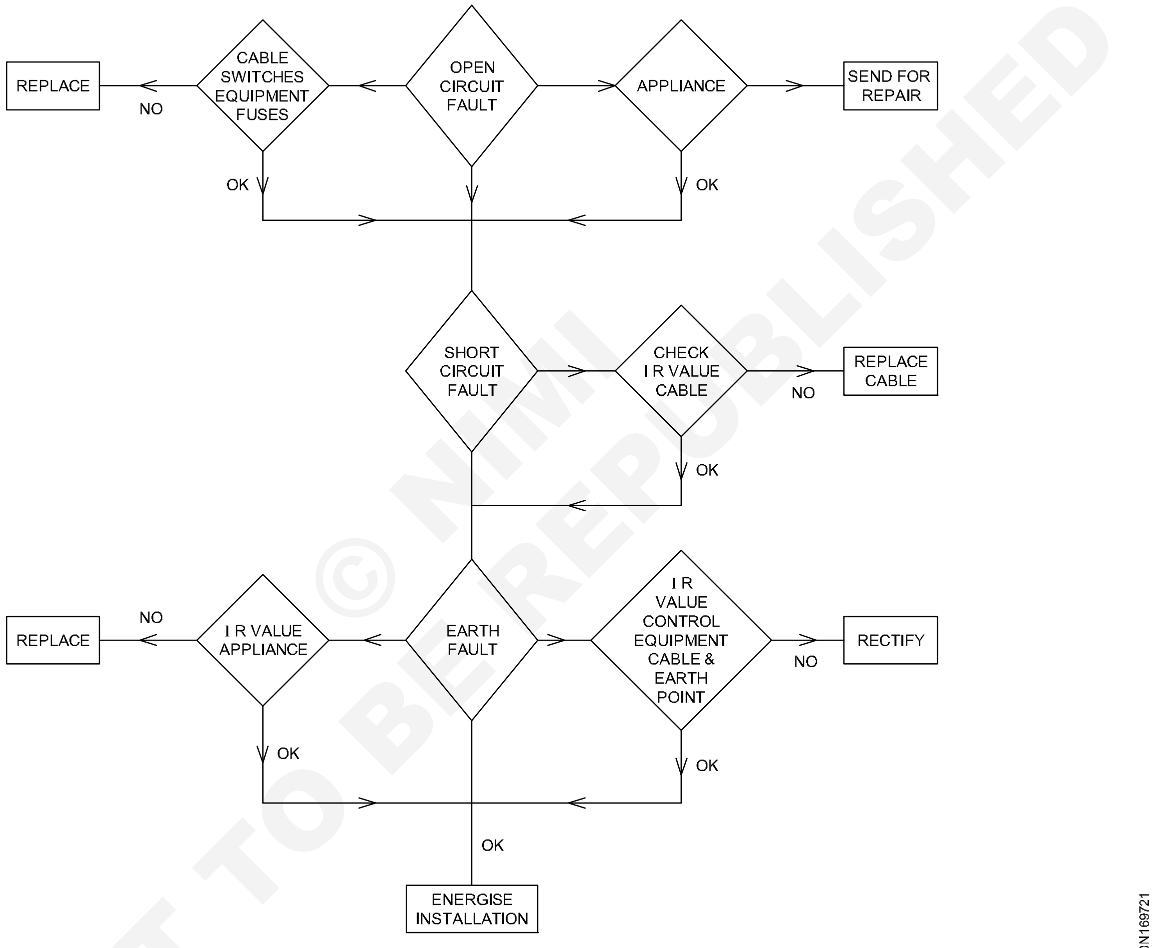
Main faults in new wiring

Wrong connections will either blow a fuse or cause lamps to operate dimly or not at all work. Works only when another circuit switch is switched ON, this indicates wrong connections in looping of wires.

Flow chart of faults

Figure 1 shows the flow chart of each fault kept in chart form.

Fig 1



FLOW CHART FOR LOCATING FAULT IN DOMESTIC WIRING INSTALLATION

Illumination terms - Laws

Objectives: At the end of this lesson you shall be able to
- **explain the nature of light**
- **state and explain different terms used in illumination**
- **state properties and advantages of good illumination**
- **state and explain laws of illumination.**

The nature of light

Light is a form of electromagnetic radiation. It is basically the same thing as the radiations used in radio, television, X-rays, gamma rays etc. Visible light is the radiation in that part of the spectrum between 380 and 760 (nm) nanometre (10^{-9}M) to which the human eye is sensitive. A nanometre (nm) is a wavelength of one millionth (10^{-6} mm) of a millimetre.

Within these limits, differences in the wavelength produce the effect of colour, blue light being at the short-wave and red at the long-wave ends of the visible spectrum. Because the human eye is more sensitive to the yellow and green light in the middle of the spectrum, more power must be expended to produce the same effect from colours at the end of the spectrum.

Standared safety norms:

Trainees may be instructed to refer the Internation Electrotechnic Commission (IEC - 60598 part 2 section 3) web site for standard safety norms related with electrical illumination system for further details

Definitions

A few principle terms in connection with illumination are defined below.

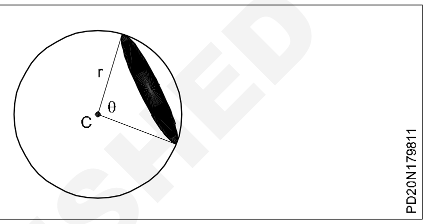
Luminous flux (F or Φ)**:** The flux of light emitted from a luminous body is the energy radiated per second in the form of light waves. The unit of luminous flux is `lumen'(lm).

Luminous intensity(I): The luminous intensity of a light source in a given direction is the luminous flux given out by the light source per unit solid angle. The angle subtended by an area r^2 on the surface of sphere of radius r, at the centre of sphere is unit solid angle. In SI, the unit of luminous intensity is the candela.

Candela: This is the amount of light emitted in a given direction by a source of one candle power. SI base unit is candela (cd). 1 candela = 0.982 international candles.

Lumen (lm)**:** It is the unit of luminous flux. This is defined as the amount of light contained in one steradian from a source of one candela at its focus. (Fig 1)

Fig 1



If the shaded area = r^2 and a source of one candela is at the centre C, the light contained within the solid angle is one lumen.

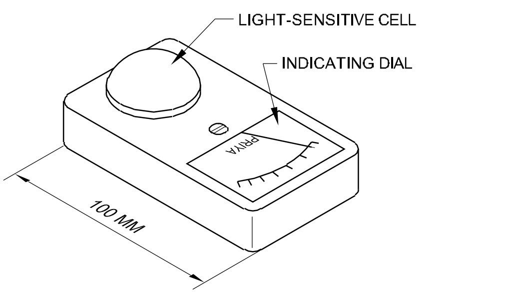
The light output of electric lamp is measured in lumens and their luminous efficiency (efficacy) is expressed in lumens per watt (lm/w).

Illuminance or Illumination (E): Illuminance of a surface is defined as the luminous flux reaching it perpendicularly per unit area. The metric unit is the lumen / m^2 or lux (lx).

Lux: This is the total output of light. Lumen per square meter (1m/m^2) or lux is the intensity of illumination produced in the inner surface of a hollow sphere of radius one meter by a standard candle at the centre. Sometimes this is also known as metre-candle.

Lighting engineers use a pocket-size instrument called a `lightmeter' to measure illuminance; and the reading in lux is read off the scale (Fig 2). This is not the same sort of instrument as a photographic exposure meter, which measures brightness, not illuminance.

Fig 2



TYPICAL POCKET-SIZE LIGHT-METER FOR MEASURING ILLUMINANCE.

Measured brightness is termed `luminance', and it should not be confused with `illuminance'. Luminance is the lumens emitted by a luminous surface of one square metre.

Two other terms that are easily confused with each other are `luminance' and `luminosity'. The first is measured brightness expressed in apostlibs or candelas per square metre, the second the apparent brightness as seen by the eye.

A simple example is the appearance of a motor car head lamps by day and by night. Their luminance is the same in both conditions but their luminosity is far greater at night than when it is seen in daylight.

Factors to be viewed for correct illumination

The following are the important factors which should be considered while planning correct and a good illumination:

Nature of work : Considering the nature of work , sufficient and suitable lighting sould be maintained. For example, a delicate work like radio and TV assembling, etc. requires good illumination to increase the production of work where as for rough work like storage, garages, etc needs very small illumination.

Design of Apartment : The design of apartment must be kept in view while planning scheme for illumination. It means that the light emitted by the illumination source should not strike the eyes of the occupants or workers.

Cost : It is an important factor which should be considered while designing an illumination scheme for particular purpose.

Maintenance Factor : While planning illumination, it should also be kept in view the amount of reduction of light due to accumulation of dust or smoke on the source of light and after how much period cleanliness is required. Where there is a possibility of heavy loss of light due to the adherence of smoke, arrangement for the extra light is to be made from the very beginning.

Properties of good illumination

An illumination source should, have the following properties.

i It should have sufficient light.

ii It should not strike the eyes.

iii It should not produce glareness in the eyes.

iv It should be installed at such a place that it gives uniform light.

v It should be of correct type as needed.

vi It should have suitable shades and refelectors.

Advantages of good illumination

i It increases production in the workshop.

ii It reduces the chances of accidents.

iii It does not strain the eyes.

iv It reduces the wastage or loss of material.

v It increases the interior decoration of the building.

vi It gives smoothing effect to mind.

Laws of illumination

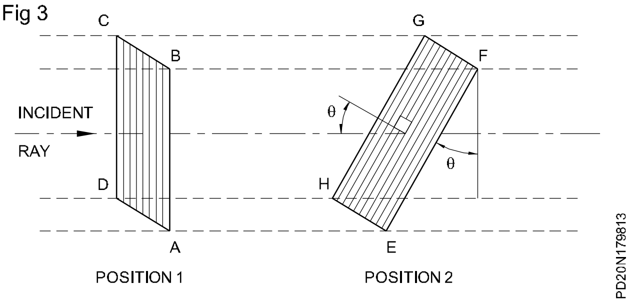
Inverse square law: If the internal radius of a sphere is increased from 1 metre to r metres, the surface area of it is increased from 4π to $4\pi r^2$ square metres. With a uniform point source of light of one candela at the centre, the number of lumen per square metre on the sphere of radius r metres.

$$= \frac{4\pi}{4\pi r^2} = \frac{1}{r^2}$$

Hence the illumination of a surface is inversely proportional to the square of its distance from the source. This is called the **Inverse Square Law of Illumination.**

Lambert's cosine law: According to this law, illumination (E) is directly proportional to the cosine of the angle made by the normal to illuminated surface with the direction of the incident flux. (Fig 3) Let Φ be the flux incident on the surface of area ABCD when in position 1. When this surface is so placed that the angle between the incident ray and the perpendicular to the surface EFGH is θ. The luminous flux falling on area EFGH is Φ.

Fig 3



Hence the illumination on the surface in position 1 is

$$E_1 = \frac{\Phi}{\text{Area ABCD}}$$

But in position 2, the illumination is

$$E_2 = \frac{\Phi}{\text{Area EFGH}}$$

(Area ABCD = AB x BC,

Area EFGH = EF x GF

$$= \frac{AB}{\cos\theta} \times BC$$

because, $\cos\theta = \frac{AB}{EF}$

Therefore, $E_2 = \frac{\Phi \times \cos\theta}{\text{Area ABCD}} = E_1 \cos\theta$

So illumination on EFGH

$$= \frac{1}{d^2} \times \cos\theta$$

where `d' is the distance of the surface from a source having a luminous intensity of one candela.

Filament lamps

Objectives : At the end of this lesson you shall be able to
- **list out the types of lamps**
- **explain the different types of lamps**
- **explain the construction and working of tungsten filament lamp.**

Types of lamps

There are many types of electric lamps now available. They differ in construction and in the principle of operation. The lamps can be grouped on the principle of operation as follows.

Filament lamps fall into a group of light producing devices called `incandescents'. They give light as a result of heating the filament to a very high temperature. The definitions of the terms are given below.

Electric lamps
- Filament lamps
  - Carbon
  - Metal
- Arc lamps
- Discharge lamps
  - Cold cathode
  - Hot cathode

Filament lamp: A lamp in which a metal, carbon or other filament is rendered incandescent by the passage of electric current.

Vacuum lamp: A filament lamp in which the filament operates in a vacuum.

Gas-filled lamp: A filament lamp in which the filament operates in an inert gas.

Halogen lamp: A tungsten filament lamp in which the tungsten filament operates in a relatively small space filled with an inert gas and halogen of iodine or bromine.

Arc lamp: An electric lamp in which the light is emitted by an arc.

Discharge lamp: An electric lamp in which the light is obtained by a discharge of electricity between two electrodes in gas or vapour.

Carbon filament lamp: The carbon filaments made today have limited application as resistance lamps (battery charging) and radiant heat apparatus. This lamp gives a reddish light and operates at a temperature about 2000°C. Above this limit, the carbon evaporates rapidly and blackens the glass bulb or envelope. The output from a carbon filament lamp is abot 3 lm/W (lumens per watt).

Tungsten filament lamp: This lamp consists essentially of a fine wire of the metal, tungsten (the filament) supported in a glass envelope and the air evacuated from the glass bulb - hence called a **vacuum lamp**.

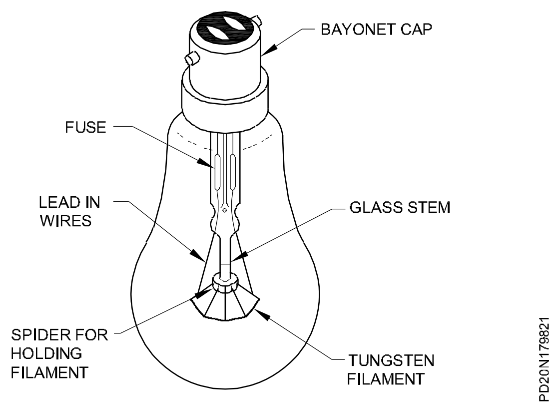
Filaments are now constructed of tungsten due to its exceptionally high melting point. It operates at a temperature of 2300° C and has an output of about 8 lm/W.

At temperatures above 2000°C, whilst the filament does not melt, it begins to break up and particles fly to the side of the lamp. This causes the glass bulb to become blackened. (Frequently observable in torch light bulbs.) The evaporation causes weak spots in the filament resulting in uneven resistance, which sets up hot spots and the filament burns out and breaks, i.e. fuses.

Filling up the bulb with an inert gas reduces the rate of evaporation. Argon and nitrogen are inert gases which do not support combustion. The operating temperature of a gas-filled lamp is about 2700°C. The output is in the region of 12 lm/W.

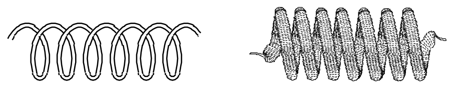
Fig 1 shows the parts of tungsten filament lamp

Fig 1



The two types of filaments (Fig 2) are

Fig 2



- single coil filament
- coiled coil filament.

The main advantage of a coiled coil lamp is the higher light output.

Most general lighting service (GLS) filament lamps used in homes have a bayonet cap (BC). Some small lamps used in special fittings have a `small' bayonet cap (SBC). Some GLS lamps have an Edison screw (ES) cap. There are also `small' Edison screw (SES) and `giant' Edison screw (GES) caps.

ES Caps are favoured for spot lights in which the lamp must be accurately positioned. Each type of lamp can be used only in an appropriate design of a lamp holder.

The rated life of GLS lamps is 1000 hours. This means that in any batch of lamps, 50 percent will have failed after 1000 hours of use. The life of an individual lamp in any batch may be greater or less than this average. The rated life is achieved in `normal conditions of use'. The normal conditions of use are

- operated cap up
- free from vibration
- not subjected to a voltage in excess of the rated voltage
- suitable light fittings.

Operating a filament lamp at a voltage higher than its rated voltage will reduce its life. Lower operating voltage will extend its life. At higher voltage, the filament gives a whiter and a more bluish light and operates at brighter and higher efficiency.

Lights and light fittings

Objectives: At the end of this lesson you shall be able to
- **name the types of bulbs for illumination**
- **explain direct and indirect lighting.**

Types of lamps used for illumination: The lamps used are:

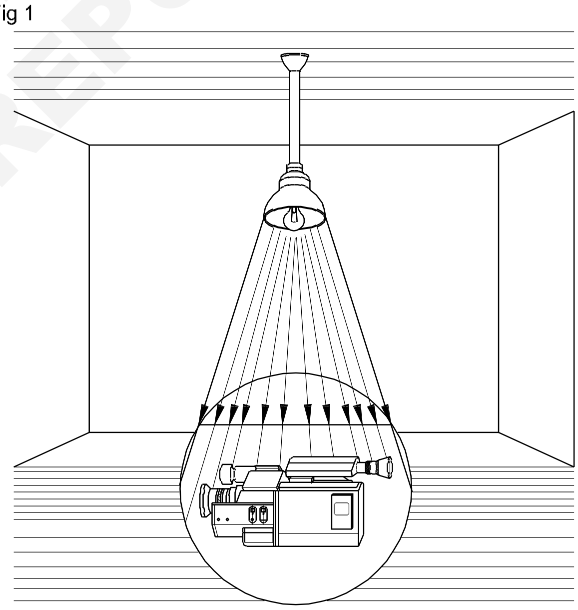
- incandescent lamps
- tube lights

Types of bulbs/incandescent lamps

- Glow lamps
- Moonlight lamps
- Luminous lamps
- Daylight lamps
- Tree light lamps
- Photo flood lamps
- Movie flood lamps
- Photo flash lamps
- Silvered bowl lamps
- Projector lamps
- Reflector lamps
- Halogen lamps.

Points to remember while designing illumination direct lighting and indirect lighting: Lighting for commercial purposes is divided into many parts such as built in direct lighting (Fig 1), indirect lighting (Fig 2), core lighting, spot lighting etc.

Fig 1

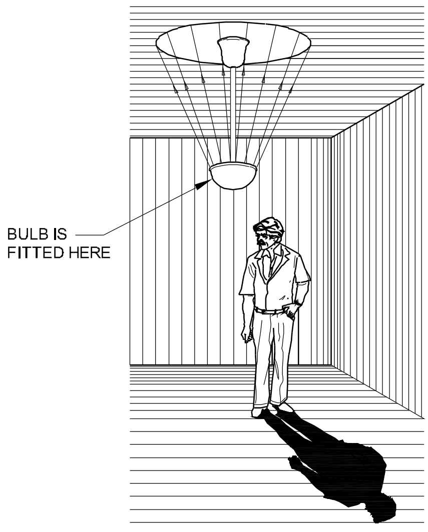


DIRECT LIGHTING

To achieve the above lighting there are ceiling fixtures, side wall fixtures, portable fixtures and other luminaries available.

The number of lumens required for the working place is 150 lumens/m^2. The lumens provided by the lamp must however be greater than this figure to allow for depreciation of the installation owing to dust and dirt on the lamps and their fittings.

Fig 2



INDIRECT LIGHTING

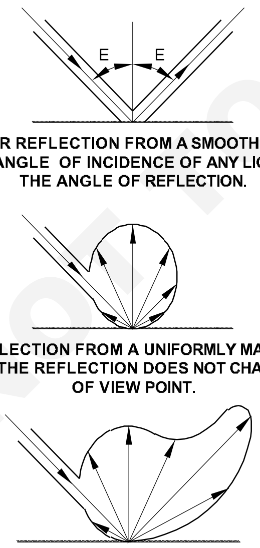
Atleast 150 lumens per square metre should be provided for adequate visual performance on rough or unskilled work. Up to 1500 lumens per square metre should be provided for difficult or fine works.

Most sources radiate light in all direction and are too bright to be viewed comfortably. The light must therefore be controlled to direct it where it is required and to soften its brilliance.

Reflection of light may be of three kinds.

- Specular reflection Fig 3(a)
- Diffuse reflection Fig 3(b)
- Spread reflection Fig 3(c)

Fig 3



a) SPECULAR REFLECTION FROM A SMOOTH OR POLISHED SURFACE THE ANGLE OF INCIDENCE OF ANY LIGHT RAY EQUALS THE ANGLE OF REFLECTION.

b) DIFFUSE REFLECTION FROM A UNIFORMLY MATT SURFACE: THE BRIGHTNESS OF THE REFLECTION DOES NOT CHANGE WITH CHANGE OF VIEW POINT.

c) SPREAD REFLECTION FROM A SEMI-GLOSSY SURFACE (EGG-SHELL) FINISH

Specular reflection: When light strikes a mirror like surface it is reflected at the same angle and in the same plane as it strikes, for example a car lamp.

Diffuse reflection: Diffuse reflection is useless for the precise control of light, but it can be used to reflect light in a general direction.

Spread reflection: Unpolished metals and satin-finish mirrored surfaces have reflection characteristics between specular and diffuse. Vitreous and synthetic enamels are widely used for reflecting surfaces of light fittings. Vitreous enamels is the more hard working.

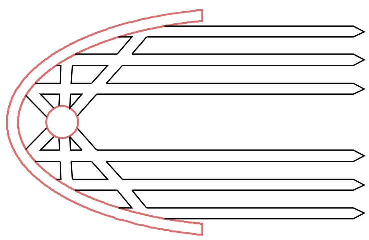
Types of reflectors: A lamp without any kind of reflector will radiate light in every direction. By placing the lamp within a reflector, you can control the light and direct it where you want it.

Dispersive type: The reflecting surface is either white enamelled or vitreous enamelled. The Viterous enamelled type is more expensive and less efficient optically but are more suitable for use in damp and corrosive atmosphere.

Mirror type reflector: These have highly polished surface for specular reflection. Silvered glass, Chromium plated; copper sheet anodized aluminium shades are typical example of this. This type is used in yard lighting

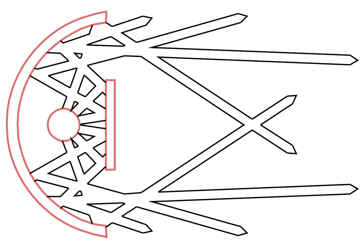
Parabolic and softlight reflector (Fig 4 & Fig 5): A parabolic reflector produces a hard light and is most commonly used with tungsten lamps. A softlight reflector has shield in front of the bulb and so produces a diffused light. A spotlight enables you to vary the light beam. In each case, the light will be softer if the reflector surface is matted or dimpled rather than highly polished.

Fig 4



PARABOLIC REFLECTOR

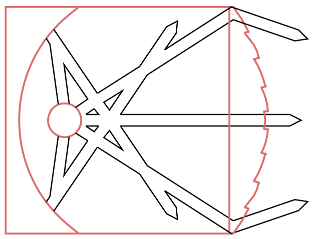
Fig 5



SOFTLIGHT REFLECTOR

Spotlighting (Figs 6 & 7)**:** Spotlighting is one way lighting, usually employed projectors with lenses but sometimes with reflectors only, and is used to give special illumination to a limited area as in theatre practice. The spotlights must be so located as to be out of the direct line of vision and produce no troublesome reflections or glare.

Fig 6



SPOTLIGHT

PD20N179836

Semi direct type designed to avoid glare and recommended for offices and other specific purposes. (Fig 8c)

Semi indirect type designed to avoid glare and recommended for specific purposes.(Fig 8d)

General diffusing type system has got low efficiency but are free from glare and has got uniform distribution of light.

Details of reflector's and their %age of light distribution is given in Table 1 for your reference.

Fig 8

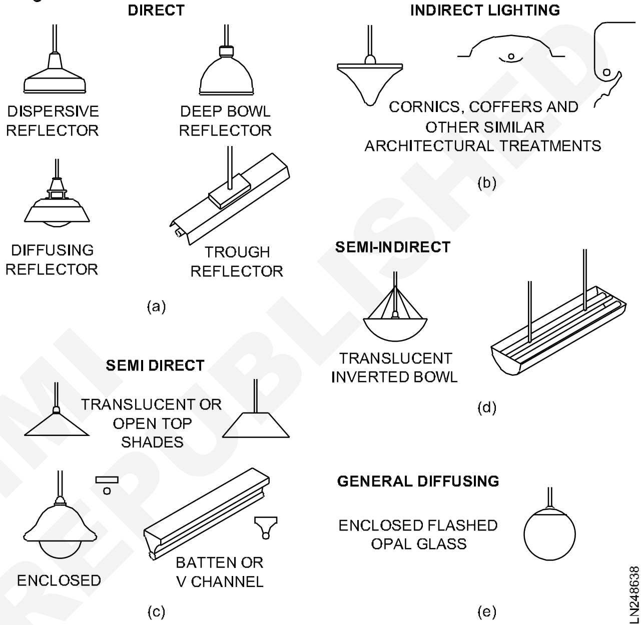


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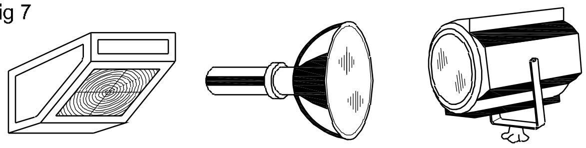
Fig 7



TYPE OF SPOTLIGHT FIXTURES

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Supplementary lighting: Supplementary lighting as the name implies, should be employed in conjunction with a general lighting system, when necessary or desirable.

Light fitting, types and performance (Fig 8)

Direct lighting type has largest efficiency from energy utilization point of view but glare is always present. Such systems are used for flood and Industrial lighting.(Fig 8a)

Indirect lighting type designed to avoid glare and recommended for specific purposes.(Fig 8b)

Table 1

Lighting systems

Types of system	**Amount of emergent light**	
	Downward	**Upward**
Shaded or reflector system		
1 Direct	90 to 100%	0 to 10%
2 Semi direct	60 to 90%	10 to 40%
3 Semi indirect	10 to 40%	60 to 90%
4 Indirect	0 to 10%	90 to 100%
Diffused system		
1 General diffused	50%	50%

Above table is in line with CIE classification of general indoor lighting luminaries

Low voltage lamps - different wattage lamps in series

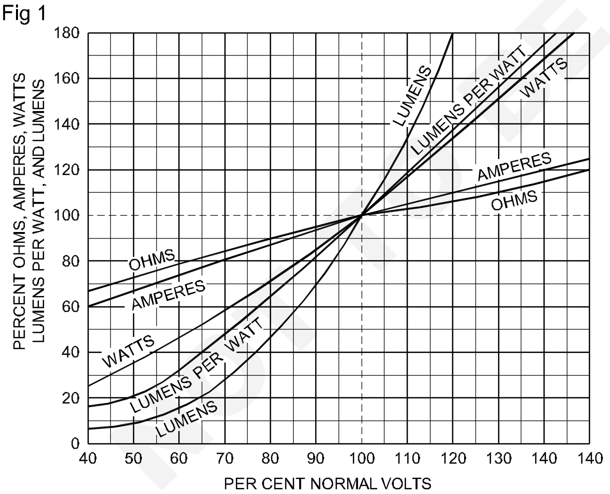
Objectives: At the end of this lesson you shall be able to
- **state the purpose of differtent voltage lamps**
- **calculate and compare the hot resistance of the same voltage but of different wattage/current lamps**
- **describe the method of measuring and calculating the 'hot resistance'**
- **state the effects of different wattage lamps in series.**

Purpose: In quite a few places we use low voltage supply i.e. 6V, 12V or 24V, such as in automobile vehicles. Automobile vehicles are equipped with many lights to provide an efficient lighting system for both day and night driving conditions. The various lights require the use of different wattage and types of light lamps to provide the amount of illumination desired.

Glow conditions of low wattage lamps with current flow through it: An electric lamp changes electrical energy into heat and light, when current flows through its filament and causes it to become incandescent. The filament is made of tungsten wire. The low voltage lamps are generally of low wattage because at a low voltage, the current taken by the filament for a given wattage is much more as compared to the domestic light.

The performance characteristics of tungsten-filament lamp is affected by voltage. The effect of operating a lamp at other than its rated voltage is shown in Fig 1. The decrease in voltage across the lamp lowers the current flow thus lowering the filament temperature. At 50% of the rated voltage, current decreases to about 68% and the resistance of the filament to 75%. The temperature of the filament lowers to an extent to give a light out of less than 10% lumens.

Fig 1



CHARACTERISTIC CURVES FOR INCANDESCENT LAMPS SHOWING THE EFFECT OF OPERATING A LAMP AT OTHER THAN ITS RATED VOLTAGE. THESE CHARACTERISTICS ARE AVERAGES OF MANY LAMPS.

Calculating the hot resistance: The lamp filament operates at a very high temperature, 1800°C to 2200°C. Therefore, there is a very big difference between 'cold resistance' and 'hot resistance'. Hot resistance (when the lamp is ON) is nearly 12 times more than the cold resistance (when the lamp is OFF).

Hot resistance

a Wattage = 12W

Voltage = 12V

Current = $\frac{W}{V} = \frac{12}{12}$ = 1 amp.

Resistance = $\frac{V}{I} = \frac{12}{1} = 12$ ohm(hot)

b Wattage = 40W

Voltage = 24V

Current = $\frac{W}{V} = \frac{40}{24}$ = 1.667 amps.

Resistance = $\frac{V}{I} = \frac{24}{1.667} = 14.4$ ohm (hot)

c

(i) Voltage = 6V

Current = 0.1 ampere

Resistance = $\frac{V}{I} = \frac{6}{0.1} = 60$ ohm (hot)

(ii) Voltage = 6V

Current = 0.15 ampere

Resistance = $\frac{V}{I} = \frac{6}{0.15} = 40$ ohm (hot)

(iii) Voltage = 6V

Current = 1 ampere

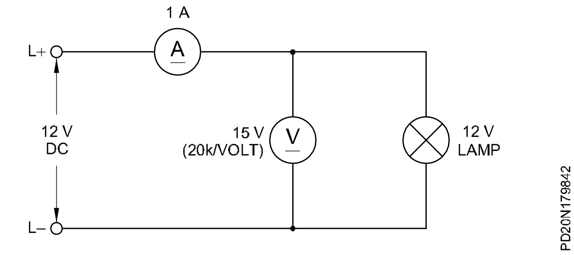
Resistance = $\frac{V}{I} = \frac{6}{1} = 6$ ohm (hot)

The resistances calculated above are always hot resistance. To find out the cold resistance, it is measured with the ohmmeter when the lamp is OFF and at room temperature.

Measuring 'hot resistance': The hot resistance of a low voltage lamp could be measured by connecting the lamp as per the circuit given, Fig 2. The lamp must operate at its rated voltage. A voltmeter of high sensitivity not less than 20 k ohms per volt is used such that the current taken by the voltmeter is negligible. The reading of the ammeter and voltmeter must be taken accurately.

Hot resistance $= \dfrac{\text{Voltmeter reading}}{\text{Ammeter reading}}$

Fig 2



Different wattage lamps in series: If the two lamps of different wattage in parallel across in A.C. circuit, it should be same voltage for proper operation. But, if they are connected in series they should have the same current ratings.

All the bulbs in house are probably connected in parallel and they will draw the current it requires, and all the lamps will glow bright.

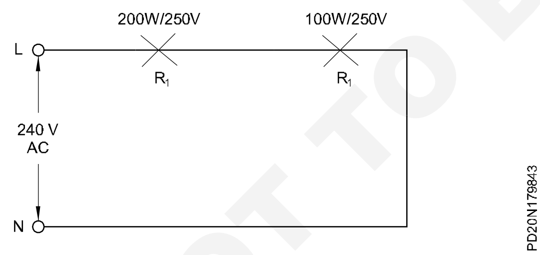
If two lamps with unequal wattages and same voltage ratings are connected in series they will divide up the available voltage between them.

Low wattage lamp will glow bright, due to high resistance and high voltage drop. High voltage lamp will glow dim, due to low resistance and low voltage drop.

Example

In a circuit the two lamps rated as 200W/ 250V, and 100W/ 250V are connected in series across 240 volt A.C. supply. (Fig 3)

Fig 3



200W (higher wattage) lamp will glow dim and

100W (low wattage) lamp will glow bright.

because,

The resistance of 200W/ 250V lamp,

$$R_1 = \frac{V^2}{W_1} = \frac{250 \times 250}{200} = 312.5\ \Omega$$

The resistance of 100W/250V lamp,

$$R_2 = \frac{V^2}{W_2} = \frac{250 \times 250}{100} = 625\ \Omega$$

Total resistance $R_T = 312.5 + 625 = 937.5\ \Omega$

$$\text{current } I = \frac{V}{R_T} = \frac{240}{937.5} = 0.256\text{A}$$

voltage drop in 200W lamp, $= IR_1 = 0.256 \times 312.5 = 80\text{V}$

Voltage drop in 100W lamp, $= IR_2 = 0.256 \times 625 = 160\text{V}$

Power V X I = 240 X 0.256 = 61.4 W

Hence,

The 100W lamp having high voltage drop due to high resistance it will glow bright than high wattge lamp 200W which is having low voltage drop and low resistance.

Various types of Lamps - Carbon arc lamps

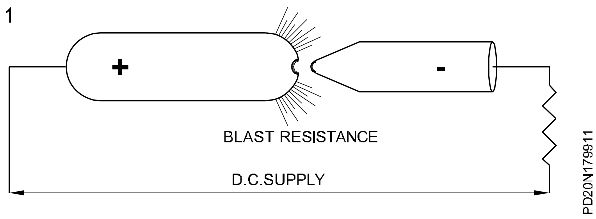
Objective: At the end of this lesson you shall be able to
- **explain the construction and working of carbon arc lamp.**

Carbon arc lamp

Construction

Two carbon electrodes placed in contact end to end, in which direct current is flowing, and on separating by about 0.6 cm., apart gives out a luminous arc . (Fig 1)

Fig 1



The arc gives path to the flow of current and the separated ends of the carbon emits light rays. The major portion of the light is due to the electrodes and only 5 per cent is given out by the arc. About 85 per cent of light is given out by the positive electrode which has a temperature of 3500°C to 4000°C and only 10 per cent light is emitted by the negative electrode which has temperature of nearly 2500°C. In the Fig 1, a ballast resistance is also shown because of the negative resistance charcteristic of the carbon arc.

Working

The production of heat due to the arc is explained as:

When the carbon electrodes are separated, the electrons flow from negative electrode to positive electrode through the air. When passing through the air they collide with neutral air atom and set the air in ionised (charged) condition. The positive ions move towards the negative electrode colliding with the carbon, there they produce a good amount of heat, which raises the temperature of the negative electrode. Similarly the negative ion will move towards the positive electrode and collide with the electrode producing enough heat to raise the temperature of the electrode about 3500°C to 4000°C.

The heat developed at the positive electrode is greater because the negative ions have less weight than positive ions and so they move with higher velocity after collision.

Due to higher operating temperature, the rate of consumption of positive electrode is nearly double than the negative electrode. Due to this reason the positive electrode is made of twice the cross sectional area to that of the negative electrode. When using arc lamp on ac supply, both electrodes burn away at equal rates and therfore they are made of equal cross-sectional area. The efficiency of the arc lamp is higher than incandescent lamp and is about 0.5 to 0.3W per candle power or 20 lumens per watt.

Advantages and disadvantages

As the rate of consumption is high due to high operating temperature, it is essential to maintain the air gap between the electrodes to obtain constant and continuous light. For this purpose an electrical and mechanical arrangement is provided in arc lamps. When the carbon becomes short in length, they are replaced.

As this lamp needs frequent adjustment and replacement of the carbon rod, it is not used in general purposes. They are only used in cinemas projectors, search lights. The operating voltage of these lamps varies between 40 to 60 V.

Neon sign lamp

Objectives: At the end of this lesson you shall be able to
- **explain the construction and working of neon sign tubes**
- **explain the colour mechanism of neon signs**
- **state the regulation for the use of neon sign lamps.**

Gas discharge lamp

A gas discharge lamp is one in which some inert gas is filled in a glass tube having two electrodes sealed into each end, which on heating allows the flow of electron through it.

To obtain a continuous flow of electron, gas is first charged but as the supply is disconnected from the bulb, the gas is discharged. Such a lamp is known as electric Gas Discharge Lamp. Electric gas discharge lamps are of two main types:

(i) Cold cathode lamp

(ii) Hot cathode lamp

In first type no filament is used to heat the electrode for starting but in the second type a filament is provided for heating the main electrode at the time of starting.

The function of both the lamps depend upon the fact that when a current is passed through the gas, it emits light rays. When a voltage is applied across the two ends of the filament contained in a gas filled glass tube, electrons start flowing from one electrode to the other. On the way they strike with neutral gas atoms separating an electron temporarily which when returns gives out light rays. The following are the different types of gas discharge lamps:

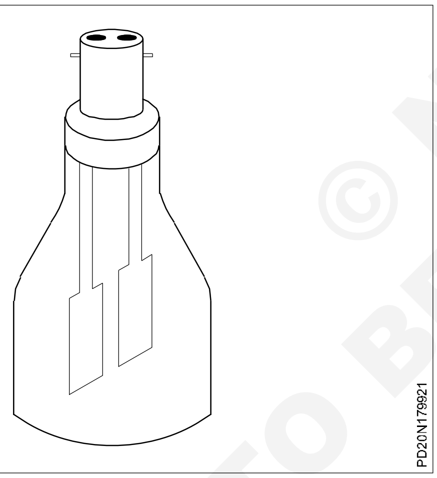
Cold Cathode Lamps (i) Neon lamp, (ii) neon sign tubes, (iii) sodium vapour lamp.

Hot Cathode Lamps (i) mercury vapour lamp (medium pressure), and (ii) fluroscent tube (low pressure mercury vapour lamp)

Types of gas discharge lamps

Neon Lamp This is a cold cathode lamp as shown in Fig 1 Neon gas at low pressure is used in it.

Fig 1



Construction

In this lamp, two flat or spiral electrodes are kept close together in a glass bulb so that the lamp can be operated at low voltage such as 150 V dc or 110 V ac. On giving supply to the electrodes, the gas becomes ionised and emits light which is reddish in colour. In usual practice a 2000Ω resistance is also connected in series with the electrodes which is placed in the cap of the lamp. This minimizes the fluctuation of current due to large variation of potential difference.

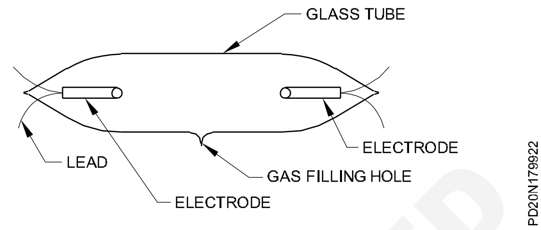
Uses

A neon lamp is generally used as an indicator lamp to indicate the presence of supply. It gives a small quantity of light and can also be used as a night lamp. A neon lamp of this type is also used in the testing pencil which is of 0.5 W.

Neon sign tube

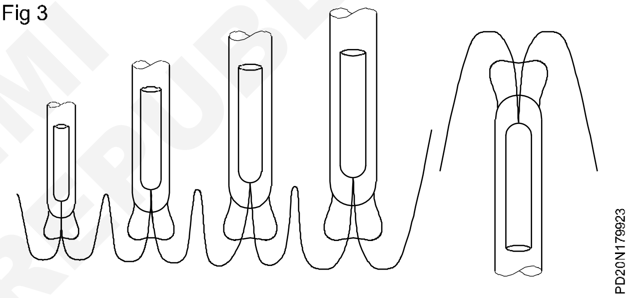
Construction of neon sign tube: Neon sign tube lamps are used mostly for advertising purposes. Fig 2 shows the construction details of a neon sign tube. A neon sign tube is made of glass.

Fig 2



The length of the tube varies from 1 metre to 5 metres, and the diameter varies from 10 mm to 20 mm. The tubes are joined with electrodes which are operated at high voltage. The electrodes are connected with nickel wires for more length or to different letters. (Fig 3)

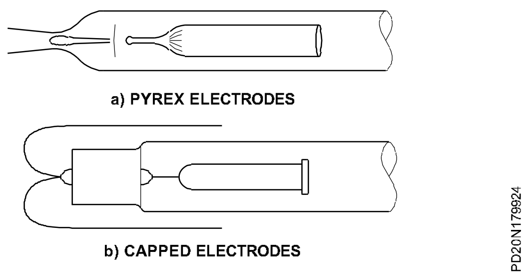
Fig 3



There are two types of electrodes.

- Pyrex electrode
- Capped electrodes (Figs 4a and 4b)

Fig 4



The shape of the electrode is cylindrical. The electrodes are made of nickel, iron or copper. The electrode consists of:

- a glass shell
- a lead in wires
- a glass jacket seal
- a ceramic collar. (heat resisting material)

The electrodes are fitted at the end of the tubes and fused. A vacuum is created in the tube before filling it up with an inert gas, such as neon or helium. After that it will be sealed. The neon sign tube will operate at 2000V to 15000V depend upon the length of the tube, and the current flow depends on the diameter of the tube. (Table 1)

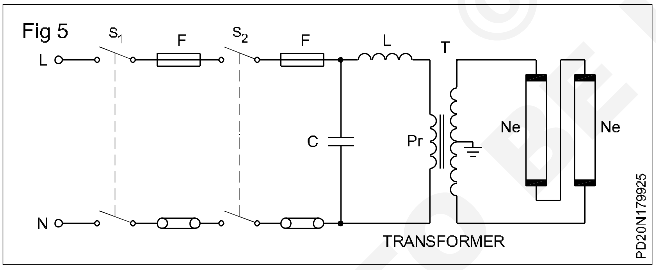
Table 1

Type	10SC	12SC	D4C	19MC	D stud
Size of electrode	10mm dia	12mm dia	15mm dia	19mm dia	15mm dia
Current	10mA	20mA	50mA	60mA	50mA

Working of neon sign tube: The neon sign tube requires a high voltage to operate. (Fig 5) This is obtained by a leakage field transformer (T) which simuntanously limits the current. The colour and the temperature of a neon tube depend on the gas inside, and we can also get various colours by using different fluorescent materials.

When high voltage is applied between the electrodes, the positive ions and the electrons drift towards the cathode and anode respectively. The movement of electrons increases with the potential and attain a very high velocity. The movement of electrons results in collision with the netural atoms, and may detach electrons from them. The high velocity of electrons is responsible for luminous discharge (light). The striking voltage of a neon sign lamp is about 1.5 times higher than the operating voltage, which is controlled by the R.F. choke)'L'.(Fig 5)

Fig 5



Circuit description and operation

Step-up transformer: The step up transformer is used to obtain a high voltage. The centre tap is earthed. The secondary output voltage is connected to the neon lamp.

R.F. choke L is connected in series with the primary of the leakage transformer to limit the surge current of the neon lamp. (Fig 5)

The capacitor C It is connected across the primary of the transformer to improve the power factor.

The fireman switch S2 It is connected alongwith the main switch and is used as an emergency switch. (Fig 5)

Main switches normally 15A 250V ICDP are used to control the circuits.

H.T. cables are used to connect the secondary of the transformer to the neon sign lamp as per IE rule No 71.

Colour mechanism of neon sign lamp: When electric current is conducted by a gas or vapour it produces luminous light. The elements most commonly used in this process of producing light by gaseous discharge are neon or mercury. The neon discharge yields orange-red light which is very popular in making advertising signs. The pressure of neon in the tubes is usually from 3 to 20 mm of the Hg. (millimeter of mercury)

Table 2

	Basic powder	Colour
1	Calcium tungstate	Blue
2	Magnesium tungstate	Blue-white
3	Calcium silicate	Pink
4	Zinc silicate	Green
5	Zinc beryllium silicate, depending upon the activating agent	Yellow, white, pink
6	Cadmium silicate	Yellow, pink
7	Cadmium borate	Pink

The ultimate colour produced by using fluorescent powders depends not only on the chemical composition of the powders but also on the gas, the pressure at which the gas was filled, the diameter of the tubing and the operating current.

Neon lighting - regulations: Maximum voltage 5000V to earth. Thus a 10KV display unit could be used provided its supply transformer is centre-tapped to earth.

H.V.Transformers: Where the input exceeds 500W, an automatic disconnection of the supply is to be provided in the event of a short-circuit or earth-leakage of current which exceeds 20% of the normal steady current.

Installation: All equipment to be housed in an earthed metal or substantial containers suitable for high voltage. A notice `Danger-High Voltage' in the type of lettering as stated in 1.E regulation No.71, to be permanently fixed near to the equipment.

For connection to high voltage cables, the insulation which is exposed by removing the metal sheath or braid must be protected from the effects of the sun's ultra-vilot rays.

Armouring may be required + cables may only be drawn through short- earthed lengths of metal tubing where they are passing through walls or ceilings. Unless easily identifiable, high voltage cables require, red on white background `DANGER' notices, at intervals not greater than 1.5 m; the minimum height of the letters to be 8 mm.

Separation and isolation: High-voltage discharge lamps to be supplied via a double-wound transformer. However auto-transformers may be used on 2-wire circuits which do not exceed 1.5KV, one pole to be connected to earth and the control switch to be of the double-pole type. Isolation of live conductors may be made by any one of the following methods.

- An interlock on self-contained fitting to be provided in addition to the switch normally used for controlling the circuit.
- Local isolation by plug and socket or similar method in addition to the normal control switch.
- Switch should be with a removable handle. Alternatively, a switch or distribution board of a type that can be locked may be fitted, if the keys are held by authorised persons. Where there are more than one switch or distribution board all removable handles and keys are to be non-interchangeable.

Fireman's switch: These emergency switches, which are required for neon lighting installations, must be provided for all exterior H.V. installations including closed markets and arcades. Internally, their use is confined to circuits that are run unattended, such as in window-display signs. The fireman's switch must also conform to the following requirements.

- The switch must be able to isolate the live conductors. One switch only should be fitted to control the whole of an exterior installation, and another for the interior.
- The switch should be coloured red with an adjoining name-plate marked `FIREMAN'S SWITCH' with regulation lettering.
- The ON and OFF positions to be clearly indicated by lettering legible to a person standing on the ground; the switch `OFF' to be positioned on the top, and the construction must be such as to prevent accidental movement of the switch to the ON position.
- The fireman's switch should be in a conspicuous position, as may be agreed to with the local fire brigade authority, at not more than 2.75 m from the ground. It is desirable that the switch be adjacent to the discharge lamps for an exterior installation and at the main entrance to the building for an interior installation.

Sodium vapour lamp

Objectives: At the end of this lesson you shall be able to
- **state the sodium vapour lamp and its types**
- **describe the construction of low and high pressure sodium vapour lamp**
- **state the functions of the parts in the circuit**
- **specify the standard sizes of sodium vapour lamps available**

Sodium vapour lamp and its types: Sodium vapour lamp is a cold cathode gas discharge lamp, which gives a yellow colour light. Sodium lamps are not suitable for locations where colour rendition is important, but due to their higher efficiency (110 lumens/watt), they are used for the lighting of streets, railways, storage yards etc. where human traffic is less and colour rendition unimportant. Sodium lamps are particularly suitable in fog as their yellow light can penetrate fog better.

The average life of a sodium vapour lamp is well over 6000 hours. There are two types of Sodium Vapour lamps as given below:

- low pressure SV lamp
- high pressure SV lamp.

Construction

Low pressure sodium vapour lamp: In the sodium vapour lamps efficiency decreases rapidly as the current density is increased above a certain value. Consequently the lamp has to be operated at a low current density and this necessitates a large surface area of the tube.

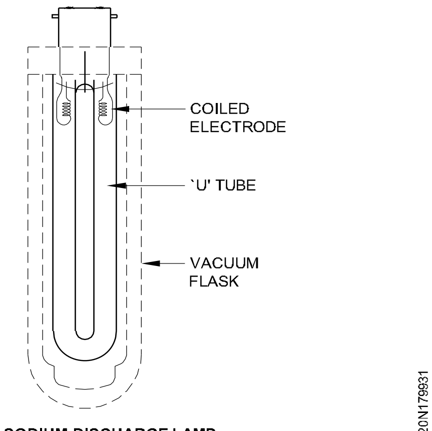
This lamp possesses a brightness of 7.5 candle per sq.cm. Because of these points the length of this tube has to be very long. Moreover its efficiency is very sensitive to the change in tube temperature. For maximum efficiency the temperature of the lamp has to be maintained at about 220^0C. So the whole tube is placed in a detachable double walled vacuum jacket.

As stated above low pressure Sodium Vapour lamps require a long tube, but as there is limit to the practicable size of such a jacket of the vacuum flask type, the long lamp tube is bent to a `U' shape to suit the jacket.

The low pressure Sodium Vapour lamp possesses a `U' shaped glass tube internally coated with fluorescent powder, consisting of Sodium together with Neon and one percent of Argon, the function of the Argon being used to reduce the initializing voltage.

In a cold lamp the Sodium is in the form of solidified drops on the inner walls. The tube contains two Barium and Strontium coated, coiled Tungsten electrodes at both ends. The two ends of the electrodes are fixed to the bayonet cap. (Fig 1) Connection diagram is Fig 3.

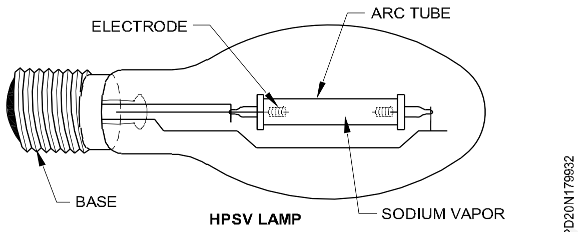
Fig 1



SODIUM DISCHARGE LAMP

High pressure sodium vapour lamp: A high pressure Sodium vapour lamp (Fig 2) operates at a much higher current which flows through a much shorter arc tube (discharge tube).

Fig 2



HPSV LAMP

This discharge tube is made of sintered aluminium ceramic discharge arc tube which is resistant to the hot ionised Sodium Vapour up to a temperature of about 1600^0C which transmits over 90% of visible radiation.

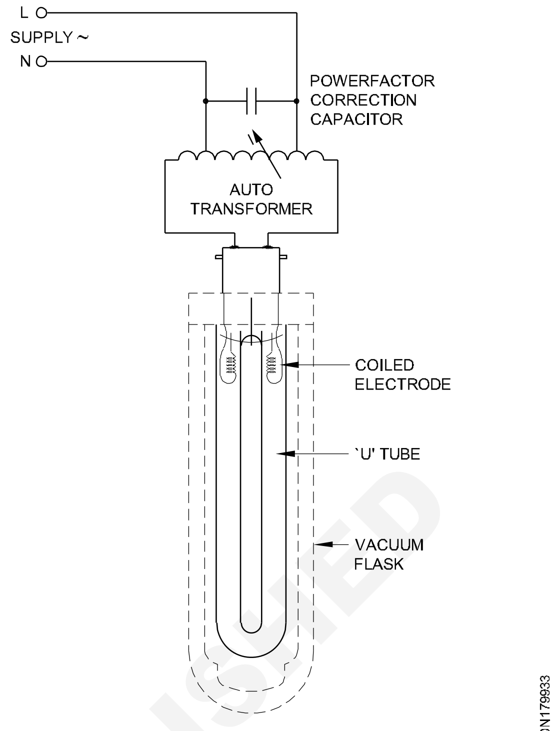
The discharge tube operates at a pressure of about half an atmosphere, and is enclosed in an evacuated hard glass envelope of elliptical shape to maintain the tube at the correct temperature. (Fig 3) The lamp gives a rich Golden light which enables colours to be easily distinguished. This discharge tube contains Sodium and Mercury, with Argon or xenon added at a low pressure for starting purposes at low pressure.

A voltage pulse of about 2.5 KV is required to initiate the discharge (Fig 4) in higher pressure Sodium Vapour lamp. This high voltage pulse is generated by high external ignitor or by built in thermal starter.

Leak transformer: The ignition voltage of sodium lamps varies from 400 to 600V. A `leak transformer' performs the dual role of providing the ignition voltage initially, and acting as a choke for limiting the current subsequently when the lamp starts conducting. The diagram of a leak transformer is shown in Fig 5.

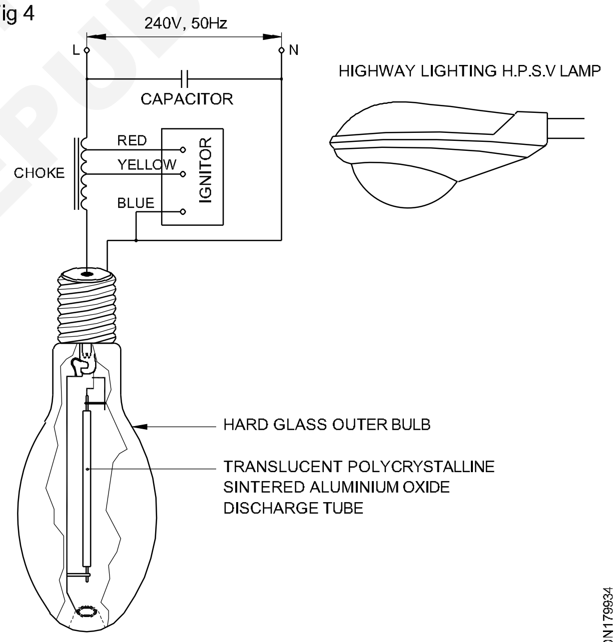
The primary and the secondary windings are connected in series and placed around the centre limb of a 3-core yoke. Between the coils, a loose iron core is clamped in

Fig 3



SODIUM DISCHARGE LAMP

Fig 4

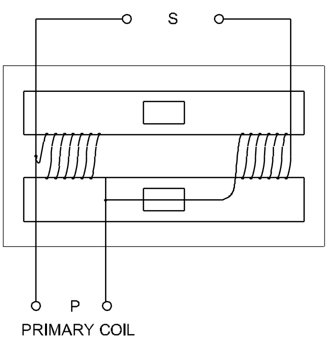


HIGH PRESSURE SODIUM VAPOUR LAMP

the yoke on either side, which acts as a shunt for the magnetic field.

Under no-load conditions, the resistance of the shunt is large due to air gaps, with the result the magnetic field moves through the limbs of the yoke, and the device acts as an auto-transformer. But when the lamp ignites and consumes current, a part of the magnetic field leaks away through the shunt due to the counter-acting field of the secondary.

Fig 5



LEAK TRANSFORMER

The device now acts as a choke coil reducing the voltage across the lamp electrodes to the required value.

Function of Sodium vapour lamp

Before the lamp starts, the sodium is usually in the form of a solid deposited on the sides of the tube walls. So in the initial stage when the potential is applied to the lamp it operates as a low pressure Neon lamp with pink colour (characteristics of the neon gas); but as the lamp warms up it vaporizes the sodium, and slowly it radiates out yellow light ,and after about ten minutes the lamp starts giving its full output.

Now the resistance of the lamp decreases and the current increases but the voltage drop across the high leakage transformer controls the current to safe values.

The lamp works at low voltage, and the working temperature is about 300^{0}C.

Operating position of sodium lamps: Sodium lamps of 45W and 60W may be operated in horizontal or any other position. The cap of the lamp should always be higher than the lamp itself, so that the Sodium does not settle behind the electrodes.

For Sodium lamps of should not exceed 20°; otherwise, the distribution of the sodium will be altered, affecting the life and performance of the lamp.

Life of sodium lamps: The average life of a sodium lamp is well over 6000 hours for three or more burning hours per switching operation. At the end of this period the light output will be less by about 15% due to ageing.

Tin-oxide sodium lamps (SOX Lamps): This lamp is an improvement over the ordinary sodium lamp the light output in its case is of the order of 150 lumens/watt.

Details of sodium vapour lamps (Std sizes)

Data on sodium lamps

Watts	Lamp voltage V	Minimum starting voltage V	Current A	Light output (lumens)	Dimensions mm
45	80	340	0.6	3500	257 x 51
60	105	340	0.6	5000	300 x 51
85	160	400	0.6	8000	414 x 51
140	160	410	0.9	13000	525 x 10
200	260	600	0.9	22000	785 x 60

Data on tin-oxide sodium lamps

Watts	Voltage	Current	Light output (lumens)	Dimensions
40	75	0.5	4400	310 x 51
60	115	0.7	7800	425 x 51
100	125	0.95	12500	528 x 64.5
150	185	0.94	20500	775 x 64.5
200	265	0.90	30000	1120 x 61.5

High pressure mercury vapour lamp (H.P.M.V)

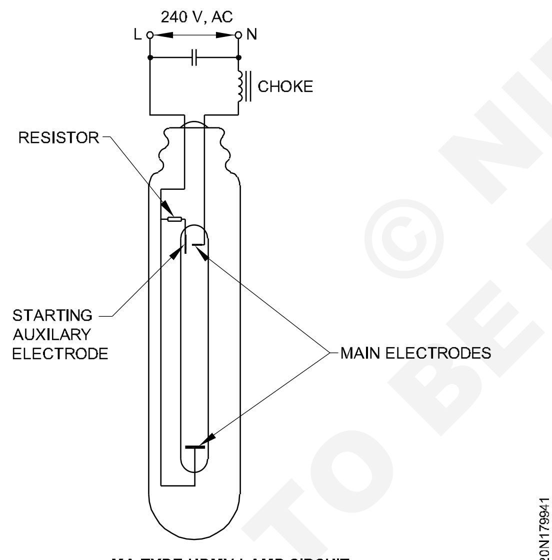
Objectives: At the end of this lesson you shall be able to
- **state the principle of discharge lamps**
- **describe the working of a `high pressure' mercury vapour lamp**
- **explain the different types of mercury vapour lamps**
- **identify the circuit elements in a mercury vapour lamp**
- **compare a sodium vapour lamp with a mercury vapour lamp.**

Discharge lamps: When an arc is struck in gas or metallic vapour, it radiates energy in characteristic wave-bonds. For example, neon gives red light, sodium yellow and mercury vapour four distinct lines in the visible, and two in the ultraviolet region of the spectrum.

All modern discharge lamps operate in a translucent enclosure. The initial discharge is usually struck in argon or neon.

The discharge occurs in an inner tube enclosed in an outer evacuated tube. (Fig 1) The inner tube of glass or quartz contains mercury and a small amount of argon to assist in the starting of the discharge. The electrodes are rich in electron-emittting materials in order to permit ease in the release of electrons.

Fig 1



MA TYPE HPMV LAMP CIRCUIT

Working of HPMV lamps

The lamp operates at high pressure. To start the discharge, an auxiliary electrode is positioned quite close to the main electrode. The auxiliary electrode is connected to the lamp terminal through a high resistor.

The high resistor limits the current. When switched on, the normal mains voltage is not sufficient to start the discharge between the main electrodes but it can start over the very short distance between the main and auxiliary electrodes.

At the beginning, the discharge current passing through the high resistance causes a potential difference to develop between the starting electrode and one of the main electrode through the argon gas. The discharge now spreads rapidly until it takes place between the main electrodes.

The argon discharge then warms up the tube and vaporises the mercury. Soon the gas content is mainly mercury vapour and the argon has less and less effect. The discharge then takes place in the mercury vapour.

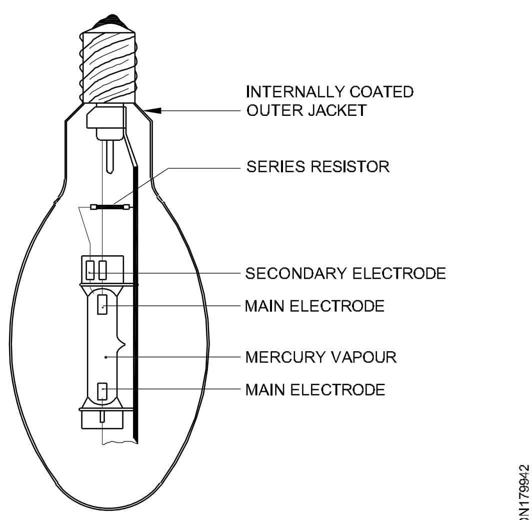
Types of HPMV lamps

Three different types of high pressure mercury vapour lamps are:

- MA type (MV lamp with auxiliary electrode)
- MAT type (MV lamp with tungsten filament)
- MB type. (MV lamp with auxiliary electrode and Bayonet cap)

MA type HPMV lamp: The discharge tube is made of borosilicate which is quite hard. The tube consisting of the main and auxiliary electrodes is sealed with an inside pressure of one and a half atmospheres. The lamp has a screw cap and is connected to the mains through the choke. (Fig 2) The lamp takes about 5 minutes to start giving full output.

Fig 2



MA TYPE HPMV LAMP

This lamp, once switched off, will not restart again until the pressure developed inside the tube falls back. It takes about 7 minutes to start again. There is no harm in keeping the switch on. The lamp should always be hung vertically, otherwise the inner tube will be damaged.

The efficiency is 45 lm/watt for 400 watts lamp.

MAT type lamp: This type of lamp is almost similar to the MA type, but the outer glass envelope, instead of being empty, consists of a tungsten filament. The tungsten filament, similar to the one in an ordinary lamp, is in series with the discharge tube. It acts as a ballast. This lamp requires no external choke (or ballast) and capacitor.

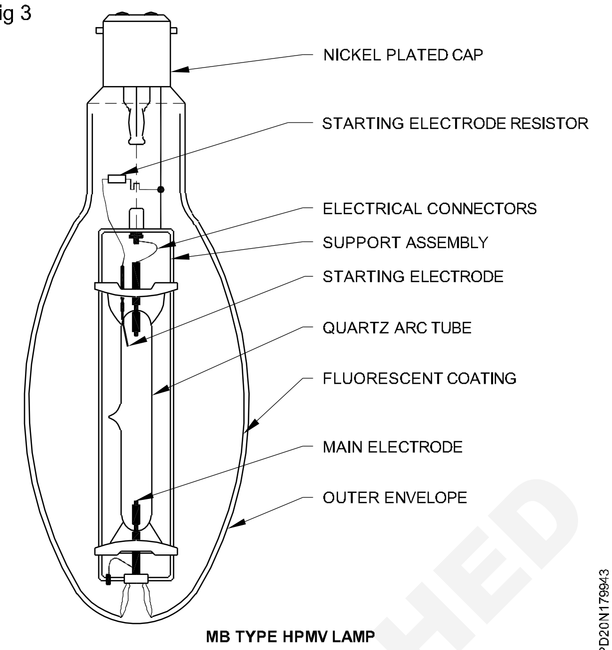
When the lamp is switched on, it works as a filament lamp does and its full output is given by the outer tube. At the same time, the discharge tube starts warming up, and when a particular temperature is attained, a thermal switch operates. The thermal switch cuts off a part of the filament so that the voltage across the discharge tube increases.

The light output is a mixture of light produced by a filament lamp and a discharge lamp.

MB type lamp: This lamp operates at an extra high pressure of 5 to 10 atmospheres. The discharge tube of this type is of quartz, about 5 cm long and has three electrodes, two main and one auxiliary. This lamp has a 3-pin bayonet cap and it cannot be put into an ordinary holder as it requires a choke and capacitor. (Fig 3)

The functioning of the tube is similar to that of a MA type lamp. Since a quartz tube can withstand high temeperature, it can be used in any position.

Fig 3



MB TYPE HPMV LAMP

The wattages available are 80 watts 125 W, 250 W, 400 W, 700 W and 1000 watts operating in 230V/250V, 50 Hz main supply.

The efficiency is about 50 lm/W.

Comparison of Sodium vapour lamp with Mercury vapour lamp

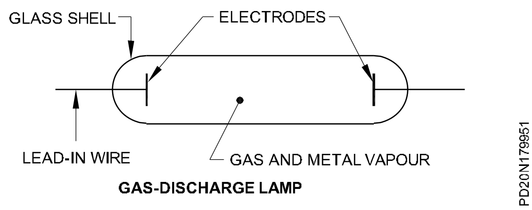
Sl.No.	Sodium vapour lamp	Mercury vapour lamp
1	It is provided with a high leakage reactance transformer.	It is provided a with choke. (Ballast)
2	Higher light efficiency: 160 lm/w.	Lower light efficiency: 50 lm/w.
3	Ignition voltage of Sodium Vapour lamp varies from 400 to 600V.	Ignition voltage of mercury vapour lamp is less.
4	Burning position critical.	Burning position not critical.
5	Yellowish light.	Greenish blue light.
6	It posses only two main electrodes.	It posses two main electrodes and one auxiliary electrode.

Fluorescent lamp

Objectives : At the end of this lesson you shall be able to
- **state the principle of discharge lamps**
- **describe the construction of single tube fluorescent lamp with its components**
- **state the function of each component in the circuit**
- **state probable causes for different problems in the circuit malfunctioning.**

Principle of a discharge lamp : The basic principle of a gas-discharge lamp is explained in Fig 1. Gases are normally poor conductors, especially at atmospheric and higher pressures, but application of suitable voltage (known as ignition voltage) between two electrodes in a sealed envelope containing gas at low pressure ionises the gas, and current passes from one electrode to the other through the gas medium.

Fig 1



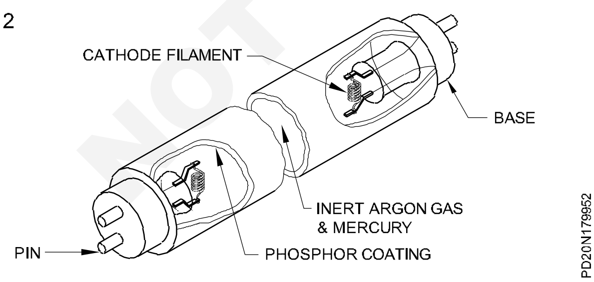
GAS-DISCHARGE LAMP

A glass shell with two electrodes apart is connected through lead in wires to the voltage source. The space within the shell is filled with low pressure vapour. When the voltage applied to the electrodes is increased to a certain value, the gas inside gets ionised and starts conducting.

The current flow through the low pressure gas is called discharge. This causes the gas/vapour to emit radiation in the ultraviolet region. The UV radiation cannot be perceived by the human eye. Certain phosphors have the property of emitting light in the visible spectrum when it is exposed to UV rays.

Construction of fluorescent tubes: A fluorescent light bulb is basically a glass tube capped by two bases. (Fig 2) These bases are fitted with pins to carry current to internal components called cathodes. Contained inside the tube are minute droplets of mercury and an inert gas.

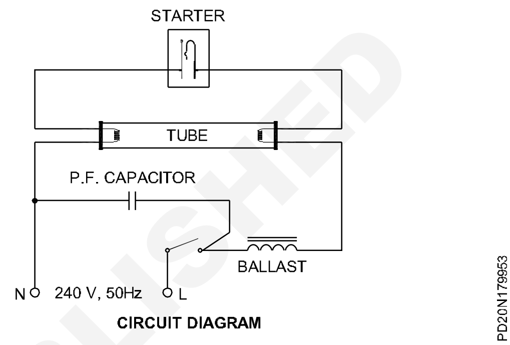
Fig 2



The inner surface of the tube is coated with a fluorescent powder or phoshphor. This phosphor emits light when exposed to ultra-violet rays. Cathodes or electrodes are made up of coiled tungsten filaments coated with a mixture of barium and strontium oxides.

Circuit diagram: The method of connecting the starter, ballast and the tube's electrodes at its either end is as in (Fig 3)

Fig 3

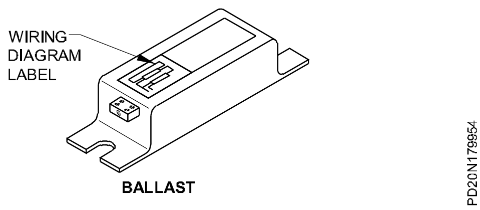


CIRCUIT DIAGRAM

Function of the various parts in a fluorescent light circuit

Ballast (Choke)**:** The ballast is basically a coil of many turns wound on a laminated iron core (Fig 4). It steps up the supply voltage to start the fluorescent tube conducting. Once the tube is conducting, it regulates the flow of heavy current to the tube cathodes to keep them from burning out.

Fig 4



BALLAST

Starters: A starter in the fluorescent tube circuit performs two functions.

- It completes the circuit at first for preheating the electrodes.
- It opens the circuit to provide voltage kick for ignition.

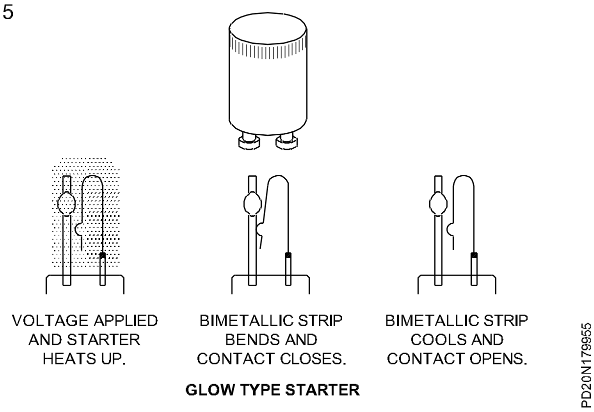
There are two types of starters.

- Glow-type
- Thermal type

Glow type starters: A glow-type starter switch (Fig 5) is the one most widely used. It consists of a gas-filled glass tube containing two electrodes, one of which is a bimetallic strip. When voltage is applied to the starter, a glow discharge occurs between the two contacts. The heat thus developed causes the bimetallic strip to deflect and close the circuit.

Current for preheating the electrodes starts flowing. At the same time the glow discharge ceases resulting in the cooling of the bimetallic strip. The contacts reopen and the voltage induced in the choke coil provides the ignition voltage.

Fig 5

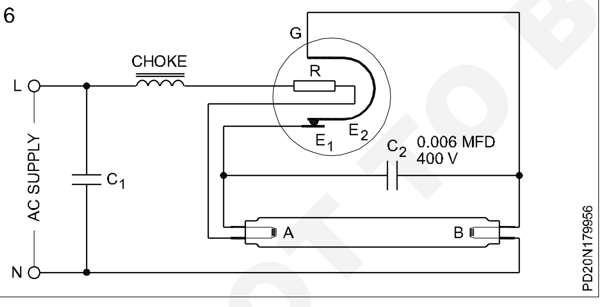


Thermal type starter: The switch has a bimetalic strip close to the resistance R which produces heat.

Thermal type starters are generally enclosed in a hydrogen - filled glass bulb G. The two switch electrodes E_1 and E_2 are normally closed when the lamp is not in operation. When normal supply is switched on, the lamp filament electrodes A and B are connected together through the thermal switch and a large current passes through them.

Consequently, they are heated to incandescence. Meanwhile the heat produced in resistance R causes the bimetallic strip E_2 to break contact. The inductive surge of about 1000V produced by the choke is sufficient to start discharge through mercury vapours as explained. The heat produced in R keeps the swtich contacts E_1 and E_2 open during the time as shown in Fig 6.

Fig 6



A 0.006 MFD capacitor (C_2) is connected across the electrodes of the starter contacts (bimetals) in the case of both thermal and glow type starters, to eliminate any radio interference effects that may be caused by the opening and closing of the bimetallic contacts.

Fluorescent tube: When the circuit in Fig 3 is energised, a small current passes through the series reactor, the two tube filaments, and the glow-tube. At the instant when the circuit is energised, the current is very small because of the high resistance of the glow-tube.

Because of the high resistance of the glow-tube, the current is small, and there is little voltage drop across the series reactor. Therefore, there is sufficient voltage at the glow-tube to produce a glow discharge between the U-shaped bimetallic strip to expand and close the contacts. Preheating takes place at both cathodes.

The current through the two filaments is relatively high but the series reactor limits the current to a safe value. In the period that the contacts of the glow-tube are closed, the temperature of the fluorescent tube electrodes increases rapidly.

However, when the contacts close in the glow-tube, the glow discharge is stopped, the bimetallic U-strip cools and the contacts open. At the instant these contacts open, an inductive voltage-kick generated by the series reactor coil starts conduction of current between the main electrodes of the fluorescent tube.

A stream of electrons flows between the filament electrodes. These electrons collide with the electrons of the argon and mercury vapour in the tube. The two gases radiate ultraviolet light. These rays bombard the phosphor coating on the tube wall. The phosphor-coating radiates visible light.

The fluorescent lamp continues to operate as long as the circuit is energised. The usual operating voltage for satisfactory operation is 110 to 125 volts AC. Once the circuit is in operation, the reactor limits the current to the rated value so that the fluorescent tube fluoresces at the proper light intensity.

Power factor correction capacitor: The reactor or voltage ballast in series with the fluorescent tube causes the power factor of fluorescent units to range between 50 and 60 percent lag. The power companies, therefore, have requested the various fluorescent lamp manufacturers to install capacitors in fluorescent lighting units. So that the operating power factor of most fluorescent lamp units is near 100 percent or unity.

Standard sizes of fluorescent lamps available in the market: The light output of a fluorescent lamp amounts to about 70 lumens per watt. The usual sizes are 10, 20, 40 and 80 watts; 1 foot (30 cm), 2 feet (60 cm), 4 feet (120 cm) and 5 feet (150 cm) respectively at 240 volts.

Comparison of a fluorescent lamp with incandescent lamps: Fluorescent lamps or tubes have several advantages over standard incadescent lamps. Their main advantage is that they can produce light at a much lower cost. Fluorescent tubes produce about four times as much light per watt of power than do incandescent lamps. This makes them much cheaper to operate. Glare level is low.

