WIREMAN

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**

Trade : **Wireman - 1st Year Trade Theory - 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, by 2020 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 Mentor Councils comprising various stakeholder's 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 **Wireman 1st Year Trade Theory NSQF Level - 4 (Revised 2022) in Power Sector.** 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 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

Addl. Secretary/Director General (Training)
Ministry of Skill Development & Entrepreneurship,
Government of India.

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 Ministry of Skill Development and Entrepreneurship) Government of India, with technical assistance from the Govt. of the Federal Republic of Germany. The prime objective of this institute is to develop and provide instructional materials for various trades as per the prescribed syllabi (NSQF LEVEL - 4) 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.

In order to perform the skills in a productive manner instructional videos are embedded in QR code of the exercise in this instructional material so as to integrate the skill learning with the procedural practical steps given in the exercise. The instructional videos will improve the quality of standard on practical training and will motivate the trainees to focus and perform the skill seamlessly.

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 organisations to bring out this Instructional Material **(Trade Theory)** for the trade of **Wireman** (NSQF LEVEL - 4) (Revised 2022) under **Power** Sector for ITIs.

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NIMI records its appreciation for 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 NIMI staff who have contributed towards the development of this Instructional Material.

NIMI is also grateful to everyone who has directly or indirectly helped in developing this Instructional Material.

INTRODUCTION

TRADE PRACTICAL

The trade practical manual is intended to be used in workshop. It consists of a series of practical exercises to be completed by the trainees during the course of the **Wireman** 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)

Module 1	-	Safety and Hand Tools
Module 2	-	Basic Workshop Practice
Module 3	-	Conductor, Connection, Soldering, UG Cables
Module 4	-	Basic Electric Current
Module 5	-	Magnetism and Capacitors
Module 6	-	Measurement of AC Circuits Single Phase and Three Phase
Module 7	-	Measuring Instruments
Module 8	-	Generation and Transmission
Module 9	-	Earthing Practice and Testing
Module 10	-	DC Machines
Module 11	-	Transformers and AC Motor with Starters
Module 12	-	Study & Draw in Symbols in Electrical Control Circuit Diagram
Module 13	-	Domestic Wiring Practice - I
Module 14	-	Domestic Wiring Practice - II
Module 15	-	Testing in Domestic Electric Wiring
Module 16	-	Control Panel Components
Module 17	-	Control Panel Wiring & Testing
Module 18	-	Cells and Batteries

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 course of the **Wireman** Trade. The contents are sequenced according to the practical exercise contained in the manual on Trade practical. Attempt has been made to relate the theoretical aspects with the skill covered in each exercise to the extent possible. This co-relation 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	**Apply safety precautions and prepare profile with an appropriate accuracy as per drawing using basic jobs of marking components, filing, drilling, riveting, fitting, joining etc. (NOS: PSS/N1707)**	**1.1.01 - 1.2.14**
2	**Prepare terminations, make good quality of electrical wire joints for single and multi strand conductors and carry out crimping, soldering and brazing. (NOS: PSS/N2512, PSS/N1331)**	**1.3.15 - 1.3.20**
3	**Draw and set up DC and AC circuits, involving R-L-C components, perform measurement of various electrical parameters with due care and safety. Carry out Sealing of energy meters and Monitor meter readings using MRI.(NOS:PSS/N1707)**	**1.4.21 - 1.7.41**
4	**Explain basic concepts of generation, transmission and distribution of electrical power including renewable energy. (NOS: PSS/N7001)**	**1.8.42 - 1.8.49**
5	**Plan and prepare Plate and Pipe earthing installations and ensure safe and effective earthing. (NOS: PSS/N6002)**	**1.9.50 - 1.9.55**
6	**Carry out wiring, testing, and maintenance of DC machines including DC motor starters. (NOS: N/A)**	**1.10.56 - 1.10.62**
7	**Carry out wiring, testing, and maintenance of small transformers, 1φ & 3φ AC motors and Alternators including AC motor starters. (NOS: N/A)**	**1.11.63 - 1.11.68**
8	**Read, understand and draw electrical Schematic drawings of power and control circuits using industry standard symbols.(NOS: N/A)**	**1.12.69 - 1.12.73**
9	**Plan, draw, assemble and perform various domestic wiring. Carry out Testing, maintenance and repair/ replacement of domestic wiring. (NOS: N/A)**	**1.13.74 - 1.16.94**
10	**Carry out wiring of control panels, assemble accessories and equipment. (NOS: PSS/N1709)**	**1.16.95 - 1.17.103**
11	**Install, test and carry out maintenance of batteries and solar cell with due care and safety. (NOS: PSS/N6003)**	**1.18.104 - 1.18.109**

SYLLABUS FOR WIREMAN

Duration	Reference Learning Outcome	Professional Skills (Trade Practical) with Indicative hours	Professional Knowledge (Trade Theory)
Professional Skill 110 Hrs; Professional Knowledge 20 Hrs	Apply safety precautions and prepare profile with an appropriate accuracy as per drawing using basic jobs of marking components, filing, drilling, riveting, fitting, joining etc. (NOS: PSS/ N1707)	1. Visit various sections of the institutes and identify locations of different installations. (03 hrs) 2. Identify safety symbols and hazards. (04 hrs) 3. Practice elementary first aid. (04 hrs) 4. Practice safe methods of fire fighting in case of electrical fire. (04 hrs) 5. Demonstrate by visual aids to isolate electric supplies and	Occupational Safety & Health: Scope of the Wireman trade and career progression. Power sector scenario in India. Safety rules and safety signs for Danger, Warning, caution & personal safety messages. Basic injury prevention, Basic first aid, Hazard identification, avoidance and PPEs. Personal safety and factory safety.

		rescue a person safely in contact with electricity. (7 hrs) 6. Demonstrate artificial respiration through visual aids. (04 hrs) 7. Identify trade tools and equipments. (03 hrs) 8. Disposal procedure of waste materials. (03 hrs) 9. Use of personal protective equipments. (03 hrs) 10. Practice on filing and hacksawing and prepare T-joints, straight joints and dovetail joints on wooden blocks. (15 hrs) 11. Practice sawing, planing, drilling and assembling for making a wooden switchboard. (15 hrs) 12. Practice in marking and cutting of straight and curved pieces in metal sheets, making holes, securing by screw and riveting etc. (15 hrs) 13. Workshop practice on drilling, chipping, internal and external threading of different sizes. (15 hrs) 14. Prepare a closed cabinet from metal sheet with holes for cables and various fittings. (15 hrs)	Disposal procedure of waste materials. Response to emergencies e.g. power failure, fire, and system failure. Concept of Standards and advantages of BIS/ISI. Familiarization with signs and symbols of electrical accessories Introduction to 5S concept. **Allied trades:** Introduction to fitting tools, safety precautions. Description of files, hammers, chisels hacksaw frames, blades, their specification and grades. Marking tools description and use. Types of drills, description &drilling machines. Various wooden joints. Marking 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. Description of carpenter's tools Care and maintenance of tools. (20 hrs)
Professional Skill 60 Hrs; Professional Knowledge 10 Hrs	Prepare terminations, make good quality of electrical wire joints for single and multi strand conductors and carry out crimping, soldering and brazing. (NOS: PSS/N2512, PSS/ N1331)	15. Demonstrate and identify various types of cables used in domestic, commercial and industrial wiring systems. (9 hrs) 16. Practice stripping and skinning of different cables. Measure thickness of wire using SWG and micrometer. (9 hrs) 17. Demonstrate and Practice bare conductors joints, viz. Rat tail, Duplex cross, Knotted type, Britannia, straight, Tee, Western union, fixture Joints, split bolt connector, etc. (21 hrs) 18. Practice in soldering. (7 hrs) 19. Practice in brazing. (07 hrs) 20. Practice on crimping thimbles, lugs and fitting of a push fit co-axial plug and socket. (7 hrs)	**Wire Joints:** Trade tools specifications. Properties of conductors, Fundamental of electricity. Electron theory; free electron, fundamental terms, definitions, units & effects of electric current. Types of wires & cables, standard wire gauge. Current carrying capacity of different conductors. Specification of wires & Cables-insulation & voltage grades - Low , medium & high voltage Precautions in using various types of cables / Ferrules. Types of Wire joints & their application. Effects of electric current on human being. Reasons for shock. Insulators, semi-conductors and resistors. Voltage grading of different types of Insulators, permissible temperature rise. Solders, flux and soldering techniques. (10 hrs)
Professional Skill 130 Hrs;	Draw and set up DC and AC circuits, involving R-L-C components,	21. Measure resistance using voltage drop method. (05 hrs) 22. Measure resistance using wheatstone bridge method. (06 hrs)	**Basic Electricity:** Introduction of National Electrical Code 2011.

Professional Knowledge 30 Hrs	perform measurement of various electrical parameters with due care and safety. Carry out Sealing of energy meters and Monitor meter readings using MRI. (NOS:PSS/N1707)	23. Verify thermal effect of electric current and change in resistance due to temperature. (06 hrs) 24. Verify Ohm's law in electrical circuit. (05 hrs) 25. Measure current and voltage in electrical circuits to verify Kirchhoff's Law. (9 hrs) 26. Verify the characteristics of series-parallel combination of resistors. (05 hrs) 27. Determine the poles and plot the field of a magnet bar. (05 hrs) 28. Wind a solenoid and determine the magnetic effect of electric current. (05 hrs) 29. Demonstrate generation of mutually induced emf. (05 hrs) 30. Identify various types of capacitors, charging / discharging and testing. Group the given capacitors to get the required capacity and voltage rating. (06 hrs) 31. Measure current, voltage, power factor and determine the characteristics of RL, RC and RLC in AC series and parallel circuits. (12 hrs) 32. Measure power, energy for lagging and leading power factors in single phase and three phase circuits. (12 hrs) 33. Demonstrate improvement of PF by use of capacitors in AC three phase circuits. (06 hrs) 34. Ascertain use of neutral by identifying wires of a 3-phase 4 wire system and find the phase sequence using phase sequence meter. (05 hrs) 35. Determine the effect of broken neutral wire in three phase four wire system. (05 hrs) 36. Measure the Power of three phase circuit for balanced and unbalanced loads. (05 hrs) 37. Practice on measuring instruments in single and three phase circuits viz., Wattmeter, Energy meter, Phase sequence meter and Frequency meter etc. (08 hrs) 38. Practice on using analog and digital multi-meter for measurement of various parameters. (05 hrs) 39. Measure electrical parameters using tong tester in three phase circuits. (05 hrs) 40. Practice installation and sealing of energy meters. (05 hrs)	Ohm's Law, Kirchoff's Laws Series and parallel circuits. Open and short circuits in series and parallel networks. Laws of Resistance and various types of resistors. Series and parallel combinations of resistors. Wheatstone bridge; principle and its applications. Different methods of measuring the values of resistance. **Magnetism;** 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. 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. Advantages of AC poly-phase system. Problems on A.C. circuits. 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. **Measuring instruments;** 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 viz., multi-meter, Wattmeter, Energy meter, Phase sequence meter, Frequency meter, etc. Measurement of energy in three phase circuit. Important common applicable IE rules. Meter Reading; - Description of MRI - Reading of Meter by MRI (30 hrs)

		41. Practice on collecting meter reading of various meters using MRI and study of MRI reports. (05 hrs)	
Professional Skill 50 Hrs; Professional Knowledge 10 Hrs	Explain basic concepts of generation, transmission and distribution of electrical power including renewable energy. (NOS: PSS/ N7001)	42. Demonstrate Thermal & Nuclear power plants using visual aids. (05 hrs) 43. Demonstrate different transmission and distribution systems using visual aids. (06 hrs.) 44. Demonstrate different renewable energy power plants viz., Solar, wind, small, mini &micro hydro power plants using visual aids. (06 hrs.) 45. Identify different types of insulators. (Video demonstration/ charts). (03 hrs) 46. Visit to distribution sub-station to familiarize with equipment and various accessories. (08 Hrs) 47. Demonstrate operation of various circuit breakers viz., ACB, VCB, SF6, OCB etc. using visual aids. (10 hrs.) 48. Demonstrate different types of substations viz., outdoor, indoor, pole mounted, etc. using visual aids. (06 hrs.) 49. Prepare a line diagram of the institute/ ITI supply system. (06 hrs.)	**Power system:** Generation, transmission and distribution of electrical power General idea about overhead transmission, distribution (LV, MV & HV) and their types and accessories used. Types of Distribution system Line protecting devices Types of substations - indoor, outdoor & Pole mounted, etc. **Substation Equipments** Switchgear; CBs - ACB, VCB, SF6, OCB etc. protection schemes, current transformer, Potential transformer, Protective relays, lightning arrestors, Different types of switches and switch gears, multi Range switches, rotary switches, cooker control panels, power circuit switches, thermostat, mercury switches etc. (10 hrs)
Professional Skill 40 Hrs; Professional Knowledge 7 Hrs	Plan and prepare Plate and Pipe earthing installations and ensure safe and effective earthing. (NOS: PSS/N6002)	50. Demonstrate and identify various components of earthing installation. (05 hrs) 51. Prepare pipe earthing and measure earth resistance by earth tester/ megger. (9 Hrs) 52. Prepare plate earthing and measure earth resistance by earth tester/ megger. (9 Hrs) 53. Demonstrate grid/ mesh earthing. (06 Hrs) 54. Practice grounding of equipment and systems. (06 Hrs) 55. Test earth leakage by ELCB and relay. (05 Hrs)	**Earthing:** Importance of Earthing. I. E. Rules for earthing conduits using earth clips and earth wire as per IS 732-1863. Plate earthing, pipe earthing grid/mesh earthing. Earth resistance, earth leakage current and circuit breaker. Difference between grounding and earthing. Awareness of circuit main earth (CME) and portable earth. (07 hrs)
Professional Skill 50 Hrs; Professional Knowledge 10 Hrs	Carry out wiring, testing, and maintenance of DC machines including DC motor starters. (NOS: N/A)	56. Identify parts of DC machines and their terminals. (04 Hrs.) 57. Carry out wiring of different DC motors and generators. (8 Hrs.) 58. Dismantle and identify parts of three point and four-point DC motor starters. (05 Hrs.) 59. Assemble, Service and repair three point and four-point DC motor starters. (9 Hrs.) 60. Practice maintenance of carbon brushes, brush holders, Commutator and slip-rings. (9 Hrs.)	**DC Machines;** General concept of rotating electrical machines. Principle of DC generator. Use of Armature, Field Coil, Polarity, Yoke, Cooling Fan, Commutator, slip ring and Brushes, Laminated core etc. E.M.F. equation Separately excited and self-excited generators. Series, shunt and compound generators. Armature reaction, Commutation, interpoles and connection of interpoles.

		61. Perform speed control of DC motors - field and armature control method. (06 Hrs.) 62. Demonstrate overhauling/ routine maintenance of DC machines. (9 Hrs.)	Parallel Operation of DC Generators. Application, losses & efficiency of DC Generators. Principle and types of DC motors. Changing the direction of rotation. Methods of speed control of DC motors. (10 hrs)
Professional Skill 60 Hrs; Professional Knowledge 10 Hrs	Carry out wiring, testing, and maintenance of small transformers, 1?& 3? AC motors and Alternators including AC motor starters. (NOS: N/A)	63. Verify terminals, identify components of various single phase and three phase transformers and carry out wiring. (05 hrs) 64. Carry out polarity, insulation, open circuit, short circuit test and voltage reguarion of a transformer. (10 hrs) 65. Identify parts and terminals of three phase AC motors, test for continuity and insulation resistance. (10 hrs) 66. Identify parts and terminals of different types of single phase AC motors. (10 hrs) 67. Identify parts and terminals of MG set, make connections and demonstrate conversion of electrical power to a different form. (10 Hrs) 68. Identify parts, service and troubleshoot/ repair & maintenance of AC motor starters viz., DOL, star-delta auto-transformer and rotor resistance starter. (15 Hrs)	**Transformers, AC motors, starters and Alternators:** Working principle, construction and classification of transformers. Single phase and three phase transformers. Testing of transformers. General concept of rotating electrical machines. Principle of operation of AC motors and generators, components and various types. **Motor Starters:** Different types of starters for AC motors, its necessity, basic contactor circuit, parts and their functions. Basic knowledge of soft starter. (10 hrs)
Professional Skill 50 Hrs; Professional Knowledge 10 Hrs	Read, understand and draw electrical Schematic drawings of power and control circuits using industry standard symbols. (NOS: N/A)	69. Identify and draw symbols used in the electrical circuit drawings. (08 hrs) 70. Interpret control and power circuits of various panel wiring drawings in simple to complex manner. (10 hrs) 71. Practice drawing of simple circuits viz. control of lamps, tube lights, fans and single phase motors, etc. (10 hrs) 72. Practice drawing of circuits using various control elements viz. timers, relays Circuit breakers, sensors, and sequential control of motors, etc. (17 hrs) 73. Draw a circuit of fully automatic star-delta starter for starting a 3-? induction motor. (05 hrs)	Different control elements and equipment, their symbols. Power and control schematic drawings with interlocks. Relay ladder logic. Relay and control panel wiring. Circuits of various electrical appliances and controls. Power Distribution network drawings. (10 hrs)
Professional Skill 175 Hrs; Professional Knowledge 35 Hrs	Plan, draw, assemble and perform various domestic wiring. Carry out Testing, maintenance and repair/ replacement of domestic wiring. (NOS: N/A)	74. Wire up simple circuits and practice control of lamps in different combinations using switching concept. (09 Hrs) 75. Calculate maximum connected load in a section of the institute. (09 hrs) 76. Demonstrate and draw electrical supply system from pole to main switch board including different components. (04 hrs.) 77. Prepare a list of typical energy consumption of electrical appliances.	

		(04 hrs) 78. Identify various accessories used in domestic wiring of different ratings/ sizes and list out their approximate cost. (09 hrs.) 79. Prepare test boards/ extension boards and mount accessories like lamp holders, switches, sockets, fuses, relays, MCB, ELCB, MCCB etc. (17 Hrs) 80. Check tripping characteristic of circuit breaker (MCB & ELCB) for over current and short circuit current. (04 hrs) 81. Demonstrate method of working with plum bob, sprit level, water level and wall chasing. (10 hrs) 82. Practice cutting, threading of different sizes of PVC conduits & laying Installations. (12 Hrs) 83. Draw layouts and practice PVC Casing-capping wiring of minimum 20 mtr length with minimum to more number of points. (12 Hrs) 84. Wire up PVC Casing-capping wiring to control one lamp from two different places (Staircase wiring). (10 Hrs) 85. Draw layouts and practice PVC Conduit wiring of minimum 20 mtr length with minimum to more number of points. (15 hrs) 86. Wire up PVC conduit wiring to control one lamp from three different places. (10 hrs) 87. Demonstrate process of concealed conduit wiring system using visual aids. (04 hrs) 88. Prepare main distribution board, mount the energy meter board. (10 hrs) 89. Wire up the consumers main board with ICDP switch and distribution fuse box. (05 Hrs) 90. Carry out polarity test and ensure correct connections of switches, fuses and accessories. (05 hrs) 91. Carry out earth continuity test and ensure resistance of earth conductor as per IE rule. (05 hrs) 92. Check line-earth and neutral-earth loop impedance and ensure effectiveness of earthing. (06 hrs) 93. Simulate faults and practice tracing of faults in different circuits. (10 Hrs) 94. Video demonstration of various wiring accessories/ electrical fittings availabe in the market viz., switches, panels, fuses, plugs, brackets, cut out relays, sensors, voltage regulators, circuit breakers etc. (05 hrs)	**Domestic Wiring:** Introduction and explanation of electrical wiring systems, cleat wiring, Casing-capping, CTS, Conduit and concealed etc. IE Rules related to wiring, National Building codes for house wiring, specification and types, rating & material. Minimum load capacities (W/m2) of various buildings. Electrical load categories. Terms; Maximum demand, Load factor and Diversity factor, etc. Various wiring accessories/ electrical fittings e.g. switches, fuses, lamp holders, plugs, brackets, ceiling rose, cut out relays, sensors, voltage regulators, MCB, ELCB, MCCB etc. Grading of cables and current ratings. Principle of laying out of domestic wiring. Selection of switchgear. Voltage drop concept. IS 732-1863. Wiring materials used for PVC cables, Indian standards regarding the above wiring such as clip distance fixing of screws, cable bending etc. Introduction to estimation procedure, PVC casing and capping materials, sizes and grades etc. Conduit pipe wiring materials and accessories, types and sizes of conduit. Branching of circuits with respect to loads such as lighting and power. Layout of Light points, fan points, heating loads etc., their controls, main switches, distribution boards as per IE rules. Difference between MCCB, MCB, ELCB, RCCB, MPCB. Different types of wiring; PVC conduit; Surface and concealed (PVC Conduit;/ metal conduit) Casing-capping wiring system. Power, control, Communication and entertainment wiring. Wiring circuits planning, permissible load in sub-circuit and main circuit. (35 hrs)

Professional Skill 80 Hrs; Professional Knowledge 18 Hrs	Carry out wiring of control panels, assemble accessories and equipment. (NOS: PSS/N1709)	95. Demonstrate various components of a control panel viz. DIN rails, plastic trunking, connector blocks, screw terminals, transformers/ toroidal inductors, resistors, capacitors, fuses, fuse holders, switches, push buttons, lamps their specifications and labelling, etc. (05 hrs) 96. Demonstrate various components of different relays and contactors, their specifications, fittings in the control panel and labelling. (05 hrs) 97. Practice cable forming including template, binding, lacing, loop tie, lock stitch, breakouts, twisted pair etc. (10 hrs) 98. Practice use of sleeves, bootlace ferrule, passing cables through strain relief plate, correct method of connections in terminal blocks and routing of cables. (10 hrs) 99. Pass cables through strain relief plate in an Electrical cabinet and secure the cables properly using cable tie/ clamp. (05 hrs) 100. Mount various control elements e.g. circuit breakers, relays, contactors, measuring instruments, sensors and timers etc. (10 hrs) 101. Practice earthing and screening of cabinets as per IE rules and ensure proper earth continuity. (10 hrs) 102. Demonstrate electro-magnetic interference and electro-magnetic compatibility. (05 hrs) 103. Practice wiring of control panel for different operations/controls of motor using various accessories and test for its performance. (20 hrs)	
Professional Skill 35 Hrs; Professional Knowledge 10 Hrs	Install, test and carry out maintenance of batteries and solar cell with due care and safety. (NOS: PSS/N6003)	104. Demonstrate use of various types of cells and practice on grouping of cells for specified voltage/current under different conditions. (03 Hrs) 105. Prepare and practice on battery charging. (03 Hrs) 106. Practice on routine, care/ maintenance and testing of batteries. (07 Hrs) 107. Practice charging of a Lead acid cell, filling of electrolytes, testing of charging, checking of discharged and fully charged battery. (12 hrs) 108. Demonstrate different types of solar cell viz., a-Si, CdTe, c-Si, CI(G)S, CVP and HCVP, etc. (05 hrs) 109. Determine the number of solar cells in series/ parallel for given power requirement. (05 Hrs)	**Battery and solar cell:** Chemical effectof 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, Safety precautions, test equipment and maintenance. Grouping of cells for specified voltage and current. Principle and operation of solar cell, Types of solar cell. (10 Hrs)

QR CODE

Module 1

Ex.No. 1.1.02&03

Ex.No. 1.1.04&05

Ex.No. 1.1.06&07

Ex.No. 1.1.08

Ex.No. 1.1.09

Module 2

Ex.No. 1.2.10

Ex.No. 1.2.11

Ex.No. 1.2.12&13

Ex.No. 1.2.14

Module 3

Ex.No. 1.3.15&16

Ex.No. 1.3.18&19

Ex.No. 1.3.20

Module 4

Ex.No. 1.4.24

Module 5

Ex.No. 1.5.27

Organization of ITI's and scope of the wireman trade

Objectives: At the end of this lesson you shall be able to
- **state brief introduction about Industrial Training Institutes (ITI)**
- **state about the organized structure of the Institute.**

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.

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.

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.