Fluorescent tubes produce less heat than incandescent lamps due to their higher light efficiency. If you touch a fluorescent tube after it has been `ON' for some time, you will note that it is cool to touch. Large incandescent bulbs will cause burns to anyone trying to remove them after they have been in operation for some time.

Under ordinary operating conditions, fluorescent lamps last five to fifteen times longer than standard incandescent lamps. However, the more often a fluorescent lamp is turned on and off, the shorter its life span. The major disadvantage of fluorescent lighting is the higher initial

cost of the fixture. This extra cost is due to the auxiliary hardware required to operate the fluorescent lamp circuit. The disadvantage is the small wattage of these lamps require a large number of fittings.

Life of fluorescent lamps: Their normal life span is 7500 hours. They are affected by both high and low voltage, frequency of switching. The average life is for three burning hours per switching operation. The actual life may vary from 5000 to 10000 hours, depending upon the operating conditions. Light output is reduced by 15 to 20% after 4000 hours operation, and it is, therefore, a good practice to replace the fluorescent lamps after 4000 - 5000 hours of burning, on economic grounds.

Fluorescent light - Trouble shooting

Fluorescent light - troubleshooting chart

Problem	Possible causes	Solution
The tube fails to start	Bulb burnt out. Defective starter. Broken lamp-holder. Incorrect bulb for ballast Fixture wired incorrectly. Line voltage too low. Air temperature too low. Defective ballast.	Replace bulb. Replace starter. Replace lamp-holder. Check ballast label for correct bulb. Check wiring diagram on ballast label. Contact electricity board. Install special low-temperature,ballast. Replace ballast.
Ends of the bulb glow but centre does not	Defective starter. Fixture wired incorrectly. Fixture not adequately grounded	Replace starter. Rewire according to ballast wiring diagram. Check ground connection on fixture.
Ends of bulb are black.	Bulb nearly burnt out.	Replace bulb.
Bulb flickers or blinks.	Tube pins making poor contact. Bulb nearly burnt out. Defective or incorrect starter. Air temperature too low.	Clean the prongs and tighten the tube in the lamp-holder. Replace bulb. Replace starter. Warm room; if necessary install special low temperature ballast.

Instant start fluorescent lamp

Objectives: At the end of this lesson you shall be able to
- **describe the construction and working of an instant start fluorescent lamp**
- **state the purpose of instant start ballast**
- **explain the advantages of instant start fluorescent lamps.**

Instant start flouresent lamp

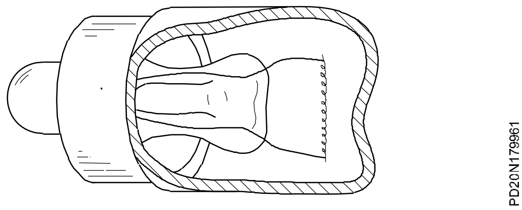
The instant start or quick start method of starting fluorescent lamps consists of an auto-transformer connected across the tube. When the electrodes become hot (usually in a fraction of a second), the tube strikes.

Construction and working

The fluorescent lamp, designed for instant starting, has only one terminal at each end. It has a filament type of cathode and operates as a hot-cathode lamp. The current passing between the two electrodes heat the segments of the small wire filaments to red-hot temperature in a fraction of a second. Therefore the need for separate starters is eliminated.

Fig 1 illustrates the construction of the filament type cathode and single terminal pin used on instant start fluorescent lamps.

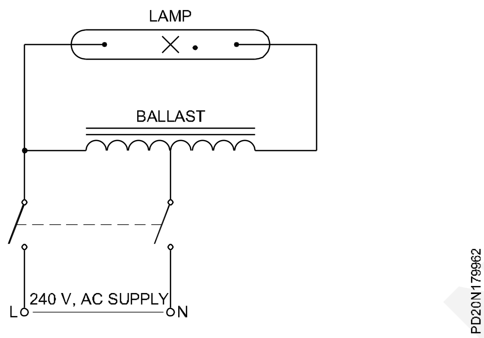
Fig 1



This type of construction results in lower electrode losses. The other details of construction for instant start fluorescent tubes are the same as for preheat fluorescent tubes with the exception that the diameter of the instant start tubes is slightly smaller than that of the pre-heat fluorescent tubes.

Fig 2 illustrates the connections for a circuit used to operate instant start fluorescent lamps.

Fig 2



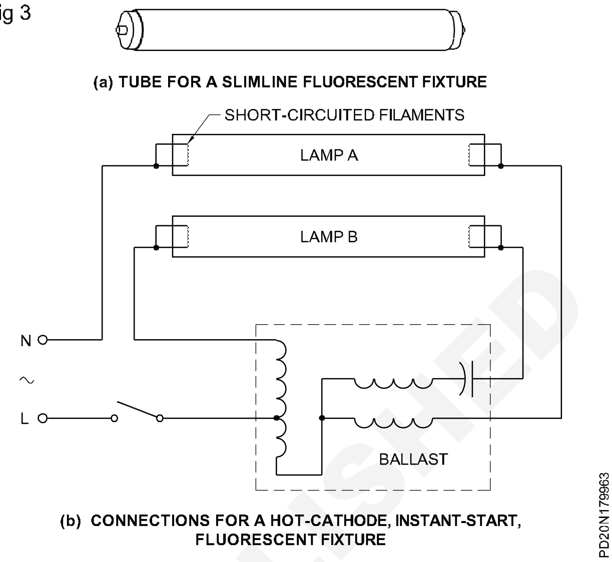
Purpose of ballst

The ballast used with the circuit is designed to:

- deliver a high starting voltage at the instant the circuit is energised to start the lamp without preheating
- deliver a normal operating voltage after the lamps are in operation.

Earlier two-lamp slimline circuit tubes were connected in parallel with lead-lag configuration. Modern circuitry has the two lamps in series, (Fig 3) and the ballast is designed to start the lamps in very rapid sequence. It requires a smaller ballast, and leads to reduced cost, and lower sound level.

Fig 3



(a) TUBE FOR A SLIMLINE FLUORESCENT FIXTURE

(b) CONNECTIONS FOR A HOT-CATHODE, INSTANT-START, FLUORESCENT FIXTURE

The use of instant circuit has the following advantages.

- The resultant power factor for the two lamp unit is 95 percent or higher.
- The phase displacement between the currents in the two lamps circuit reduces any stroboscopic effect.
- This type of lighting unit starts the instant the circuit is energised.

Rapid start fluorescent lamp

Objectives: At the end of this lesson you shall be able to

- **describe the working of a rapid start fluorescent lamp**
- **explain the connection circuit of a rapid start fluorescent lamp and its ballast in the circuit**
- **state the advantages of a rapid start circuit.**

Rapid start fluorescent lamp

The rapid start lamps are widely used in modern installations. The cathodes are heated continuously and the lamp gets illuminated very quickly after the circuit is energised.

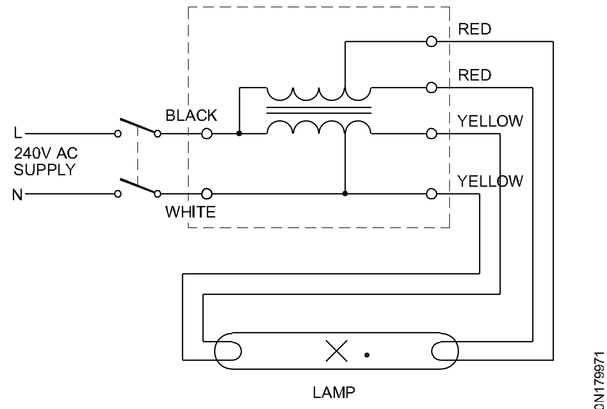
Fig 1 illustrates a rapid start circuit. The ballast has separate windings to heat the cathodes continuously. Therefore, when the lighting switch is placed in the ON position, the lamps light very quickly, and no flicker occurs.

This lamp requires a special ballast and a metal starting aid, which is at ground potential. One popular arragnement for metal starting is to provide 1 or 2 mm strip of metal coating over the tube between the caps, which is grounded.

Proper polarity is very important when connecting a rapid start fixture. The black wire from the ballast must be connected to the ungrounded (hot/phase) wire from the supply.

Since the cathodes are already heated, the amount of voltage required to cause the lamp to fluorescent is smaller than the voltage required for the instant start lamp. As a result, the rapid start system is very efficient particularly because of the small amount of loss in the ballast.

Fig 1



RAPID START FLUORESCENT LAMP CIRCUIT

Fig 2 illustrates the connections for 'two rapid start lamps' fixture. It is a series circuit and is commonly used. Once lamp 1 is on, the voltage across it drops to a low value and nearly all of the ballast voltage appears across lamp 2, which is the starting voltage required to start one lamp. The result is that the size of the ballast can be small.

Advantages:

1 The rapid start lamp can be used in dimming and flashing circuits.

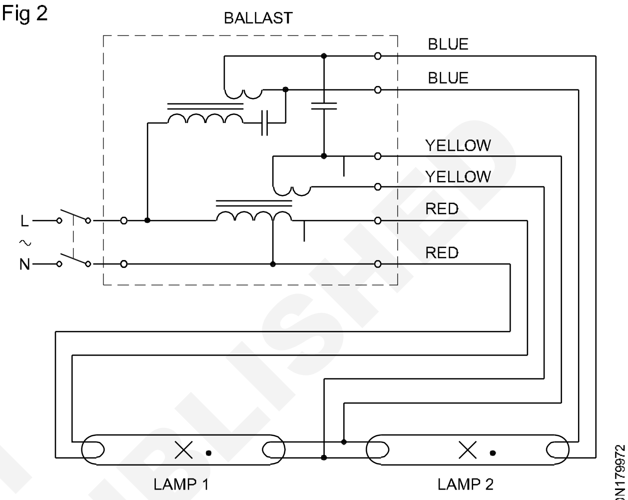
2 Certain types of rapid start lamps work very well in the preheat system.

3 A rapid start lamp can be obtained for almost any type of weather conditions.

4 It has longer life than the instant start lamp, yet requires minimal starting time.

5 In the rapid start system, as in the instant start system, there is no need for a separate starter and starter socket as is required in the preheat system.

Fig 2



RAPID START TWIN FLUORESCENT LAMPS CIRCUIT

Fluorescent lamp - Twin-tube

Objectives: At the end of this lesson you shall be able to
- **state the necessity of twin-tube connections**
- **explain the methods to prevent stroboscopic effect**
- **compare with a neon sign lamp with a fluorescent lamp.**

Necessity of twin-tube connections: If a suitable wattage choke (ballast) is not available, then two tubes of half wattage rating of choke can be connected in series to get the correct performance of the two tubes.

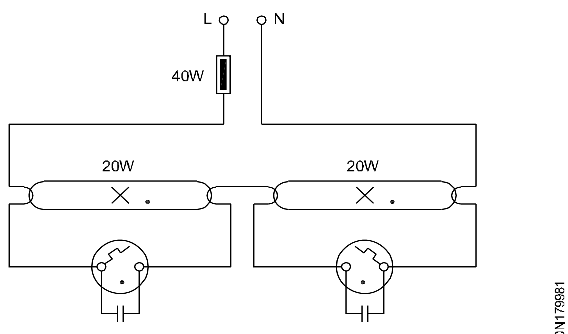
Example: If a 40 watt choke and two 20 watts tubes are available, then the twin tubes may be connected in series Fig 1.

Unlike incandescent lamps which emit light due to heat, a fluorescent lamp extinguishes itself every time the voltage wave passes through zero, i.e. 100 times in a second. This results in a feeling of discomfort if rapidly moving objects are viewed in this light.

To prevent this discomfort (stroboscopic effect), connect the twin-tube lights in parallel as lag-lead circuit.

Stroboscopic effect: In an AC cycle, zero value occurs twice per cycle, and theoretically lamps should go out twice per cycle or every hundredth part of a second on a standard 50Hz supply. In tungsten lamps, the heating of the filament results in a `carrying over' of this null period, which, therefore, prevents lamps from being extinguished or even flicker.

Fig 1



TWIN-TUBE LIGHT SERIES (TANDEM) CONNECTION

In discharge lights although the flickering may not be noticeable a peculiar dangers referred to as the stroboscopic effect, can arise where moving machinery is present. Spokes of a wheel, when rotating at the same speed as that of the supply, appear to be stand still.

If the interval of time between the zero points is exactly equal to the time taken for one revolution of the wheel, the object will appear to be stationary because the same spoke will be illuminated while in the same position each time.

The wheel will appear to be revolving backwards if the intervals of time are slightly shorter. If the intervals are longer the wheel will appear to be moving slowly forwards.

Methods adopted to prevent the stroboscopic effect: The stroboscopic effect is reduced to a minimum in fluorescent lamps by utilizing fluorescent powder having a slight afterglow. They can be further eliminated in a large three-phase installation by connecting adjacent lighting points to different phases of the supply, so that minima occur on different lamps at different times. Where only a single phase supply is available, lamps may be operated in pairs.

Types of twin-tube connections

Mainly these are of two types.

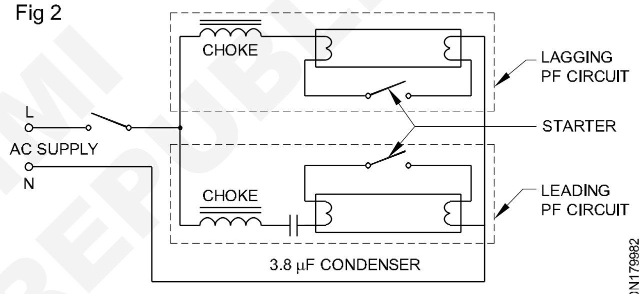
- Twin-tube light series connections
- Twin-tube light parallel connections

Twin-tube light series connection: For each fluorescent lamp, the right type of choke has to be used. For example a 40 watt choke must be used with a 40 watt lamp, a 60 watt choke with a 60 watt lamp and so on. It is, however, possible to operate two 20 watt lamps with one 40 watt choke, and two 40 watt lamps with one 80 watt choke. Each lamp must, however, have its own starter. Fluorescent lamps which are connected in this way are connected in TANDEM. (Fig 1)

Twin-tube light-parallel connections: The stroboscopic effects in flurescent lamps can be avoided by wiring twin lamp fixtures with one lamp wired inductively and the other with a leading current by the use of a capacitor. (Fig 2) The recommended capacitor rating is 3.8 mfd, 380V.

The normal P.F. capacitor is omitted but another is connected in series with one of the lamps and the choke windings are dissimilar. The lagging current in one lamp is balanced by the leading current in the capacitor circuit, thus the currents, and, therefore, the light outputs differ in phase by approximately 120 degrees and the total P.F. is nearly unity.

Fig 2



TWIN-TUBE LIGHT PARALLEL CONECTIONS

Differences between fluorescent lamp and neon sign lamps

Issue	Neon sign lamp	Fluorescent lamp
Construction	1 Two ends of the tube are fitted with electrode.	The two ends are fitted with filament.
	2 Maximum length of the tube - 1 metre.	Maximum length of the tube - 1.5 metres (5 feet)
	3 Diameter of the tube 10 mm to 20 mm.	Diameter of the tube 20 mm to 40 mm.
	4 The tubes are to be matched with high voltage transformer	It can operate on medium voltage,ie. 250 V.
	5 We can set any design or shape.	Only straight or circular tube.
	6 Electrode is cylindrical-shaped and is made of nickel, iron or copper.	Electrode is of a spiral form and is made of tungsten, coated with an electrode emitting material.
Colour	1 Colour can be obtained by using different gases and chemicals.	Colour can be obtained by using chemical coating on the tube walls.
	2 Only gas such as neon or helium. and a small quantity of argon gas.	The tube contains a small amount of mercury
Application	1 These tubes are used for advertising purposes as neon signs and letters.	These tubes are used for domestic/industrial lighting purposes.
	2 These tubes are not readily available as per requirements.	Readily available.

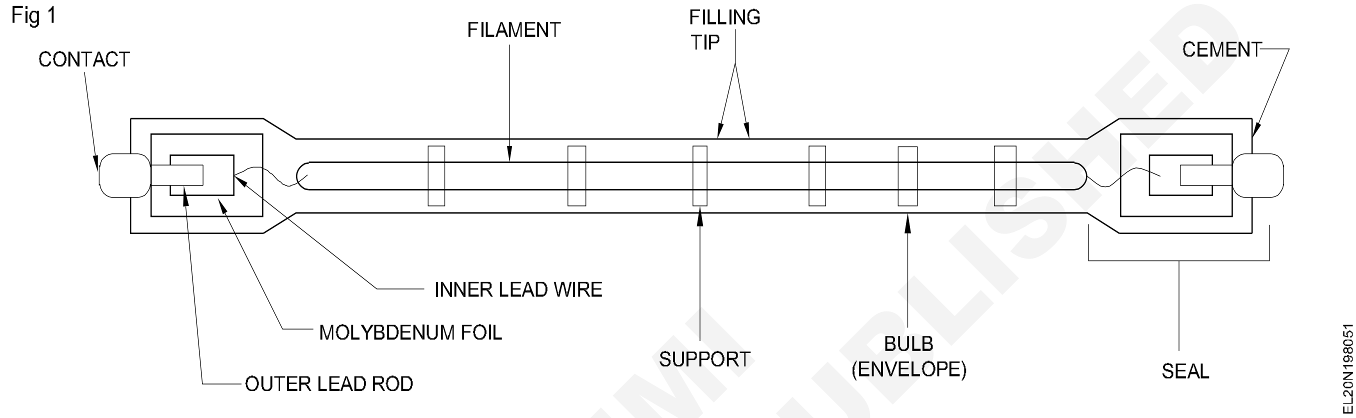
Halogen lamp

Objectives: At the end of this lesson you shall be able to
- **explain Halogen lamp construction**
- **describe the principle of tangsten halogen regenerative cycle process**

Construction

Halogen lamps are the most advanced and multi-purpose incandescent lamps. Although they belong to the incandescent family of lamps, they are designed to provide a superior quality of crisp white light, long life, high efficiency and constant lumen maintenance. Due to their reduced size, the halogen lamps allow for the most compact and stylish fixture designs. Halogen lamps operate on the tungsten halogen regenerative principle which eliminates filament evaporation and bulb blackening. As a result, the initial lumens and color temperature are maintained throughout the lamp life. The use of bromine, which is a transparent gas, increases efficiency by 28 -33 lumens/watt as compared with iodine because there is less absorption of light by the filled gas (Fig 1).

Fig 1



Principle of tungsten halogen regenerative cycle process

1 If the lamp is turned on, tungsten particles evaporate from filament and attach on to bulb wall. At the same time, halogen is decomposed and becomes atomic halogen.

2 Atomic halogen is diffused on the bulb wall and combines with free tungsten particle to become transparent and volatile tungsten halide.

3 Due to the high temperature (over 500°F) on the bulb wall, tungsten halide is volatilized and circulated back to filament.

4 After tungsten halide is decomposed around the filament at a high temperature, halogen gas is released, ready to combine again, and tungsten is re-deposited on the filament, whereby the process is ready to begin again.

The halogen lamp's envelope is made of quartz glass because of the high operating temperature and pressure required to permit the halogen regenerative cycle process. Quartz also renders the lamp extremely resistant to heat impact. The small dimensions of halogen lamps allow accurate control over the light beam for a better focused and precise light.

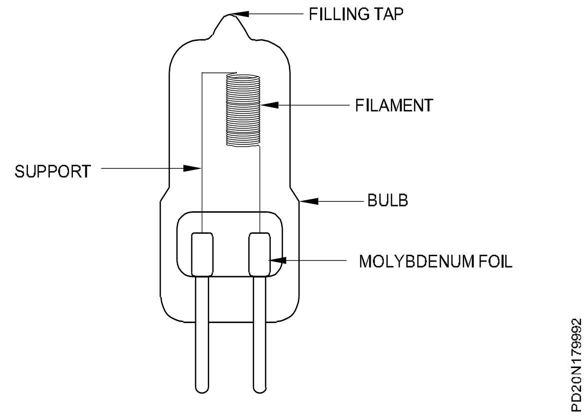
Tungsten Halogen Lamp

Halogen is the name given to group of gaseous elements like flourine, chlorine, bromine and Iodine.In incandescent lamp the life of filament is affected by evaporation of tungsten.

To prevent this a small amount of halogen gas (say iodine) is added to the argon gas filling of the lamp. Evaporated tungsten iodine is very volatile and suffers thermal diffusion in direction of filament and gets decomposed into tungsten and halogen.

Tungsten so relesed is deposited back on filament restoring its strength. Thus addition of halogen results in formation of a regenerative cycle and evaporation of tungsten is prevented. This also results in increased efficiency as tungsten filament can now be heated to much more temperature (Fig 2).

Fig 2

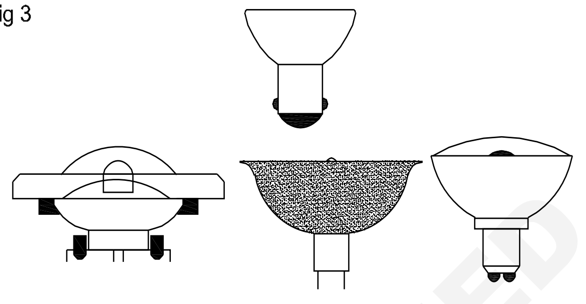


To maintain this regenerative cycle, it is necessary that the wall temperature is maintained high to 2500^{0}C. The lamp envelope is therefore made of quartz due to which it is possible to miniaturise, as filling gas can now be filled at high gas pressure.

The efficacy of this lamp is 50% more as compared to GLS for equal watage and life is just double. These lamps have better colour rendition. These are available in sizes of 500 W to 5kW. Halogen lamp with much better efficiency and lesser sizes but having very less life are manufactured for TV photography and film camera purpose.

The Fig 3 shows the different shapes of halogen lamps.

Fig 3



LAMP SHAPES

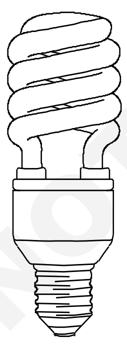
Compact Fluorescent Lamp (CFL)

Objectives: At the end of this lesson you shall be able to
- **explain the construction of CFL**
- **describe the working principle of CFL**
- **state the types of CFL's and tubes.**

CFL Lamp

Construction: A compact fluorescent lamp (CFL), also called compact fluorescent light, energy-saving light, and compact fluorescent tube, is a fluorescent lamp designed to replace an incandescent lamp; some types fit into light fixtures formerly used for incandescent lamps. The lamps use a tube which is curved or folded to fit into the space of an incandescent bulb, and a compact electronic ballast in the base of the lamp (Fig 1)

Fig 1



A CFL has a higher purchase price than an incandescent lamp, but can save over five times its purchase price in electricity costs over the lamp's lifetime.

Working principle : The principle of operation in a CFL bulb remains the same as in other fluorescent lighting: electrons that are bound to mercury atoms are excited to states where they will radiate ultraviolet light as they return to a lower energy level; this emitted ultraviolet light is converted into visible light as it strikes the fluorescent coating on the bulb (as well as into heat when absorbed by other materials such as glass).

CFLs radiate a spectral power distribution that is different from that of incandescent lamps. Improved phosphor formulations have improved the perceived color of the light emitted by CFLs, such that some sources rate the best "soft white" CFLs as subjectively similar in color to standard incandescent lamps.

Types of CFL

There are two types of CFLs:

1 Integrated lamps

2 Non-integrated lamps.

Integrated lamps: Integrated lamps combine the tube and ballast in a single unit. These lamps allow consumers to replace incandescent lamps easily with CFLs. Integrated CFLs work well in many standard incandescent light fixtures, reducing the cost of converting to fluorescent.

Non-integrated lamps: Non-integrated CFLs have the ballast permanently installed in the luminaire, and only the lamp bulb is usually changed at its end of life. Since the ballasts are placed in the light fixture, they are larger and last longer compared to the integrated ones, and they don't need to be replaced when the bulb reaches its end-of-life. Non-integrated CFL housings can be both more expensive and sophisticated.

Types of tubes

There are two types of tubes (i) a bi-pin tube designed for conventional ballast, and a (ii) quad-pin tube designed for an electronic ballast or a conventional ballast with an external starter. A bi-pin tube contains an integrated starter, which obviates the need for external heating pins but causes incompatibility with electronic ballasts.

CFLs have two main components: a CFLs have two main components: a magnetic or electronic ballast and a gas-filled tube (also called bulb or burner). Replacement of magnetic ballasts with electronic ballasts has removed most of the flickering and slow starting traditionally associated with fluorescent lighting, and has allowed the development of smaller lamps directly interchangeable with more sizes of incandescent bulb.

CFL light output is roughly proportional to phosphor surface area, and high output CFLs are often larger than their incandescent equivalents. This means that the CFL may not fit well in existing light fixtures. To fit enough phosphor coated area within the approximate overall dimensions of an incandescent lamp, standard shapes of CFL tube are a helix with one or more turns, multiple parallel tubes, circular arc, or a butterfly.(Fig 2)

CFLs typically have a rated service life of 6,000–15,000 hours, whereas standard incandescent lamps have a service life of 750 or 1,000 hours.

The life of a CFL is significantly shorter if it is turned on and off frequently. In the case of a 5-minute on/off cycle the lifespan of some CFLs may be reduced to that of incandescent light bulbs.

Decorative lamp circuits with drum switches - serial set design - Flasher

Objectives: At the end of this lesson you shall be able to
- **state the functions of a drum switch**
- **explain the designing of a lighting sequence with the drum switch.**

Drum switch

It is the usual practice to illuminate houses, workshops marriage halls, temples etc. during festivals with flash lights, flickering lights and running lights with the help of rotating drum switches.

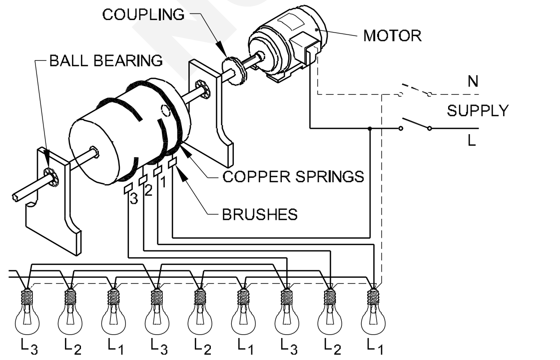
A drum switch is used for decorative lamp circuits. This switch can be used for sequential switching `on' of the decorative lamps. It is coupled with a slow speed motor so that the lamp will glow at proper intervals.

Preparation of decorative lights

The decorative effect of lights is usually obtained by means of a flasher, which consists of a wooden cylinder which rotates into the two ball bearings at the two ends. The wooden cylinder is connected to the motor through a belt or a coupling. The speed of the motor and the selection of pulley should be so made such that the wooden cylinder rotates at low r.p.m. On the wooden cylinder a copper ring is provided (to which the live wire is connected through a brush), and 3 copper segments 120° apart from each other, and each end of these segments is permanently connected to the copper ring.

As the cylinder rotates, the three segments make contact in turn with the brushes 1,2 and 3 in turn. The brush No.1 is connected to lamps L_1, the brushes No.2 and 3 are connected to lamps L_2 and L_3 respectively. Fig 1 shows the instant when the copper segment No.1 makes contact through 1/3rd of the revolution, the circuit No.1 goes off, and just at the same instant circuit No.2 becomes live and lights the lamps L_2, and after a further 1/3rd of the revolution the circuit No.3 becomes live and lights the lamps L_3. This process is repeated to make it appear that the lights move from the right to the left.

Fig 1

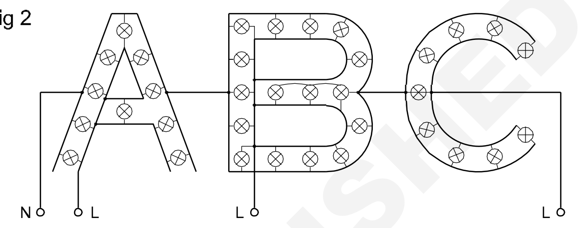


CIRCUIT FOR MOVING LIGHTS WITH A FLASHER

Waving, flickering or lightning effects can be achieved by such a system of lights.

Design of display: Draw the layout of the required display, for example ABC, on the board. (Fig 2)

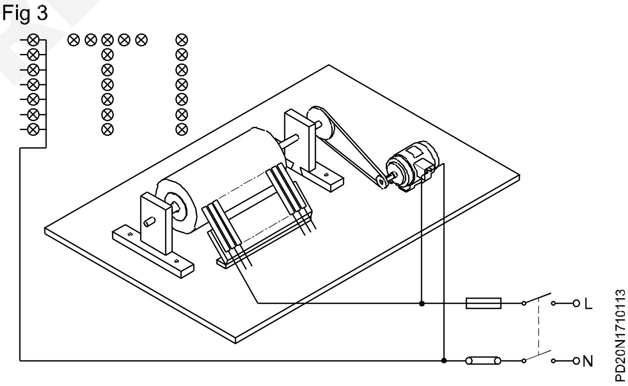
Fig 2



Mark the lamp position on the layout, connect all the lamps in parallel of letters A, B and C as shown in Fig 2, and then test the lamps for each letter by effecting supply. The neutral is run to all the lamps commonly.

Construction of a drum switch: The cylindrical drum is made of dry, soft wood, having low weight. (Fig 3)

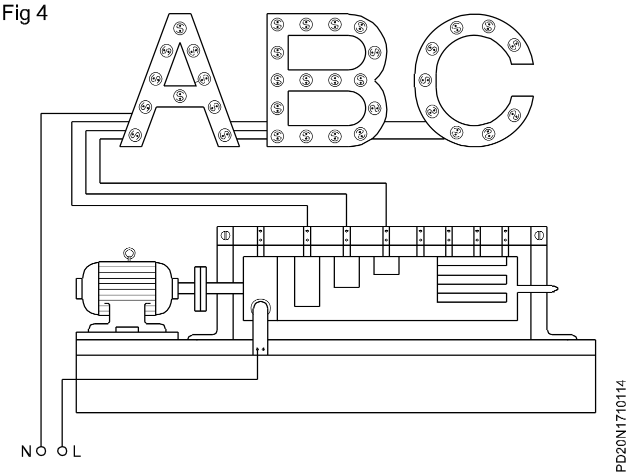
Fig 3



The length of the drum is determined by the number of finger-strips, and the diameter of the drum depends on the number of circuits to be incorporated. The speed of the drum must be as low as possible which is obtained by using two pulleys of different sizes to create a high ratio. (Fig 3) The drum-plates are usually made of brass/ copper, and are nailed. The contact strips are fixed by screws or wire nails. (Fig 4)

The drum-plate is designed keeping in view the time required to make and break the contact in one revolution. The strip should be fixed in such a way as to establish good contact through. To avoid sparking, conductive grease should be applied over the drum-plate.

Fig 4



Electrical motor: A single phase, low speed motor usually the shaded pole motor with sufficient power to drive the drum, is used for this purpose.

Lighting for decoration

Objectives: At the end of this lesson you shall be able to
- **state the methods used for decoration**
- **state the names of flasher and their function.**

Use of decoration lights

Electric light decoration for special occasions like wedding parties, festivals and fairs is a common feature nowadays. Special electric light sign circuits add much colour, fun and pleasure on the occasion. Electric signs, particularly neon signs, are extensively used in advertisements which have tremendous eye catching effects. Decoration with electric signs improves the appearance of a building and makes the place more attractive.

Two methods are mainly used for decoration.

- Signs employing miniature low voltage incandescent lights which can be switched on and off in sequence to produce the desired effect.
- Neon signs employing tubes shaped to produce designs in various colours, the colour being determined by the type of gas used in the tube.

Miniature incandescent lamps: Miniature incandescent lamps are normally available with 6V, 9V, 12V & 16V ratings with different colours which may be grouped in series or series parallel combinations for operation in available 240V supply.

For getting different messages and decoration effects the following types of flasher signs are used.

Speller type flashers are used for spelling out signs letter by letter or word by word for building up or down, plain on-off flashing, with changing colour.

Speed type flashers are used for operating spectacular signs such as lighting waving-flags, - flame, revolving wheels etc.

Script type flashers as the name implies are used when the effect of handwriting in script letters is desired.

An example of a speed type flasher for revolving is shown in Fig 1. The speed of running light/ rotating light can be adjusted. In this three-point running light (the sign flasher) there are three groups of lamps, each group switched on and off, in sequence, for running effect (Fig 2) with the help of a small induction motor which is running on eddy current principle and is connected to 240V/115V 50 Hz. Cans or drums are mounted on a shaft which is rotated by the motor.

Fig 1

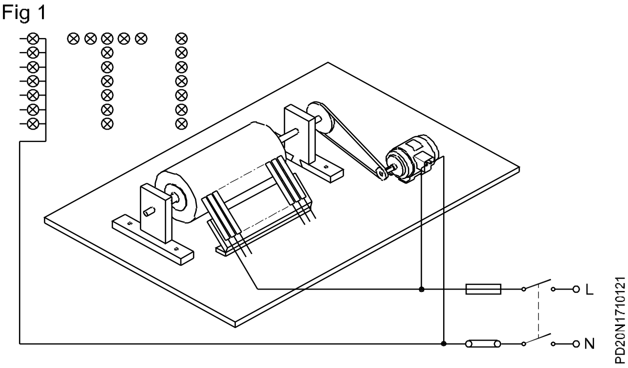
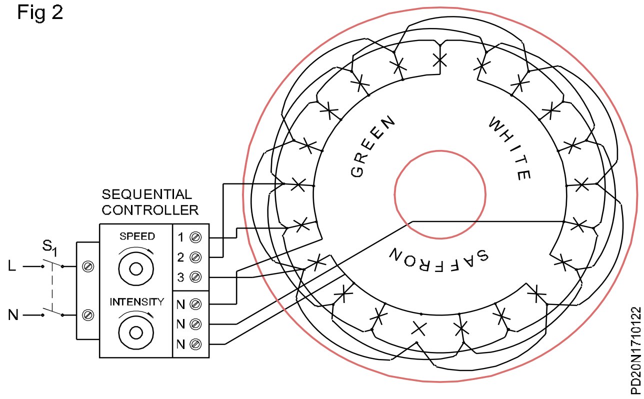


Fig 2



The circumference of the cans or the drums are so cut that the brushes will make contact only during the fixed portion of the revolution, thus completing the circuit. We can make three independent circuits by the 3-point sign flashers which are switched 'ON' and 'OFF' successively.

Designing a decorative serial lamp for a given supply voltage

Objectives: At the end of this lesson you shall be able to
- **calculate the number of bulbs to be connected in series for a given supply voltage**
- **state the condition of glow of all the lamps in series and precaution to design serial set.**

Serial set design

We have to design a row of 6 or 9 volts lamps. If these lamps are connected directly to the 240V supply, the lamps will get fused immediately. Therefore the lamps are to be connected in series. The calculation as shown will be -

1 For 6 volts lamps

Total No. of lamps required = $\frac{240}{6} = 40$ lamps.

Taking 5% allowance for fluctuations in the supply voltage

Total No. of lamps = 40 + (5% of 40)
= 40 + 2 = 42 lamps.

2 For 9 volts lamps

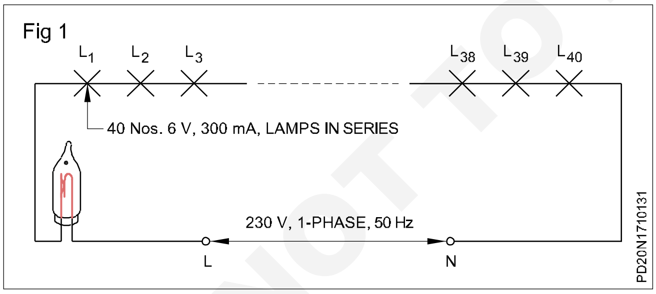
Total No. of lamps required= $\frac{240}{9} = 26.6$ or 27 lamps

Taking 5% allowance for fluctuations in the supply voltage

Total No. of lamps = 27 + (5% of 27)
= 27 + 2 = 29 lamps.

The circuit for a series lamp connection of 6V lamp and supply voltage 240V. (Fig 1)

Fig 1



Precautions

- Never connect the low volt lamps directly to the mains.
- Never touch the exposed wires.

In the above case we discussed for 6V and 9V lamps. In the market we get for 6 volts different current ratings viz. 100mA, 150mA, 300mA, 500mA. The shape of the lamp for the above current ratings however remains the same.

For the series lamps to work satisfactorily the current rating of all the lamps should be the same.

We can prepare serial lamps with different voltages but of the same current rating.

Example

You have 25 lamps of 6V, 300mA rating and 20 numbers of 9V,300mA lamps. How will you design a 'serial lamp' circuit for 240V supply mains

a using all the available 6V lamps and for the rest of 9V lamps.

b using all the available 9V lamps and for the remaining 6V lamps.

The important factor is that the sum of the voltages of the lamps in series should be equal to or slightly greater than the supply voltage.

Calculation

a Voltage drop across 25 lamps of 6 volts rating in series = 25 x 6 = 150V

Supply voltage : 240V

Voltage to be dropped by 9 volts lamps
= 240 –150 = 90 volts

Number of 9V lamps in series

$$= \frac{90}{9} = 10$$

25 Nos. of 6V lamps and 10 Nos. of 9V lamp in series.

b Voltage drop across 20 Nos. of 9 volt lamps

20 x 9 = 180

Voltage to be dropped by 6V lamps in series
= 240 – 180 = 60V

Number of 6 volt lamps in series $\frac{60}{6} = 10$

20 Nos. of 9 volt lamps and 10 Nos. of 6 volt lamps in series.

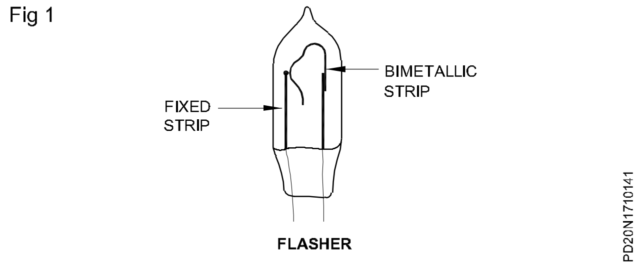
The number of bulbs in series is always kept more than the calculated value. The purpose is to reduce the current through each lamp slightly. The reduced current makes the fusing of the lamps rather remote.

Flasher

Objectives: At the end of this lesson you shall be able to
- **state the purpose of the flasher in the series lamp circuit**
- **explain the constructional details and working by rejecting and accepting bad and good flashers.**

Flasher: In the row of lamps of low voltage, a small lamp (flasher) of filament type is connected in series with the other lamps. This lamp (flasher) does not give light but acts as a switch for the other lamps. This lamp contains a bimetal strip, which is in contact with a fixed strip (Fig 1).

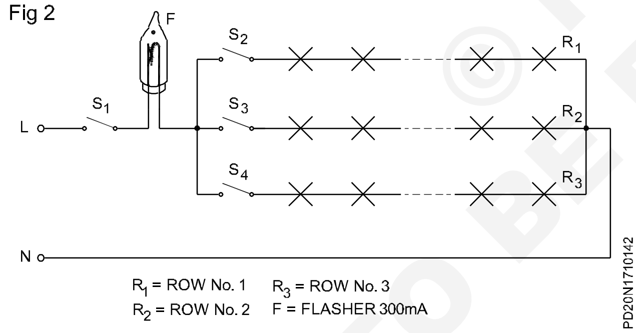
Fig 1



When the row of lamps is connected across the supply and switched ON, the bimetal strip gets heated up, this breaks the contacts and disconnects supply to the other lamps, making the lamps OFF.

After a few seconds, the bimetal strip cools down and makes contact. The supply to the other lamps is ON and the lamps light up. This is a twinkling type row of lamps used for decoration (Fig 2).

Fig 2



The rating of the flasher in each row of (small) low voltage lamps must be the same as that of the other lamps in that series circuit. If the lamps are of different ratings, then the flasher should be of the lowest current capacity in that circuit.

Though the flasher can be connected anywhere in the series circuit, it should be connected at the supply (phase) considering it as a switch.

The operating condition of the flasher can be decided by observation. If the bimetal strip is found welded to a fixed strip, then the flasher is not useful and if it is in an unserviceable condition. It can also be found out by connecting in circuit and tested for its condition, i.e. whether it is operating or not.

When a number of series lamp rows are connected in parallel the flasher should be connected at the input of supply as shown in Fig 2.

Example

Each row 100mA, 3 rows in parallel

The current-carrying capacity of such a flasher in the parallel circuit should be equal to the total current drawn by the parallel circuit say 300 mA.

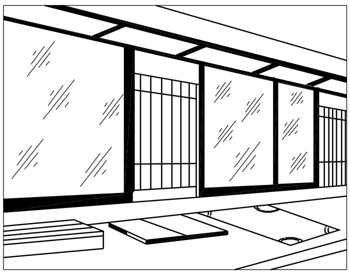
Show case lights and fittings - calculation of lumens efficiency

Objectives: At the end of this lesson you shall be able to
- **state the types of bulbs for illumination**
- **explain direct and indirect lighting and showcase lighting**
- **explain the luminuous efficiency calculation.**

Show case lighting: A number of commercial establishments use visual representation to their products, using a lighting system called show case lights. Some of them are discussed below.

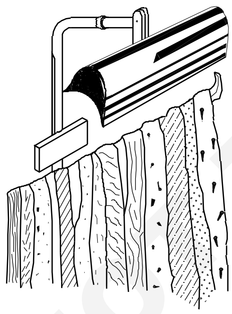
Counters and dealing shelves: In bank cages and ticket offices supplementary trough lighting equipment is usually located at the top of the cages to produce a band of light lengthwise on the counter. Troughs may be covered with diffusing glass or fitted with longitudinal louvers to shield the lamps. Sixty watt lamps on 15 to 18 inch centres will generally be adequate. (Fig 1)

Fig 1



Small metal bracket type reflectors luminary or regular 25 or 40 watt tubular lamps effectively illuminate small vertical display racks, stands and cabinets. (Fig 2)

Fig 2



Small compact lens posts available in both 250 and 400 watt size, mounted on columns or ceiling brackets, give sales emphasis to small counter or table displays. Adjustable in spot size for 12 to 48 inches diameter spot at 10 ft. a 250 watt unit at 10 ft. will deliver 200 to 250 feet candles, with a 12 to 15 inches spot size: the 400 watt unit will give 350 to 400 foot candles. (Fig 3)

Louversed concentrating reflector spotlights available in 200 to 500 watt sizes give a less sharply defined beam than lens units. The spot size cannot be adjusted except by changing the projection distances. A 200 watt unit at 10 ft. will produce about 90 foot candles. (Fig 4)

Fig 3

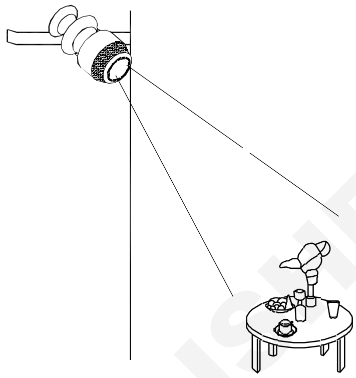
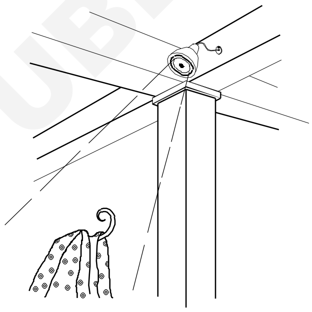
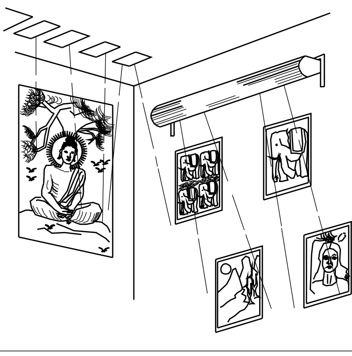


Fig 4



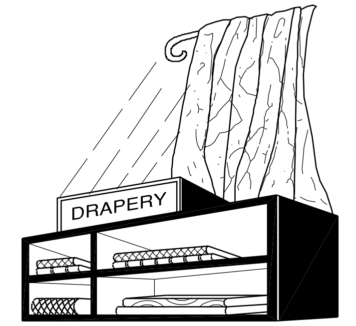
For extended vertical surface displays - rungs, tapestries, draperies, paintings - a series of 150 or 200 watt lens plate units at the ceiling is suitable for fixed display locations. Bracket type parabolic, polished metal troughs produce equivalent results and have some advantage in greater mobility. (Fig 5)

Fig 5



Footlight type trough lighting for counter and shelf displays ranges from single lumiline reflectors for counter cards and small displays to extended shelf troughs as illustrated. Trough footlights with changeable, luminous sign panels transform waste space into valuable display. (Fig 6)

Fig 6



For necessity and impulse items such as groceries, where attention rather than critical seeing is the requirement, less engineering refinement is needed in shelf lighting equipment. Concentrating trough reflectors which incorporate luminous panels for changeable advertising copy are satisfactory. Sockets 30 cms apart may be fitted with 40 to 100 watt lamps, as conditions dictate. (Fig 7)

Fig 7

For lighting displays on columns or built-in shelving a metal nosing along the front edge of each shelf effectively conceals small 25 watt tubular lamps as shown in the sketch. Lamps should be spaced not more than 30 cms apart. Lumiline lamps are, of course, equally suitable in many cases.

Displays of glassware and bottled goods are highly attractive and colourful if lighted by transmitted light as shown in Fig 8. An opal glass panel, illuminated uniformly from behind the lamps spaced not more than 1½ times their distance at the back of the glass will provide a suitable luminous background.

Circline tubes used for window show case: For circline tubes the ballasts are specially designed and are easily adaptable to assembly on the stem of portable lamps and in shallow wall and ceiling fixtures, and in some designs they can be mounted within the circle of the tube.

Ballast equipments designed for use with the 8¼ inch 22 watt, 12-inch 32 watts. circle line include two single lamp ballasts, one with uncorrected power factor. The other with high power factor. Many of the portable lighting equipments - dressing table, desk lamp, vanity mirror, tie rack, display unit and boudoir lamps such as Fig 9 and 10 - in which the 8¼ inch circline will be used which have small thin bases and slender stems.

Fig 8

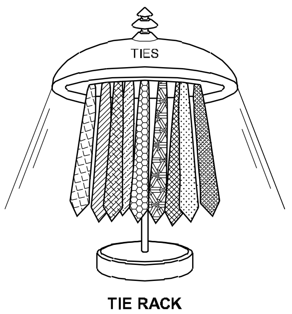
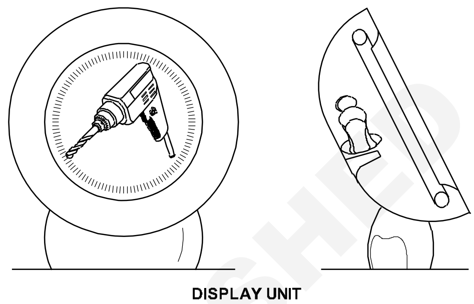


Fig 9



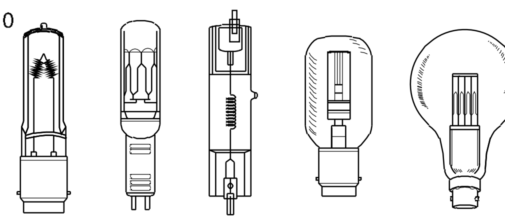
There are varieties of goods which are being displayed in showcases of different colours, size, shape, fineness etc. Hence Different shades and colour layers will be used to get the proper colour of goods or fineness of detail or both by proper illumination.

Merchandise will change from time to time and for this type, illumination will change from time to time. Hence there is a necessity to have a larger number of electrical points than normally required .

Precaution should be taken while putting the merchandise in showcases so that wiring will not be damaged. Also the wiring and merchandise should not get damaged due to the excessive heat of lamps.

Quartz lights (Halogen lamps) (Fig 10)**:** Also known as tungsten-halogen or quartz-iodine, lamps. Now they are smaller, lighter and more efficient than tungsten lights. This consist of a metal tungsten filament inside a small quartz glass tube filled with a halogen gas - usually iodine. The presence of the iodine guarantees that the bulb does not darken and that the light output and colour temperature remain constant.

Fig 10

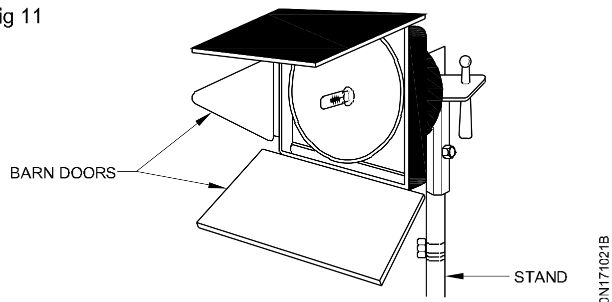


Most quartz lamps last as long as 250 hours and have a colour temperature rating of 3,200°K. Outputs vary from 150 to 350 watts for battery lights and from 200 to 10,000 watts for main power supply use. The quartz bulb itself should never be touched with a bare hand, even when unlit, as acid from the skin can cause premature failure of the bulb. Always handle the bulb with a small piece of tissue paper.

Quartz bulbs set in open reflectors are probably the most common quartz lights. They are available in a wide range of wattages, usually from 200 to 2,000 but also as high as 10,000 watts. On many models the light may be focused by moving the quartz bulb to and fro. Nowadays, many of the better lamps are made with fiberglass housings to reduce transmission of the bulbs' heat.

Basic quartz lighting kits usually consists of three lights, each of which might be 1,000 watts. They are often equipped with "barndoors" and stands. (Fig 11)

Fig 11



QUARTZ REFLECTOR LANE

Luminous Efficiency Calculation

Luminous Efficiency: Luminous efficiency is a measure of how will a light source produces a visible light. It is a quantity of measurement for light source and it is defined as the ratio of luminous flux to power of the lamp in watts. It's unit is **lumen/watt** in SI unit.

$$\text{Luminous efficiency} = \frac{\text{Luminous flux in lumen}}{\text{Power in watt}}$$

This is important, it describes how much light is being given compare to the amount of electricity is used.

Purpose of calculating luminous efficiency

Typical house hold spends 30% of the electricity bill in lighting. Money can be saved by bringing the most cost efficient lighting option in home needs.

For example : A 60w light bulb usually produces 860 lumens. Calculate the luminous efficiency.

$$\text{So, efficiency} = \frac{\text{Luminous flux in lumen}}{\text{Power in watt}}$$

$$= \frac{860}{60} = 14.3 \quad \text{lumen/watt} \quad .$$

This calculation can be taken for any light source as long as the data pertaining to its power and luminous flux are available. The higher efficiency lamps will save more money.

It is usefull when you are shopping for light bulbs/lamps most of its box will have the bulb voltage and luminous produced . Use this calculation method to see, how the cost efficient a bulb will be for your home needs.

The luminousity function or luminous efficiency function describes the average special sensitivity of human visual preception of brightness.

By comparing LED's to compact fluorescent lamp (CFL) with 55 - 70 lumens per watt and incandescent lamp bulbs with 13 -18 lumen per watt.

The LED bulbs require much less wattage than the CFL (or) incandescent light bulbs. CFL are 4 times more efficient and 10 times longer than incandescent lamps.

The most popular energy saving bulbs available are:

- halogen incandescent bulbs
- Compact fluorescent lamps (CFLs)
- Light emitting diodes (LED)

Their initial cost is 5 to 10 times more than traditional incandescent lamps, but they save the money due to lesser energy.

Light Emitting Diodes (LEDs)

Objectives: At the end of this lesson you shall be able to
Objectives: At the end of this lesson you shall be able to
- **define the LED**
- **state the advantages of LEDs over-conventional bulbs**
- **explain the principle of working of LED**
- **state the popular types of LED**
- **explain the method of testing of LED**
- **calculate the resistor value to be used with LED for a given application**
- **state how to protect LEDs from high reverse voltage.**

Light emitting diodes (LED)

In recent years, the use of filament lamps/bulbs which consume quite an amount of power, has less life became absolute as indicators of electric systems. One of the most common and popular of new devices in the optical electronics is the **Light Emitting Diode** abbreviated as **LED**. These LEDs are now used as indicators in almost all electrical and electronic circuits and equipments.

The advantages of LEDs over incandescent bulbs are listed below:

1 LEDs have no filaments to heat and so require less current to glow.

2 LEDs require lower voltage level (typically 1.2 to 2.5 V) than the conventional bulbs.

3 LEDs last much longer - upto several years.

4 Because there is no filament to heat up, LEDs are always cool.

5 LEDs can be switched ON and OFF at a much faster rate compared with conventional lamps.

Principle of working of LEDs

Although LED is also a type of diode, it cannot and should not be used for the purpose of rectifying AC to DC.A LED is a semi conductor device which emits visible ligt when it is property connected with the electric supply.

Recall that a general purpose diode or a rectifier diode conducts when energy is supplied to the electrons (Si=0.7V, Ge=0.3V) to cross the barrier junction. Each electron, after acquiring the supplied extra energy, crosses the junction and falls into the hole on the P side of the junction while the electron recombines with a hole, the electron gives up the extra energy by it. This extra energy is dissipated in the form of heat and light.

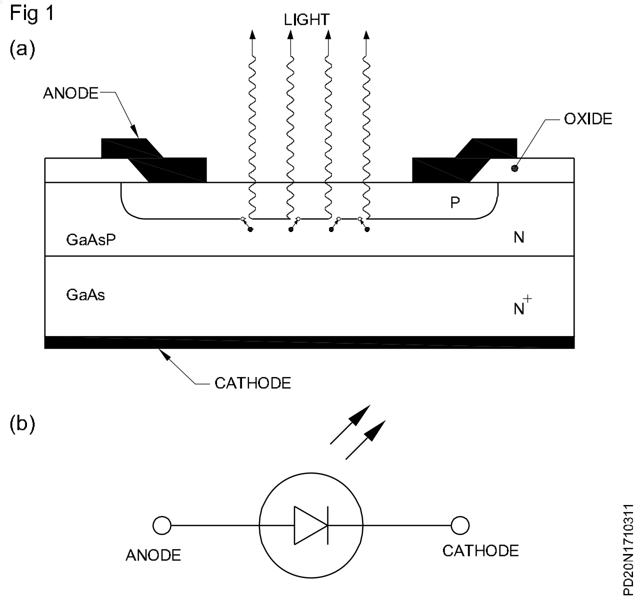
In general purpose diodes because the silicon material is not transparent(opaque), the light produced by the electrons does not escape to the outer environment. Hence, it is not visible. But LEDs are made using semi-transparent materials instead of silicon.

Because the material used in making LEDs is semi-transparent, some of the light produced by the electrons escapes to the surface of the diode, and, hence, is visible. (Fig 1a)

LEDs are typically doped with gallium arsenic, gallium phosphate or gallium arseno-phosphate. Different dopes cause the LED to emit light of different colours (wave-lengths) such as red, yellow, green, amber, or even invisible infrared light.

The schematic symbol of LED Non-integrated lamps is as shown in (Fig 1b). The arrows are used to indicate that light is radiated from the device.

Fig 1



Types of LEDs

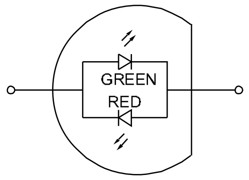
Single colour LEDs: Most of the commercially available and commonly used LEDs are single colour LEDs. These LEDs radiate one of the colours such as red, green, yellow or orange. Different coloured LEDs will have different forward voltages as given in the table below:

Colour of LED	Red	Orange	Yellow	Green
Typical Forward voltage drop	1.8V	2V	2.1V	2.2V

These typical forward voltage drops are at a typical LED forward current I_f = 20 mA

Two colour LEDs: These LEDs can give two colours. Actually, these are two LEDs put in a single package and connected . (Fig 2)

Fig 2



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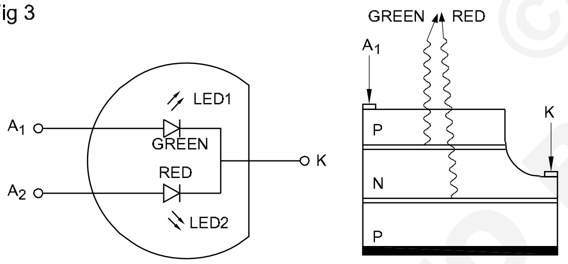
In a two-colour LED, two LEDs are connected in inverse parallel, so that one of the colour is emitted when the LED is biased in one direction and the other colour is emitted when the LED is biased in the other direction. These LEDs are more expensive than the single colour LEDs. These LEDs are useful to indicate +ve, –ve polarities, GO-NOGO indication, null detection etc.

Multicolour LEDs: These are special types of LEDs which can emit more than two colours. These LEDs comprises of a green and a red LED mounted in a three-pin common cathode package. (Fig 3)

Fig 3



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Output colour	Red	Orange	Yellow	Green
LED-1 current	0	5mA	10mA	15mA
LED-2 current	15mA	3mA	2mA	0

This LED will emit green or red colour by turning ON only one LED at a time. This LED will emit orange or yellow by turning on the two LEDs with different current ratios as shown in the table given.

Sizes and shapes of LEDs (Fig 4)

LEDs are available commercially in different shapes and sizes to suit varied commercial applications. Fig 4 shows some of the most popular shapes and sizes of LEDs.

The light output of LED may be guided as point-source or diffused. The point-source LED provides a small point of light while the diffused type has a lens which diffuses the light into a wide angle viewing area.

Terminals of LEDs

Since LEDs are basically diodes, they have anode and cathode terminals/leads as in any general purpose diode. Fig 5 shows the methods to identify the terminals of a LED.

Fig 4

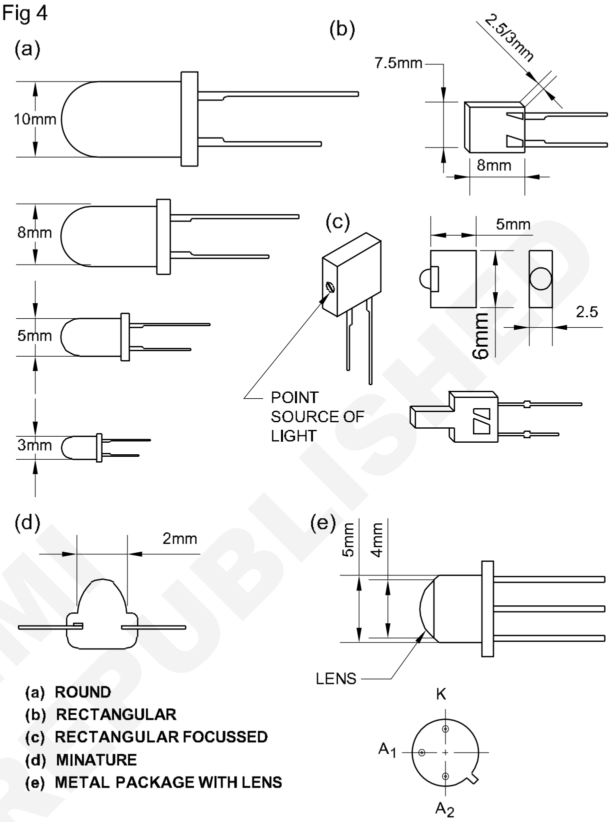

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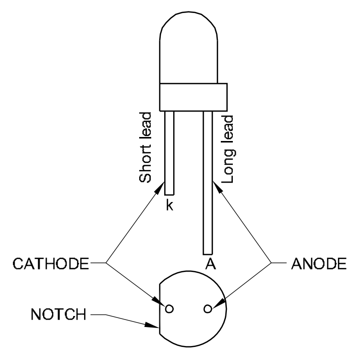
Fig 5



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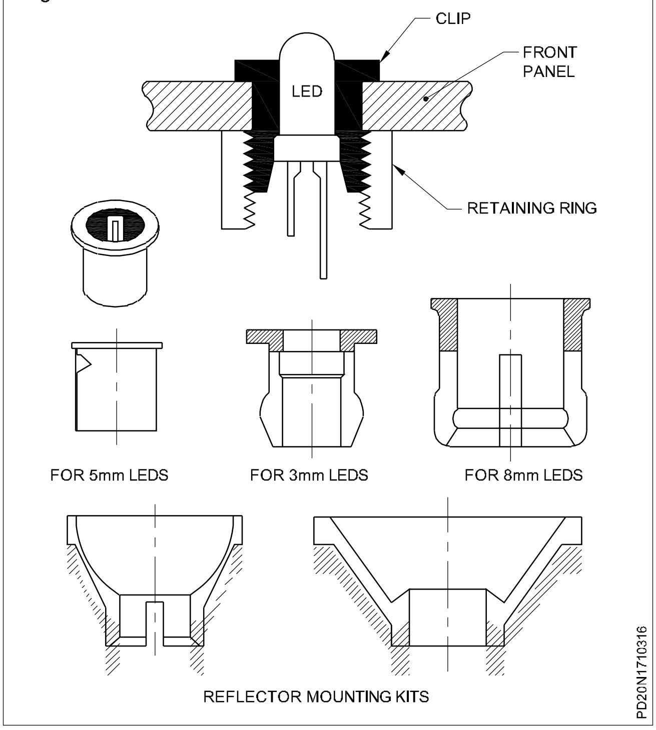
Mounting kits for LEDs (Fig 6)

Special mounting kits Fig 6, are available for fixing the LEDs on to the printed circuit boards and monitoring panels. These kits not only extend the life of the LED by way of protecting it from mechanical stress but also make the output of the LED clearly visible.

Testing of LEDs

The anode and cathode terminals of a general purpose diode can be checked easily using an ohmmeter. But, in the case of LEDs, unlike general purpose diodes, the forward voltage of LED ranges from 1.5 to 3 volts (in some

Fig 6



cases it is higher than 3 V), and a typical forward current ranges from 2 mA to more than 50mA. Because of this large forward voltage and current requirement of the LEDs, it is not always possible to test the LEDs using an ohmmeter.

Hence, when an LED is tested using an ohmmeter, the glow of the LED may be very dim or the LED may not glow at all depending on the condition of the battery inside the meter. Hence, the condition of an LED cannot be confidently confirmed using a meter. However, since meter testing is the quickest, this can be used while purchasing an LED from the vendor where other equipments may not be available for testing.

Characteristics	Min.	Typical	Max.
Forward current, I_f		2 mA	50 mA
Forward voltage, V_f		1.7V	3V
Reverse voltage, V_R		8V	
Axial luminous intensity	0.8 mcd	2 mcd	
Angle of half intensity		±20°	
Peak wave-length		665 nm	

Specifications of LEDs

Specifications sheet of a typical LED is given in the table above:

A Typical LED-specification sheet
(For: FairChild, FLV117 Red LED)

From the specifications of a typical LED given above, the following important points are to be noted;

- The forward voltage drop of the LED is much higher (1.7V to 3V) than that of general purpose diodes.
- The reverse voltage that can be applied to the LED is much lower than in general purpose diodes.

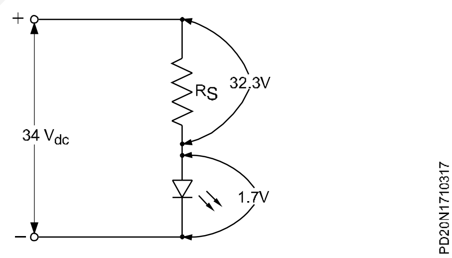
The above two important points confirm that, LEDs do not have the same characteristics as general purpose diodes.

In the typical LED specification, for instance, if 8 V or more is applied across the LED in the reverse biased polarity, the LED will be damaged.

Example: What value of R_S is required, if a red colour LED is to be used in a circuit with a source of 34V dc.

Using the specifications of the red LED given in the table, it is clear beyond doubt that the LED cannot be connected across 34 volts supply directly (maximum Vf = 3V). Hence,a resistor is to be used in series with the LED (Fig 7) which must drop to 32.3 volts if the voltage across LED should be 1.7 V.

Fig 7

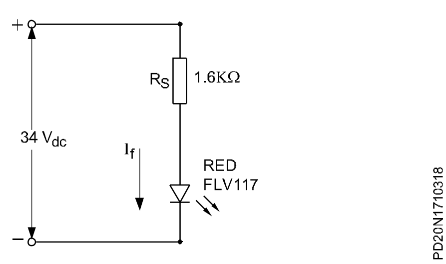


For the LED to give reasonably good light, the current through the LED has to be 20 mA, as indicated in the specifications sheet. So, the value of R_S must be,

$$R_S = \frac{V}{I} = \frac{32.3\text{ V}}{0.02\text{ A}} = 1615\ \Omega$$

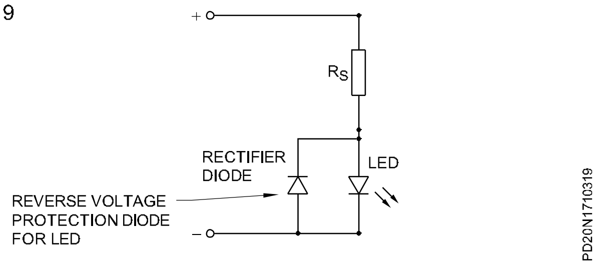
Since the maximum permissible current through the LED is given as 50 mA, it is possible to use a standard 1.6KΩ resistor. This will make a current of 20.2 mA to flow through the LED which is well within the permitted maximum current rating. The LED can now be safely connected across a source voltage of 34 V. (Fig 8)

Fig 8



Note that, the maximum reverse voltage that can be applied for the chosen LED is only 8 volts. If accidentally a reverse voltage greater than 8 volts is applied, the LED will get damaged permanently. One way to protect the LED is by connecting a rectifier diode in parallel to the LED Fig 9.

Fig 9



In Fig 9, when a reverse voltage across the LED becomes more than 0.7 V, the rectifier diode conducts with a forward voltage of 0.7 V. Thus the reverse voltage across the LED is restricted to 0.7 V which is much less than the maximum reverse voltage of 8 V of the LED, and hence the LED is safe.

Solar lamps

Objectives: At the end of this lesson you shall be able to
- **state the features of solar lamps**
- **state the components of solar street lights.**

Solar lamp

A solar lamp is a light fixture composed of an LED lamp, a photovoltaic solar panel, and a rechargeable battery. Outdoor lamps may have a lamp, solar panel and battery integrated in one unit.

Indoor solar lamps, also referred to as shaftless skylights or tubeless skylights, have separately-mounted solar panels and are used for general illumination where centrally generated power is not conveniently or economically available.

Solar-powered household lighting may displace light sources such as kerosene lamps, saving money for the user, and reducing fire and pollution hazards.

Solar lamps recharge during the day. Automatic outdoor lamps turn on at dusk and remain illuminated overnight, depending on how much sunlight they receive during the day. Indoor solar lamps may or may not store power.

Solar garden lights are used for wide decoration. They are frequently used to mark footpaths or the areas around swimming pools. Some solar lights do not provide as much light as a line-powered lighting system, but they are easily installed and maintained, and provide a cheaper alternative to wired lamps.

Solar street light

Solar street lights provide public lighting without use of an electrical grid; they may have individual panels for each lamp of a system, or may have a large central solar panel and battery bank to power street lights.

To reduce the overall cost of a solar lighting system, energy saving lamps of either the fluorescent or LED lamp type are used, since incandescent bulbs consume more energy for a given quantity of light.

Solar-powered lighting consists of a solar panel or photovoltaic cell that collects the sun's energy during the day and stores it in a rechargeable gel cell battery. The intelligent controller senses when there is no longer any energy from the sun and automatically turns the LED light on using a portion of the stored energy in the rechargeable battery.

High pressure metal halide lamps

Objectives: At the end of this lesson you shall be able to
- **describe the working principle of metal halide lamp (M.H.L)**
- **explain the starting of M.H lamp**
- **state the parts of MH lamp and its starting methods**
- **explain the features of MH lamps and state its advantages.**

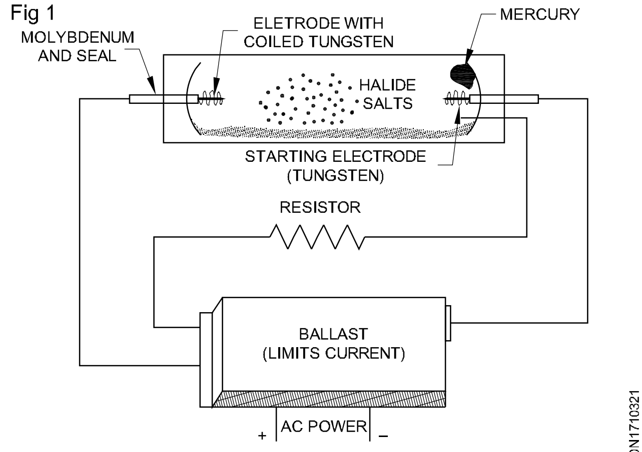
Metal halide lamps

This type of lamp is also known as an `MH' lamp. It is an HID lamp (High intensity Discharge), which means it provides most of its light from the electric arc within a small discharge tube. It is becoming increasingly popular due to its good quality white light and good efficiency. The most prominent use of the MH lamp is in stadiums and sports fields. It is also used widely for parking lots and street lighting in urban areas. Its competitors include the HPS lamp, mercury vapor lamp, LPS lamp, halogen lamps, and LEDs. MH lamps have advantages over the rest which make it more useful for certain applications.

Working Principle

Fig 1 shows the schematic connection diagram of a metal Halogen lamp in to the AC supply. A resistor is connected to limit the current so as to increase the life of ballast?

Fig 1



METAL HALIDE LAMP SCHEMATIC

When the lamp is cold the halides and mercury are condensed on the fused quartz tube. When the lamp is turned on current passed through the starting electrode and jumps the short distance to the main electrode (Fig 1), this is aided by argon gas. The argon strikes an arc at low temperatures.

After the initial small arc the tube heats up and the mercury is vaporized. Electric arcs fight to works through the distance of a gas, but over time more molecules of the gas become ionized. This makes it even easier for more electric current to pass through, so the arc gets wider and hotter.

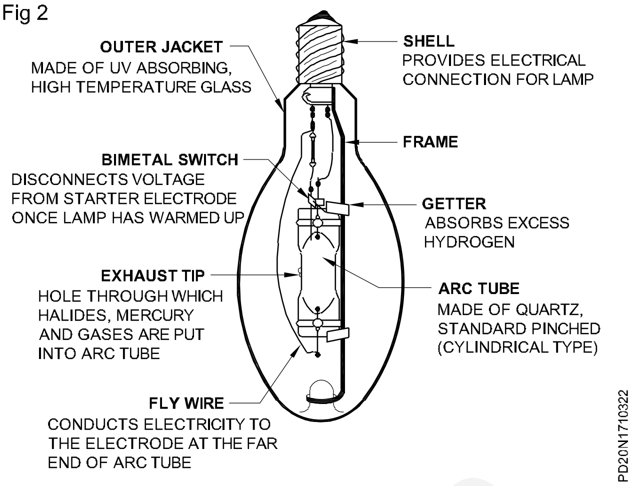
In the lamp as the first arc heats up, it begins to turn the solid mercury into a vapor, soon the arc is able to travel through the mercury vapor to reach the other main electrode on the opposite side of the discharge tube. There is less resistance on this path now and current stops flowing through the starting electrode, just as a river changes course to a path of least resistance, drying out the previous channel.

Parts of Metal Halide lamps.

Fig.2 shows the inner parts and its various function of a metal halide lamp. The inner tube contains the electrodes and various metal halides, along with mercury and inert gases that make up the mix. The typical halides used are some combination of Sodium, Thallium, and Scandium and Dysprosium Iodides. These iodides control the lamp's spectral power distribution and provide color balance by combining the spectra of the various iodides used.

Light is generated by creating an arc between the two electrodes located inside the inner arc tube. The inner arc tube is typically made of quartz, and this is a very harsh environment, with high temperatures approaching 1000°C and pressure of 3 or 4 atmospheres.

Fig 2



To start a metal halide lamp, a high starting voltage is applied to the lamp's electrodes to ionize the gas before current can flow and start the lamp. The outer jacket is usually made of Borosilicate glass to reduce the amount of UV radiation emitted from the lamp.

It also provides a stable thermal environment for the arc tube and contains an inert atmosphere that keeps the arc tube's components from oxidizing at high temperatures.

Starting Metal Halide Lamps

A metal halide lamp's starting requirements are important because they impact the type of ballast that the lamp requires. Two methods are used to start MH lamps: probe start (standard start) and pulse start.

Probe start refers to the method used to ignite the arc in the tube. A traditional or probe start metal halide lamp has three electrodes - two for maintaining the arc and a third internal starting electrode, or probe.

A high open circuit voltage from the ballast initiates an arc between the starting electrode and the operating electrode at one end of the arc tube. Once the lamp reaches full output, a bi-metallic switch closes to short out the probe, thereby discontinuing the starting arc.

Pulse-start MH lamps do not have a starting probe electrode. An igniter in the pulse start system delivers a high voltage pulse (typically 3 to 5 kilovolts) directly across the lamp's operating electrodes to start the lamp, eliminating the probe and bi-metallic switch needed in probe start lamps.