Scope of the wireman trade

Objectives: At the end of this lesson you shall be able to
- **state the key skills and carrier pathway for wireman**
- **list out the job opportunities and self employment opportunities.**

Welcome to the wireman trade

Wireman 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 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

Reference NCO - 2015

i 7411.0301 - Wireman, light and power

ii 7422.0800 - Cable jointer

iii 7411.0500 - Meter sealer, electrical

iv 7421.0701 - Field technician, other home appliances

v 7411.0600 - Electrician, stage and audio

Duties of Wireman - General and Electrical - Fitter

Wireman - 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. 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.

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

Key Skills of Wireman

After passing the Wireman 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.

Presently Wireman syllabus again revised and sequentially structured by National Skill Qualification Framework NSQF - level 4 and implemented from August 2022.

Carrier Progress Pathways

After passing the Wireman trade the trainee can appear in 10^{th} examination through National Institute of Open Schooling (NIOS) for acquiring higher secondary certificate and can go further for general Technical education.

- 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

- Wireman in local electricity boards, railways, Telephone department, airport and other government and semi-government establishments
- Assembler of electrical control gears and switches on panel boards at switch gear factories.
- Winder of electrical motors in winding shops
- Electrician to Install, service and maintain electrical equipment and circuits in hotels, resorts hospitals and flats
- Assembler in the domestic appliances manufacturing factories
- Solar technician
- Lineman in TNEB

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.
- Contractor for domestic wiring and industrial wiring
- 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.

Power sector scenario in India

India is a third largest produce of electricity in the world

Electricity coverage 99.93 (as on 31 march 2019)

Installed capacity 399.467 MVA

Production 1,387 TWh

Share of fossi/energy 75.38%

Share of renewable energy 21.26%

Green House Gas (GHG) emission from electricity generation 2,307.78 metric Co24

Average electricity 1208 kwh - per capital

Transmission & distribution losses 20.66%

Consumption by sector

Residential	24.01	(FY2020)
Industrial	42.69	(FY2020)
Agriculture	17.67	(FY2020)
Commercial	8.04	(FY2020)
Traction 1.52	(FY2020)	

Tariff and financing

India has surplus power generation capacity but lack adequate fuel supply, transmission and distribution infrastructure. India electricity sector is dominated by fossil fuel (particularly coat) which produced about those quarter of the counter electricity.

Palominos for renewable

Coat not - non -renewable

Renewable energy

Renewable energy is energy that is collected from renewable sources that are naturally, replenished on a human line scale.

1 Sunlight, 2 Wind, 3 Water, 4 Tidal

And 5 Geothermal heat - heat inside the earth

Green energy, Solar, Wind, geothermal, hydro electric

The air is the push the sector onto a trajecton of sound commercial growth and to enable the state and the center to move in harming and co-ordination.

Governor of India has on ambition mission of "Power for all". This mission would require all that the installed capacity should be at least 3,00,000 MW.

1 Reliable power

2 Quality power

3 Operation power

4 Commercial ability of power

5 Power for all

6 Rural electrification

India power sector is one of the max diversified in the world. Source of power ranges from conventional sources such as coal, lignite, natural gas oil hydro and nuclear power.

Power sector play vital in the eccentric growth and human development. Improves the quality of life of human and the biotic of this sphere.

India is world sixth larger energy consumer.

Safety rules - Safety signs - Hazards

Objectives: At the end of this lesson you shall be able to
- **explain the necessity of adopting the safety rules**
- **list the safety rules to be followed by the wireman**
- **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 Wireman 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 Wireman 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.
- Do not touch bare conductors
- When soldering, place the hot soldering irons in their stand.
- Use only correct capacity fuses in the circuit.
- Replace or remove fuses only after switching off the circuit switches.
- Use accessories like sockets, plugs, switches and appliances only when they are in good condition.
- Stand on a wooden stool, or an insulated ladder while repairing live electrical circuits/ appliances.
- Stand on rubber mats while working/operating switch panels, control gears etc.
- Position the ladder, on firm ground.
- Always use safety belts while working on poles or high rise points.
- Never place your hands on any moving part of rotating machine.
- Only after identifying the procedure of operation, operate any machine or apparatus.
- 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.

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.

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

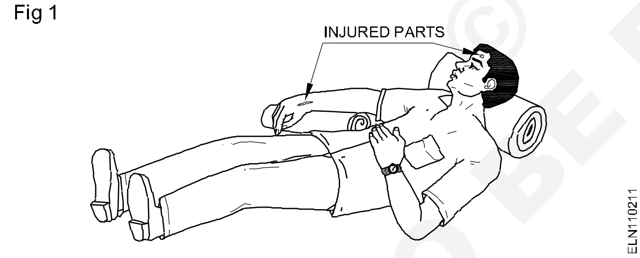
Any wound which is bleeding profusely, especially in the wrist, hand or fingers must be considered serious and must receive professional attention. As an immediate first aid measure, pressure on the wound itself is the best means of stopping the bleeding and avoiding infection.

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

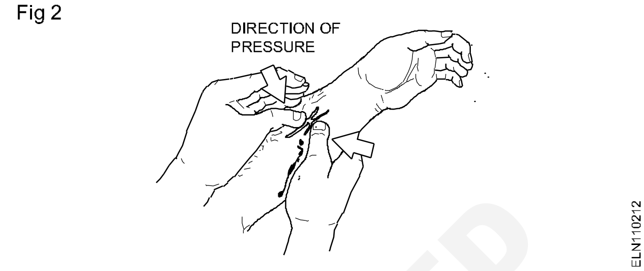


- apply pressure to the wound
- call for medical assistance

To control severe bleeding

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)

Fig 2

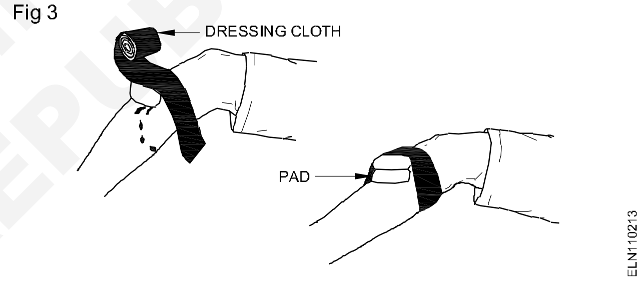


For an abdominal wound which may be caused by falling on a sharp tool, keep the patient bending over the wound to stop internal bleeding.

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 practice - Safety signs

Objectives: At the end of this lesson you shall be able to
- **state the responsibilities of employer and employees**
- **state the safety attitude and list the four basic categories of 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.

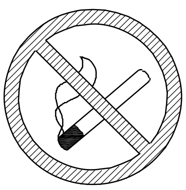
Safety signs fall into four separate categories. These can be recognised by their shape and colour. Sometimes they may be just a symbol; other signs may include letters or figures and provide extra information such as the clearance height of an obstacle or the safe working load of a crane.

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

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.

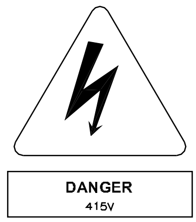
Mandatory signs

Fig 2

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

Warning signs

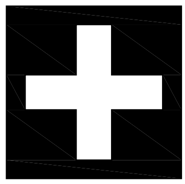
Fig 3



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

Information signs

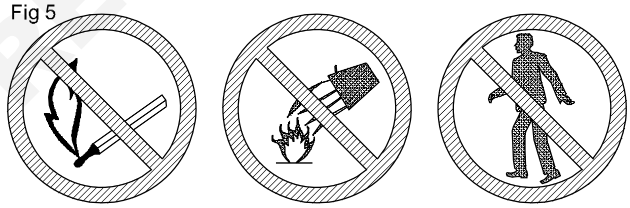
Fig 4



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



SMOKING AND NAKED FLAMES PROHIBITED | DO NOT EXTINGUISH WITH WATER | PEDESTRIANS PROHIBITED

ELN110235

Mandatory signs

Fig 6

MANDATORY SIGNS

Warning signs

Fig 7

WARNING SIGNS

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.**

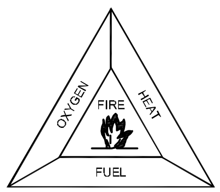
Fire

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.

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.

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.**

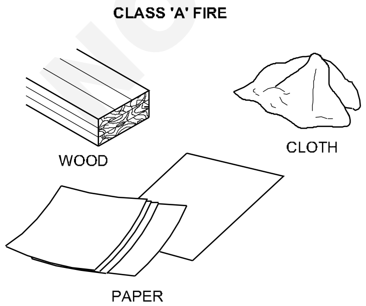
Preventing fires: The majority of fires begin with small outbreaks which burn unnoticed until they have a secure hold. Most fires could be prevented with more care and by following some simple common sense rules.

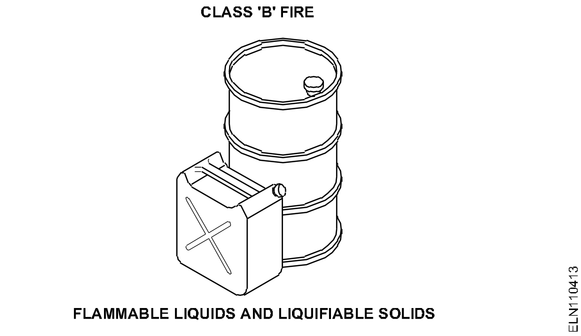
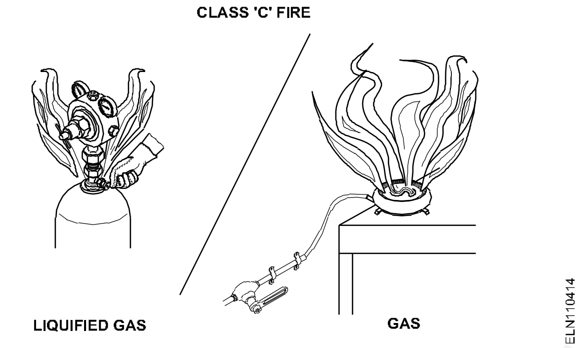
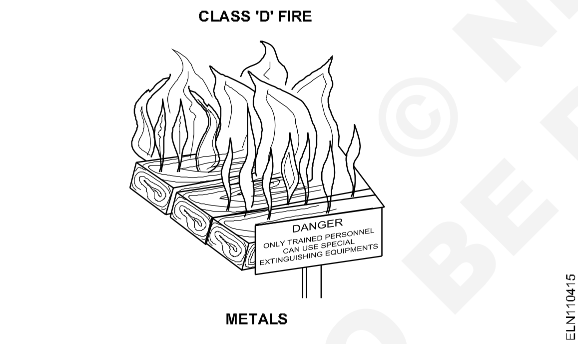
Highly flammable liquids and petroleum mixtures (thinner, adhesive solutions, solvents, kerosene, spirit, LPG gas etc.) should be stored in the flammable material storage area.

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.

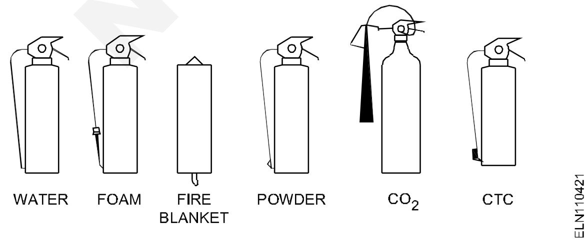
Fire Classification and Fuel	Extinguishing Method
Fig 2 	Most effective ie., cooling with water. Jets of water should be sprayed on the base of the fire and then gradually upwards.

Fire Classification and Fuel	Extinguishing Method
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. Dry powder extinguishers are used on this type of fire.
Fig 5 	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

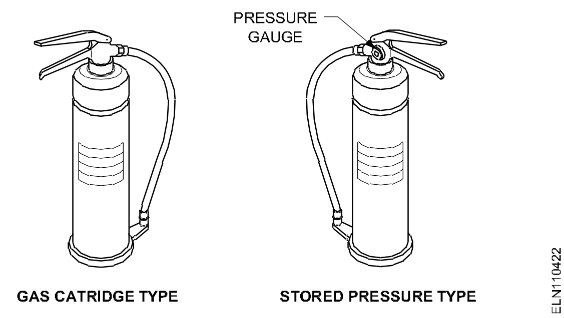


Water-filled extinguishers: There are two methods of operation. (Fig 2)

- 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



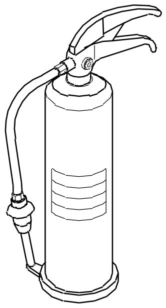
Foam extinguishers (Fig 3):These may be of stored pressure or gas cartridge types. Always check the operating instructions on the extinguisher before use.

Most suitable for

- flammable liquid fires
- running liquid fires

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

Fig 3

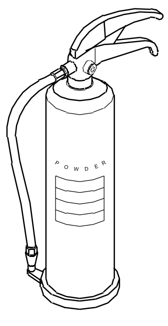


FOAM EXTINGUISHERES

ELN110423

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

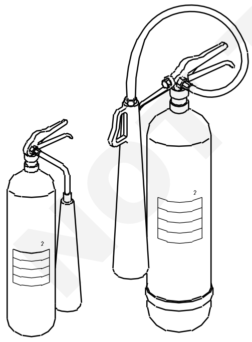


DRY POWDEER EXTINGUSHERS

ELN110424

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

Fig 5



CARBAN DIOXIDE(CO_2)

ELN110425

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.

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.
- Inform fire service or arrange to inform immediately.
- Open emergency exist and ask them to go away.
- Put "OFF" electrical power supply.

Don't allow people to go nearer to the fire

- 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

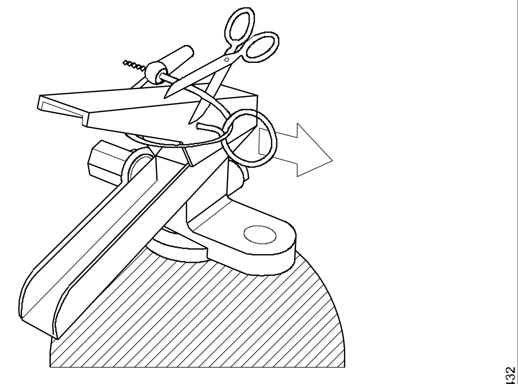
Assume the fire is 'B; type (flammable liquifiable solids)

- Slect CO_2 (Carbon di oxide) fire extinguisher.
- Locate and pickup, CO_2 fire extinguisher. Click for its expiry date.
- Break the seal (Fig 7)
- Pull the safety pin from the handle (Pin located at the top of the fire extinguisher) (Fig 8)
- Aim the extinguisher nozzle or hose at the base of the fire (this will remove the source of fuel fire) (Fig 9)

Keep your self low and safe distance

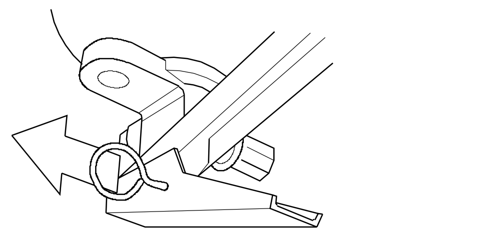
- Squeeze the handle lever slowly to discharge the agent (Fig 10)
- Sweep side to side approximately 15 cm over the fuel fire until the fire is put off (Fig 10)

Fig 7



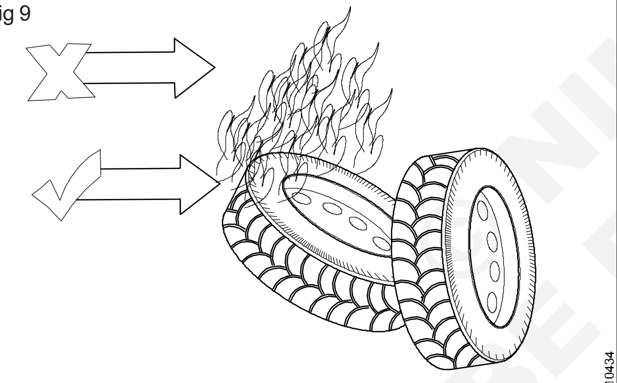
BREAK THE SEAL

Fig 8



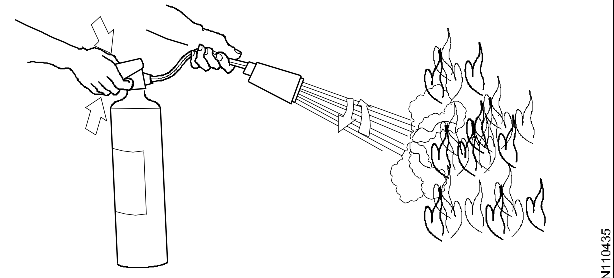
PULL THE SAFTY PIN

Fig 9



AIM THE EXTINGUISHER

Fig 10



Fire extinguishers are manufactured for use from the distance.

Caution

- **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

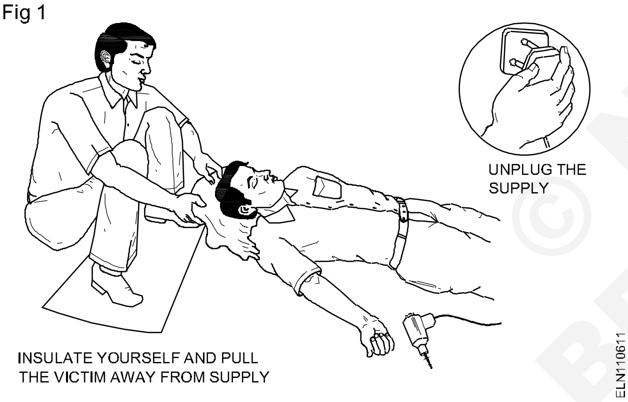
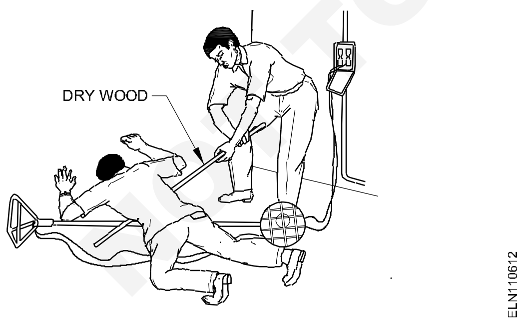


Fig 2



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.

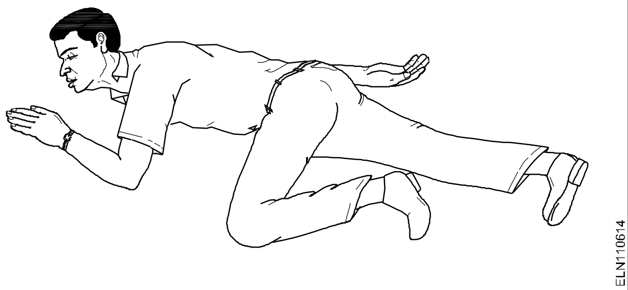
If the casualty is unconscious but is breathing, loosen the clothing about the neck, chest and waist (Fig 3) and place the casualty in the recovery position.

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.

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.

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.
- **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.

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.

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.

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.

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**.

Maintain the hygiene

Most important, the first aider need to wash hands and dry before giving any first aid treatment to the patient

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.

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.

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.

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.

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.

- Airway - Does the person have an unobstructed airway?
- Breathing - Is the person breathing?
- Circulation - Does the person show a pulse at major pulse points (wrist, carotid artery, groin)

Unconsciousness (COMA)

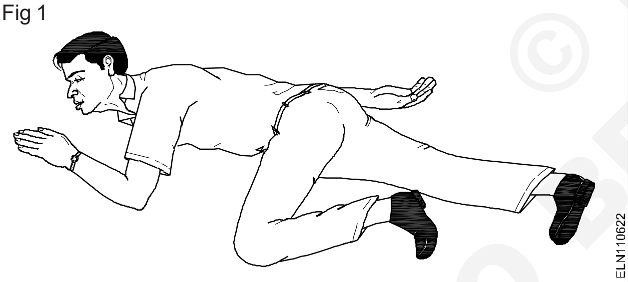
Unconscious also referred as Coma, is a serious life threatening condition, when a person lie totally senseless and do not respond to calls, external stimulus. But the basic heart, breathing, blood circulation may be still intact, or they may also be failing. If unattended it may lead to death.

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 1). If breathing or pulse stops at any time, roll the person on to his back and begin CPR.

Fig 1



- 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.

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

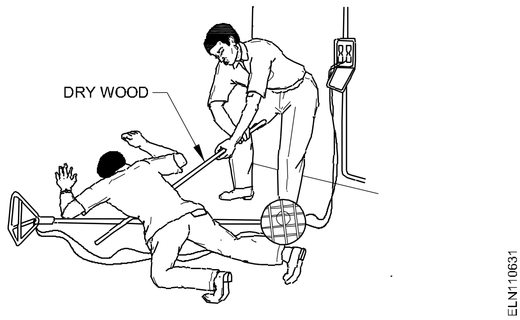
Prompt treatment is essential.

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 etc. (Fig 2)

Fig 2



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.

Disposal of waste material

Objectives: At the end of this lesson you shall be able to
- **state about the waste material**
- **state the types of waste material and source of waste**
- **list out the waste material in workshop**
- **explain the methods of disposal of waste material.**

Waste

Waste are unwanted or unusable materials. Waste is any substance which is discarded after primary use, or it is worthless, defective and of no use.

Waste is the by product of all the matter which is consumed by living organisms and is used in the industries as well as in agriculture and other fields. Usually this waste is thrown on areas outside the cities but this open disposal decreases the usable land into non-usable land and also polluting the environment.

Waste can be broadly classified as follows

a Rural waste

b Urban waste

 i Solid waste

 ii Liquid waste

a Rural waste

Rural waste is the waste from agricultural and dairy forms. These can be reused by burning agricultural waste and composing. The waste produced by the man and animal is now used in the production of fuel by bio-gas plants.

b Urban waste

It is the waste from house hold articles or from industries within municipal limit

It can be again classified into two types.

i Solid waste

Solid waste is the material is hard (from industries) such as newspaper, cans, bottles, broken glass, plastics container, polythene bags etc.

ii Liquid waste

It is the water based waste which is produced by the main activation sources of waste.

Sources of waste

i Industrial waste

It contains solid as well as liquid waste and is formed by the processing of various materials and it contains harmful chemical and solid metal waste.

ii Domestic waste

It includes all rubbish, garbage, dust, sewage waste etc. It contains combustible and non-combustible materials. When these waste disposal off openly cause various harmful effects.

iii Agricultural waste

It includes the waste produced from the crops and cattle etc. Open disposal of thin waste create problems for health of man and other animals.

iv Flu ash produced by interval power plants.

v Hospital waste is most harmful waste off contains micro organisms which cause both communicable and non-communicable deseases.

List out the waste material in workshop (Fig 1)

- Oily waste such as lubricating oil, coolant etc.
- Cotton waste.
- Metal chips of different materials.
- Electrical waste such as used and damaged accessories, wires, cables, pipes etc.