Without the probe electrode, the amount of pinch (or seal) area at the end of the arc tube is reduced, which allows for increased full pressure and reduced heat loss. Furthermore, using an ignitor with a lamp reduces tungsten sputtering by heating up the electrodes faster during starting, reducing the lamp's warm-up time.

Advantages of MH Lamps

- **Excellent Color Rendering**

Metal halide offers excellent color rendering, with a 65-90 CRI (color rendering index).

- **Compact Size**

Metal halide generates high light levels from a compact light source. This allows for smaller, more controllable luminaires.

- **Versatility**

Metal halide lamps are relatively unaffected by ambient temperature, equally suited for indoor or outdoor use. Extensive style and wattage options allow for many application.

- **High Efficiency**

Metal halide lamps generate 65-115 lumens per watt, more than incandescent, fluorescent or mercury vapor lamps.

- **Positive Environmental Impact**

Since metal halide lamps deliver light more efficiently than incandescent, lower electrical power generating requirements means less air pollution. Efficient long-life system means less landfill waste.

- **Long Life**

Metal halide lamps have an average life of 15,000-20,000+hours, more than ten times that of incandescent.

- **Better Light Quality**

The output of metal halide lamps is closer to natural sunlight than most other light sources.

- **Designable Color**

Metal halide lamps can be designed to produce almost any color including blue, green, aqua and pink.

- **The Most Advanced Technology**

A mojor advancement in metal halide lighting was the introduction of Venture's revolutionary Unit-Form pulse start system. Unit-Form pulse start systems offer up to 50% more lumens per system watt than do traditional metal halide lamps and ballasts.

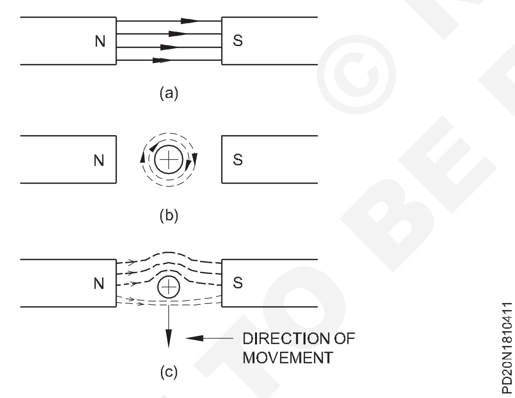
DC motor - principle and types

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of a DC motor**
- **state the different types of DC motors.**

Introduction: A DC motor is a machine which converts DC Power energy into mechanical energy. It is similar to a DC generator in construction. Therefore, a DC machine can be used as a generator or as a motor.

Principles of a DC motor: It works on the principle that whenever a current-carrying conductor is kept in a uniform magnetic field, a force will be set up on the conductor so as to move it at right angles to the magnetic field. It can be explained as follows. Fig 1a shows the uniform magnetic field produced by a magnet, whereas Fig 1b shows the magnetic field produced around the current-carrying conductor. Combining the effects of Fig 1a and Fig 1b in one figure, Fig 1c shows the resultant field produced by the flux of the magnet and the flux of the current-carrying conductor. Due to the interactions of these two fields, the flux above the conductor will be increased and the flux below the conductor is decreased as represented in Fig 1c. The increased flux above the conductor takes a curved path thus producing a force on the conductor to move it downwards.

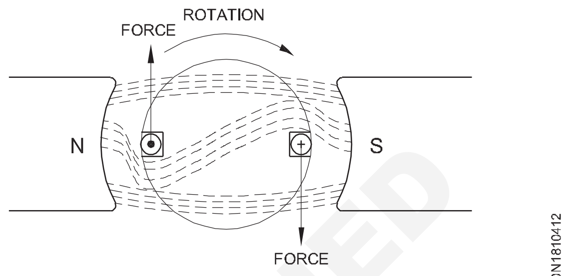
Fig 1



If the conductor in Fig 1 is replaced by a loop of wire as shown in Fig 2, the resultant field makes one side of the conductor move upwards and the other side move downwards. It forms a twisting torque over the conductors, and they tend to rotate, if they are free to rotate. But in a practical motor, there are a number of such conductors/coils. Fig 3 shows the part of a motor. When its armature and field are supplied with current, the armature experiences a force tending to rotate in an anticlockwise direction as shown in Fig 3.

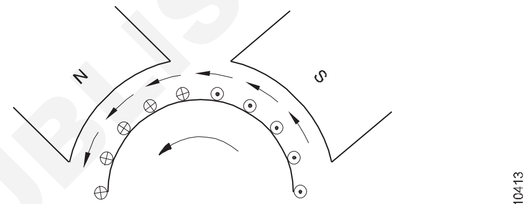
The direction of rotation or movement can be determined by Fleming's left hand rule. Accordingly, the direction of rotation of the armature could be changed either by changing the direction of armature current or the polarity of the field.

Fig 2



REACTION OVER A CURRENT CARRYING LOOP BY THE MAGNETIC FIELD

Fig 3



REACTION OVER THE ARMATURE CURRENT CARRYING CONDUCTORS BY THE MAGNETIC FIELD

Fleming's Left Hand Rule: The direction of force produced on a current-carrying conductor placed in a magnetic field can be determined by this rule. As shown in Fig 4a, hold the thumb, forefinger and middle finger of the left hand mutually at right angles to each other, such that the forefinger is in the direction of flux, and the middle finger is in the direction of current flow in the conductor; then the thumb indicates the direction of motion of the conductor. For example, a loop of coil carrying current, when placed under north and south poles as shown in Fig 4b, rotates in an anticlockwise direction.

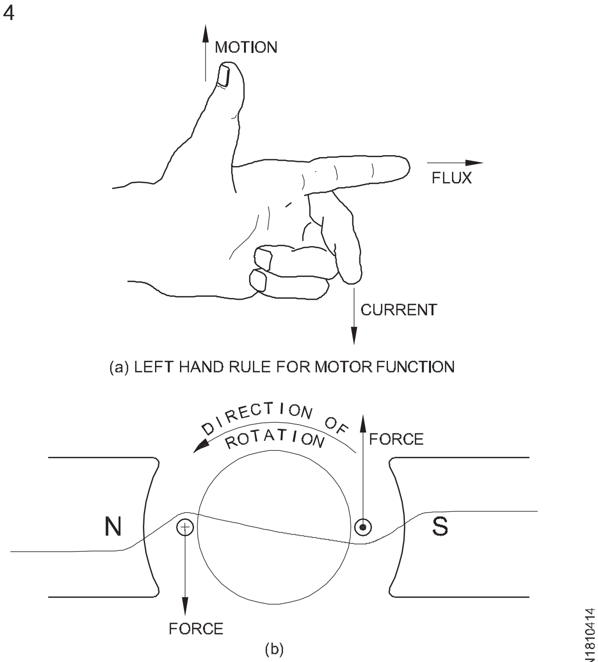
Types of DC motors: As the DC motors are identical in construction to that of DC generators, they are also classified as series, shunt and compound motors, depending upon their connection of field winding with the armature and supply.

When the armature and field are connected in series, as shown in Fig 5, it is called a series motor.

When the armature and field are connected in parallel across supply, as shown in Fig 6, it is called a shunt motor.

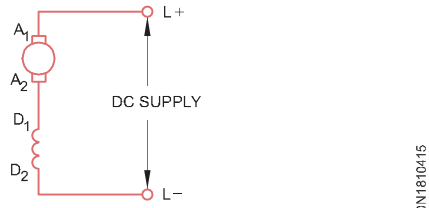
When the motor has two field coils, one in series with the armature and the other in parallel with the armature, as shown in Fig 7, it is called a compound motor.

Fig 4



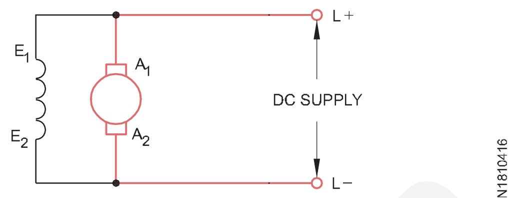
FLEMING'S LEFT HAND RULE

Fig 5



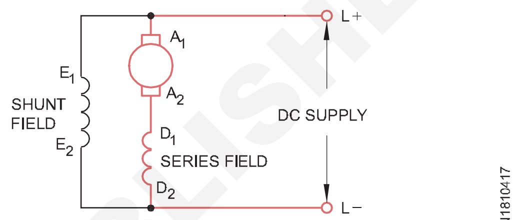
SERIES MOTOR

Fig 6



SHUNT MOTOR

Fig 7



COMPOUND MOTOR

The relation between applied voltag e, back emf, armature voltage drop, speed and flux of DC motor - method of changing direction of rotation

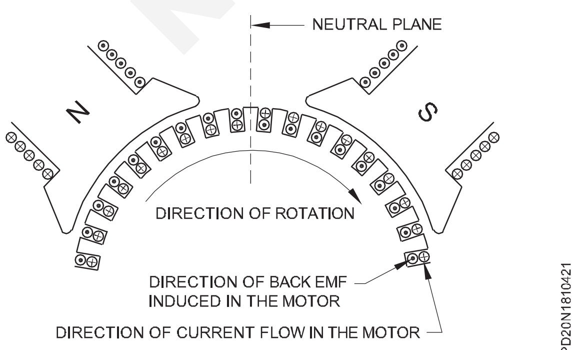
Objectives: At the end of this lesson you shall be able to

- **explain the relation between applied voltage, back emf, armature voltage drop - speed - flux**
- **describe the method of changing the direction of rotation of a DC motor.**

Back emf: As the armature of a DC motor starts rotating, the armature conductors cut the magnetic flux produced by the field poles. Due to this action, an emf will be produced in these conductors. The induced emf is in such a direction as to oppose the flow of current in the armature conductor as shown in Fig 1. As it opposes the supply voltage it is called `BACK EMF' and is denoted by Eb. Its value is the same as that found in the generator It could be written as

$$E_b = \frac{\varnothing ZNP}{60A} \text{ volts}$$

Fig 1



The direction of the induced (back) emf could be determined by Fleming's right hand rule.

Applied voltage: The voltage applied across the motor terminals is denoted by `V'.

Armature voltage drop: Since armature conductors have some resistance, whenever they carry current a voltage drop occurs. It is called IaRa drop because it is proportional to the product of the armature current Ia and armature resistance Ra. It has a definite relation with the applied voltage and back emf as shown by the formula

V = Eb+IaRa.

Alternatively, IaRa = V – Eb.

Further the back or counter emf Eb depends upon flux per pole 'Ø' and speed `N'. Therefore, the applied voltage, back emf, armature drop, flux and speed are related to one another as follows.

$$Eb = V - IaRa$$

$$\frac{\varnothing ZNP}{60A} = V - I_a R_a$$

$$\therefore N = \frac{(V - I_a R_a) \times 60A}{\varnothing ZP} \text{ rpm}$$

For a given motor ZPA and 60 are constants and can be denoted by a single letter K

where

$$K = \frac{60A}{ZP}$$

Therefore N = K Eb/Ø.

It shows that the speed of a DC motor is directly proportional to Eb and inversely proportional to the flux Ø.

Reversing the direction of rotation of DC motors: The direction of rotation of a DC motor can be changed either by changing the direction of the armature current or by changing the direction of the field current. The direction of rotation of a DC motor cannot be changed by interchanging the supply connections because this changes the direction of the field as well as the armature current. Its effect is as shown in Figs 2 and 3.

Fig 2

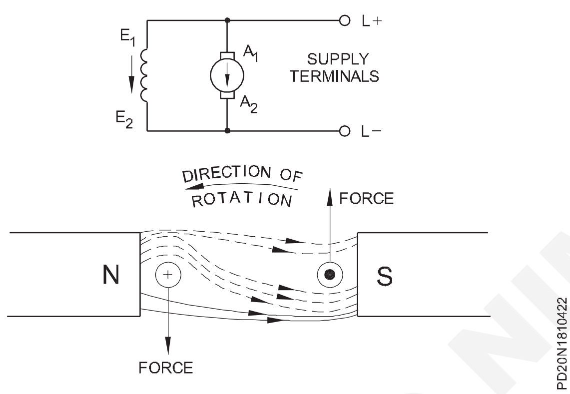
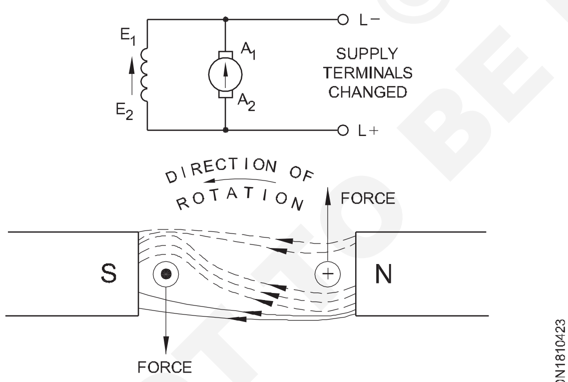


Fig 3

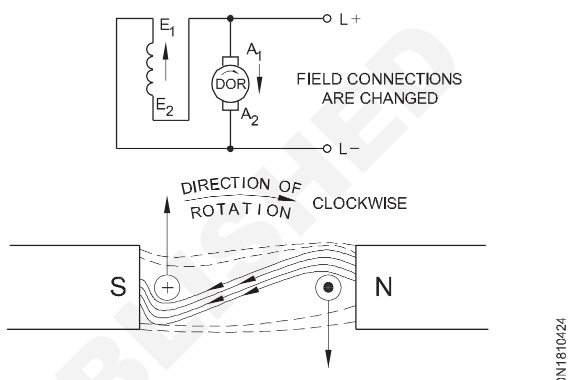


EFFECT OF CHANGING SUPPLY TERMINALS

But when the field current direction alone is changed, the direction of rotation changes as shown in Fig 4. When the armature current direction alone is changed, the direction of rotation changes as shown in Fig 5.

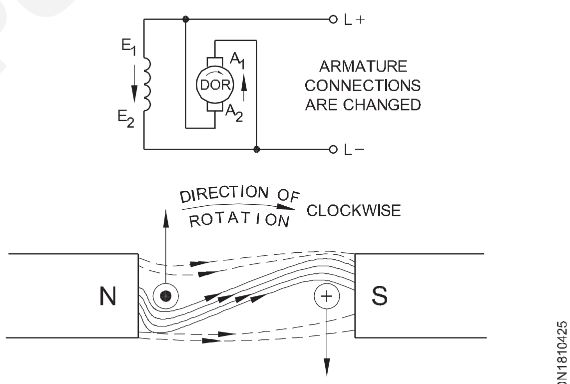
To reverse the direction of rotation of a compound motor without changing its characteristics, the best method is to change only the armature current direction. In case, changing the direction of rotation needs to be done by changing the field terminals, it is essential to change the current direction in both the shunt and series windings. Otherwise, the machine, which was running as cumulatively compounded, will change its characteristic as differentially compounded or vice versa.

Fig 4



EFFECT OF CHANGING THE FIELD CURRENT DIRECTION

Fig 5



EFFECT OF CHANGING THE ARMATURE CURRENT DIRECTION

DC motor starters

Objectives: At the end of this lesson you shall be able to
- **state the necessity of starter for a DC motor**
- **state the different types of starters - construction and working principle of 2-point, 3-point and 4-point starters.**

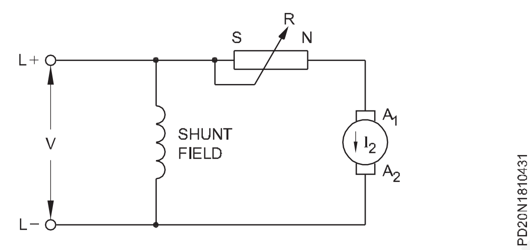
Necessity of starters: Since the armature is stationary before starting, the back emf which is proportional to speed is zero. As the armature resistance is very small, if the rated voltage is applied to the armature, it will draw many times the full load current, and thereby, there is every possibility of damaging the armature due to heavy starting current. Therefore, the starting current should be limited to a safe value. This is done by inserting a resistance in series with the armature at the time of starting for a period of 5 to 10 seconds. As the motor gains in speed, back emf is built up, and then the starting resistance could be gradually cut off. Fig 1 shows such an arrangement.

Resistance R is fully included in the armature circuit by keeping the moving arm in position `S' at the time of starting, and then it is moved towards position `N' to exclude the resistance `R' when the motor has picked up its speed. But such an arrangement will be purely manual and needs constant monitoring. For example, if the motor is running, the resistance `R' will be excluded, and the moving arm position will be at position `N'. In case the supply fails, the motor will stop but the moving arm will still be in position `N'. When the supply returns, as there is no resistance included in the armature circuit through `R', the armature may draw heavy current and may get damaged. To prevent such a happening a device called starter is used in motor circuits.

Types of starters: Starters used to start the DC motors are generally of three types.

- Two-point starter
- Three-point starter
- Four-point starter

Fig 1



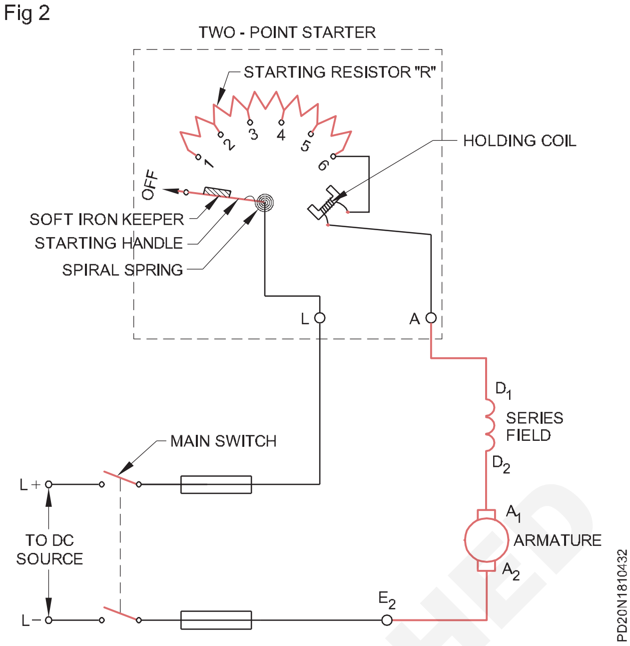
Two-point starter: This contains the following components.

- The series resistor required for starting a motor.
- The contacts (brass studs) and switching arm required to include or exclude the resistor in the armature circuit.
- A spring on the handle to bring the handle to the `OFF' position when supply fails.
- An electromagnet to hold the handle in the `ON' position.

The two-point starter is frequently used with a DC series motor. The starting resistance, electromagnet armature and the series field are all connected in series as shown in Fig 2.

Three-point starter: Fig 3 shows the internal diagram of a three(terminal) point starter connected to a DC shunt motor. The direct current supply is connected to the starter, the motor circuit through a double pole switch and suitable fuses. The starter has an insulated handle or knob for the operator's use. By moving the starter handle from the `off' position to the first brass contact (1) of the starter, the armature is connected across the line through the starting resistance. Note that the armature is in series with the total starting resistance. The shunt field, in series with the holding coil, is also connected across the line. In this mode of operation, the rush of the initial current to the armature is limited by the resistance. At the same time, the field current is at the maximum value to provide a good starting torque.

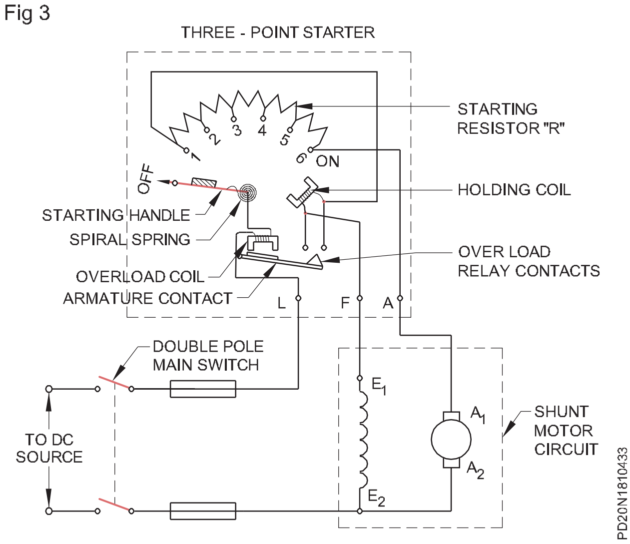
Fig 2



As the handle arm is moved to the right, the starting resistance is reduced and the motor gradually accelerates. When the last contact is reached, the armature is connected directly across the supply; thus, the motor is at full speed.

The holding coil is connected in series with the shunt field to provide a `no-field release'. If the field circuit opens by accident, the motor speed will become excessive should the armature remain connected across the line. To prevent this increase in speed, the holding coil is connected in series with the field. In case of an open circuit in the field, there will be no current through the holding coil, and hence, it will be demagnetized, and the spring action returns the arm to the `off' position.

Fig 3

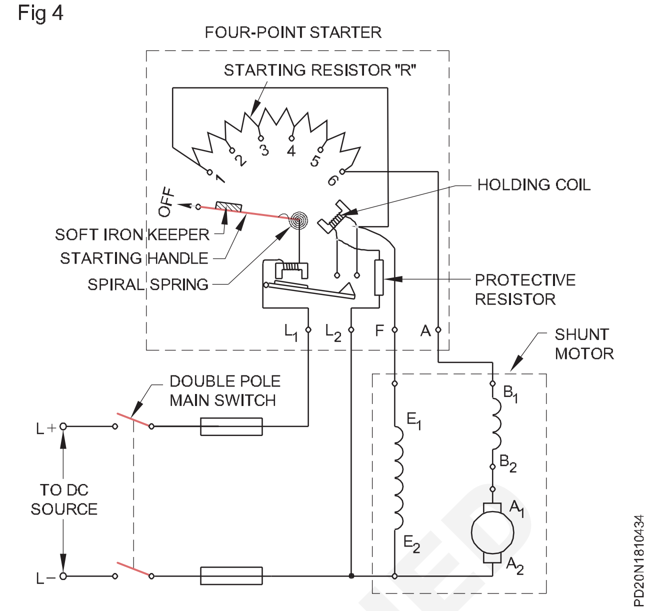


An overload coil is provided to prevent damage to the motor from overload. Under normal load condition, the flux produced by the O/L coil will not be in a position to attract the armature contact. When the load current increases beyond a certain specified value, the flux of the O/L coil will attract the armature. The contact points of the armature then short-circuit the holding coil and demagnetize it. This enables the handle to come to the `OFF' position due to the tension of the spiral spring.

This type of starter can be used to start both shunt and compound motors.

Four-point starter: In applications where many motor speeds are to be increased beyond their rated value, a four-terminal, face plate starter is used with the motor. The four(terminal) point starter, shown in Fig 4, differs from the three-point starter in that the holding coil is not connected in series with the shunt field. Instead, it is connected across the supply in series with a resistor. This resistor limits the current in the holding coil to the desired value. The holding coil serves as a no-voltage release rather than as a no-field release. If the line voltage drops below the desired value, the magnetic attraction of the holding coil is decreased, and then the spring pulls the starter handle back to the `off' position.

Fig 4



Speed control methods of a DC motor and their applications

Objective: At the end of this lesson you shall be able to
- **explain the principle and the methods of controlling the speed of a DC motor.**

Principle of speed control in DC motors: In certain industrial applications, the variation of speed is a necessity. In DC motors the speed can be changed to any specified value easily. This is the main reason for certain industries to prefer DC motors for drives rather than AC motors. The speed of a DC motor can be varied, based on the following simple relationship.

It is known that the applied voltage = back e m f + armature resistance voltage drop

V = Eb + IaRa.

Hence Eb = V – IaRa and also

the back emf

where K is a constant.

Therefore

From the above expression, it is clear that the speed of a DC motor is directly proportional to the back emf Eb, and inversely proportional to flux (Ø). Thus the speed of the DC motor can be varied by changing either the back emf Eb or the flux Øor both. In fact, if the back emf is decreased across the armature, the speed decreases, and if the flux is decreased the speed increases. The following are the most common methods of controlling the speed of DC motors based on the above principle.

Methods of speed control in DC shunt motors and compound motors

Armature control method: This method works on the principle that the speed of the DC motor could be varied by varying the back emf. As the back emf = V – IaRa, by varying the armature resistance we can obtain various speeds. A variable resistance called controller is connected in series with the armature as shown in Fig 1. The controller should be selected to carry the armature current for a longer period.

Let the initial and final speeds of the motor be N1 and N2, and the back emf be Eb1 and Eb2 respectively,

Then $N1 = \dfrac{E_{b1}}{k}$ .....Eqn.2.

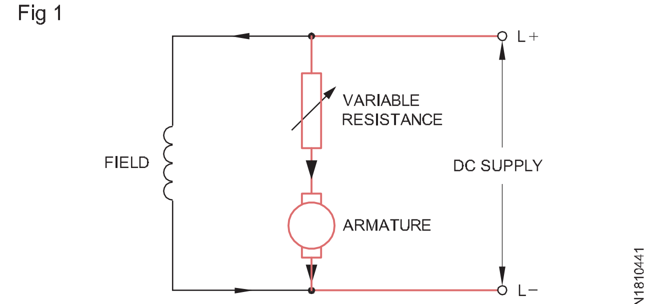
$N2 = \dfrac{E_{b2}}{k}$ .....Eqn.3.

By dividing Eqn.3 by Eqn.2 we have

$N_2 = \dfrac{E_{b2}N_1}{E_{b1}}.$

By varying the controller resistance value in the armature circuit, the back emf can be varied from Eb1 to Eb2, thereby, the speed can be varied from N1 to N2.

Fig 1



SPEED CONTROL BY ARMATURE RESISTANCE METHOD

Advantages

This method is suitable for constant load drives where speed variations from low speed up to normal speed are only required.

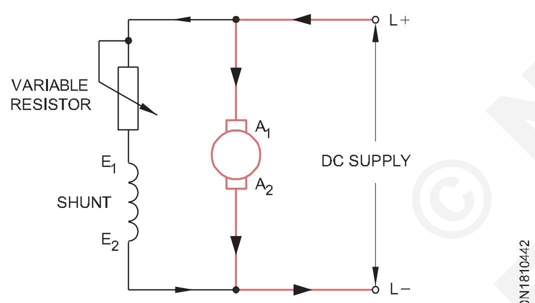
Disadvantages

- Speeds below normal can only be obtained.
- After setting the required speed, it changes with the change in the load because of speed variations not only due to control resistance but also due to load. Hence a stable speed cannot be maintained when the load changes.
- Power loss in the control resistance is high due to the higher current rating, leading to low efficiency of the motor.
- Cost of control resistance is high due to the fact it has to be designed to carry the armature current.
- Requires expensive arrangement to dissipate the heat developed in the control resistance.

Application of the armature control method: Suitable for DC shunt and compound motors used in printing machines, cranes and hoists where the duration of low speed operation is minimum.

The shunt field control method: This method works on the principle that the speed of the DC motor could be varied by varying the field flux. For this, a variable resistance (rheostat) is connected in series with the shunt winding as shown in Fig 2.

Fig 2



SHUNT FIELD CONTROL CIRCUIT

When the resistance is increased in the field circuit, the field current and the flux are reduced. Due to the reduction of flux, the speed is increased.

Advantages

- Higher speeds i.e. above normal speed only can be obtained which will be stable from no load to full load.
- As the magnitude of the field current is low, the power loss in the field rheostat is minimum.
- Control is easy, economical and efficient.

Disadvantages

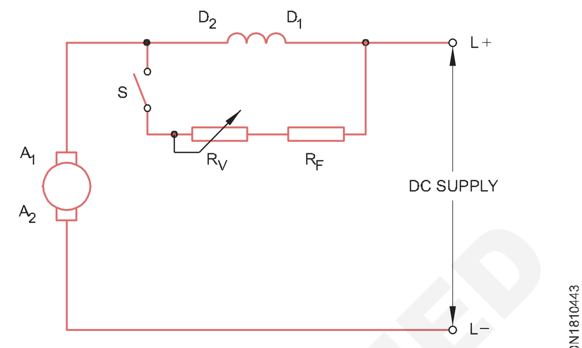
- Owing to the very weak field, a reduced torque is obtained at top speeds.
- The operation at high speeds with a weak field leads to commutation difficulties unless inter-poles are used.

Application of shunt field control: This method is the most widely used speed control method where speeds above normal are required, and at the same time, the load applied to the motor changes often.

Method of speed control in DC series motors

Field diverter method: A variable resistance, called a diverter, is connected in parallel with the field winding as in Fig 3. RV represents the variable portion of the divertor and RF the fixed portion. The function of RF is to prevent the series winding being short-circuited, when the diverter is operated.

Fig 3



FIELD DIVERTER CONTROL CIRCUIT

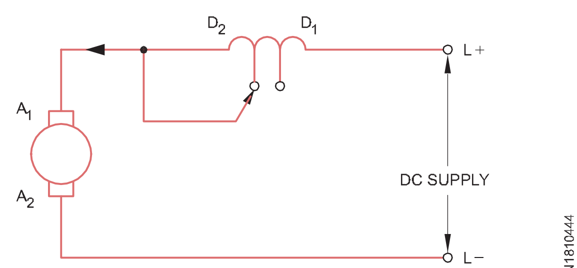
The smaller the value of RV + RF, the greater is the current diverted from the series winding, and, higher the speed of the motor. The minimum speed for a given input current is obtained by opening the switch `S', thereby breaking the circuit through the diverter.

Application of the series field diverter method: This method is mainly used in the speed control of electric trains. By this method, speeds above normal only could be obtained, and the power loss in the diverter is quite considerable.

Field tapping method: A tap changing arrangement is made on the series field winding as shown in Fig 4. By varying the number of effective turns of the field winding, the speed can be controlled. The motor circuit should be started with all the winding included, and the speed can be changed then, by setting at a suitable tapping.

This provision should be incorporated in the switch gear. Otherwise, if the tapping is kept at a lower setting and the motor is started, the motor races to a high speed at the time of starting itself, which is undesirable.

Fig 4



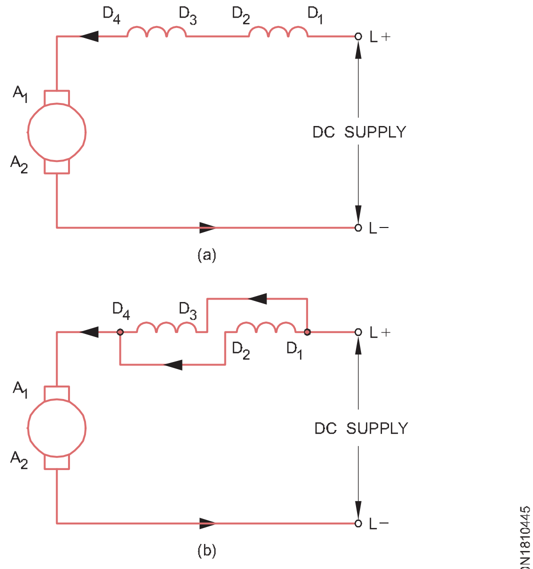
FIELD TAPPING CONTROL CIRCUIT

Application of series field tapping method: This method is used in small motors like food mixers, fans etc.

Series parallel method: Fig 5(a) shows a series motor with two halves of the field winding connected in series. If the two halves of the field winding are connected in parallel as in Fig 5(b), then for a given current 'I' taken from the supply, the current in each field coil is reduced to half and the flux is, therefore, reduced and the speed increased.

Application of series parallel method: This is the simplest method though only two speeds are possible. This method is often used for controlling the speed of fan motors.

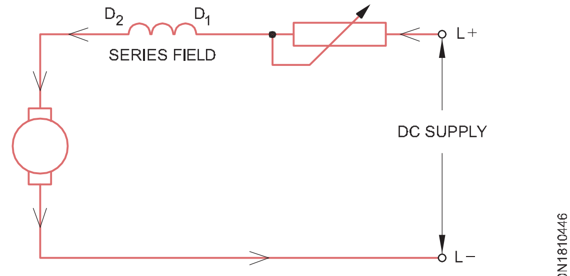
Fig 5



SERIES-PARALLEL METHOD OF CONTROL

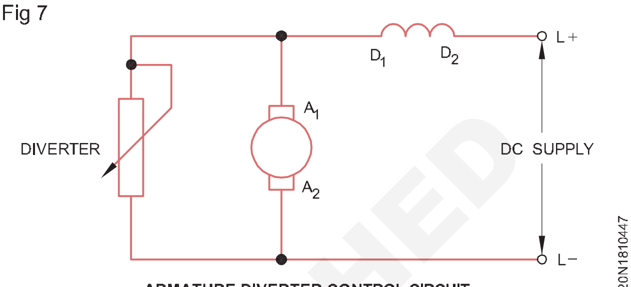
Supply voltage control method: A controller (variable resistance) is connected in series with the motor as shown in Fig 6. This method can be used to control the speed from zero up to full normal speed.

Fig 6



VOLTAGE CONTROL CIRCUIT

Fig 7



ARMATURE DIVERTER CONTROL CIRCUIT

The disadvantage in this method is that there is loss of energy in the control resistance in the form of heat. But with the introduction of SCR based control circuit, obtaining a variable supply voltage to motor is achieved with the least power loss. This method is widely used in larger modern machines where power loss is a major concern.

Armature diverter method: In this method, a variable resistor called a diverter is connected across the armature as shown in Fig 7. By this method, the armature current is controlled to vary the speed below the rated value for series motors.

Principle of induction motor

Objectives: At the end of this lesson you shall be able to
- **explain briefly the method of producing a rotating field**
- **state the principle of a 3-phase induction motor.**

The three-phase induction motor is used more extensively than any other form of electrical motor, due to its simple construction, trouble-free operation, lower cost and a fairly good torque speed characteristic.

Principle of 3-phase induction motor: It works on the same principle as a DC motor, that is, the current-carrying motor in fact that the rotor of the induction motor is not electrically connected to the stator, but induces a voltage/ current in the rotor by the transformer action, as the statormagnetic field sweeps across the rotor. The induction motor derives its name from the fact that the current in the rotor is not drawn directly from the supply, but is induced by the relative motion of the rotor conductors and the magnetic field produced by the stator currents.

The stator of the 3-phase induction motor is similar to that of a 3-phase alternator, of revolving field type. The three-phase winding in the stator produces a rotating magnetic field in the stator core as it will be explained later. Tfierotor of the induction motor may have either shorted rotor conductors in the form of a squirrel cage or in the form of a 3-phase winding to facilitate the circulation of current through a closed circuit.

Let us assume that the stator field of the induction motor is rotating in a clockwise direction as shown in Fig 1. This makes for the relative motion of the rotor in an anticlock wise direction as shown in Fig 1. Applying Fleming's right hand rule, the direction of emf induced in the rotor will be wards the observer as shown in Fig 2. As the rotor conductors have a closed electric path, due to their shorting, a current will flow through them as in a short-circuited secondary of a transformer.

The magnetic field produced by the rotor currents will be in a counter-clockwise direction as shown in Fig 2 according to Maxwell's Corkscrew rule.The interaction between the stator magnetic field and the rotor magnetic field resuts in a force to move the rotor in the same direction as that of the rotating magnetic field of the stator as shown in Fig 3.As such the rotor follows the stator field the same direction by rotating at a speed lesser than the synchronous speed of the stator rotating magnetic field.

Fig 1

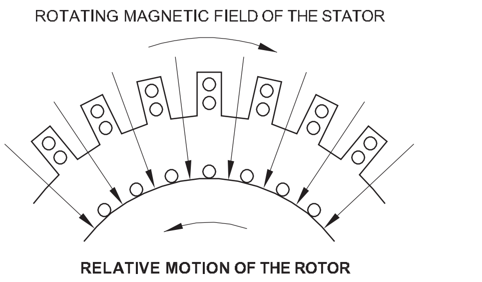


Fig 2

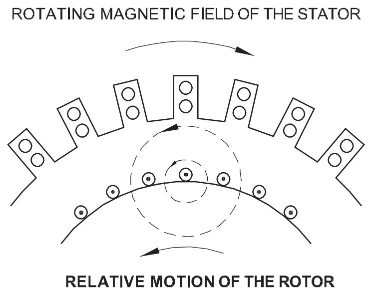
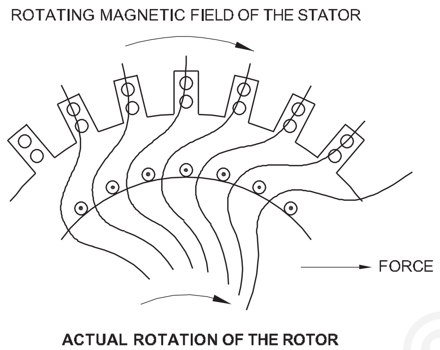


Fig 3



At higher speeds of the rotor nearing to synchronous speeds, the relative speed between the rotor and the rotating magnetic field of the stator reduces and results in a smaller induced emf in the rotor. Theoretically, if we assume that the rotor attains a speed equal to the synchronous speed of the rotating magnetic field of the stator, there will be no relative motion between the stator field and the rotor, and thereby no induced emf or current will be there in the rotor. Consequently there will not be any torque in the rotor. Hence the rotor of the induction motor cannot run at a synchronous speed at all. As the motor is loaded, the rotor speed has to fall to cope up with the mechanical force; thereby the relative speed increases, and the induced emf and current increase in the rotor resulting in an increased torque.

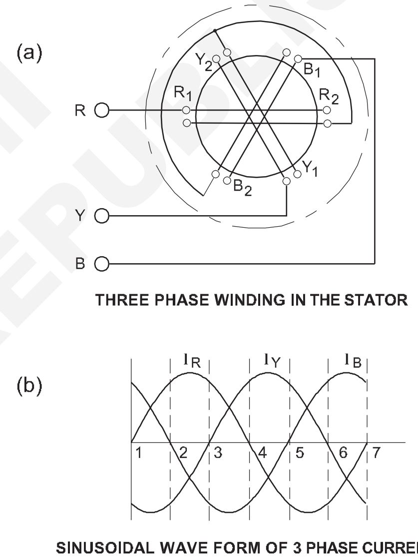
To reverse the direction of rotation of a rotor: The direction of rotation of the stator magnetic field depends upon the phase sequence of the supply. To reverse the direction of rotation of the stator as well as the rotor, the phase sequence of the supply is to be changed by changing any two leads connected to the stator.

Rotating magnetic field from a three-phase stator: The operation of the induction motor is dependent on the presence of a rotating magnetic field in the stator.

The stator of the induction motor contains three - phase windings placed at 120 electrical degrees apart from each other. Thses windings are placed on the stator core to form non- salient stator field poles. When the stator energized from a three-phase voltage supply, in eachphase winding will set up a pulsating field. However, by virtue of the spacing between the windings, and the phase difference, the magnetic fields combine to produce a field rotating at a constant speed around the inside surface of the stator core. This resultant movement of the flux is called the rotating magnetic field and its speed is called the synchronous speed.

The manner in which the rotating field is set up, may be described by considering the direction of the phase cur rents at successive instants during a cycle. Fig 4a shows a simplified star-connected, three-phase stator winding. The winding shown is for a two-pole induction motor. Fig 4b shows the phase currents for the three-phase windings. The phase currents will be120electrical degrees apart as shown in Fig 4b. The resultant magnetic field produced by the combined effect of the three currents is shown at increments of 60° for one cycle of the current.

Fig 4



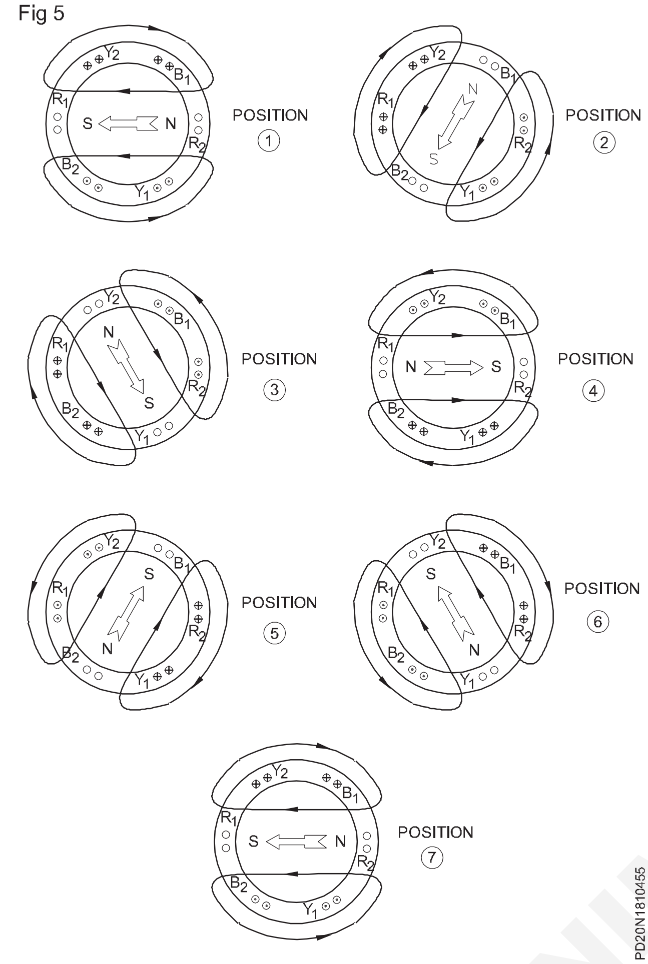
At position (1) in Fig 4b, the phase current I_R is zero, and hence coil R will be producing zero flux. However, the phase current I_B ispositive and I_Y is negative.

Considering the instantaneous current directions of these three phase windings, as shown in Fig 4b at position 1, we can indicate the current direction in Fig 5(1).

For convenience the +ve current is shown as +ve sign, and the-ve current is shown as dot(•) sign. AccordinglyY_2 and B_1 are shown as positive and Y_1 and B_2 are shown as negative. Using Maxwell's corkscrew rule,the resulting flux by these currents will produce a flux as shown in Fig 5(1). The arrow shows the direction of the magnetic field and the magnetic poles in the stator core.

At position 2, as shown by Fig 5(2), 60 electrical degrees later,the phase current I_B iszero, the current I_R is positive and the current I_Y is negative. In Fig 5a the current is now obseNed to be flowing into the conductors at the coil ends R_1 and Y_2, and out of the conductors at coil R_2 and Y_1.

Fig 5



Therefore, as shown in Fig 5c(2), the resultant magnetic poles are now at a new position in the stator core. In fact the poles in position 2 have also rotated 60° from position (1).

Using the same reasoning as above for the current wave positions 3, 4, 5, 6 and 7, it will be seen that for each successive increment of 60 electrical degrees, the result ant stator field will rotate a further 60° as shown in Fig 5. Note that from theresultant flux from position (1) to position (7), it is obvious that for each cycle of applied voltage the field of the two-pole stator will also rotate one revolution around its core.

From what is stated above it will be clear that the rotating magnetic field could be produced by a set of 3-phase stationary windings, placed at 120° electrical degrees apart, and supplied with a 3-phase voltage.

The speed at which the field rotates is called synchronous speed, and, it depends upon the frequency of supply and the number of poles for which the stator is wound.

Hence

N_S = Synchronous speed in r.p.m.

$$= \frac{120F}{P}$$

where 'P' is the number of poles in the stator, and 'F'is the frequency of the supply.

Construction of A 3-phase squirrel cage induction motor - relation between slip, speed, rotor frequency, copper loss and torque

Objectives: At the end of this lesson you shall be able to

- **describe the construction of a 3 - phase, squirrel cage induction motor**
- **describe the construction of double squirrel cage motor and its advantage**
- **explain slip, speed, rotor frequency, rotor copper loss, torque and their relationship.**

Three-phase induction motors are classified according to their rotor construction. Accordingly, we have two major types.

- Squirrel cage induction motors
- Slip ring induction motors.

Squirrel cage motors have a rotorwith short-circuited bars whereas slip ring motors have wound rotors having three windings, either connected in star or delta. The terminals of the rotorwindings of the slip ring motorsare brought out through slip-rings which are in contact with stationary brushes.

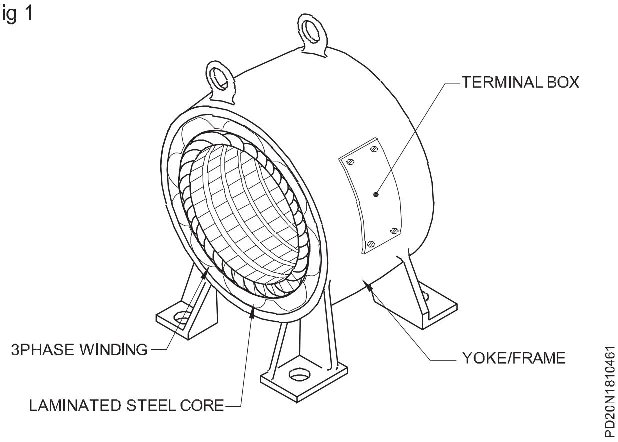
Development of these two types of induction motors is due the fact that the torque of the induction motor depends upon the rotor resistance. Higher rotor resistance offers higher starting torque but the running torque willbe low with increased losses and poor efficiency. For certain applica tions of loads where high starting torque and sufficient running torque are the only requirements, the rotor resist ance should be high at the time of starting, and low while the motor is running. If the motor circuit is left with high resistance, the rotor copper loss will be more, resulting in low speed and poor efficiency Hence it is advisable to have low resistance in the rotor while in operation.

Both these requirements are possible in slip-ring motors by adding external resistance at the start and cutting it off while the motor runs. Asthis is not possible in squirrel cage motors, the above requirements are met by developing a rotor called double squirrel cage rotor where there will be two sets of short circuited bars in the rotor.

Rator of an induction motor: There is no difference oetween squirrel cage and slip-ring motor stators.

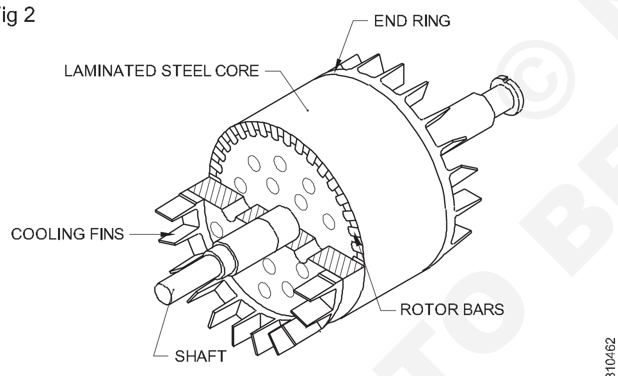
The induction motor stator resembles the stator of a revolving field, three-phase alternator. The stator or the stationary part consists of three-phase winding held in place in the slots of a laminated steel core which is enclosed and supported by a cast iron or a steel frame as shown in Fig 1. The phase windings are placed 120 electrical degrees apart, and may be connected in either star or delta externally, forwhich six leads are brought out to a terminal box mounted on the frame of the motor. When the stator is energised from a three-phase voltage it will produce a rotating magnetic field in the stator core.

Fig 1



Rotor of a squirrel cage induction motor: The rotor of the squirrel cage induction motor shown in Fig 2 contains no windings. Instead it is a cylindrical core constructed of steel laminations with conductor bars mounted parallel to the shaft and embedded near the surface of the rotor core. These conductor bars are short circuited by an end-ring at either end of the rotor core. On large machines, these conductor bars and the end-rings_are made up of copper with the bars brazed or welded to the end rings as shown in Fig 3. On small machines the conductor bars and end-rings are sometimes made of aluminium with the bars and rings cast in as part of the rotor core.

Fig 2

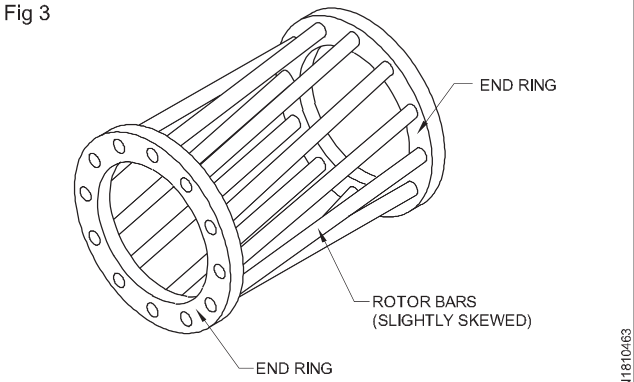


CAGE-TYPE ROTOR IN PART SECTION SHOWING CAST ALUMINIUM BARS AND END RINGS

The rotor or rotating part is not connected electrically to the power supply but has voltage induced in it by transformer action from the stator. For this reason, the stator is sometimes called the primary, and the rotor is referred to as the secondary of the motor.Since the motor operates on the principle of induction and as the construction of the rotor with tha bars and end-rings resembles a squirrel cage, the name squirrel cage induction motor is used. (Fig 3)

The rotor bars are not insulated from the rotorcore because they are made of metals having less resistance than the core. The induced current will flow mainly in them. Also,the bars are usually not quite parallel to the rotor shaft but are mounted in a slightly skewed position. This feature tends to produce a more uniform rotor field and torque;also it helps to reduce some of the internal magnetic noise when the motor is running.

Fig 3



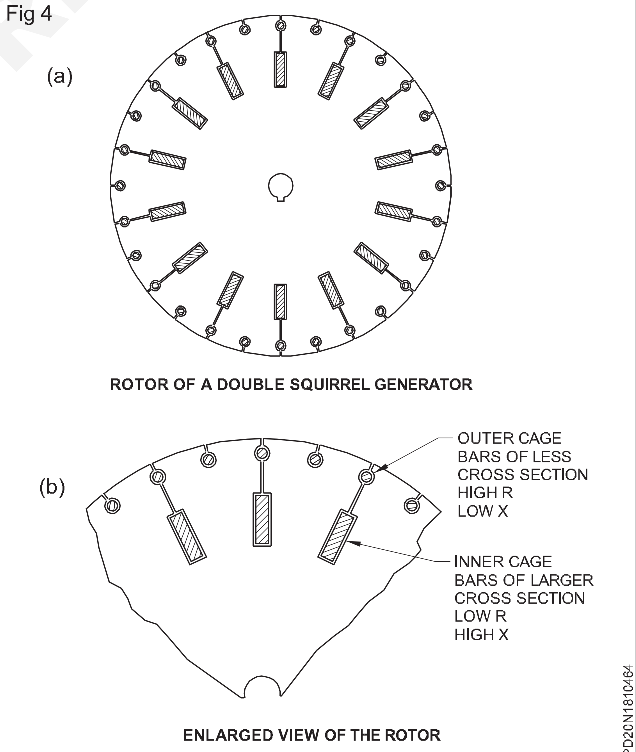
DETATCHED VIEW OF THE SQUIRREL CAGE MOTOR ROTOR BARS

End shields: The function of the two end shields which are to support the rotor shaft. They are fitted with bearings and attached to the stator frame with the help of studs or bolts.

Double squirrel cage induction motor

Rotor construction and its working: Thisconsists of two sets of conductor bars called outer and inner cages as shown in Fig 4. The outer cage consists of bars of high resistance metals like brass, and is short-circuited by the end-rings. The inner cageconsists of low resistance metal bars like copper, and is short-circuited by the end-rings. The outer cage has high resistance and low reactance, whereas the inner cage has low resistance but being situated deep in the rotor core, has a large ratio of reactance to resistance.

Fig 4



At the time of starting, the rotor frequency is the same as the stator frequency. Hence the inner cage which has higher inductive reactance offers more resistance to the current flow. As such very little current flows through the inner cage at the time of starting.

The major part of the rotor current at the time of starting could flowthrough the outer ring which has highresistance. This high resistance enables to produce a high starting torque.

As the speed increases,the rotor frequency is reduced. At low frequency, the total resistance offered for the current flowin the inner cage reducesdue to reduction of reactance (X = 2rcf L), and the major part of the rotor current will be in Lr the inner cage rather than in the highly resistant outer cage.

As such, t11e low resistance of the inner cage becomes responsible for producing a torque just sufficient to main tain the speed.

Slip and rotor speed: We have already found that the rotor of an induction motor must rotate in the same direction as the rotating magnetic field, but it cannot rotate at the same speed as that of the magnetic field. Only when the rotor runs at a lesser speed than the stator magnetic field, the rotor conductors could cut the stator magnetic field for an emf to be induced. The rotor current could then flow and the rotor magnetic field will set up to produce a torque.

The speed at which the rotor rotates is called the rotor speed or speed of the motor. The difference between the synchronous speed and the actual rotor speed is called the 'slip speed'. Slip speed is the number of revolutions per minute by which the rotor continues to fall behind the revolving magnetic field.

When the slip speed is expressed as a fraction of the synchronous speed, it is called a fractional slip.

Therefore, fractional slip S

Ns - Nr

= NS

Then percentage slip (% slip)

N -N

= s r X 100

NS

where N. = synchronous speed of the stator

magnetic field

N, = Actual rotating speed of the rotor in r.p.m.

Starter for 3 - phase induction motor, its necessity - basic contactor circuit - its parts and their functions

Objectives: At the end of this lesson you shall be able to
- **state the necessity of starters for a 3-phase induction motor and name the types of starters**
- **draw and explain the basic contactor circuit with a single push-button station for start and stop**
- **state the function of the overload relay, different types of overload relays (magnetic and thermal types), construction and method of setting overload relays according to the current rating of the motor**
- **state the function of a no-volt coil, its rated voltage, position of operation, its common troubles, their causes and remedies.**

Necessity of starter: A squirrel cage induction motor just before starting issimilarto a polyphase transformer with a short-circuited secondary. If normal voltage is applied to the stationary motor, then, as in the case of a transformer, a very large initial current, to the tune of 5 to 6 times the normal current, will be drawn by the motor from the mains. This initial excessive current is objectionable, because it willproduce large line voltage drop, which in turn will affect tie operation of other electrical equipment and lights connected to the same line.

The initial rush of current is controlled by applying a reduced voltage to the stator winding during the starting period, andthen the full normal voltage is applied when the motor has run up to speed. For small capacity motors, say up to 3 Hp, full normal voltage can be applied at the start. However, to start and stop the motor, and to protect the motor from overload currents andlowvoltages, astarter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to themotor at thetime of starting.

Types of starters: Following are the different types of starters used for starting squirrel cage induction motors.

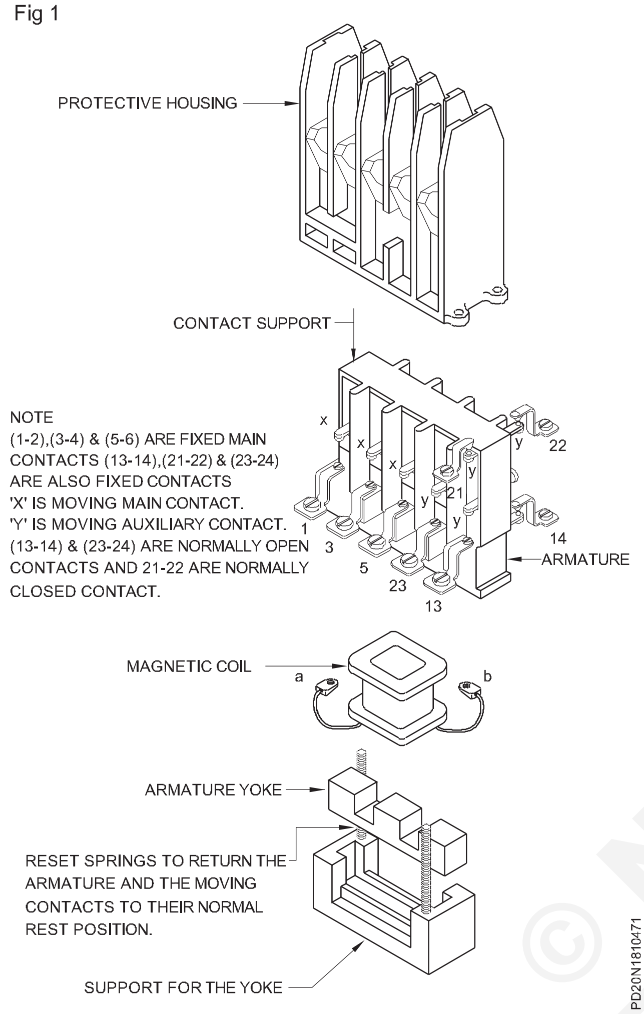
- Direct on-line starter
- Star-delta starter
- Step-down transformer starter
- Auto-transformerstarter

In the above starters, except for the direct on-line starter, reduced voltage is applied to the stator winding of the squirrel cage induction motor at the time of starting, and regular voltage is applied once the motor picks up the speed.

Selection of starter: Many factors must be considered when selecting starting equipment. These factorsinclude starting current, the full load current, voltage rating of motor, voltage (line) drop, cycle of operation,type of load, motor protection and safety of the operator.

Contactors: The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 60 cycles per hour or more. It may be operated by hand (mechanical), electromagnetic, pneu matic or electro-pneumatic relays.

Fig 1



The contactors shown in Fig 1 consist of main contacts, auxiliary contacts and no-volt coil. As per Fig 1, there are three sets of normally open, main contacts between terminals 1 and 2, 3 and 4, 5 and 6, two sets of normally open auxiliary contacts between terminals 23 and 24, 13 and 14, and one set of normally closed auxiliary contact between terminals 21 and 22. Auxiliary contactscarry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an inte grated part, but will have to be used as separate accessories along with the contactor to form the starter function.

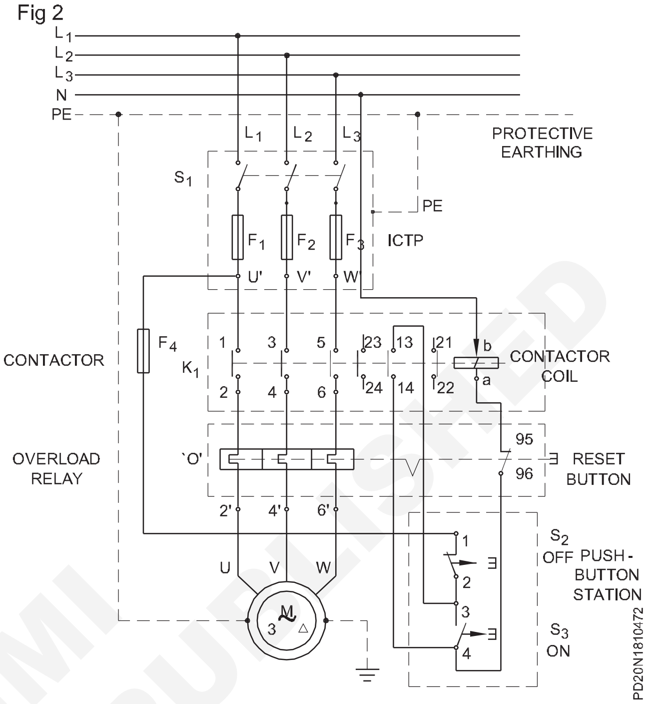
The main parts of a magnetic contactor are shown in Fig 1, and Fig 2 shows the schematic diagram of the contactor when used along with fused switches (ICTP), push-button stations and OL relay for connecting a squirrel cage motor for starting directly from the main supply. In the same way the direct on-line starter consists of a contactor, OL relay and push-button station in an enclosure.

Functional description

Power circuit: As shown in Fig 2, when the main ICTP switch is closed and the contactor K_1 is operated, all the three windings UV & W of the motor are connected to the supply terminals RY B via the ICTP switch, contactor and OL relay.

The overload current relay (bimetallic relay) protects the motor from overload (‘ motor protection’), while the fuses F1/F2/F3 protect the motor circuit in the event of phase-to-phase or phase-to-frame short circuits.

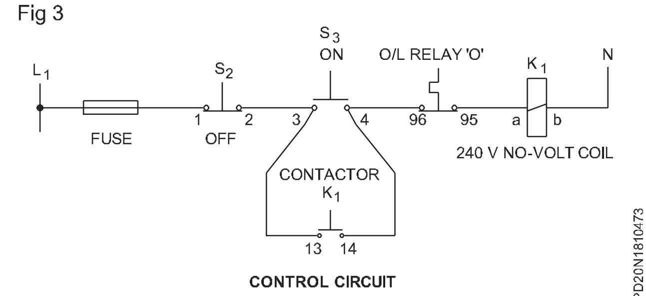
Fig 2



Control circuits

Push-button actuation from one operating location: As shown in the complete circuit Fig 2, and the control circuit Fig 3, when the ‘ON’ push-button S is pressed, the control circuit closes, the contactor coil is energised and the contactor K closes. An auxiliary, a normally open contact 13,14 is a1so actuated together with the main contacts of K_1.If this normally open contact is connected in parallel with S_3, it is called a self-holding auxiliary contact.

Fig 3



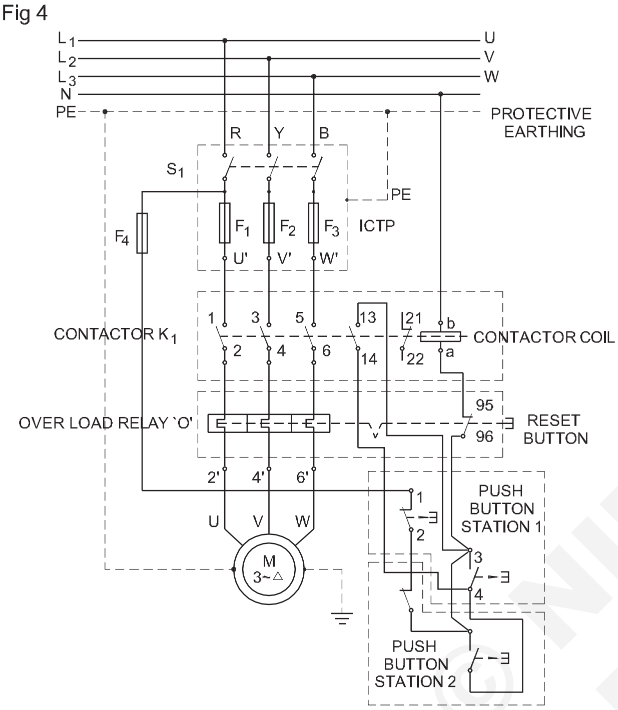
After S_3, is released, the current flows via this self-holding contact 13,14, and the contactor remains closed. In order to open the contactor, S_2 must be actuated. If S_3 and S_2 are actuated simultaneously, the contactor is unaffected.

In the event of overloads in thepower circuit, the normally closed contact 95 and 96 of overload relay ‘O’ opens, and switches off the control circuit. Thereby K_1 switches ‘OFF’ the motor circuit.

Once the contact between 95 and 96, is opened due to the activation of the overload relay ‘o’, the contacts stay open and the motor cannot be started again by pushing the 'ON' button S_3. It has to be reset to normally closed position by pushing the reset button. In certain starters, the reset could be done by pushing the'OFF' button which is in line with the overload relay 'O'.

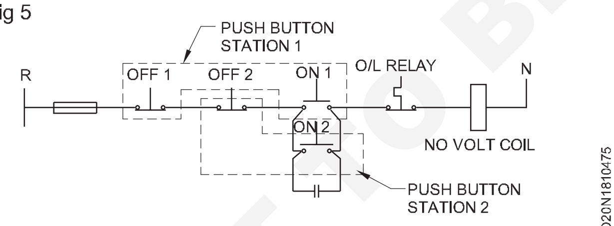
Push-button actuation from two operating locations: If it is desired to switch a contactor off and on from either of the two locations, the corresponding OFF push-buttons should be connected in series, and the ON push-buttons in parallel, asshown in the complete diagram Fig 4 and the control diagram Fig 5.

Fig 4



COMPLETE CIRCUIT DIAGRAM OF THE CONTACTOR AND THE 3 PHASE SQUIRREL CAGE INDUCTION MOTOR

Fig 5



If either of the two ON Push - buttons is actuated, K_1 is energised and holds itself closed with the help of normally-open contact 13 & 14 which is closed by contactor K_1 If either of the two OFF push-buttons is actuated, the contactor opens.

purpose of overload relays: The overload relays protect the motoragainst repeated, excessive momentary surges or normal overloads existing for long periods, or high currents caused in two phases by the single-phasing effect. These relays have characteristics which help the relay to open the contactor in 10 seconds if the motor current is 500percent of the fullload current, orin4minutes if the current is 150 percent of the full load current.

Types of overload relay

There are two types of overload relays. They are :

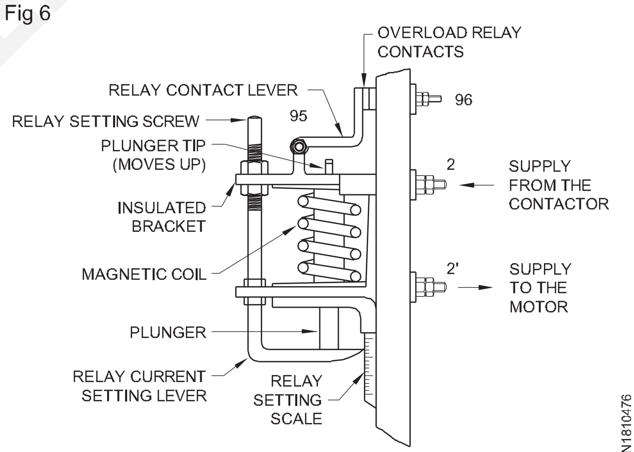
- magnetic overload relay
- thermal (bimetallic) overload relay.

Normally there are 3 coils in a magnetic relay and 3 sets of heater coils in a bimetallic relay so that two coils will operate in case of single phasing which helpin avoiding the burning out of the motor.

Magnetic overload relay: The magnetic overload relay coil is connected in series with the motor circuits as shown in Fig 2. The coil of the magnetic relay must be wound with wire, large enough in size to pass the motor current. As these overload relays operate by current intensity and not by heat, they are faster than bimetal relays.

As shown in Fig 6, the magnetic coil carries the motor currentthroughterminals 2 and 2'which isin series with the power circuit. The relay contacts, 95 and 96, are in series with the control circuit. When a current more than a certain stipulated value, as set by the relay set scale, passes through the power circuit, the magnetic flux produced by the coil will lift the plunger in an upward direction. This upward movement makes the plungertip to pushthe relay contact lever, and the contact between terminals 95 and 96 opens. Thisbreaks the no volt coil circuit and the contactor opens the power circuit to the motor. The relay contacts between terminals 95 and 96 stay open till the rest-button (not shown in the figure) is pressed.

Fig 6

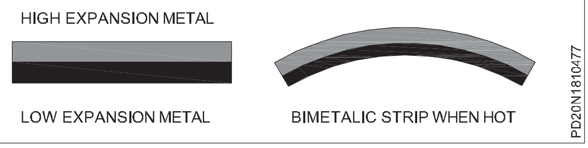


MAGNETIC OVERLOAD RELAY

Bimetallic overload relays: As we know that different material have different coefficient of thermal expansion. So if two different metals joined together are heated then the metal having the greater value of coefficient of thermal expansion will expand more as compared to other and this will cause a bend in the bimetallic strip. This phenomenon is used in Thermal Overload Relay.

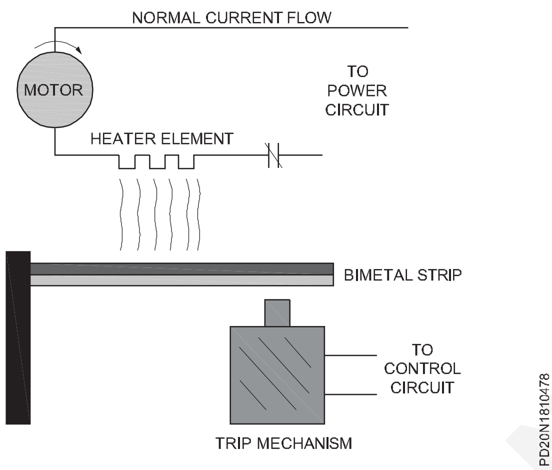
It can be seen from the above figure that metal having greater coefficient of thermal expansion has more expansion when heated. Now we want to use this feature in the protection of a Motor.

Fig 7



A bimetallic overload relay consists of a small heater element wired in series with the motor and a bimetal strip that can be used as a trip lever. The bimetal strip is made of two dissimilar metals bonded together. The two metals have different thermal expansion characteristics, so the bimetal strip bends at a given rate when heated. Under normal operating conditions, the heat generated by the heater element will be insufficient to cause the bimetal strip to bend enough to trip the overload relay.

Fig 8

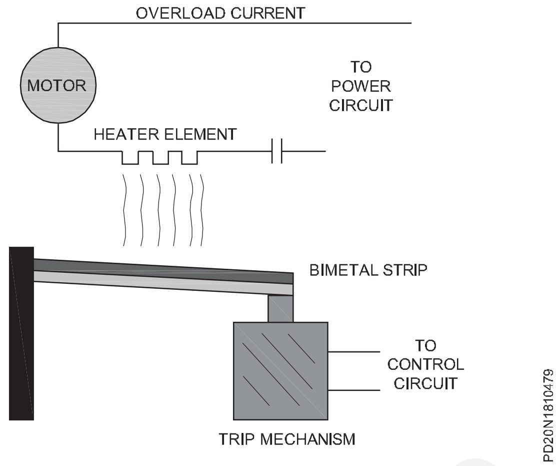


As current rises, heat also rises. The hotter the bimetal strip becomes, the more it bends. In an overload condition, the heat generated from the heater will cause the bimetal strip to bend until the mechanism is tripped, stopping the motor. Some overload relays equipped with a bimetal strip are designed to reset the circuit automatically when the bimetal strip has cooled and reshaped itself, restarting the motor. If the cause of the overload still exists, the relay will trip again and reset at given intervals. Care must be exercised in the selection of this type of overload relay, since repeated cycling will eventually damage the motor.

It should be noted that the bimetallic strip of Overload Relay will not instantly heat up to bend rather will take some finite time to heat up and bend and therefore Thermal Overload Relay is proffered where over current for some short duration is permitted.

If overload or over current falls down to normal value before this predetermined time, the relay will not be operated to trip the protected equipment. A typical application of thermal relay is overload protection of electric motor.

Fig 9



Relay setting: The overload relay unit is the protection centre of the motor starter. Relays come in a number of ranges. Selection of arelay for a starter depends upon the motor type, rating and duty.

For all direct on-line starters, relays should be set to the actualload current of the motor. This value should be equal to or lower than the full load current indicated on the name-plate of the motor. Described here is a simple procedure for setting the relay to the actual load current.

Set the relay to about 80% of the full load current. If it trips, increase thesetting to 85% or more tillthe relay holds. The relay should never be set at more than the actual current drawn by the motor. (The actual current drawn byamotor will be less than the full load current in most cases, as motors may not be loaded to capacity.)

Tripping of starters: Astarter may tripdue to the following reasons.

- Low voltage or failure of power supply
- Persistent overload on the motor

In the first instance, the tripping occurs through the coil which opens the contacts when the voltage falls below a certain level. The starter can be restarted as soon as the supply is back to normal.

The relay trips the starter when there is an overload. It can be restarted only after the relay is reset and t11e k1ad becomes normal.

No-volt coil: A no-volt coil consists of generally more number of turns of thin gauge of wire.

Coil voltages: Selection of coils depends on the actua_l supply voltage available.Awide variety of coil voltages like 24V, 40V, 110V, 220 V 230/250 V, 380V 400/440V AC or DC are available as standard for contactors and starters.

Troubleshooting in contactor: Table 1 gives the common symptoms their causes and remedies.

Table 1

Symptoms	Causes	Remedies
Motor does not start when the start button is pressed.However on pressing the armature of the contator manually, motor starts and runs.	Open in no-volt coil circuit.	Check the main voltage for lower than acceptable value.Rectify the main voltage.Check the control circuit wiring for loose connection.Check the resistance of the no - volt coil winding. If found incorrect respect the coil.
Motor starts when 'ON' button is pressed. It however stops immediately when 'ON' button is released.	Auxiliary contact in parallel with the start - button is not closing.	Check the parallel connection from 'ON' button terminals to the auxillary contact of the contactor.Rectify the defect.
Motor does start when the start button is pressed. However, a humming or chattering noise comes from the starter.	Movable armature and fixed limb of electromagnet are not stably attracted.	Check the auxillary contact points of the contactor for erosion and pittings. Replace, if found defective. Dust or dirt or grit between the mating surfaces of the electromagnetic core. Clean them.
Failure of contactor due to too much heating of the 'No' volt coil.	Higher incoming supply rating. No-volt coil rating is not high.	Low voltage supply.Find the cause and rectify the defect. Break in the shading ring in the case of AC magnet.
Motor does not restart immediately after tripping of OL relay even though OL relay was reset.	It takes a little time for the thermal bimetal to cool and reset.	Higher supply voltage than normal. Reduce the incoming voltage.
Coil does not get energised even though supply voltage is found across the no-volt coil terminals.	Open - circuited NVC. NVC burnt out.	Voltage rating of the no - volt coil is less.Replace with standard rating, according to the main supply. Wait for 2 to 4 minutes before re-starting.
Relay coil has been changed.However motor does not start when the start - button is pressed.	Control circuit of relay open.	Check the nylon strip on relay. Check the nylon button below the start button Replace, if necessary. Check the control station contacts. Overload relay not reset.
Humming or Chattering noise.	Low voltage. Magnetic face between yoke and armature is not clean. Shading ring on iron core missing.	Feed the rated voltage. Clean the surfaces of yoke and armature. Provide shading ring in the iron core

D.O.L. starter

Objectives: At the end of this lesson you shall be able to
- **state the specification of a D.O.L. starter, explain its operation and application**
- **explain the necessity of a back-up fuse and its rating according to the motor rating.**

A O.0.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incor porated in an enclosure.