Methods of disposal of waste (Fig 2)

Disposal process : This is the final step of the waste management. From this disposal point or site the materials are selected steps as

- Recycling
- Composing

Fig 1

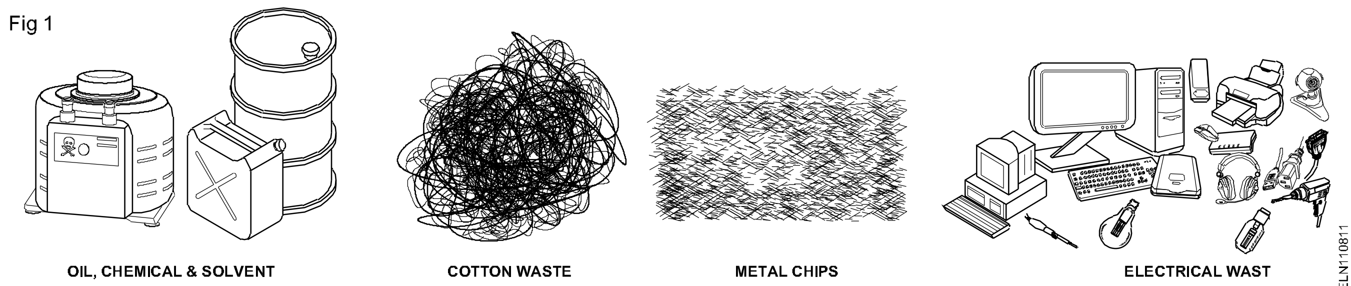
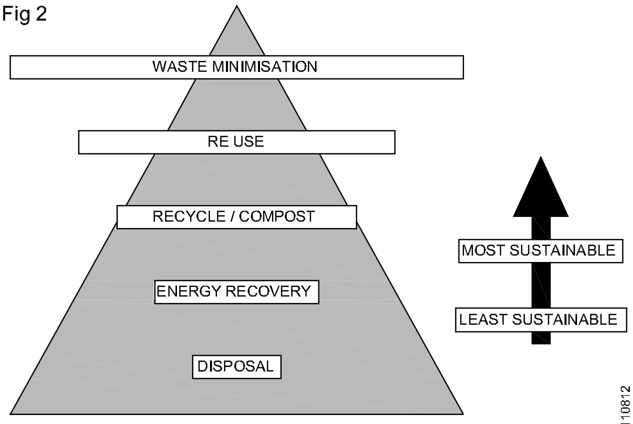


Fig 2



METHOD OF WASTE DISPOSAL

- Landfill
- Incineration
- Waste compaction
- Reuse
- Animal Feed
- Fire Wood

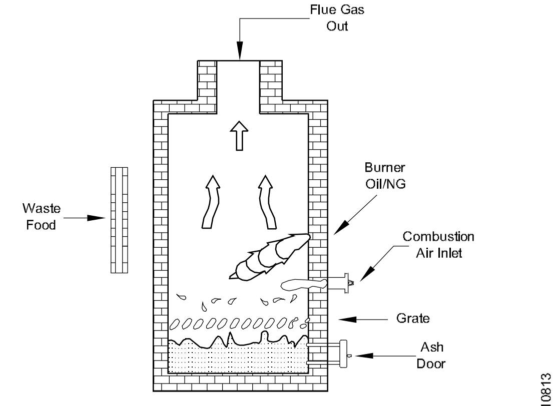
Recycling: Recycling is one of the most well known method of managing waste. It is not expensive and can be easily done by you. If you carry out recycling, you will save a lot of energy, resources and thereby reduce pollution.

Composting: This is a natural process that is completely free of any hazardous by-products. This process involves breaking down the material into organic compounds that can be used as manure.

Landfill: In this process, the waste cannot be reused or recycled separated out and spread as a thin layer in some low-lying areas across the city. A layer of soil added after each layer of garbage. Once this process is complete, this area declared unfit for building construction and is only used as a playground or a park.

Incineration (Fig 3): It is the process of controlled combustion of garbage to reduce it to incombustible matter, ash, waste gas and heat. It is treated and released into the environment (Fig 3). This reduced 90% volume of waste, some time the heat generated used to produce electric power.

Fig 3



INCINERATION PROCESS

Waste compaction: The waste materials such as cans and plastic bottles compact into blocks and send for recycling. This process need space, thus making transportation and positioning difficult.

Reuse: The amount of waste disposal can be reduced by carefully considering the exact throwing away. Before discarding the item think for the possibility to wash and reuse them. Plastic tubs contents butter or icecream can become effective storage containers for a range of small item like nails or screws.

Animal Feed: Vegetable peel and food scraps can be retained to feed small animals such as lamsters rabbit etc. Large meat bones will be greately reused by feeding dog.

Fire Wood: A small amount of waste disposal can be reused when it comes to refurnishing have or replacing furniture. before dicarding the furniture, cut it into more meaningful process and use as fire wood.

Electrical accessories: The items used in domestic and industrial electrical wiring are called electrical accessories. Example switch, holder, socket, plug top, ceiling rose, fuse etc. The electrical accessories are briefly explained in exercise no -1.14.87-89.

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

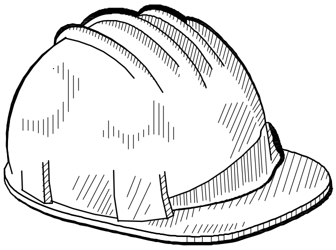
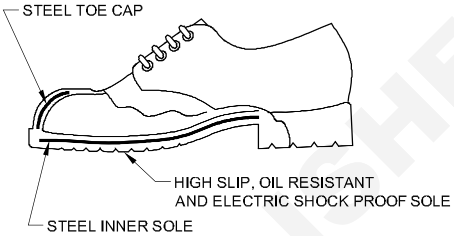
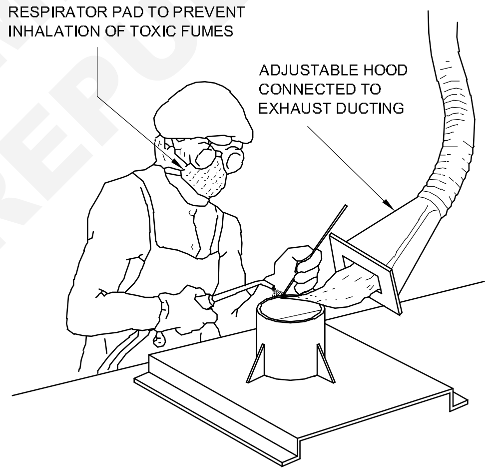
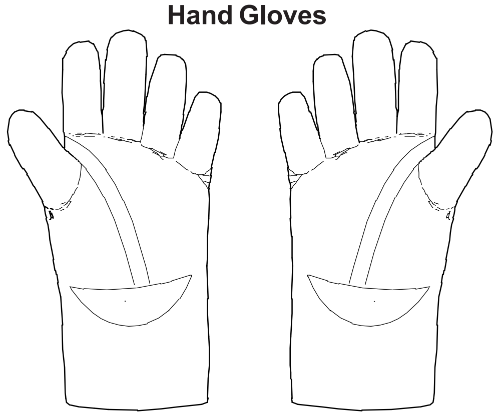
2 **Respiratory:** Those used for protection from harm due to inhalation of contaminated air.

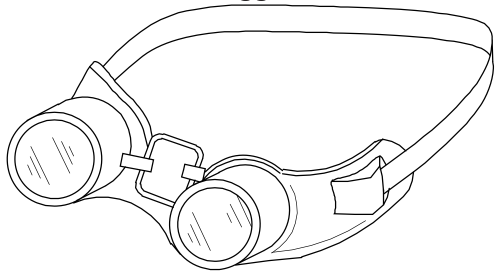
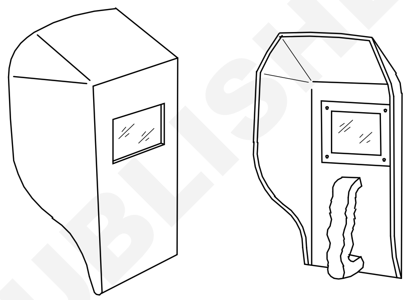
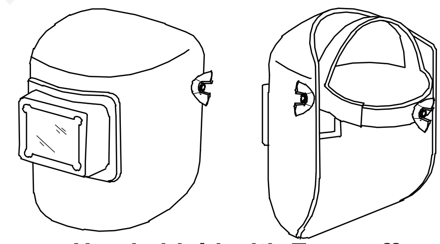
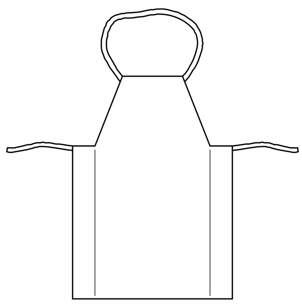
The guidelines on 'Personal Protective Equipment' is issued to facilitate the plant management in maintaining an effective programme with respect to protection of persons against hazards, which cannot be eliminated or controlled by engineering methods listed in table1.

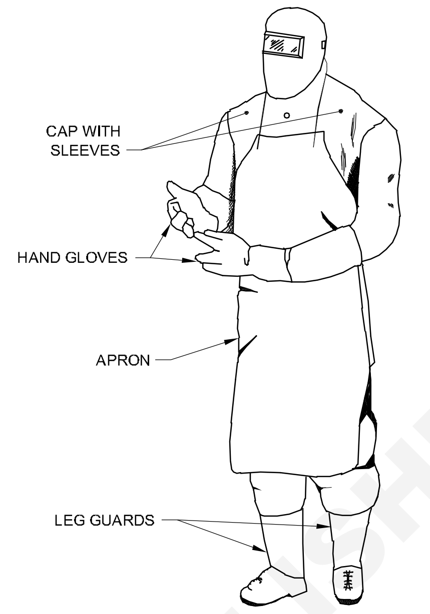
Table1

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

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 
Foot protection (Fig 2)	1. Hot spatter 2. Falling objects 3. Working wet area	Fig 2  INDUSTRIAL SAFETY SHOE
Nose (Fig 3)	1. Dust particles 2. Fumes/ gases/ vapours	Fig 3 **Nose Mask** 
Hand protecion (Fig 4)	1. Heat burn due to direct contact 2. Blows sparks moderate heat 3. Electric shock	Fig 4 **Hand Gloves**  GLOVES

Types of protection	Hazards	PPE to be used
Eye protection (Fig 5, Fig 6)	1. Flying dust particles 2. UV rays, IR rays heat and High amount of visible radiation	Fig 5 **Googgles** 
Face Protection (Fig 6, Fig 7)	1. Spark generated during Welding, grinding 2. Welding spatter striking 3. Face protection from UV rays	**Face Shield** **Head Shield with or without Ear Muff** **Helmets with screen for welders** Fig 6  HAND SCREEN
Ear protection (Fig 7)	1. High noise level	Fig 7  **Head shield with Ear muff**
Body protection (Fig 8, Fig 9)	1. Hot particles	Fig 8  APRON

Types of protection	Hazards	PPE to be used
		Fig 9  Body Guard

Quality of PPE's

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.

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.

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.

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.

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
- Illumination etc.,

2 Chemical hazards

- Inflammable
- Explosive

3 Biological hazards

- Bacteria
- Virus

4 Physiological

- Old age
- Sex
- Ill health
- Sickness
- Fatigue.

5 Psychological

- Wrong attitude
- Smoking
- Alcoholism
- Unskilled
- Emotional disturbances
  - voilence
  - bullying
  - sexual harassment

6 Mechanical

- Unguarded machinery
- No fencing

7 Electrical

- No earthing
- Short circuit
- No fuse or cut off device etc,

8 Ergonomic

- Poor manual handling technique
- Wrong layout of machinery
- Wrong design
- Poor housekeeping

Safety Slogan

A Safety rule breaker, is an accident maker

Response to emergencies

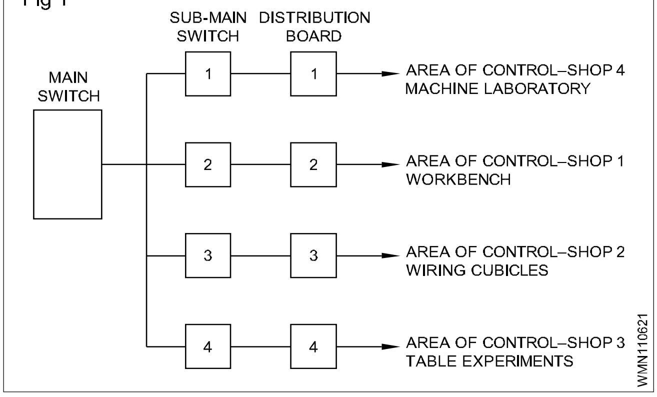
Objectives: At the end of this lesson you shall be able to
- **explain the term 'emergency'**
- **explain operation of electrical mains**
- **explain the need to switch off the circuit during emergency**
- **explain the method of locating the area, sub-main and main switches in the shop floor**
- **explain tools response during power and system failures.**

Emergency: An emergency is an unexpected occurrence and requires immediate action. In a place like a workshop such a situation can arise when fire occurs or a person gets a shock due to electrical current, or a person gets injured by the rotating part of a machine.

Operation of electrical circuits: In such situation, switching off the supply will be the first and best solution to avoid further damage to the victim. For this, every person involved in the workshop should know which switch controls the area and where the victim of shock remains.

Normally the total wiring in a workshop is controlled by a main switch and the different areas within the workshop may have two or more sub-main switches as shown in Fig 1.

Fig 1



To ascertain the area of the sub-main control, switch off one of the sub-main switches and try to switch 'on' the lights, fans and power points in that suspected area. If they do not work, then the area covered by the fan, light and power points are controlled by the sub-main switch. One after another, switch off the submain switches and locate their area of control. Mark the area of control of the switch in the plan of the electrical section.

In a well organised workshop, the main switch, the submain switches and distribution ways will have clear marking to show their area of control. (Fig 1) If this is not found, do this now. However, if you are not sure about the area of control of sub-main switches, it is always better to switch ‘off; the main switch itself.

Power failure: Power outages can be caused by a variety of circumstances. Emergency lighting is providing in all buildings for a brief period of time after power outages to allow for safe evacuation. Because emergency lighting is only available for a brief time, areas with no natural lighting will need evacuate immediately during an outage.

Be prepared

- Keep a flashlight with spare batteries immediately accessible
- Know how to locate the closet exit.

If a power outage occurs

- Remain calm
- Assess the extent of the outage in your area
- Help persons in darkened work areas move to safety
- Unplug personal computers and non-essential equipment, turn off light switches
- Open windows for additional light and ventilation
- **Do not light candles or other types of flames for lighting**
- If you are in an elevator that stops working, stay calm. The elevator should return to a predesignated floor and the doors will open automatically. Use the intercom or the emergency button inside the elevator to notify the University Emergency Operator in Facility Operations if you are not able to exit the elevator. Consult the elevator malfunction section for further information.
- If asked to evacuate, secure any hazardous materials if it is safe to do so and proceed directly to the designated Emergency Assembly Point (EAP) for the building you are in and check in. Consult Evacuation Procedures for additional information.

Emergency generators: Some buildings in campus are equipped with emergency generators that activate automatically in the event of an outage. If your building has a generator:

- Become familiar with the location of electrical outlets provided with emergency power
- Ensure that critical equipment is plugged in to emergency outlets
- Keep lab refrigerators/freezers closed during the outage

System failure: A system failure can occur because of a hardware failure or a severe software issue, causing the system to freeze, reboot, or stop functioning altogether. A system failure may or may not result in an error being displayed on the screen. The computer may shut off without warning and without any error message. If an error message is displayed, it often is displayed as a Blue Screen of Death error.

Notes: If your computer is failing without any errors, we suggest you start with our basic troubleshooting guide. If you are getting an error, try searching for it.

System failures may result from a hard drive with bad sectors, causing the operating system to not be able to read data from the hard drive. A failingmotherboard can cause a system failure because the computer is not able to process requests or operate in general. A bad processor can and usually causes a system failure because the computer cannot operate if the processor is not working properly or at all. A bad RAM chip can also cause system failures because the operating system is not able to access data stored on the RAM chip.

System failures due to software issues can occur if the issue in the software, such as a bad line of code, is severe enough. The system failure and subsequent computer shut down occurs as an attempt to prevent damage to other software or the operating system.

Concept of BIS/ISI

Advantage: Providing safe reliable quality goods, minimizing health hazard to consumer, promoting export and import substitute.

Control over proliferation of varieties etc. Through standardization, certification and testing.

Concept: BIS is responsible for the harmonious development activities of standardization, marking and quality certification of goods. Now BIS specifically addressing various national priorities and other government initiatives like Swacch Bharat Abhiyan, digital India. Make in India and case of doing business through it activities of standardization and certification.

To provide thrust to standardization and quality control of growth and development of industry on one hand and to meet the need of consumer on the other.

Introduction to 5S concept

5S is a system to reduce waste and optimize productivity through maintaining an orderly workplace and using visual aids to achieve more consistent operational result.

5S pillar

1 Sort (Seiri) - eliminating unnecessary item
2 Set in order (seiton) - arrange item for easy to use and to label them.
3 Shine (Seiso) - cleaning work area.
4 Standardise (Seiketsu) - maintain on first 3S.
5 Sustain (Shietsuke) making a habbit of properly maintaining correct procedure.

This 5 pillar provide a methodology for organizing, cleaning, developing and sustaining a productive work environment.

Standard and standardisation

Standardisation 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

Fitting tools - marking tools - specification - uses

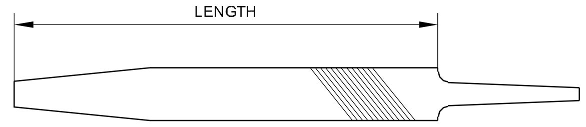
Objectives : At the end of this lesson you shall be able to
- **state the different types of files and their grades, shapes, specification and application.**
- **state the different cuts of files and their uses**
- **state the parts of file**

File : File is a filing tool, which is used to file the rough surface & smooth surface on metals

File specification: Files are specified according to their

- length
- grade
- cut
- shape

Fig 1



Length is the distance from the tip to the heel (Fig 1). It may be 300mm, 250mm, 200mm,150mm or 100mm.

Rough, bastard, second cut, smooth and dead smooth are the different **grades** of files commonly available.

A rough file is used for removing more quantity of metal quickly. (Fig 2a)

A bastard file is used for ordinary filing purposes. (Fig 2b)

A second cut file is used for good finishing purposes. (Fig 2c)

A smooth file is used for removing less metal and for giving good surface finish. (Fig 2d)

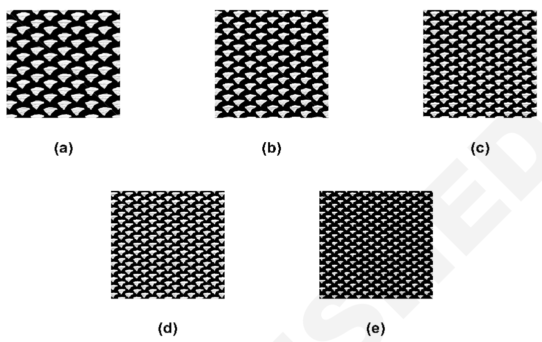
A dead smooth file is used for high degree finishing. (Fig 2e)

Cut of file: The rows of teeth determine the cut of a file.

Types of cut

Single cut, double cut, rasp cut and curved cut are the different types of cuts of files.

Fig 2



GRADES OF FILES

Parts of file

File : A file is a cutting tool with multiple cutting edges used for filing different materials.

Parts of a file (Refer Fig 3 below)

Tip or point: This is the end of the file opposite to tang.

Face or side: The broad part of the file with teeth cut on it.

Edge: The thin part of the file with a simple row of parallel teeth.

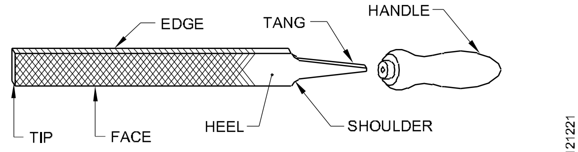
Heel: It is the broad part of the file without teeth.

Shoulder : It is the curved part of a file separating the tang from the body.

Tang: Narrow and thin part of a file which fits into the handle.

Handle: The part fitted to the tang to hold and use the file.

Fig 3



PARTS OF A FILE

Bench vice

Objectives: At the end of this lesson you shall be able to
- **name the parts and state the uses of a bench vice.**

Bench vice: Vices are used for holding workpieces. They are available in different types.

The vice used for bench work is the bench vice (Engineer's vice).

A bench vice is made of cast iron or cast steel, and it is used to hold work for filing, sawing, threading and other hand operations.

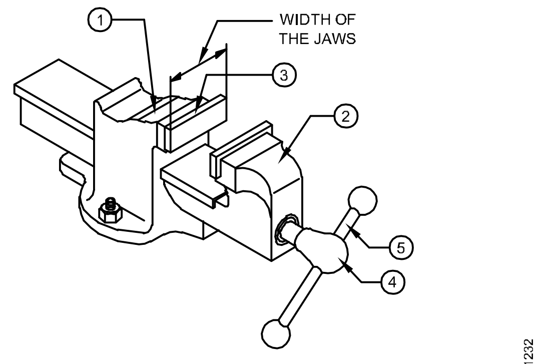
The size of the vice is stated by the width of the jaws.

Parts of a bench vice (Fig 1)

- Fixed jaw (1)
- Movable jaw (2)
- Hard jaw (3)
- Spindle (4)
- Handle (5)
- Box nut (6)
- Spring (7)

The box nut and the spring are the internal parts.

Fig 1



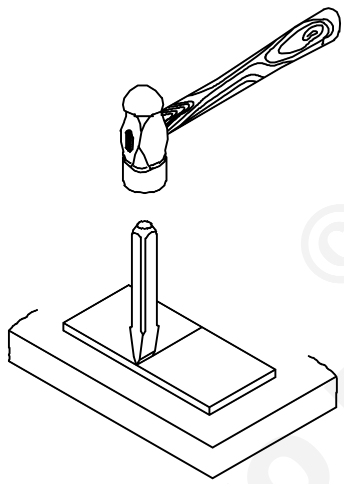
BENCH VICE

Hammer

Objectives: At the end of this lesson you shall be able to
- **state the uses of an engineer's hammer**
- **name the parts of an engineer's hammer and state their functions**
- **name the types of engineer's hammers with specifications**

Hammer: Engineer's hammer is a hand tool used for various striking purposes like punching, bending, straightening, chipping, forging and riveting. (Fig 1)

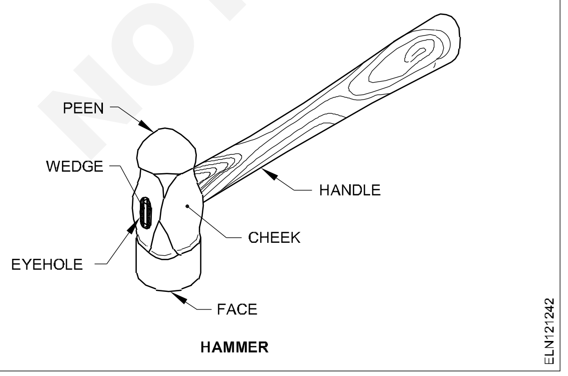
Fig 1



STRIKING WITH HAMMER

Major parts of a hammer (Fig 2)

Fig 2



HAMMER

- Head
- Handle

The head is made of drop-forged carbon steel, and the wooden handle must be capable of absorbing shock.

The parts of the hammer head are:

- face
- peen
- cheek
- eyehole

Before using a hammer:

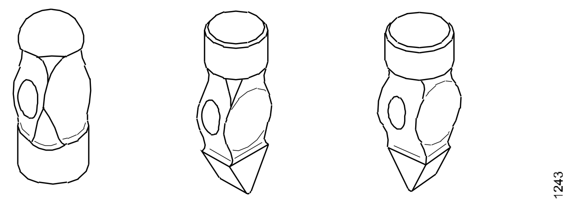
- make sure the handle is properly fitted
- select the correct weight of hammer suitable for the type of work
- ensure the face of the hammer is free from oil or grease.

Face: Face is the striking portion. A slight convexity is given to it, to avoid digging of the edge.

Peen: Peen is the other end of the head. It is used for shaping and forming work like riveting and bending. The peen is of different shapes. (Fig 3) They are:

- Ball peen
- Cross peen
- Straight peen

Fig 3



BALL PEEN   CROSS-PEEN   STRAIGHT PEEN

Chisel and hacksaw frame

Objectives: At the end of this lesson you shall be able to
- **list the uses of a cold chisel**
- **name the parts of a cold chisel and it's types**
- **state the different types of hacksaw frames, blades and their uses.**

The cold chisel is a hand cutting tool used by fitters for chipping and cutting operations.

Chipping is an operation of removing excess metal with the help of a chisel and hammer. The chipped surfaces being rough, they should be finished by filing.

Parts of a chisel (Refer Fig 1)

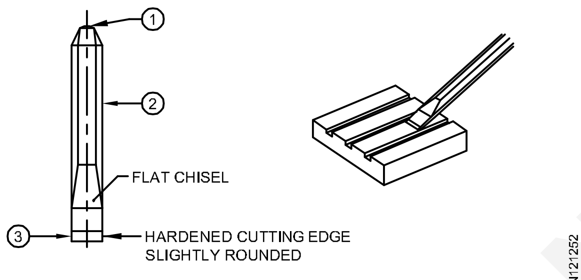
– Head (not hardened) (1)

– Body (2)

– Point or cutting edge (3)

Chisels are made from high carbon steel or chrome-vanadium steel. The cross-section of chisels is usually hexagonal or octagonal.

Fig 1



FLAT CHISEL

Common types of chisels

- Flat chisel
- Cross-cut chisel
- Half-round nose chisel
- Diamond point chisel

Flat chisels are used to:

- remove metal from large flat surfaces
- chip excess metal off from welded joints and castings

Hacksaw frame and blade

The hand hacksaw is used along with a blade to cut metals of different sections. It is also used to cut slots and contours.

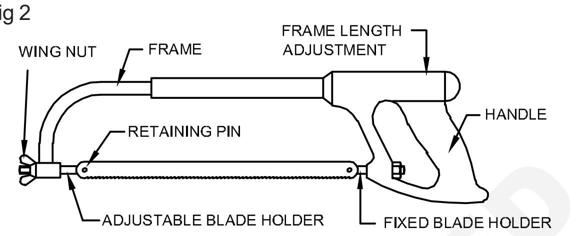
Types of hacksaw frames

Bold frame: Only a particular standard length of blade can be fitted.

Adjustable frame (flat)**:** Different standard lengths of blades can be fitted.

Adjustable frame tubular type (Fig 2)**:** This is the most commonly used type. It gives a better grip and control while sawing.

Fig 2



HACKSHAW FRAME

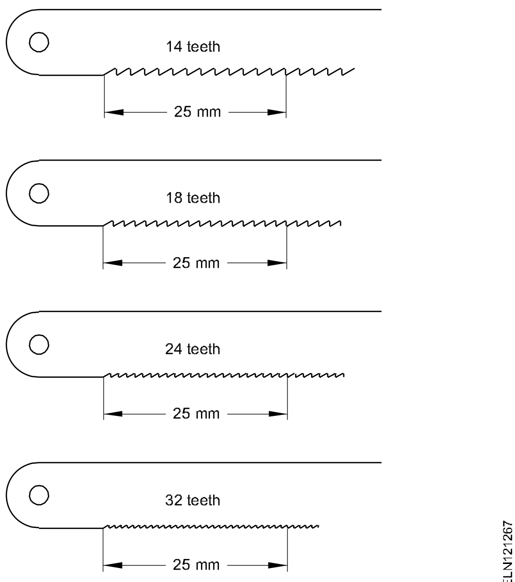
Hacksaw blades : The hacksaw blade is a thin, narrow, steel band with teeth and two pin holes at the ends. It is used along with a hacksaw frame. These blades are made of either low alloy steel (la) or high speed steel (hs) and are available in standard lengths of 250mm and 300mm.

For proper working, it is necessary to have frames of rigid construction.

Saw blades for hacksaws are available with small and large cutting of teeth, depending on the type and size of material they are to cut. The size of the teeth is directly related to their pitch, which is specified by the number of teeth per 25mm of the cutting edge. Hacksaw blades are avaialable in pitches of: (Fig 3)

- 14 teeth per 25 mm • 18 teeth per 25 mm
- 24 teeth per 25 mm • 32 teeth per 25 mm.

Fig 3



Carpenter tools - planes - wooden joints

Objective : At the end of this lesson you shall be able to
- **state about the timber.**

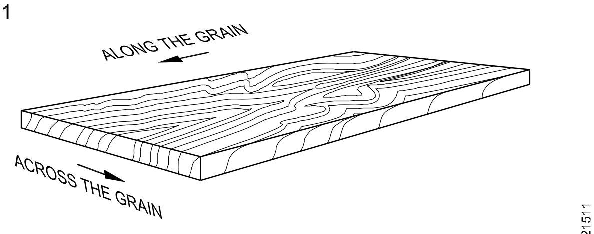
Timber is a raw material used for manufacturing wooden articles. Timber is a product of a tree.

Wood is made up of numerous tube like cells packed closely together. During the growth of the tree, these cells are positioned in a certain direction. The direction of these cells is referred to as the `grain'. The direction of the grain can be identified by the visible lines on the surface of the timber.

Any operation performed in the grain direction is called an operation `along the grain'. (Fig 1)

Any operation performed at right angle to the grain direction is called `across the grain'.

Fig 1



GRAIN DIRECTION IN WOOD

Any irregularity occuring in the timber is a defect in the timber. These defects in the timber reduce its strength, durability and utility value.

Marking and measuring tools

Objectives : At the end of this lesson you shall be able to
- **name the marking and measuring tools and their functions**
- **state the functions of straight edge, marking gauge and wooden folding rule**

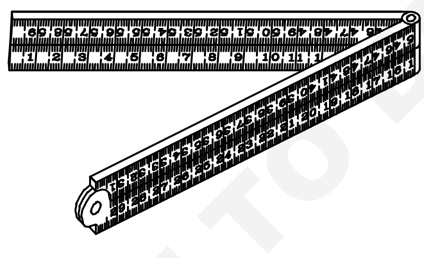
Marking and measuring tools are used in woodwork for marking, measuring and checking the work at various stages.

Common marking tools

- Wooden folding rule
- Steel rule

Wooden folding rule: A wooden folding rule is graduated both in centimetres and inches. The most commonly used is the two feet, 4-fold wood rule which is shown in Fig 1.

Fig 1



WOODEN FOLDING RULE

It is used for taking linear measurements, to an accuracy of 1 mm or 1/16th of an inch.

Steel rule : It is graduated in centimetres/inches with their subdivisions. The reading accuracy is 0.5 mm.

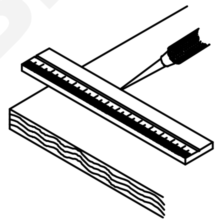
Common marking tools

They are:

- straight edge
- marking gauge
- try square.

Straight edge: It is made of steel with perfect straight and parallel edges. It is normally used for drawing straight lines on a job. It can also be used for testing flatness of a surface and straightness of an edge. (Fig 2)

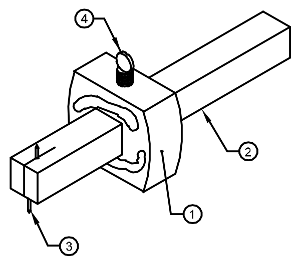
Fig 2



STRAIGHT EDGE

Marking gauge: It is a marking tool,consisting of (1)stock,(2)stem ,(3)spur and (4) thumb (locking) screw as shown in Fig 3.

Fig 3



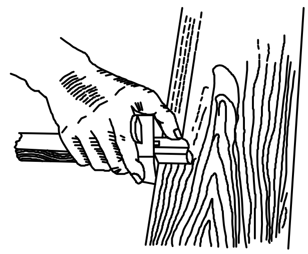
MARKING GAUGE

The stock can be adjusted over the stem to set the required distance between the spur and the face of the stock. The thumb screw is tightened to retain the measurement. The spur, a pointed steel, inscribes lines on the surface of the wood.

It is used for marking lines parallel to the face or edges. (Fig 4)

Try square : It is used for checking marking lines at right angles. It is also used for checking right angles and flatness of surfaces.

Fig 4

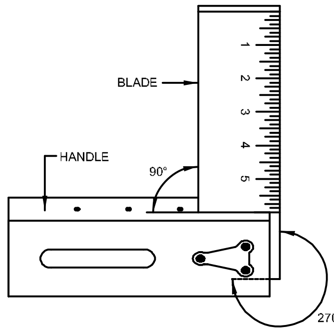


MARKING LINES WITH MARKING GAUGE

The parts of a try square are shown in Fig 5. It is available in different sizes, from 150 mm to 800 mm.

> **Remember: Keep these tools separately from the other tools to prevent damage.**
>
> **Avoid dropping or knocking them off the workbench.**

Fig 5



TRY SQUARE

Wood working saws

Objectives: At the end of this lesson you shall be able to
- **state the functions and use of a handsaw**
- **name the various holding tools and their application.**

The saws are used to cut the timber to the required shapes and sizes.

The saws most commonly used by an electrician are:

- handsaw
- tenon-saw.

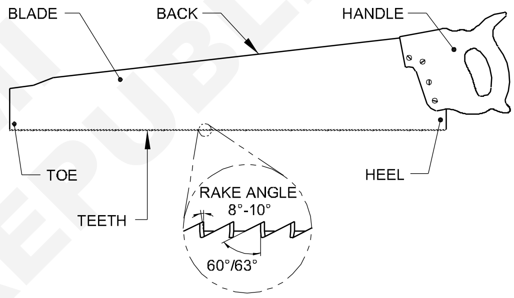
Handsaw: Figure 1 shows the parts of a handsaw. They are the handle and the blade.

Handle: It is generally made of wood.

Blade: It is made of tempered steel having teeth on the lower edge. The best quality saws are made from spring steel which decreases in thickness slightly from the teeth to the back.

The blade is about 66cm (26 inches) long, and normally has 2 1/4 teeth per cm (6tpi). The number of teeth of a handsaw varies up to 4 teeth per cm (10tpi).

Fig 1



RIP SAW/HANDSAW/PANEL SAW

A saw blade with less number of teeth per inch has bigger teeth. Therefore, it is used for rough work as it cuts quickly.

Bench planes

Objectives: At the end of this lesson you shall be able to
- **state the different types of planes and their functions.**

Planes are used for producing flat and smooth surfaces by taking off thin shavings of wood. Different types of planes are used for this purpose.

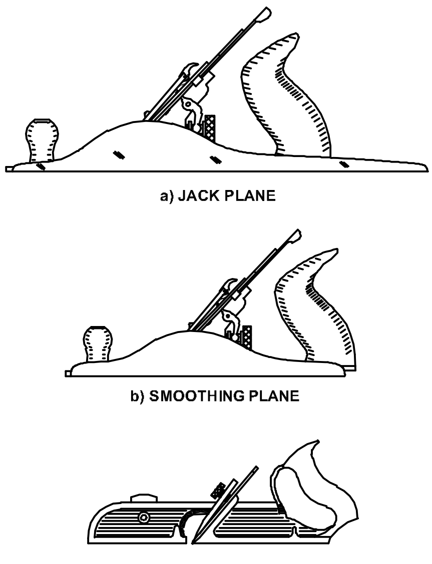
Types of planes

The most commonly available types of planes are:

- jack plane (Fig 1a)
- smoothing plane (Fig 1b)
- rebate plane. (Fig 1c)

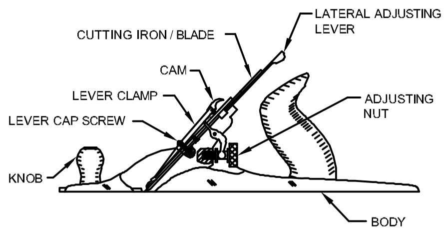
Jack plane: It is used for initial planing of timber to bring the size nearer to the required measurements. Its main parts are indicated in Fig 2.

Fig 1



TYPES OF PLANES

Fig 2



JACK PLANE

Half- lap joints - types - uses

Objectives: At the end of this lesson you shall be able to
- **state the necessity of lap joints**
- **state the types of lap joints.**

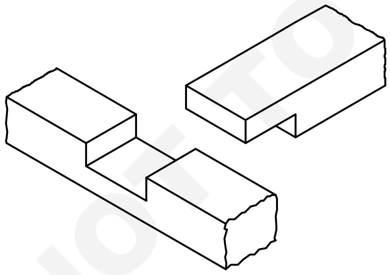
Necessity of lap Joint:

Half-lap joints are employed in frame construction where two parts of a job meet either near the ends or at a distance. To keep them flush, laps are made equal to half the thickness in each part. These joints are strengthened by fixing screws.

Types of half-lap joints

End-lap joint (Fig 1)**:** This joint is used where two parts of a job cross each other at the ends, say at the corners.

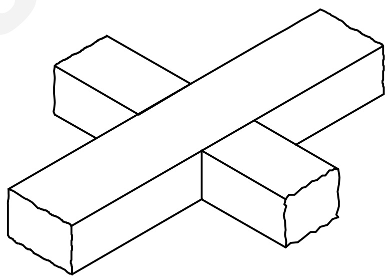
Fig 1



MIDDLE-LAP JOINT

Middle-lap joint (Fig 2)**:** This joint is used where one part of a job meets another part at some distance from the ends.

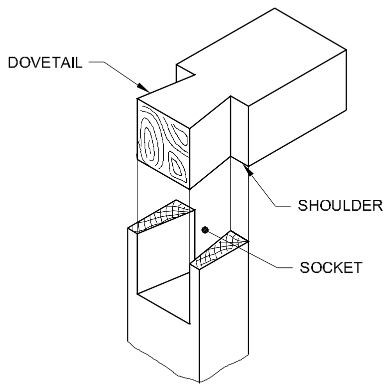
Fig 2



CROSS-LAP JOINT

Single dovetail Joint (Fig 3): This joint consists of only one dovetail filling into the dovetail socket in the second piece. A very strong joint used for narrow pieces such as brackets top, bottom rails of carcases etc.

Fig 3



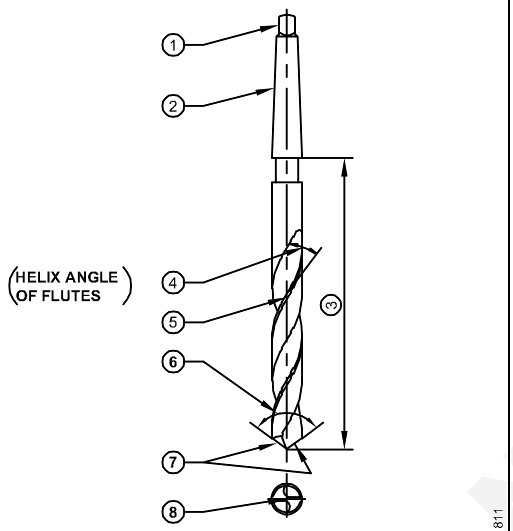
Drills and drilling machines - Internal and external threads

Objectives : At the end of this lesson you shall be able to
- **state the functions of drills**
- **name the parts of a drill**
- **name the drill bit holders.**

Drill: Drilling is a process of making holes on workpieces by using a drill.

Parts of a drill (Fig 1)

Fig 1



DRILL

- Tang (1)
- Shank (2)
- Body (3)
- Flute (4)
- Land (5)
- Point angle (6)
- Cutting lip (7)
- Chisel edge (8)

Tang: Tang is the part that fits into the slot of the drilling machine spindle.

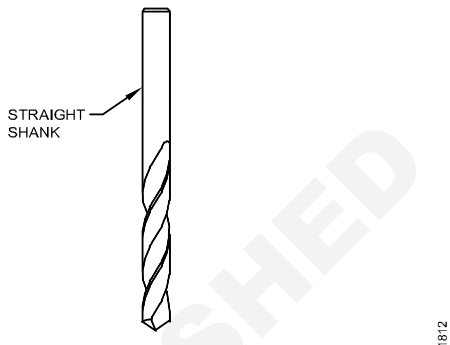
Shank: This is the driving end of the drill which is fitted on the machine. Shanks are of two types.

- Taper shank: for larger diameter drills. (Fig 3)
- Straight shank: for smaller diameter drills. (Fig 2)

The shank may be parallel or tapered.(Figs 2 and 3) Drills with parallel or straight shanks are made in small sizes, up to 12mm (1/2 in) diameter and the shank has the same diameter as the flutes.

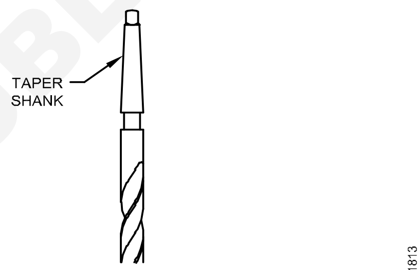
Taper shank drills are made in sizes from 3mm (1/8 in) diameter up to 50mm (2 in) diameter.

Fig 2



STRAIGHT SHANK DRILL

Fig 3



TAPER SHANK DRILL

Body: The body is the portion between the point and shank.

Flutes: Flutes are the spiral grooves which run to the length of the drill.

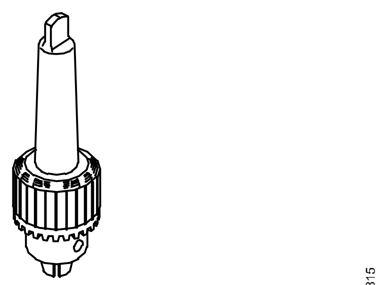
The flutes help:

- to form the cutting edges.
- to curl the chips and allow them to come out.
- the coolant to flow to the cutting edge.

Drill bit holder

Drill chuck: Drill chuck is attached to the main spindle for straight shank basis. (Fig 4)

Fig 4



DRILL CHUCK

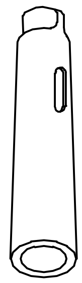
Sleeve: This is used to match bit tapers and the spindle taper holes. (Fig 5)

Socket: This is used when the main spindle length is too short, and the bit is changed frequently. (Fig 6)

Taper shank drills are held in taper sockets in the machine.(Fig 7)

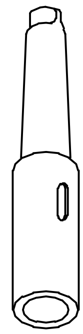
Use of a coolant: A coolant is used to cool the cutting tool and the job.

Fig 5



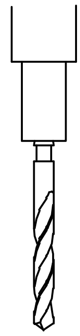
SLEEVE

Fig 6



SOCKET

Fig 7



TAPER SHANK DRILL

PARTS OF DRILL HOLDERS

ELN121816

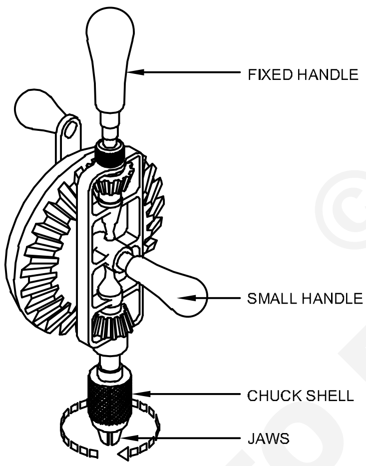
Drilling machines

Objectives: At the end of this lesson you shall be able to
- **state the types of hand drilling machines and their uses**
- **state the parts of bench drilling machine.**

It is necessary to drill holes when working with heavy material.

The holes can be drilled by hand or by machine. When drilling by hand, a hand drilling machine (Fig 1) or the electric hand drilling machine (Fig 2) is used.

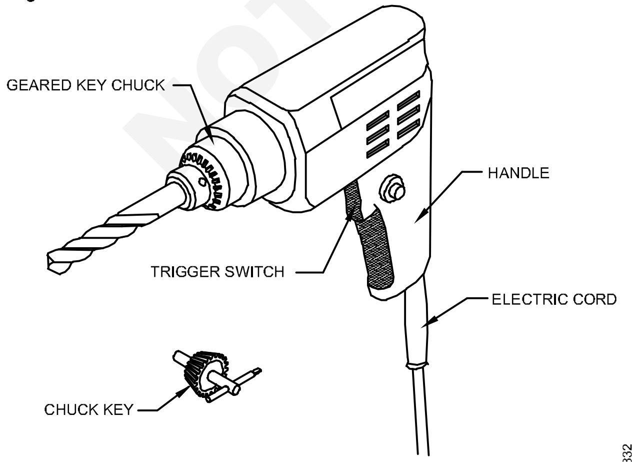
Fig 1



HAND DRILLING MACHINE

ELN121831

Fig 2



ELECTRIC - HAND DRILLING MACHINE

ELN121832

Twist drills are used as a cutting tool for drilling holes. The hand drill is used for drilling holes up to 6.5 mm diameter.

The portable electric hand drilling machine is a very popular and useful power tool. It comes in different sizes and capacities.

The handle shown in Fig 2 is called a pistol grip handle.

The parts of an electric hand machine are shown in Fig 2.

Precautions to be observed : Make sure the holes are properly located and punched with a centre punch.

Be sure the drill is properly centred in the chuck by turning (rotating).

Be sure the work is mounted properly in a holding device such as a vice or `G' clamp.

Types of Electric Drilling Machines: Some of the electric drilling machines are listed here.

- The sensitive bench dilling mchine
- The pillar drilling machine
- The radial arm drilling machine. (Radial drilling machine)

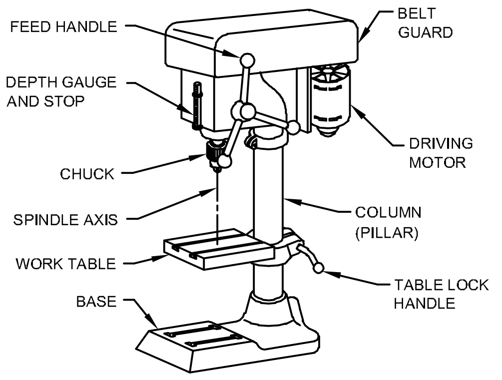
(As you are not likely to use the column and radial type of drilling machines now, only the sensitive type machine is explained here.)

Sensitive bench driling machine: The simplest type of sensitive bench drilling machine is shown in the with its various parts marked. This machine is used for light duty work. (Fig 3)

This machine is capable of drilling holes up to 12.5mm diameter. The drills are fitted in the chuck or directly in the tapered hole of the machine spindle.

For normal drilling, the work surface is kept horizontal. If the holes are to be drilled at an angle, the table can be tilted.

Fig 3



BENCH DRILLING MACHINE

ELN121841

Hand taps and wrenches

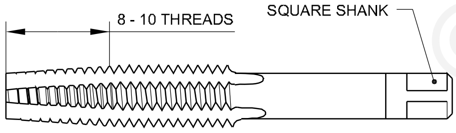
Objectives: At the end of this lesson you shall able to
• list the uses of hand taps
• state the different types of tap wrenches, and state their uses.

Taps: A tap cuts an internal (female) thread either left or right hand. Taps are usually made in sets of three.

- First tap or taper tap
- Second tap or intermediate tap
- Plug or bottoming tap.

The taper tap is tapered off for 8 to 10 threads and is used first, cutting to the full thread gradually. (Fig 1)

Fig 1

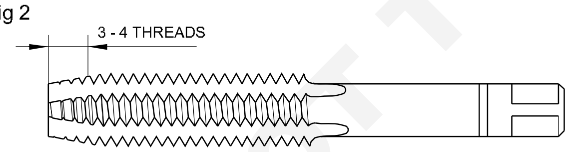


TAPER TAP (OR) 1ST TAP

ELN121881

The intermediate tap usually has three or four threads chamfered. This second tap can finish a through hole. (Fig 2)

Fig 2



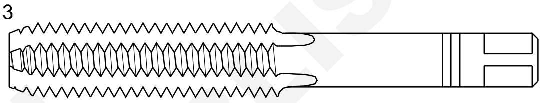
INTERMEDIATE TAP (OR) 2ND TAP

ELN121882

The plug tap has a full-sized untapered thread to the end, and is the main finishing tap. In the case of a blind hole, a plug tap must be used. (Fig 3)

Beware of the cutting edges of taps when handling them.

Fig 3



PLUG TAP (OR) BOTTOMING TAP

ELN121883

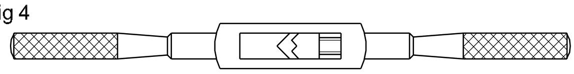
Tap wrenches: Tap wrenches are used to align and drive the hand taps correctly into the hole to be threaded.

Tap wrenches are of different types.

- Double - ended adjustable wrench
- T-handle tap wrench
- Solid type tap wrench

Double-ended adjustable tap wrench (Bar type tap wrench) (Fig 4)

Fig 4



DOUBLE ENDED ADJUSTABLE TAP WRENCH

ELN121884

This is the most commonly used type of tap wrench. These tap wrenches are available in various sizes. They are more suitable for large diameter taps, and can be used in open places where there is no obstruction to turn the tap. It is important to select the correct size of the wrench.

Tap drill size

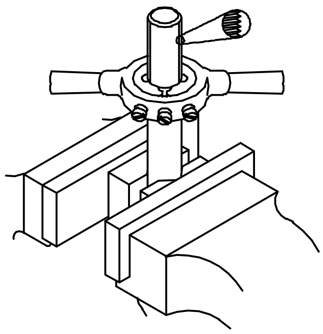
Before a tap is used for cutting internal threads, a hole is to be drilled. This hole diameter should be such that is should have sufficient material in the hole for the tap to cut the thread.