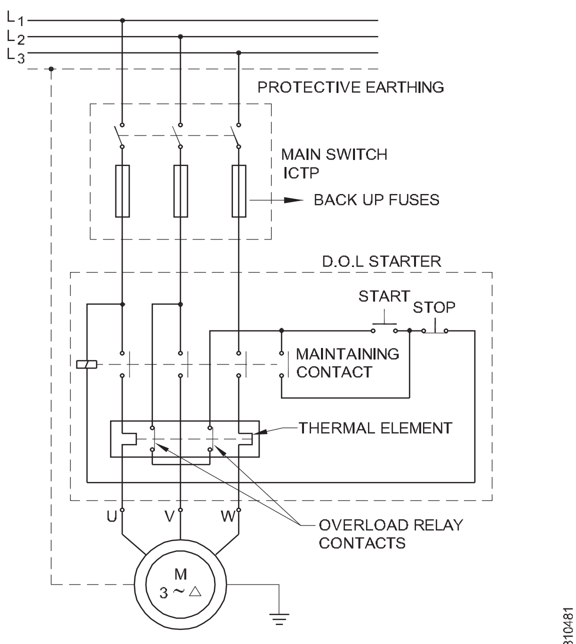
Construction and operation: A push-button type, direct on-line starter, which is in common use, is shown in Fig 1. It isa simple starterwhich is inexpensive andeasy to install and maintain.

There is no difference between the complete contactor circuit explained in Exercise 12 and the O.O.L.starter,

except that the D.0. L. starter is enclosed in a metal orPVC case, and in most cases, the no-volt coil is rated for 415V and is to be connected across two phases as shown in Fig 1.Furtherthe overload relay can be situated between ICTP switch and contactor,or between the contactor and motor as shown in Fig 1, depending upon the starter design. Trainees are advised to write the working of the O.0.L. starter on their own by going t11rough the explanation given in Exercise 12 which is for a complete contactor circuit.

Specification of 0.0.L. starters: While giving specifica tion, the following data are to be given.

Fig 1



WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES

O.O.L. STARTER

Phases - single or three. Voltage 230 or 415V.

Current rating 10. 16. 32, 40, 63. 125 or 300 amps.

No-volt coil voltage rating AC or DC 12, 24, 36, 48,110, 230/250, 360,380 or400/440 volts.

Number of main contacts 2, 3 or 4 which are normally open.

Number of auxiliary contacts 2 or 3. 1 NC+ 1 NO or 2 NC+ 1 NO respectively.

Push-button - one 'ON' andone 'OFF' buttons.

Overload from setting-amp-to-amp. Enclosure- metal sheet or PVC.

In an induction motorwith a O.O.L. starter, the starting current will be about 6 to 7 times the full load current. As such, O.O.L. starters are recommended to be used only up to 3 HP squirrel cage induction motors, and up to 1.5 kW double cage rotor motors.

Necessity ofback-up fuses: Motor startersmust never be used without back-up fuses. The sensitive thermal relay mechanism is Designed and calibrated to provide effective protection against overloads only. When sudden short circuits take place in a motor circuit, the overload relays, due to their inherent operating mechanism, take a longer time to operate and open the circuit. Such delays will be sufficient to damage the starter motor and connected circuits due to heavy in-rush of short circuit currents. This could be avoided by using quick-action, high-rupturing capacity fuses which, when used in the motor circuit, operate at a faster rate and open the circuit. Hence H.R.C. diazed (OZ) type fuses arerecommended forprotecting the installation as well as the thermal overload relay of the motor starter against short circuits. In case of short circuits, tile back-up fuses melt and open the circuit quickly. A reference table indicating fuse ratings for differ ent motor ratings is given.

It is recommended that the use of semi-enclosed,rewirable, tinned copper fuses may be avoided as for as possible.

The given full load currents apply in the case of single phase, capactor - start type motors, and in the case of 3-phase, squirrel cage type induction motors at full load having average power factor and efficiency.The motors should have speeds not less than 750 r.p.m.

Fuses upto and including 63 A are DZ type fuses. Fuses from 100 A and above are IS type fuses (type HM).

TABLE OF RELAY RANGES AND BACK-UP FUSES FOR MOTION PROTECTION

SI.No	Motor ratings 240V 1 - phase	Motor ratings 415 V 3 - phase	Relay range A a	Norminal back - up fuse recommended
	kW			
1		0.05		
2	0.05 0.04	0.1		
3		0.25		
4	0.125 0.11	0.50		
5	0.5 0.18 2.0	1.0		
6	0.5 0.4 3.6	1.5		
7		2.0		
8	0.75 0.55	2.5		
9		3.0		
10	1.0 0.75 7.5	5.0		
11	2.0 1.5 9.5	7.5		
12	3.0 2.25 14	10.0		

Manual star-delta switch/starter

Objectives: At the end of this lesson you shall be able to
- **state the necessity of a star-delta starter for a 3-phase squirrel cage induction motor**
- **draw and explain the construction, connection and working of a star-delta switch and starter**
- **specify the back-up rating of the fuse in the motor circuit**
- **compare voltages across the windings of the motor, current taken, power absorbed and torque produced in star and delta positions of the starter.**

Necessity of star-delta starter for 3-phase squirrel cage motor: If a 3-phase squirrel cage mot Jr is started directly, it takes about 5-6 times the full load current for a fewseconds, and then the current reduces to normal value once the speed accelerates to itsrated value. Asthe motor is of rugged construction and the starting current remains for a fewseconds, the squirrel cage induction motorwill not get damaged by this high starting current.

However with large capacity motors, the starting current will cause too much voltage fluctuations in the power lines and disturb the other loads. On the other hand, if all the squirrel cage motors connected to the power lines are started at the same time, they may momentarily overload the power lines, transformers and even the alternators.

Because of these reasons, the applied voltage to the squirrel cage motorneeds to be reduced during the starting periods, and regular supply could be given when the motor picks up its speed.

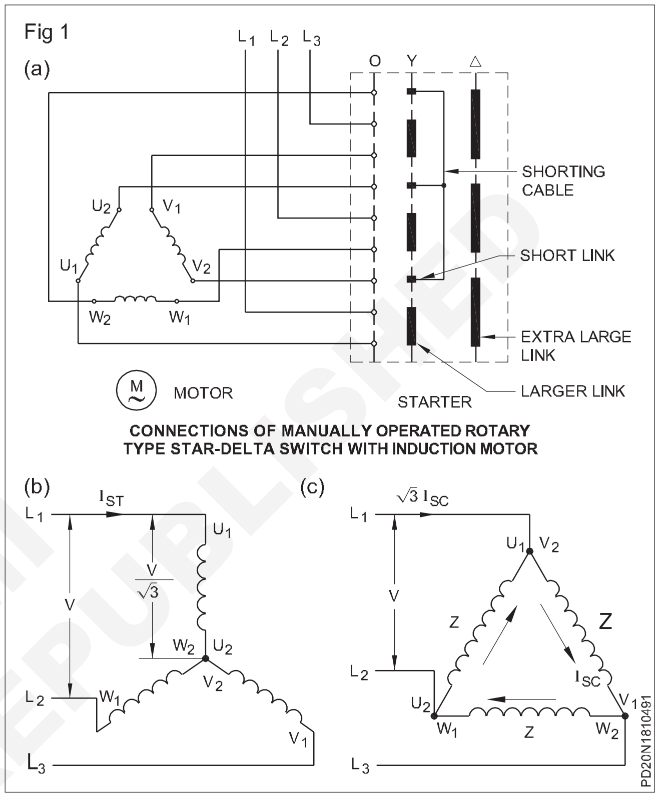
Following are the methods of reducing the applied voltage to the squirrel cage motor at the start.

- Star-delta switch or starter
- Auto-transformerstarter
- Step-down transformer starter

Star-delta starter: Astar-delta switch is a simple arrange ment of a cam switch which does not have any additional protective devices like overload or under-voltage relay except fuse protection through circuit fuses, whereas the star-delta starter may have overload relay and under voltage protection in addition to fuse protection. In a star-delta switch/starter, at the time of starting, the squirrel cage motor is connected in star so that the phase voltage. is reduced to 1/ √ 3 times the line voltage, and then when the motor picks up its speed, the windings are connected in delta so that the phase voltage is the same as the line voltage. To connect a star-delta switch/starterto a3-phase squirrel cage motor, all the six terminals of the three-phase winding must be available.

As shown in Fig 1a, the star-delta switch connection enables the 3 windings of the squirrel cage motor to be connected instar, and then in delta. In starposition, the line supply L_1 L_2 and L_3 are connected to the beginning of windings U_1,W_1 and V_1 respectively by the larger links, whereas the short !inks which connect V_2 U_2 and W_2, are shorted by the shorting cable to form the star point. This connection is shown as a schematic diagram. (Fig 1b)

When the switch handle is changed over to delta position, the line supply L_1 L_2 and L_3 are connected to terminals U V_2 W_1 U_2 and V_1 W_2 respectively by the extra large links to form a delta connection. (Fig 1c)



Manual star-delta starter: Fig 2 shows the conventional manual star-delta starter. As the insulated handle is spring-loaded, it will come back to OFF position from any position unless and until the no-volt (hold-on) coil is energised. When the hold-on coil circuit is closed through the supply taken from U_2 and W_2, the coil isenergised and 2 it holds the plunger, and thereby the handle is held in delta position against the spring tension by the lever plate mechanism. When the hold-on coil is de-energised the plunger fallsand operates the lever plate mechanism soas to make the handle to be thrown to the off position due to spring tension. The handle also has a mechanism (not shown in Fig) which makes it impossible forthe operatorto put the handle in delta position in the first moment. It isonly when the handle is brought to star position first, and then when the motor picks up speed, the handle is pushed to delta position.

The handle has a set of baffles insulated from each other and also from the handle. When the handle is t11rown to star position, the baffles connect the supply lines L , L and L to beginning of t11e 3-phase winding W., V. and U1 respectively. At the same time the small baffles connect V , W and U through the shorting cable to form the star point. (Fig 2b)

When the handle is thrown to delta position, the larger end of the baffles connect the main supply line L1, 2 and L3 to thewindingterrninalsW1U2, V1W2and U1V2 respectively to form the della connection. (Fig 2c)

The overload relay current setting could beadjusted by the worm gear mechanism of the insulated rod. When the load current exceeds a stipulated value, the beat developed in therelay heater element pushes the rod to open the hold-on coil circuit, and thereby the coil is de-energised, and the handle returns to the off position due to the spring tension.

The motor also could be stopped by operating the stop button which in turn de-energises the hold-on coil.

Back-up fuse protection: Fuse protectionis necessary in the star-delta started motor circuit against short circuits. In general, as a thumb rule for 415V, 3-phase squirrel cage motors, the full load current can be taken as 1.5 times the

H.P. rating. For example, a 10 HP 3--phase 415V motorwill have approximately 15 amps as its full load current.

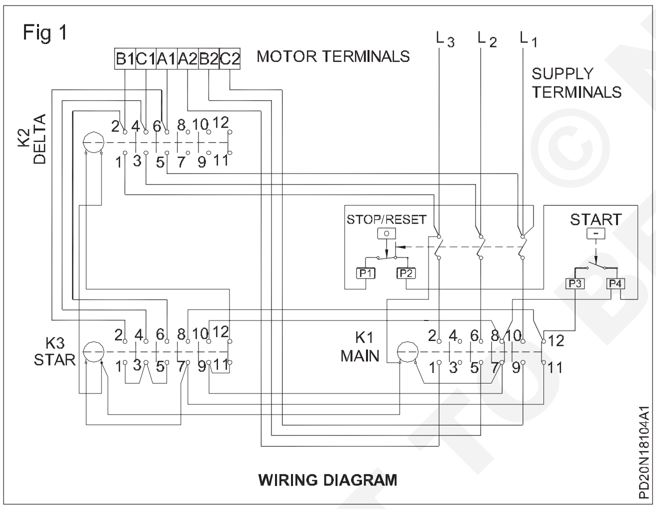
To avoid frequent blowing of the fuse and at the same time for proper protection, the fuse wire rating should be 1.5 times the full load current rating of the motor. Hence for 10 HP, 15 amps motor, the fuse rating will be23 amps, or say 25 amps.

Semi-automatic star-delta starter

Objectives: At the end of this lesson you shall be able to
- **explain the wiring diagram of semi-automatic star-delta starter**
- **describe the operation of semi-automatic star-delta starter.**

The proper use of manual star-delta starter demands a special skill in handling the starter. The sluggish operation of the manual lever often causes damage to the moving and fixed contacts in a manual star-delta starter.

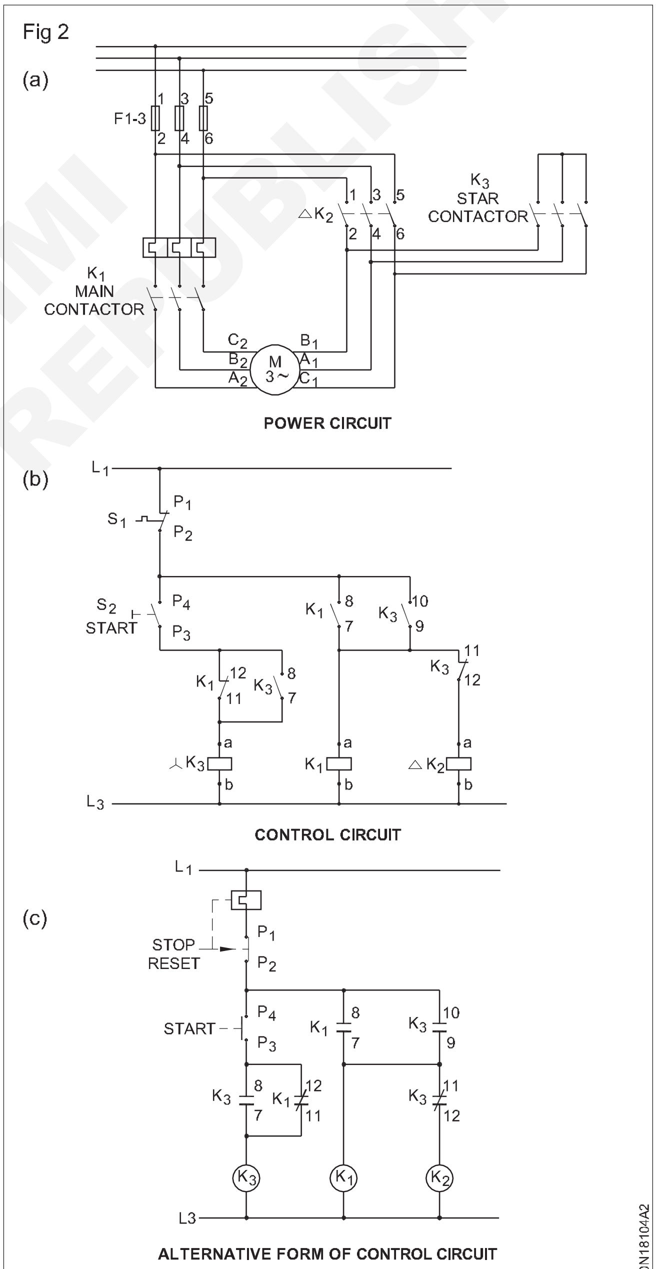
The contactors are employed for making and breaking the main line connections. Fig 1 shows the wiring diagram and Fig 2 shows the line diagram of power circuit and the control circuit.



WIRING DIAGRAM

Operation: Refer to the control circuit and power circuit diagrams shown in Fig 2. When the start button S2 is pressed the contactor coil K3 energises through P4, P3 and K1 normally closed contact 12 and 11. When K3 closes, it opens the normally closed contact K3 between 11 and 12 and makes contact between 10 and 9 of K3. The mains contactor K1 energies through P4, 10 and 9 of K3. Once K1 energises the NO contact of K1 point 8 and 7 establishes a parallel path to K3 terminals 10 and 9.

The star contactor K3 remains energised so long as the start button is kept pressed. Once the start button is released, the K3 coil gets de-energised. The K3 contact cannot be operated because of the electrical interlock of K1 and normally closed contacts between terminals 12 and 11.



LINE DIAGRAM OF SEMI - AUTOMATIC STAR - DELTA STARTER

When the K3 contactor get de-energised the normally closed contact of K3 between terminals 11 and 12 establishes contact in the contactor K2 - coil circuit. The delta contactor K2 closes.

The operator has to observe the motor starting and reaching about 70% of the synchronous speed for satisfactory starting and running of the induction motor.

Figure 2c shows the alternative form of drawing control circuit.

Automatic star-delta starter

Objectives: At the end of this lesson you shall be able to
- **state the applications of automatic star-delta and overload relay setting**
- **describe the operations of automatic star-delta starter.**

Applications: The primary application of star-delta motor is for driving centrifugal chillers of large central air-conditioning units for loads such as fans, blowers, pumps or centrifuges, and for situations where a reduced starting torque is necessary. A star-delta motor is also used where a reduced starting current is required.

In star-delta motors all the winding is used and there are no limiting devices such as resistors or auto-transformers. Star-delta motors are widely used on loads having high inertia and a long acceleration period.

Overload relay settings: Three overload relays are provided on star-delta starters. These relays are used so that they carry the motor winding current. This means that the relay units must be selected on the basis of the winding current, and not the delta connected full load current. The motor name-plate indicates only the delta connected full load current, divide this value by 1.73 to obtain the winding current. Use this winding current as the basis for selecting and setting the motor winding protection relay.

Operation: Fig 1 shows the line diagram of the power circuit and the control circuit of the automatic star-delta starter. Pressing the start button S-energises the star contactor K3. (Current flows through K4 T NC terminals 15 & 16 and K2 NC terminals 11 & 12). Once K3 energises the K3 NO contact closes (terminals 23 & 24) and provide path for the current to close the contactor K1. The closing of contactor K1 establishes a parallel path to start button via K1 NO terminals 23 & 24.

Fig 1

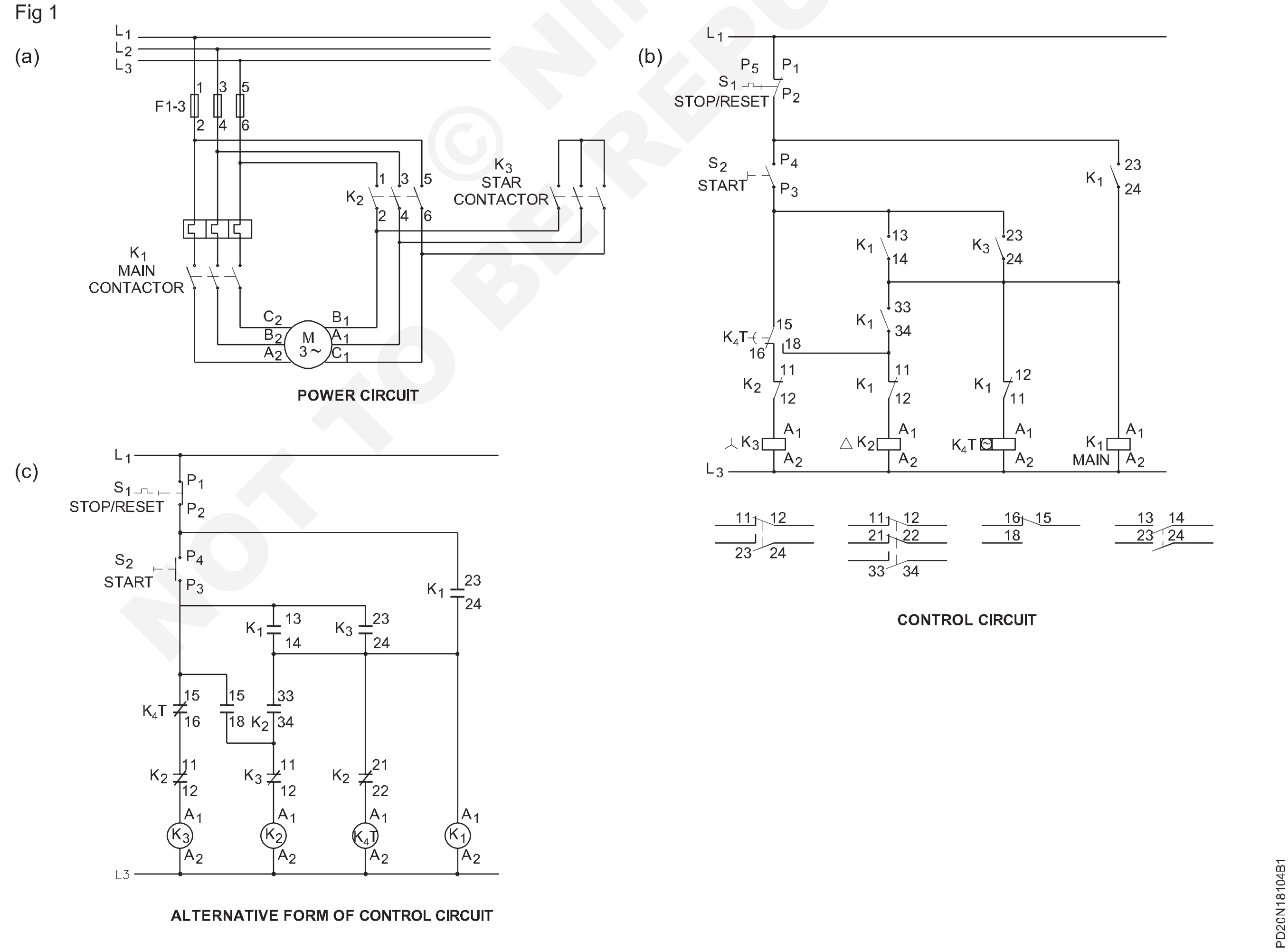


Fig 2 shows the current direction and closing of contacts as explained above.

Similarly Fig 3 shows the action taking place after the timer relay operating the contact K4T.

Time delay contact changes opening star contact.

Fig 4 shows the connections established while the motor is running in delta with the contactors K1 and K2 closed.

Delta contact closes.

Fig 2

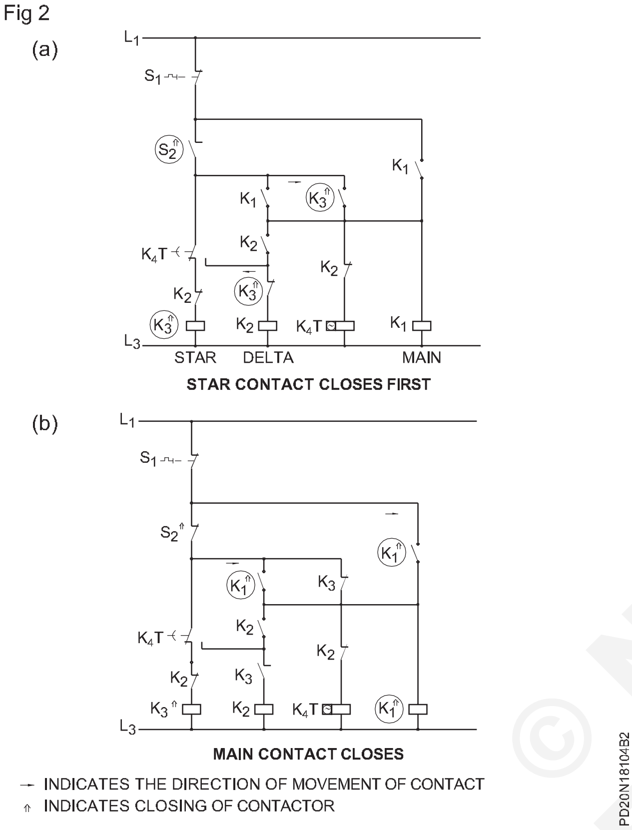


Fig 3

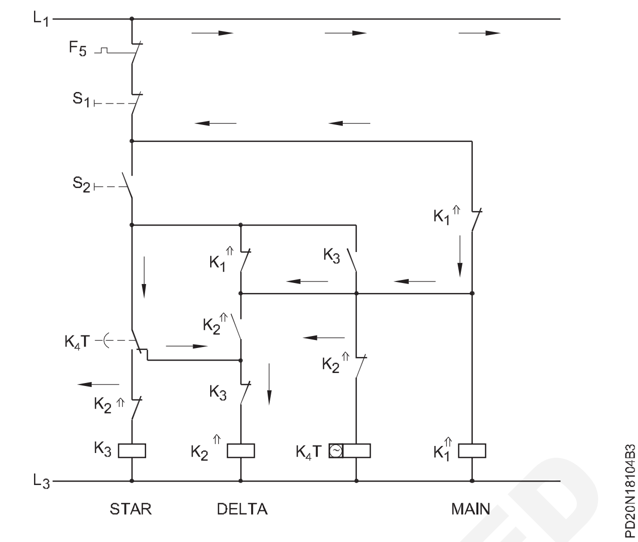
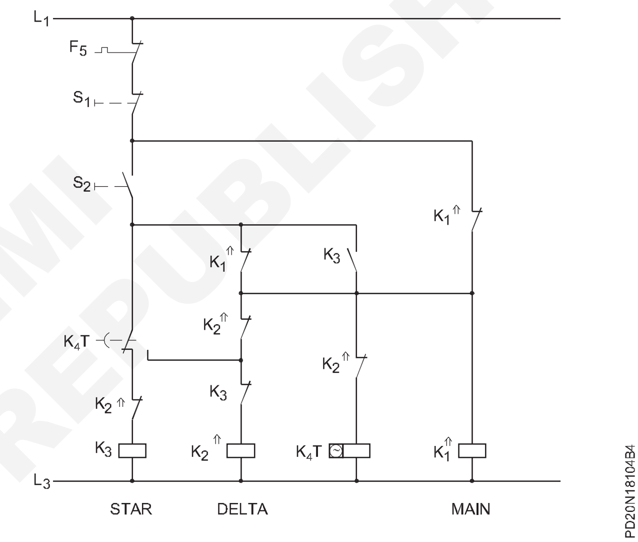


Fig 4

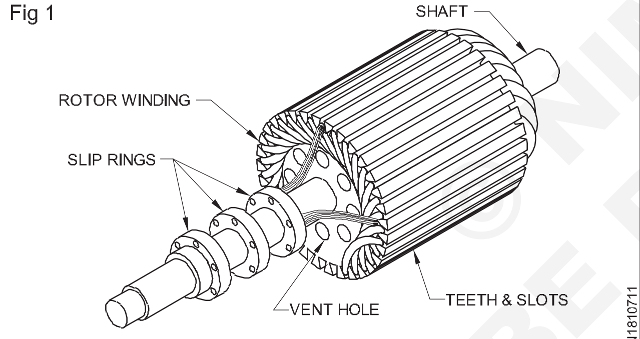


Three-phase, slip-ring induction motor

Objectives: At the end of this lesson you shall be able to
- **explain briefly the construction and working of a three-phase, slip-ring induction motor**
- **explain how the starting torque is high due to insertion of rotor resistance**
- **state the characteristic of the slip-ring induction motor**
- **compare the slip-ring induction motor with the squirrel cage induction motor**
- **explain a soft starter its function and its application.**

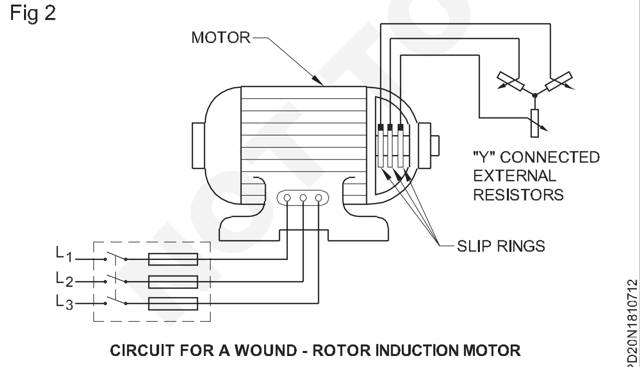
Construction: The slip-ring induction motor could be used for industrial drives where variable speed and high starting torque are prime requirements. The stator of the slip-ring induction motor is very much the same as that for a squirrel cage motor but the construction of its rotor is very much different. Stator windings can be either star or delta connected depending upon the design. The rotor consists of three-phase windings to form the same number of poles as in a stator. The rotor winding is connected in star and the open ends are connected to three slip-rings mounted in the rotor shaft, as shown in Fig 1. The rotor circuit is, in turn, connected to the external star-connected resistances through the brushes, as shown in Fig 2.

Fig 1



WOUND ROTOR FOR SLIP RING INDUCTION MOTOR

Fig 2



CIRCUIT FOR A WOUND - ROTOR INDUCTION MOTOR

Working: When the stator-winding of the slip-ring motor is connected to the 3-phase supply, it produces a rotating magnetic field in the same way as a squirrel cage motor. This rotating magnetic field induces voltages in the rotor windings, and a rotor current will flow through the closed circuit, formed by the rotor winding, the slip-rings, the brushes and the star-connected external resistors.

At the time of starting, the external resistors are set for their maximum value. As such, the rotor resistance is high enabling the starting current to be low. At the same time, the high resistance rotor circuit increases the rotor power factor, and thereby, the torque developed at the start becomes much higher than the torque developed in squirrel cage motors.

As the motor speeds up, the external resistance is slowly reduced, and the rotor winding is made to be short-circuited at the slip-ring ends. Because of the reduced rotor resistance, the motor operates with low slip and high operating efficiency. The motor could be started for heavy loads with higher resistance or vice versa. However at increased rotor resistance, the motor's slip will be greater, the speed regulation poorer and it will have low efficiency. The resistance in the external circuit could be designed and varied to change the speed of the slip-ring motor between 50 to 100 percent of the rated speed. However, the I2R losses in the rotor due to increased resistance is inevitable.

Starting torque: The torque developed by the motor at the instant of starting is called the starting torque. In some cases it is greater than the normal running torque whereas in some other cases it is somewhat less.

Let E_2 be the rotor emf per phase at standstill

X_2 be the rotor reactance per phase at standstill and R_2 be the rotor resistance per phase.

Therefore $Z_2 = \sqrt{(R_2)^2 + (X_2)^2}$ = rotor impedance per phase at standstill.

Then $I_2 = \frac{E_2}{Z_2}, \cos\theta_2 = \frac{R_2}{Z_2}$

Standstill or starting torque $T_{st} = K_1\ E_2\ I_2 \cos q_2$ or

$$T_{st} = K_1 E_2 \text{ x } \frac{E_2}{\sqrt{(R_2)^2 + (X_2)^2}} \text{ x } \frac{R_2}{\sqrt{(R_2)^2 + (X_2)^2}}$$

If the supply voltage V is constant, then the flux, f and hence E_2 is constant.

Therefore Tst = $K_2 \frac{R_2}{Z_2}$ where K2 is another constant.

The starting torque of such a motor is increased by adding external resistance in the rotor circuit. The resistance is progressively cut out as the motor gain speed.

Rotor emf and reactance under running condition : When the starter is stationary i.e. S = 1, the frequency of the rotor emf is the same as that of the stator supply frequency. The value of emf induced in the rotor at standstill is maximum because the relative speed between the rotor and the rotating stator flux is maximum.

When the rotor starts running, the relative speed between the rotor and the rotating stator flux is decreased. Hence the rotor induced emf is also decreased. The rotor emf become zero if the rotor speed become equal to the speed of stator rotating flux.

Hence, for a slip (s), the rotor induced emf will be s times the induced emf at standstill.

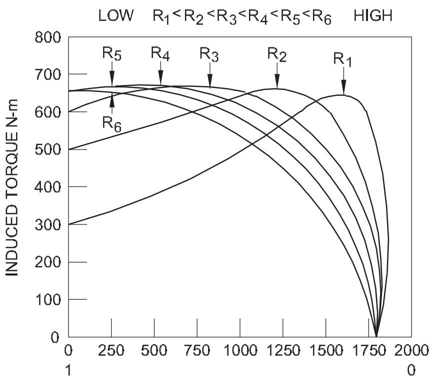
Therefore, under running condition $E_r = sE_2$.

The frequency of induced emf will likewise become $f_r = sf_2$ where f_2 is the rotor current frequency at standstill.

Due to decrease in frequency of the rotor emf, the rotor reactance will also decrease.

Therefore $X_r = sX_2$.

Fig 3



THE TORQUE-SPEED CHARACTERISTIC FOR A WOUND - ROTOR INDUCTION MOTOR

Characteristic and application of slip-ring induction motor: Insertion of higher, external resistance alters the starting torque to a higher value, as shown in Fig 3, by the torque speed characteristic.

By inserting the suitable value rotor resistance, the speed of the slip ring motor could be controlled in spite of power loss in resistance.

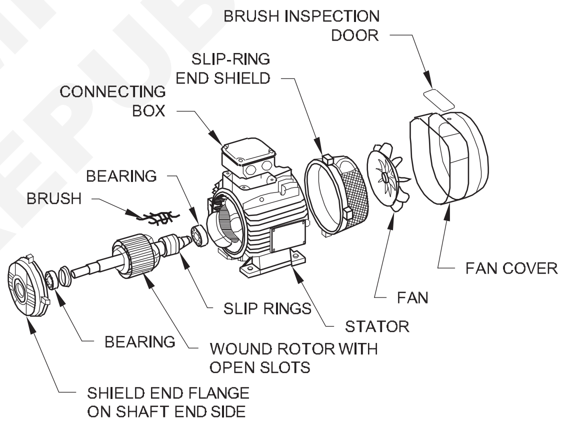
As shown in the curve, higher, external resistance improves the starting torque to a higher value. However the maximum torque remains constant for the variation of the rotor resistance.

By these curves, it is clear that the slip-ring motor could be used to start heavy loads by insertion of high resistance in the rotor to facilitate higher starting torque. At the same time the running efficiency of the motor could be achieved by cutting out the external resistance when the motor picks up its speed.

This motor could be used for drive which demands a higher starting torque and also a variable speed control - like compressors, conveyors, cranes, hoists, steel mills and printing presses.

Fig 4 shows the exploded view of the slip ring induction motor.

Fig 4



PARTS OF 3 PHASE SLIP RING INDUCTION MOTOR

Comparison between squirrel cage and slip-ring induction motors is given below:

Sl. No.	Property	Squirrel cage	Slip-ring motor
1	Rotor construction	Bars are used in rotor. Squirrel cage rotor is very simple, rugged and long lasting No slip-rings	Winding wire is used. Wound rotor requires attention Slip-ring and brush gear need frequent maintenance.
2	Starting	Can be started by DOL star-delta auto-transformer starters.	Rotor resistance starter is required
3	Starting torque	Low	Very high
4	Starting current	High	Low

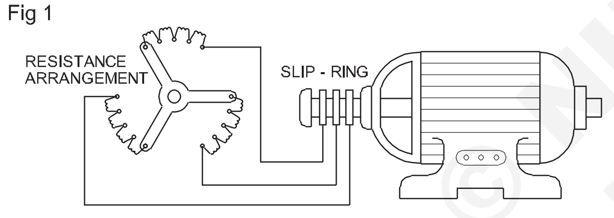
5	Speed variation	Not easy, but could be varied in larger steps by pole-changing or smaller incremental steps through thyristors or by frequency variation.	Easy to vary speed,but speed change through pole-changing is not possible. Speed change possible by - insertion of rotor resistance - using thyristors - using frequency variation - injecting emf in the rotor circuit - cascading
6	Acceleration on load	Just satisfactory	Very good
7	Maintenance	Almost nil	Requires frequent maintenance
8	Cost	Low	Comparatively high

Resistance starter for 3-phase, slip-ring induction motor

Objective: At the end of this lesson you shall be able to
- **explain the rotor resistance starters used for a 3-phase, slip-ring induction motor.**

Slip-ring induction motors are started with full-line voltage across the stator winding. However, to reduce the heavy rush of the starting current, a star-connected external resistance is added in the rotor circuit as shown in Fig 1. The external resistances are cut out, and the rotor winding ends are shorted once the motor picks up its speed.

Fig 1



SLIP RING INDUCTION MOTOR WITH RESISTANCE STARTER

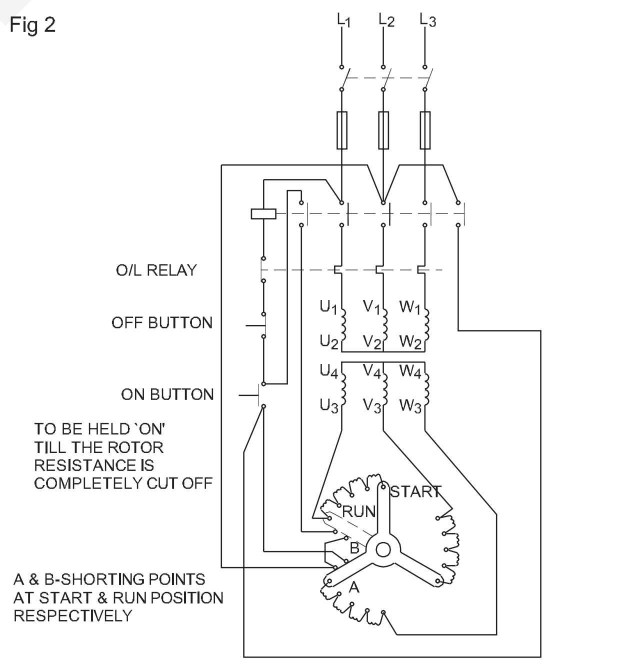
If such a manual starter is used, there is a possibility that someone may apply full voltage to the stator when the rotor resistance is in a completely cut-out position, resulting in heavy rush of the starting current and poor starting torque. This could be eliminated by the use of a protective circuit in the resistance starter; thereby motor cannot be started until and unless all the rotor resistances are included in the rotor winding. Such a semi-automatic starter is shown in Fig 2.

By pressing the 'ON' button, the contactor will close, only when the shorting point 'A' at the rotor resistance is in a closed position. This is possible only when the handle is in the start position. Once the motor starts running, the handle of the rotor resistance should be brought to 'run' position to cutout the rotor resistance.

The position of the handle clearly indicates that at the start position, the contact 'A' is in the closed position, and at the run position, contact 'B' is in the closed position, but both cannot close at the same time. The 'ON' push-button needs to be held in the pushed-position till the handle is brought to the run-position. During the run-position, the handle contact 'B' closes the no-volt coil circuit, and the pressure on the 'ON' button can be released.

In general, for small machines, the rotor resistance is air-cooled to dissipate the heat developed during starting. For larger machines, the rotor resistance is kept in an insulating oil tank for cooling. The starter shown is intended to start the motor only. As speed regulation through the rotor resistance needs intermediate positions, they are specially designed and always oil-cooled.

Fig 2



ROTOR RESISTANCE STARTER FOR SLIP RING INDUCTION MOTOR

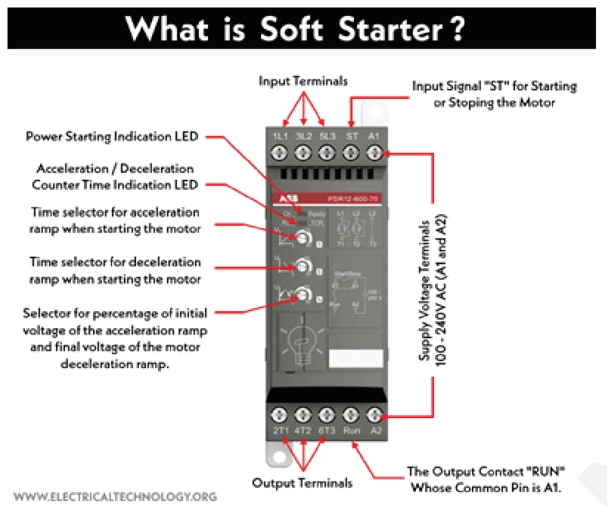
Soft Starter

Objectives: At the end of this lesson you shall be able to
- **explain the particularity of softstarter, its working principle**
- **describe the advantages and disadvantages of soft starter and its application.**

The soft starter is a type of motor starter that uses the voltage reduction technique to reduce the voltage during the starting of the motor.

The soft starter offers a gradual increase in the voltage during the motor startup. This will allow the motor to slowly accelerate & gain speed in a smooth fashion. It prevents any mechanical tear & jerking due to sudden supplying of full voltage.

Fig 1



The torque of an induction motor is directly proportional to the square of current. & the current depends on the supply voltage. So the supply voltage can be used to control the starting torque. In a normal motor starter, applying full voltage to the motor generates maximum starting torque which possess mechanical hazard to the motor.

Therefore we can say that a soft starter is a device that reduces the starting torque & gradually increase it in a safely manner until it reaches it rated speed. One the motor attains its rated speed, the soft starter resumes the full voltage supply through it.

During motor stopping, the supply voltage is gradually reduced to smoothly decelerate the motor. Once the speed reaches zero, it breaks the input voltage supply to the motor.

The main component used for the regulation of voltage in a soft starter is a semiconductor switch such as a Thyristor (SCR). Adjusting the firing angel of the thyristor regulates the voltage supplying through it. Other components such as OLR (overload relay) used for overcurrent protection is also used.

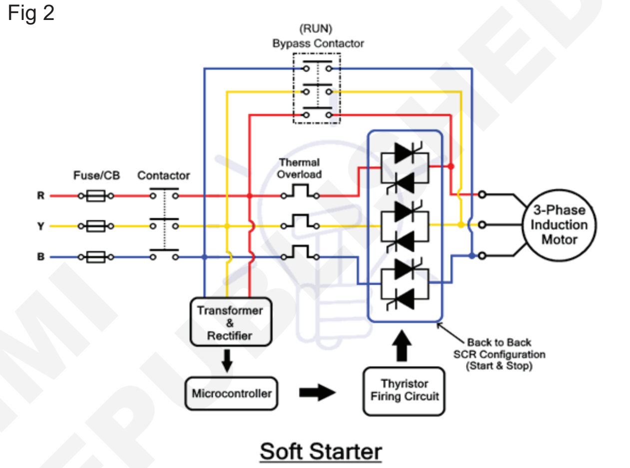
Diagram of Soft Starter

In a three phase induction motor, two SCRs are connected in an anti-parallel configuration along each phase of the motor making it a total of 6 SCRs. These SCRs are controlled using a separate logic circuitry that can be a PID controller or a microcontroller. The logic circuitry is powered from the mains using a rectifier circuit as shown in the figure.

Apart from the Power switches & logic circuitry, other protection components such as the circuit breaker or fuse, magnetic contactor for isolation & an OLR (Overload relay) for prevention of overcurrent is used.

A bypass switch is also used to resume the full voltage across the motor when it attains the full rated speed.

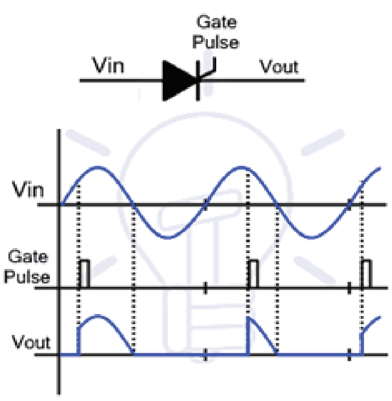
Fig 2



Working Principle of Soft Starter

The main component used for controlling the voltage in a soft starter is a thyristor. It is a controlled rectifier that starts conduction of the current flow in only one direction when a gate pulse is applied called the firing pulse.

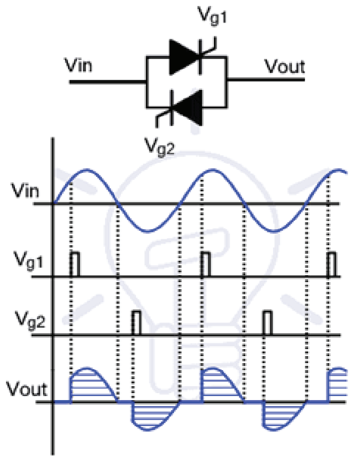
Fig 3



The angle of the firing pulse determine how much of the input voltage cycle should be allowed through it. Since AC swings between maximum & minimum peak forming a complete 360° cycle, we can use the angle of firing pulse to switch on the thyristor for a specific duration and control the supplied voltage.

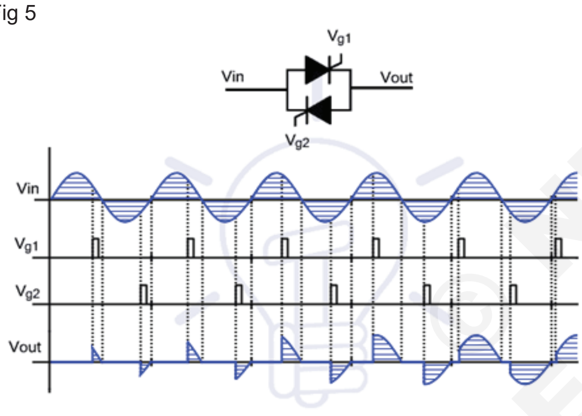
The firing pulses can vary between 0° to 180°. The decrease in the angle of firing pulse increases the conduction period of thyristor, thus allowing high voltage through it.

Fig 4



Two such thyristors are connected in back-to-back formation for each phase. So it can control the current in both directions. Each half cycle, the firing angle

Fig 5



Thyristor-Pair Operation for each phase of Soft Starter

The three pairs of thyristors, each pair for individual phase are used for controlling the voltage to start & stop the motor. The thyristor conduction period depends on the firing angle controlled by the logic circuitry.

The logic circuitry contains PID controller or a simple microcontroller programmed to generate pulses. The controller is isolated from the supply mains using opto-isolator & a rectifier is used for supplying DC source. The pulses generated by microcontroller are fed to a thyristor firing circuit that amplifies it before triggering the SCR.

When the motor starts up, the controller generates pulses for each individual SCR. The pulse is generated based on the zero crossing that is detected using a zero crossing detector. The first firing pulse angle is approximately near 180° (very low conduction period) to allow minimum voltage.

Gradually after each zero crossing, the angle of firings pulses starts decreasing, increasing the conduction period of thyristor. The voltage through thyristor starts increasing. Hence the motor speed gradually increases.

Once the motor attains its full rated speed (at 0° firing angle), the thyristors are completely bypassed using a bypass contactor under normal operation. It increases the efficiency of the soft starter since the SCR stops firing. During motor stopping, the SCR takes the control & starts firing in orderly fashion to reduce the supply voltage.

The bypass contactors can be internal or external. The internal bypass contactors are embedded inside the power switches. Each SCR have a bypass switch in parallel that supply the current under normal condition. Such contactors configuration takes small space & the starters are in compact design. While the external bypass contactors are connected externally in parallel with the soft starter. Such soft starter are bulky.

The bypass contactors are not meant to break or make the current supply to the circuit, thus it can be a low rated contactors.

Advantages of Soft Starter

Smooth Startup: Unlike conventional motor starter, it provides very gradual increase of voltage thus speed that results in a very smooth startup. There is no mechanical stress whatsoever or jerks that can damage the motor.

Acceleration & Deceleration Control: It offers a fully adjustable acceleration & deceleration of the motor. Varying the firing angle slowly or quickly can control the acceleration during startup & deceleration during stopping of motor. This is used in application where startup acceleration needs to be adjusted.

No Power Surges: Since the conventional motor starter allows full voltage across the motor, a huge inrush current start flowing into the motor that cause a power surge in the circuit. the soft starter limits such current thus preventing the power surges.

Multiple Startups: Some applications require the motor to start & stop multiple times in small period of time. such motor if used with a conventional starter will experience overheating due to high starting current. However, soft starters drastically increases the number of startups for a motor in a specific duration.

Reduction of Overheating: The motor overheating is a very serious problem. It occurs due to the high winding current during its startup. The soft starter allows a very small amount of starting current which prevents the overheating of motor.

Increased Life Span: The soft starter as compared to a conventional starter improves the life time of the motor. it is due to the smooth operation & absence of electrical & mechanical stress on the motor.

Less Maintenance: Due to its smooth operation, the induction motor is less likely to have any mechanical faults, which is why it require less maintenance as opposed to conventional motor starter.

Efficiency: A conventional motor starter supply full voltage (very high inrush current) to the motor that consumes too much energy. A soft starter significantly reduces it & allows a gradual increase in energy consumption. Also the power switches are controlled using very low voltage level. It improves the overall efficiency of the motor.

Compact & Small Size: The soft starter has a very compact design that takes up very small space. Unlike other motor starters, it has very small size.

Low Cost: compared to other starters such as VFD, this sure does cost cheaper.

Disadvantages of Soft Motor Starter

No Speed regulation: The soft starter only allows the control of input voltage supply i.e. from 0 volts to line voltage with a fixed line frequency. Since the frequency is constant the motor speed is constant & only regulates by the load connected with it. The speed of induction motor is regulated by varying the supply frequency below or above the line frequency according to the need. Such feature is only available in VFD (variable frequency drive).

Heat dissipation: The semiconductor switches inside the soft starter dissipates some energy in the form of heat. Therefore, it also requires heat sinks for cooling the power switches.

Reduced starting Torque: Since it reduces the input voltage that corresponds to the input current which is directly proportional to the starting torque of the induction motor, it significantly reduces the starting torque. This is why Soft starters are used for low or medium starting torque application.

Applications of Soft Starter

The soft starter is used in industries & is more appropriate to be used for motors that run on a constant speed.

Fans: The huge fans used in industries runs at a constant speed. However, they do require the startup protection. A soft starter is a best option for such fans.

Conveyer belts: The conveyer belts in industries are used for moving objects & it needs extra care. The sudden jerks during starting or stopping using conventional starter may misalign the belts, damages the belt due to mechanical stress & damage the objects placed on it. It requires a smooth starting & stopping offered by a soft starter

Motors using belt & pulleys: The motor that drives load through belts & pulleys cannot tolerate the sudden jerks. It wears the belt that couples it to the load. A soft starter offers a smooth starting for such motor applications.

Water or liquid Pump: Any type of pump connected with a motor requires a smooth starting & stopping due to the sudden pressure building inside the pipes. A conventional starter may generate enough pressure at startup to break the line. A soft starter offer gradual increase in the pressure to such liquid pumps. However, there is no speed control of the pump during normal operation. A VFD is a better choice for variable pump speed.

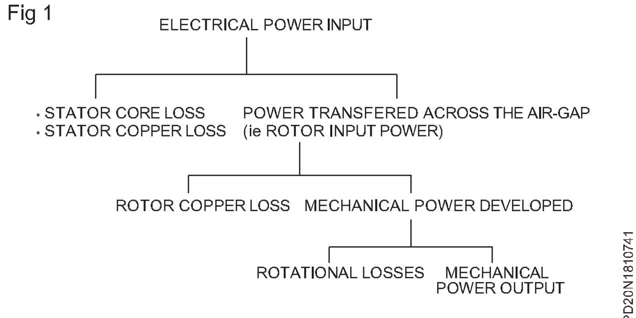
Efficiency - characteristics of induction motor- no load test - blocked rotor test

Objectives: At the end of this lesson you shall be able to
- **state the power flow diagram of an induction motor indicating the losses**
- **calculate the efficiency from the given data.**

When the three-phase induction motor is running at no-load, the slip has a value very close to zero. The torque developed in the rotor is to overcome the rotational losses consisting of friction and windage. The input power to the motor is to overcome stator iron loss and stator copper loss. The stator iron loss (consisting of eddy current and hysteresis) depends on the supply frequency and the flux density in the iron core. It is practically constant. The iron loss of the rotor is, however, negligible because the frequency of the rotor currents under normal condition is always small.

If a mechanical load is then applied to the motor shaft, the initial reaction is for the shaft load to drop the motor speed slightly, thereby increasing the slip. The increased slip subsequently causes I2 to increase to that value which, when inserted into the equation for torque calculation (i.e T = Kfs I2 cos fs), yields sufficient torque to provide a balance of power to the load. Thus an equilibrium is established and the operation proceeds at a particular value of slip. In fact, for each value of load horsepower requirement, there is a unique value of slip. Once slip is specified then the power input, the rotor current, the developed torque, the power output and the efficiency are all determined. The power flow diagram in a statement form is shown in Fig 1. Note that the loss quantities are placed on the left side of the flow point. Fig 2 is the same power flow diagram but now expressed in terms of all the appropriate relationships needed to compute the performance.

Fig 1



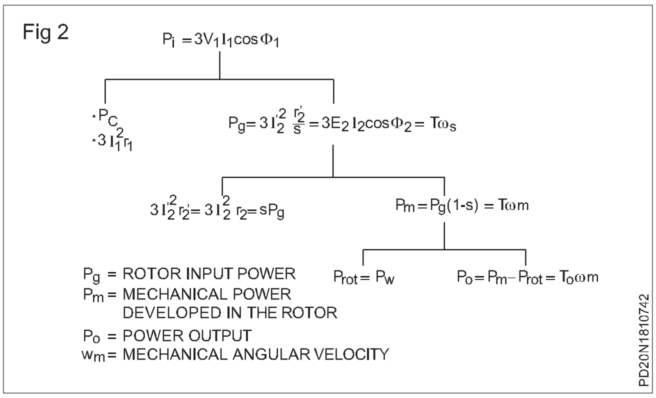
Torque, Mechanical power and Rotor output : Stator input Pi = stator output + stator losses.

The stator output is transferred fully inductively to the rotor circuit.

Obviously, rotor input Pg = stator output.

Rotor gross output, Pm = rotor input Pg - rotor cu. losses.

Fig 2



This rotor output is converted into mechanical energy and gives rise to the gross torque T. Out of this gross torque developed, some is lost due to windage and friction losses in the rotor, and the rest appear are useful torque T_o.

Let n r.p.s be the actual speed of the rotor and if it is in Nm, then

T x $2\pi n$ = rotor gross output in watts, P_m.

$$\text{Therefore, } T = \frac{\text{rotor gross output in watts}, P_m}{2\pi\, n} \text{ N.m}$$

The value of gross torque in kg.m is given by

$$T = \frac{\text{rotor gross output in watts}}{9.81 \times 2\pi\, n} \text{Kgm}$$

$$= \frac{P_m}{9.81 \times 2\pi\, n} \text{Kgm}$$

If there were no copper losses in the rotor, the rotor output will equal the rotor input and the rotor will run at synchronous speed.

$$\text{Therefore, } T = \frac{\text{rotor input } P_g}{2\,\pi\, n_s}$$

From the above two equation we get,

Rotor gross output = P_m = Tw = T x $2\pi n$

Rotor input = P_g = TW_s = T x $2\pi n_s$

The difference between the two equals the rotor copper loss.

Therefore, rotor copper loss = s x rotor input

= s x power across air gap

= sP_g.

$$\text{Also rotor input, } P_g = \frac{\text{rotor copper loss}}{s}$$

Rotor gross output P_m = Input P_g - rotor cu.loss

= (1 - s) P_g

$$\text{or } \frac{\text{rotor gross output, } p_m}{\text{rotor input, } p_g} = 1 - s$$

rotor gross output. P_m = (1 - s)P_g

$$\text{Therefore rotor efficiency} = \frac{n}{n_s}$$

Example

The power input to a 4-pole, 3-phase, 50 Hz. induction motor is 50kW, the slip is 5%. The stator losses are 1.2 kW and the windage and friction losses are 0.2 kW. Find (i) the rotor speed, (ii) the rotor copper loss, (iii) the efficiency.

Data given

No. of poles	P = 4
Frequency	f = 50 Hz
Phases	= 3
Input power	= 50kW
% Slip	s = 5%
Stator losses	= 1.2 kW
Friction & Windage losses	= 0.2 kW
Find:	
Rotor speed	= N
Rotor copper loss	= s x input power to rotor
efficiency	= η

SOLUTION

$$\text{Synchronous speed} = N_s = \frac{120f}{p} = \frac{6000}{4} = 1500 \text{ rpm}$$

$$\text{Fractional slip} = s = \frac{N_s - N_r}{N_s}$$

$$\frac{5}{100} = \frac{1500 - N_r}{1500}$$

$$75 = 1500 - N_r$$

Therefore, rotor speed, Nr = 1500 - 75 = 1425 rpm.

Input power to rotor = (50 - 1.2)kW

Rotor copper loss = s x input power to rotor

= 0.05 x 48.8

= 2.44 kW.

Rotor output = Rotor input - (Friction and windage loss + rotor cu.loss)

= 48.8 - (0.2 + 2.44)

= 46.16 kW

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{44.56 \times 100}{50} = 92.32\%.$$

Characteristics of squirrel cage induction motor

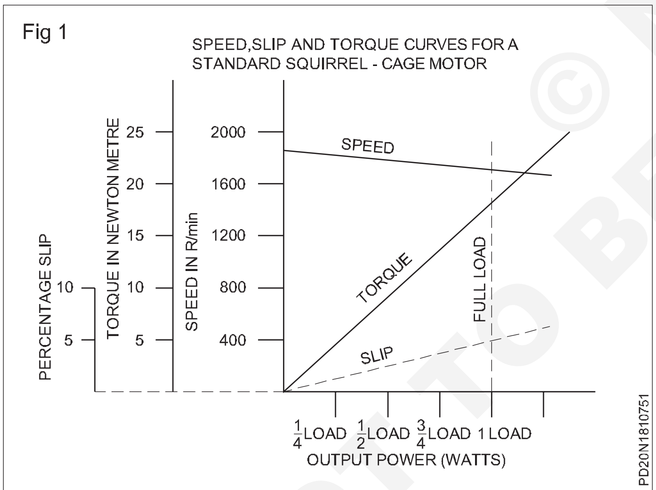
Objective: At the end of this lesson you shall be able to
- **describe the characteristics and application of a 3-phase squirrel cage induction motor.**

The most important characteristic of the induction motor is the speed torque characteristic which is also called the mechanical characteristic. A study of this characteristic will give an idea about the behaviour of the motor in load conditions. As the torque of the motor is also dependent on the slip, it will be interesting to study the characteristic of the squirrel cage induction motor to find the relationship between load, speed, torque and slip.

Speed, torque and slip characteristics: It has already been made clear that the rotor speed of a squirrel cage motor will always lag behind the synchronous speed of the stator field. The rotor slip is necessary in order to induce the rotor currents required for the motor torque. At no load, only a small torque is required to overcome the motor's mechanical losses, and the rotor slip will be very small, say about two percent. As the mechanical load is increased, however, the rotor speed will decrease, and hence, the slip will increase. This increase in slip inturn increases the induced rotor currents, and the increased rotor current in turn, will produce a higher torque to meet the increased load.

Fig 1 shows the typical speed torque and slip characteristic curves for a standard squirrel cage motor. The speed curve shows that a standard squirrel cage motor will operate at a relatively constant speed from no load to full load.

Fig 1



SPEED,SLIP AND TORQUE CURVES FOR A STANDARD SQUIRREL - CAGE MOTOR

Since the squirrel cage rotor is constructed basically of heavy copper/aluminium bars, shorted by two end rings, the rotor impedance will be relatively, low and hence, a small increase in the rotor induced voltage will produce a relatively large increase in the rotor current. Therefore, as the squirrel cage motor is loaded, from no-load to full load, a small decrease in speed is required to cause a relative increase in the rotor current. For this reason, regulation of a squirrel cage motor is very good. But the motor is often classified as a constant speed device.

The slip curve shows that the percentage slip is less than 5% load, and is a straight line.

Since the torque will increase in almost direct proportion to the rotor slip, the torque graph is similar to the slip graph which also has a straight line characteristic as shown in Fig 1.

Relationship between torque, slip rotor resistance and rotor inductive reactance: It was stated earlier that torque is produced in an induction motor by the interaction of the stator and the rotor fluxes. The amount of torque produced is dependent on the strength of these two fields and the phase relation between them. This may be expressed mathematically as

$T = K\,\phi_s I_R \cos\phi$

where T = torque in Newton metre

K = a constant

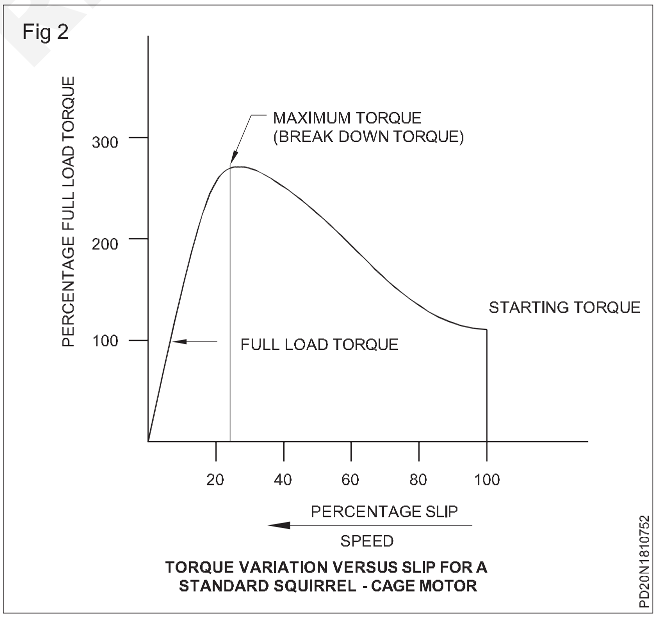
ϕ_s = stator flux in weber

I_R = rotor current in ampere

Cos ϕ = rotor power factor

From no load to full load, the torque constant (K), the stator flux (ϕs) and the rotor power factor (Cos ϕ) for a squirrel cage motor will be practically constant. Hence the motor's torque will vary almost directly with the induced rotor current (I_R) since the rotor current inturn will vary almost directly with its slip. Variation of the torque of a squirrel cage motor is often plotted against its rotor slip as shown in Fig 2.

Fig 2



TORQUE VARIATION VERSUS SLIP FOR A STANDARD SQUIRREL - CAGE MOTOR

The increase in the rotor current, and hence, the increase in the rotor torque for a given increase in the rotor slip is dependent on the rotor power factor. The rotor resistance for a squirrel cage motor will be constant. However, an increase in slip will increase the rotor frequency, and the resulting inductive reactance of the rotor from no load to full load and even upto 125 percent of rated load, the amount of rotor slip for a standard squirrel cage motor is relatively small and the rotor frequency will seldom exceed 2 to 5 Hz. Therefore, for the above range of load the effect of frequency change on impedance will be negligible, and as shown in Fig 2, the rotor torque will increase in almost a straight relationship with the slip.

In between 10 to 25 percent slip the squirrel cage motor will attain its maximum possible torque. This torque is referred to as the maximum breakdown torque, and it may reach between 200 and 300 percent of the rated torque as shown in Fig 2. At the maximum torque, the rotor's inductive reactance will be equal to its resistance.

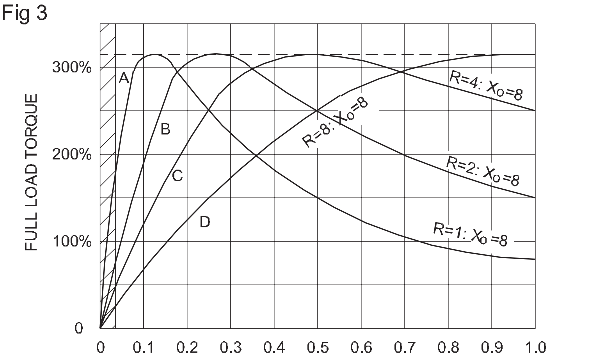
However, when the load and the resulting slip are increased much beyond the rated full load values, the increase in rotor frequency, and hence, the increase in rotor reactance and impedance become appreciable. This increase in rotor inductive reactance and the resulting decrease in rotor power factor will have two effects; first, the increase in impedance will cause a decrease in the rate at which the rotor current increases with an increase in slip, and second, the lagging rotor power factor will increase; that means, the rotor flux will reach its maximum sometime after the stator peak flux has been swept by it. The out-of-phase relationship between these two fields will reduce their interaction and their resulting torque. Hence, if the motor load is increased beyond the breakdown torque value, the torque falls rapidly due to the above two effects and the motor operation becomes unstable, and the motor will stall.

Effect of rotor resistance upon the torque/slip relationship: Fig 3 shows the relationship between torque and slip when the rotor resistance is changed. The shaded portion of the curve shows the actual operating area. Curve A for an induction motor with low rotor resistance, say 1 ohm, Curve B is for 2 ohm, Curve C is for 4 ohm and Curve D for 8 ohm.

Breakdown torque: In all these cases the standstill inductive reactance of the rotor is the same, say 8 ohm. From the curves it is clear that the maximum (breakdown) torque is the same for the four values of R. Further it is also clear that the maximum torque occurs at greater slip for higher resistance.

Starting torque: At the time of starting, the fractional slip is 1, and the starting torque is about 300% of the

Fig 3



FRACTIONAL SLIPS TORQUE/SLIP CURVES FOR AN INDUCTION MOTOR

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full load torque for the rotor having maximum resistance as shown by curve D of Fig 3, and at the same time the rotor having low resistance will produce a starting torque of 75% of the full load torque only, as shown by curve A of Fig 3. Hence, we can say that an induction motor having high rotor resistance will develop a high torque at the time of starting.

Running torque: While looking at the normal operating region in the shaded portion of the graph, it will be found the torque at running is appreciably high for low resistance rotor motors and will be conspicuously less for high resistance rotor motors.

As squirrel cage induction motors will have less rotor resistance, their starting torque is low but running torque is quite satisfactory. This is partly compensated by the double squirrel cage motors which produce high starting and normal running torque. On the other hand, the slip ring induction motor, due to its wound rotor, has the possibility of inclusion of resistance at the time of starting and reducing the same while running.

Application of squirrel cage induction motor: Single squirrel cage motors are used widely in industries and in irrigation pump sets where fairly constant speed is required. This motor has fairly high efficiency, costs less and is found to be robust in construction.

Double squirrel cage induction motors are used in textile mills and metal cutting tool operations where high starting torque is essential.

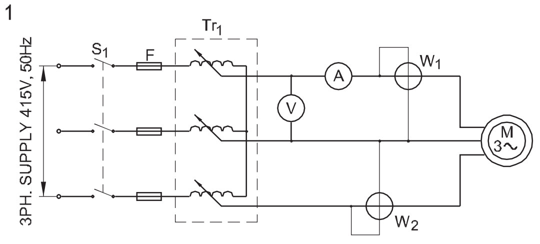
No-load test of induction motor

Objectives: At the end of this lesson you shall be able to
- **determine the constant (mechanical and iron losses of induction motor) by no-load test**
- **calculate the total equivalent resistance per phase.**

No-load test

The induction motor is connected to the supply through a 3-phase auto-transformer (Fig 1). The 3-phase auto-transformer is used to regulate the starting current by applying low voltage at the start, and then gradually increased to rated voltage. The ammeter and voltmeters are selected based upon the motor specification. The no-load current of the motor will be very low, up to 30% of full load.

Fig 1



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As the power factor of the motor on no-load is very low, in the range of 0.1 to 0.2, the wattmeters selected are such as to give a current reading at low power factor. The wattmeter full scale reading will be approximate equal to the product of the ammeter and voltmeter full scale deflection values.

The calculation is done as follows to determine the constant losses of the induction motor.

At no-load, the output delivered by the motor is zero. All the mechanical power developed in the rotor is used to maintain the rotor running at its rated speed. Hence the input power is equal to the no-load copper loss plus iron losses and mechanical losses.

Calculation

V_{NL} is ® line stator voltage

I_{NL} is ® line current

P_{NL} is ® Three-phase power input.

The input power consists of the core loss P_c, friction and windage loss $P_{(rot)}$, and the stator copper loss.

$P_{NL} = P_c + P_{rot} + 3\, I^2_{NL}\, R_S$

This permits the sum of rotational loss to be evaluated.

$P_{rot + C} = P_{NL} - 3\, I^2_{NL}\, R_S$

where the stator resistance Rs per phase obtained from a resistance measurement at the stator terminal.

In star connection R_S = R/2.

Delta connection R_S = 2/3 R.

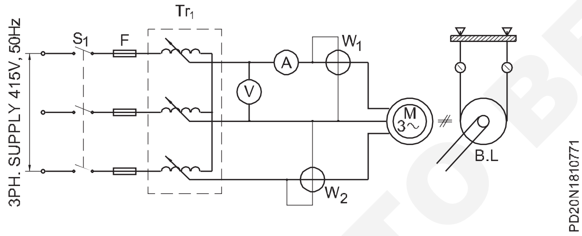
Blocked rotor test

Objectives: At the end of this lesson you shall be able to
- **determine the full load copper loss of a 3-phase induction motor by blocked rotor test**
- **calculate the total equivalent resistance per phase and efficiency.**

The connections are made similar to that of the no-load test. In this case the ammeter is selected to carry the full load current of the motor. Wattmeters will be of a suitable range and its power factor is 0.5 to unity.

An auto-transformer is used to give a much lower percentage of the rated voltage. The rotor is locked by a suitable arrangement such that it cannot rotate even if the supply is given to the motor. One such arrangement is shown in Fig 1. The belt is over-tightened on the pulley to prevent rotation.

Fig 1



As the rotor is in a locked condition it is equivalent to the short circuit secondary of a transformer. Therefore, a small induced voltage in the rotor cage winding will be sufficient to cause a large current to flow in the cage.

It is very essential to limit the supply voltage to a value less than 5% at start and then gradually increase until the starter current is equal to the full load current. The frequency of the starter supply voltage is maintained at normal rated supply frequency.

The method of calculating the copper losses from the result is illustrated through the example given below.

Example

A 5 HP 400V, 50 Hz, four-pole, three-phase induction motor was tested and the following data were obtained.

Blocked rotor test: V_s = 54, P_s = 430, I_s = 7.5 A.

The resistance of the stator winding gives a 4 V drop between the terminals' rated DC current flowing.

Find the power factor at short circuit and Re and Xe and full load copper loss.

Given:

Output	= 5 HP
Voltage	= 400 V
Frequency	= 50 Hz.
Blocked rotor voltage, VS	= 54 V
Power PS,	= 430 W
Current, IS	= 7.5 A

Find:

Power factor at short circuit	= Cos θ_S
Equivalent resistance, R_e/phase	
Equivalent reactance X_e/phase	
Full load copper loss	= $3I^2 R_e$.

Known:

$W_S = \sqrt{3}\, V_S I_S \quad \text{Cos } \varnothing_S$

$$\text{Equivalent impedance}\, Z_e = \frac{V_s}{\sqrt{3 I_s}} = \sqrt{R_e^2 + X_e^2}$$

$$R_e = \text{equivalent resistance} = \frac{P_s}{3 I_s^2}$$

$$X_e = \text{equivalent reactance} = \sqrt{Z_e^2 - R_e^2}$$

Solution:

$$W_S = \sqrt{3}\, V_S I_S \quad \text{Cos}\ \text{Ø}_S$$

$$\text{Cos}\phi_s = \frac{W_s}{\sqrt{3}\ V_s I_s}$$

$$\text{Cos}\,\phi_S = \frac{430}{1.72 \times 54 \times 7.5}$$

$$= \frac{430}{696.6}$$

$$= 0.61$$

$$\text{Equivalent resistance} R_e/\text{phase} = \frac{P_s}{3\ X\ I_s^2}$$

$$= \frac{430}{3 \times (7.5)^2}$$

$$= \frac{430}{168.75} = 2.5\Omega$$

$$X_e = \text{equivalent reactance/phase} = \sqrt{Z_e^2 - R_e^2}$$

$$Z_e = \frac{54}{\sqrt{3} \times 7.5} = \frac{54}{12.90} = 4.1\Omega.$$

$$X_e = \sqrt{4.1^2 - 2.5^2} = \sqrt{16.81 - 6.25}$$

$$= \sqrt{10.56} = 3.24\Omega.$$

Full load copper loss $= 3\ I^2\ R_e$

$= 3 \times 7.5^2 \times 2.5 = 421.875$ watts

Answer

i cos ϕ_s = 0.61

ii Equivalent resistance R_e /phase = 2.5 Ω

iii Equivalent reactance X_e/phase = 3.24 Ω

iv Full load copper loss = 421.875 watts

Auto-transformer starter

Objectives: At the end of this lesson you shall be able to

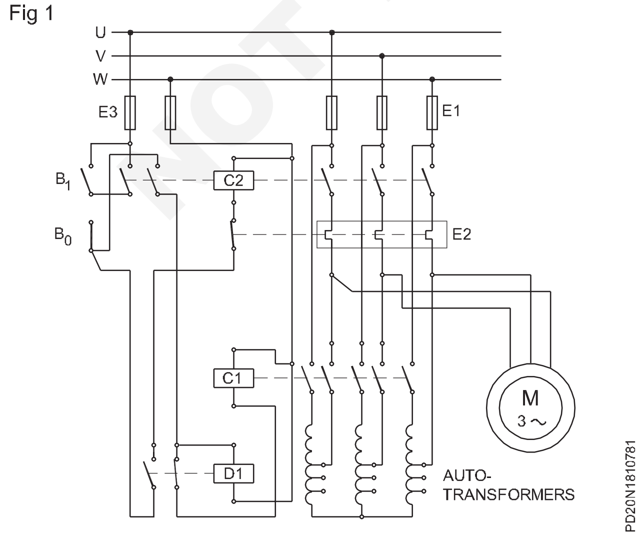
- **explain the construction and operation of auto-transformer starter**
- **explain power circuit and control circuit of auto-transformer starter.**

Auto-transformer starter

By connecting series resistances reduced voltage is obtained at the motor leads. It is simple and cheap, but more power is wasted in the external series resistances.

In auto transformer starting method the reduced voltage is obtained by taking tappings at suitable points from a three phase auto -transformer as shown in Fig 1. The auto transformers are generally tapped at 55, 65, 75 percent points. So that the adjustment at these voltages may be made for proper starting torque requirements. Since the contacts frequently break, large value of current acting some time quenched effectively by having the auto-transformer coils immersed in the oil bath.

Fig 1



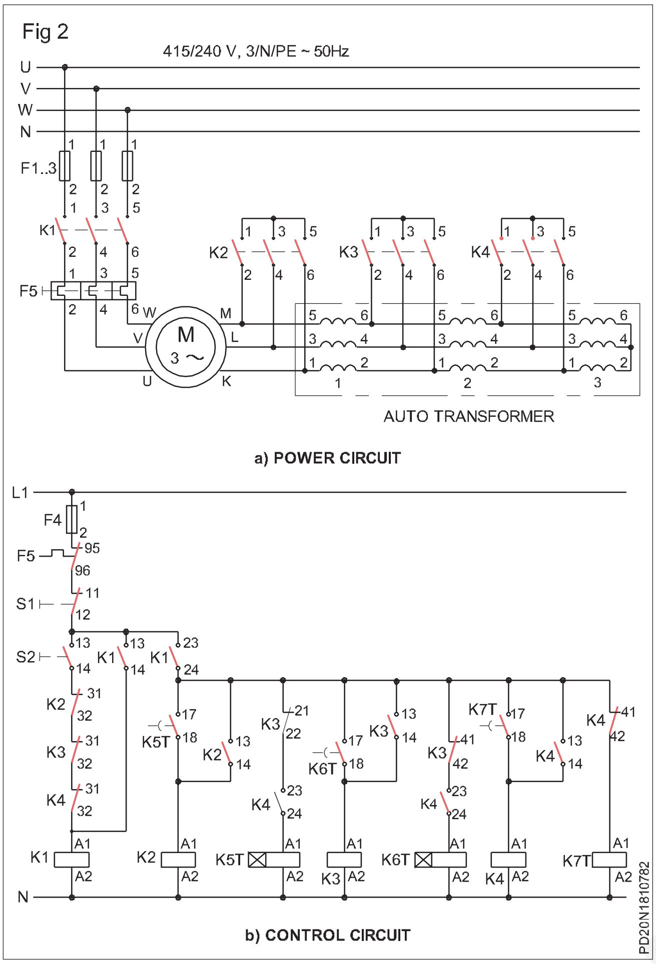
The power circuit of the auto-transformer is shown in Fig 2a and control circuit of auto-transformer is shown in Fig 2b.

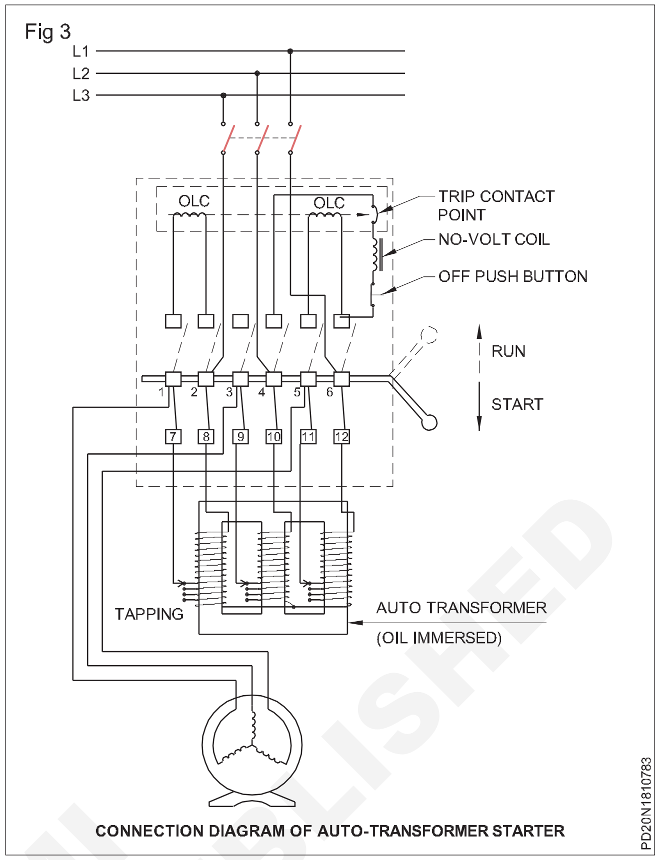
Auto-transformer starter - operation

In this type of starter reduced voltage for starting the motor is obtained from a three-phase star connected auto-transformer. While starting, the voltage is reduced by selecting suitable tappings from the auto-transformer. Once the motor starts rotating 75% of its synchronous speed, full line voltage is applied across the motor and the auto-transformer is cut off from the motor circuit.

Fig 3 shows the connection of an auto-transformer starter. To start the motor the handle of the starter is turned downward and the motor gets a reduced voltage from the auto-transformer tappings. When the motor attains about 75% of its rated speed the starter handle is moved upward and the motor gets full voltage. The auto-transformer gets disconnected from the motor circuit.

Hand operated auto-transformer starters are suitable for motors from 20 to 150 hp whereas automatic auto-transformer starters are used with large horse-power motors upto 425 hp.





Single phasing preventer/phase failure relay

Objectives: At the end of this lesson you shall be able to
- **define single phasing**
- **state the effects of single phasing**
- **explain the necessity of a single phasing preventer**
- **classify the single phasing preventers**
- **explain the installation procedure**
- **explain the procedure for troubleshooting and servicing of single phasing preventer.**

Single phasing preventer/phase failure relay: When one of the three lines of a three-phase supply system fails or opens, the load current flows between the other two lines only and the fault is known as single phasing.

Effect of single phasing: The effect of single phasing is different with different types of loads as follows

- In 3-phase heating loads, the heat produced decreases to around 50% at the same time it does not harm the equipment.
- In three-phase motors, the effect of single phasing is different on different occasions. i) During starting, if single phasing occurs, the motor fails to start or stalls as proper rotating magnetic field is not created. But the motor draws a very large current and motor windings gets heated up. ii) During running, if single phasing occurs, the motor may or may not run depending upon the load condition and the phase in which supply is available will draw a large current and the winding is likely to burn out due to overheating.

Necessity of single phasing preventer/phase failure relay: If two phases of the supply to a three-phase induction motor are interchanged, the motor will reverse its direction of rotation. This action is called phase reversal. In the operation of elevators and in many industrial applications, phase reversal may result in serious damage to the equipment and injury to people using the equipment. In other situations, if a fuse blows or a wire connected to the motor breaks while the motor is running, the motor will continue to operate on two phase but will experience serious overheating. To protect motors against these conditions of phase failure, a single phase preventer is used.

Types of preventers: Single phasing preventers are available in three types.

- Mechanical
- Current sensing
- Voltage sensing

Single phasing preventer - voltage sensing : In an AC three-phase supply the order in which three -phase voltages reach the maximum value is known as phase sequence. The phase voltage reaches their maximum positive value one after another at 120o in clockwise known as positive phase sequence and in anti-clock wise known as negative phase sequence. In the case of phase reversal or unbalanced voltages or no voltage in a line it results in a super-imposition of negative phase sequence over the normal positive phase sequence of supply voltages. This negative sequence is filtered by a resistance capacitance or resistance, capacitance and inductor network and de-energise the relay in the voltage the sensing single phasing preventer.

Fig 1 and Fig 2 shows the block diagram and circuit diagram of a typical voltage sensing single phasing preventor. In this a resistance, capacitance network is utilized to sense the negative phase sequence. When phase sequences and voltages are correct, no voltage will be generated across the filtered output i.e. across capacitor. C4 in the circuit which drives the transistor Q1 to cut off transistor Q2 to drive the relay.

Fig 1

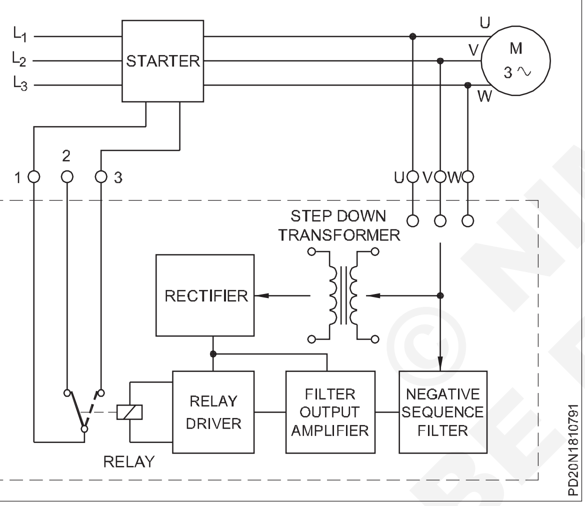
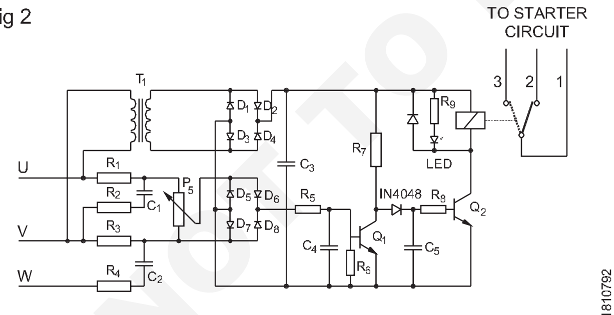


Fig 2



CIRCUIT DIAGRAM OF TYPICAL VOLTAGE SENSING SINGLE PHASING PREVENTOR

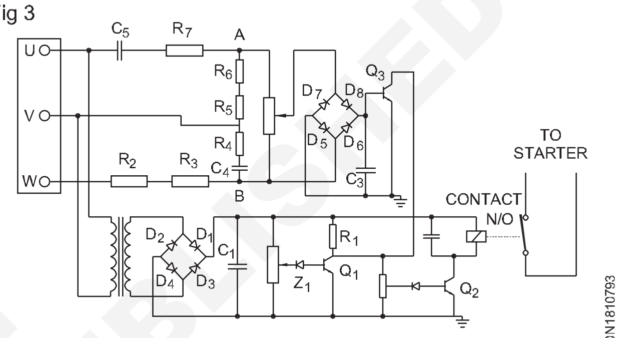
When the negative sequence occurs due to unbalanced supply voltage or phase reversal, a voltage is developed across the capacitor C4 which drives the transistor Q1 to saturation and transistor Q2 to cut off. This results in switching off the relay circuit.

Some of the single phasing preventors are provided with the facility to adjust unbalanced settings. For example when the relay is found to operate very frequently for the set value, the unbalanced pre-set can be changed by operating the pre-set P5 in Fig 2.

Single phasing preventor with over-voltage and under voltage cut off (Total motor protection): When a motor is fed with reduced voltage, the motor draws excess current to drive the load and with an over -voltage, also it draws excess current. To protect the motor from under-voltage or over-voltage and also from single phasing a preventer with over and under voltage protection is used for total motor protection.

Fig 3 shows an arrangement of over-voltage and under -voltage cut off circuit along with single phasing preventer.

Fig 3



TYPICAL CIRCUIT DIAGRAM FOR TOTAL MOTOR PROTECTION

In the circuit transistor Q1 serves as over-voltage cut off and transistor Q2 serves as under-voltage cut off whereas transistor Q3 serves as single phasing preventer.

Installation of single phasing preventer: Installation and connection of single phasing preventor shall be done as recommended by the manufacturer. Preferably single phasing preventers shall be located nearer to the equipment and not subjected to abnormal vibration. Care should be taken to locate the unit away from a heat generating source such as oven, furnace etc.

A single phase preventer shall be connected with the supply line and starter to the appropriate terminals and circuits.

Some of the commonly used single phasing preventors and their connection with starter are shown in Figs 4 & 5 for your reference.

Troubleshooting and maintenance of single phasing preventer: The arrangement of components and their circuits of single phasing preventers vary from one make to another make as well as from one type to another type.

It is preferred to follow the manufacturer's recommendations for troubleshooting and maintenance of single phase preventers. A few general guide lines for troubleshooting of single phase preventers are given in the Table-1.

Fig 4

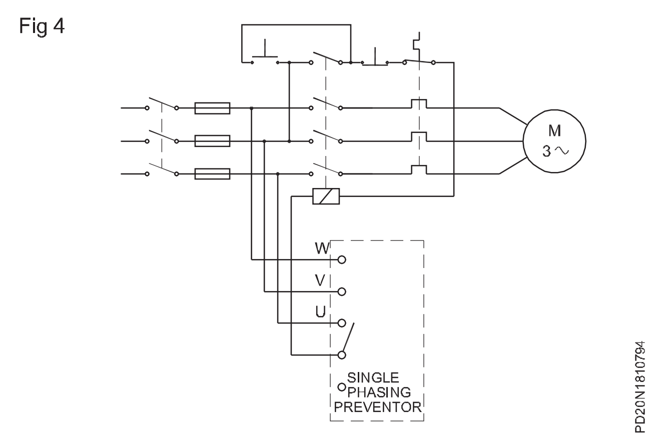


Fig 5

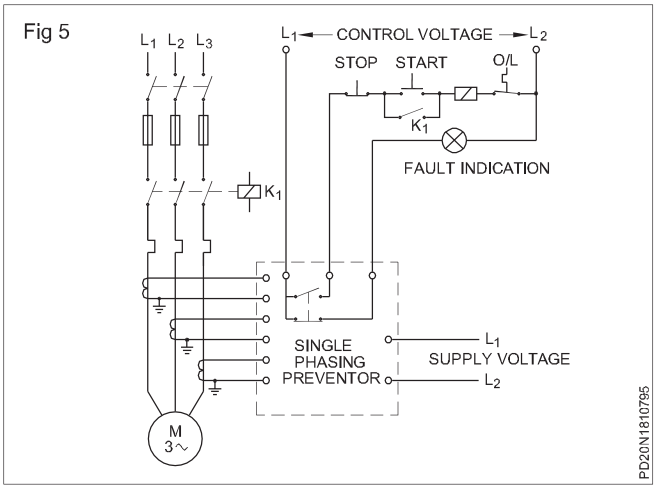


Table 1

S.No.	Symptoms	Possible causes	Remedy
1	Starter with single phase preventer does not start.	No supply. Low supply voltage.	Check and resume supply. Verify and correct the voltage.
		Unbalanced line voltages.	Verify and correct.
		Improper phase sequence.	Reverse the phase sequence by interchanging any two incoming lines.
		Single phasing	Check and rectify.
		No control circuit voltage.	Check and rectify.
2	Starter with single phase preventer does not hold on.	Low supply voltage. Unbalanced line voltages.	Verify and correct. Verify and correct.
		Single phasing.	Verify and correct.
		Improper phase sequence.	Reverse the phase sequence.
		Defect in single phase preventer electronic circuit.	Check, repair or replace.
		Relay of single phase preventer is not energised.	Check, rectify or replace.
		Improper function of relay contacts.	Check, rectify or replace.
		Open in holding circuit.	Check and correct.
3	Starter with single phase preventer trips frequently.	Abnormal fluctuations in line voltages.	Check and rectify.
		Improper settings or unbalanced settings.	Adjust the unbalanced settings.
		Loose contact in supply lines/ control circuit.	Check and rectify.

Braking system of motors

Objectives: At the end of this lesson you shall be able to
- **state the necessity of braking system for motors**
- **list and explain each type of braking system.**

Necessity of braking system

The term braking comes from the term brake. The brake is an equipment to reduce the speed of any moving or rotating equipment, like vehicles, locomotives etc. The process of applying brakes can be termed as braking.

The term braking in two parts i) Mechanical braking and the ii) Power braking. In mechanical braking the speed of the machine is reduced solely by mechanical process but in Powerbraking the whole process is depended on the flux and torque directions. Each type of Power braking is the reversal of the direction of the flux. Braking is the process of reducing speed of any rotating machine. The application of braking is in factories, industrial areas or be it in locomotives or vehicles. Everywhere the use of mechanical and Power brakes is inevitable.

Types of braking

Brakes are used to reduce or cease the speed of motors. There are various types of motors available (DC motors, induction motors, synchronous motors, single phase motors etc.) and the specialty and properties of these motors are different from each other, hence this braking methods also differs from each other. Braking can be divided in to three methods mainly, which are applicable for almost every type of motors.

1 Plugging type braking

2 Regenerative Braking

3 Dynamic braking.

1 **Plugging type braking:** In this method the terminals of supply are reversed, as a result the generator torque also reverses which resists the normal rotation of the motor and as a result the speed decreases. During plugging external resistance is also introduced into the circuit to limit the flowing current. The main disadvantage of this method is that here power is wasted.

2 **Regenerative braking:** Regenerative braking takes place whenever the speed of the motor exceeds the synchronous speed. This braking method is called regenerative braking because here the motor works as generator and supply itself is given power from the load, i.e. motors. The main criteria for regenerative braking is that the rotor has to rotate at a speed higher than synchronous speed, only then the motor will act as a generator and the direction of current flow through the circuit and direction of the torque reverses and braking takes place. The only disadvantage of this type of braking is that the motor has to run at super synchronous speed which may damage the motor mechanically and electrically, but regenerative braking can be done at sub synchronous speed if the variable frequency source is available.

3 **Dynamic braking:** Another method of reversing the direction of torque and braking the motor is dynamic braking. In this method of braking the motor which is at a running condition is disconnected from the source and connected across a resistance. When the motor is disconnected from the source, the rotor keeps rotating due to inertia and it works as a self -excited generator. When the motor works as a generator the flow of the current and torque reverses.

Method of speed control of 3 phase induction motor

Objectives: At the end of this exercise you shall be able to
- **list the speed control methods from stator and rotor side**
- **explain the speed control methods of 3 phase induction motor.**

In 3 phase induction motor, speed can be controlled from both stator and rotor side

1 Speed control methods from stator side
  - By changing the applied voltage
  - By changing the applied frequency
  - By changing the number of stator poles

2 Speed control from rotor side
  - Rotor rheostat control
  - Cascade operation
  - By injecting EMF in rotor circuit

1 Speed control from stator side

a By changing the applied voltage: Torque equation of induction motor is

$$T = \frac{k_1 sE_2^2 R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$= \frac{3}{2\pi N_s} \frac{sE_2^2 R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

Rotor resistance R2 is constant and if slip s is small then sX_2 is so small that it can be neglected. Therefore, $T \alpha$ sE_2^2 where E_2 is rotor induced emf and $E_2 \alpha V$

And hence $T \alpha V^2$, thus if supplied voltage is decreased, torque decreases and hence the speed decreases.

This method is the easiest and cheapest, still rarely used because

1 A large change in supply voltage is required for relatively small change in speed.

2 Large change in supply voltage will result in large change in flux density, hence disturbing the magnetic conditions of the motor.

b By changing the applied frequency: Synchronous speed (Ns)of the rotating magnetic field of induction motor is given by,

$$N_s = \frac{120f}{P} \text{rpm}$$

where, f = frequency of the supply and P = number of stator poles.

Thus, synchronous speed changes with change in supply frequency, and thus running speed also changes. However, this method is not widely used. This method is used where, only the induction motor is supplied by a generator (so that frequency can be easily changed by changing the speed of prime mover).

c Changing the number of stator poles: From the above equation, it can be also seen that synchronous speed (and hence, running speed) can be changed by changing the number of stator poles. This method is generally used for squirrel cage induction motors, as squirrel cage rotor adapts itself for any number of stator poles. Change in stator poles is achieved by two or more independent stator windings wound for different number of poles in same slots.

For example, a stator is wound with two 3phase windings, one for 4 poles and other for 6 poles.

For supply frequency of 50 Hz

i Synchronous speed when 4 pole winding is connected, Ns = 120 x (50/4) = 1500 RPM

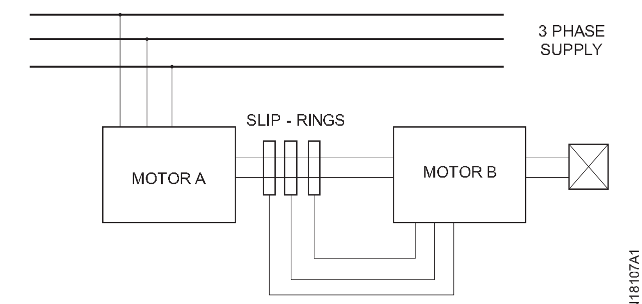
ii Synchronous speed when 6 pole winding is connected, Ns = 120 x (50/6) = 1000 RPM

2 Speed control from rotor side

a Rotor rheostat control: This method is similar to that of armature rheostat control of DC shunt motor. But this method is only applicable to slip ring motors, as addition of external resistance in the rotor of squirrel cage motors is not possible.

b Cascade operation: In this method of speed control, two motors are used. Both are mounted on a same shaft so that both run at same speed. One motor is fed from a 3phase supply and other motor is fed from the induced emf in first motor via slip-rings. The arrangement is as shown in Fig 1.

Fig 1



CASCADE OPERATION

Motor A is called main motor and motor B is called auxiliary motor.

Let, N_{s1} = frequency of motor A

N_{s2} = frequency of motor B

P_1 = number of poles stator of motor A

P_2 = number of stator poles of motor B

N = speed of the set and same for both motors

f = frequency of the supply

Now, slip of motor A, $S_1 = (N_{s1} - N) / N_{s1}$.

Frequency of the rotor induced emf in motor A, $f_1 = S_1 f$. Now, auxiliary motor B is supplied with the rotor induce emf therefore, $N_{s2} = (120f_1) / P_2 = (120S_1 f) / P_2$. Now putting the value of $S_1 = (N_{s1} - N) / N_{s1}$

$$N_{s2} = \frac{120f\left(N_{s1} - N\right)}{P_2 N_{s1}}$$

At no load, speed of the auxiliary rotor is almost same as its synchronous speed. i.e. N = Ns2. From the above equations, it can be obtained that

$$N = \frac{120f}{P_1 + P_2}$$

With this method, four different speeds can be obtained

1 When only motor A works, corresponding speed = Ns1 = 120f / P1

2 When only motor B works, corresponding speed = Ns2 = 120f / P2

3 If cumulative cascading is done, speed of the set = N = 120f / (P1 + P2)

4 If differential cascading is done, speed of the set = N = 120f (P1 - P2)

c By injecting EMF in rotor circuit: In this method, speed of induction motor is controlled by injecting a voltage in rotor circuit. It is necessary that voltage (emf) being injected must have same frequency as of slip frequency. However, there is no restriction to the phase of injected emf. If we inject emf which is in opposite phase with the rotor induced emf, rotor resistance will be increased. If we inject emf which is in phase with rotor induced emf, rotor resistance will decrease. Thus, by changing the phase of injected emf, speed can be controlled. The main advantage of this method is a wide range of speed control (above normal as well as below normal) can be achieved. The emf can be injected by various methods such as Kramer system, Scherbius system etc.

Maintenance, service and troubleshooting in AC 3 phase squirrel cage induction motor and starters

Objectives: At the end of this lesson you shall be able to
- **list and state about the maintenance schedule of AC 3 phase motor**
- **list out the possible faults, causes and remedies in 3 phase motors**
- **explain the mechanical problems in motor, bearings and their remedies**
- **state the lubrication techniques on learning**
- **explain the troubleshooting of AC motor starters and maintenance of starters.**

Generally due to the rugged construction of the AC squirrel cage induction motor, it requires less maintenance. However to get trouble-free service and maximum efficiency, this motor needs a scheduled routine maintenance. As found in most of the industries the AC squirrel cage motor is subjected to full load for 24 hours a day and 365 days a year. Therefore the maintenance should be scheduled to have periodic maintenance for a selected area on daily, weekly, monthly, half yearly and yearly periods for increasing the working life of the motor and to reduce the break down time.

Maintenance schedule: Suggested maintenance schedule for the AC squirrel cage induction motor is given below as a guide.

Daily maintenance

- Examine earth connections and motor leads.
- Check motor windings for overheating. (Note that the permissible maximum temperature is above that which can be comfortably felt by hand.)
- Examine the control equipment.

In the case of oil ring lubricated machines

i examine bearings to see that oil rings are working

ii note the temperature of the bearings

iii add oil if necessary

iv check end play.

Weekly maintenance

- Check belt tension. In a case where this is excessive it should immediately be reduced and in the case of sleeve bearing machines, the air gap between the rotor and stator should be checked.
- Blow out the dust from the windings of protected type motors, situated in dusty locations.
- Examine the starting equipment for burnt contacts where motor is started and stopped frequently.
- Examine oil in the case of oil-ring lubricated bearings for contamination by dust, dirt etc. (This can be roughly ascertained on inspection by the colour of the oil).

Monthly maintenance

- Overhaul the controllers.
- Inspect and clean the oil circuit breakers.
- Renew oil in high speed bearings in damp and dusty locations.
- Wipe brush holders and check the bedding of brushes of slip-ring motors.
- Check the condition of the grease.

Half-yearly maintenance

- Clean the winding of the motors which are subjected to corrosive or other such elements. Also bake and varnish if necessary.
- In the case of slip ring motors check slip rings for grooving or unusual wear.
- Renew grease in ball and roller bearings.
- Drain all oil bearings, wash with kerosene, flush with lubricating oil and refill with clean oil.

Annual maintenance

- Check all high speed bearings and renew if necessary.
- Blow out clean dry air over the windings of the motor thoroughly. Make sure that the pressure is not so high as to damage the insulation.
- Clean and varnish dirty and oily windings.
- Overhaul motors that are subject to severe operating conditions.
- In the case of slip ring motors, check the slip ring for pittings and the brush for wear. Badly pitted slip rings and worn out brushes should be replaced.
- Renew switch and fuse contacts if badly pitted.
- Renew oil in starters that are subjected to damp or corrosive elements.
- Check insulation resistance to earth and between phases of motor windings, control gear and wiring.
- Check resistance of earth connections.
- Check air gaps.

Records: Maintain independent cards or a register (as per specimen shown in trade practical) giving a few pages for each machine and record therein all important inspections and maintenance works carried out from time to time. These records shall show past performance, normal insulation level, gap measurements, nature of repairs and time between previous repairs, and other important information which would be of help for good performance and maintenance.

Faults which occur in AC 3-phase squirrel cage motor can be broadly divided into two groups

They are

1 Electrical faults

2 Mechanical faults.

In most of the cases both the faults may be individually present or both may be present, as one type of fault creates the other fault. The following charts give the cause, the test to be carried out and possible remedy.

Chart 1

Motor fails to start

S.No	Cause	Test	Remedy
1	Overload relay tripped.	Wait for overload coils to cool. Push the reset button if separately provided. In some starters the stop button has to be pushed to reset the overload relay.	If motor could not be started check the motor circuit for other causes as outlined in this chart.
2	Failure of power supply.	Test the power supply at the starter incoming terminals.	If the supply is present in the incoming terminals of the starter, check the starter for fault. If not, check the main switch and fuses. Replace the fuses if necessary or restore power supply.
3	Low voltage.	Measure the voltage at the mains and compare with the name-plate rating.	Restore normal supply or check the cables for underrating.
4	Wrong connection.	Compare the connection with the original diagram of the motor.	Still if motor does not start, reconnect, after disconnecting the connection of the motor.
5	Overload.	Measure the starting torque required by load.	Reduce load, raise tapping on auto-transformer, install a motor of a higher output.
6	Damaged bearings.	Open the motor and check the play of bearings.	Replace if required.
7	Faulty stator winding.	Measure current per phase and they should be equal, if required measure resistance per phase; check insulation resistance between winding and earth.	Repair the fault if possible or rewind stator.
8	Wrong control connections.	Check the control circuit and compare it with the circuit diagram.	Reconnect the control circuit according to the manufacturer's circuit diagram.
9	Loose terminal connections at mains or at starter or at motor.	Check the terminal connection of the main switch, starter and motor for discolouring and loose nuts.	Tighten the terminals.

S.No	Cause	Test	Remedy
10	Driven machine is locked.	Disconnect the motor from the load. the driven machine and rectify the	If the motor starts satisfactorily check defect.
11	Open circuit in stator or rotor.	Check visually and then with multimeter/megger.	Rectify the defect or wind.
12	Short circuit in stator winding.	Check the phases and coil groups with the help of an ohmmeter or use internal growler.	Repair the winding or rewind.
13	Winding is grounded.	Test with a Megger or test lamp.	If the fault is found, repair or rewind.
14	Bearing stiff.	Rotate the rotor by hand.	If the rotor is stalled, dismantle the motor and rectify the defect.
15	Overload.	Check the load and belt tension.	Reduce the load or loosen the tight belts.

Chart 2

Motor starts but does not share load (Runs at low speed when loaded.)

S.No	Cause	Test	Remedy
1	Too low a voltage.	Measure voltage at the motor terminals and verify it with the name-plate.	Renew bad fuses; repair circuit and remove the cause of low voltage, loose or bad contacts in starter, switches, distribution box,etc.
2	Bad connection.	Check the connection and contact of starter for loose contact.	Remove the fault as required.
3	Too low or high tension on driving belt.	Measure the tension and verify it with the instruction of the manufacturer.	Adjust the belt tension.
4	Open circuit in rotor winding.	Examine the rotor bars and joints.	Re-solder the rotor bars.
5	Faulty stator winding.	Check for continuity, short circuit and leakage.	Repair the circuit if possible or rewind the stator.
6	Defective bearings.	Examine bearings for play.	Replace the bearings.
7	Excessively loaded.	Measure the line current of the motor and compare it with its rated current.	Reduce the mechanical load on the motor.
8	Low frequency. frequency meter.	Measure the line frequency with a	If the line frequency is low inform the supply authorities and get it corrected.

Chart 3

Motor blows off fuses

S.No	Cause	Test	Remedy
1	Incorrect size of fuses	Check the size of the fuse wire (it should be rated for 1½ times its normal current); connect the ammeter in the circuit and test for excess load current.	Replace the fuse wire if necessary; repair the motor if it is due to electrical fault of stator or rotor.
2	Low voltage	Measure the line voltage.	Remove the cause of low voltage.

3	Excessively loaded	Measure the line current and compare it with its rated current.	Rectify the cause of overload or install a motor of higher output rating.
4	Faulty stator winding	Check for open circuit, short circuit or leakage of the stator as explained earlier.	Repair the fault; if not possible then rewind the stator.
5	Loose connection in starter	Check for loose or bad connection in the starter because it may cause unbalancing of current.	Rectify the loose connection; loose all the contact points of the starter with sandpaper and align the contacts.
6	Wrong connection	Check the connection with the original diagram.	Reconnect the motor if it still does not start.

Chart 4

Over Heating of the motor

S.No	Cause	Test	Remedy
1	Too high or low voltage or frequency.	Check the voltage and frequency at the terminal of the motor.	Rectify the cause of low or high voltage or frequency as the case may be
2	Wrong connection.	Compare the connection with the given circuit diagram.	Reconnect the connection if required.
3	Open circuit in rotor.	Loose joints of rotor bars cause heat.	Resolder the joints of rotor bars and end rings.
4	Faulty stator winding.	Check for continuity, short circuit and leakage as stated before.	Remove the fault if possible; otherwise rewind the stator winding. Remove dirt and dust from them if any
5	Dirt in ventilation ducts. dust or dirt in them.	Inspect ventilation ducts for any Rectify the single phasing defect.	Reduce the load or loosen the belt.
6	Overload.	Check the load and the belt.	If the defect is with the driven machine repair it. If the problem is with the bearing, investigate and repair or replace with new one.
7	Unbalanced electrical supply.	Check the voltage for single phasing. Check the connections and fuses. Remove the load and check the rotor for free rotation.	If required replace the motor designed for this purpose.
8	Motor stalled by driven machine or tight bearing.	Check the motor - starter contactor	Loose the machine bearing or grease the bearing or replace the bearing.
9	Motor when used for reversing heats up.	Check the connection	Check the manufacturer's instructions.

Chart 5

Vibration and noise in motors

S.No	Cause	Test	Remedy
1	Loose foundation bolts or nuts.	Inspect nuts and bolts of foundation for loose fittings.	Tighten the foundation nuts.
2	Wrong alignment of coupling.	Check alignment with a spirit level through dial test indicator.	Realign the coupling.

3	Faulty magnetic circuit of stator or rotor.	Measure the current in each phase and they should be equal. Check also per-phase resistance and they should be equal. Check the insulation resistance between the windings and the frame. In a newly wound motor there smay be reversed coils in a pole-phase group which can be detected by the compass test.	Repair fault if possible or rewind the motor.
4	Motor running on single phase.	Stop the motor, then try to start. (It will not start on single phase). Check for open in one of the lines or circuits.	Rectify the supply.
5	Noisy ball bearing.	Check the lubrication for correct grade and low noise in the bearing.	If found, replace the lubricant or replace the bearing.
6	Loose punching or loose rotor on shaft.	Check the parts visually.	Tighten all the holding bolts.
7	Rotor rubbing on the stator.	Check for rubbing marks on the stator and rotor.	If found, realign the shaft to centre it or replace the bearings.
8	Improper fitting of end-covers.	Measure the air gap at four different points for uneven position of rotor covers.	Open the screws of the side covers, and then tighten one by one. If trouble still persists, remove the end cover, shift for next position and tighten the screws again.
9	Foreign material in air-gap.	Examine the air-gap.	File or clean out air-gap.
10	Loose fan or bearings.	Check looseness of the fan screw or bearings.	Tighten the fan screws or refit new bearings, if necessary.
11	Slackness in bearing on shaft or in housing.	Remove the bearings and inspect the inner looseness of the race on the shaft and outer race in the housing.	Send the motor to the repair shop for removing the looseness of the shaft and housing, if any.
12	Improper fitting of bearings.	Remove the end-covers and examine the assembly of bearings on the shaft or in the housing.	Refit the bearings on the shaft or in the housing.
13	Minor bend in shaft.	Check for alignment on the lathe.	Remove the bend or replace the shaft, if required.

Troubleshooting of motor starters

Objectives: At the end of this lesson you shall be able to
- **state the troubles in the D.O.L. starter, their cause and their remedy**
- **check out the troubles in the mini manual starter, their cause and their remedy.**

Introduction: The D.O.L. starter consists of the fixed contacts, movable contacts, no-volt coil, overload relay and start button which is in green colour and a stop button in red colour with a locking arrangement. The main purpose of the contactor is to make and break the motor circuit. These contacts in the contactor suffer maximum wear, due to frequent use and hence these contacts are made of silver alloy material.

A no-volt coil acts as under-voltage release mechanism disconnecting supply to the motor when the supply voltage fails or is lower than the stipulated value. Thus the motor will be disconnected from supply under these conditions.

A thermal overload relay unit is provided for the protection of the motor. This unit consists of a triple pole, bimetallic relay housed in a sealed bimetallic enclosure. This is provided with a current setting arrangement. After tripping on overload, the relay has to be reset by pressing the stop button. The relay can be reset only after bimetallic strips get cooled sufficiently.

In case the motor does not start even though the start button is pressed, observe whether the stop button is locked with a metallic locking piece provided near the stop button. Release it and press the start button, then observe the functioning of the motor.

Suppose the three phase supply is available and starter NVC is energising but the motor does not start, check for any foreign material in between the contact points. Remove it and test the starter again. Visually observe whether the contacts are closing properly.

If any contact is not closing properly or any burns and pittings are noticed on the contact surface, then remove the contact strips. Dress up properly with zero number sandpaper or with a smooth file or replace it if necessary.

When the no-volt coil is activated by the start button, the auxiliary contact of the starter should close to complete the NVC circuit and should remain in the closed position even after the start button is released.

If the overload relay is not functioning properly i.e. not tripping the motor as per setting of the current rating, then replace it with a new one as per with the original specification of the manufacturer.

If a humming and chattering noise is observed in the starter then check for the rated voltage. If the voltage is okay, then check for any gummy material adhered to the pole faces. If found, clean it properly. See whether the shading ring over the pole faces of the NVC is loose. Tighten it properly and also check the spring tension of NVC housing.

Suppose the starter trips often then, check up the load on the motor. (Might be due to overload or over tension of the belt) Reduce the load or tension of the belt. Further check up the motor current in each phase. If the motor takes higher current than specified even though the load is normal, then the fault is with the motor and not with the starter. After attending to the faults and rectifying them, reassemble the starter, connect it to the motor for proper functioning.

Starter check - chart given below could be used to locate trouble in a D.O.L. starter.

Maintenance of DOL starters

	Trouble	Cause	Remedy
I	**Starter check chart**		
1	Contacts chatter	Low voltage, coil is not picking up properly. Broken pole shading ring. Poor contact between the pole faces of the magnet. Poor contact between fixed and movable contacts.	Correct the voltage condition. In case there is persistent low voltage, check the supply of the transformer tapping. Replace. Clean the pole faces. Clean contacts and adjust, if necessary.
2	Welding or overheating.	Low voltage preventing magnet from sealing. Abnormal in rush current. Short circuit in the motor. Foreign matter preventing contacts from closing. Rapid inching.	Correct the voltage condition. In case of low voltage, which is accepted normal change the NVC to lower voltage coil. Check excessive load current or use larger contactor. Remove the fault and check to ensure that the fuse rating is correct. Clean contacts with suitable solvent. Install larger device or caution the operator not to operate the inch button too quickly.
3	Short life of contact points	Weak contact pressure.	Adjust or replace contact springs.
4	Noisy magnets	Broken shading coil. Magnet faces not mating. Dirt or rust on magnet faces.	Replace magnet. Align or replace magnet assembly. Clean with suitable solvents.
5	Failure to pick up and seal the contacts.	Low voltage. Coil open or short-circuited. Mechanical obstruction for the moving parts.	Check system voltage. In case persistent low voltage, change to a lower voltage coil. Replace the coil. Clean and check for free movement of contact assembly.
6	Failure of moving mechanism to drop out.	Voltage not removed. Worn or rusted parts causing binding. Residual magnetism due to lack of air gap in magnet path. Gummy substance on pole faces causing binding.	Check wiring in the NVC coil circuit. Replace parts. Replace worn out magnet parts or demagnetise the parts. Clean with suitable solvent.

7	Overheating of coil	Over-voltage. Short circuited turns in coils caused by mechanical damage or corrosion. High ambient temperature. area or use a fan. Dirt or rust on pole faces increasing the air gap.	Check and correct terminal voltage. Replace coil. Relocate starter in a more suitable Clean pole faces.
II	**Overload relays/ release**		
1	Starter is tripping often. Sustained overload.	Incorrect setting of over load relay.	Reset properly. Check for faults/excessive motor currents.
2	Failure to trip (causing motor burn out).	Wrong setting of O.L relay. Mechanical binding due to dirt, corrosion etc.	Check O.L relay ratings and set a proper relay. Clean or replace. Incorrect control wiring. Check the circuit and correct it.
III	**Fuses**		
1	Constant blowing of fuses	Short circuit or poor insulation in winding/wiring.	Check the motor and the circuit for insulation resistance.
2	Fuse not blowing under short circuit condition.	Fuse rating too high.	Replace with suitable fuse.
3	Fuse blowing off frequently.	Fuse rating too low. Overloading of feeder.	Replace with suitable fuse. Check for over-current, leakage and short circuit.

Single phase motors - split phase induction motor - induction-start, induction-run motor

Objectives: At the end of this lesson you shall be able to
- **explain briefly the types of AC single phase motors**
- **explain the necessity and methods of split-phasing the single phase to obtain a rotating magnetic field**
- **explain the principle, construction, operation characteristic and application of single phase resistance / induction-start / induction-run motors.**

Single phase motors perform a great variety of useful services at home, office, farm, factory, and in business establishments. These motors are generally referred to as fractional horsepower motors with a rating of less than 1 H.P.

Single phase motors may be broadly classified as split-phase induction motors and commutator motors according to their construction and method of starting.

Split-phase induction motors can be further classified as:

- resistance-start, induction-run motors
- induction-start, induction-run motors
- permanent capacitor motors
- capacitor-start, induction-run motors
- capacitor-start, capacitor-run motors
- shaded pole motors.
- stepper motor

Commutator motors can be classified as:

- repulsion motors
- series motors.

The basic principle of operation of a split-phase induction motor is similar to that of a polyphase induction motor. The main difference is that the single phase motor does not produce a rotating magnetic field but produces only a pulsating field. Hence to produce the rotating magnetic field, phase-splitting is to be done to make the motor to work as a two-phase motor for starting.

Producing a rotating field from two 90° out-of-phase fields: One of the methods of producing a rotating magnetic field is by split-phasing. This could be done by providing a second set of winding in the stator called the starting winding. This winding should be kept physically at 90 electrical degrees from the main winding, and should carry a current out of phase from the main winding. This, out of phase current, could be achieved by making the reactance of the starting winding being different from that of the main winding. In case both the windings have similar reactance and impedance, the resulting field, created by the main and starting windings, will alternate but will not revolve and the motor will not start.

By split-phasing, the two (main and starting) fields would combine to produce a rotating magnetic field.

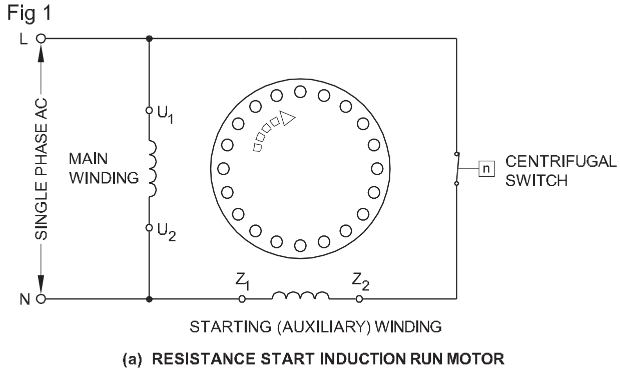
Working of split-phase motor: At the time of starting, both the main and starting windings should be connected across the supply to produce the rotating magnetic field. The rotor is of a squirrel cage type, and the revolving magnetic field sweeps past the stationary rotor, inducing an emf in the rotor. As the rotor bars are short-circuited, a current flows through them producing a magnetic field. This magnetic field opposes the revolving magnetic field and will combine with the main field to produce a revolving field. By this action, the rotor starts revolving in the same direction of the rotating magnetic field as in the case of a squirrel cage induction motor, which was explained earlier.

Hence, once the rotor starts rotating, the starting winding can be disconnected from the supply by some mechanical means as the rotor and stator fields form a revolving magnetic field.

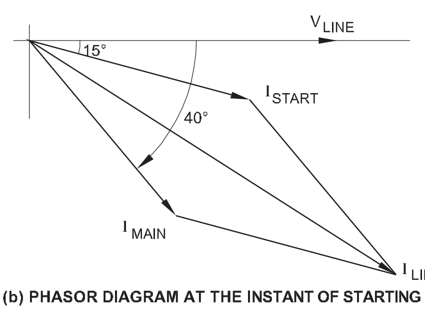
Resistance-start, induction-run motor: As the starting torque of this type of motor is relatively small and its starting current is high, these motors are most commonly used for rating up to 0.5 HP where the load could be started easily.

The essential parts are as shown in Fig 1a.

Fig 1



(a) RESISTANCE START INDUCTION RUN MOTOR



(b) PHASOR DIAGRAM AT THE INSTANT OF STARTING

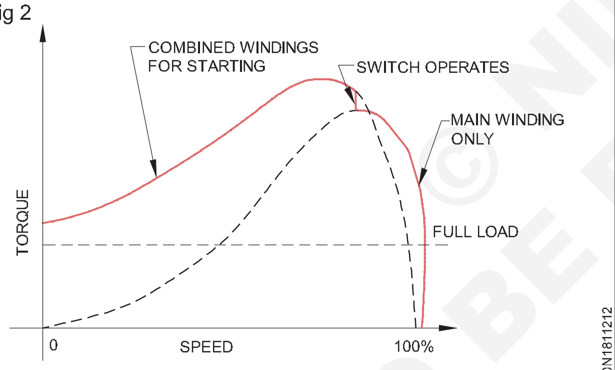
- Main winding or running winding

- Auxiliary winding or starting winding
- Squirrel cage type rotor
- Centrifugal switch

The starting winding is designed to have a higher resistance and lower reactance than the main winding. This is achieved by using smaller conductors in the auxiliary winding than in the main winding. The main winding will have higher inductance when surrounded by more iron, which could be made possible by placing it deeper into the stator slots. It is obvious that the current would split as shown in Fig 1b. The starting current `I start' will lag the main supply voltage `V' line' by 15° and the main winding current. `I main' lags the main voltage by about 40°. Therefore, these currents will differ in time phase and their magnetic fields will combine to produce a rotating magnetic field.

When the motor has come up to about 75 to 80% of synchronous speed, the starting winding is opened by a centrifugal switch, and the motor will continue to operate as a single phase motor. At the point where the starting winding is disconnected, the motor develops nearly as much torque with the main winding alone as with both windings connected. This can be observed from the typical torque-speed characteristics of this motor, as shown in Fig 2.

Fig 2



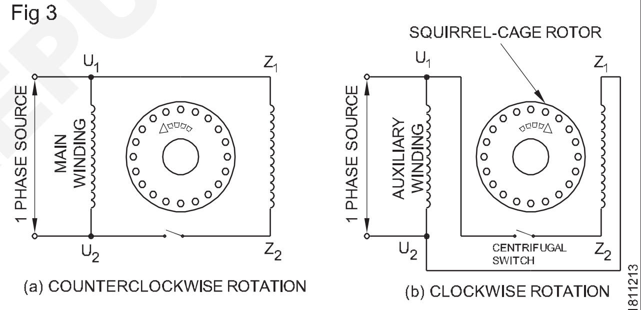
TORQUE SPEED CHARACTERISTIC OF SPLIT PHASE MOTOR

The direction of rotation of a split-phase motor is determined by the way the main and auxiliary windings are connected. Hence, either by changing the main winding terminals or by changing the starting winding terminals, the reversal of direction of rotation could be obtained. Rotation will be, say counter-clockwise, if Z_1 is joined to U_1 and Z_2 is joined to U_2 as per Fig 3a. If Z_1 is joined to U_2 and Z_2 is joined to U_1, then the rotation will be clockwise, as shown in Fig 3b.

Application of resistance-start, induction-run motor: As the starting torque of this type of motors is relatively small and its starting current is high, these are manufactured for a rating up to 0.5 HP where the starting load is light. These motors are used for driving fans, grinders, washing machines and wood working tools.

Induction-start, induction-run motor: Instead of resistance start, inductance can be used to start the motor through a highly inductive starting winding. In such a case, the starting winding will have more number of turns, and will be imbedded in the inner areas of the stator slots so as to have high inductance due to more number of turns, and the area will be surrounded by more iron. As the starting and main windings in most of the cases are made from the same gauge winding wire, resistance measurement has to be done to identify the windings. This motor will have a low starting torque, higher starting current and lower power factor.

Fig 3



METHOD OF CHANGING THE DIRECTION OF ROTATION OF RESISTANCE START INDUCTION RUN MOTOR

Centrifugal switch

Objectives: At the end of this lesson you shall be able to
- **explain the working, the method of maintenance and testing of a centrifugal switch**
- **explain the necessity of a manual D.O.L. starter and its working**
- **explain the operation of overload relays.**

The centrifugal switch: The centrifugal switch is located inside the motor and is connected in series with the starting winding in the case of capacitor-start, induction-run motors, and for disconnecting the starting capacitor in the case of a two value, capacitor-start, capacitor-run motor. Its function is to disconnect the starting winding after the rotor has reached 75 to 80% of the rated speed. The usual type consists of two main parts. Namely, a stationary part as shown in Fig 1, and a rotating part as shown in Fig 2. The stationary part is usually located on the front-end plate of the motor and has two contacts, so that it is similar in action to a single-pole, single-throw switch. When the rotating part is fitted in the rotor, it rotates along with it. When the rotor is stationary, the insulator ring of the rotating part is in an inward position due to spring tension. This inward movement of the insulator ring allows the stationary switch contacts to be closed which is due to the movable lever pressure against the leaf-spring tension in the switch.

When the rotor attains about 75% of the rated speed, due to centrifugal force, the governor weights fly out, and this makes the insulator ring to come outward. Due to this forward movement of the insulated ring, it presses the movable lever, and the contacts connected through terminals CS_1 and CS_2 open the starting winding.

Fig 1

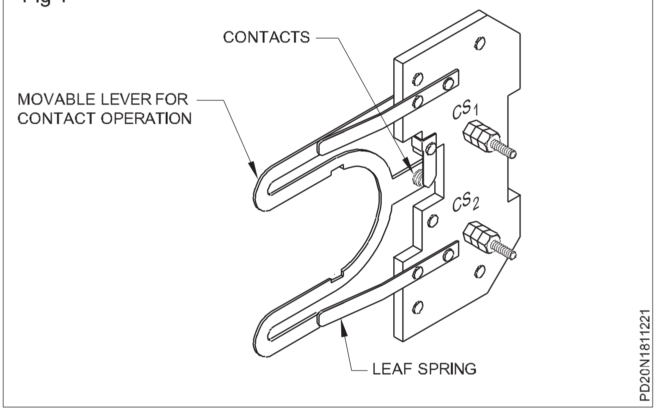
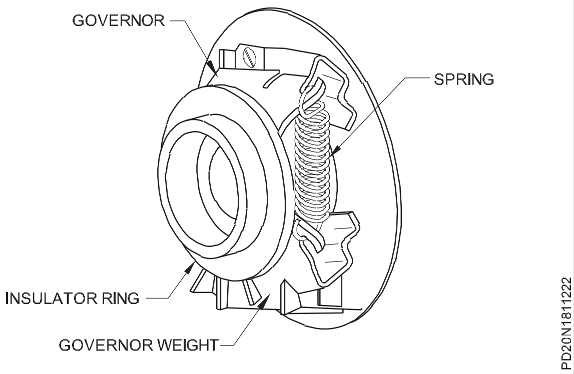


Fig 2



Manual D.O.L. starter: A starter is necessary for starting and stopping the motor, and for providing overload protection.

A manual starter, as it appears, is shown in Fig 3, an open view of the starter is shown in Fig 4, and the internal parts are shown in Fig 5, as a schematic diagram. A manual starter is a motor controller with a contact mechanism operated by hand.

Fig 3

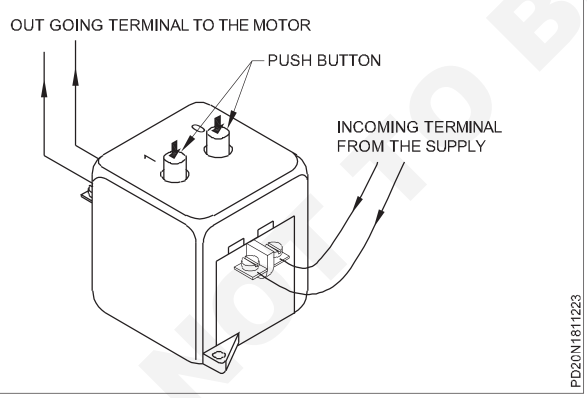
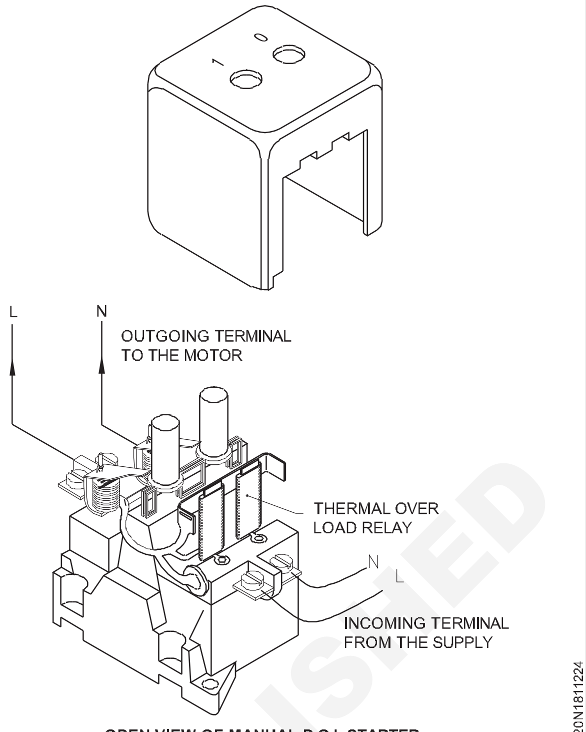
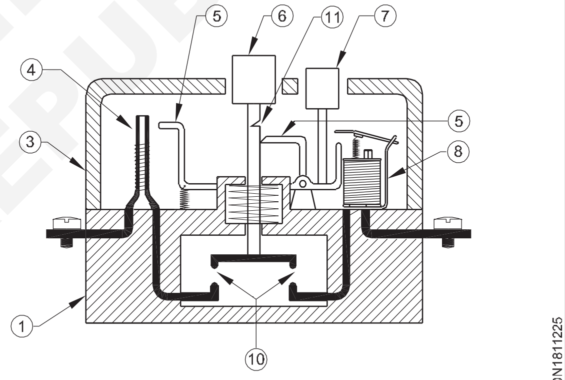


Fig 4



OPEN VIEW OF MANUAL D.O.L STARTER

Fig 5



SCHEMATIC DIAGRAM OF A MANUAL D.O.L STARTER

A push-button operates the mechanism through a mechanical linkage. As shown in Figs 4 & 5, the starter may have both a thermal overload relay and a magnetic overload relay for overload protection and short circuit protection respectively.

Both the relays are made to operate independently, in case of overload or short circuit, to release the start-button for disconnecting the motor from supply. Most of the present day, manual starters have either of the two relays only. Basically, a manual starter is an ON-OFF switch with overload relay only.

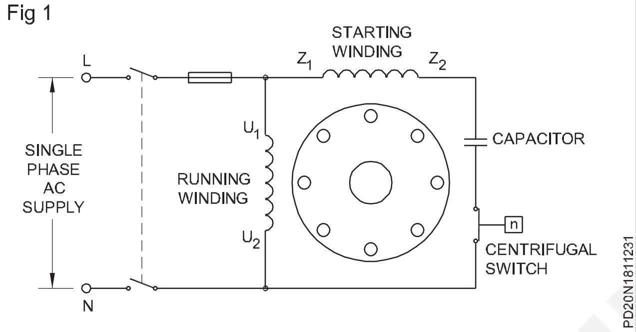
Capacitor - start, induction - run motor

Objectives: At the end of this lesson you shall be able to
- **explain the construction and working of an AC single phase, capacitor-start, induction-run motor**
- **explain the characteristic and application of a capacitor- start, induction-run motor.**

A drive which requires a higher starting torque may be fitted with a capacitor-start, induction-run motor as it has excellent starting torque as compared to the resistance-start, induction-run motor.

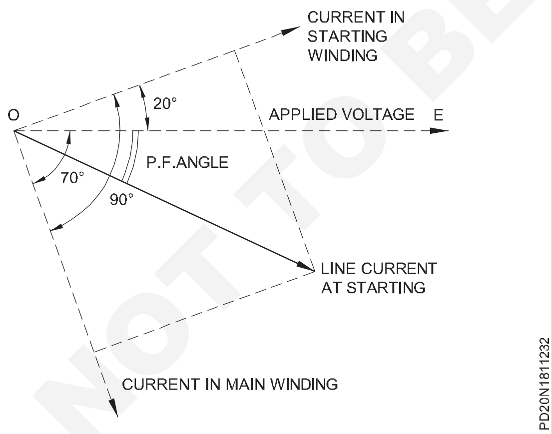
Construction and working: Fig 1 shows the schematic diagram of a capacitor-start, induction-run motor. As shown, the main winding is connected across the main supply, whereas the starting winding is connected across the main supply through a capacitor and a centrifugal switch. Both these windings are placed in a stator slot at 90 electrical degrees apart, and a squirrel cage type rotor is used.

Fig 1



As shown in Fig 2, at the time of starting, the current in the main winding lags the supply voltages by about 70 electrical degrees, depending upon its inductance and resistance. On the other hand, the current in the starting winding due to its capacitor will lead the applied voltage, by say 20 electrical degrees.

Fig 2



Hence, the phase difference between the main and starting winding becomes near to 90 electrical degrees. This in turn makes the line current to be more or less in phase with its applied voltage, making the power factor to be high, thereby creating an excellent starting torque.

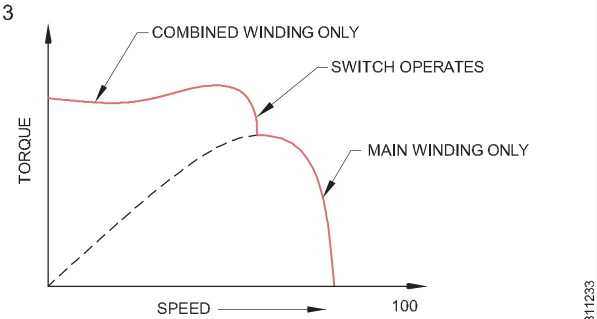
However, after attaining 75% of the rated speed, the centrifugal switch operates opening the starting winding, and the motor then operates as an induction motor, with only the main winding connected to the supply.

Reversing the direction of rotation: In order to reverse the direction of rotation of the capacitor start, induction-run motor, either the starting or the main winding terminals should be changed. This is due to the fact that the direction of rotation depends upon the instantaneous polarities of the main field flux and the flux produced by the starting winding. Therefore, reversing the polarity of any one of the fields will reverse the torque.

Characteristics: As shown in Fig 2, the displacement of current in the main and starting winding is about 80/90 degrees, and the power factor angle between the applied voltage and line current is very small. This results in producing a higher power factor and an excellent starting torque, several times higher than the normal running torque, as shown in Fig 3. The running torque adjusts itself with load by varying inversely with respect to speed as shown in the characteristic curve in Fig 3.

Application: Due to the excellent starting torque and easy direction-reversal characteristic, these machines are used in belted fans, blowers, dryers, washing machines, pumps and compressors.

Fig 3



TORQUE-SPEED CHARACTERISTIC OF CAPACITOR START INDUCTION RUN MOTOR

Permanent capacitor motor - capacitor-start, capacitor-run motor and shaded pole motor

Objectives: At the end of this lesson you shall be able to

- **distinguish between the single and two-value, capacitor-start, capacitor-run motors**
- **explain the working of a permanent capacitor motor, state its characteristic and use**
- **explain the working of a capacitor-start, capacitor-run motor, state its characteristic and use.**

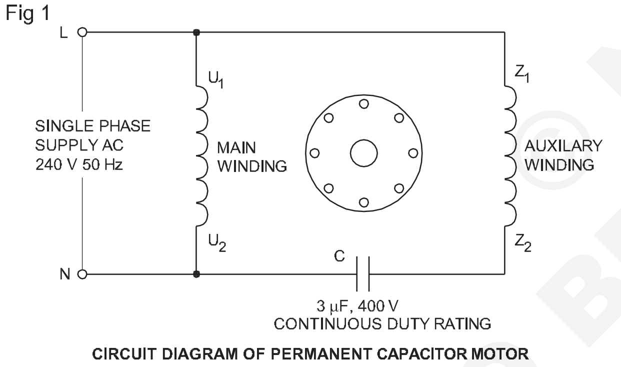
Capacitor-start, capacitor-run motors are of two types as stated below.

- Permanent capacitor motor (Single value capacitor motor)
- Capacitor-start, capacitor-run motor (Two-value capacitor motor)

Permanent capacitor motor: This type of motor is shown in Fig 1 which is most commonly used in fans. This motor is preferred in drives where the starting torque is not required to be high, while at the same time elimination of the centrifugal switch in the motor is necessary for easy maintenance. The capacitor is connected in series with the auxiliary winding, and remains so throughout the operation. These capacitors should be of oil-type construction and have continuous duty rating.

To avoid low efficiency, the capacity of the condensers is kept low, which, in turn, brings down the starting torque to about 50 to 80% of the full-load torque.

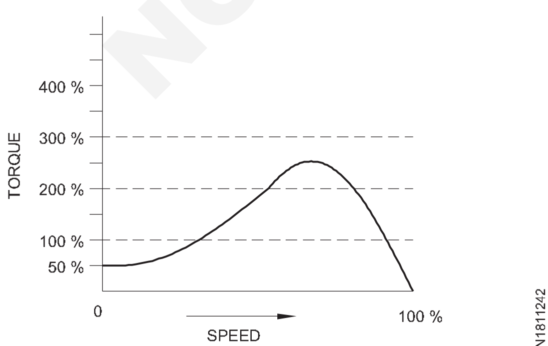
Fig 1



CIRCUIT DIAGRAM OF PERMANENT CAPACITOR MOTOR

The torque-speed characteristic of the motor is shown in Fig 2. This motor works on the same principle as the capacitor-start, induction-run motor with low starting torque but with higher power factor, during starting as well as in running.

Fig 2



TORQUE-SPEED CHARACTERISTIC OF PERMANENT CAPACITOR MOTOR

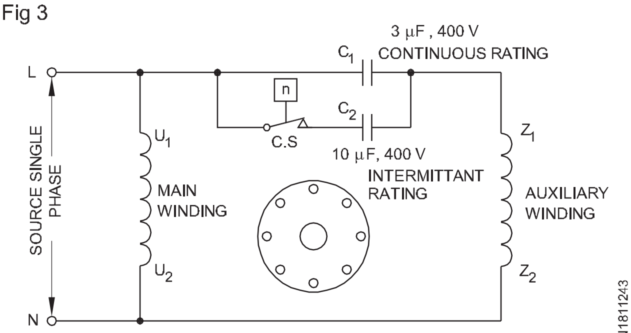
This motor is most suitable for drives, which require a lower torque during start, easy changes in the direction of rotation, stable load operation and higher power factor during operation. *Examples* - fans, variable rheostats, induction regulators, furnace control and arc welding controls. This motor is cheaper than the capacitor-start, induction-run motor of the same rating.

Capacitor-start, capacitor-run motors: As discussed earlier capacitor-start, induction-run motors have excellent starting torque, say about 300% of the full load torque, and their power factor during starting is high. However, their running torque is not good, and their power factor, while running, is low. They also have lesser efficiency and cannot take overloads.

These problems are eliminated by the use of a two-value capacitor motor in which one larger capacitor of electrolytic (short duty) type is used for starting, whereas a smaller capacitor of oil-filled (continuous duty) type is used for running, by connecting them with the starting winding as shown in Fig 3. A general view of such a two-value capacitor motor is shown in Fig 4. This motor also works in the same way as a capacitor-start induction-run motor, with the exception, that the capacitor C1 is always in the circuit, altering the running performance to a great extent.

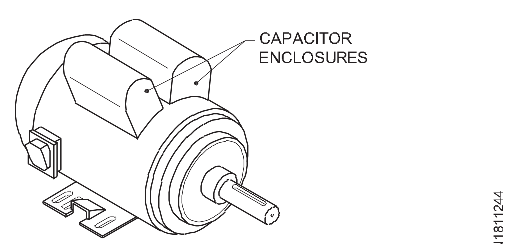
The starting capacitor which is of short-duty rating will be disconnected from the starting winding with the help of a centrifugal switch, when the starting speed attains about 75% of the rated speed.

Fig 3



SCHEMATIC DIAGRAM OF A CAPACITOR-START CAPACITOR-RUN MOTOR

Fig 4



CAPACITOR-START CAPACITOR-RUN MOTOR

Characteristic

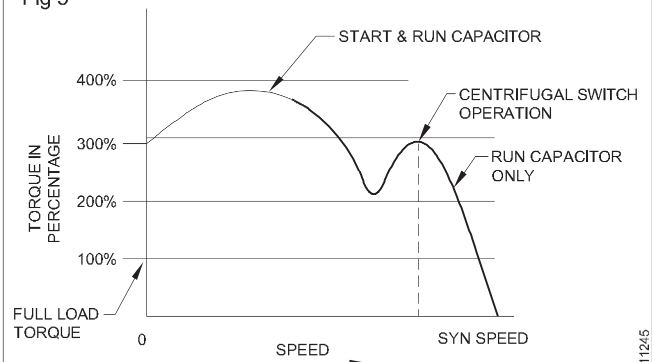
The torque-speed characteristic of this motor is shown in Fig 5. This motor has the following advantages.

- The starting torque is 300% of the full load torque.
- The starting current is low, say 2 to 3 times of the running current.
- Starting and running P.F. are good.
- Highly efficient running.
- Extremely noiseless operation.
- Can be loaded up to 125% of the full-load capacity.

Application

These motors are used for compressors, refrigerators, air-conditioners etc. where the duty demands a higher starting torque, higher efficiency, higher power factor and overloading. These motors are costlier than the capacitor-start, induction- run motors of the same capacity.

Fig 5



TORQUE-SPEED CHARACTERSTIC OF CAPACITOR-START CAPACITOR-RUN MOTOR

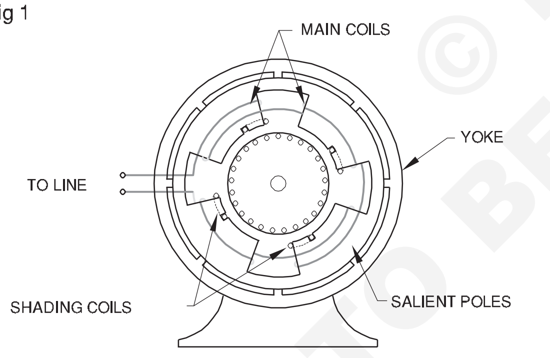
The shaded pole motor

Objectives: At the end of this lesson you shall be able to
- **explain the construction of a shaded pole motor and their functions**
- **explain the principle of working of the shaded pole motor**
- **explain the characteristics of the shaded pole motor and its application.**

Shaded pole motor (construction)

The motor consists of a yoke with salient poles as shown in Fig 1 and it has a squirrel cage type rotor.

Fig 1



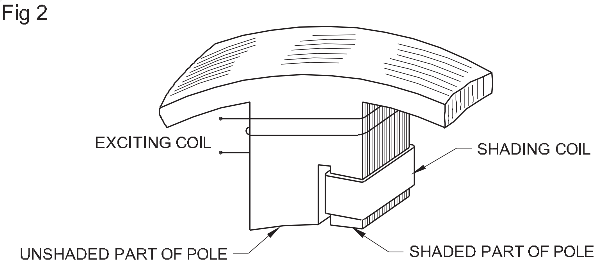
A SINGLE-PHASE MOTOR WITH SHADING COILS FOR STARTING

Construction of a shaded pole

A shaded pole made up of laminated sheets has a slot cut across the lamination at about one third the distance from the edge of the pole. Around the smaller portion of the pole, a short circuited copper ring is placed which is called the shading coil and this part of the pole is known as the shaded part of the pole. The remaining part of the pole is called the unshaded part which is clearly shown in Fig 2.

Around the poles, exciting coils are placed to which an AC supply is connected. When AC supply is given to the exciting coil the magnetic axis shifts from the unshaded part of the pole to the shaded part as explained in the next paragraph. This shifting of axis is equivalent to the physical movement of the pole. This magnetic axis which is moving, cuts the rotor conductors, and hence, a rotational torque is developed in the rotor. Due to this torque, the rotor starts rotating in the direction of the shifting of the magnetic axis that is from the unshaded part to the shaded part.

Fig 2



A TYPICAL SHADED-POLE CONSTRUCTION

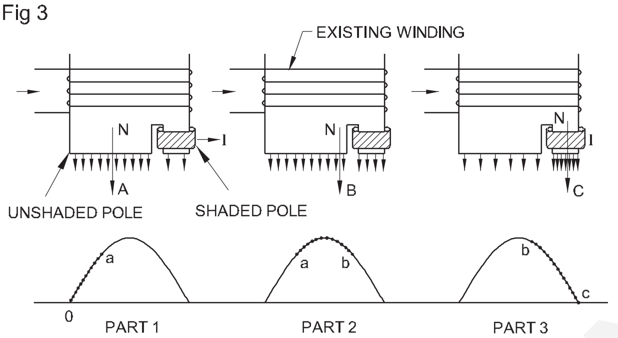
Shifting of the magnetic flux from the unshaded part to the shaded part could be explained as stated below.

As the shaded coil is of thick copper, it will have very low resistance but as it is embedded in the iron core it will have high inductance.

When the exciting winding is connected to an AC supply a sine wave current passes through it. Let us consider the positive half cycle of the AC current as shown in Fig 3. When the current raises from 'zero' to point 'a', the change in current is very rapid (fast), hence induces an emf in the shading coil by the principle of Faraday's laws of electromagnetic induction. The induced emf in the shading coil produces a current which in turn produces a flux which is in opposite direction to the main flux in accordance with Lenz's law. This induced flux opposes the main flux in the shaded portion and reduces the main flux in that area to a minimum value as shown in Fig 3 in the same form of flux arrows. This makes the magnetic axis to be in the centre of the unshaded portion as shown by the arrow (longer one) in part 1 of Fig 3. On the other hand as shown in Part 2 of Fig 3 when current rises from point 'a' to 'b' the change in current is slow, the induced emf and resulting current in the shading coil is minimum and the main flux is able to pass through the shaded portion. This makes the magnetic axis to be shifted to the centre of the whole pole as shown by the arrow in part 2 of Fig 3.

In the next instant, as shown in part 3 of Fig 3, when the current falls from 'b' to 'c', the change in current is fast and its value of change is from maximum to minimum. Hence a large current is induced in the shading ring which opposes the diminishing main flux, thereby increasing the flux density in the area of the shaded part. This makes the magnetic axis to shift to the centre of the shaded part as shown by the arrow in part 3 of Fig 3.

Fig 3

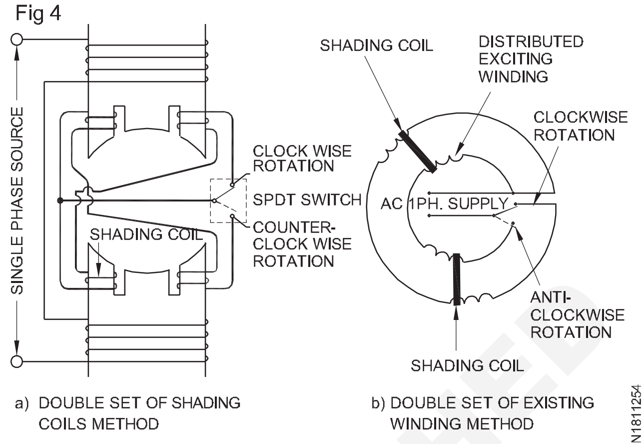


CHANGE OF MAGNETIC AXIS SHOWN FROM POSITION A TO C

From the above explanation it is clear that the magnetic axis shifts from the unshaded part to the shaded part which is more or less physical rotary movement of the poles.

Simple motors of this type cannot be reversed. Specially designed shaded pole motors have been constructed for reversing the direction. Two such types are shown in Fig 4. In a) the double set of shading coils method is shown and in b) the double set of exciting winding method is shown.

Fig 4



METHODS FOR REVERSING SHADED-POLE MOTORS-TWO-POLE CONSTRUCTION

Shaded pole motors are built commercially in very small sizes, varying approximately from 1/250 HP to 1/6 HP. Although such motors are simple in construction and cheap, there are certain disadvantages with these motors as stated below:

- low starting torque
- very little overload capacity
- low efficiency.

The efficiency varies from 5% to 35% only in these motors.

Because of its low starting torque, the shaded pole motor is generally used for small table fans, toys, instruments, hair dryers, advertising display systems and electric clocks etc.

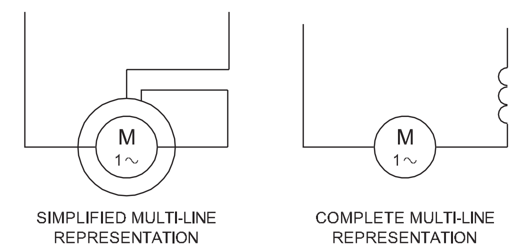
Universal motor

Objectives: At the end of this lesson you shall be able to
- **compare a universal motor with the DC series motor with respect to its construction**
- **explain the operation, characteristic and application of a universal motor**
- **explain the method of changing the direction of rotation**
- **describe the methods of controlling the speed of a universal motor.**

Comparison between a universal motor and a DC series motor: A universal motor is one which operates both on AC and DC supplies. It develops more horsepower per Kg. weight than any other AC motor, mainly due to its high speed. The principle of operation is the same as that of a DC motor. Though a universal motor resembles a DC series motor, it requires suitable modification in the construction, winding and brush grade to achieve sparkles commutation and reduced heating when operated on AC supply, due to increased inductance and armature reaction.