Die and die stock

Objectives: At the end of this lesson you shall be able to
- **state the use of die**
- **list the different types of dies.**

Uses of dies: Threading dies are used to cut external threads on cylindrical workpieces. (Fig 1)

Fig 1



EXTERNAL THREADING

ELN121891

Types of dies: The following are the different types of dies.

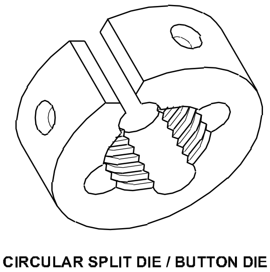
Circular split die (Button die)

Half die

Adjustable screw plate die

Circular split die\ button die (Fig 2)**:** This has a slot cut to permit slight variation in size.

Fig 2

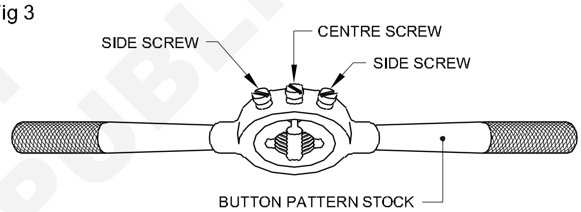


CIRCULAR SPLIT DIE / BUTTON DIE

ELN121892

When held in the diestock, variation in the size can be made by using the adjusting screws. This permits increasing or decreasing of the depth of cut. When the side screws are tightened the die will close slightly. (Fig 3) For adjusting the depth of the cut, the centre screw is advanced and locked in the groove. This type of die stock is called button pattern stock.

Fig 3



DIE STOCK & DIE FOR BUTTON DIE

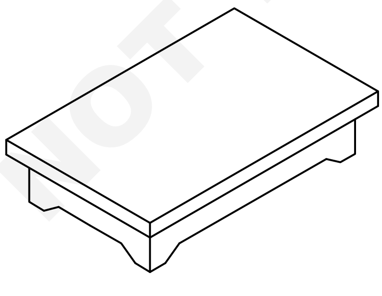
ELN121893

Marking accessories

Objectives : At the end of this lesson you shall be able to
- **state the uses of a surface plate**
- **state the uses of an angle plate.**

Surface plate (Fig 1)**:** This plate with a flat surface of great accuracy is used for testing the flatness of other surfaces together with other instruments for measuring, testing and marking out purposes.

Fig 1



SURFACE PLATE

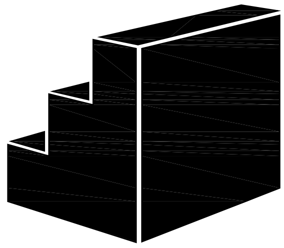
ELN1218C2

The surface plate is usually made of cast iron or granite.

Angle plate: It is made of cast iron. Granite angle plates are also available.(Fig 2)

It is used as a fixture for holding the work to be laid out and machined. Faces are right angles, may have slots and may be fitted with clamps for holding workpieces. (Fig 3)

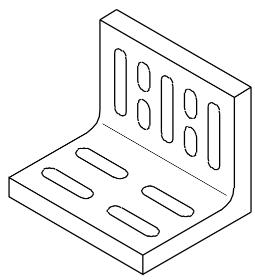
Fig 2



GRANITE ANGLE PLATE

ELN1218C3

Fig 3



CAST IRON ANGLE PLATE

ELN1218C4

Thread gauge

Objectives: At the end of this lesson you shall be able to
- **state the purpose of a screw pitch gauge**
- **state the features of a screw pitch gauge.**

Purpose

A screw pitch gauge is used to determine the pitch of a thread.

It is also used to compare the profile of threads.

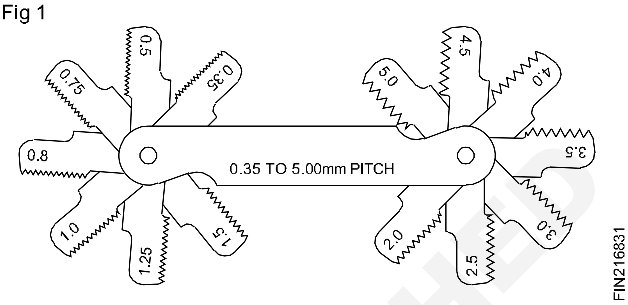
Constructional features

Pitch gauges are available with a number of blades assembled as a set. Each blade is meant for checking a particular standard thread pitch. The blades are made of thin spring steel sheets, and are hardened.

Some screw pitch gauge sets will have blades provided for checking British Standard threads (BSW, BSF etc.) at one end and the metric standard at the other end.

The thread profile on each blade is cut for about 25 mm to 30 mm. The pitch of the blade is stamped on each blade. The standard and range of the pitches are marked on the case. (Fig 1)

Fig 1



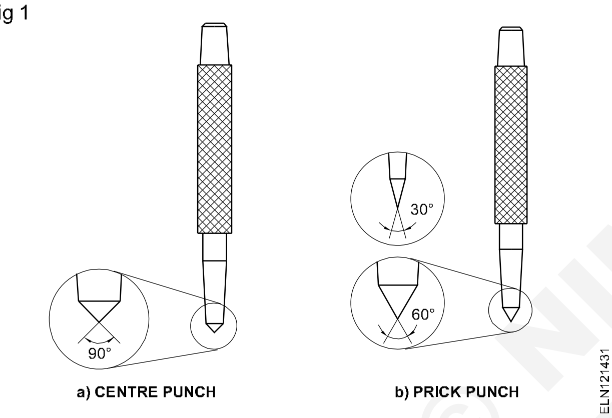
Marking tools - punches - calipers - scriber, divider

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.

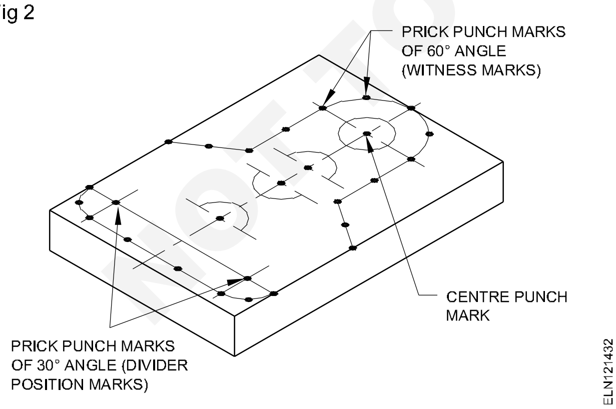
Centre punch: The angle of the point is 90°. The punch mark made by this is wide and not very deep. This punch is used for locating holes. The wide punch mark gives a good seating for starting the drill. (Figs 1a)

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



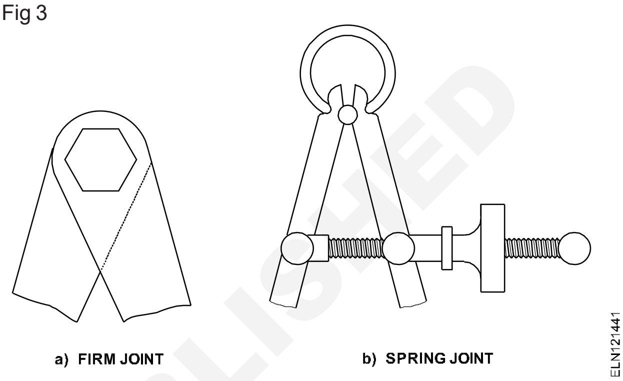
Types of calipers

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

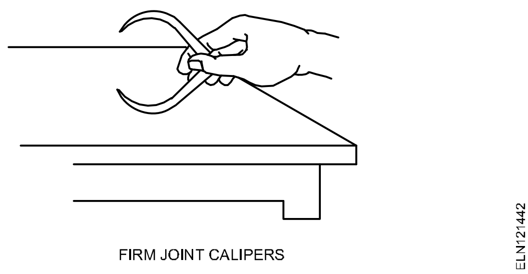
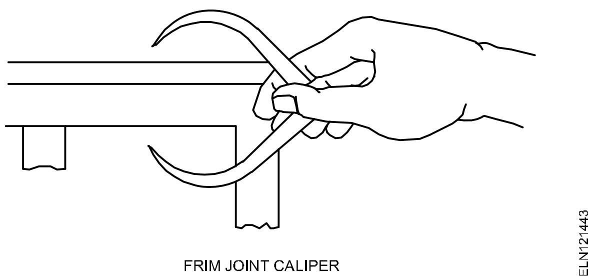


Fig 5



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.

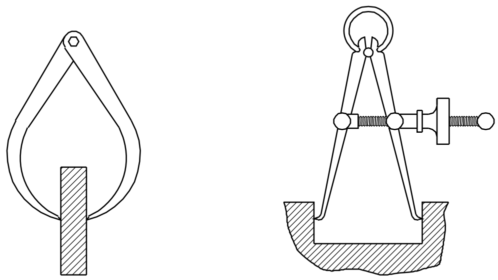
Spring calipers have the advantage of quick setting. The setting made will not change unless the nut is turned. Caliper sizes are specified by the length which is the distance between the pivot centre and the tip of the leg.

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



a) OUTSIDE CALIPERS b) INSIDE CALIPERS

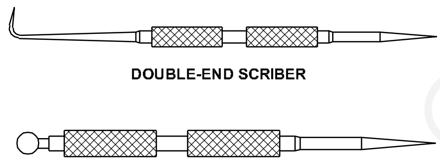
ELN121444

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



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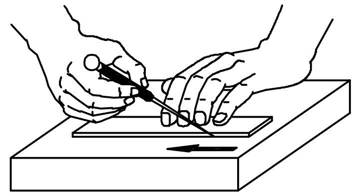
Uses: Used for scribing lines on the metal being laid out. (Fig 8)

Fig 8



SCRIBING LINES

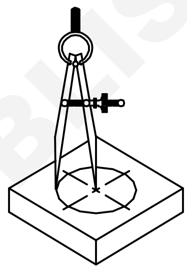
ELN121472

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



SCRIBING CIRCLES

ELN121473

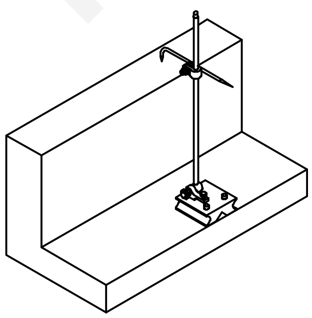
Universal surface gauge

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

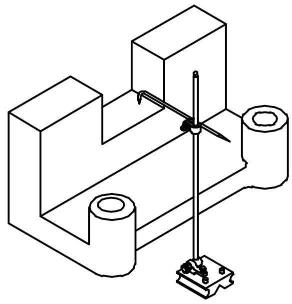


JOB SETTING ON MACHINE

ELN121491

- 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



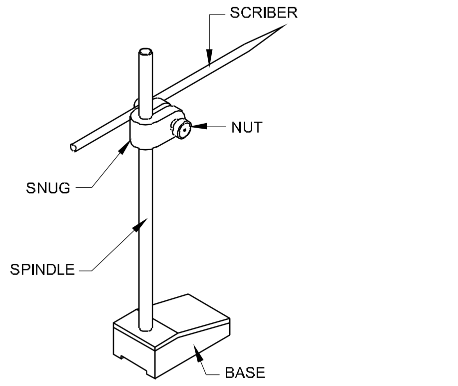
JOB SETTING ON MACHINE

ELN121492

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

- Fixed Surface gauge (Fig 3)

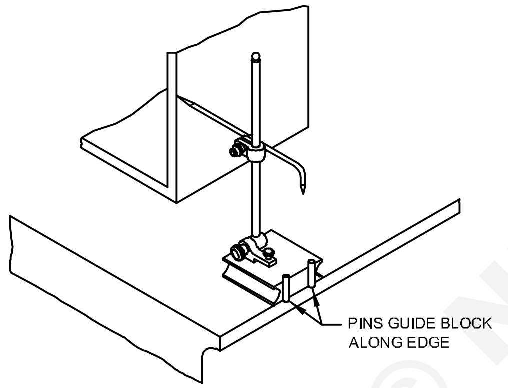
Fig 3



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)

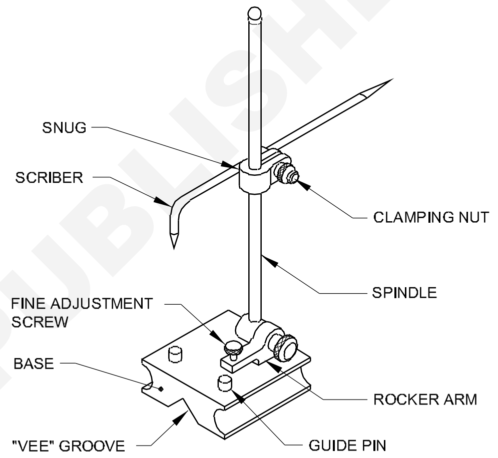
Base: The base is made of steel or cast iron with a `Vee' groove at the bottom. The `Vee' helps to seat on the circular work. The guide pins fitted in the base are helpful for scribing lines from any datum edge.

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

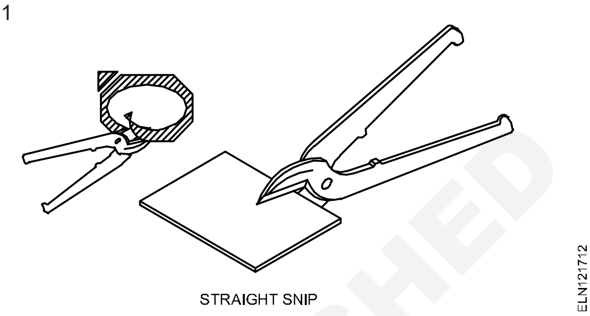
Snips: A snip is a cutting tool and is used for cutting thin sheets of metal.

There are two types of snips.

- Straight snips
- Bent snips

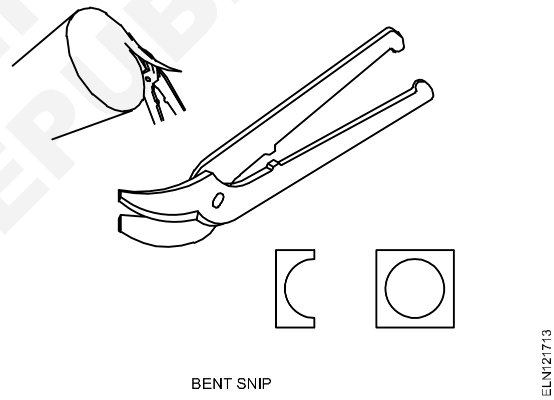
Straight snips: A straight snip has straight blades for straight line cutting. It can also be used for external curved cuts. (Fig 1)

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 2



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.

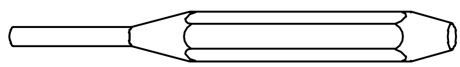
- Solid cold punch
- Hollow cold punch

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)

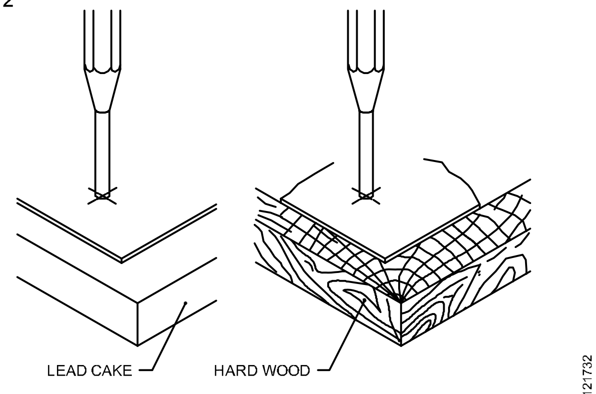
Fig 1



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

Folding tools

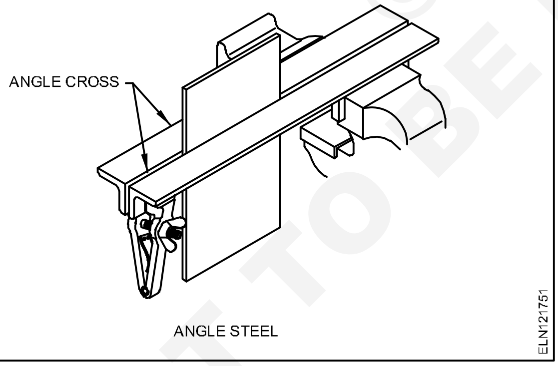
Objectives: At the end of this lesson you shall able to
- **list out the different folding tools**
- **state the uses of folding tools.**
- **state the types of notches and their uses**
- **state the types of hem and their application**

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

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

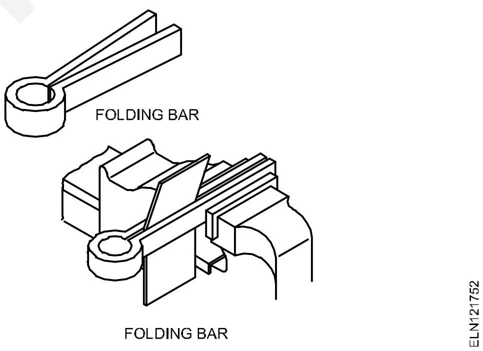
Angle steel: Two pieces of angles are used for folding at 90°. For longer sheets lengthy angles will be used along clamp (or) hand vice. (Fig 1)

Fig 1



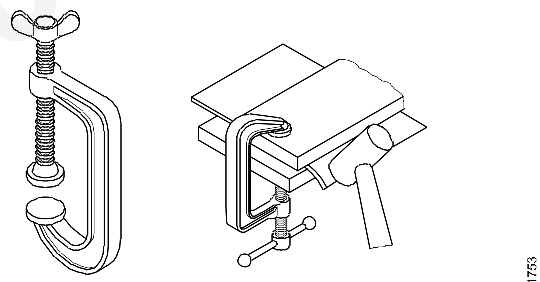
Folding bar: The sheet metal to be bent is clamped in the folding bars. The folding bars are clamped in the vice as shown in the figure. (Fig 2)

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 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.

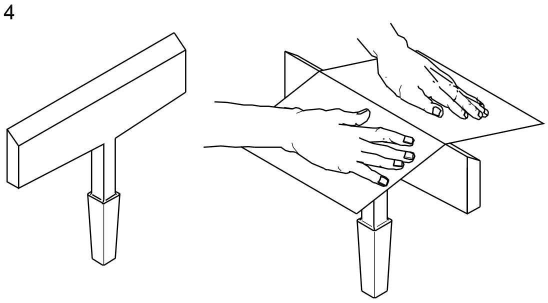
Types of stakes

- 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)

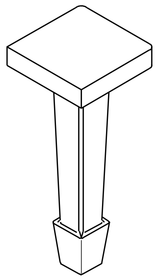
Square stake: A square stake has a flat and square-shaped head with a long shank. It is used for general purposes. (Fig 5)

Fig 4



HATCHET STAKE

Fig 5



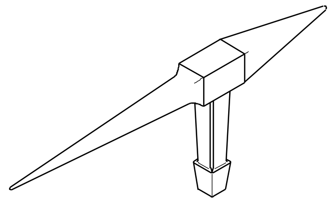
SQUARE STAKE

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)

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

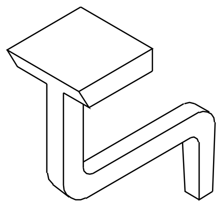
Mallet: A mallet is used for working on sheet metal. It will not damage the sheet surface while working. Mallets are made of wood, rubber, copper etc.(Fig 8)

Fig 6



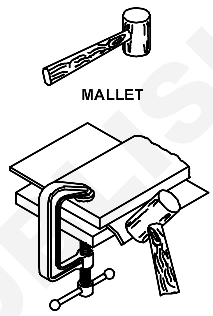
BLOW HORN STAKE

Fig 7



BEVEL-EDGED SQUARE STAKE

Fig 8



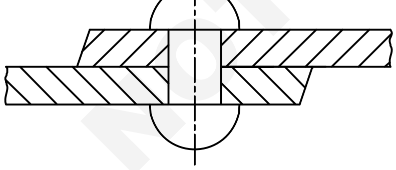
USE OF MALLET

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



RIVET

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.

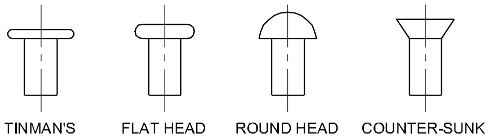
Material: In riveting, the rivets are secured by deforming the shank to form the head. These are made of ductile materials like low carbon steel, brass, copper and aluminium.

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.

Fig 2



TYPES OF RIVETS

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

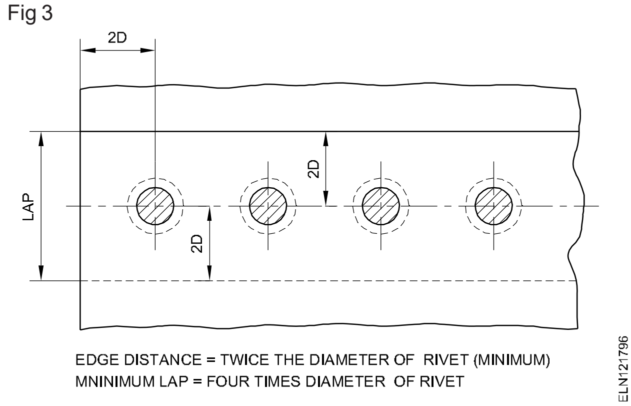
Sizes of rivets: Sizes of rivets are determined by the diameter and length of the shank.

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

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.

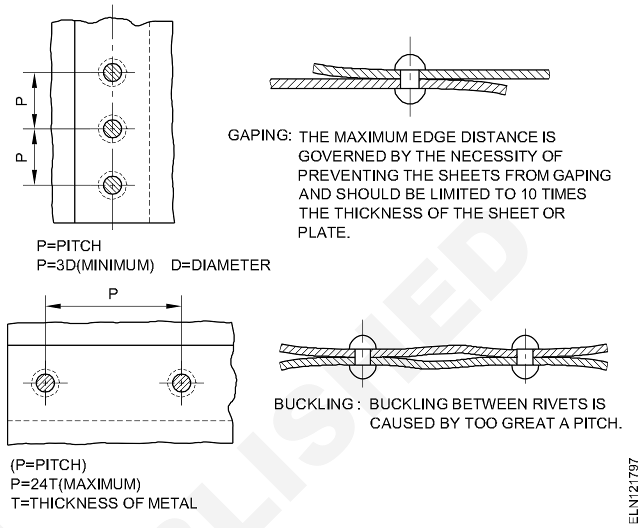
Fig 3



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.

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



Hand tools - specification

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

It is important that the wireman 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 wireman will find the working efficiency increases and the skills becomes a work habit.

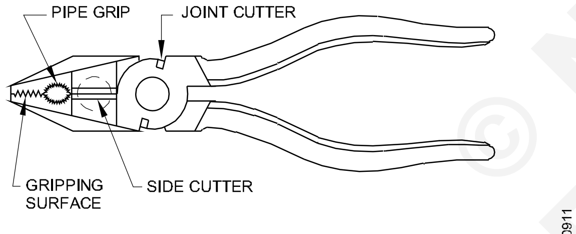
Listed below are the most commonly used tools by wireman.

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



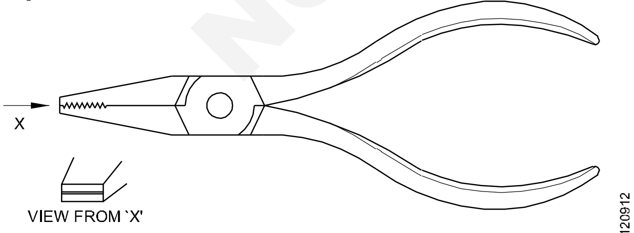
COMBINATION SIDE CUTTING PLIERS (ENGINEER'S PLIERS, COMBINATION PLIERS)

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

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

3 **Side cutting pliers** (Diagonal cutting pliers) BIS 4378 (Fig 3) Size 100 mm, 150 mm etc.