A universal motor could, therefore, be defined as a series or a compensated series motor designed to operate at approximately the same speed and output on either direct current or single phase alternating current of a frequency not greater than 50 Hz, and of approximately the same RMS voltage. Universal motor is also named as AC single phase series motor, and Fig 1 shows the multi-line representation according to B.I.S. 2032, Part IV.

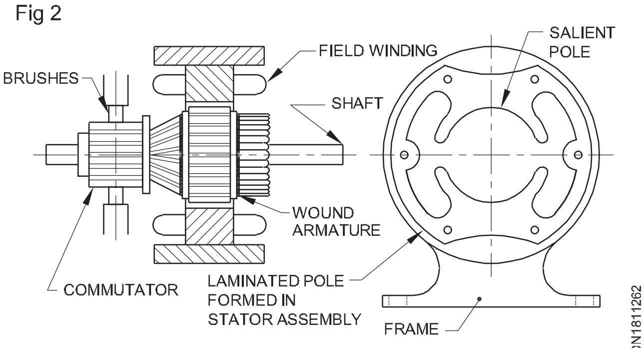
Fig 1



MULTILINE REPRESENTATION OF AC SINGLE PHASE SERIES MOTOR (BIS 2032-PART IV.)

The main parts of a universal motor are an armature, field winding, stator stampings, frame, end plates and brushes as shown in Fig 2.

Fig 2



PARTS OF A UNIVERSAL MOTOR

The increased sparking at the brush position in AC operation is reduced by the following means.

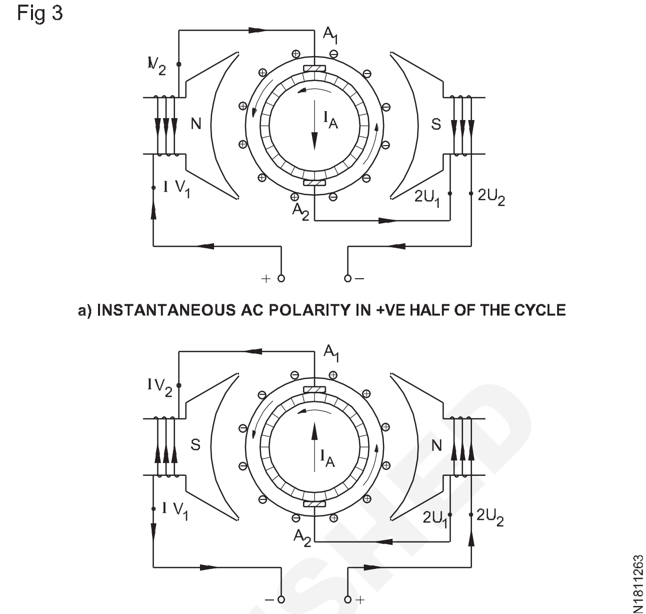
- Providing compensating winding to neutralize the armature M.M.F. These compensating windings are either short-circuited windings or windings connected in series with the armature.
- Providing commutating inter-poles in the stator and connecting the inter-pole winding in series with the armature winding.
- Providing high contact resistance brushes to reduce sparking at brush positions.

The table given below indicates the differences between a universal motor and a DC series motor.

Universal motor	DC series motor
Can run on AC and DC supplies.	Can run smoothly on DC supply. However when connected to AC supply, it produces heavy sparks at brush positions and becomes hot due to armature reaction and rough commutation.
Compensating winding is a must for large machines.	Does not require compensating winding.
Inter-poles provided in larger machines.	Does not require inter-poles normally.
High resistance grade brushes are necessary.	Normal grade brushes will suffice.
Air gap is kept to the minimum.	Normal air gap is maintained.

Operation: A universal motor works on the same principle as a DC motor, i.e. force is created on the armature conductors due to the interaction between the main field flux and the flux created by the current-carrying armature conductors. A universal motor develops unidirectional torque regardless of whether it operates on AC or DC supply. Fig 3 shows the operation of a universal motor on AC supply. In AC operation, both field and armature currents change their, polarities, at the same time resulting in unidirectional torque.

Fig 3

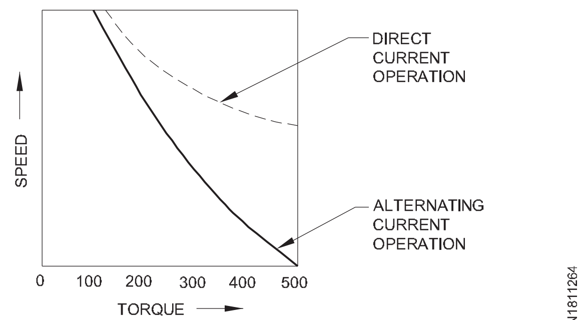


b) INSTANTANEOUS AC POLARITY IN -VE HALF OF THE CYCLE

Characteristic and application: The speed of a universal motor is inversely proportional to the load, i.e. speed is low at full load and high on no load. The speed reaches a dangerously high value due to low field flux at no loads. In fact the no-load speed is limited only by its own friction and windage losses. As such these motors are connected with permanent loads or gear trains to avoid running at no-load, thereby avoiding high speeds.

Fig 4 shows the typical torque speed relation of a universal motor, both for AC and DC operations. This motor develops about 450 percent of full load torque at starting, as such, higher than any other type of single phase motor. Universal motors are used in vacuum cleaners, food mixers, portable drills and domestic sewing machines.

Fig 4

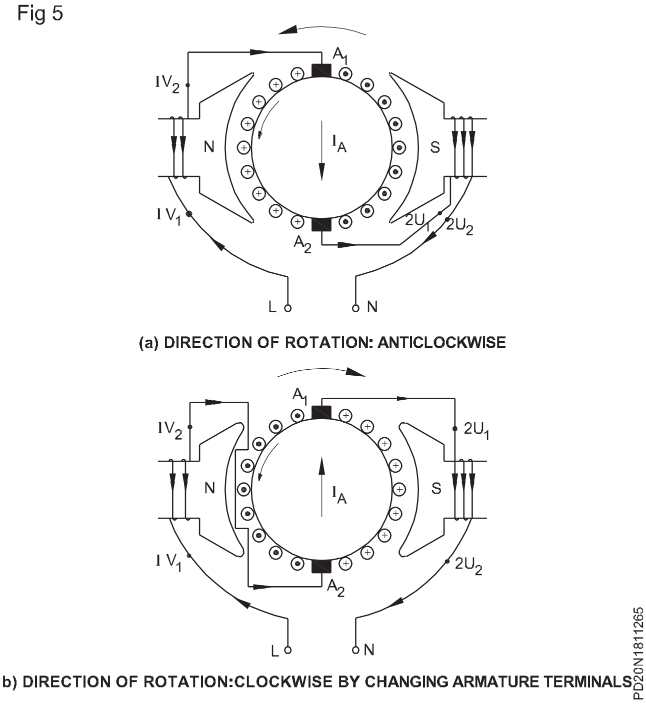


TORQUE-SPEED CHARACTERISTIC OF A UNIVERSAL MOTOR

Change of rotation: Direction of rotation of a universal motor can be reversed by reversing the flow of current through either the armature or the field windings. It is easy to interchange the leads at the brush holders as shown in Fig 5.

However, when the armature terminals are interchanged in a universal motor having compensating winding, care should be taken to interchange the compensating winding also to avoid heavy sparking while running.

Fig 5



Speed control of universal motor: The following methods are adopted to control the speed of a universal motor.

Series resistance or applied voltage control method: The motor speed is controlled by connecting a variable resistance in series with the motor. Foot-pedal operated sewing machines incorporate such a control. Fig 6 shows the connections.

Tapped field method: In this method, the field winding is tapped at 2 or 3 points and the speed is controlled by the varying field MMF. Fig 7 shows such a connection. Most of the domestic food mixers employ this method of speed control.

Fig 6

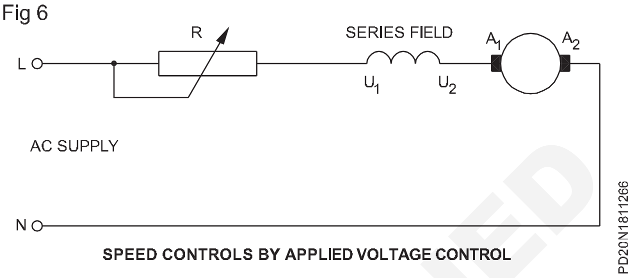
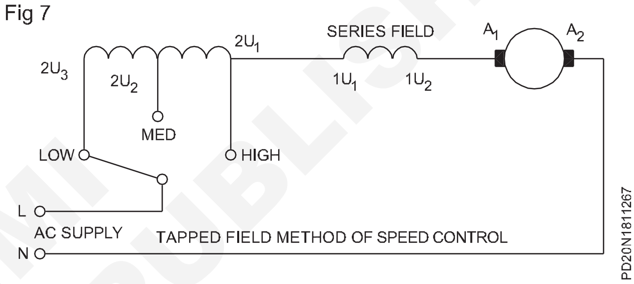


Fig 7



Troubleshooting of universal motor

Objectives: At the end of this lesson you shall be able to
- **state the advantages and disadvantages of universal motor**
- **explain the method of troubleshooting in universal motor.**

As the name suggest universal motors can operate on either AC or DC supply. By a compromise of design fractional horse power motors may be built to operate satisfactorily on either 240 V 50 Hz AC or direct current at 240 volts. Such motors are known as universal motors.

Advantages of universal motors

- These motors develop high starting torque and have the ability to adjust the torque and speed proportionally when loaded.
- Universal motors can operate on direct current or AC supply.
- Tapped fields provide an easy method of controlling speed.

Disadvantages of universal motors

- Since these motors operate at very high speed upto 40,000 rpm considerable air noise is present.
- Because of the large increase in the power input under stalled conditions and the loss of motor cooling, they can burn out within a short time when overloaded too much.
- Useful for intermittent duty application only.
- They produce radio and television interference.

Troubleshooting chart for universal motor: Table 1 gives possible faults, which occur in universal motor, their causes, mode of testing and suggested rectification. As a universal motor is similar in design to the DC machine, trainees are advised to refer trouble shooting chart pertaining to DC machines also.

Table 1

Troubleshooting chart for universal motor

Trouble	Causes	Mode of testing	Rectification
Motor fails to start	a) No voltage due to blown fuse	a) Test by test lamp or voltmeter	a) Replace the blown fuse.
	b) Open overload relay of starter.	b) Test by test lamp or voltmeter	b) Reset or rectify the overload relay contact
	c) Low voltage due to improper supply voltage.	c) Test by voltmeter.	c) Rectify the loose connections at the switch & fuse.
	d) Open circuited field or armature.	d) Test by ohmmeter or Megger.	d) If possible join properly or replace the winding.
	e) Improper contact of carbon brushes with commutator.	e) Visual inspection and test by test lamp	e) Adjust for proper contact of carbon brush with commutator.
	f) Dirty commutator.	f) Visual inspection and test by test lamp.	f) Clean by buffing the commutator using smooth sandpaper.
Shock to the operator	a) Grounded field or armature circuit due to weak insulation.	a) Test by Megger or test lamp.	a) Rectify the defect and apply shellac varnish to armature and field winding
	b) Insufficient earth.	b) Test by Megger or test lamp.	b) Provide proper earth to the motor.
Over heating of motor	a) Shorted coil of field or armature.	a) Visual inspection and resistance measurement	a) Rewind field or armature coil which is shorted
	b) Tight bearing due to worn out or locked bearing.	b) Test the shaft for free rotation. Check the shield for over heating.	b) Clean the bearings and check for damage. Replace bearing if necessary.
	c) Heavy sparking at commutator due to pitted commutator.	c) By visual inspection.	c) Clean the commutator and true the surface of the commutator.
	d) Shorted commutator.	d) Test the armature by growler.	d) Replace or repair the commutator
	e) Grounded field or armature.	e) Test by Megger.	e) Repair or rewind the field or armature.
Humming sound. Lack of torque due to overheat	a) Short circuited field.	a) Test by ohmmeter.	a) Rewind the field winding.
	b) Shorted armature coil.	b) Test by Growler.	b) Rewind shorted armature winding.

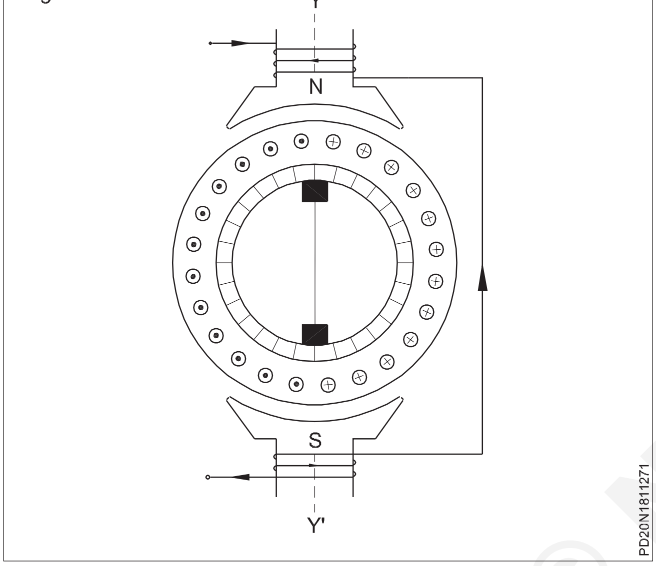
Repulsion motor

Objectives: At the end of this lesson you shall be able to
- **explain the principle, working, types and construction of the repulsion motor**
- **explain the characteristic and application of the repulsion motor.**

Repulsion motors, though complicated in construction and higher in cost, are still used in certain industries due to their excellent starting torque, low starting current, ability to withstand long spell of starting currents to drive heavy loads and their easy method of reversal of direction.

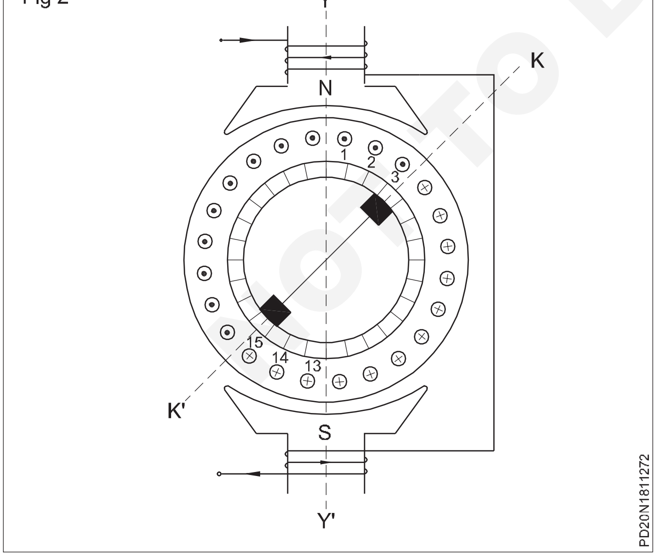
The repulsion principle: The principle of torque production in a repulsion motor could be explained as follows. Fig 1 shows a two-pole motor with its magnetic axis vertical. An armature, having a commutator which is short-circuited through the brushes, is placed in the magnetic field. When the stator winding is connected to an AC supply, it produces an alternating magnetic field. Assume that at an instant, a north pole at the top and a south pole at the bottom are produced by this alternating magnetic field. Because of this a voltage will be induced in all the rotor conductors by the transformer action. The direction of current in the conductors will be in accordance with Lenz's law such that they create a north pole at the top just below the stator north pole, and a south pole at the bottom just at the top of the stator south pole to oppose the induction action. Hence the stator poles and the rotor poles will oppose each other in the same line. There will, therefore, be no torque developed due to the absence of the tangential component of the torque.

Fig 1



Let us assume that the short-circuited brush-axis is moved to a position as in Fig 2. Due to the present brush position, the magnetic axis of the armature is no longer co-linear with respect to the vertical axis of the main poles.

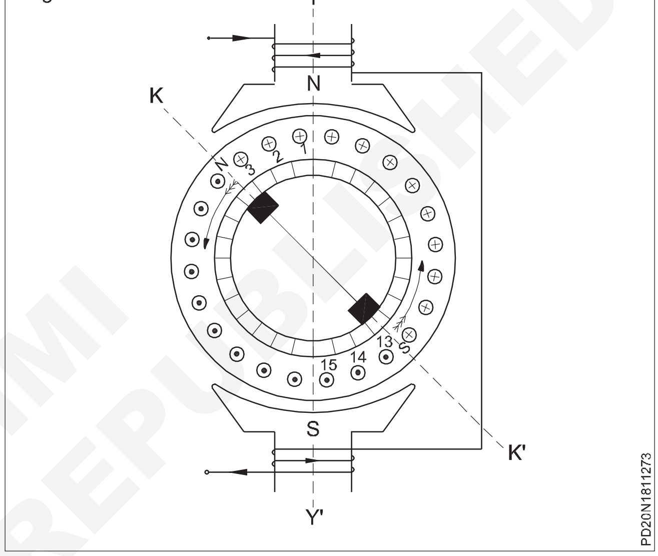
Fig 2



It will now be along the axis `KK' with north and south poles shifted around by an angle `A°' depending upon the shifting of the brushes. In this position, the direction of current in the conductors 1,2,3 and 13,14,15 is reversed, and hence, the armature becomes an electromagnet having the north (N) and south (S) poles in the `KK' axis just at an angle of `A°' from the main magnetic axis. Now there is a condition that the rotor north pole will be repelled by the main north pole, and the rotor south pole is repelled by the main south pole, so that a torque could be developed in the rotor. Now due to the repulsion action between the stator and the rotor poles, the rotor will start rotating in a clockwise direction. As the motor torque is due to repulsion action, this motor is named as repulsion motor.

Direction of rotation : To change the D.O.R. of this motor, the brush-axis needs, to be shifted from the right side as shown in Fig 2 to the left side of the main axis in a counter-clockwise direction as shown in Fig 3.

Fig 3



This working principle applies equally well for all types of repulsion motors having distributed windings in the stator.

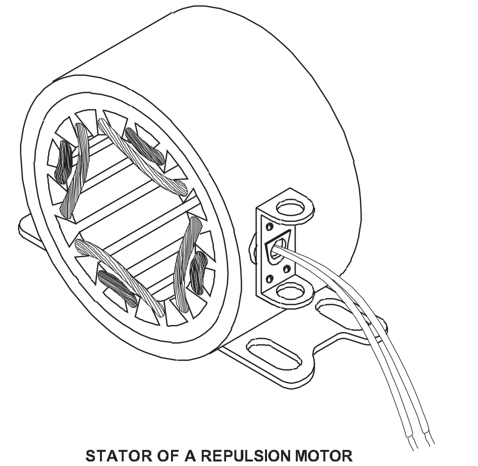
Types of repulsion motors : There are four types of induction motors as stated below.

- Repulsion motor
- Compensated-repulsion motor
- Repulsion-start, induction-run motor
- Repulsion-induction motor

Construction: The construction of stators is the same in all the types, except for certain variation in the compensated-repulsion motor. In general, for all types of repulsion motors the stator winding is of the distributed, non-salient pole type, housed in the slots of the stator, and only two terminals as shown in Fig 4 are brought out. It is wound for four, six or eight poles. The rotor for each type of motor is different, and will be explained under each type.

Repulsion motor: The general construction of the repulsion motor is similar to the one explained under the `Repulsive principle'. However the rotor of the repulsion motor is like a DC armature that is as shown in Fig 5, having a distributed lap or wave-winding. The commutator may be similar to the DC armature, that is axial type, having commutator bars in parallel to the shaft or radial or vertical bars on which brushes ride horizontally. The shorted brush position can be changed by a lever attached to the rocker-arm. The B.I.S. symbol for the repulsion motor is shown in Fig 6.

Fig 4



STATOR OF A REPULSION MOTOR

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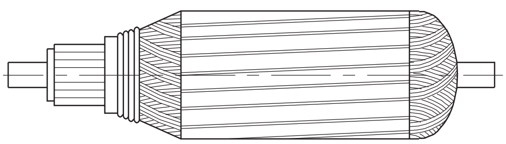
Fig 5



ROTOR OF A REPULSION MOTOR

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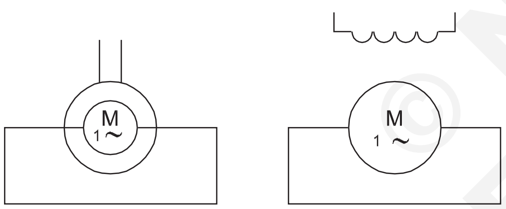
Fig 6



SIMPLIFIED MULTI LINE REPRESENTATION

COMPLETE MULTI LINE REPRESENTATION

REPULSION MOTOR

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As explained earlier, the torque developed in a repulsion motor will depend upon the amount of brush-shaft as shown in Fig 7, whereas the direction of shift decides the direction of rotation. Further, the speed also depends upon the amount of brush-shift and the magnitude of the load.

Repulsion-start, induction-run motor : The rotor of this motor is similar to that of a repulsion motor but the commutator and the brush mechanism are entirely different. This motor starts like a repulsion motor, and after attaining about 75% of the rated speed, there is a necklace-type shorting mechanism, activated by a centrifugal force which short circuits the entire commutator. From then on, this motor works as an induction motor with a short-circuited rotor (armature). After the commutator is short-circuited, in some machines, there is a special mechanism to lift the brushes to avoid wear and tear of the brushes and the commutator.

Fig 7

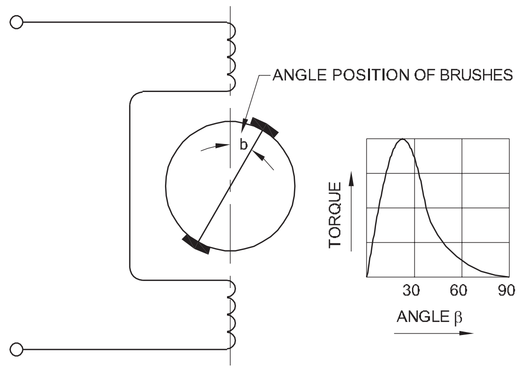

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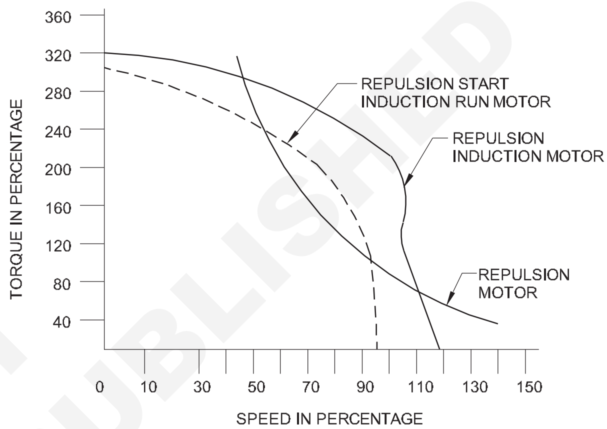
Fig 8



SPEED LOAD CHARACTERISTIC OF REPULSION MOTOR

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The torque speed characteristic of this motor is shown in Fig 8.

Repulsion-induction motor : The rotor of this motor has a squirrel cage winding deep inside the rotor, in addition to the usual winding. The brushes are short-circuited, and they continuously ride over the commutator. Generally the starting torque is developed in the wound part of the rotor, while the running torque is developed in the squirrel cage winding. The speed torque characteristic is shown in Fig 8. This develops a little less torque, say about 300% of the full load torque, and can start with a load and run smoothly on no load. This motor has its starting characteristic similar to DC compound motor, and running characteristic similar to an induction motor.

APPLICATION: In these motors the average starting torque varies from 300-400 percent of the full load torque, and these motors are preferred in places where the starting period is of comparatively long duration, due to heavy load. These motors are used in refrigerators, air-compressors, coil winders, petrol pumps, machine tools, mixing machines, lifts and hoists, due to their excellent starting torque, ability to withstand sustained overloads, good speed regulation and easy method of reversal of direction of rotation.

Stepper motor

Objectives: At the end of this exercise you shall be able to
- **state the basic theory and open loop operation of stepper motor**
- **list and explain the each type of stepper motor**
- **state the advantages, disadvantages and application of stepper motor.**

Basic theory

A stepper motor is basically a synchronous motor. There are no brushes. It is an electromechanical device converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shaft rotation. The speed of the motor shaft rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of pulses applied.

This device does not rotate continuously, but it rotates in the form of pulses. There are different types of motors available based on the stepper rotation, manufactured with steps per revolution of 12,24,72,144,180 and 200 in stepping angles of 300, 150, 50, 2.50, 20 and 1.80 per steps.

Open loop operation

One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. The position is known simply by keeping track of the input step pulses.

Stepper motor types: There are three basic stepper motor types. They are

1 Variable-reluctance (Fig 1)

2 Permanent-magnet (Fig 2)

3 Hybrid (Fig 3)

Fig 1

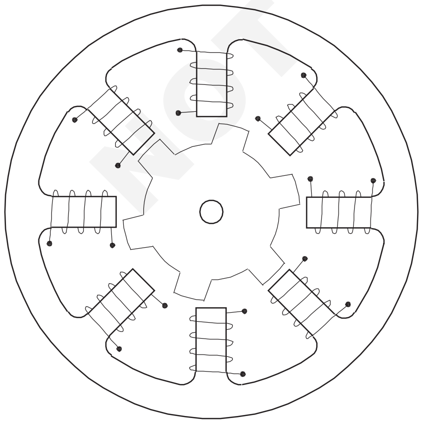


Fig 2

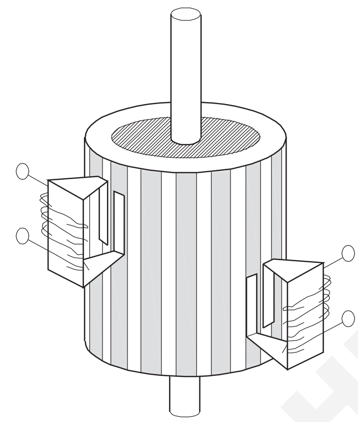
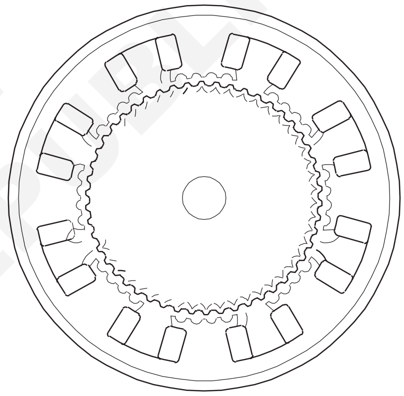


Fig 3



1 Variable-reluctance (VR): This type of stepper motor has been around for a long time. It is probably the easiest to understand from a structural point of view (Fig 1) shows a typical VR stepper motor. This type of motor consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles.

2 Permanent magnet (PM): Often referred to as a “tin can” or “can stock” motor the permanent magnet step motor is a low cost and low resolution type motor with typical step angles of 7.50 to 150 (48 - 24 steps/ revolution) PM motors as the name implies have permanent magnets added to the motor structure (Fig 2). The rotor no longer has teeth as with VR motor. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and because of this the PM motor exhibits improved torque characteristics when compared with the VR type.

3 **Hybrid (HB):** The hybrid stepper motor is more expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the HB stepper motor range from 3.60 to 0.90 (100 - 400 steps per revolution) The hybrid stepper motor combines the best features of both the PM and VR type stepper motors. The rotor is multi-toothed like the VR motor and contains an axially magnetized concentric magnet around its shaft (Fig 3). The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the air gap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types.

The two most commonly used types of stepper motors are the permanent magnet and the hybrid types.

Advantages and disadvantages

Advantages

1 The rotation angle of the motor is proportional to the input pulse.

2 The motor has full torque at stand still (if the windings are energized)

3 Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3-5% of a step and this error is non cumulative from one step to the next.

4 Excellent response to starting/stopping/reversing.

5 Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependent on the life of the bearing

6 The motor's response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.

7 It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.

8 A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

1 Resonances can occur if not properly controlled

2 Not easy to operate at extremely high speeds.

Application

There are different applications. Some of these include printers, plotters, high-end office equipment, hard disk drives, medical equipment, fax machines, automotive and many more.

Alternator - principle - relation between poles, speed and frequency

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of an alternator**
- **draw and explain the method of production of sine wave voltage by a single loop alternator**
- **describe the relation between frequency, number of poles and synchronous speed.**

Principle of an alternator: An alternator works on the same principle of electromagnetic induction as a DC generator. That is, whenever a conductor moves in a magnetic field so as to cut the lines of force, an emf will be induced in that conductor. Alternatively whenever there is relative motion between the field and the conductor, then, the emf will be induced in the conductor. The amount of induced emf depends upon the rate of change of cutting or linkage of flux.

In the case of DC generators, we have seen that the alternating current produced inside the rotating armature coils has to be rectified to DC for the external circuit through the help of a commutator. But in the case of alternators, the alternating current produced in the armatrue coils can be brougt",t out to the external circuit with the help of slip-rings. Alternatively the stationary conductors in the stator can produce alternating current when subjected to the rotating magnetic field in an alternator.

Production of sine wave voltage by single loop alternator: Fig 2a shows a single loop alternator. As it rotates in the magnetic field, the induced voltage in it varies in its direction and magnitude as follows.

To plot the magnitude and direction of the voltage induced in the wire loop of the AC generator in a graph, the electrical degrees of displacement of the loop are kept in the 'X' axis as shown in Fig 1 through 30 electrical degrees. As shown in Fig 2c, three divisions on the 'X' axis represent a quarter turn of the loop, and six divisions a half turn. The magnitude of the induced voltage is kept in the 'Y' axis to a suitable scale.

The part above the X-axis represents the positive voltage, and the part below it the negative voltage as shown in Fig 1.

The position of the loop at the time of starting is shown in Fig 2a and indicated in Fig 2c as 'O'· position. At this position, as the loop moves parallel to the main flux, the loop does not cut any lines of force, and hence, there will be no voltage induced. This zero voltage is represented in the graph as the starting point of the curve as shown in Fig 2c. The magnitude of the induced emf is given by the formula Eo = BLV Sinθ.

where

B is the flux density in weber per square metre,

L is the length of the conductors in metres,

V is the velocity of the loop rotation in metres per second and

θ is the angle at which the conductor cuts the line of force.

As sin θ = 0

E at o position is equal to zero. As the loop turns in a clockwise direction at position 30° as shown in Fig 2c, the loop cuts the lines of force and an emf is induced (E30) in the loop whose magnitude will be equal to BLV Sinθ where 0 is equal to 30°.

Applying the above formula, we find the emf induced in the loop at 90° position will be maximum as shown in Fig 2c.

Fig 1

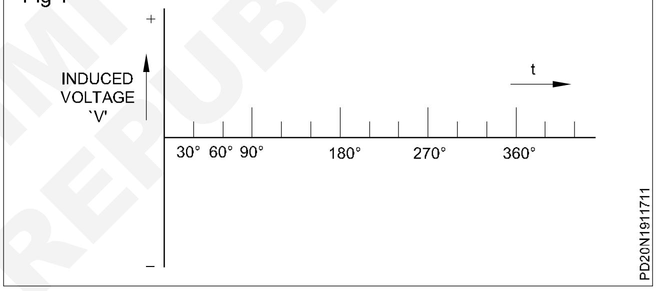
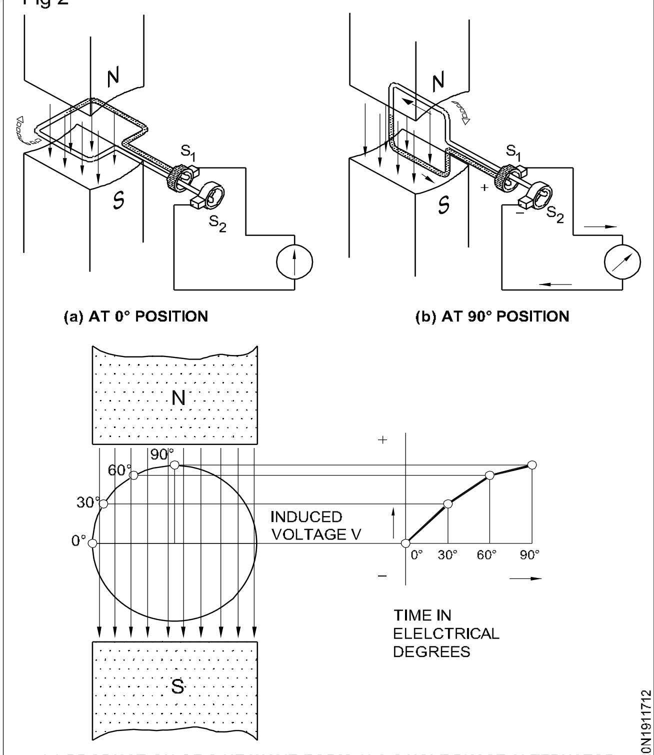


Fig 2



(a) AT 0° POSITION

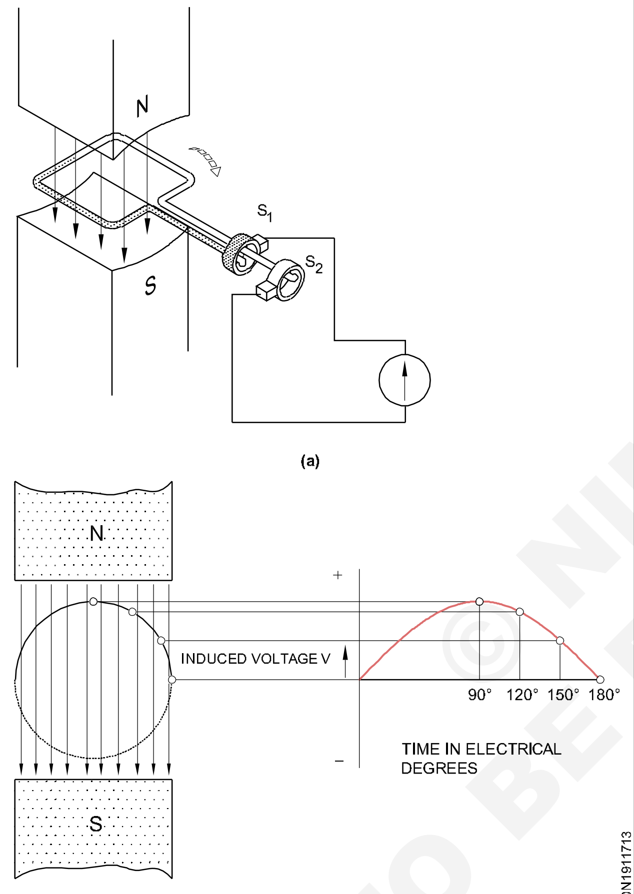
(b) AT 90° POSITION

(c) PRODUCTION OF SINE WAVE FORM IN A SINGLE PHASE ALTERNATOR

As the loop turns further towards 180° it is found the number of lines of force which are cut will be reduced to zero value. If the quantity of emf induced at each position is marked by a point and a curve is drawn along the points, the curve will be having a shape as shown in Fig 3b.During the turn of the loop, from o to 180 ° , the slip ring 81 will be positive and S2 will be negative.

However, at 180 ° position, the loop moves parallel to the lines of force, and hence there is no cutting of flux by the loop and there is no emf induced in the loop as shown in Fig 3b.

Fig 3



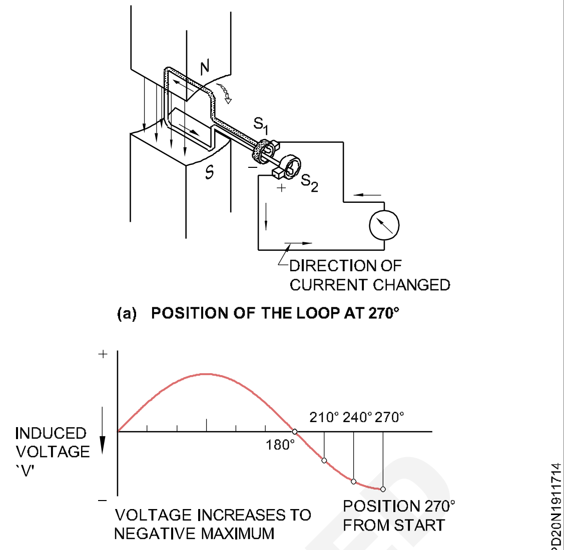
(a)

(b) VALUE OF INDUCED E.M.F. AT POSITION 180° FROM START

Further during the turn of the loop from the position 18Q0 to 270Â° , the voltage increases again but the polarity is reversed as shown in Fig 4b. During the movement of the loop from 180 to 360Â° , the slip ring S2 will be positive and S 1 will be negative as shown in Fig 4a. However, at 270Â° the voltage induced will be the maximum and will decrease to zero at 360Â°. Fig Sb shows the variation of the induced voltage in both magnitude and direction during one complete revoluÂ-tion of the loop. This is called a cycle.

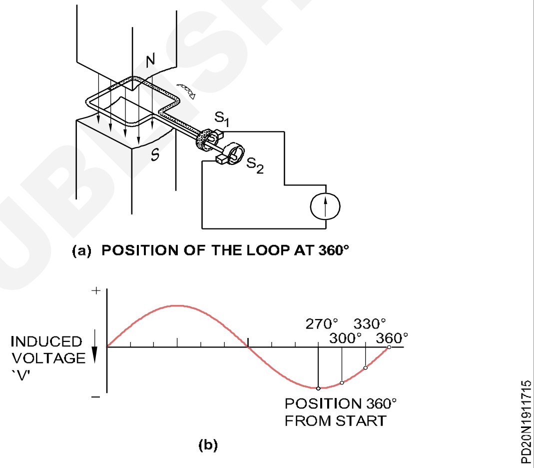
This type of wave-form is called a sine wave as the magnitude and direction of the induced emf, strictly follows the sine law. The ni.Jm ber of cycles completed in one second is called a frequency. In our country, we use an AC supply having 50 cycles frequency which is denoted as 50 Hz.

Fig 4



(a) POSITION OF THE LOOP AT 270°

Fig 5



(a) POSITION OF THE LOOP AT 360°

(b)

Relation between frequency, speed and number of poles of alternator: If the alternator has got only two poles, the voltage induced in one revolution of the loop undergoes one cycle. If it has four poles, then one complete rotation of the coil produces two cycles because, whenever it crosses a set of north and south poles, it makes one cycle.

Fig 6 shows the number of cycles which are produced in each revolution of the coil, with 2 poles, 4 poles and 6 poles. It is clear from this that the number of cycles per revolution is directly proportional to the number of poles, 'P' divided by two. Therefore the number of cycles produced per second depends on P/2, and the speed in revolutions per second.

Therefore frequency F =

where 'n is in r.p.s.

'P' is the number of poles.

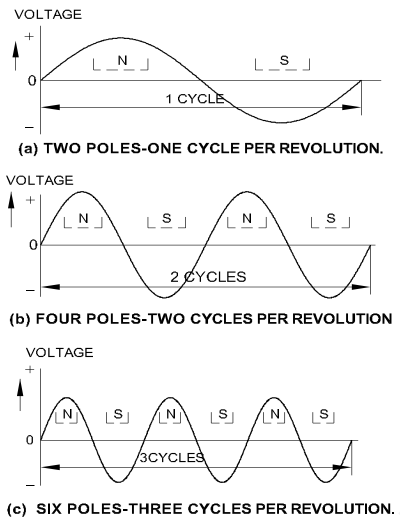
Generally speed is represented in r.p.m.

Then we have requency F =

where P is number of poles and N is speed in r.p.m.

Accordingly we can state that the frequency of an alternator is directly porportional to the number of poles and speed.

Fig 6



‘Types’ and construction of alternators

Objectives: At the end of this lesson you shall be able to
- **explain the construction, and the various types of alternators.**

Types of alternators: DC and AC generators are similar in one important respect, that is, they both generate alternating emf in the armature conductors. The AC generatorsends out the electrical energy in the same form of alternating emf to the external load with the help of slip rings.

AC generators, named as alternators, must be driven at a very definite constant speed called synchronous speed, because the frequency of the generated emf is determined by the speed. Due to this reason these machines are called synchronous alternators or synchronous generators'.

Classification according to the type of rotating part: One way of classifying the alternator is the way in which the rotating part is chosen. In the earlier lessons, we discussed how an alternator can have either stationary or rotating magnetic field poles. Accordingly an alternator) having d stationary magnetic field and a moving armature is called a rotating armature type, and an alternator with a stationary armature and moving magnetic field is called a rotating field type. There are definite advantages in using rotating field type alternators.

Advantages of using rotating field type alternators

Only two slip rings are required for a rotating field type alternator whatsoever the number of phases may be.

As the main winding is placed over the stator, more conductors can be housed in the stator because of more internal peripheral area. More conductors result in higher voltage/current production.

As the winding in which the emf is induced is stationary, there is no possibility of breaking or loosening the winJing and its joints, due to rotational forces.

There is no sliding contact between the stationary armature and the external (load) circuit, as the supply could be taken direct. Only two slip rings are provided in the rotor for low power low voltage field excitation. Thus less sparking and less possibility of faults.

The main winding being stationary, the conductors can be easily and effectively insulated, and the insulating cost also will be less for higher output voltage (less dielectric strength insulation will be sufficient).

Stationary main conductors need less maintenance.

As the rotar has a field winding which is lighter for the given capacity than in the rotating armature type, the alternator can be driven at a higher speed.

Classification according to the number of phases: Another way of classifying the alternators is based on production of single or 3-phase by the alternator. Accordingly the types are 1) single-phase alternators 2) three-phase alternators.

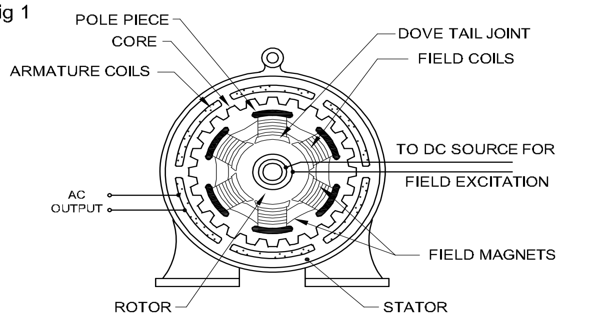
Single-phase alternators: A single-phase alternator is one that provides only one voltage. The armature coils are connected in ·series additive'. In other words, the sum of the emf induced in each coil produces the total output voltage. Single phase alternators are usually constructed in small sizes unly. They are used as a temporary standby power for construction sites and for permanent installation in remote locations.

Three-phase alternators: This alternator provides two different voltages, namely, phase and line voltages. It has 3 windings placed at 120° to each other, mostly connected in a star having three main terminals U,V,Wand neutral 'N'.

These alternators are driven by prime movers such as diesel engines, steam turbines, water wheels etc. depending upon the source available.

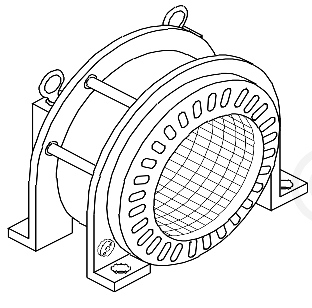
Construction of alternators: The main parts of a revolving field type alternator are shown in Fig 1.

Fig 1



Stator: It consists of mainly the armature core formed of laminations of steel alloy (silicon steel) having slots on its inner periphery to house the armature conductors. The armature core in the form of a ring is fitted to a frame which may beof cast ironor welded steel plate. The armature core is laminated to reduce the eddy current losses which occur in the stator core when subjected to the cutting of the flux produced by the rotating field poles. The laminations are stamped out in complete rings (for smaller machines) or in segments (for larger machines), and insulated from each other with paper or varnish. The stampings also have holes which make axial and radial ventilating ducts to provide efficient cooling. A general view of the stator with the frame is shown in Fig 2.

Fig 2

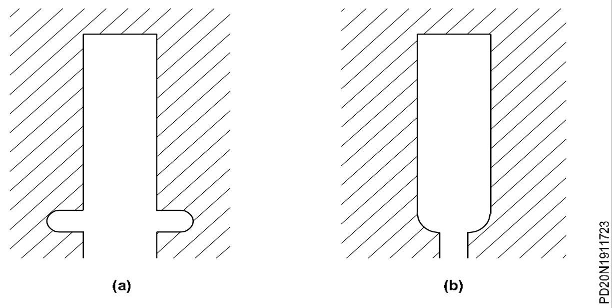


Slots provided on the stator core to house the armature coils are mainly of two types, (i) open and (ii) semi-closed slots, as shown in Fig 3(a) and (b) respectively.

The open slots are more commonly used because the coils can be form-wound and pre-insulated before placing in the slots resulting in fast work, less expenditure and good insulation. This type of slots also facilitates easy removal and replacement of defective coils. But this type of slots creates uneven distribution of the flux, there producing ripples in the emf wave. The semi-closed type slots are better in this respect but do not permit the use of form- wound coils, thereby complicating the process of winding. Totally closed slots are rarely used, but when used, they need bracing of the winding turns.

Rotor: This forms the field syslem, and is similar to DC generators. Normally the field system is excited from a separate source of low voltage IJC supply. The excitation source is usually a DC shunt or compound generator, known as an exciter, mounted t:J the same alternator shaft. The exiting current is supplied to the rotor with the

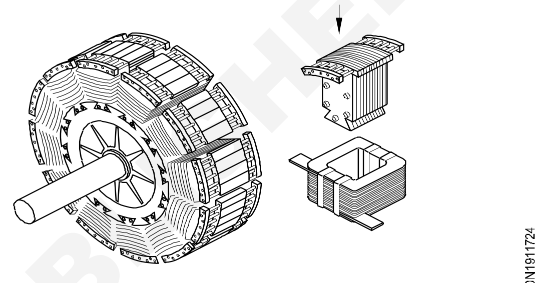
Fig 3



help of two slip- rings and brushes. The field poles created by the excitation are alternately north and south.

Rotating field rotors are of two types, namely (i) salient pole type as shown in Fig 4 and (ii) smooth cylindrical type or non-salient pole type, 3S shown in Fig 5.

Fig 4



SALIENT POLE FIELD STRUCTURE

Salient pole type: This type of rotor is used only for slow and medium speed alternators. This type is less expensive, having more space for the field coils and vast heat dissipating area. This type is not suitable for high speed alternators the salient poles create a lot of neise while running in addition to the difficulty of obtaining sufficient mechanical strength.

Fig 4 shows the salient pole type rotor in which revised steel laminations are fitted to the shaft fitting with the help of adovetailed joint. Pole faces are curved to have uniform distribution of the flux in the air gap leading to production of sinusoidal wave form of the generated emf. These pole faces are also provided with slots to carry the damper winding to prevent hunting. The field coils are connected in series in such a way is to produce alternate north and south poles, and the field winding ends are connected to the slip rings. The DC excitation source is connected to the brushes which are made to contact the slip rings with the required pressure.

Salient pole type alternators could be identified by their larger diameter, short axial length and low or medium speed of operation.

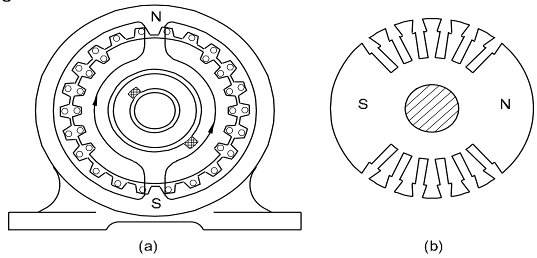
Smooth cylindrical or non-salient pole type rotor: This type is used in very high speed alternatqrs, driven by steam turbines. To have good mechanical strength, the peripheral velocity is lowered by reducing the diameter of the rotor and alternatively with the increased axial length. Such rotors have either two or four poles but run at higher speeds.

To withstand such speeds, the rotor is made of solid steel forging with longitudinal slots cut ar, shown in Fig 5a which shows a two-pole rotor with six slots. The winding is in the form of insulated copper strips, held securely in the slots by proper wedges, and bound securely by steel bonds.

One part of the periphery of the rotor in which slots are not made is used as poles as shown in Fig 5b.

Smooth cylindrical pole type alternators could be identified by their shorter diameter, longer axial length and high speed of operation.

Fig 5



NON-SALIENT POLE TYPE FIELD STRUCTURE

Generation of 3-phase voltage and general test on alternator

Objectives: At the end of this lesson you shall be able to
- **draw and explain the method of generating 3-phase voltage wave-forms by a 3-phase alternator**
- **explain what is meant by phase sequence**
- **state the method of testing an alternator for continuity insulation and earth connection**
- **state the I.E.E. regulations and B.I.S. recommendations rertaining to earthing of the alternator.**

An AC three-phase system is the most common system used in the present world. It is because of its high efficiency, less cost of material required for the Jeneration, transmission and distribution for a given capacity. The three-phase system supplies power to drive three-phase motors in industry as well as supplying power to single phase motors and lighting loads for both industrial and domestic purposes. Present day electricians may be employed in a generating station or may be employed in a standby power station where three-phase alternators are used. Hence a fairly good knowledge about production of 3-phase voltages, their phase sequence and general testing of alternators is essential.

Generation of three-phase voltage: Basically the principle of a three-phase alternator (generator) is the same as that of a single phase alternator (generator), except that there are three equally spaced coils or windings which produce three output voltages which are out of phase by 120° with each other.

A simple rotating-loop, three-phase generator with its output voltage wave-forms is shown in Fig 1 c.

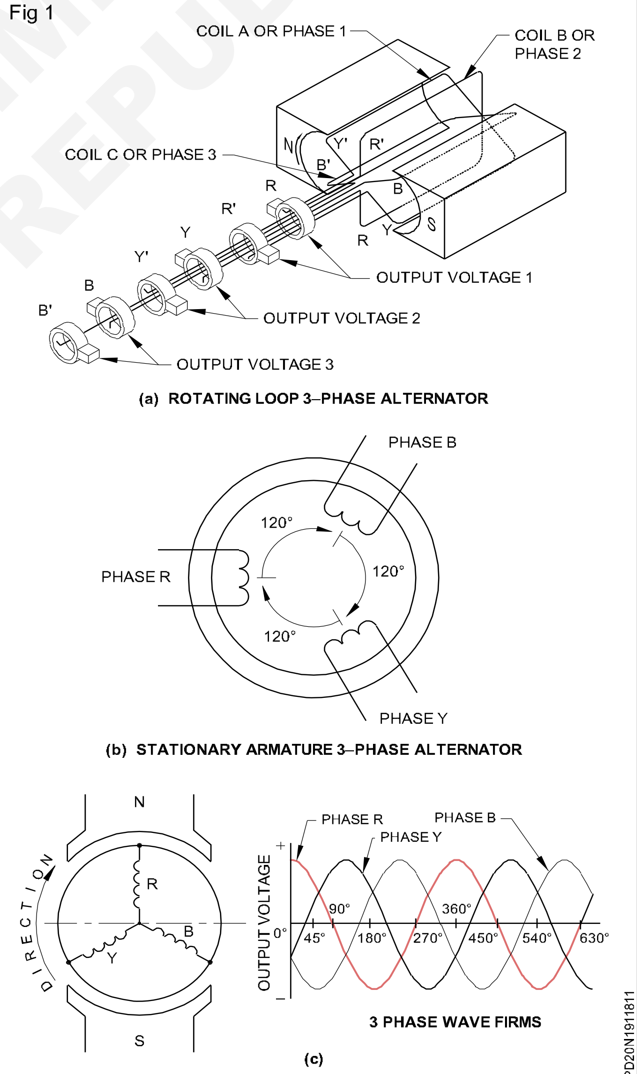
As shown in Fig 1a, three independent loops spaced about 120 ° apart are made to rotate in a magnetic field with the assumption that the alternator shown is a rotating armature type. As showr1 In Fig 1 a, the three loops are electrically Isolat ed from each other and the ends of the loops are connected to individual slip rings. As the loops are rotating in a uniform magnetic field, they produce sine waves. In a practical alternator, these loops will be replaced by a multi-turn winding ele ment and distributed throughout the slots eut spaced apart at 120° electrical degrees from each other. Further in practice, there will not be six slip rings as shown in Frg 1 a but will have either four or three slip rings depending upon whether the three windings are connected in a star or delta respectively.

We also know, as discussed earlier, that the rotating magnetic field type alternators are mostly used. In such cases only two slip rings are required for exciting the field poles with DC suppiy. Fig 1 b shows a stationary, 3-phase armature which individual loops of each winding are replaced by coils spaced at 120 electrical degrees apart.

However, the rotating part having the magnetic poles is not shown.

Fig 1 c shows the rotating armature type alternator in which the 3 coils of the three-phases are connected in star which rotates in a two-pole magnetic field. According to Fig 1 c, the coil 'R' moves under the influence of the'N' pole cutting the flux at right angles, ancl produces the

Fig 1



maximum induced voltage at position ‘O’ as shown in the graph as per Faraday's Laws of Electromagnetic induction. When the coil ’R' moves in a clockwise direction, the emf induces falls to zero at 90 degrees, and then increases to -ve maxim um under the influence of the south pole at 180 degrees. Likewise the emf induced in the ‘R' phase will become zero at 270 degrees and attain +ve maximum at 360 degrees. In the same manner the emf produced by coils ‘Y’ and ‘B’ could be plotted on the same graph. A study of the sine wave-forms produced by the three coils RYB shows that the voltage of coil ‘R' leads voltage of coil ‘Y' by 120°, and the voltage of coil ‘Y' leads voltage of coil 'B' by 120°.

Phase sequence: The phase sequence is the order if which the voltages follow one another, i. e reach their maximum value. The wave-form in Fig 1c show s that the voltage of coil R or phase Freaches its positive maximum value first, earlier the voltage of coil Y or phase ‘Y', and after that the voltage of coil B or phase B reaches its positive maximum value. Hence the phase sequence is said to the RYB.

If the rotation of the alternator shown in Fig 1 c is changed from clockwise to anticlockwise direction. the phase sequence will be changed as RBY. It is the most important factor for parallel connection of polyphase generators and in polyph ase windings. Further the direction of rotation of a 3-phase induction motor depends upon the phase sequence of the 3-phase supply. If the phase sequence of the alternator is changed, all the 3-phase motors, connected to that alternator, will run in the reverse direction though it may not affect lighting and heating loads.

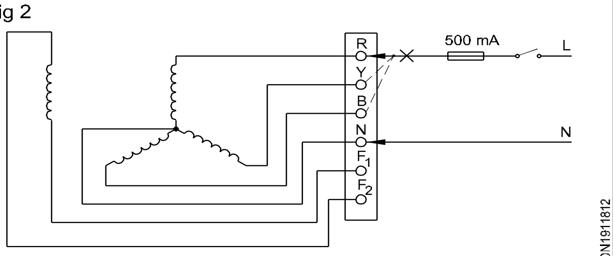
The only difference in the construction of a single phase alternator and that of a 3-phase alternator lies in the main winding.Otherwise both the types of alternators will have similar construction.

General testing of alternator: Alternators are to be periodically checked for their general condition as they will be in service continuously. This comes under preventive maintenance, and avoids unnecessary breakdowns or damage to the machine. The usual checks that are to be carried out on an altenator are

- continuity check of the windings
- insulation resistance value between windings
- insulation resistance value of the windings to the body
- checking the earth connection of the machine.

Continuity test: The continuity of the windings is checked by the following meth od as shown in Fig 2.

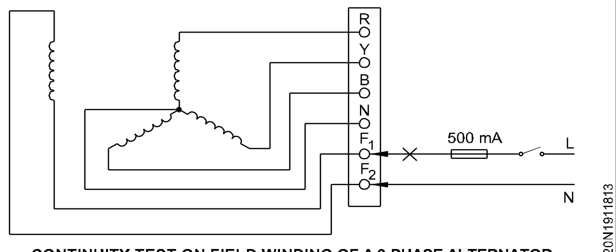
Fig 2



CONTINUITY TEST ON MAIN WINDING OF A 3-PHASE ALTERNATOR

A test lamp is connected in series with one end to the neutral (star point) and the other end to one of the winding terminas (R Y B). If the test lamp glows equally brig lit on all the terminals RY8 then the continuity of the winding is all right. In the sam e way, as sh own in Fig 2., we can test the field leads F1 a"d F2 for field continuity.

Fig 3



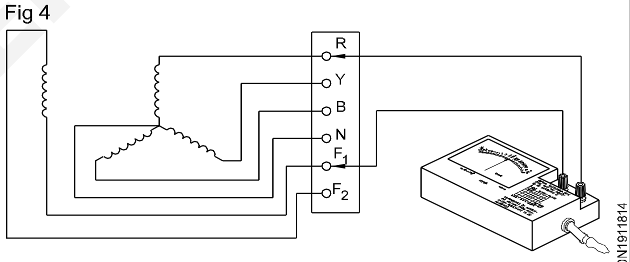
CONTINUITY TEST ON FIELD WINDING OF A 3-PHASE ALTERNATOR

Testing continuity with the test lamp only indicates the continuity in between two terminals but will not indicate short between the same windings. A more reliable test will be to use an ohmmeter to check he individual resistances of the coils, and compare them to see that sir pilar coils have the same resistance. The readings, when recorded, will be useful for future reference also.

For insulation resistance test

Between windings: As shown in Fig 4, one end of the Megger lead is connected to any one terminal of the RYS and the other is connected to F1 or F2 of th e field winding. In the Megger reads one megohm or more, then the insulation resistance is accepted as okay.

Fig 4

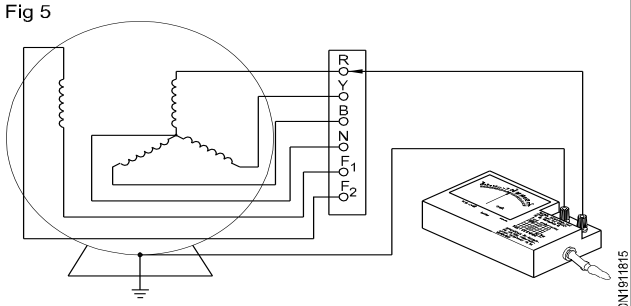


INSULATION TEST BETWEEN WINDINGS

If there is short, between the armatur e and fie ld windings, the Megger reads zero ohms. If it is weak, it shows less than one megohm.

Testing insulation resistance between body and windings: As shown in Fig 5, one lead of the Megger is connected to on e of the leads of the RYB, and the other lead of the Megger is connected to the body. If the insulation between the windings and the frame is all right, the Megger reads more than one megohm.

Fig 5



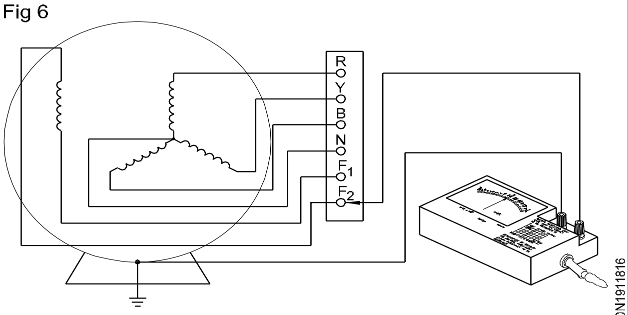
INSULATION TEST BETWEEN MAIN WINDING AND FRAME

The field is tested by connecting one terminal of the Megger to F1 er F2 of the field and the other terminal to the body as shown in Fig 6. If the insulation between the field and the frame is all right, the Megger reads more than one megohm. A lower reading than one megohm shows weak insulation and leakage to the ground.

Caution:

While conducting the insulation resistance test, if the Megger reads zero, then it should be concluded that the insulation of tile winding has failed completely and needs thorough checking.

Fig 6



INSULATION TEST BETWEEN FIELD WINDING AND FRAME

The permissible insulation resistance should not be less than 1 megohm.

Earthing of a lternators: This consists of two equally important requirments as stated below.

- Earthing of the n eutra l of the alterna t or
- Earthing of the alternator frame.

Earthing of neutral: According to B.I.S. 3043-1966 , it is recommended to use one of the following methods f or earthing the neutral of the alternator.

- Solid earthing
- Resistance earthing
- Reactance earthing
- Arc-s uppre ssion coil earthing

The selection and the type of earthing depends to a large extent on the size of the unit, the system voltage protection scheme used, the manufacturer's recommendation and the approval of the electrical inspectorate authority. Trainees are advised to refer to B. I.S. 3043-1966 for further details. As earthing of neutral is essential for the operation of protective relays , to maintain proper voltage in the system and for safety reasons, trainees are advised to identify the method of neutral earthing adopted in the available alternator, maintain the continuity of earth connections and keep the earth electrode resistance within the specified value.

Earthing alternator frame: This earthing is essential for the safety of the workers, and to keep the frame of the alternator at zero earth potential. Operation of the earth fault relays or fuses to open the electrical circuits in case of earth faults is fully dependent upon earthing of the frame.

As per I.E. rules No.61, all the electrical equipment/ machines are to be provided with double earthings for safe operation. The condition of earth must be checked periodically, and the earth electrode and the earth conductor resistance must also be measured and recorded at repeated intervals of time. The earth electrode and the earthing conductors should be maintained such that the resistance valueis lower than the stipulated value according to the design of the system.

Emf equation of the alternator

Objectives: At the end of this lesson you shall be able to

- **explain the emf equation and apply the emf equation to calculate the induced emf in an alternator.**

Equation of induced (EMF): The emf induced in an alternator depends upon the flux per pole, the number of conductors and speed. The magnitude of the induced emf could be derived as stated below.

Let z	=	No.of conductors or coil sides in series/ phase in an alternator
p	=	No.of poles
F	=	frequency of induced emf in Hz
0	=	flux per pole in webers
k,	=	form factor= 1.11 - if emf is assumed to be sinusoidal
N	=	rotative speed of the rotor in r.p.m.

According to Faraday's Law of Electromagnetic Induction we have the average emf induced in a conductor rate of change of flux linkage.

$$= \frac{d\varnothing}{dt}$$

$$= \frac{\text{change of total flux}}{\text{time duration in which the flux change takes place}}$$

In one revolution of the rotor (ie in 60/N seconds), each stator conductor is cut by a flux equal to P0 webers.

Hence the change of total flux = $d\varnothing = P\varnothing$ and the time duration in which the flux changes takes place

= dt = 60/N seconds.

Hence the average emf induced in a conductor

$$= \frac{d\varnothing}{dt} = \frac{P\varnothing}{\frac{60}{N}} \text{ volts}$$

Substituting the value for $N = \frac{120F}{P}$ in eqn 1 we have the average emf induced in a conductor =

$$= \frac{P\varnothing 120F}{P60} = \text{volts} = 2\varnothing F \text{ volts}$$

If there are Z conductors in series per phase we have the average emf per phase = 20FZ volts.

Then r.m.s. value of emf per phase= average value x form factor

$= V_{AV} X K_F$

$= V_{AV} x 1.11$

$= 2\varnothing FZ x 1.11$

$= 2.22\varnothing FZ$ volts.·

Alternatively r.m.s. value of emf per phase= $2.22\varnothing F2T$ volts

$= 4.44\varnothing FT$ volts

where T is the number of coils or turns per phase and Z = 2T.

This would have been the actual value of the induced voltage if all the coils in a phase were (i)full pitched and (ii) concentrated or bunched in one slot. (In actual practice, the coils of each phase are distributed in several slots under all the poles.) This not being so, the actually available voltage is reduced in the ratio of these two factors which are explained below.

Pitch factor (K_P or K_c.): The voltage generated in a fractional pitch winding is less than the full pitch winding. The factor by which the full pitch voltage is multiplied to get voltage generated in fractional pitch is called pitch factor, and it is always less than one; and denoted as K_p or K_c. Normally this value is given in problems directl/ occasionally this value needs to be calculated by a formula

$K_p = K_c = \text{Cos } \alpha/2$

where a is the electrical angle by which the coil span falls short of full pitch .

Example: Calculate the pitch factor for a winding having 36 stator slots, 4 poles with a coil span of 1 to 8.

$$\text{For full pitch} = \frac{\text{Number of stator slots}}{\text{Number of slots}} = \frac{36}{4} = 9$$

Hence winding should start at 1 and end at 10.

In actual practice the coil span is taken as 1 - 8.

Hence actual pitch = 8 - 1 = 7.

Hence the coil span is short pitched by= 9 - 7 = 2.

$$\text{The angle } \alpha = \frac{\text{Differnce in pitch}}{\text{full pitch}} X 180^\circ$$

$$= \frac{2}{9} X 180^\circ = 40^\circ$$

where 180° is the complete angle for full pitch.

$$\text{Pitchfactor}K_C = \text{Cos}\frac{\alpha}{2} = \frac{40}{2} = \text{Cos}20 = 0.94$$

Distribution factor (K_c): It is imperative that the conductors of the same phase need to be distribiued in the slots instead of being concentrated at one slot. Because of this, the emf generated in different conductors will not be in phase with each other, and hence, cannot be added together to get the total induced emf per phase but to be added vectorially. This has to be taken into account while determining the induced voltage per phase.

Therefore, the factor by which the generated voltage must be multiplied to obtain the correct value is called a distribution factor, denoted by K_d and the value is always less than one. The formula for finding the value of K_c is given below.

$$K_d = \frac{\text{Sin } m\,\beta/2}{m \text{ Sin } \beta/2}$$

where m is the number of slots per phase per pole

Example: A six-pole alternator rotating at 1000 r.p.m. has a single-phase winding housed in three slots per pole; the slots in groups of three being 20° apart. Find the distribution factor.

$$K_d = \frac{\text{Sin } m\,\beta/2}{m \text{ Sin } \beta/2}$$

where m = 3 slots per phase per pole

$\beta = 20^\circ$

$$K_d = \frac{\text{Sin } 3 X 20/2}{3 \text{ Sin } 20/2} = \frac{\text{Sin } 30^\circ}{3 \text{ Sin } 10^\circ}$$

$$= \frac{0.5}{3 x 0.1736} = 0.96$$

Example: A 3-phase, 12-pole, star-connected alternator has 180 slots with 10 conductors per slot, and the conductors of each phase are connected in series. The coil span is 144° (electrical). Find the distribution factor and the pitch factor K_p

$$K_d = \frac{\text{Sin } m\,\beta/2}{m \text{ Sin } \beta/2}$$

$$m = \frac{180}{3 x 12} = 5 \text{ slots per phase per pole.}$$

$$\beta = \frac{180^\circ}{\frac{180}{12}} = 12^\circ$$

$$K_d = \frac{\text{Sin}5x\frac{12}{2}}{5\text{Sin}\frac{12}{2}} = \frac{\text{Sin}30^\circ}{5\text{Sin}6^\circ} = \frac{0.5}{5x0.1045} = 0.957$$

$$K_p = \text{Cos}\frac{\alpha}{2}$$

= Cos (180-144)/2 = Cos 36/2 = Cos 18° = 0.95.

From the foregoing, it is found that the pitch factor and the distribution factor are to be used to multiply the induced emf to get the actual induced volt- age. Thus emf induced in an alternator E_O per phase = 4.44 K_pK_d FØT volts

In the case of a star-connected alternator, the line voltage = E_L = √3E_p = √3E_O and in the case of a delta-connected alterator the line voltage E_L = E_P = E_O However, if the value of either K_d or K_p is not given in the problem it can be assumed to be one.

Example: Calculate the effective voltage in one phase of an alternator, given the following particulars. F = 60Hz turns/phase T = 240 flux per pole Ø = 0.0208 webber

Solution: As K_c / K_p and Kd values are not given, we an assume they are equal to one.

Voltage/phase E = 4.44 ØFT volts

= 4.44 x 60 x 0.0208 x 240 volts

= 1329.86V or 1330 volts.

Example: The following information is given in conne tion with a 3-phase alternator. Slots = 96, poles = r .p.m.=1500 turns/coil 16 in single layer, Ø = 2.58 10° lines. Calculate the voltage generated/phase.

$$F = \frac{PN}{120} = \frac{4x1500}{120} = 50Hz$$

$$\text{Coilsperphase} = \frac{\text{No.ofslots}}{\text{No.ofphases}} = \frac{96}{3} = 32$$

Therefore turns/phase = 32 x 16 = 512

= 2.58 x 10^6 lines = 2.58 x 10^6 x 10^{-8} weber

V = 4.44 FØT

= 4.44 x 50 x 512 x 2.58 x 10^6 x 10^{-8} = 2932 volts

Example: The stator of a 3-phase, 16-pole alternator ha 144 slots, and there are 4 conductors per slot connecte in two layers, and the conductors of each phase al connected in series. If the speed of the alternator is 375 r.p.m. calculate the emf induced per phase. The resulta flux in the air gap is 5 x 10^{-2} webers per pole, sinusoidall distributed. Assume the coil span as 150° electrical.

Sinusoidal distribution, hence the wave form is sine wav and the emf induced

E_o = E_p = 4.44 K_cK_d,FØT volts

$$K_c = \text{Cos}\frac{\alpha}{2}\text{Cos}(180-150)/2 = \text{Cos}\frac{30}{2}$$

$$m = \frac{144}{3x16} = 3$$

$$\beta = \frac{180^\circ}{\frac{144}{16}} = \frac{180}{9} = 20^\circ$$

$$K_d = \frac{\text{Sin}\,3\,x\,\frac{20}{2}}{3\,\text{Sin}\frac{20}{2}} = 0.96$$

$$\text{Number of slots/phase} = \frac{144}{3} = 48$$

Number of conductors/slots = 4

Number of conductors in series per phase = 48 x 4

$$\text{Number of turns in series per phase} = \frac{48 \text{ x } 4}{2} = 96$$

$$\text{Frequency} = \frac{PN}{120} = \frac{16 \text{ x } 375}{120} = 50\text{ Hz}$$

E_{ph} = 4.44 K_c K_d FØT

= 4.44 x 0.966 x 0.96 x 50 x 5 x 10^{-2} x 96

= 988 volts.

Characteristic and regulation of the alternator

Objectives: At the end of this lesson you shall be able to
- **explain the load characteristic of an alternator and the effect of the P.F. on terminal voltage**
- **explain the regulation of alternators and solve problems therein.**

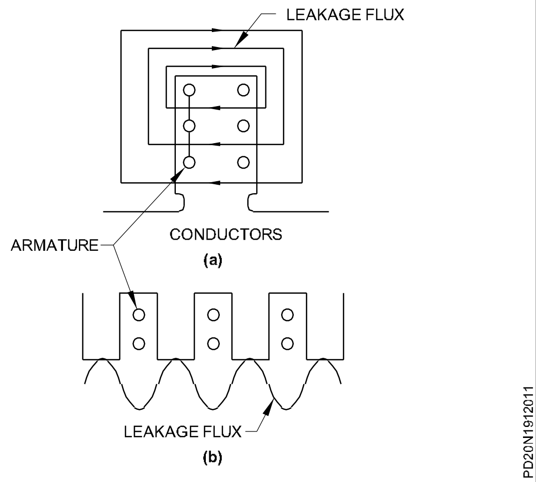
Load characteristic of an alternator: As the load on the altemator is changed, its terminal voltage is also found to change. The reason for this change is due to the voltage drop in the alternator because of

- armature resistance R
- armature leakage reactance X
- armature reaction which, in turn, depends upon the power factor of the load.

Voltage drop in armature resistance: Resistance of each phase winding of the alternator causes a voltage drop in the alternator, and it is equal to I_p R_a where I_p is the phase current and R_a is the resistance per phase.

Voltage drop in armature leakage reactance: When the flux is set up in the alternator due to the current flow in the armature conductors, some amount of flux strays out rather than crossing the air gap. These fluxes are known as leakage fluxes. Two types of leakage fluxes are shown in Figs 1a and b.

Fig 1



Though the leakage fluxes are independent of saturation, they do depend upon the current and the phase angle between the current and the terminal voltage "V". These leakage fluxes induce a reactance voltage which is ahead of the current by 90°. Normally the effect of leakage flux is termed as inductive reactance X and as a variable quantity. Sometimes the value x_{1} is named as synchronous reactance to indicate at it refers to working conditions.

Voltage drop due to armature reaction: The armature reaction in an alternator is similar to DC generators. But the load power factor has considerable effect on the armature reaction in the alternators

The effects of armature reaction have to be considered in

three cases, i.e. when load power factor is

- unity
- zero lagging
- zero leading.

At unity P.F. the effect of armature reaction is only cross-magnetising. Hence there will be some distortion of the magnetic field.

But in the case of zero lagging P.F. the effect of armature. reaction will be de-magnetising. To compensate this de-magnetising effect, the field excitation current needs to be increased.

On the other hand, the effect of armature reaction due to zero leading P.F. will be magnetising. To compensate the increased induced emf, and to keep the constant value of the terminal voltage due to this additional magnetising effect, the field excitation current has to be decreased.

Effect of armature resistance and reactance in the alternator: The induced emf per phase in an alternator is reduced by the effect of armature resistance, and reactance drops as shown vectorially in Fig 2 where

V is the terminal voltage per phase

I is the phase current

θ is the power factor angle between phase current and terminal voltage

E_o is the induced emf per phase

R_a is the armature resistance per phase

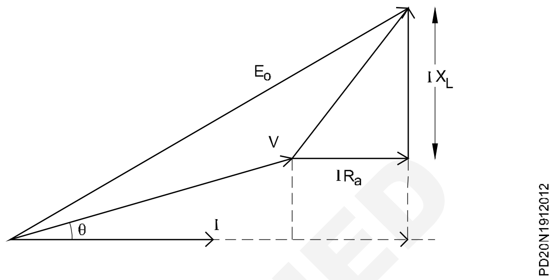
X_L is the armature reactance per phase.

The induced emf can be calculated either vectorially or mathematically.

Mathematically the induced emf

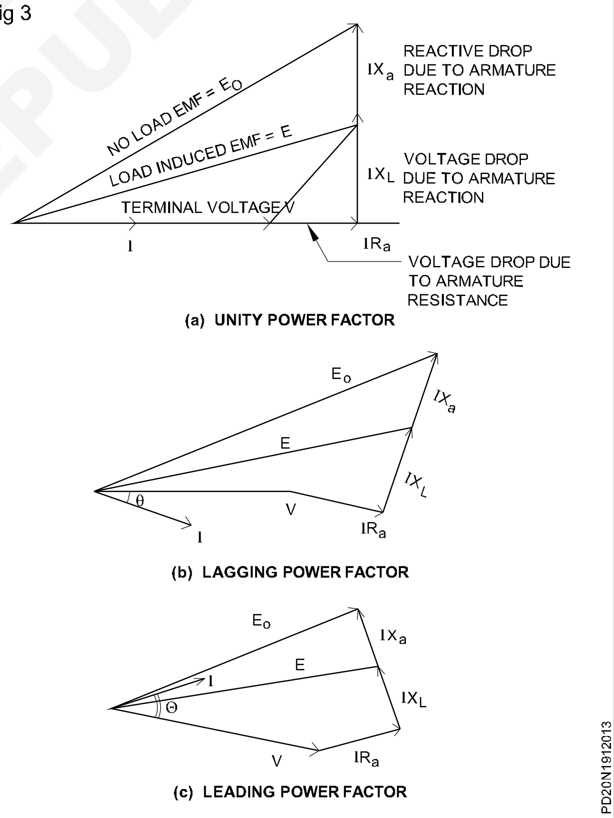
$$E = \sqrt{(V\cos\theta + IR_a)^2 + (V\sin\theta + IX_L)^2}$$

Fig 2



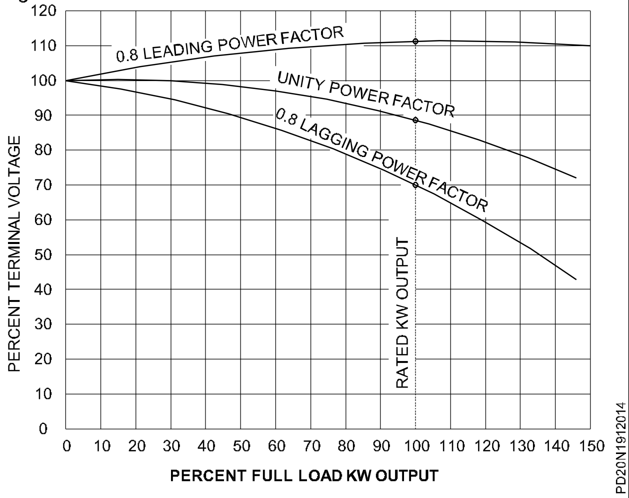
For any value of P.F. either lagging or leading, a combination of the effects of cross-magnetising, de-magnetising or magnetising takes place. In all the effects of armature reaction, it is shown vectorially as a force acting in line with the reactance drop as shown in Fig 3 by a vector IX, However this value is not readingly measurable.

Fig 3



On the basis of the above information, it is found that the terminal voltage of an alternator with unity power factor load will fall slightly on load as shown in Fig 4. Also it is found that the terminal voltage falls considerably for an alternator having lagging power factor. On the contrary, with leading P.F. the terminal voltage of the alternator on load increases even beyond the no-load terminal voltage as shown in Fig 4.

Fig 4



Rating of alternators: As the power factor for a given capacity load determines the load current, and the alternator's capacity is decided on load current, the rating of the alternator is given in kVA or MVA rather than kW or MW in which case the power factor also is to be indicated along with the wattage rating.

Example: A3-phase, star-connected alternator supplies a load of 5 MW at P.F. 0.85 lagging and at a voltage of 11 kv. Its resistance is 0.2 ohm per phase and the synchronous reactance is 0.4 ohm per phase. Calculate the line value of the emf generated.

$$\text{Full load current} = I_L = \frac{P}{\sqrt{3}\,E_L\,Cos\theta}$$

$$\frac{5 \times 1000 \times 1000}{\sqrt{3} \times 11000 \times .85} = 309 \text{ Amps}$$

In star I_L	=	I_p
IR_a drop	=	309 x 0.2 = 61.8V
Ix_L drop	=	309 x 0.4 = 123.6 V
Terminal voltage (line)	=	11000 V

$$\text{Terminal voltage (phase)} = \frac{11000}{\sqrt{3}} = 6350V$$

Power factor	=	0.85
Power factor angle = θ	=	$Cos^{-1}(.85)$
	=	Cos 31.8°
Sin θ	=	0.527.

Drawing the vector, as shown in Fig 5, with the above data, we have

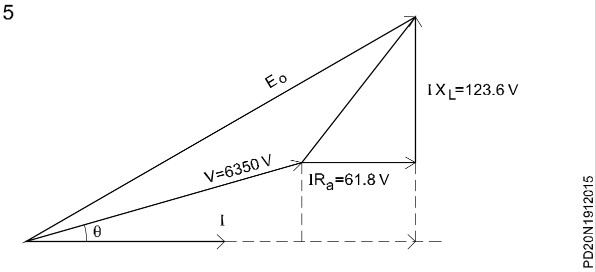
$$E_o = \sqrt{(V\cos\theta + IX_L)^2}$$

$$= \sqrt{(6350X0.85 + 61.8)^2 + (6350X0.527 + 123.6)^2}$$

$$= 6468.787\text{volts}$$

$$\text{Line voltage} = \sqrt{3}E_P = \sqrt{3} \text{ X } 6469 = 11204V$$

Fig 5



The voltage regulation of an alternator: The voltage regulation of an alternator is defined as the rise in voltage when the load is reduced from the full rated value to zero, with the speed and field current remaining constant. It is normally expressed as a percentage of the full load voltage.

$$\% \text{ of voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} X100$$

where V_{NL}	-	no load voltage of the alterator
V_{FL}	-	Full load voltage of the alternator

The percentage regulation varies considerably, depending on the power factor of the load, and as we have seen for leading P.F. the terminal voltage increases with load, and for lagging P.F. the terminal voltage falls with the load.

Example: When the load is removed from an AC generator, its terminal voltage rises from 480V at full load to 660V at no Ind. Calculate the voltage regulation.

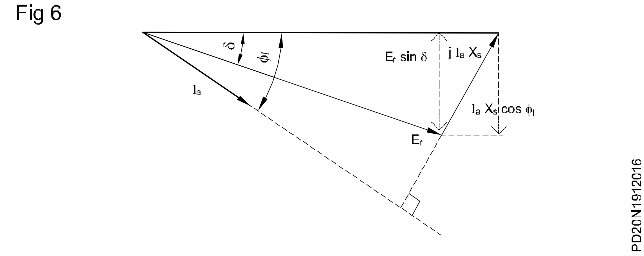
$$\% \text{ regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} X100$$

$$\frac{660 - 480}{480} X100 = 37.5\%$$

Motor Starting by Using damper{:tun:ottiss-eur) Winding:

As already mentioned earlier most of the large synchronous motors are provided with damper windings, in order to nullify the oscillations of the rotor whenever the synchronous machine is subjected to a periodically varying load. Damper windings are special bars laid into slots cut in the pole face of a synchronous machine and then shorted out on each end by a large shorting ring, similar to the squirrel cage rotor bars. A pole face with a set of damper windings. When the stator of such a synchronous machine is connected to the 3-Phase AC supply, the machine starts as a 3-Phase induction machine due to the presence of the damper bars, just like a squirrel cage induction motor. Just as in the case of a 3-Phase squirrel cage induction motor, the applied voltage must be suitably reduced so as to limit the starting cutTent to the safe rated value. Once the motor picks up to a speed near about its synchronous speed, the DC supply to its field winding is connected and the synchronous motor pulls into step i.e. it continues to operate as a Synchronous motor running at its synclu-onous speed.

Fig 6



5.3.3 Effect of changes in load on amature current, power angle, and power factor of synchronous motor

The effects of cl1anges in mechanical or shaft load on am1ature current, power angle, and power factor can be seen from the phasor diagram as already stated, the applied stator voltage, frequency, and field excitation are assumed, constant. The initial load conditions are represented by the thick lines. The effect of increasing the shaft load to twice its initial value are represented by the light lines indicating the new steady state conditions. These are drawn in accordance with Eqn. 69 and Eqn. 70, when the shaft load is doubled both I a cos ¢iand E f sin 15 are doubled. While redrawing the phasor diagrams to show new steady-state conditions, the line of action of the new jlaX5 phasor must be perpendicular to the new Ia phasor. Furthermore, if the excitation is not changed, increasing the shaft load causes the locus of the Er phasor to follow a circular arc, thereby increasing its phase angle with increasing shaft load. Note also that an increase in shaft load is also accompanied by a decrease in <!>; resulting in an increase in power factor. As additional load is placed on the machine, the rotor continues to increase its angle of lag relative to the rotating magnetic field, thereby increasing both the angle of lag of the counter EMF phasor and the magnitude of the stator current. It is interesting to note that during all this load variation, however, except for the duration of transient conditions whereby the rotor assumes a new position in relation to the rotating magnetic field, the average speed of the machine does not change. As the load is being increased, a final point is reached at which a further increase in o fails to cause a corresponding increase in motor torque, and the rotor pulls out of synchronism. In fact as stated earlier, the rotor poles at this point, will fall behind the stator poles such that they now come under the influence of like poles and the force of attraction no lon..er exists. Thus, the point of maximum torque occurs at a power angle of approximately 90 for a cyl indrical-rotor machine, as is indicated by Eqn. 5.12. This maximum value of torque that causes a synchronous motor to pull out of synchronism is called the pull-out torque. In actual practice, the motor will never be operated at power angles close to 90 °as armature current will be many times its rated value at this load.

5.3.4 Effect of changes in field excitation on synchronous motor performance:

Intuitively we can expect that increasing the strength of the magnets will increase the magnetic attraction, and thereby cause the rotor magnets to have a closer alignment with the corresponding opposite poles of the rotating magnetic poles of the stator. This will obviously result in a smaller power angle. This fact can also be seen in Eqn. 5.11 When the shaft load is assumed to be constant, the steady-state value of £ f sinomust also be constant. An increase in Efwill cause a transient increase in£/ sino, and the rotor will accelerate. As the rotor changes its angular position, o decreases until £ f sinobas the same steady-state value as before, at which time the rotor is again operating at synchronous speed, as it should run only at the synchronous speed. This change in angular position of the rotor magnets relative to the poles of rotating magnetic field of the stator occurs in a fraction of a second. The effect of changes in field excitation on armature cun-ent, power angle, and power factor of a synchronous motor operating with a constant shaft load, from a constant voltage, constant frequency supply, is illustrated in Fig. 5.7. From Eqn. 5.13, we have for a constant shaft load.

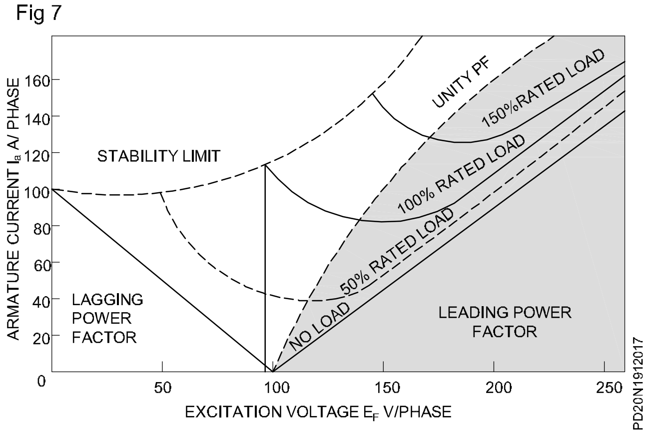
5.3.5 V curves

Curves of armature current vs. field current (or excitation voltage to a different scale) are called V curves, and are shown in Fig. 58 for typical values of synchronous motor loads. The curves are related to the phasor diagram in Fig. 5.7, and illustrate the effect of the variation of field excitation on amrnture current and power factor for typical shaft loads. It can be easily noted from these curves that an increase in shaft loads require an increase in field excitation in order to maintain the power factor at unity.

The V curves can be determined experimentally in the laboratory by varying Ir at constant shaft load and noting Iaas Ir is varied) Alternatively the V curves shown in can be detennined graphically by plotting from a family of phasor diagrams.

The family of V curves shown in Fig. 5.8 represent computer plots of Eqn. 5.17

Fig 7



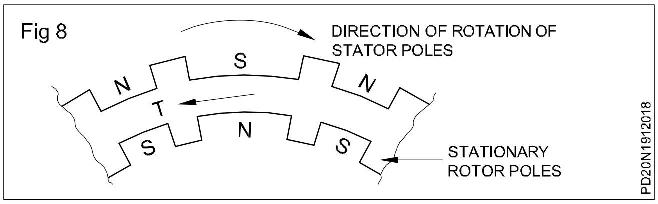


Fig. 5.2. Force of repulsion between stator poles and roter poles - resulting in production of torque in anticlockwise direction.On the contrary if the rotor is brought to near synchronous speed by some extemal means say a small motor (known as pony motor which could be a D.C or AC induction rotor) mounted on the same shaft as that of the rotor, the rotor poles get locked to the unlike poles in the stator and the rotor continues to run at the synchronous speed even if the supply to the pony motor is disconnected,Thus the synchronous rotor cannot start rotating on its own or usually we say that the synchronous rotor has no starting torque. So, some special provision has to be made either inside the machine or outside of the machine so that the rotor is brought to near about its synchronous speed. At that time, if the armature is supplied with electrical power, the rotor can pull into step and continue to operate at its synchronous speed. Some of the commonly used methods for starting synchronous rotor are described in the following section.

5.2: Methods of starting synchronous motor.

Basically there are three methods that are used to start a synchronous motor.

- To reduce the speed of the rotating magnetic field of the stator to a low enough value that the rotor can easily accelerate and lock in with it during one half-cycle of the rotating magnetic field's rotation. This is done by reducing the frequency of the applied electric power. This method is usually followed in the case of inverter-fed synchronous motor operating under variable speed drive applications.
- To use an external prime mover to accelerate the rotor of synchronous motor near to its synchronous speed and then supply the rotor as well as stator. Of course care should be taken to ensure that the directions of rotation of the rotor as well as that of the rotating magnetic field of the stator are the same. This method is usually followed in the laboratory- the synchronous machine is started as a generator and is then connected to the supply mains by following the synchronization or paralleling procedure. Then the power supply to the prime mover in disconnected so that the synchronous machine will continue to operate as a motor.
- To use damper windings or-amortisseur windings if these are provided in the machine. The damper windings or amortisseur windings are provided in most of the large synchronous motors in order to nullify the oscillations of the rotor whenever the synchronous machine is subjected to a periodically varying load.

Each of these methods of starting a synchronous motor are described below in detail

5.2.1 Motor Starting by reducing the supply Frequency

If the rotating magnetic field of the stator in a synchronous motor rotates at a low enough speed, there will be no problem for the rotor to accelerate and to lock in with the stator's magnetic field. The speed of the stator magnetic field can then be increased to its rated operating speed by gradually increasing the supply frequency 'f up to its normal 50- or 60-Hz value

This approach to starting of synchronous motors makes a lot of sense, but there is a big problem: Where from can we get the variable frequency supply? The usual power supply systems generally regulate the frequency to be 50 or 60 Hz as the case may be. However, variable-frequency voltage source can be obtained from a dedicated generator only in the olden days and such a situation was obviously impractical except for very unusual or special drive applications. But the present day solid state power converters offer an easy solution to this We now have the rectifier- inverter and cycloconverters, which can be used to convert a constant frequency AC supply to a variable frequency AC supply. With the development of vich modern solid-state variable-frequency drive packages, it is thus possible to continuously control the frequency of the supply connected to the synchronous motor all the way from a fraction of a hertz up to and even above the normal rated frequency. If such a variable-frequency drive unit is included in a motor-control circuit to achieve speed control, then starting the synchronous motor is very easy-simply adjust the frequency to a very low value for starting, and then raises it up to the desired operating frequency for normal running. When a synchronous motor is operated at a speed lower than the rated speed, its internal generated voltage (usually called the counter EMF) EKfu will be smaller than normal. As such the terminal voltage applied to the motor must be reduced proportionally with the frequency in order to keep the stator current within the rated value. Generally, the voltage in any variable-frequency power supply varies roughly linearly with the output frequency.

5.2.2 Motor Starting with an External Motor:

The second method of starting a synchronous motor is to attach an external starting notor““(pony motor) to it and bring the synchronous machine to near about its rated speed (but not““exactly equal to it, as the synchronization process may fail to indicate the point of closure of the““main switch connecting the synchronous machine to the supply system) with the pony motor.““Then the output of the synchronous machine can be synchronised or paralleled with its power““supply system as a generator, and the pony motor can be detached from the shaft of the machine““or the supply to the pony motor can be disconnected. Once the pony motor is turned OFF, the““shaft of the machine slows down, the speed of the rotor magnetic field By falls behind Bea““momentarily and the synchronous machine continues to operate as a motor. As soon as it begins““to operate as a motor the synchronous motor can be loaded in the usual manner just like any motor .

32-26. Parallel Operation of Alternators:

The operation of connecting an alternator in parallel with another alternator or““with common bus-bars is known as synchronizing. Generally, alternators are used in a“power system where they are in parallel with many other alternators. It means that the alternator is connected to a live system of constant voltage and constant frequency. Often the electrical system to which the alternator is connected has already so many alternators and loads connected to it that no matter what power is delivered by the incoming alter- nator, the voltage and frequency of the system remain the same. In that case, the alternator is said to be connected to infinite bus-bars.

“It is never advisable to connect a stationary alternator to live bus-bars because, stator induced e.m.f. being zero, a short-circuit will result. For proper synchronization of alternators, the following three conditions must be satisfied:-

1. The terminal voltage (effective) of the incoming alternator must be the same as bus-bar voltage.
2. The speed of the incoming machine must be such that its frequency (=PN/120) equals bus-bar frequency.
3. The phase of the alternator voltage must be identical with the phase of the bus-bar voltage. It means that the switch must be closed at (or very near) the instant the two voltages have correct phase relationship.

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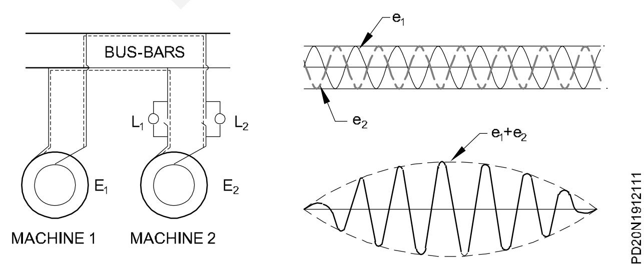
Condition (1) is indicated by a voltmeter, conditions (2) and (3) are indicated by synchronizing lamps or a synchranoscope.

32-27. Synchronizing of Alternators

(a) Single pham Alternatore““Suppose machine 2 is to be synchronized with ot put on the hus-bars to which machine I is already connected. This is done with the help of two lamps L_1 and L_2 (known as synchronizing lamps) connected as shown in Fig 1.

It should be noted that & E_1 and E_2 are in-phase relative to are in direct phase opposition in the loost circuit (shown dotted) the external circuit but““If the speed of the incoming machine 2 is not brought up to that of machine 1. then its frequnury will also be different, henes there will be phase differenen betwee their voltages (even when they are equal in magnitude which is determined by Gobi eszita tion)

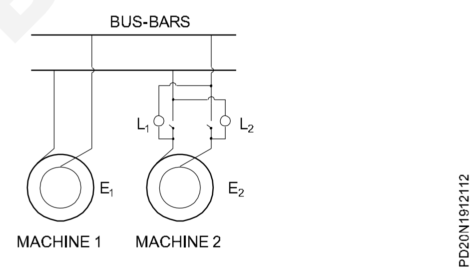
Fig 1



This phase difference will be continuously ehanging with the changes in their frequencies. The result is that their resultant voltage will undergs changes similar to the frequency changes of anata produced when two sound sourens of nearly equal frequency are sounded together as shown in Fig 1(b).

Sometimes the resultant voltage is maximum and some other times minimum. Hence, the current is alternatingly maximum and minimum. Due to this changing current through the lamps, a flicker will be produced, the feaquency of flicker boing (ft. Lamps will dark out and glow up alternately. Darkness indicates that the two voltages E and E, are in exact phase opposition relative to the local circuit and hence there is no resul tant current through the lamps. Synchronizing is done at the middle of the dark period. That is why, sometimes, it is known as 'lamps dark synchronizing. Some engine- ers prefer lamp bright synchronization because of the fact the lamps are much more sensitive to changes in voltage at their maximum brightness than when they are dark. Hence, a sharper and more accurate synchronization is obtained. In that case, the lamps are connected as shown in Fig 2. Now, the lamps will glow brightest when the two voltages are in-phase with the bus-bar voltage because then voltage across them is twice the voltage of each machine.

Fig 2



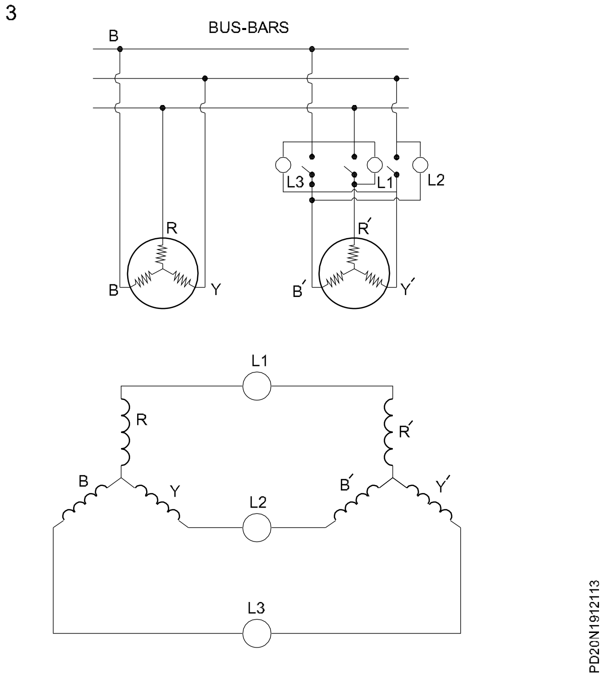
(b) Three-phase Alternators In 3. alternators, it is necessary to synchronize one phase only, the other two phases will then be synchronized automatically. However, first it is necessary that the incoming alternator is correctly 'phased out' i.e. the phases are connected in the proper crder of R, Y, B and not R, B, Y

In this case, three lamps are used.But they are deliberateil connected asymmetrically as shown in Fig 3 and Fig 3(a).

This transposition of two lamps, suggested by siemens and Halske helps to indicate whether the incoming machine is running too slow. IF lamps were connected symmetrically, they would dark out or glow up simultaneously (if the phase rotation is the same as that of the bus-bars)

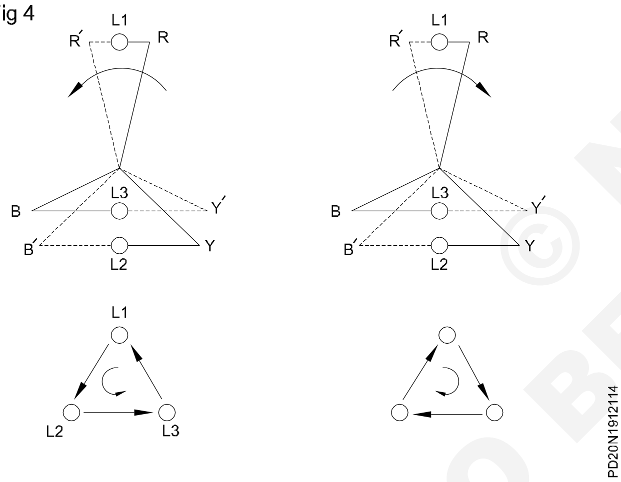
Lamp L1 is connected between R and R L3 between Y and B (not Y and Y) and L3 between B and Y (and not B and B) as shown in Fig 3(a).

Fig 3



Voltage stars of two machines are shoen superimposed on each other in Fig. 32-71

Fig 4



Two sets of star vectors will rotate at unequal speeds if the frequencies of the two mach““ines are different. If the incoming alternator is running faster, then voltage star RYBwill appear to rotate anticlockwise with respect to the bus-har voltage star RYB at a speed.

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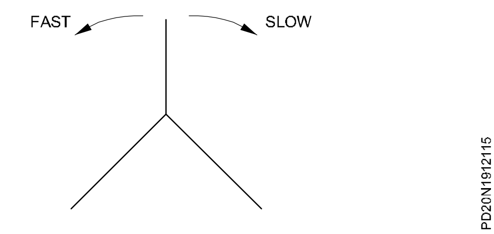
corresponding to the difference between their frequencies. Withreference to Fig 4, it is seen that voltage across is RR' and isseen to be increasing from zero, that across L1 is Y * B' which is decreasing, having just passed through its maximum, that across La isBY which is increasing and approaching its maximum. Hence, thelamps will light up one after the other in the order 2, 3, 1;2, 3, 1 or 1,2, 3. Now, suppose that the incoming machine is slightly slower. Thenthe star R'Y' will appear to be rotating clockwise relative to voltagestar RFB (Fig 4a). Here, we find that voltage across L_{2}*i . Y' * B isdecreasing having just passed through its maximum, that'across L1 i.e.YB is increasing and approaching its maximum, that across dot L_{1} isdecreasing having passed through its maximum earlier. Hence, the lamps will light up oneafter the other in the order 3, 2, 1, 3, 2, 1, etc. which is just the reverse of the first order.Usually, the three lamps are mounted at the three corners of a triangle and the apparentdirection of rotation of light indicates whether the incoming alternator is running too fastor too slow (Fig 5). Synchronization is done at the moment the uncrossed lamp L_{1}is in the middle of the dark period. When the alternator voltage is too high for the lampsto be used directly, then usually step-down transformers are used and the synchronizing lamps are connected to the secondaries.

It will be noted that when the uncrossed lamp L_{1} is dark, the other two 'crossed'lamps L_{1} and L_{1} are dimly but equally bright. Hence, this method of synchronizing is alsosometimes known as "two bright and one dark' method.

It should be noted that synchronization by lamps is not quite accurate, because toa large extent, it depends on the sense of correct judgement of the operator. Hence, toeliminate the element of personal judgment in routine operation of alternators, themachines are synchronized by a more accurate device called a synchronoscope. It consistsof 3 stationary coils and a rotating iron vane which is attached to a pointer. Out of threecoils, a pair is connected to one phase of the line and the other to the correspondingmachine terminals, potential transformer being usually used. The pointer moves to oneside or the other from its vertical position depending on whether the incoming machine is too fast or too slow. For correct speed, the pointer points vertically up.

Fig 5



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Synchronous motor

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of synchronous motor**
- **explain the constructional details of synchronous motor**
- **state the different methods of starting a synchronous motor**
- **compare the features of synchronous motor and induction motor**
- **state the applications of synchronous motors.**

Synchronous motor

An alternator which runs as a motor is called as synchronous motor. 3-phase AC supply is required for the AC winding and suitable DC voltage is required for the field winding excitation. The synchronous motors are not self starting.

Working principle

When the stator winding of a three-phase synchronous motor is connected to a three-phase supply, a rotating field is set up in the machine. If the rotor is then started in the direction of rotation of the rotating field, the north pole of the rotating field draws the south pole of the rotor with it, and the south pole of the rotating field draws the north pole of the rotor. The rotor continues to turn at a speed of rotation which can be calculated from the familiar formula, Ns = 120f/p. It turns synchronously with the rotating field. The machine is now working as a motor.

Construction

In construction, synchronous motors are almost identical with the corresponding alternator, and consist essentially of two elements.

1 Stator (armature)

2 Rotor (field)

A synchronous motor may have either a revolving armature or a revolving field, although most synchronous motors are of the revolving field type. The stationary armature which is wound for the same number of poles as rotor is attached to the stator frame while the field magnets are attached to a frame which revolves with the shaft.

The field coils are excited by direct currents, either from a small DC generator (usually mounted on the same shaft as the motor and called as an exciter), or from other DC source. (Fig 1 & 2)

Methods of starting a synchronous motor

1 By using a pony motor

2 By using damper windings

3 By synchronisation

1 By using a pony motor

A three-phase current is fed to the stator winding of three-phase synchronous machine and its rotor is started by a pony (starting) motor, having same number of poles as that of synchronous motor. The small induction motor coupled to the synchronous machine for starting purpose is called the pony motor. The pony motor brings the motor very close to the synchronous speed, then the DC is supplied to the field and the switch of the pony motor is switched 'off'. Then the motor pulls itself to the synchronous speed.

Fig 1

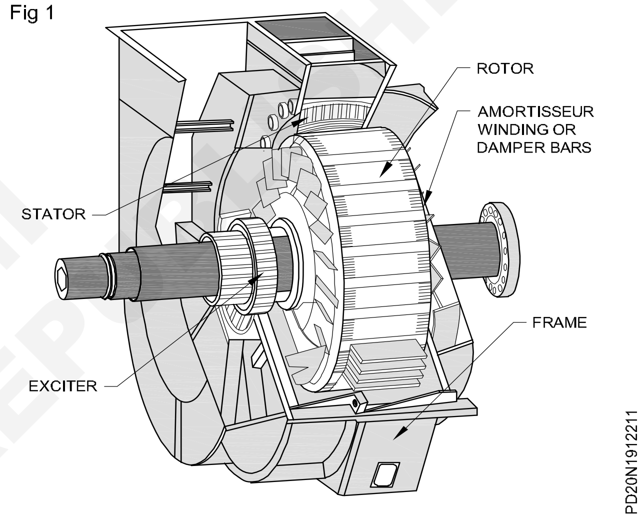
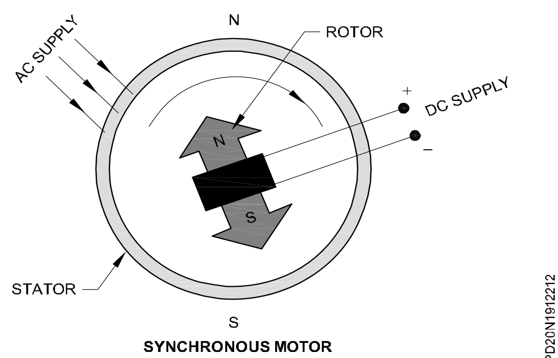


Fig 2



SYNCHRONOUS MOTOR

2 By using damper windings

The damper winding is just like squirrel cage winding consisting of copper embedded in the pole shoe and short circuited at both sides.

Action of damper winding at start

While starting a synchronous motor set up a rotating magnetic field that cuts the cage (damper) winding on the field system (rotor) and induces current in it. A torque is developed and the motor runs to a speed a little less than that of synchronous speed as an induction motor. The DC excitation is then switched on and definite poles on the rotor are set up. Now the two sets of poles suddenly lock each other by which the motor pulls into synchronous speed.

While starting a synchronous motor provided with damper windings, first the main field windings is short circuited and AC supply is switched on to stator terminals through suitable starter. The motor starts up and when a steady speed is reached DC excitation is applied after removing the short on the field winding. If the excitation is sufficient the machine will be pulled into synchronism.

3 By synchronisation

Initially the synchronisation motor is run as an alternator and it is synchronised with the main supply bus by following one of the synchronisation methods. After synchronisation the prime mover is disconnected. Now the alternator, ie the synchronous motor continues to run at synchronous speed by drawing power from supply mains.

Comparison of Synchronous and Induction motor

	Aspects	Synchronous motor	Induction motor
1	Speed	Synchronous speed constant is independent of load condition.	Less than synchronous speed. Decreases with increasing load.
2	Power factor	Operates at all power factors whether lagging or leading.	Operates at only lagging power factor.
3	Efficiency	Very good	Good
4	Cost	Costlier	Cheaper
5	Starting	Not self-starting	Self-starting
6	Speed control	No question	Can be controlled to small units.
7	Application	Used for mechanical load and also to improve power factor as synchronous condenser.	Limited to supply of mechanical load.

Application

Synchronous motors are employed exclusively as power factor correction devices, they are termed as synchronous condenser, because the effect on the power system is the same as that of a static capacitor which also produces a leading current.

1 Induction motors of all types particularly when they are under loaded

2 Power transformers and voltage regulators

3 Arc welders

4 Induction furnaces and heating coils

5 Choke coils and magnetic systems and

6 Fluorescent and discharge lamps, neon signs, etc.

Causes of low power factor

The principle cause of a low power factor is due to the reactive power flowing in the circuit. The reactive power depends on the inductance and capacitance of the apparatus.

The disadvantages of low power factor are as follows

1 Overloading of cables and transformer

2 Decreased line voltage at point of application

3 Inefficient operation of plant and

4 Penal power rates

The advantages of increasing power factor are as follows

1 Reduction in the current

2 Reduction in power cost

3 Reduced losses in the transformers and cables

4 Lower loading of transformers, switch gears, cables etc.

5 Increased capability of the Power system (additional load can be met without additional equipment)

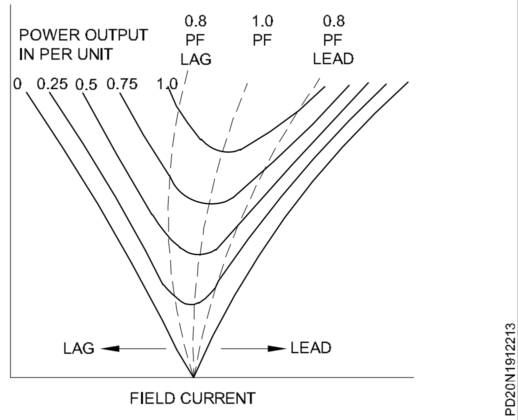
6 Improvement in voltage conditions and apparatus performance and

7 Reduction in voltage dips caused by welding and similar equipment

V Curves of synchronouos machines

V-Curve of a synchronous machine shows the relation between the armature current and excitation current, when the load and input voltage to the machine is constant. At a constant load, if excitation is changed the power factor of the machine changes, i.e. when the field current is small (machine is under-excited) the P.F. is low and as the excitation is increased the P.F. improves so that for a certain field current the P.F. will be unity and machine draws minimum armature current. This is known as normal excitation. If the excitation is further increased the machine will become over-excited and it will draw more line current and P.F. becomes leading and decreases. Therefore, if the field current is changed keeping load and input voltage constant, the armature current changes to make $VI\cos\theta$ constant. Variation of armature current with excitation are called 'V' curves (Fig 3).

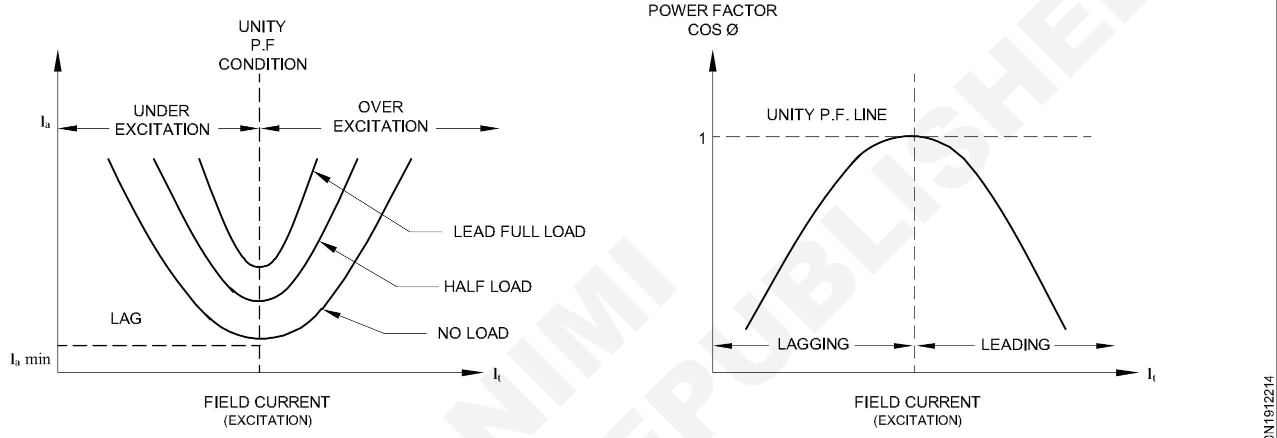
Fig 3



The Fig 4 shows V and inverse V curves of synchronous motor.

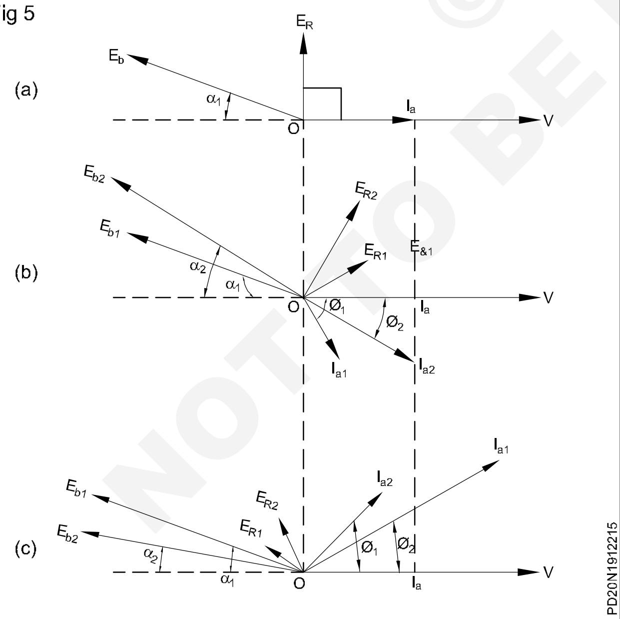
Effect of Changing Excitation on Constant load : As shown in Fig. (5a), suppose a synchronous motor is operating with normal excitation ($E_b = V$) at unity p.f. with a given load. If R_a is negligible as compared to X_S, then I_a lags E_R by 90° and is in phase with V because p.f. is unity. The armature is drawing a power of $V.I_a$ per phase which is enough to meet the mechanical load on the motor. Now, let us discuss the effect of decreasing or increasing the field excitation when the load applied to the motor remains constant

Fig 4



V AND INVERSE V CURVE OF SYNCHRONOUS MOTOR

Fig 5



a Excitation Decreased

As shown in Fig (5b), suppose due to decrease in excitation, back e.m.f. is reduced to E_{b1} at the same load angle α_1. The resultant voltage E_{R1} causes a lagging armature current I_{a1} to flow. Even though I_{a1} is larger than I_a in magnitude it is capable of producing necessary power $V.I_a$ for carrying the constant load because $I_{a1}\cos\phi_1$ component is less than I_a so that $V.Ia_1\cos\phi_1 < V.I_a$.

Hence, it becomes necessary for load angle to increase from α_1 to α_2. It increases back e.m.f. from E_{b1} to E_{b2} which, in turn, increases resultant voltage from E_{R1} to E_{R2}. Consequently, armature current increases to I_{a2} whose in-phase component produces enough power ($VI_{a2}\cos\phi_2$) to meet the constant load on the motor.

b Excitation Increased

The effect of increasing field excitation is shown in Fig 5c where increased E_{b1} is shown at the original load angle α_1. The resultant voltage E_{R1} cause a leading current I_{a1} whose in-phase component is larger than I_a. Hence, armature develops more power than the load on the motor. Accordingly, load angle decrease from α_1 to α_2 which decreases resultant voltage from E_{R1} to E_{R2}. Consequently, armature current decreases from I_{a1} to I_{a2} whose in-phase component $I_{a2}\cos\phi_2 = I_a$. In that case, armature develops power sufficient to carry the constant load on the motor.

Hence, we find that variations in the excitation of a synchronous motor running with a given load produce variations in its load anlge only.

Methods of improvement of power factor

The power factor can be improved by following methods

1 Static capacitor or capacitor bank

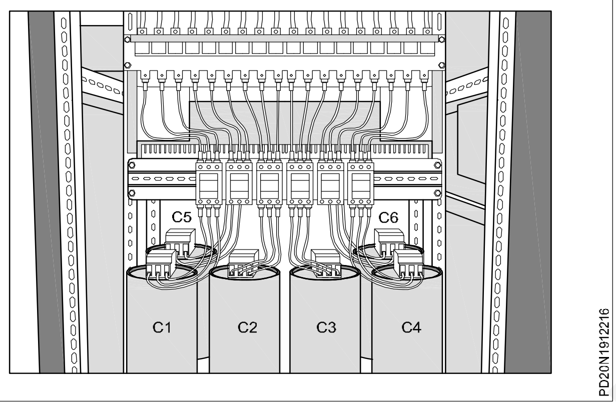
2 Synchronous motor

Capacitor bank

A capacitor bank is a group of several capacitors that are of same specifications connected in parallel to form a capacitor bank that store electrical energy. The capacitor bank so formed in then used to correct lagging power factor into leading power factor or phase shift in an AC supply as shown in Fig 6.

C1, C2, C3, C4, C5, C6 = capacitors

Fig 6



Different Torques of a Synchronous Motor

Various torques associated with a synchronous motor are as follows:

1 starting torque

2 running torque

3 pull-in torque and

4 pull-out torque

a Starting Torque

It is the torque (or turning effort) developed by the motor when full voltage is applied to its stator (armature) winding. It is also sometimes called breakaway torque. Its value may be as low as 10% as in case of centrifugal pumps and as high as 200 to 250% of full-load torque as in the case of loaded reciprocating two-cylinder compressors.

b Running Torque

As its name indicates, it is the torque developed by the motor under running conditions. It is the driven machine. The peak horsepower determine the maximum torque that would be required by the driven machine. The motor must have a break-down or a maximum running torque greater than this value in order to avoid stalling.

c Pull-in Torque

A synchronous motor is stated as induction motor till it runs 2 to 5% below the synchronous speed. Afterwards, excitation is switched on and the rotor pulls into step with the synchronously - rotating stator field. The amount of torque at which the motor will pull into step is called the pull-in torque.

d Pull-out- Torque

The maximum torque which the motor can develop without pulling out of step or synchronism is called the pull-out torque.

Normally, when load on the motor is increased, its rotor progressively tends to fall back in phase by some angle (called load angle) behind the synchronously-revolving stator magnetic field though it keeps running synchronously. Motor develops maximum torque when its rotor is retarded by an angle of 90° (or in other words, it has shifted backward by a distance equal to half the distance between adjacent poles). Any further increase in load will cause the motor to pull out of step (or synchronism) and stop.

MG set and rotary converter

Objectives: At the end of this lesson you shall be able to
- **list the advantages of direct current over alternating current**
- **list the methods of converting AC to DC**
- **state the advantages and disadvantages of MG-set**
- **describe the rotary converter construction and its working.**

The AC system has been adopted universally for the generation, transmission and distribution of electric power. It is more economical than a DC system of generation, transmission and distribution. There are applications where DC is either essential or more advantageous over AC.

DC is essential in the following applications.

- Electrochemical process such as electroplating, electro-refining etc.
- Storage battery charging.
- Arc lamp for search light and cinema projectors.

Direct current is more advantageous in the following applications.

- Traction purposes - DC series motor.
- Operating telephones, relays, time switches.
- Rolling mills, paper mills, elevators where fine speed control, frequent starting against heavy torque and rotation in both directions are required, DC motors are more suitable.

The conversion of AC to DC has become a necessity due to the above reasons.

Methods : The methods of conversion of AC to DC

- Motor-generator set
- Rotary converter
- Mercury arc rectifier
- Metal rectifiers
- Semi-conductor diodes and SCR

Out of the above five the motor generator sets and semi-conductor rectifiers are now mostly in use. The other types have become obsolete for obvious reasons.

Motor generator set : It consists of a 3-phase AC motor directly coupled to a DC generator. In the case of larger units, the AC motor is invariably a synchronous motor and the DC generator is usually compound.

Advantages

1 The DC output voltage is practically constant. The output (DC) voltage is not affected by changes in AC supply voltage.

2 DC output voltage can be easily controlled by the shunt field regulator.

3 The M.G set can also be used for power factor correction, where synchronous motor is used for driving the generator.

Disadvantages

1 It has a comparatively low efficiency.

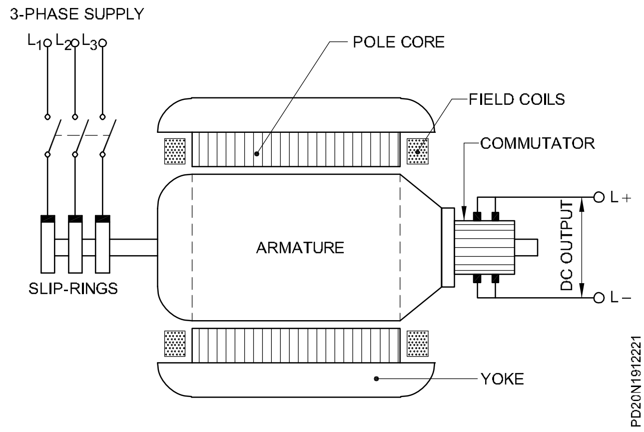
2 It requires more floor space.

Rotary or synchronous converter

A rotary converter is used when a large DC power is required. It is a single machine with one armature and one field. It combines the function of a synchronous motor and a DC generator. It receives alternating current through a set of slip rings mounted on one side of the armature rotating synchronously (N_s = 120 f/P) and delivers direct current from the opposite end through the commutator and brushes.

Construction : In general construction and design, a rotary converter is more or less like a DC machine. It has interpoles for better commutation. Its commutator is larger than that of a DC generator of the same size because it has to handle a larger amount of power.

Fig 1



The only added feature are -

- a set of slip-rings mounted at the end opposite to the commutator end
- dampers in the pole faces as in a synchronous motor.

A simple sketch illustrating the main parts of a rotary (synchronous) converter is shown in Fig 1.

The fact that the emf induced in the armature conductors of a DC generator is alternating and that it becomes direct (unidirectional) only due to the rectifying action of the commutator, the slip-rings are to be connected to some suitable points on the armature winding to use this machine as an alternator.

The rotary converter armature is mostly lap wound. The number of parallel paths in the armature is equal to the number of poles. Therefore the number of equi-potential points on the armature is equal to the number of pairs of poles. The number of tappings taken to each slip-ring is, therefore, equal to the number of pairs of poles. For a 3-phase lap wound rotary converter, it is essential that the number of armature conductors per pole should be divisible by 3.

Operation : In its normal role, the machine is connected to a suitable AC supply through the slip-rings and it delivers direct current at the commutator. In this application the machine runs as a synchronous motor receiving AC power from the slip-ring side and as viewed from the commutator end, it runs as a DC generator delivering DC power.

Converter aspects for comparison	M.G.Set	Rotary converter
Machinery	Two machines i.e. one AC another one DC generator	Single machine
Cost	Very costly	Costly
Noise	Noisy	Noisy
Efficiency	Very low because of two rotating machines	Low
Maintenance cost	High	High

Overloading capacity	Cannot be over loaded	Cannot be overloaded
Power factor of AC factor	Low power factor	Good power
Attention during its operation	Less attention required	No attention required
Space required	Very high	Low

Maintenance of MG set

Objective: At the end of this exercise you shall be able to
- **list out the points to be considered for maintenance of MG set.**

The MG set must be maintained by inspecting electrically and mechanically. The following points to be considered while carrying out maintenance.

Electrical inspection list

- General cleaning of all electrical components and control panels
- Check/rectify motor insulation resistance by megger
- Check/rectify earth wiring
- Check/rectify main switch fuses
- Check/rectify stator, brushes etc.
- Check/rectify bearings of motor, rotating parts and use oil grease for proper lubrication
- Check/rectify/check starting panel
- Check/rectify over load relays
- Check/rectify loose connections and tighten them
- Replace damaged flexible conductors and cables
- Check/rectify the control system
- Replace the carburized non operative contactor if necessary.

Carry out the maintenance work in MG set by referring the mechanical inspection list and lubrication instruction given below

Mechanical inspection list

- Clean thoroughly and do visual inspection
- Check/rectify motor couplings and bearings
- Check for tightness of coupling, checking formulation both,
- Checking of pipeline flanger
- Check/rectify machine for functional operation and verify with the operator
- Lubrication, Maintenance prints
- Check/rectify the bearings for the lubrication
- Use oil gun/grease to lubricate the same.

A separate register is to be maintained by the maintenance authority to keep the records for each maintenance on all working days.

Attend the breakdown maintenance of mechanical and electrical nature, during the operation of the MG set.

Speed control of 3 phase induction motor by VVVF/AC drive

Objectives: At the end of this lesson you shall be able to
- **state about AC drives (VFD/VVFD) and changing of speed of AC motor by AC drive**
- **explain the operation of AC drive with block diagram**
- **list out the advantages and disadvantages of AC drive**
- **explain the components / parts and power and control terminals of AC drive**
- **state the parameter setting - speed control changes of direction of AC & DC drives / VFD/VVVFD (variable frequency drive/ variable voltage variable frequency drive)**
- **state the speed control of universal motor.**

Variable Voltage Variable Frequency Drive (VVVFD)

The AC drive industry is growing rapidly and it is now more important than ever for technicians and maintenance personnel to keep AC drive installations running smoothly. AC drives change the speed of AC motor by changing voltage and frequency of the power supplied to the AC motor. In order to maintain proper power factor and reduce excessive heating of the motor, the name plate volts / hertz ratio must be maintained. This is the main task of VFD (Variable frequency drive).

Applications of AC drives

1 AC drives are used to stepless speed control of squirrel cage induction motors mostly used in process plants due to its ruggedness and maintenance free long life.

2 AC drives control the speed of AC motor by varying output voltage and frequency through sophisticated microprocessor controlled electronics device.

3 AC drive consists of rectifier and inverter units. Rectifier converts AC to DC voltage and inverter converts DC voltage back to AC voltage.

Changing of speed of AC motors by using AC drive

From the AC motor working principle, that the synchronous speed of motor N_s in rpm, is dependent upon frequency. Therefore by varying the frequency of the power supply through AC drive, it can control the synchronous speed.

Speed (rpm) = Frequency (Hertz) x 120 / No. of poles.

Where

Frequency = Electrical frequency of the power supply in Hz., No. of poles = Number of electrical poles in the motor stator. Thus the speed of AC motor can conveniently be adjusted by changing the frequency applied to the motor. There is also another way to make the AC motor work on different speed by changing the no. of poles, but this change would be a physical change of the motor. The VFD provides the controls over frequency and voltage of motor input to change the speed of a motor. Since the frequency is easily variable as compared with the poles variation of the motor. AC drives are frequently used.

Constant V/F ratio operation

If the same voltage is applied at the reduced frequency, the magnetic flux would increase and saturate the magnetic core, significantly distorting the motor performance. The magnetic saturation can be avoided by keeping the ϕ_m constant.

All AC drives maintain the voltage -to- frequency (V/F) ratio constant at all speeds for the reason that follows. The phase voltage V, frequency F and the magnetic flux ϕ of motor are related by the equation.

$V=4.444\ f\ N\ \phi_m$

or

$V/f = 4.444x\ N\ \phi_m$

Where N = number of turns per phase

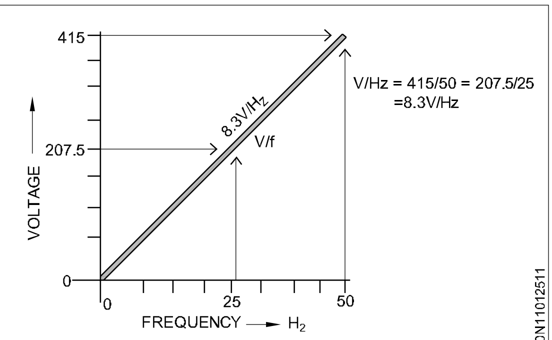
ϕ_m = magnetic flux

Moreover, the AC motor torque is the product of stator flux and rotor current. For maintaining the rated torque at all speeds the constant flux must be maintained at its rated value, which is basically done by keeping the voltage - to - frequency (V/f) ratio constant.

An AC drive is capable of operating a motor with constant flux (Φ) from approximately zero (0) to the motor's rated nameplate frequency (typically 50Hz). This is the constant torque range. As long as a constant volts per hertz ratio is maintained the motor will have constant torque characteristics. AC drives change frequency to vary the speed of a motor and voltage proportionately to maintain constant flux. The Fig1 is the graph illustrates the volts per hertz ratio of a 415 volt, 50 hertz motor. To operate the 415 volt motor at 50% speed with the correct ratio, the applied voltage and frequency would be 207.5V volts, 25 Hz. The voltage and frequency ratio can be maintained for any speed up to 50Hz. This usually defines the upper limits of the constant torque range.

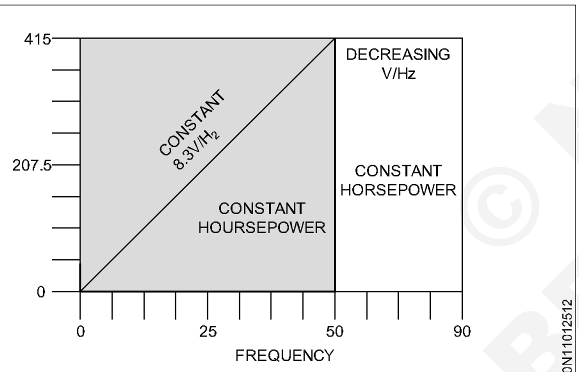
Some applications require the motor to be operated above base speed. The nature of these applications requires less torque at higher speeds. Voltage, however, cannot be higher than the available supply voltage. This can be illustrated as in Fig 2. Voltage will remain as 415 volts for any speed above 50Hz. A motor operated above its rated frequency is operating in a region known as a constant horsepower. Constant volts per hertz and torque is maintained up to 50Hz. Above 50Hz the volts per hertz ratio decreases. The V/Hz ratio at 25 Hz is 8.3, at 50Hz is 8.3, at 70Hz is 5.93 and at 90Hz is 4.61. Flux (Φ) and torque (T) decrease. Operation of the motors above rated nameplate speed (base speed) is possible, but is limited to conditions that do not require more power than the nameplate rating of the motor. This is sometimes called "field weakening" and, for AC motors, means operating at less than rated V/Hz and above rated nameplate speed.

Fig 1



V/F RATIO CHART

Fig 2



V/F CHART

Block diagram of AC drive

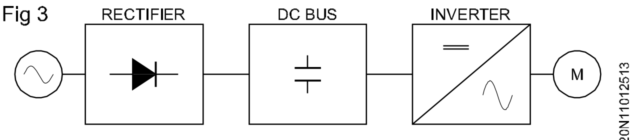
The Insulated - Gate - Bipolar- Transistor (IGBT) is in the past two decades come to dominate VFD as an inverter switching device.

IGBTs (insulated gate bipolar transistor) provide a high switching speed necessary for PWM (Pulse width Modulation) inverter operation. IGBTs are capable of switching ON and OFF several thousand times a second. An IGBT can turn on in less than 400 nanoseconds and off in approximately 500 nanoseconds. An IGBT consists of a gate, collector and an emitter. When a positive voltage (typically +15 VDC) is applied to the gate the IGBT will turn on. This is similar to closing a switch. Current will flow between the collector and emitter.

An IGBT is turned off by removing the positive voltage from the gate. During the off state the IGBT gate voltage is normally held at a small negative voltage (-15 VDC) to prevent the device from turning on. So the gate can control the switching on/off operation of an IGBT.

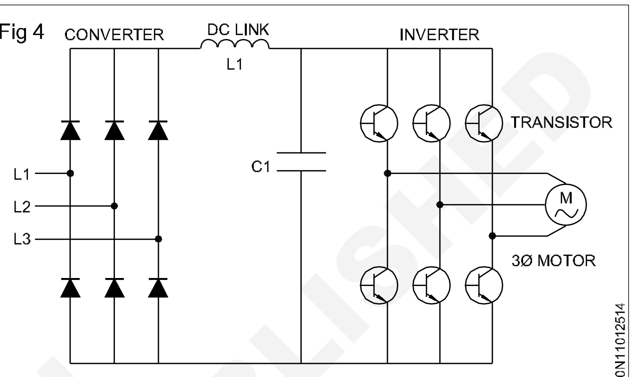
Fig 3 shows the block diagram of AC drive and Fig 4 shows the internal connection diagram. There are three basic sections of the AC drive; the rectifier, DC bus, and inverter.

Fig 3



BLOCK DIAGRAM OF AC DRIVE

Fig 4



INTERNAL CONNECTION OF AC DRIVE

The rectifier in an AC drive is used to convert incoming AC power into direct current (DC) power. Rectifiers may utilize diodes, silicon controlled rectifiers (SCR), or transistors to rectify power . An AC drive using transistors in the rectifier section is said to have an "active front end.

After the power flows through the rectifiers it is stored on a DC bus. The DC bus contains capacitors to accept power from the rectifier, store it, and later deliver that power through the inverter section. The DC bus may also contain inductors, DC links, chokes, or similar items that add inductance, thereby smoothing the incoming power supply to the DC bus.

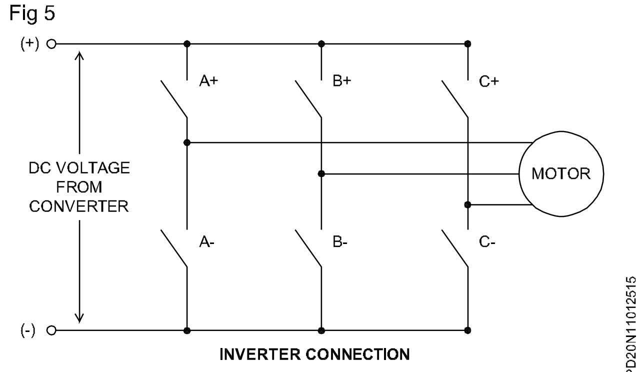
Inverter : An inverter is a device which converts DC into AC. The inverter contains transistors that deliver power to the motor. The "Insulated Gate Bipolar Transistor" (IGBT) is a common selection in modern AC drives. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. The IGBT uses a method named "Pulse Width Modulation" (PWM) to simulate a current sine wave at the desired frequency to the motor.

The following example, explains how one phase of a three-phase output is developed and controlled. Switches replace the IGBTs for convenience. A voltage that alternates between positive and negative is developed by opening and closing switches in a specific sequence. For example, during steps one and two A+ and B- are closed. The output voltage between and A and B is positive. During step three A+ and B+ are closed. The difference of potential from A to B is zero. The output voltage is zero.

During step four and five A- and B+ are closed. The output voltage from A to B is negative. During step 6. A- and B- closed. The difference of potential A to B is again zero.

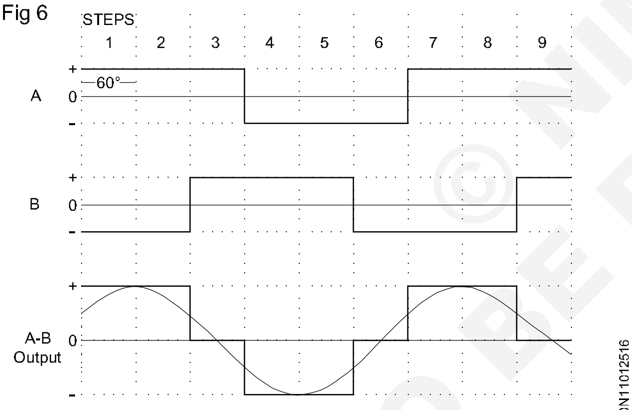
The same action from step 1 to 6 is repeated from step 7 onwards. This will continue. The Fig 5 shows the internal connection of inverter which converts DC into AC. The Fig 6 shows the output wave form of inverter. Only one single waveform due to switching action between A and B is shown. There are other two waveforms between B & C and A & C together which form a 3 phase AC supply. The magnitude and frequency of output voltage is dependent on the speed of the switching action of IGBTs.

Fig 5



INVERTER CONNECTION

Fig 6



OUTPUT WAVE FORM OF INVERTER

Advantages and disadvantages of AC drive

Advantages

- They use conventional low cost 3 phase AC induction motors for most applications
- AC motors require virtually no maintenance and are preferred for application where the motor is mounted in an area not easily reached for servicing or replacement.
- AC motors are smaller, lighter, more commonly available and less expensive than DC motors.
- AC motors are better suited for high speed operation (over 2500 rpm) since there are no brushes, and commutation is not a problem.
- Whenever the operating environment is wet, corrosive or explosive, special motor enclosures are required. Special AC motor enclosure types are more readily available at lower prices.
- Multiple motors in a system must operate simultaneously at a common frequency/speed.

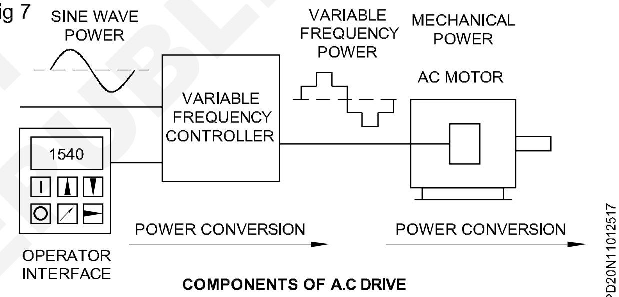
Disadvantages

- A standard motor can not adequately cool its winding at slow speed or handle the irregular electrical waveform from the AC drive.
- An AC drive requires installation of motor with heavier windings.
- AC drive has complicated electronics circuit, so fault rectification is costly.
- AC drives produce a simulated waveform, not a perfect sine wave. That degrade the power equality.

Components of AC drive

A variable frequency drive is a device used in a drive system consisting of the following three main sub-systems. AC motor, main drive controller assembly, and drive / operator interface as in Fig 7.

Fig 7



COMPONENTS OF A.C DRIVE

AC motor

The AC electric motor used in a VFD system is usually three - phase induction motor. Some types of single - phase motors can be used, but three - phase motors are usually preferred. Various types of synchronous motors offer advantages in some situations, but three - phase induction motors are suitable for most purposes and are generally the most economical motor choice. Motors that are designed for fixed - speed operation are often used. Elevated - voltage stresses imposed on induction motors that are supplied by VFDs require that such motors are designed for definite - purpose inverter-fed duty.

Controller

The VFD controller is a solid - state power electronics conversion, system consisting of three distinct sub-systems, a rectifier bridge converter, a direct current (DC) link, and an inverter. Voltage - source inverter (VSI) drives are the most common type of drives. Most drives are AC to AC drives in that they convert AC line input to AC inverter output. However, in some applications such as common DC bus or solar applications, drives are configured as DC-AC drives. The most basic rectifier converter for the VSI drive is configured as a three -phase, six -pulse, full-wave diode bridge.

In a VSI drive, the DC link consists of a capacitor which smooths out the converter's DC output ripple and provides a stiff input to the inverter. This filtered DC voltage is converted to quasi-sinusoidal AC voltage output using the inverter's active switching elements. VSI drives provide higher power factor and lower harmonic distortion than phase- controlled current - source inverter (CSI) and load - commutated inverter (LCI) drives.

In variable -torque applications suited for volts - per- Hertz (V/Hz) drive control. AC motor characteristics require that the voltage magnitude of the inverter's output to the motor be adjusted to match the required load torque in a linear V/Hz relationship. For example, 415V, 50Hz motors, this linear V/Hz relationship is 415/50=8.3V/Hz.

Although space vector pulse- width modulation (SVPWM) is becoming increasingly popular, sinusoidal PWM (SPWM) is the most straight forward method used to vary drives motor voltage (or current) and frequency. With SPWM control quasi- sinusoidal, variable - pulse-width output is constructed from intersections of a saw-toothed carrier signal with a modulating sinusoidal signal which is variable in operating frequency as well as in voltage (or current).

An embedded microprocessor governs the overall operation of the VFD controller. Basic programming of the microprocessor is provided as user - inaccessible firmware. User programming of display, variable, and function block parameters is provided to control, protect, and monitor the VFD, motor, and driven equipment.

Operator interface

The operator interface provides a means for an operator to start and stop the motor and adjust the operating speed. Additional operator control functions might include reversing, and switching between manual speed adjustment and automatic control from an external process control signal. The operator interface often includes an alphanumeric display and /or indication lights and meters to provide information about the operation of the drive.

An operator interface keypad and display unit is often provided on the front of the VFD controller shown in the Fig 7. The keypad display unit can often be cable - connected and mounted a short distance from the VFD controller. They are also provided with input and output (I/O) terminals for connecting push buttons, switches, and other operator interface devices or control signals. A serial communications port is also often available to allow the VFD to be configured, adjusted, monitored, and controlled using a computer.

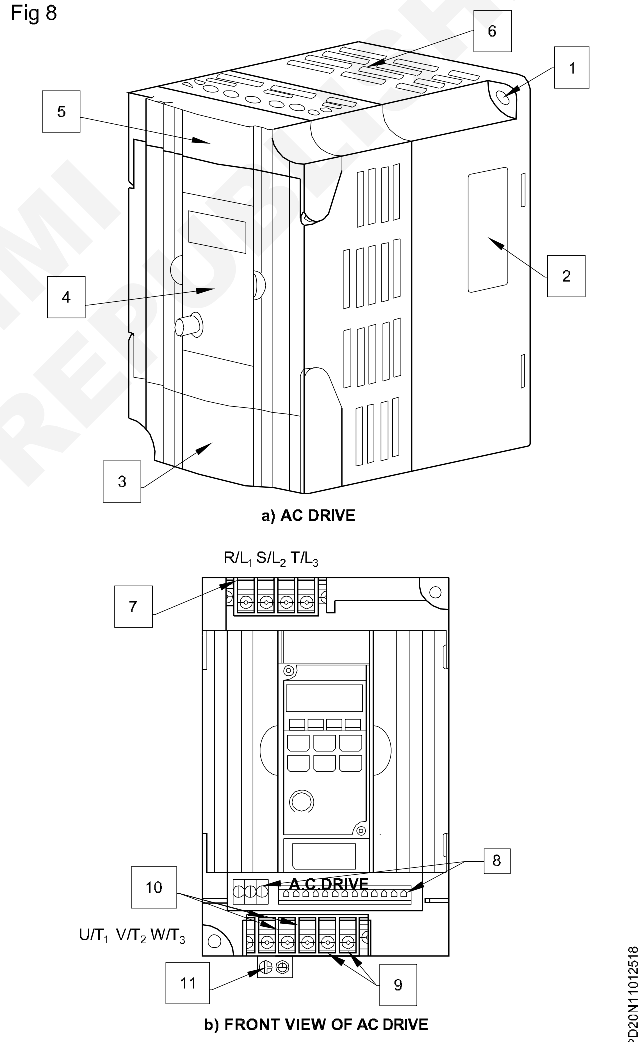
Operation of AC drive

When the VFD is started the applied frequency and voltage are increased at a controlled rate or ramped up to accelerate the load. This starting method typically allows a motor to develop 150% of its rated torque while the VFD is drawing less than 50% of its rated current from the mains in the low - speed range. A VFD can be adjusted to produce a steady 150% starting torque from standstill right up to full speed. However, motor cooling deteriorates and can result in overheating as speed decreases such that prolonged low -speed operation with significant torque is not usually possible without separately motorized fan ventilation.

With a VFD, the stopping sequence is just the opposite as the starting sequence. The frequency and voltage applied to the motor are ramped down at a controlled rate. When the frequency approaches zero, the motor is shut off. Additional braking torque can be obtained by adding a braking circuit (resistor controlled by a transistor) to dissipate the braking energy.

Part of AC drive (Fig 8a & 8b)

Fig 8



AC drives of various brand with different ratings are available in the market. It is generally assembled in a metallic enclosure. The front panel has the power input and output terminals, control terminals, keypad (operator interface) for controlling the drive etc. It has provision for connecting to PC for programming the drive.

The main parts are given below and shown in Fig 8a and 8b.

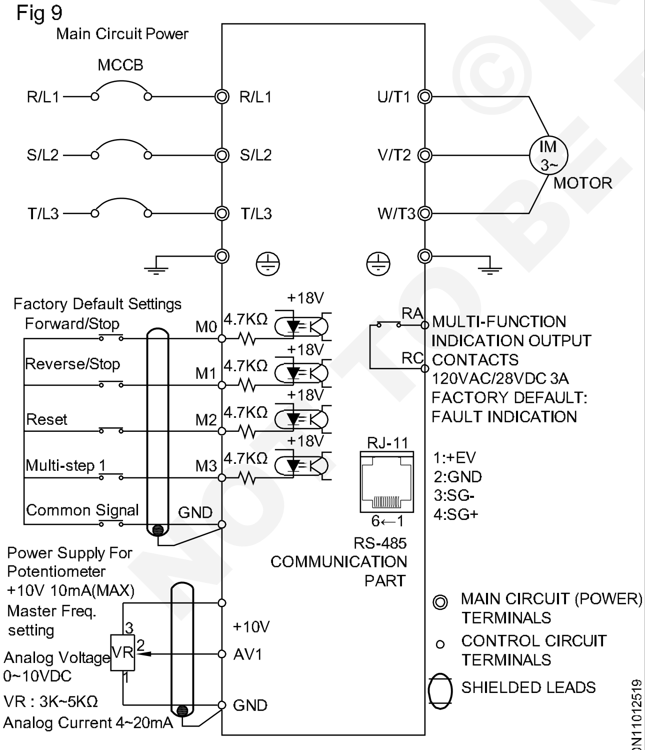
1 Mounting screw holes
2 Name plate label
3 Bottom cover
4 Digital keypad
5 Upper cover
6 Ventilation hole
7 Input terminals
8 Control Input/Output terminals
9 External brake resistor terminal
10 Output terminals
11 Grounding

Power and control terminals

In AC drive, the front panel has the input power terminals viz R/L_1, S/L_2 and T/L_3 where 3 phase AC 415V, 50Hz supply is connected. The 3 phase induction motor is connected of output power terminals viz. U/T1, V/T2 and W/T3.

There are control terminals viz M0, M1, M2, M3, GND, +10V, AV1 etc. for starting/stopping/ reversing and speed control actions. Names and locations are given in Fig 9

Fig 9



CONNECTION DIAGRAM OF AC DRIVE & MOTOR

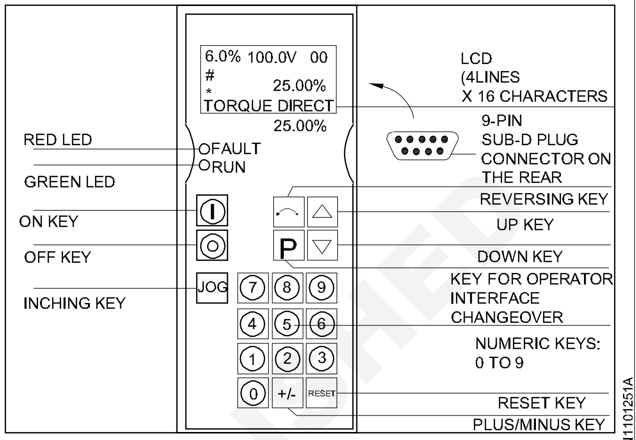
Parameter settings of DC drive

As discussed in previous chapter, the speed of DC motor is directly proportional to the armature voltage (E_b) and inversly proportional to the field current(I_f) and also the armature current (Ia) is proportional motor torque.

In armature controlled DC drives, the drive unit provides a rated current and torque at any speed up to rated speed.

The Fig 10 shows **Basic Operator Panel (BOP)** keypad provided on the front panel meant for controlling the drive.

Fig 10



BASIC OPERATOR PANEL (BOP) KEY PAD

The LCD is used to monitor the parameter. To start the motor, 'ON' key is to be pressed, and to stop the motor 'OFF' key is to be pressed. There is 'JOG' key provided for inching operation.

There is a key 'P' given for operator interface, changing over the parameter setting can be done by using this key in association with (Δ) key and key (∇). Parameters like, voltage current, Torque etc will be displayed turn by turn on each pressing of 'P' key /button.

The (Δ) or (∇) keys are used to increase or decrease the values. Numeric keys are also can be used to enter the values directly.

LED indicators are provided to indicate the status of drive. Green LED indicates the system running where as Red LED indicates when fault is occurred.

Programming of DC drive is possible through, personal computer (PC) also. For this purpose a connector for connecting PC through interfacing cable is provided at the rear panel.