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

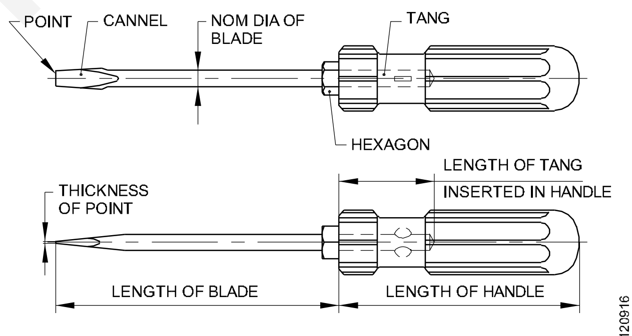
Fig 3

DIAGONAL CUTTING PLIERS/NIPPER

4 **Screwdriver BIS 844 (Fig 4)**

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.

Fig 4



NOMENCLATURE FOR SCREWDRIVERS

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 screw driver: It is used for driving star headed screws.

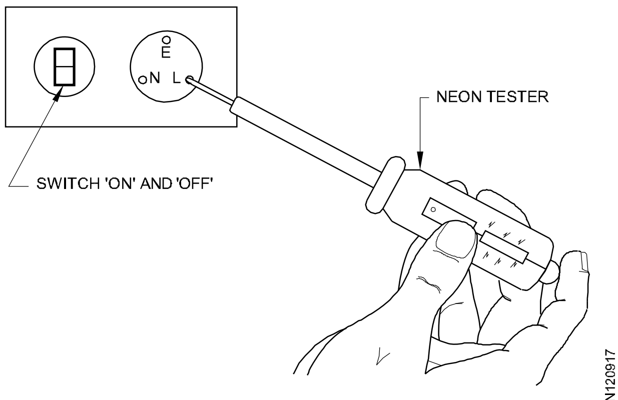
Care and maintenance

- 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.

5 Neon tester BIS 5579 - 1985 (Fig 5)

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

Fig 5



NEON TESTER

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.

Care and maintenance

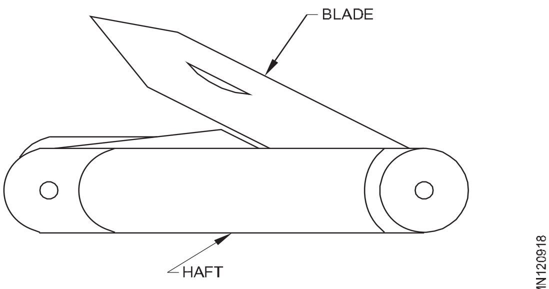
- Never use the neon tester for voltage higher than the specified range.
- While testing see the circuit is completed through the body.

6 Electrician's knife (Double blade) (Fig 6)

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.

Fig 6



ELECTRICIAN'S KNIFE

Care and maintenance

- Do not use the knife for cutting wires.
- Fold the knife blade when not in use.

7 Try-square (Engineer's square) (Fig 7) BIS 2103

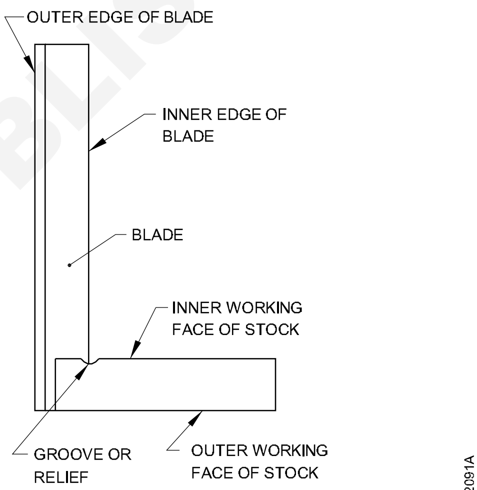
This is specified by its blade length.

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.

Fig 7



TRY-SQUARE

8 Firmer chisel (Fig 8)

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

- Use mallet for chiseling.
- Grind on a water stone and sharpen on an oilstone.

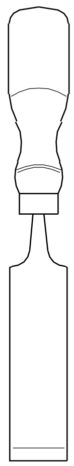
9 Tenon-saw (Fig 9) BIS 5123, BIS 5130, BIS 5031

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

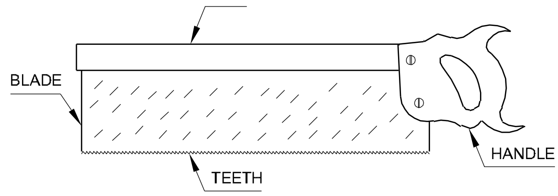
- Keep free from rust.
- Apply grease when not in use.

Fig 8



FIRMER CHISEL

Fig 9

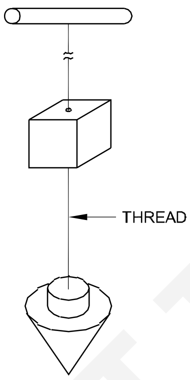


TENON-SAW

10 Plumb bob (Fig 10)

It has a pointed tip with a centre hole at the top for attaching a string as shown in Fig 15. It is used for checking the vertical alignment of the wall.

Fig 10



PLUMB BOB

Care and maintenance

- String to be changed in a period of time intervals.

11 Bradawl square pointed (or poker) (Fig 11) BIS 10375 - 1982

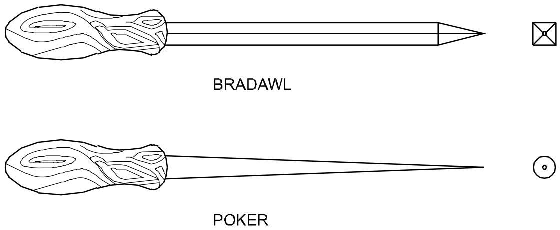
It is specified by its length and diameter eg. 150 mm x 6 mm.

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.

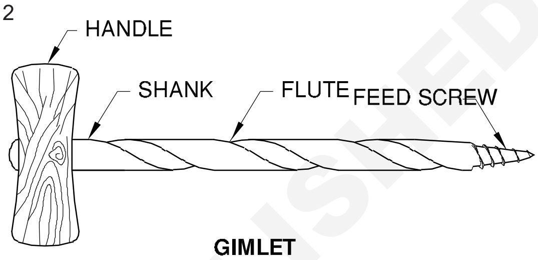
Fig 11



12 Gimlet (Fig 12)

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.

Fig 12



GIMLET

Care and maintenance

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

13 Mallet (Fig 13)

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

eg. 50 mm x 150 mm

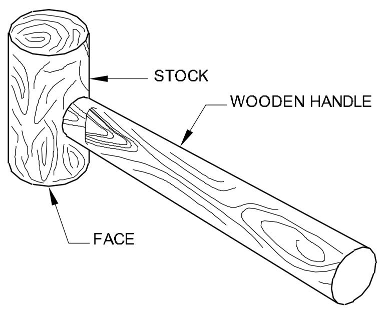
75 mm x 150 mm or 500gms, 1 Kg.

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 for coil winding alignment.

Care and maintenance

- Do not use it for fixing nails.

Fig 13



MALLET

14 Flat cold chisel (Fig 14) BIS 402

Its size is given by the nominal width and length.

ie. 14 mm x 100 mm

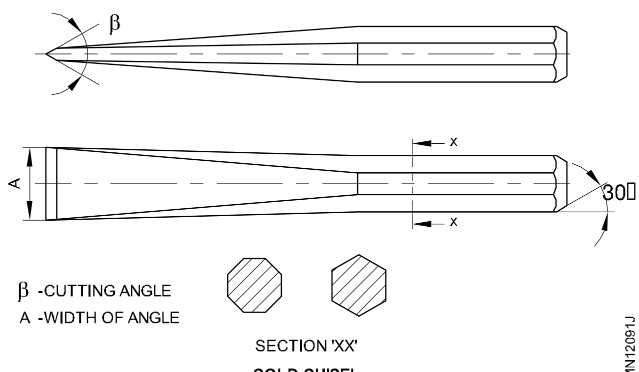
15 mm x 150 mm

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.

Fig 14



COLD CHISEL

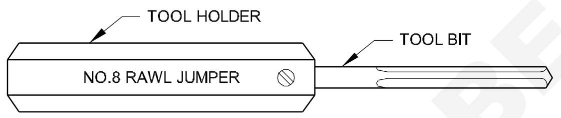
Care and maintenance

- 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.

15 Rawl plug tool and bit (Fig 15)

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.

Fig 15



RAWL PLUG TOOL

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.
- Keep its head free from mushrooms.

16 Spanner: double ended (Fig 16) BIS 2028

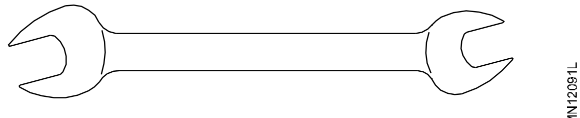
The size of a spanner is indicated so as to fit on the nuts. They are available in many sizes and shapes.

The sizes, indicated in double-ended spanners are the distance between two jaws of a side.

10-11 mm	12-13 mm	14-15 mm
16-17 mm	18-19 mm	20-22 mm
21-23 mm		

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

Fig 16

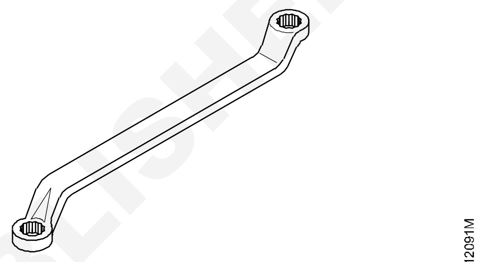


DOUBLE ENDED OPEN JAW SPANNER

17 Ring spanner set (Fig 17) BIS 2029

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

Fig 17

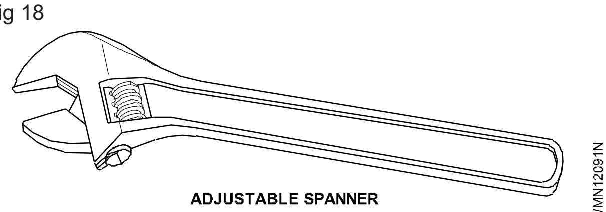


RING SPANNER

18 Single ended open jaw adjustable spanner (Fig 18) 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.

Fig 18



ADJUSTABLE SPANNER

Care and maintenance

- Use correct size spanner suitable to the size of nut and bolt.
- Prevent the grease and oil traces on its jaws.

19 Measuring steel tape (Fig 19)

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

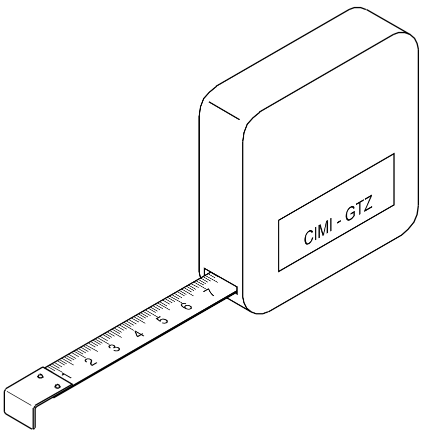
The measuring tape is made of thin steel blade, bearing dimensions on it.

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.

Fig 19



MEASURING STEEL TAPE

WMN12091O

20 Pincers (Fig 20) BIS 4195

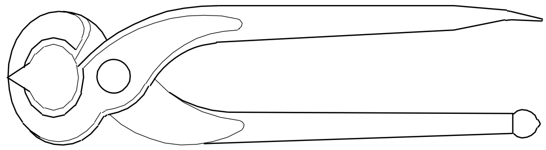
The size is given by its length. Eg. 100 mm, 150 mm, 200 mm.

It is used for extracting nails from the wood.

Care and maintenance

- Do not use it as a hammer.

Fig 20



PINCERS

WMN12091Q

Introduction to National Electrical Code - 2011 - Conductors - Insulators - Wires - Types - Size measurements

Objective: At the end of this lesson you shall be able to
- **read and interpret basic concepts of National Electrical code 2011.**

National Electrical Code - 2011

National electrical code describes several indian standards 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 electrical item/ devices, equipment etc.

Here, 20 sections of the part - 1 is 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.

Properties of conductors - insulators and semi-conductors, SWG, micrometer

Objectives: At the end of this lesson you shall be able to
- **state the differentiate between conducting and insulating materials**
- **state the types and propertites of insulating materials.**
- **describe the method of measurement of wire size using SWG**
- **explain the method of measuring wire size by outside micrometer.**

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.

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.

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.

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.

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 Wireman 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.

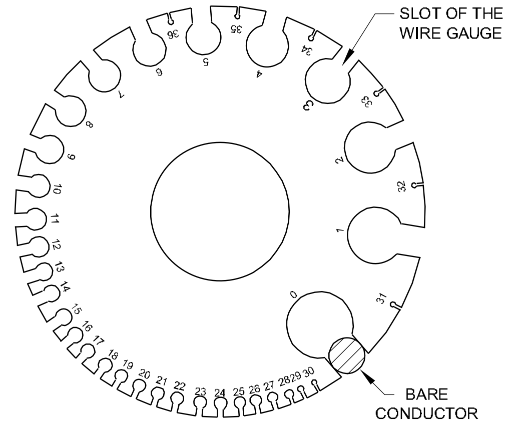
To measure the size of conductors, a Wireman can use normally a standard wire gauge or an outside micrometer for more accurate results.

Standard Wire Gauge (SWG)

The size of the conductor is given by the standard wire gauge number. According to the standards each number has an assigned diameter in inch or mm. The standard wire gauge, shown in Figure 1 could measure the wire size in SWG numbers from 0 to 36. It should be noted that the higher the number of wire gauge the smaller is the diameter of the wire.

For example, SWG No. 0 (zero) is equal to 0.324 inch or 8.23 mm in diameter whereas SWG No.36 is equal to 0.0076 inch or 0.19 mm in diameter.

Fig 1



STANDARD WIRE GAUGE

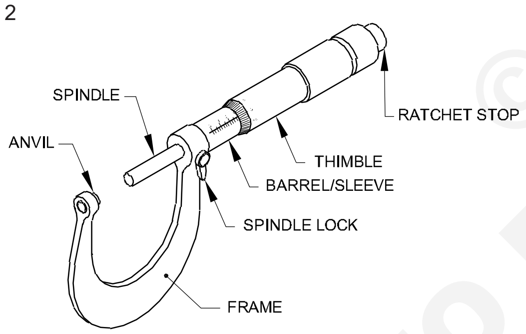
WMN131611

While measuring the wire, the wire should be cleaned and then inserted into the slot of the wire gauge to determine the SWG number. The slot in which the wire just slides in is the correct slot and the SWG number could be read in the gauge directly. In most of the wire gauges to save the trouble of referring to the table, the wire diameter is inscribed on the reverse of the gauge.

Measurement of wire size by outside micrometers: A micrometer is a precision instrument used to measure a job, generally within an accuracy of 0.01 mm.

Micrometers used to take the outside measurements are known as outside micrometers. (Fig 2)

Fig 2



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The parts of a micrometer

- Frame
- Barrel/sleeve
- Thimble
- Spindle
- Anvil
- Spindle lock-nut
- Ratchet stop

Principle of the micrometer

The micrometer works on the principle of screw and nut. The longitudinal movement of the spindle during one rotation is equal to the pitch of the screw. The movement of the spindle to the distance of the pitch or its fractions can be accurately measured on the barrel and thimble.

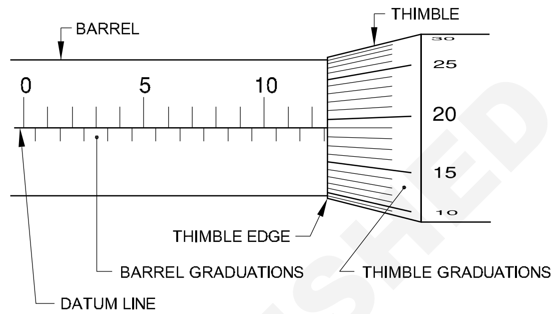
Graduations

In metric micrometers the pitch of the spindle thread is 0.5mm.

Thereby, in one rotation of the thimble, the spindle advances by 0.5 mm.

In a 0-25 mm outside micrometer, on the barrel a 25 mm long datum line is marked. (Fig 3) This line is further graduated in millimetres and half millimetres (ie. 1 mm & 0.5 mm). The graduations are numbered as 0, 5, 10, 15, 20 & 25 mm on the barrel.

Fig 3



WMN131614

The circumference of the bevel edge of the thimble is graduated into 50 divisions and marked 0-5-10-15... 45-50 in a clockwise direction.

The distance moved by the spindle during one rotation of the thimble is 0.5 mm.

Movement of one division of the thimble

= 0.5 x 1/50 = 0.01 mm.

This value is called the least count of the micrometer.

The accuracy or least count of a metric outside micrometer is 0.01 mm.

Outside micrometers are available in ranges of 0 to 25 mm, 25 to 50 mm, and so on. For electrician, to read the size of the wire 0 to 25 mm is only suitable.

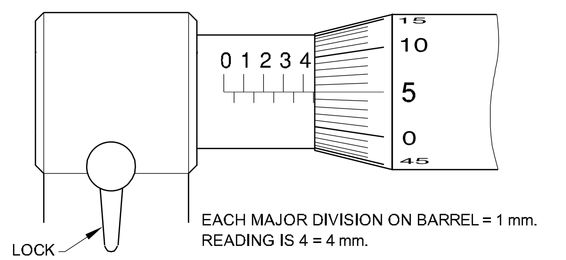
Reading micrometer measurements

How to read a measurement with an outside micrometer?

a Read on the barrel scale, the number of whole millimetres that are completely visible from the bevel edge of the thimble. It reads 4 mm. (Fig 4)

b Add to this any half millimetre that is completely visible from the bevel edge of the thimble and away from the whole millimetre reading.

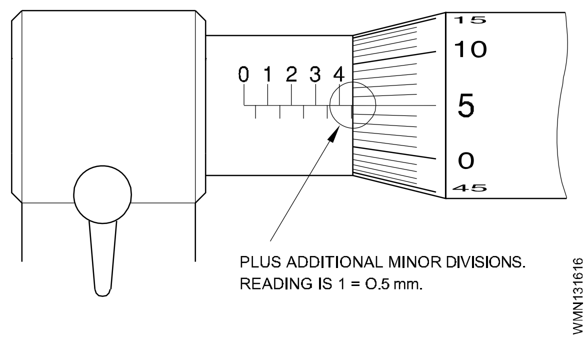
Fig 4



WMN131615

The figure reads one division (Fig 5) mm after the 4 mm mark. Hence 0.5 mm to be added to the previous reading.

Fig 5



c Add the thimble reading to the two earlier readings.

The figure shows the 5th division of the thimble is coinciding with the datum line of the barrel. Therefore, the reading of the thimble is 5 x 0.01 mm = 0.05 mm. (Fig 6)

The total reading of the micrometer.

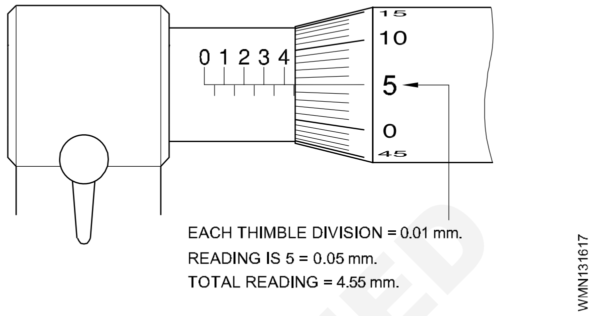
a 4.00 mm

b 0.50 mm

c 0.05 mm.

Total reading = 4.55 mm (Fig 6)

Fig 6



Fundamental of electricity term, effect of electric current and joints

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 effects of electric current.**

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.

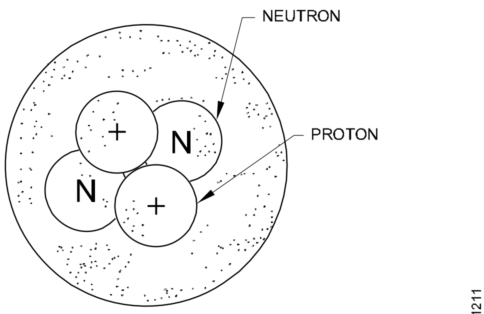
Basically, an atom contains three types of sub-atomic particles that are of relevance to electricity. They are the electrons, protons and neutrons. The protons and neutrons are located in the centre, or nucleus, of the atom, and the electrons travel around the nucleus in orbits.

Atomic structure

The Nucleus (Fig 1)

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

Fig 1



NUCLEUS OF AN ATOM

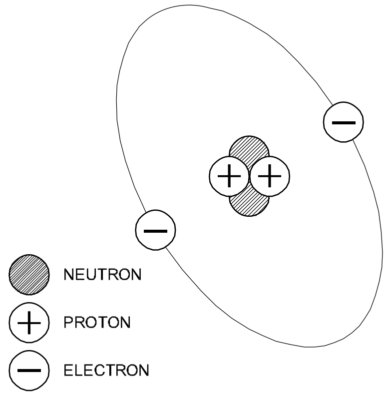
Protons

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.

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



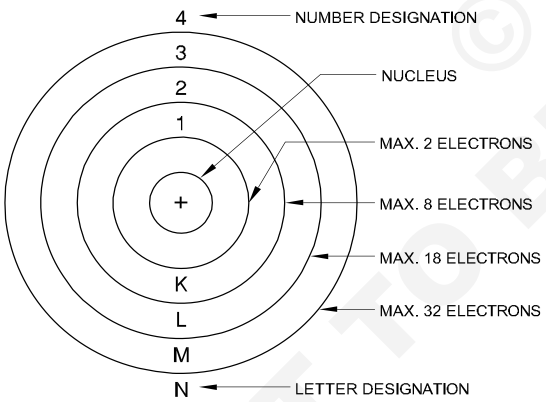
Neutron

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.

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

Fig 4

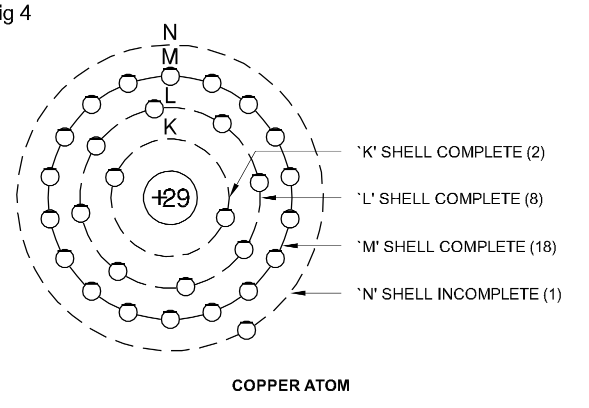
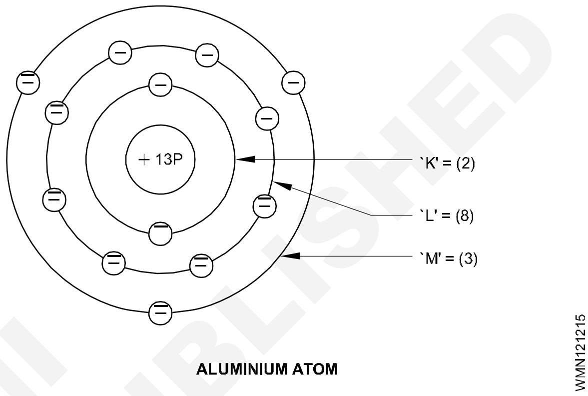


Fig 5



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.

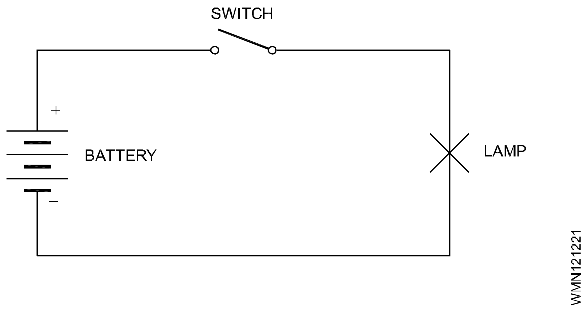
Fundamental terms

Objectives: At the end of this lesson you shall be able to
- **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.**

Electric current

Flow of electric current is nothing but the flow of free electrons also called as electric current. 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. (Fig 1)

Fig 1



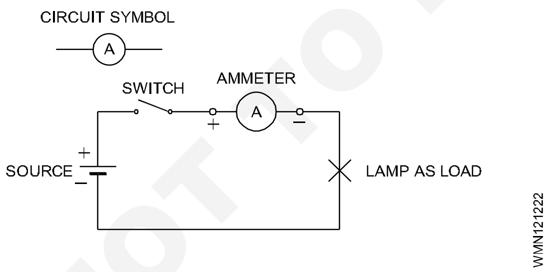
Ampere

The unit of current (abbreviated as I) is an ampere (symbol A). If 6.24×10^{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. It should be connected in series with the resistance (Load). (Fig 2)

Fig 2

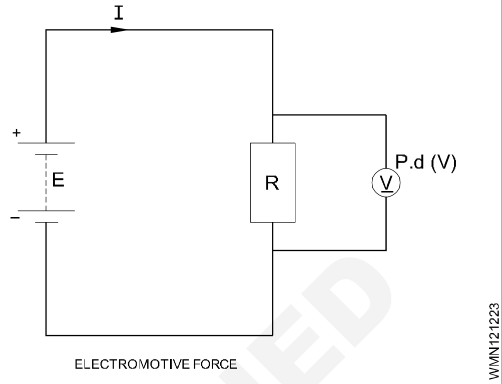


Electro Motive Force (EMF) (Fig 3)

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 3



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 or force across two points in a circuit is called a potential difference (p.d) and is measured in volts.

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 (V_T): 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.

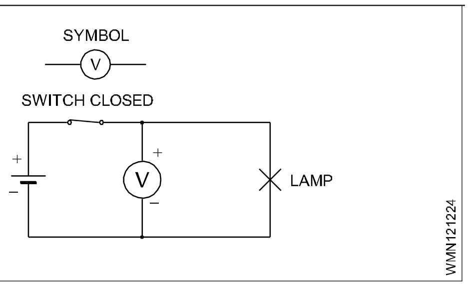
V_T = EMF - IR

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 4. The voltmeter connection is across or it is a parallel connection.

Fig 4



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.

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).

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 at 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

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.

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 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 bells, motors, fans, electric instruments, etc.

4 **Gas ionization effect:** When electrons pass through gas 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.

Current carrying capacity of copper & aluminium cables - voltage grading

Objectives: At the end of this lesson you shall be able to
- **list out the factors for selection of cables**
- **state the size and number of strands available in copper and aluminium cables and their current carrying capacity**
- **state the rating factor and determine the current capacity of cables with respect to temperature.**

Selection of cables

The current carrying capacity of a particular area of cross-section cable depends upon the following factors.

- Type of conductors (metal)
- Type of insulation
- Cable run in conduit or in open surface
- Single or three phase circuit
- Type of protection - coarse or close excess current protection
- Ambient temperature
- Number of cables in bunches
- Length of circuit (permissible voltage drop)

Depending upon the above factors the current rating of cables may vary to a great extent.

Information in this lesson will enable the wireman to select the correct cable under normal working conditions.

Current rating of cables based on type of protection

Cables insulated with PVC, may sustain serious damage when subjected, even for relatively short periods, to higher temperature than the temperature permissible for continuous operation.

Therefore, current ratings of cables insulated with PVC are determined not only by the maximum conductor temperature admissible for continuous rating but also by the temperature likely to be attained under conditions of excess current.

Hence, the current rating of cables are given under two headings:

- cables provided with coarse excess current protection
- cables provided with close excess current protection.

Coarse excess current protection

In this type of protection, circuit protection will not operate within four hours at 1.5 times the designed load current of the circuit which it protects.

The devices affording coarse excess current protection include:

- fuses which are having a fusing factor exceeding 1.5 times the marked rating.
- carriers and bases used in rewirable type electrical fuses.

Close excess current protection

In this type of protection the circuit protection will operate within four hours at 1.5 times the designed load current of the circuit which it protects.

Devices include:

- fuses fitted with fuse links having fusing factor not exceeding 1.5 times the marked rating (H R C & cartridge etc.)
- miniature and moulded case circuit breakers.
- circuit breakers set to operate at an overload not exceeding 1.5 times the designed load current of the circuit.

Electrical inspectors, who are assigned by the Government to test installation and give permission for effecting supply, now recommend close excess current protection devices like MCB and HRC fuses to be included in the circuit for safety to the user and to reduce fire accidents.

Rating factor with respect to protection

For circuits with coarse excess current protection (rewirable fuse unit) current rating of cables is given in Table 1. Though the cables can carry a higher value of current than the current notified in the Table 1, for circuits having coarse excess current protection, the permissible current in cables is obtained by multiplying the normal current capacity by a rating factor of 0.81, whereas for circuits protected by close current protection the normal current capacity is multiplied by a rating factor of 1.23.

The following example will clarify the above information.

Normal current carrying capacity of 1.5 sq mm copper cable = 16 amps (normal rating)

Current capacity of the same cable when protected by coarse excess current protection (Rating factor 0.81)

= Normal capacity x Rating factor

= 16 x 0.81 = 13 amps.

Close excess current protection (Rating factor 1.23)

= Normal capacity x Rating factor

= 16 x 1.23 = 19.7 = 20 amps.

Current capacity for close excess current protection could be obtained by the following formula also.

$$= \frac{\text{Coarse excess current protection rating}}{\text{Rating factor of coarse protection}} \times \text{Rating factor of close excess current protection}$$

Table 1

Current rating for single core PVC insulated sheathed copper and aluminium conductor cables of size 1 to 50 sq. mm at ambient temperature of 40°c (Refer to IS 694 Part I -1964). (Cables provided with coarse excess current protection.)

Nominal cross-sectional area	Number and diameter of wires	Bunched and enclosed in conduit or trunking			
		2 cables single phase AC or DC		3 or 4 cables 3-phase AC	
mm²	Number of strands/ dia, in mm	Copper Amps.	Aluminium Amps.	Copper Amps.	Aluminium Amps.
1	1/1.12	11	--	9	--
1.5	1/1.40	13	8	11	7
2.5	1/1.80	18	11	16	10
4	1/2.24	24	15	20	13
6	1/2.80	31	19	25	16
10	1/1.40	42	26	35	22
16	7/1.70	57	36	48	30
25	7/2.24	71	45	60	38
35	7/2.50	91	55	77	47
50	19/1.80	120	69	100	59

Rating factor for ambient temperature

Further the current rating of cables is greatly affected by the ambient temperature. As such if the ambient temperature is other than 40°C the current rating shown in the above table should be multiplied by the rating factor given in Table 2.

Table 2

SL. No.	Ambient Temp. °C Rating factor for cables	25	30	35	40	45	50	55	60	65
1	Having coarse excess current protection	1.09	1.06	1.03	1.00	0.97	0.94	0.82	0.67	0.46
2	Having close excess current protection	1.22	1.15	1.08	1.00	0.91	0.82	0.70	0.57	0.40
3	Flexible cords	--	1.09	1.04	1.00	0.95	0.77	0.54	--	--

Advantages of stranded conductors over solid conductors

As stranded conductors are more flexible, chances of break of conductors and crack of insulation at the bend is less. They can be easily handled and laid.

Connections and joints of stranded conductors are stronger and have longer life.

Current rating of flexible cables is given in Table 3.

Table 3

Current ratings for copper conductor flexible cords, insulated with PVC according to BIS No.694

Nominal cross-sectional area of conductor mm²	Number and diameter of wires Number/mm	Current rating DC, single phase or 3-phase AC (Amperes)
0.50	16/0.20	4
0.75	24/0.20	7
1.00	32/0.20	11
1.50	48/0.20	14
2.50	80/0.20	19
4.00	128/0.20	26

In stranded conductors the insulation has a better grip on the wire.

Solid conductors between supports of overhead lines may break due to vibration. This breakage is less in stranded conductors.

The space between the strands permits flow of oil in U G cables enabling better insulation properties and cooling.

For a given area of cross- section stranded cables carry more current than solid conductors.

Classification of voltage grading

Voltage is classified as

1 Low voltage (L.V): Normally not exceeding 250V (i.e.) from 0 to 250 volts.

2 Medium voltage (M.V): Exceeding 250V but not exceeding 650V from 250 to 650 volts

3 High voltage (H.V): Exceeding 650V but not exceeding 33000V.(650-33000 volts)

4 Extra high voltage: All voltages above 33000V comes under this category.

Joining of different wires

Objectives: At the end of this lesson you shall be able to
- **state the necessity of joints, their types and uses.**

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.

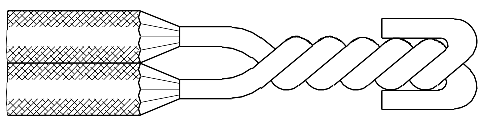
On the other hand, the joints made in overhead conductors, need to be not only electrically conductive but also mechanically strong to withstand the tensile stress due to the weight of the suspended conductor and wind pressure.

Some of the commonly used joints are listed below.

- Pig-tail or rat-tail or 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

WMN121241

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

Fig 2

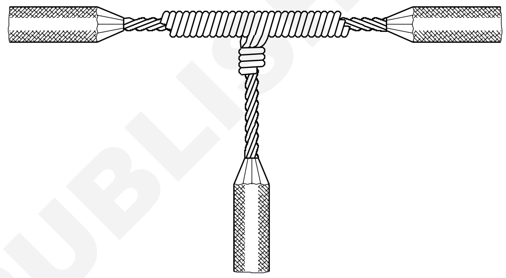
MARRIED JOINT

WMN121242

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

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

Fig 3



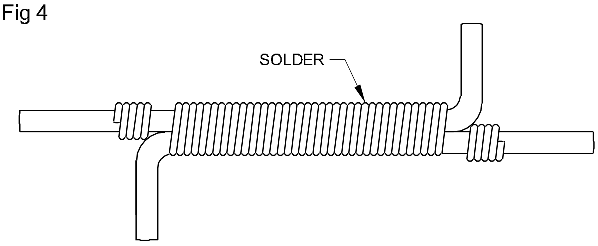
TEE JOINT

WMN121243

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 4

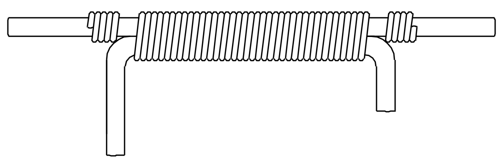


BRITANNIA JOINT

WMN121244

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 5

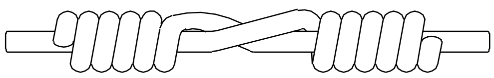


BRITANNIA TEE JOINT

WMN121245

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.

Fig 6

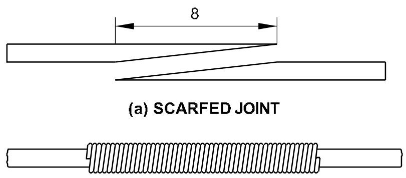


WESTERN UNION JOINT

WMN121246

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 7



(b) SCARFED JOINT

WMN121247

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

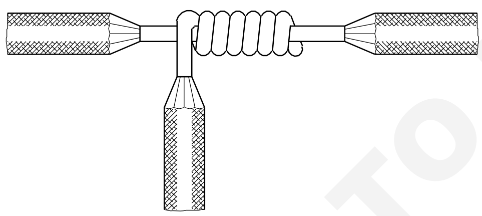
By definition, a tap is the connection of the end of one wire to some point along the run of another wire.

The following types of taps are commonly used.

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

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

Fig 8

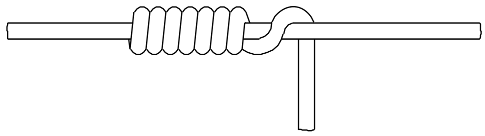


PLAIN TAP JOINT

WMN121248

Aerial tap joint: 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. (Fig 9)

Fig 9

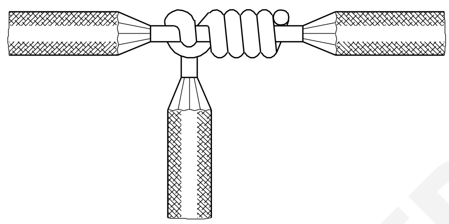


AERIAL TAP JOINT

WMN121249

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

Fig 10

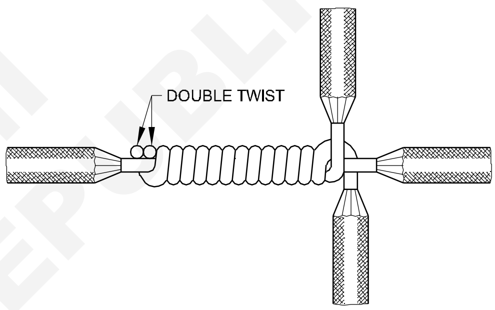


KNOTTED TAP JOINT

WMN12124A

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 11

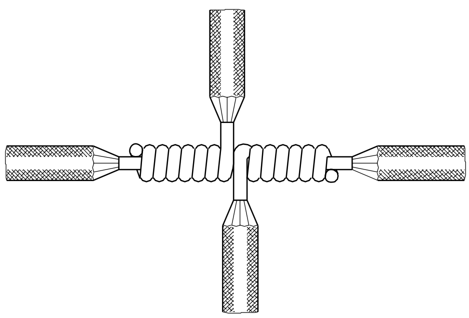


DUPLEX-CROSS TAP JOINT

WMN12124B

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

Fig 12



DOUBLE-CROSS TAP JOINT

WMN12124C

Solders, flux and soldering technique

Objectives: At the end of this lesson you shall be able to
- **explain different methods of soldering and technique of soldering**
- **explain types of solder and flux used to solder aluminium conductor.**

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.

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.

Flux

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

Solders

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

S.No	Designation	Composition	Working Temp.	Uses
1	Electrician's solder	Tin-60% Lead-40%	185°C. or 365°F.	Tinning and soldering electrical joints etc.

The following table lists the fluxes used for soldering.

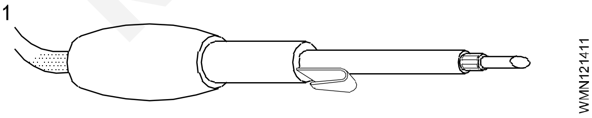
Table

Sl. No.	Suitable flux	Metals/job - used for	Type of solder
1	Sal ammonia rosin (Not fully acid-free)	Copper, brass, tin plate, gun-metal: for clean and finer soldering work.	Coarse solder
2	Rosin	Joining electrical conductors	Electrician's solder
3	Tallow - (turpentine, acid free)	For joining electrical conductors, for soldering.	Electrician's fine solder

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



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

Ratings

Voltage	230 or 240
Wattage	5,10,25,75, 125,250,500

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

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.

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

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

Fig 2

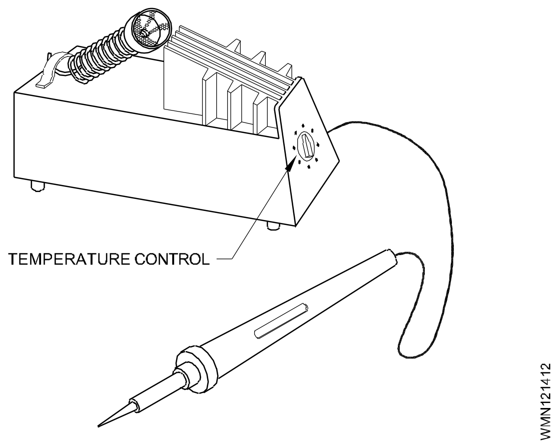
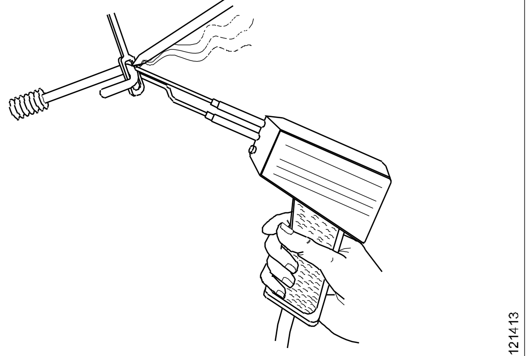


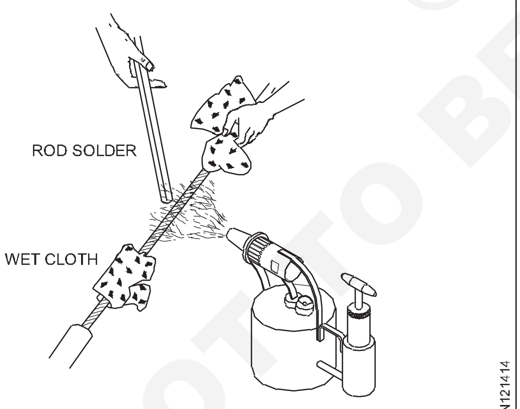
Fig 3



SOLDERING WITH A SOLDERING GUN

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.

Fig 4



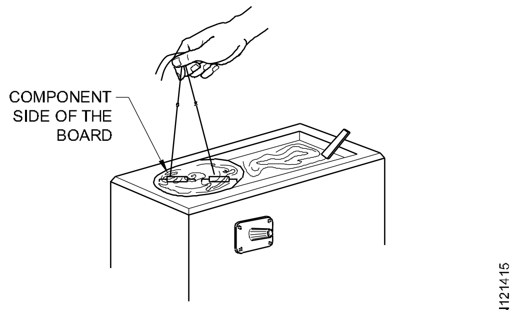
SOLDERING WITH BLOWLAMP

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.

Soldering involves the following main operations.

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

Fig 5



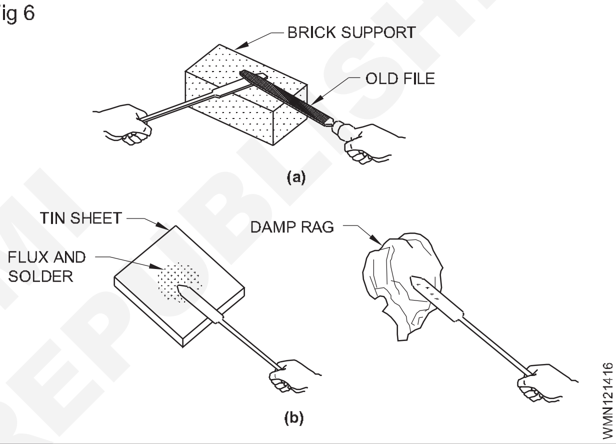
DIP SOLDERING

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.

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

Fig 6

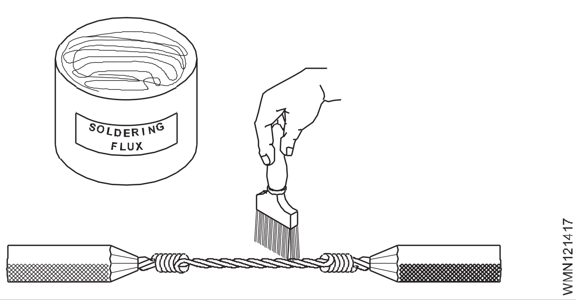


The surface should present a bright silvery appearance when properly tinned.

Cleaning the surface to be soldered: The parts to be soldered should be well cleaned for perfect soldering.

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



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

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.

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.

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.

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.

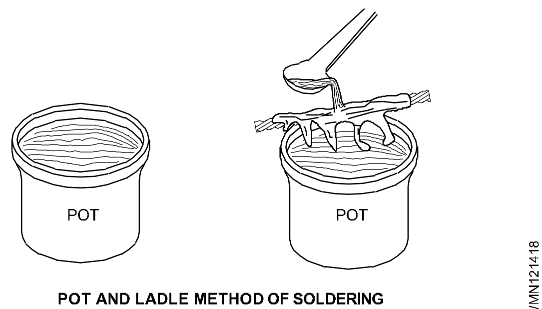
This oxide film does not allow the solder to wet the surface to be soldered, and also prevents the solder from entering the interior surface by capillary action. Hence special solders and fluxes are used for aluminium soldering.

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 300^0C.) 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.

Fig 8



POT AND LADLE METHOD OF SOLDERING

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

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.

Beware of the naked flames to avoid a fire risk.

Reconditioning of solder which is subjected to repeated melting.

Table 1

Grade	**% of alloying elements**			**Melting temp. in °C**	**Flux type**	**Applications**
	Zinc	**Lead**	**Tin**			
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-

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

Wire - wound resistance and metal film resistors are explained here

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. 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

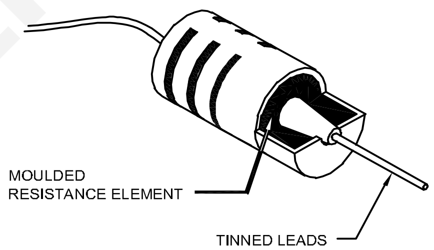
ELN143821

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

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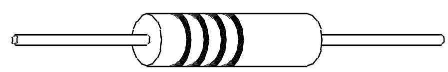
3 Metal film resistors (Fig 3)

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.

Thin film resistors are processed by depositing a metal vapour on a ceramic base. Metal film resistors are available from 1 ohm to 10 MW, upto 1W. Metal film resistors can work from 120°C to 175°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.

Fig 3



METAL FILM RESISTOR

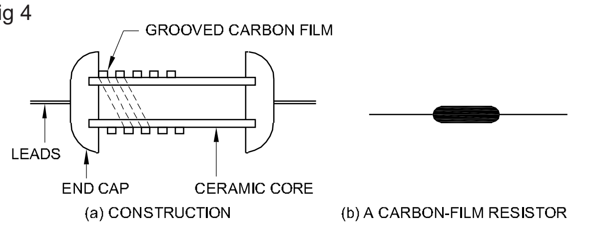
ELN143823

Carbon film resistors (Fig 4)

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.

Fig 4



CARBON – FILM RESISTOR

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 100W.

The actual value of resistance may be between 90W to 110 W, and the loading capacity is maximum 1 watt.

The resistors can also be classified with respect to their function as

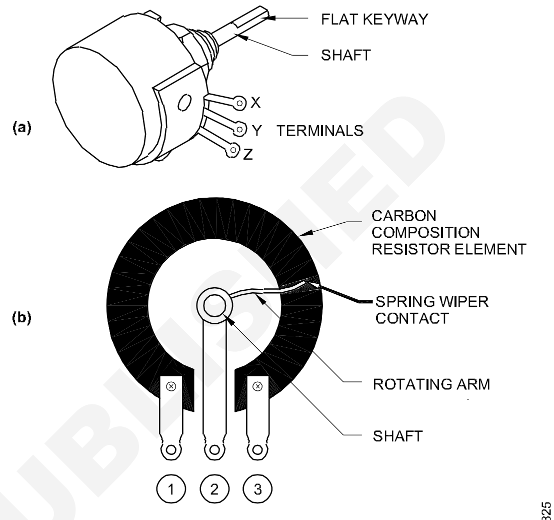
1 Fixed resistors
2 Variable resistors

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.

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.

It is provided with 3 terminals as shown in Fig 5

Fig 5



VARIABLE CARBON-RESISTANCE (a) EXTERNAL VIEW
(b) INTERNAL VIEW OF CIRCULAR RESISTANCE ELEMENT

Crimping tool - crimping thimbles and lugs

Objectives: At the end of this lesson you shall be able to:
- **describe the parts and their functions of crimping tool**
- **state the advantages of crimping termination.**

Crimping and crimping tool: The ends of cables can be prepared for termination with lugs by the soldering process or by mechanical means - compression or crimp fitting.

In crimp compression fitting, a ring-tongued terminal (lug) is to be compressed to the bared end of an insulated multi-strand cable. The process is called crimping and the tool used is called crimping pliers or crimping tool.

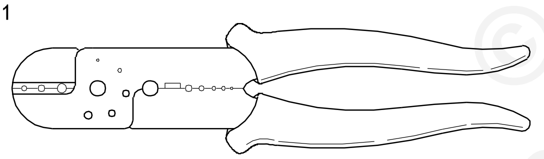
Compression type connectors apply and maintain pressure by compressing the connector around the conductor.

The principal purpose of the pressure is to establish and maintain suitable low contact resistance between the contact surfaces of the conductor. Improper crimping will create increased contact resistance and will cause overheating while carrying electrical load.

Crimping tools

The crimping pliers illustrated in Fig 1 is of a type which crimps from 0.5 to 6 mm cables.