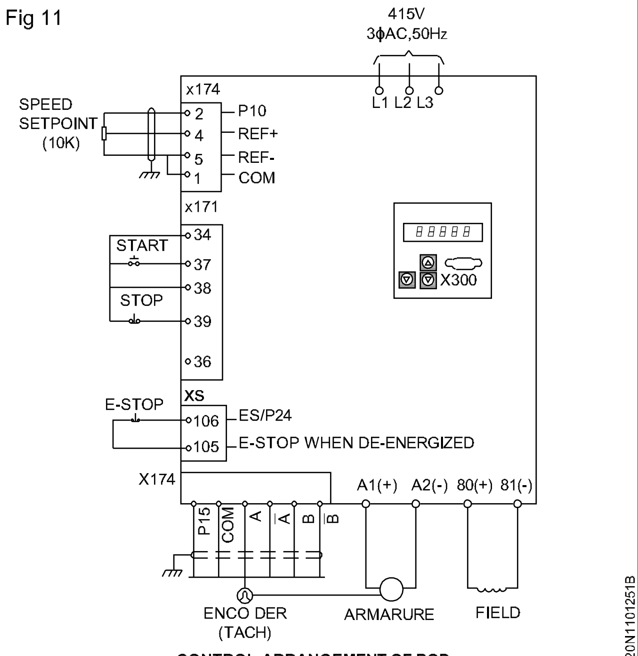
There may be variations in terms of names of key, display setting etc for different brands.

Operation of motor through DC drive

Fig 11 shows the operation of controls arrangement which is called as basic operator panel (BOP) .

The input supply connections and armature and field connections are well illustrated in Fig 11. Input 3 phase AC, 415V, 50Hz supply can be connected L_1, L_2 and L_3. The armature is connected across A_1 and A_2 where as the field is connected across B_0 and B_1 (The terminal names may vary depends on the type and make) an equipment ground conductor (Ground wire) must be connected to the controller mounting panel. Separate equipment grounding conductors from other major components Viz, motor, drive enclosure isolation transformer case (if used) in the system must also be connected continuously to a control connection point.

Fig 11



CONTROL ARRANGEMENT OF BOP

The AC input supply is provided should match the voltage and frequency given on the controller's name plate. Improper voltage may damage the equipment and insufficient current will cause erratic operation of the drive.

The shielded cable is recommended for the tachometer and all low level signal circuit to eliminate the possibility of electrical interference.

In some DC drives a speed adjusting potentiometer is provided to vary motor speed by controlling armature input voltage after the controller has been started. Some time a torque adjusting potential meter is used in place of speed adjusting potentiometer. It controls motor torque by controlling the DC current in the motor armature.

Starting and controlling the speed of DC motor

When the 'ON' button in BOP is pressed, the motor will start running. The desired speed can be attained by using 'P' button and Δ & ∇ buttons.

When the "OFF" button is pressed the motor will stop but AC line voltage remains connected to the controller and full field voltage is present. Armature voltage is reduced to zero. When pressing the "ON" button again the motor will accelerate to the preset speed.

Inching operation

For inching operation the 'JOG' position should be selected. Then the controller will operate only as long as the "ON" button is held pressed.

Changing the direction of rotation

In some model a 'reversing switch' is provided to change the direction of rotation of the motor. This switch is responsible for changing the polarity at the motor armature connection. First start the motor by pressing 'ON' button. The motor will run in forward direction. To change the direction of rotation, press "OFF" button and ensure that the motor is completely stopped. Now press the reversing button and then press the "ON" button. The motor will now run in the reverse direction. The reversing key has a provision which prevents direct transfer from one direction to the other.

Precautions during installation, connection and operation of DC drive

- Ensure all screws are tightened to the proper torque rating.
- During installation, follow all local electrical and safety codes.
- Ensure that appropriate protective devices (circuit breaker MCB or fuses) are connected between the power supply and DC drive.
- Make sure that the drive is properly earthed.
- Do not attach or remove wiring when power is applied to the DC drive.

Parameter setting of AC drive

As explained earlier the speed (N) of AC induction motor is directly proportional to the voltage (V) and frequency (f) of the applied power supply. Within the base speed limit, the torque (T) can be kept constant by maintaining a constant voltage / frequency (V/F) ratio. By increasing of speed to above base speed limit is also possible but at the cost of the torque.

(VFD /VVVFD (Variable Voltage Variable Frequency Drive) drives are used for efficient speed control of AC motors. The advantages of using drives to control the speed is already explained.

The AC drive has a front panel which includes two parts. Display panel and keypad. The display panel is provided with the parameter display and shows operation status of the AC drive. Keypad provides programming interface between users and AC drives. The Fig 12. shows the location of buttons and display unit on the front panel of AC drive.

Mode /Reset button

By pressing this button repeatedly the display will show status at the AC drive such as the reference frequency and output current. If the drive stops due to a fault, correct the fault first, then press this button to reset the drive.

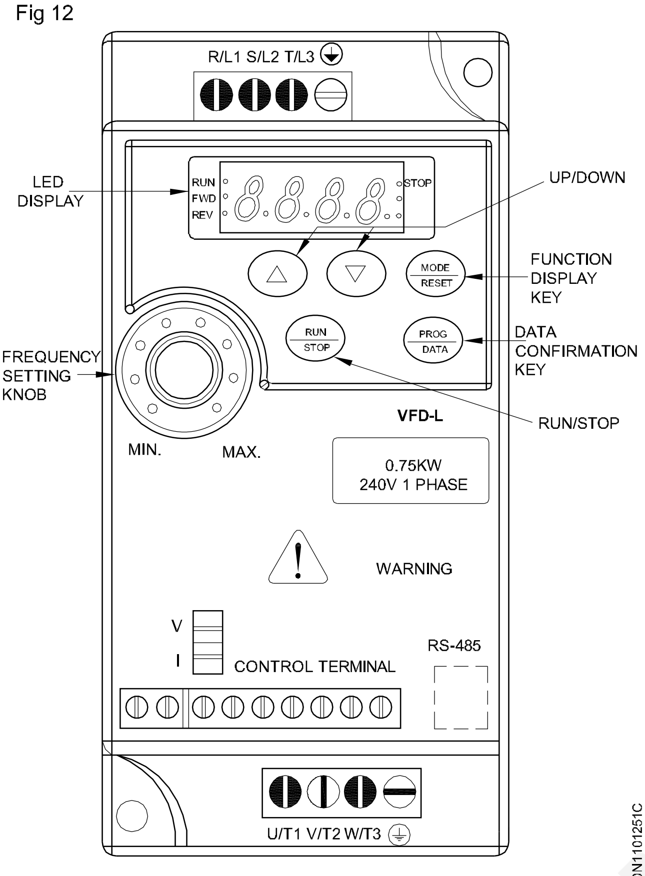
Prog/Data button

By pressing this button will store the entered data or can show factory stored data.

Run/Stop button

To 'start' or 'stop' the AC drive operation this button is to be pressed.

Fig 12



DISPLAY UNIT OF AC DRIVE

This button can only be used to 'stop' the AC drive, when it is controlled by the external control terminals.

UP∆ / down ∇ button

By pressing the 'Up' or 'Down' button momentarily parameter setting can be changed. These key may also be used to scroll through different operating values or parameters. Pressing the 'Up' or 'Down' button momentarily it will change the parameter setting in single unit increments. To quickly run through the range of settings, press 'Down' and hold the button.

Frequency setting knob

By using this knob, the frequency variation can be done.

'RS 485' communication port

Programming of AC drive can be done through personal computer (PC) also. For this, the drive should be interfaced with PC through 'RS 485' port.

LED displays are also given in the display unit to indicate the status of drive like 'RUN', 'FWD' and 'REV'.

Operation of AC motor through drive

The motor and drive connections are well illustrated in Fig 13. A 3∅ , 415V, 50Hz AC supply is connected to the drive input terminals R/L_1, S/L_2 & T/L_3. Similarly output terminals of this drive is such as U/T_1, V/T_2 & W/T_3 are connected to 3 phase induction motor. (The terminal names may vary depends on the type and make)

Both input end and output ends are earthed separately.

Changing of speed

The AC input supply provided, should match the voltage and frequency given on the nameplate. Improper voltage may damage the drive.

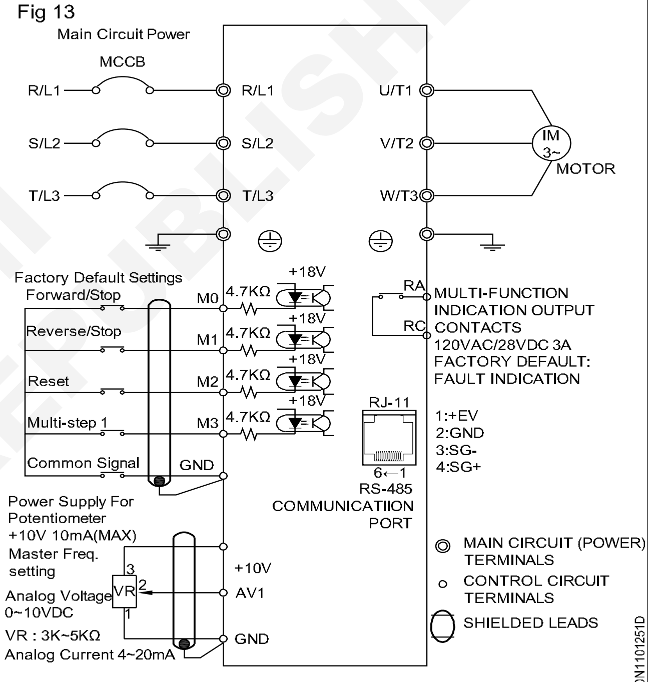
Programming can be done through 'MOD/RESET' button in association with ∆ and ∇ button and the drives speed can be changed by using these buttons. The drive is started through 'RUN'/STOP' button.

The motor can be run at different speed by programming for the required speed.

Changing the direction of rotation

The direction of rotation can be changed. To do this, press 'RUN/STOP' button. When the motor is completely stopped, select 'rev' parameter and press 'RUN/STOP' button again. Now the motor will run in opposite direction.

Fig 13



CONNECTION DIAGRAM OF AC DRIVE AND MOTOR

Same procedure can be followed to change the direction of rotation of double cage induction motor also.

Precautions to be observed during installation, connection and operation of AC drive

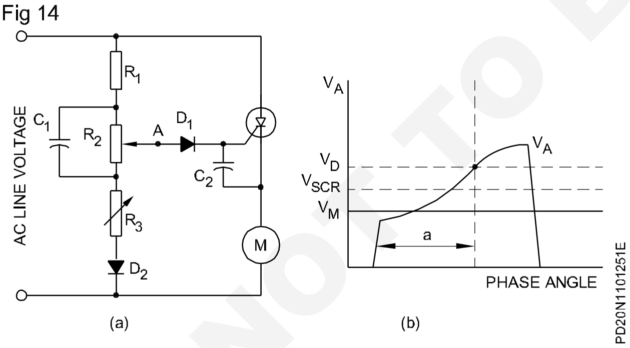
- Do not connect the AC power to the U/T1, V/T2, W/T3 terminals, as it will damage the AC drive.
- Ensure all screws are tightened to the proper torque rating.
- During installation, follow all local electrical and safety codes.
- Ensure that the appropriate protective devices (circuit breaker or fuses) are connected between the power supply and AC drive.

- Make sure that the leads are connected correctly and the AC drive is properly grounded. (Ground resistance should not exceed 0.1Ω)
- Use ground leads that comply with standards and keep them as short as possible.
- Multiple VFD-L units can be installed in one location. All the units should be grounded directly to a common ground terminal.
- Make sure that the power source is capable of supplying the correct voltage and required current to the DC drive.
- Do not attach or remove wiring when power is applied to the AC drive.
- Do not monitor the signals on the circuit board while the AC drive is in operation.
- If filter is required for reducing EMI (Electro Magnetic interference), install it as close as possible to AC drive.

Speed control of universal motors using SCR : Majority of domestic appliances like electric drilling machine, mixer etc., incorporate universal electric motors. Any of the half wave or full wave controls discussed earlier can be used to control speed of universal motors. Universal motors have some unique characteristics which allow their speed to be controlled very easily and efficiently with a feedback circuit is in Fig 14.

The circuit at Fig 14a provides phase controlled half wave power to the motor; that is, one the negative half cycle, the SCR blocks current flow in the negative half cycle, the SCR blocks current flow in the negative direction causing the motor to be driven by a pulsating direct current whose amplitude is dependent in the phase control of the SCR. The operation of the circuit shown in Fig 14 is as follows.

Fig 14



- Assuming that the motor is running, the voltage at point A in the circuit must be larger than the forward drop of diode D_1, the gate to cathode drop of the SCR, and the emf generated by the residual mmf in the motor, to get sufficient forward flow to trigger the SCR.
- The wave form at point A (V_A) for one positive half cycle is in Fig 14b and with V_{SCR}, V_D and motor generated emf V_M. The phase angle at which the SCR would trigger is shown by the vertical dotted line.
- For any reason if the motor speed increases, then V_M will increase, the trigger would move upwards and to the right along the curve so that the SCR would trigger later in the half - cycle thus providing less power to the motor, causing it to slow down. Similarly, if the motor speed decreases, the trigger point will move to the left and down the curve, causing the SCR to trigger earlier in the half cycle providing more power to the motor thereby speeding it up.
- Resistors R_1, R_2, R_3 along with diode D_1 and C_1 forms a ramp generator. Capacitor C_1 is charged by the voltage divider R_1, R_2 and R_3 during the positive half cycle. Diode D_2 prevents negative current flow during the negative half cycle, therefore C_1 discharges through R_2 and R_3 during negative half cycle. Varying the value of R_2 varies the trigger angle α.

A practical version of the circuit for controlling the speed of universal motors is in Fig 15.

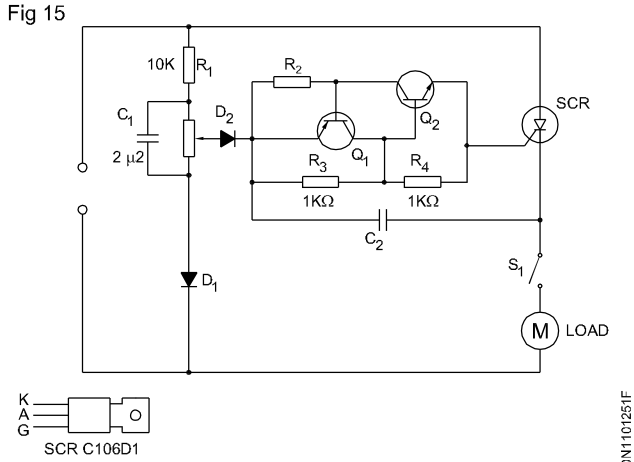
As can be seen, the circuit at Fig 15 is quite similar to that at Fig 14 but for the addition of two transistors and a few resistors.

In Fig 6, the action of Q_1 - Q_2 is to provide adequate gate current to trigger the SCR into conduction.

Q_1 - Q_2 and their associated resistors acts as a voltage sensitive switch. In each half cycle, C_2 is able to charge via R_1. As soon as voltage across C_2 rises to suitable value. Q_1 and Q_2 both switch- on and partially discharge C_2 into the gate of the SCR, thus delivering a pulse of high current to the SCR gate, independent of any current drive limitations of RV1. The Q_1 - Q_2 and C_2 network thus enables virtually any SCR to be used in the circuit almost irrespective of its sensitivity characteristics.

The universal motor speed control circuit is in Fig 15 enables the motor speed to be smoothly varied from zero to 75% of maximum via a single control. It also incorporates built - in feedback compensation to maintain the motor speed virtually constant at any given speed setting, regard-less of load changes.

Fig 15



CIRCUIT DIAGRAM OF UNIVERSAL MOTOR SPEED CONTROLLER

Voltage stabilizer and UPS

Objectives: At the end of this lesson you shall be able to
- **state the basic concept of stabilizer**
- **draw the block diagram and explain the function of each blocks**
- **state the working various types of voltage stabilizers**
- **state the basics of UPS system**
- **explain the block diagram of OFF line UPS and its various controls and functions**
- **explain the block diagram ON line UPS and advantages and disadvantages.**

Voltage stabilizer

It is an electrical supply device controlled by electronic circuit which gives the constant output voltage irrespective of the variation in the high input supply voltage or disconnect the output circuit if the input voltage is very low or very high.

Every electrical device is designed to operate at a certain rated voltage for optimum efficiency and maximum length of service. Power supply voltages should not drop or rise by more than 5% of rated voltage as per IS.

The effect of voltage variations in commonly used electrical appliances are given below.

Sl.No.	Name of the equipment	Low voltage	High voltage
1	Incandescent lamp	Lamp efficiency decreases if the voltage is decreased.	Life of the lamp decreases or the lamp fuses in extreme cases.
2	Fluorescent lamp	If voltage is too low, lamp will not light up.	Life of the tube/choke decreases.
3	Electric stove, electric iron, water heaters, toasters etc.	Increases the heating time as heat produced is low.	Shortens the life of heating elements or heating elements burnt out.
4	Fans, vacuum cleaners	Efficiency decreases.	Life of the equipment is decreased
5	Washing machines, refrigerators and air-conditioners	Motor of the machine will draw more current from the line that results in overheating of the motor which may lead to burn out.	The motor insulation may fail and draw excess current which can lead to burn out.
6	Radios and television sets	Poor quality of reception, picture will not be clear in the television sets.	Life of the equipment is decreased

Some of the electronic equipment such as colour television sets are designed by the manufacturers with built in electronic stabilizers like Switch Mode Power Supplies (SMPS). Hence there is no need to provide an additional external stabilizers for these equipments.

Types of AC voltage stabilizers

1 Stepped voltage stabilizer
   a) Manual
   b) Automatic relay type
2 Servo voltage stabilizer
3 Constant voltage transformer

Stepped voltage stabilizer

In the stepped voltage stabilizer, an auto-transformer is used for regulating the output voltage. A manually operated switch as in Fig 1 regulates the output voltage in the manual type. In automatic relay type stabilizers a sensing circuit actuates the relays which regulates the output voltage. The schematic diagram is in Fig 2 is for an automatic relay type stabilizer.

Fig 1

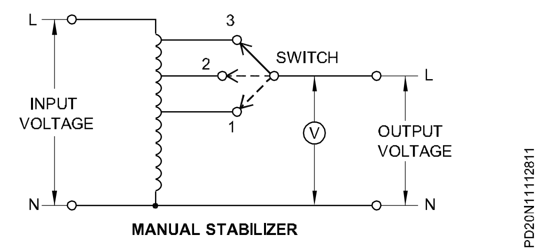
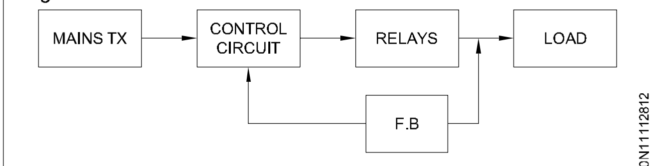


Fig 2



BLOCK DIAGRAM OF VOLTAGE STABILIZER

Mains Tx

This transformer supplies two level voltage i.e, low voltage and high voltage, which is to be supplied according to the needs. Some stabiliser working in buck boost operation to meet special application for load requirements. The auxiliary supply also provides for control circuit requirements by the mains transformer.

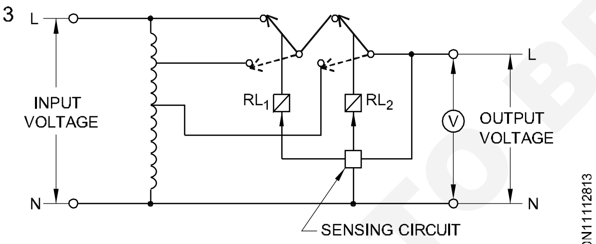
Control circuit

In the ordinary voltage stabilisers, control circuit regulate the relay operation, irrespect or output voltage. When input voltage falls below the set voltage H.T side relay will operate and incase high voltage condition LT side relay will operate and maintain the stipulated operate voltages. The relay operation controls by controlling relay coil supply which is set for separate DC regulated voltage levels.

Relays

It is a electromagnetic relay which operates two different coil voltage. the DC coil voltage decides which relay has to be operate depends on the input AC voltage supplied to the transformer. Fig 3 shows an automatic relay type stabilizer.

Fig 3



AUTOMATIC STABILIZER RELAY TYPE

Feed back

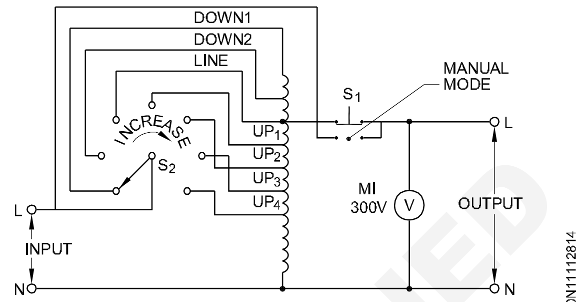
In non automatic voltage stabiliser DC voltage are taken on the feed back quantity, which operates the relay coil. The coil DC voltage will be two different voltage to activate the relay in case of low and high voltage AC input conditions.

Load

Load can be anything connected to the stabiliser. Some electrical equipments requires a constant input voltage to operate. such case a stabiliser is required. But in automatic stabiliser have the disadvantage of transient line (Change over to one voltage to other voltage level) which may cause the stabiliser to OFF condition few milli seconds.

Stepped voltage stabilizer - manual type : Fig 4 shows an auto-transformer in which the output voltage increases as the tap changing switch S_1 is turned clockwise. The output voltage can be seen by connecting a voltmeter in the output side as in Fig 4. Increasing or decreasing the output voltage near to the set value is possible by rotating the tap changing switch S_2 in the appropriate direction within ±10% of the desired output voltage. A push-button switch S_1 enables to measure the incoming voltage.

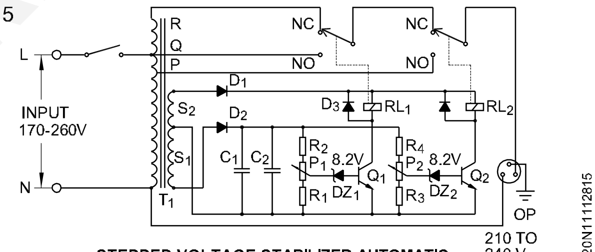
Fig 4



STEPPED VOLTAGE STABILIZER-MANUAL

Stepped voltage stabilizer - automatic type : Fig 5 shows a stepped voltage stabilizer of the automatic type operated by relays. T_1 is an auto-transformer with multiple tappings. S_1 and S_2 are two secondaries for relay operation. The secondary voltage of S_1 is rectified and filtered for the use of the sensing circuit while voltage S_2 is rectified and filtered for the use of the relay operation. P_1 and P_2 are pre-set resistors (variable resistors) used for adjustment. R_1, P_1 and R_2 provide sensing voltage to the zener diode. DZ_1 and R_3P_2 and R_4 to the zener diode DZ_2. Q_1 and Q_2 are two transistors used as switches. RL_1 and RL_2 are two relays.

Fig 5



STEPPED VOLTAGE STABILIZER-AUTOMATIC

When the input voltage is low, say less than 200V, both DZ_1 and DZ_2 do not conduct as the voltages at the preset tappings are less than their zener diode voltages. This causes both transistors to cut off and the relays are in the off position. At the off position of the relays, NO contacts of both the relays connect terminal R of the auto-transformer to output which results in booster output voltage.

When the input voltage increases above 210V, but below 240V voltage across S_1 increases proportionally. This increases the pre-set tap voltage, thereby the zener diode DZ_1 conducts and hence make the transistor Q_1 to ON. The relay RL_1 operates and connects the supply voltage directly to the output through NO. contact of RL_1 and NC contact of RL_2. By this operation the output voltage will be the same as the input voltage.

When the input supply voltage increases above 240V the zener diode DZ_2 gets voltage from P_2 and hence conducts which makes Q_2 to ON. This results relay RL_2 energise and output is taken from NO. point of RL_2. The output voltage reduces or bucks.

Usually 12V DC relays with the required current ratings of contacts are preferred for stabilizers. Diodes or capacitors are used across the relay coil to protect the transistors from reversed induced emf when the relays become OFF. LED indicators are sometimes used to indicate the mode of operation such as buck, normal, boost etc.

Stepped voltage stabilizers are available with different types of electronic circuits with one to three relays to provide an output voltage of 200-240V. They are specified for maximum input voltage variation and for their output, KVA ratings say 170 to 270 volts 1 KVA or 135 to 260 volts 0.5 KVA.

Some of the stabilizers are provided with over-voltage and under-voltage cut off to protect the connected equipment.

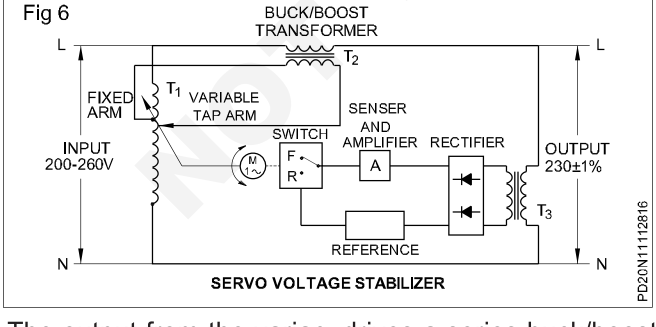
Applications : Stepped voltage stabilizers are used along with refrigerators, air conditioners, TVs, VCRs etc. Colour TVs with self-contained switch mode power supplies do not require voltage stabilizer as they are designed to operate from 130 to 260 volts.

Servo - voltage stabilizer

The servo voltage stabilizer employs a toroidal auto-transformer and a servo motor driven by a sensing circuit which senses the voltage. The difference between the output and nominal voltage is sensed by a sensing circuit which drives the servo motor. Any variations in mains cause the motor to move clockwise or anticlockwise thus correcting the voltage.

A servo voltage stabilizer is provided with three transformers function along with control circuits and a servo motor as in Fig 6. T_1 is a continuously variable toroidal auto-transformer (variac) driven by a servo motor M.

Fig 6



SERVO VOLTAGE STABILIZER

The output from the variac, drives a series buck/boost transformer T_2 so that boost takes place when the variable tap arm moves down and bucks the voltage when the arm moves up. The transformer T_3 provides the required reference voltage and sensing voltage for the electronic circuit which drives the motor.

When the output voltage is less than the reference voltage, the electronic circuit senses the difference, drives the motor in one direction which results in increase in the output voltage.

When the output voltage increases above the ratings, the motor is driven in the opposite direction so that the output voltage increases. When the voltage difference in output and the reference are equal, the servo motor is switched off by the circuit.

A servo stabilizer provides constant voltage to an accuracy around ±1% or ±0.5% and a correction range 10 to 30 volt/sec.

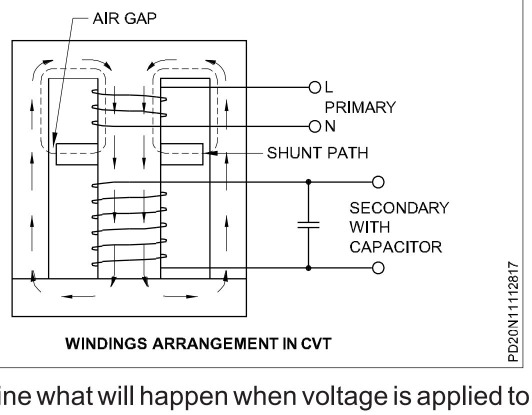
A servo stabilizer is more accurate and also costlier, and, therefore, used with costlier equipments such as computers, xerox machines, medical electrical equipments etc.

Constant voltage transformer

A constant voltage transformer works on ferro-resonant principle. The variation in the primary flux with an unsaturated iron core does not affect the secondary flux with saturated iron core. Thus, the secondary induced voltage remains relatively independent of the voltage impressed upon the primary winding.

In an ordinary transformer, the primary and secondary coils are closely coupled. Any change in primary voltage is directly transferred to the secondary in the ratio of the number of turns. In a CVT, the primary and secondary coils are loosely coupled. These are wound on separate sections of the transformer core as in Fig 7. In between the coils, a separate shunt path is provided for the flux to flow but an air gap is provided in the shunt path. A capacitor is provided in parallel with the secondary.

Fig 7



WINDINGS ARRANGEMENT IN CVT

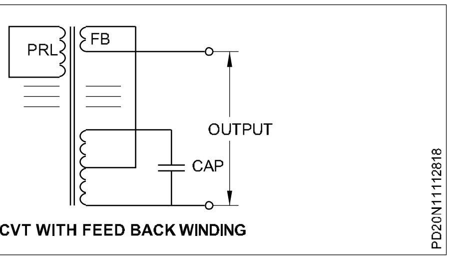
Now imagine what will happen when voltage is applied to the primary. Starting from zero, if the voltage increases slowly, initially, all the flux generated by the primary voltage will pass through the lower half of the transformer core because the air gap in the shunt path will prevent it from taking this path. This is shown by bold arrows in Fig 6. As a result, the rise in secondary voltage is proportional to the primary. But as voltage in the secondary coil rises, at a certain point the impedance of the coil will become equal to the impedance of the capacitor, i.e.

$$X_L = X_C \text{ or } 2\pi fL = \frac{1}{2\pi fC}$$

This is the condition of resonance, and at this point a high current will flow in the LC circuit. This high current will result in a sudden rise of voltage across the secondary (Fig 6), and the core in this section of the transformer will saturate.

Once the core gets saturated, it prevents the entry of further flux coming from the primary side. Therefore, any increase in flux due to increase in primary voltage has to take an alternate shunt path as in Fig 7. Hence, very little increase in the secondary voltage takes place. This little increase can also be nullified by a feedback-FB winding connected as in Fig 8. The output winding can be separated from the capacitor circuit if the voltage required is low or tappings can be taken out of the capacitor.

Fig 8

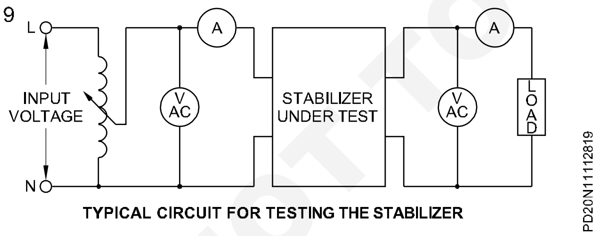


CVT WITH FEED BACK WINDING

CVT may not be suitable for an instrument in which SCR power supply is used or an inductor or a capacitor is coming in the AC circuit or a motor drawing a heavy in-rush current is used inside the instrument. But it is suitable for electronic machines such as TVs, computers, FAX machines etc.

Testing a stabilizer : To test a stabilizer for its operating range, a variac and rated load along with voltmeters/ ammeters are necessary. A simplified circuit for testing the stabilizer is given in Fig 9.

Fig 9



TYPICAL CIRCUIT FOR TESTING THE STABILIZER

By connecting the stabilizer as shown in the figure above and varying the input voltage to the range specified in the name-plate detail such as 170 to 260V or 130 to 270V etc. The output voltage should be satisfied with the specified voltage such as 200 to 240V. There should not be any undue heating or failures with the rated load for a continuous working.

Basics of UPS systems

Most people take the mains AC supply for granted and use it almost casually without giving the slightest thought to its inherent defects and the danger posed to sophisticated and sensitive electronic instruments. For ordinary household appliances such as incandescent lamps, tubes, fans, TV and fridge, the mains AC supply does not make much of a difference, but when used for computers, medical equipments and telecommunication systems, a clean, stable, interruption-free power supply is of utmost importance.

As more and more personal computers, word processors and data terminals find their way into small business, UPS systems that meet the power requirements and price range needs for small business and offices are being manufactured.

The ever increasing importance of computers in industry and commerce will increase the need for quality, high stability and interruption-free power supplies.

Earlier Data Operating System (DOS) does not have any shut- down procedure. So in case power failure it does not affect the operating system. Latest operating system Windows 9x and application softwares require proper shuting down and exit procedures. This procedures requires time which is provided by UPS in case of mains power failure.

UPS (Uninterrupted Power Supply) is the only solution available to an individual customer faced with the problem of ensuring high quality of power for critical loads. All UPS designs contain a battery charger to keep the battery fully charged by the power from mains. Small UPS normally comes with a sealed maintenance free (SMF) batteries which can provide 10 to 15 minutes of power backup, the backup time increases with the capacity of the battery. Tubular batteries or automotive batteries are used in medium and large capacity UPSs.

UPS classification

There are two broad categories of UPS topologies - OFF line, and ON line . These topologies differ in the way they serve the load when the mains is present and is healthy. They vary in features & pricing.

OFF-Line and ON-Line

OFF-Line UPS filters the mains and feeds it directly to the load for most of the time. When the mains is unhealthy, perhaps due to a slight drop in voltage, the load is switched by a fast relay, in typically less than half a cycle, to an inverter deriving its power from a battery. The inverter generates a square or stepped waveform to emulate the mains-satisfactorily for most computers. This particular technique represents the lowest cost solution.

Online UPS converts AC mains into DC before inverting again to AC to power the load with a synthetic sine wave. A battery connected across the DC link acts as the backup power source.

This gives a supply for the computer that totally isolates the input mains from the load, removing all mains noise and with no break when the mains fails.

Standby/OFF Line block diagram (Fig 10)

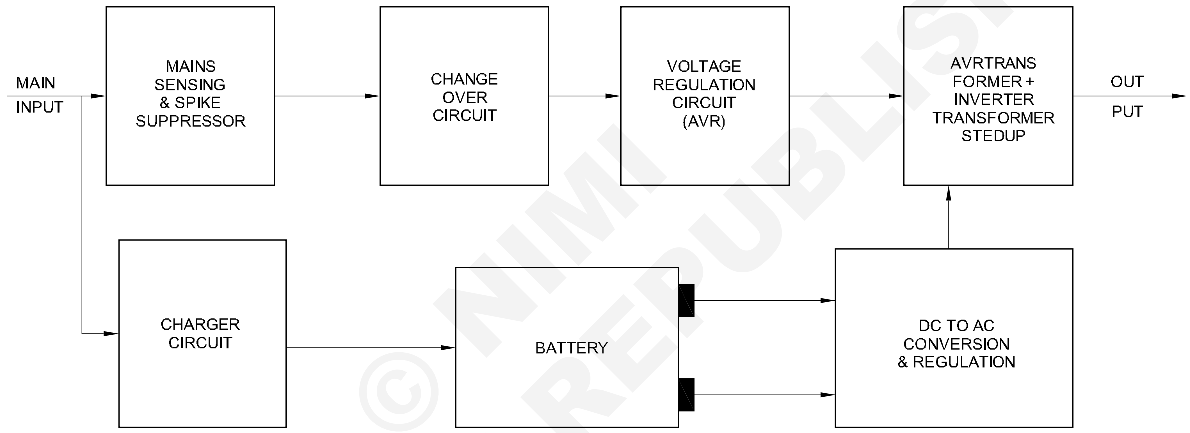
In the off line UPS, the load is connected directly to the mains when the mains supply is available. When working over voltage/under voltage conditions are detected on the mains, the off line UPS transfers the load to the inverter. When the line is present, the battery charger charges the battery and the inverter may either be shut down or will be idling. Thus in an off line UPS, there is a load transfer involved every time, the mains is interrupted and restored. This transfer is effected by change- over relays or static transfer switches. In any case there will be a brief period during which the load is not provided with voltage.If the load is a computer and the transfer time is more than 5ms, then there is a chance that the computer will reboot.

Some modified designs incorporate a limited range of voltage regulation by transformer tapping and a certain degree of transient protection by using RF filters and MOV's (Metal Oxide Varistor). Off line UPS is an economical and simple design and hence it is preferred for small rating, low cost units aimed at individual PC user's market. When the load is really a critical one an off line UPS is not acceptable. Usually square wave output off line UPS are available in market with lower loading capacities.

Advantages of OFF line UPS: High efficiency, small size, low cost.

Disadvantages: There can be change over complaint in offline UPS. Off line very much depends on battery. If battery fails entire system fails. Sometimes during change-over computer re-boots which causes loss of files. Another disadvantage is that output voltage will be a varying one. Usually in the range of 200V-240V and hence not suitable to all electronic gadgets.

Fig 10



Front panel indications and rear panel sockets/ switches used in UPS

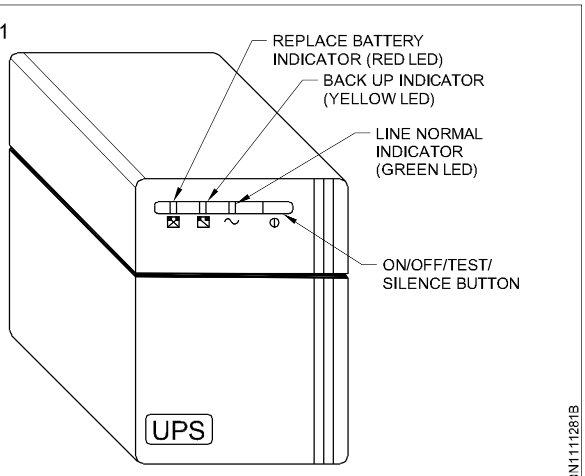
All UPS systems have

- Fuse/Fuse holder
- Switches
- Sockets
- Panel indicator (LED and Neon lamp)
- Meters (Volt/Ampere)

Fig 11 and 12 shows the front and rear panel controls/ sockets.

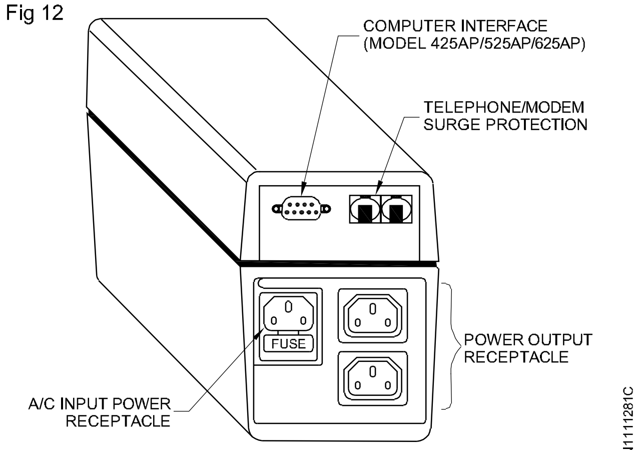
Switches: On/Off switch and reset switch are commonly used in UPS. Reset switch is used to cut off an overload circuit and restart the supply. This is a push to off switch. In normal position this switch keeps the circuit on and when pushed, it cuts off the circuit.

Fig 11



UPS FRONT PANEL

Fig 12



UPS REAR PANEL

Socket: A common 5 Amp. or 15 Amps. three pin power output socket is used in UPS to provide UPS output to the various devices. One can connect an ordinary 5/15Amp. plug to the UPS output.

Different LED indications/buzzers that are used in UPS

Mains ON indication: It indicates mains input is present and UPS is working on mains.

Mains Low indication: It indicates that mains input is low and is below a rated value.

Mains high indication: It indicates mains input is high.

Inverter ON indication: It indicates that UPS is working in the battery mode and mains is absent.

To get the output from UPS switch ON the 'Inverter ON' switch.

UPS Trip indication: It indicates that UPS output is Off or tripped.

Overload indication: Which indicates that the load current is above a pre-determined value.

Overload buzzer: It beeps whenever overload occurs.

Low battery warning: It indicates battery voltage is below a pre-determined value along with a buzzer .

Battery charging indication: It indicates that battery is charging properly.

Output voltage low indication: It indicates that output voltage is below a pre-determined value.

General specifications & UPS protections

UPS are available from 500VA to 20KVA or above.VA is voltampere.

Power factor specification will be different for different manufactures. Suppose for 1 KVA UPS with a power factor 0.6 the load will be 1000 x0.6 = 600 watts.

Normally a single PC takes around 180 watts. There are sine wave, square wave and quasi square wave output UPS. Usually sine wave out UPS is better than square wave output UPS.

General specifications

Output capacity = Output capacity will be in volt amperes (VA)

Input voltage = 230V AC ±20%, 50 Hz single phase sine wave

Output voltage = 230V AC ±10%, 50 Hz square wave or sine wave

= 230V AC ±2%, 50 Hz (for ON-Line)

Battery = 7 AH, 12V Sealed Maintenance Free (SMF) for OFF-Line (depends on the capacity of the UPS)

= Tubular batteries from 40 AH to 160 AH (12V to 120V) for ON-Line (depends on the capacity of the UPS).

Availability of Automatic Voltage Regulation (AVR) feature.

Typical recharge time to charge 90% of the full capacity of the battery is 5 hours.

Different types of protection in UPS

Input fuse on mains: It protects the system from high voltage inputs, line disturbances and short circuiting etc.

MOV (Metal Oxide varistor) protection: MOV conducts when high input voltage appears thereby blowing the fuse

Polyester capacitor for lightening protection: This is connected across the transformer winding. It burns when lightening occurs and protects the transformer.

Fuses to protect the MOSFETS: MOSFETS are highly sensitive to rapid changing currents. These fuses are used to protect the MOSFET.

Charger fuse to protect the charger circuit: If any fault in charger circuit occurs, fuse blows to protect SCRs.

Output high voltage protection MOV: This MOV is connected across output sockets phase and neutral. If feedback circuit fails the output voltage will jump to more than 300 volts. In such situation the MOV conducts to protect the load.

Overload protection: It protects the UPS especially MOSFET/IGBT when output current exceeds a preset value (overloading the UPS). When this occurs, UPS output becomes OFF along with an indication.

Battery over charge/discharge protection: It protects the battery from charging to a high value (SMF batteries will charge upto 15.8V) and tubular batteries upto 14.1V. It also protects the battery from getting discharged below a level (low battery protection). If the battery voltage is discharged below 10.5V, then the UPS gets automatically switched OFF.

General tips for testing a UPS

- Connect the battery to the terminals using a fuse wire. If any fault occurs in testing the fuse will blow to protect the UPS.
- Do the testings on no load condition.
- Check the gate voltages of the two MOSFET banks it should be the same. If PWM gate pulses are not present gate voltage will be around 5.6V. If the PWM gate pulses are present then the gate voltage will be around 2-2.5 volts.
- Some frequency meters are designed to measure pure AC frequency only. If the UPS output is square wave, then the reading will not be correct. To mea- sure the correct frequency connect a 60/100W load at the output of the UPS. Then the frequency meter shows a near correct frequency.
- For overload setting in ON-Line UPS, the load current is calculated by dividing the maximum load with the output voltage. This can also be measured using a clamp meter on the output terminal. Overload is set at this value of load current.
- While using extension boxes either in the input or on the output of an UPS, ensure proper earth connection. Improper earthing may lead to poor line filtering and shock hazards.
- If number of MOSFETs are connected in parallel,care should be taken to see that all the MOSFETs are of the same Rds. For MOSFET Rds value (drain to source resistance) and current rating are important.

Changeover in OFF-Line UPS system

In this type of UPS, the relay controls the battery voltage which is applied for relay coils. If the battery voltage is too low then relay coil will not get sufficient supply to trigger the switch.This may lead to the absence of mains voltage, even if mains is present and is healthy. This type of OFF-Line systems are battery dependent.

Some OFF-Line systems are battery independent. The coil supply is provided by the mains itself. Mains supply is reduced and rectified. This rectified supply is given to the changeover relay coil . Battery low voltage does not affect the relay coil supply. This type of OFF-Line UPS provides mains output irrespective of the battery condition.

Isolation of inverter

Another important point is that the isolation of the inver ter section during the presence of mains , this is done by the change over relay. For inverter side isolation a switching transistor is used . This switching transistor controls the shut down pin voltage of oscillator IC. This transistor makes this pin high when mains is present.

Once shut down pin becomes high, oscillator IC stops generating pulses to MOSFETs. MOSFEET becomes OFF and inverter section becomes inactive. When mains failure occurs this pin voltage is changed by the transistor to generate gate pulses.

The inverter section of OFF-Line and ON-Line UPS are almost same expect in the mains section.

OFF-Line UPS employs a mains delay capacitor. This is a prevention to fast varying mains input voltage. If mains condition is changing rapidly (Mains ON/OFF) then the UPS has to switch alternately to battery mode and mains mode. Since MOSFET cannot respond to these fast varying currents it will burn.To avoid this, a delay capacitor in mains mode (.1Mf) to delay the mains input. As soon as mains is sensed by the opto coupler, mains on indication glows. Changeover relay will respond after a few seconds to mains because of this capacitor. Removing this capaci-tor decreases changeover time. But this may cause damage of MOSFET.

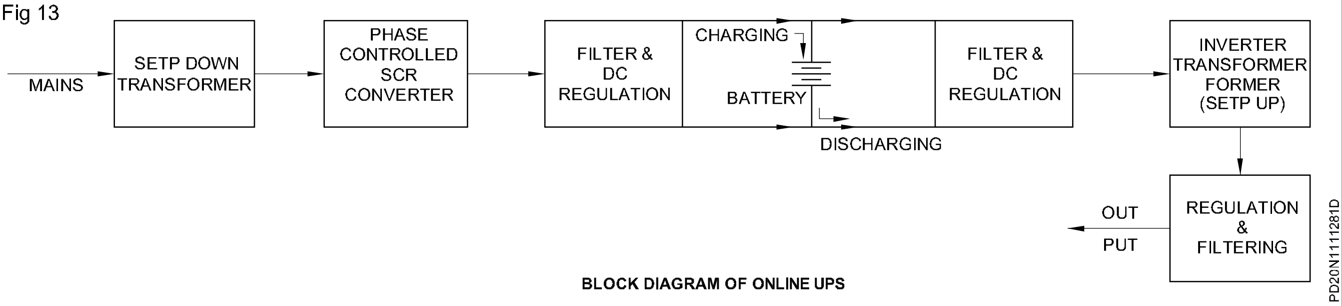
ON line UPS

In an ON line UPS, the inverter always supplies the load irrespective of whether mains power is available or not. The load is always left connected to inverter and hence there is no transfer process involved. When the mains power is present, it is rectified and applied in parallel with the battery. Hence all the supply system transients are isolated at the battery and the inverter always delivers pure sine wave of constant amplitude to the load.

Fig 13 represents a basic block diagram of an ON Line UPS.

In the block diagram (Fig 13), the mains input is stepped down to a lower level and applied to a thyristor based phase controlled AC to DC converter, employing firing angle(α) control. The PWM inverter which usually employs pulse width modulation using triangular/square wave carrier runs in battery mode. The output is filtered and given to the load. The PWM inverter is switched in the frequency range (50Hz) depending on the power rating and hence the DC side current drawn by the inverter will contain switching frequency components.

Fig 13



BLOCK DIAGRAM OF ONLINE UPS

Along with the charging current the second harmonic component of DC side current of the inverter also flows into the battery. This second harmonic is quite large in value and this represents unnecessary strain on the battery. This is one of the major disadvantages of this design since it affects the battery life adversely.

When the mains is present the load power flows though the converter, reaches the battery node and from there flows into the inverter i.e there is double conversion of power. The converter, Inverter and the two level shifting transformers incur power losses in this process. Hence the efficiency of this design is lower than the OFF line design.

In a properly designed control system the battery voltage is measured and compared with a set float voltage. The error is processed in a proportional controller and the processed error decides the charging current that should flow into the battery. Charging current will be a constant one for ON line UPS.

Often it is found that the battery is in discharge mode even when mains is present i.e the battery shares the load current with the mains. This happens when the mains voltage is low and/or the output is loaded to above 75%. The efficiency of ON line UPS can be increased by using boost type power factor correction circuit.

Advantages

- Constant output voltage (No AVR card) free from changeover problem.
- Constant charging current.

Disadvantages

- complex in design, lower efficiency, higher cost, bigger in size and strain on the battery.

Presets of an ON-Line UPS

The presets of ON Line UPS are different from the OFF Line.

ON-Line UPS presets

Output high cut preset: Suppose there occurs a failure in PWM or feedback section. The output voltage will jump above 300V AC. This much output voltage causes harm to the output load. To prevent this output high cut preset is used. When the output voltage reaches set limit, this preset cuts the output. To set this limit, increase the output voltage using the PWM output voltage control preset till it reaches 265V and set the output high cut preset to shut off the output.

Battery charger and inverter

Objectives: At the end of this lesson you shall be able to
- **explain the working of battery charger with the help of block diagram**
- **describe various batteries and its maintenance, rating, methods of charging**
- **explain the battery charging circuit and its auto-cut-off**
- **state the principle of inverter with the help of block diagram**
- **explain power inverter and input output voltage, frequency, power relations.**

Battery charger

Proper selection and maintenance of the battery is very essential for the proper working of battery wherever is used: such as inverter,UPS etc

Many types of battery used for different purpose.Each have more advantages and disadvantages.

Commonly the following four types of batteries are used with the inverter systems, UPS etc.

- Automobile batteries
- Tubular/Industrial lead acid batteries
- Sealed maintenance free (smf)batteries
- Nickel cadmium batteries

Automobile batteries

This type of batteries are commonly used in automobile, cars, trucks etc. It is cheapest of the other batteries used. It has many draw backs one major draw back with these batteries are during stand by use.(i.e) In long duration under float charger they develops positive grid corrosion, which will reduce the back up time provided by it.

A good quality of automobile lead acid battery has a life an of only about 250-300 full charge /discharge cycle.

Tubular/Industrial lead acid battery

This type of batteries are designed for the heavy duty charge required .

The operating life is more than 1000 charge/discharge cycles. These type of battery requires regular maintenance. Because of the acid in these batteries irritating smell gases and It can not be kept in computer rooms and other AC rooms.

Sealed maintenance free (SMF)batteries

These batteries are completely sealed, so they do not require any kind of regular maintenance. In side of battery, do not contain any wet acid, (ie) lead paste batteries. It is small in size, and it can be kept in the ac room along with inverter.

It is more expensive when compared to the other batteries. It is more sensitive than other batteries. If the operating temperature is more than 40 degree centigrade half the capacity and life of batteries are reduced to half.

Nickel cadmium batteries

These are very expensive batteries and used in defence, space, nuclear science etc applications.It has extra any life operation .

Rating of battery

Commonly the batteries are available in 6V,12V,24V,48V, and 120V and so on. Normally 6 ,12 and 24 V rating are mostly available. The capacity of the battery is rated the Ampere/Hour(AH)

The back up time depends on the AH capacity of the battery. higher the AH capacity more the back up time.

Charging of battery

The life of battery is very much depends on the charging method used to charge the battery.

Three types of charging used to change the batteries.

- Constant voltage
- Constant current
- Constant voltages- constant current

Constant voltage

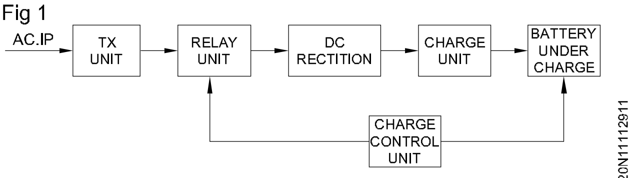
This type of charging method using series regulators is suitable for the SMF batteries but not useful in automobile and tubular lead acid batteries.

Constant current

This charging method using shunt regulators, is useful for automobile and tubular /Industrial lead acid batteries, but it can damage the SMF batteries by overcharging them.

A simplified block diagram of battery charger is explained to understand the function of battery charger. (Fig 1)

Fig 1



BLOCK DIAGRAM OF BATTERY CHARGER

Transformer

The mains transformer primary is connected through auto transformer and the supply to auto transformer controlled through relays. The automatic charge control supply is always present at the primary of charge control unit transformer.

Relay unit

The relay unit supplies the DC rectifier input supply to the required DC input to the battery for charging. This relay unit also cut-off the rectifier input AC in case of the battery is fully charged.

DC rectifier

This rectifier unit always is a full wave bridge rectifier to handle heavy charging current. High current metal rectifiers are found mostly used in this circuit, but high current capacity semi conductor diode are in use.

Charging unit

This indicates the charging current taken by the battery and it is controlled by ON-OFF switches. A test switch is provided to test the charging condition of the battery.

Battery section

The battery under charger is always to kept in a well ventilated room and also open the vent plug for easy evaporation of exhausted gases from cells.

Charge control unit

Once the battery fully charged; then the DC supply to battery to be cut-off automatically. The voltage sensing circuit enables the control unit to trip the AC input to the rectifier unit thereby stop the charging voltage.

Constant voltage

This type of charging method using series regulators is suitable for the SMF batteries but not useful in automobile and tubular lead acid batteries.

Constant current

This charging method using shunt regulators, is useful for automobile and tubular /Industrial lead acid batteries, but it can damage the SMF batteries by overcharging them.

Constant voltage and constant current

This charging method contains more advantages .This method is suitable for automobile and tubular /Industrial lead acid batteries and also for SMF batteries.

This method provide regulated charging to improve the battery life.

Charging operation of battery

When the mains A.C is available, the mains supply is connected to 0-240V taping of auto transformer through a relay.

The transformer works on step down which has 0-240 V, taping at the primary and 12-0-12 V at the secondary.

The voltage at the secondary is used to charge the batteries connected.

Trickle charging

In an inverter, when the mains A.C is available the battery get charged. After the battery is fully charged the charger is cut-off. After the battery get fully charged if the charger is not cut off then the battery will get damaged.

Trickle charging is a special charging method used to keep the battery constantly in full charge position by keeping the battery charged constantly.

This method of charging is slightly different from the normal charging method.

For trickle charging 100th part of the normal charging current is provided to the battery.

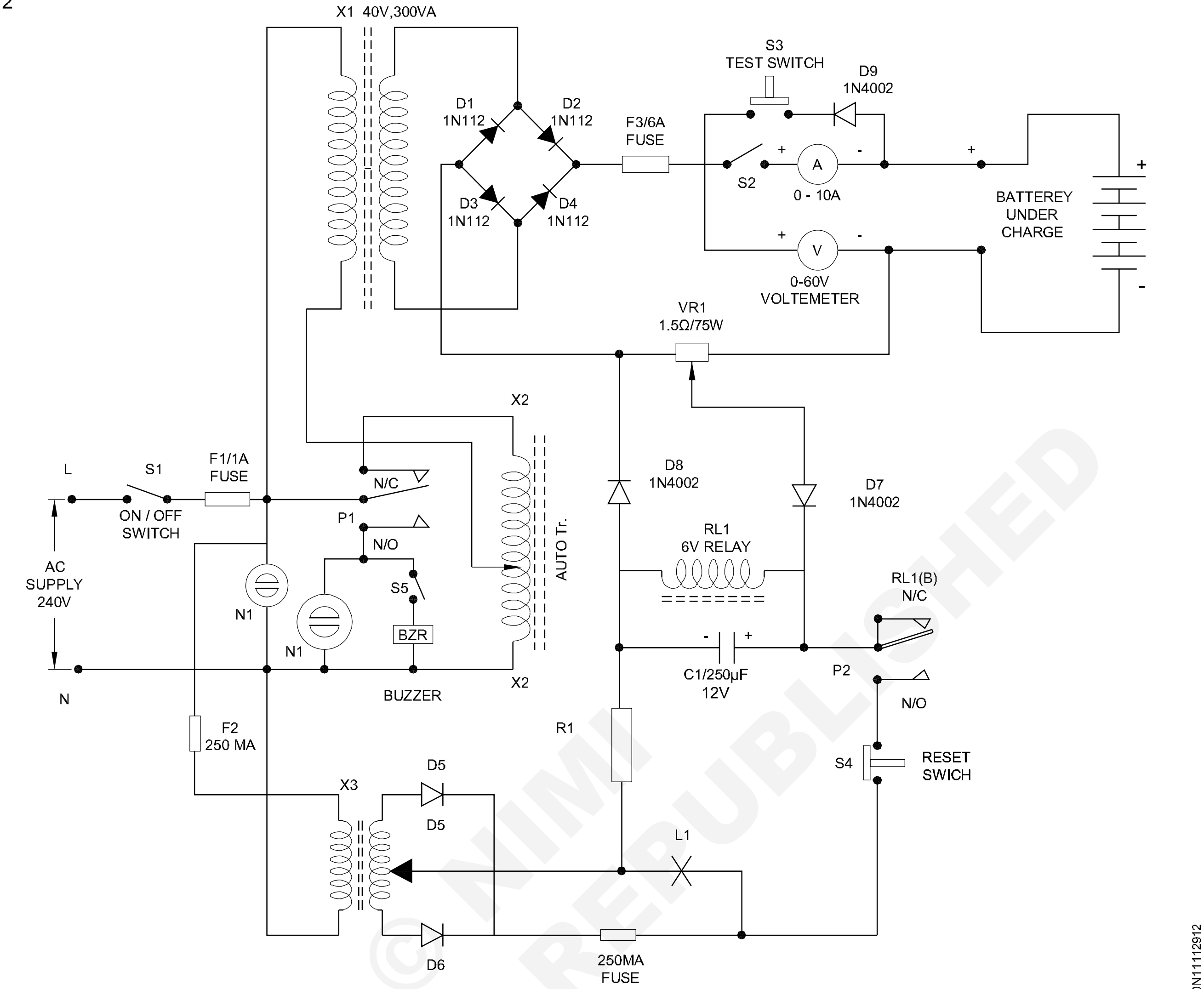
A Simple battery charger

The charger can charge 6V,12Vand 24V battery at Suitable current rate. This circuit has many protection built in it to protect the battery from overcharge and reverse polarity etc.

The charger consist of an auto transformer $X_{2,}$ (Fig 2) for supplying constant current and voltage.

A charger transformer 'X_1' is connected to the auto transformer and the secondary of the X_1 (Fig 2)is rectified through full wave bridge rectifier and supplied to the battery under charger through. Ammeter voltmeter and a potentiometer (Fig 2)

Fig 2



AUTOMATIC BATTERY CHARGER

A step down transformer X_3 is used to keep cut off relay is energised condition when the mains AC supply is cut off to the charger circuit. Relay RL_1 used to cut off the AC mains supply to the charger circuit. Pole P_1 of relay RL_1 is connected to AC mains supply and pole P_2 is connected to cut off circuit.

Relay is energised by the centre tapping of potentiometer, which is set such that, the current in the charger circuit exceeds then it is energised and poles P_1 & P_2 are connected to normally opened (NO)pin, switching 'Off' A/C mains supply to the circuit.

The test switch S_3 is connected to check battery polarity, reset switch S_4 is used to reset the charger, when any fault occurs. Then the charger is cut off and the Switch 'S_1' is mains ON/OFF switch.

A fully charged lead acid battery must be 2.1 volt/cell during on charge.It will increase upto 2.7V/cell.The voltage of a battery is multiple of the number of cells.

In discharged condition the voltage is 1.8V/cell,it should not be further discharged in this condition as it may permanently damage the cell.

E.g A 100AH (ampere hour)battery requires (100 AH/ 10Hr=10 Amp) 10 Amp. Charging current for 10 hours for fully charged. To get complete discharge at the rate of 5Amps will require 20 Hrs.

The fully discharged battery requires about 11/2 times more to get charged .If the battery is in dead (or)not in use for long time even in normal changing current is passed. These dead batteries require higher charge voltage to start the charging current.

Checking of battery

Acid level and specific gravity of electrolyte, will indicate the condition of battery whether it requires charging or not.

The hydro meter is used for checking the acid level in a battery .The scale in marked in the hydrometer from 1100 to 1300.when it is inserted in the battery, the reading

i) 1100-1150 -indicates battery is down

ii) 1200-1250- indicates battery is o.k.

iii) 1250-1300 indicates excess acid

Voltage testing

By using high rate discharge tester, the voltage the each cell must be 2.1V, If it indicates below than 1.8V, then it shows the battery is in fully discharged. It is still below 1.8V.Then the battery becomes dead condition.

Never connect the high rate discharge tester for long duration while checking voltage, it will load the battery heavily and the cell, will discharge.

If the electrolytic level down in the container shell of the battery, top up with distilled water. Never add electrolyte prepared separately to the battery.

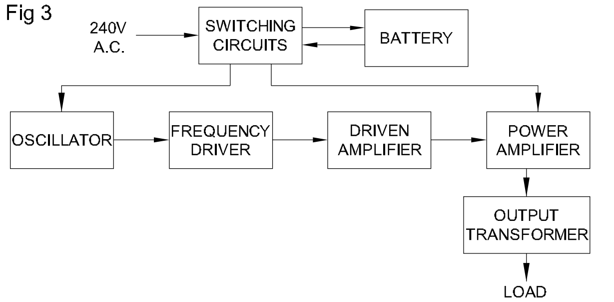
In a lead acid battery the electrolyte level of the battery should be checked and maintained every 15 days in summer season.

Inverter

It is an electronic device, which converts a D.C potential (voltages) normally derived from a lead-acid battery into a stepped-up AC potential (voltage) which is similar to the domestic AC voltage.

Locating the fault and troubleshooting of an inverters which provide sine wave outputs or the use of PWM(Pulse Width Modulation) technology is very difficult. (Fig 3)

Fig 3



BLOCK DIAGRAM OF A DRIVEN INVERTER

Switching circuits

It is the input stage of a inverter. This circuits supplying the power to further stages and connected to battery. The DC supply of battery in this supplies to the switching circuits for various needs.

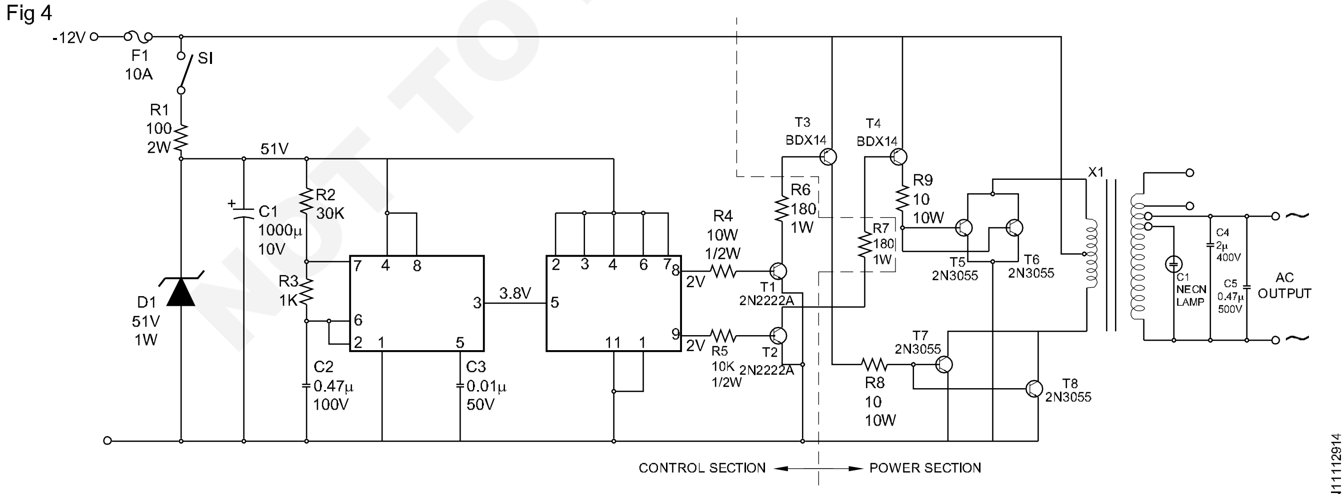
Oscillator

It is an electronic circuit which generates the oscillating pulses either through an IC circuit or a transistorized circuit. This oscillations are the production of alternate pulse of positive and negative (ground) voltage peaks of a battery and at a specified frequency (No.of positive peaks per second). These are generally in the form of square waves and the inverters are called square wave inverters.

The complete circuit diagram of a static 50Hz static inverter is in Fig 4.

The oscillator section of the inverter used a IC circuit to produce control signal frequency to the control and driner section. The received oscillating frequency is amplified to a high current level using power transistor or MOSFET.IC 7473(JK Flip type) used to power amplification and control the frequency to the driver transistors T1 and T2 driving the power transistor to the required level as in the Fig 4.

Fig 4



COMPELETE CIRCUIT DIAGRAM OF 50Hz STATIC INVERTER

The two parallel connected power transistor T5, T6 and T7, T8 are connected to the output transformer which is used to step up the low level AC from the amplifies stage into the specified level.

The transformer secondary is supplied the required level of AC 240V. The generation of the oscillations due to which the process of voltage induction is able to take place across the windings of the transformer.

The inverter does not produce any power and the power produced by DC source. The inverter requires a relatively stable power source capable of supplying of enough current for the intended power demands of the system.

An inverter can produce square wave, modified sine wave, pulsed sine wave, pulse width modulated wave (PWM) or sine wave depending on circuit design.

The inverters more than three stages are more complex and expensive. Most of the electric devices are working with pure sine wave and AC motors directly operated on non-sinusoidal power may produce extra heat, and have different speed-torque characteristics.

Emergengy light

Objectives: At the end of this lesson you shall be able to
- **explain the block diagram of emergengy light**
- **explain the emergency light circuit diagram and charging of battery.**

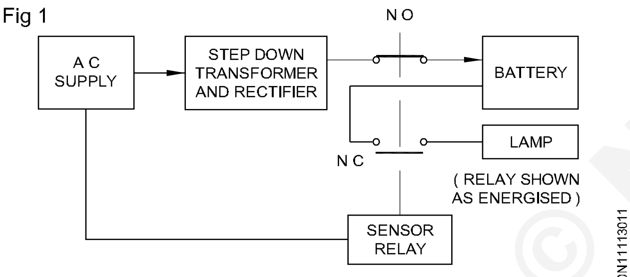
Emergency light

Emergency lighting system is commonly used in public building, work places, residences etc., The main function of the emergency lamp in the industry are

- to indicate ESCAPE routes
- to provide illumination to path ways and exit
- indicate the location of the fire fighting equipments.

The block diagram of an emergency light is in Fig 1. The circuit is discussed here are basic circuits without over charging protection for battery or trickle charging facility. Modern emergency lights have these facilities.

Fig 1



BLOCK DIAGRAM OF AN EMERGENCY LIGHT HAVING INCANDESCENT LAMP

As shown in the block diagram AC main supply is fed to the step down transformer, then it is rectified to charge the battery through a sensor relay. A lamp is connected in the battery circuit through the relay. When AC supply fails the relay enables the battery to the connected lamp circuit through the normally closed contact and the lamp will glow.

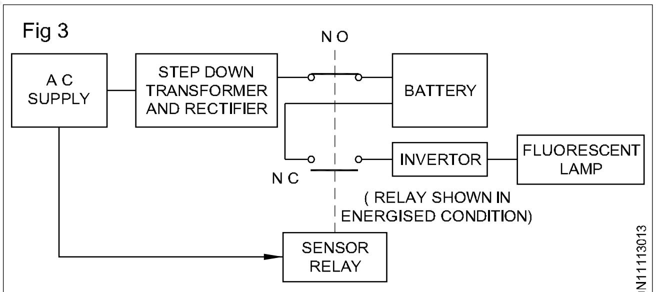
When the AC supply is restored, the battery will be getting charged through the normally open contact of the relay. The charging current is regulated by the series resistances of 2.2 ohm, 5 watt. as in Fig 2. The two LEDs, one is red and the other is green are provided in the circuit to indicate the presence of AC and the lighting of the lamp through the battery supply respectively.

One 1000 microfarad capacitor is used in the rectifier circuit to smoothen the output D.C. supply and one 10 microfarad capacitor is used across the relay to increase the efficiency of relay operation.

Emergency tube light circuit: The emergency light which is connected to an ordinary incandescent lamp will give less light. If the fluorescent tube is used in emergency light it will give about 3 times more light consuming same wattage. Hence most of the emergency lights are incorporated with fluorescent tube lights.

The inverter circuit is incorporated with the ordinary incandescent lamp could be replaced by a tube light as shown in the block diagram, (Fig 3). The tube light requires a high voltage for its operation. The inverter is used to convert DC supply to AC and then it is stepped up to light the fluorescent tube. The inverter circuit is made operative by the sensor (relay). When AC supply is not available, during power failure battery voltage operates the inverter, in which DC is converted to AC and then stepped up to high voltage to enable the fluorescent tube to light up.

Fig 3



BLOCK DIAGRAM OF AN EMERGENCY LIGHT HAVING FLUORESCENT LAMP

Fig 2

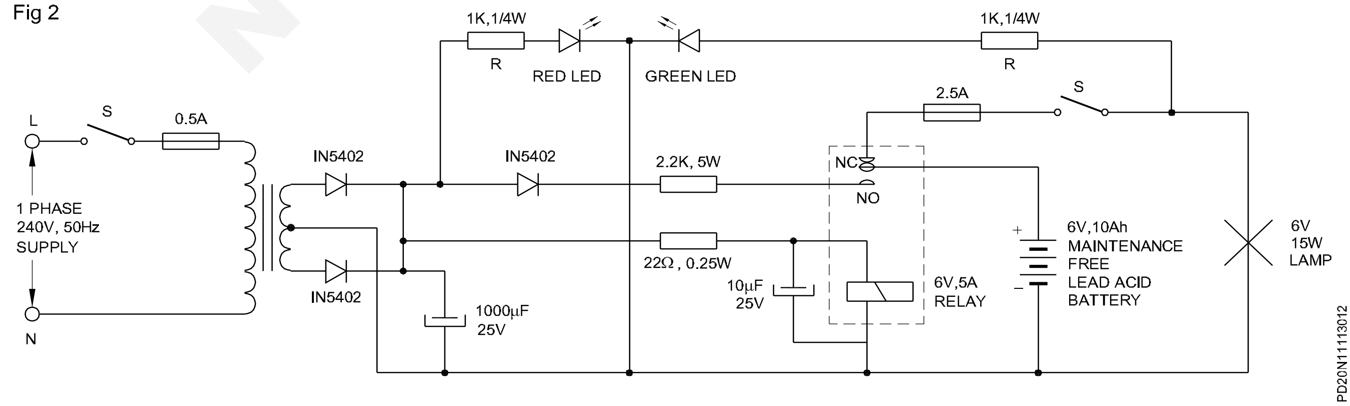
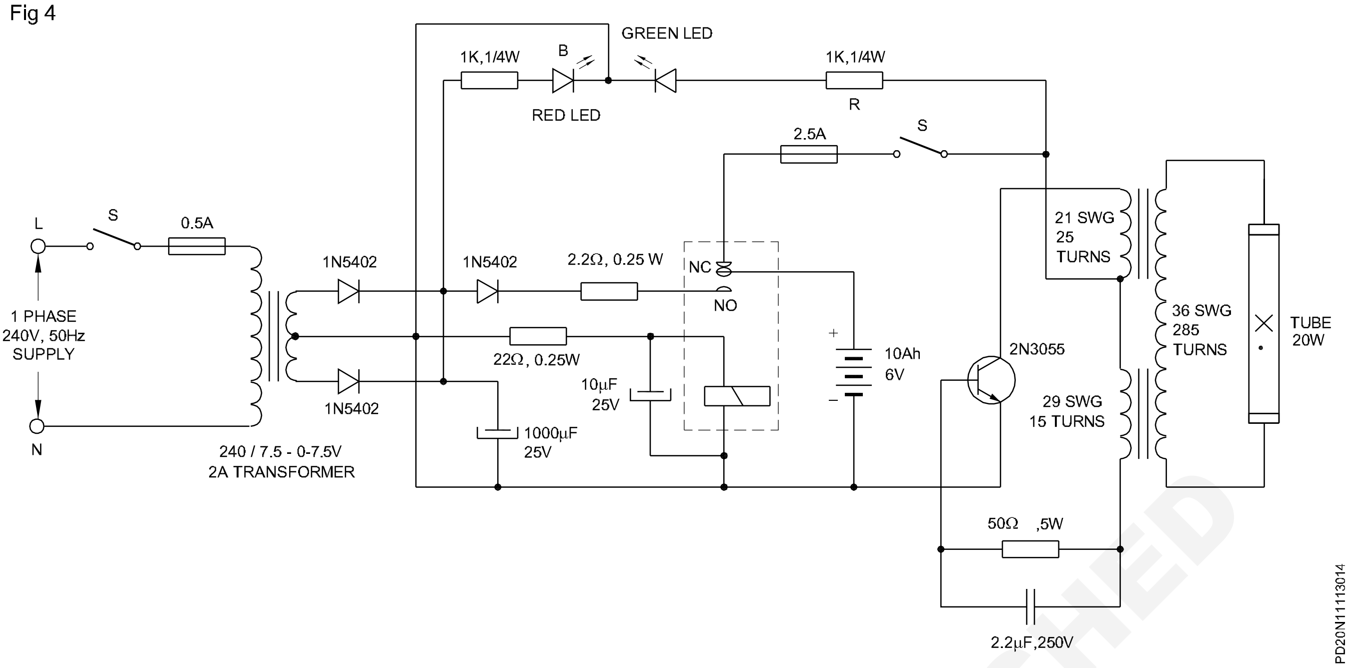


Fig 4



Inverters are basically transistorised oscillators as in Fig 4. They can be made to oscillate at the frequency of about 6.6 kHz. The frequency of the circuit can be changed by changing the value of resistor and capacitor in the circuit which is connected in the base of the transistor.

When the AC supply is resumed the sensor relay connects the battery terminals to the rectified DC circuit for charging and the inverter circuit is disconnected from the circuit by the relay.

For keeping the temperature of the power transistor within its temperature range suitable heat sink should be mounted over the power transistor.