Fig 1



HAND CRIMPING PLIERS

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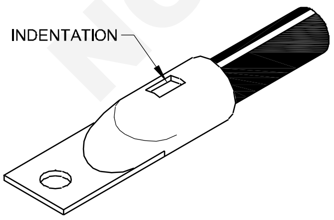
The tool is operated by squeezing the handles. The jaws move together, grip and then crimp the fitting. Using the crimping tool that matches the specific crimp lug will give the correct crimping force for a properly executed crimp. Properly executed crimp will indent the top of the lug and the indentation will hold the conductor securely as shown in Fig 2.

Fig 2



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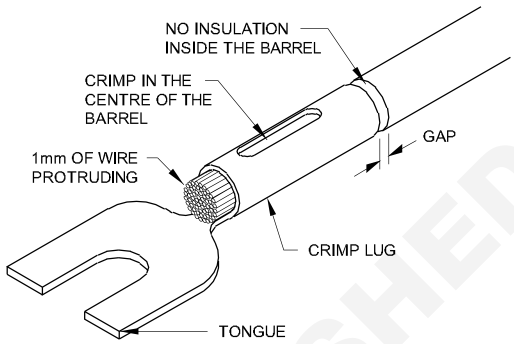
If the terminal has too deep a crimp, the strength of the joint is reduced. With too shallow a crimp, the electrical contact has a high resistance. Selection of the correct crimping tool is essential. A properly crimped terminal is shown in Fig 3.

Fig 3



A PROPERLY CRIMPED TERMINAL

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Terminal lug crimping pliers are available in lengths ranging from 180 to 300 mm. Crimping tools are available in sets. For higher capacity cables crimping tools are operated by hydraulic force.

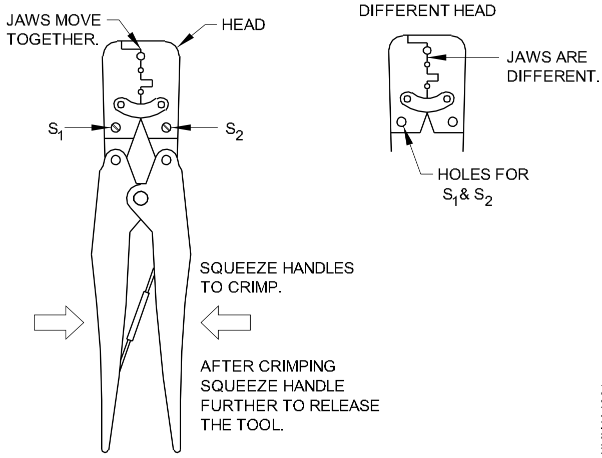
Fig 4 shows another type of crimping tool which crimps from 26 to 10 SWG.

The head and jaws, may be removed, by unscrewing the screws S_1 and S_2. A head with different shaped jaws may then be secured to the tool. The shape of the jaws determines the shape of the crimp (indent).

Safety

When using this type of crimping tool care must be taken not to trap the finger, as the operating cycle of the tool is non-reversible i.e. once the handles are squeezed together the jaws can only be released by applying further pressure to the handles as shown in Fig 4.

Fig 4



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Permissible temperature rise of insulators

Objectives: At the end of this lesson you shall be able to:
- **state permissible temperature rise of different types of insulators.**

Temperature classes of material used for various insulators

Once the temperature classes of insulation have been established, those of the individual materials of each insulator become important.

It should be noted that in the table 1 every material is not always classified into a specific temperature class: rather, the table provides information for reference purposes only. The performance (durability) of a material can be easily changed through the combination of materials, treatment of varnish, and method of use.

Table 1

Permissible temperature rise

S.No	Insulation class	Material	Maximum permissable temperature (°C)
1	Y	Cotton, Silk, Paper	90°
2	A	Impregnated varnish insulation of polyamide fibric base	105°
3	E	Cotton lamination paper lamination polythylene terephthalate fibric Varnish treated polythylene cloth	120°
4	B	Glass fibric Asbestos Mica Glass Enamel wire	
5	F	Resin Adhesives Silicone	155°
6	H	Varnish asbestos Rubber glass cloth Silicone rubber	180°
7	C	Ceramic Quartz	Above 180°

Precautions while using various types of cables

1 The cables and wiring external to rthe equipment must have flame retardant properties and should be installed in such a manner that it should not interfere with original flame retarding properties.

2 Cables and wiring for emergency equipment, lightings, communicatrion and the signal should be kept away from spacies like gallary, laundries, machinary space of high risk areas.

3 Special precautions are to be taken for cable installation in the hazardons area as it might lead to an explosion in case of an electrical fault.

4 Termination and joints are to be made in such a manner that it should retain its original fire resisting properties.

5 Avoid cable for damage during installation.

6 Fire proof glands to be used in case of the cable passing through the back head as it would prevent the fire from one compartment to other.

Methods of measuring the value of 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.**

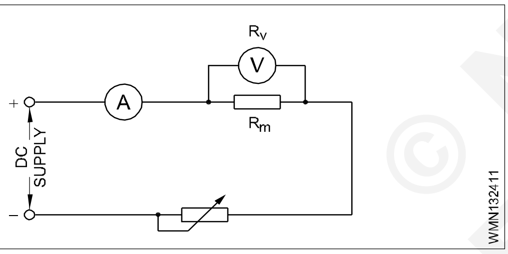
Methods of measuring low resistance: The following three methods are used to measure low resistance.

- 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 a voltmeter connected across resistance R_v. A 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

Fig 1



$$R_m = \frac{\text{Voltmeter reading}}{\text{Ammeter reading}}$$

R_m = Measured value

Measurement of resistances

Medium resistances could be measured by instruments like Kelvin's bridge, Wheatstone bridge, Slide wire bridge, Post Office box and Ohmmeter.

However, for measuring high resistances, instruments like megohmmeter or megger are used.

Ohmmeter

The ohmmeter is an instrument that is used for measuring resistance. There are two types of ohmmeters: the series ohmmeter is used for measuring medium resistances and the shunt type ohmmeter is used for measuring low and medium resistances. The ohmmeter in it basic form consists of an internal dry cell, a PMMC meter movement and a current limiting resistance.

Before using an ohmmeter in a circuit, for resistance measurement, the current in the circuit must be switched off and also any electrolytic capacitor in the circuit should be discharged. Remember that the ohmmeter has its own source of supply.

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.

Dependency of resistance on temperature is explained in detail below:-

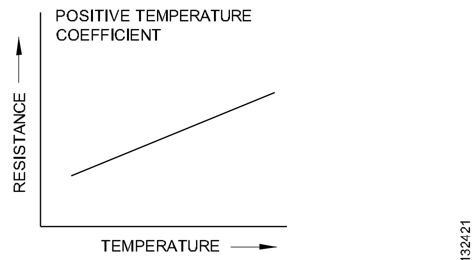
Effect of temperature on resistance: Actually, the relative values of resistance that were given earlier apply to the metals when they are at about room temperature. At higher or lower temperatures, the resistances of all materials change.

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, copper, aluminium, brass etc. (Fig 1)

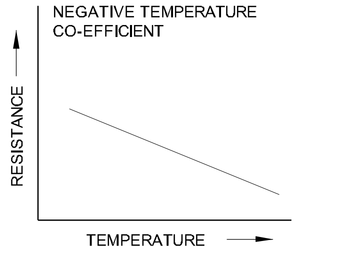
Fig 1



RESISTANCE INCREASES WITH TEMPERATURE

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)

Fig 2



RESISTANCE DECREASES WITH TEMPERATURE

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This applies in the case of electrolytes, insulators such as paper, rubber, glass, mica etc. and partial conductors 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 = 1Ω, 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:

$$R_2 = R_o(1 + \alpha_o t_2) \text{ and}$$
$$R_1 = R_o(1 + \alpha_o t_1).$$

$$\text{Therefore } \frac{R_2}{R_1} = \frac{1 + \alpha_0 t_2}{1 + \alpha_0 t_1}$$

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)
Copper (annealed)	1.72	39.3
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
Silver	1.64	38
Tungsten	5.5	47

Insulators	**Resistivity in ohm-metre at 20°C**	**Temperature coefficient at 20°C**
Bakelite	10^{10}	
Glass	10^{10}– 10^{12}	10^{12}
Mica	10^{15}	
Rubber	10^{16}	
Shellac	10^{14}	

Laws of resistance

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 diameter of a conductor**
- **calculate the resistance and diameter of a conductor from the given data (i.e. dimensions etc).**

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

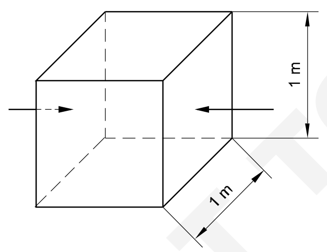
$$R = \frac{\rho L}{a}$$

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

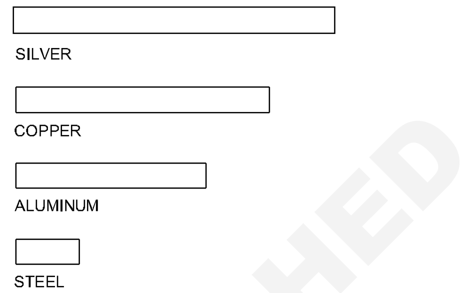


Hence the unit of specific resistance is ohm metre (Ωm).

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.

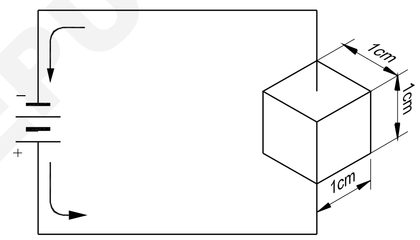
Since different metals have different conductance ratings, they must also have different resistance ratings. The resistance ratings of the different metals can be found by experimenting with a standard piece of each metal in an electric circuit. If you cut a piece of each of the more common metals to 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 2



THE CONDUCTANCE OF DIFFERENT MATERIALS

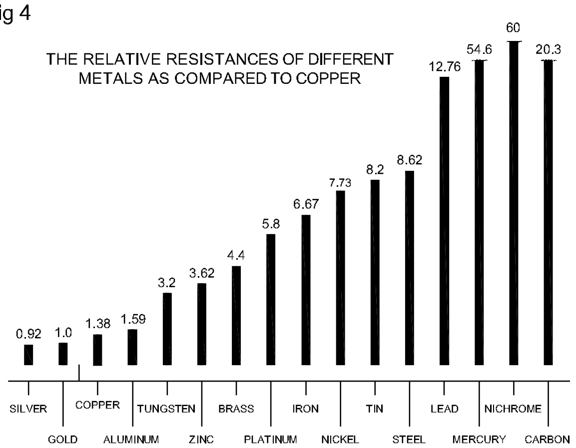
Fig 3



THE MORE RESISTANCE A MATERIAL HAS, THE LESS CURRENT THE MATERIAL WILL CONDUCT. GOOD INSULATORS, SUCH AS GLASS, RUBBER, MICA, POLYSTYRENE, ETC., HAVE CONSIDERABLY MORE THAN A MILLION TIMES THE RESISTANCE OF ANY GOOD CONDUCTOR

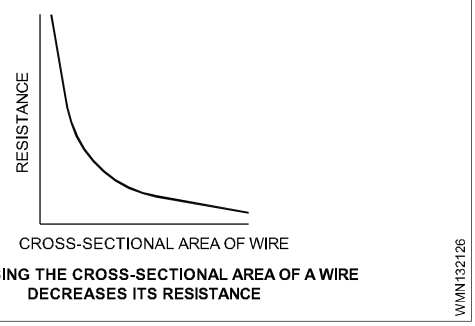
The bar graph (Fig 4) shows the resistance of some common metals as compared to copper. Silver is a better conductor than copper because it has less resistance. Nichrome has 60 times more resistance than copper, and copper will conduct 60 times as much current as Nichrome, if they were connected to the same battery, one at a time.

Fig 4



In general, we may, therefore, say that the resistance of a given length of a conductor is inversely proportional to its cross-sectional area. (Fig 5)

Fig 5



INCREASING THE CROSS-SECTIONAL AREA OF A WIRE DECREASES ITS RESISTANCE

The other factor that influences the resistance is the nature of the material. Hence, we may now say that resistance of a wire.

$$= \frac{\text{length}}{\text{area}} \times \text{(a constant) } \rho \text{ given material}$$

$$R(\text{ohms}) = \frac{L\,(\text{metres})}{a\,\text{metre}^2} \times \rho$$

So that $\rho = Ra \div L$ 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.

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.

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.

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.

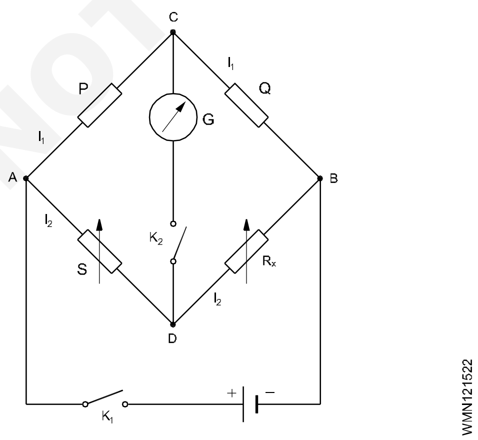
Wheatstone bridge

Objectives: At the end of this lesson you shall be able to
- **state wheatstone bridge circuit**
- **state the construction and working principle of the wheatstone bridge**
- **determine the unknown resistance by the wheatstone bridge.**

Wheatstone bridge: For meaning accurately low and medium resistances, various instruments are used. Most of these instruments, like the post office box and slide wire bridge, work on the principle of the wheatstone bridge.

Initially let us review the wheatstone bridge principle. The ratio (fixed) arms 'P' and 'Q' the adjustable arm 'S' and the unknown resistance 'R' the galvanometer 'G' and the cell 'E' along with keys K_1 & K_2 are connected as shown in Fig 1 in a wheatstone bridge configuration.

Fig 1



The bridge is said to be balanced when there is no current passing through the galvanometer even though the keys K_1 & K_2 are in closed position. This can be obtained by adjusting the adjustable resistance in arm'S' and making the potential at C and D the same.

In a balanced condition, the potenrial difference between junction C and D is zero.

Hence, $I_1P=I_2S$ Eqn. ....(1)

Similary $I_1Q=I_2R_X$ Eqn. ....(2)

By dividing equation (1) by (2) we have

$$\frac{P}{Q} = \frac{S}{R_X}$$

$$R_X = S \times \frac{Q}{P}$$

The principle of the wheatstone bridge is applied in the post office box and slide (metre) wire bridge for measuring the known resistance.

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?

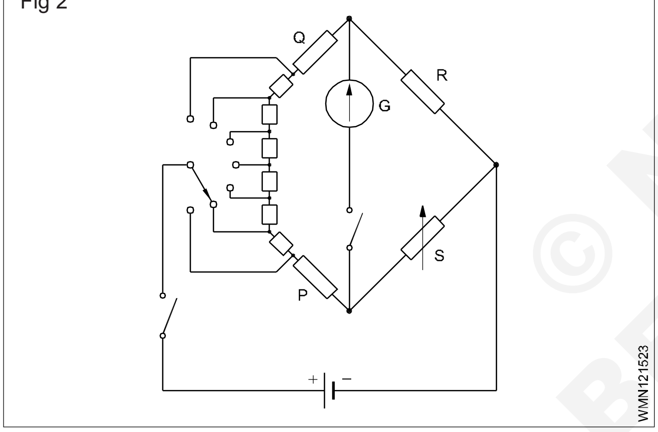
In the professional Wheatstone bridges, the galvanometer is provided with a parallel resistance and switch. The bridge connection is made only by pressing a push button. This enables the user to check a momentary deflection of the meter. In the case of excessive deflection, adjustment of the variable 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.

The Wheatstone Bridge is used for measurements in the range of about 1.0 ohm to 1.0 megohm. In Fig 2, resistors P,Q and S are internal to the instrument. R is the resistor of unknown value to be measured. (Fig 2)

Fig 2



The instrument is adjusted until the ratio $\frac{Q}{P} = \frac{R}{S}$

This is indicated by a zero reading on the galvanometer with its switch in the closed position.

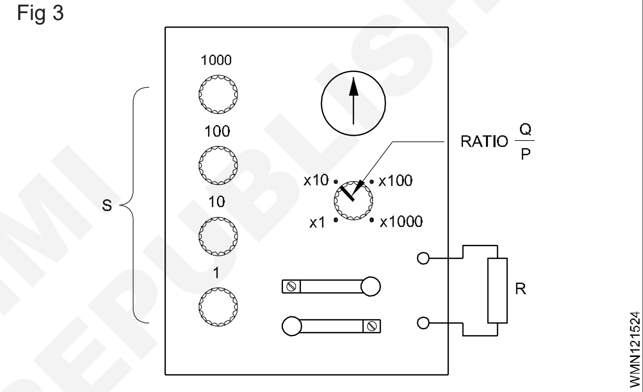
The resistors P and Q are called ratio arms. P and Q are varied in steps to give a range of values and the resistance value of 'S' is set by the decade resistance S. (Fig 3)

$R = \frac{Q}{P}$ 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 3



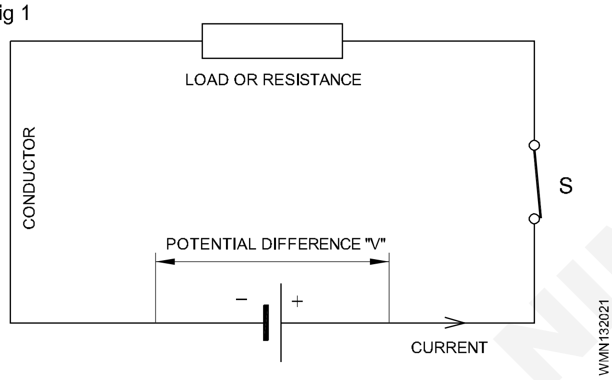
Ohm's law - simple electrical circuits and problems

Objectives: At the end of this lesson you shall be able to
- **describe a simple electric circuit**
- **state the Ohm's law**
- **apply Ohm's law in an electrical 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



- 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

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) $I \propto V$ (When 'R' is kept constant)

$I \propto R$ (When 'V' is kept constant)

$I \propto V/R$ (Relation between I,V and R)

It means I = V/R

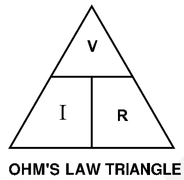
V = Voltage applied to the circuit in 'Volt'

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



For example for finding 'V' close the value 'V' then readable values are IR, so V = IR.

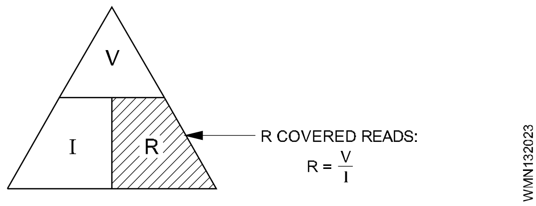
Again for finding 'R', close the value R, then readable values are V/I so R = V/I, like that

Written as a mathetical expression, Ohm's Law is

$$\text{Resistance} = \frac{\text{Voltage(V)}}{\text{Current(I)}}$$

$$\text{(or) } R = \frac{V}{I} \qquad \text{(Refer Fig 3)}$$

Fig 3

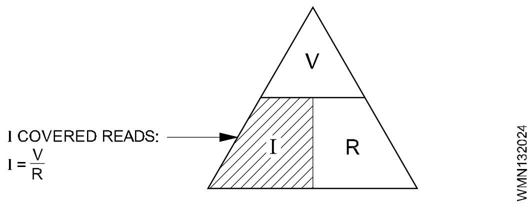


Of course, the above equation can be rearranged as:

$$\text{Current(I)} = \frac{\text{Voltage(V)}}{\text{Resistance (R)}}$$

$$\text{(or)} I = \frac{V}{R} \qquad \text{(Refer Fig 4)}$$

Fig 4

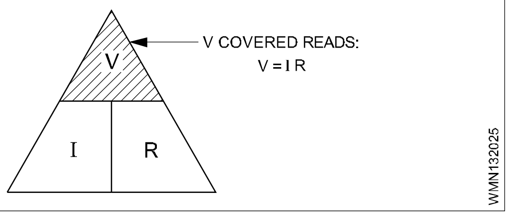


In the same way, 'V' can be found by covering 'V'

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 having a source of 10V battery and a load of 5 Ohms resistance. Now we can find out the current through the conductor.

$$I = \frac{V}{R}$$

$$I = \frac{10}{5} = 2 \text{ amps}$$

Electrical Power (P) & Energy (E)

The product of voltage (V) and current (I) is called electrical power. 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 for power (P).

(i) P = V X I

= IR x I

P = I^2R

(ii) P = V X I

$$= V \times \frac{V}{R}$$

$$P = \frac{V^2}{R}$$

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 x t

= (V x I) x t

E = V x I x 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

(R) Resistance = 312.5 Ohm

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 = 107 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

$$p = \frac{F \times S}{t}$$

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

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

(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).

Kirchoffs law

Objectives: At the end of this lesson you shall be able to
- **state Kirchhoff's first law**
- **state Kirchhoff's second law and apply the same to find the voltage drop in branches.**

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

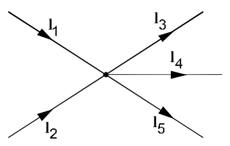
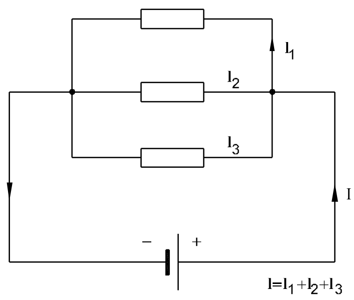


Fig 2



If all inflowing currents have positive signs and all outflowing 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.

$$\Sigma I = 0$$

$$I = I_1 + I_2 + I_3 + \ldots\ldots\ldots\ldots$$

Kirchhoff's second law

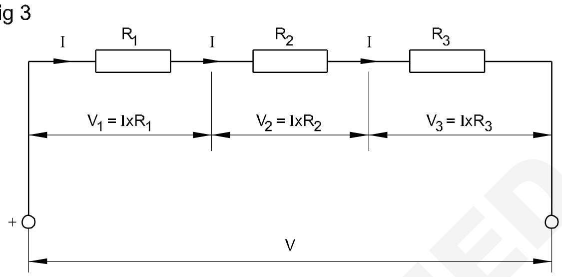
A simple case: In closed circuits, the applied terminal voltage V is equal to the sum of the voltage drops $V_1 + V_2$ and so forth. (Fig 3)

If all the generated voltages are taken as positive, and all the consumed voltages are taken as negative, then it can be stated that:

in each closed circuit the sum of all voltages is equal to zero. $\Sigma V = 0$

Suggested steps for the application of Kirchhoff's Laws to solve problems.

Fig 3

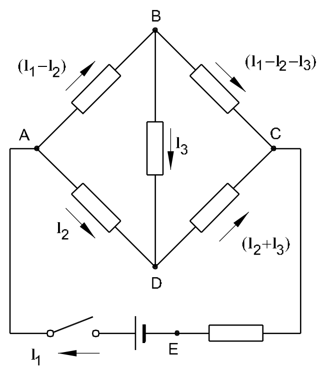


1 Mark the nodes (junction points) in the given network.

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 4)

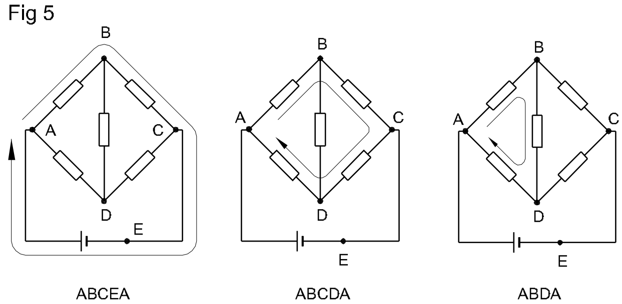
Fig 4



4 Once the current and its direction are marked over an element, keep it the same until the problem is solved.

5 Select the windows, (closed loops) in the circuit and name the window. eg. Fig 5

Fig 5



6 Each element should be included atleast once in any one of the closed loops selected in the above step.

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.

Open and short circuit 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.**

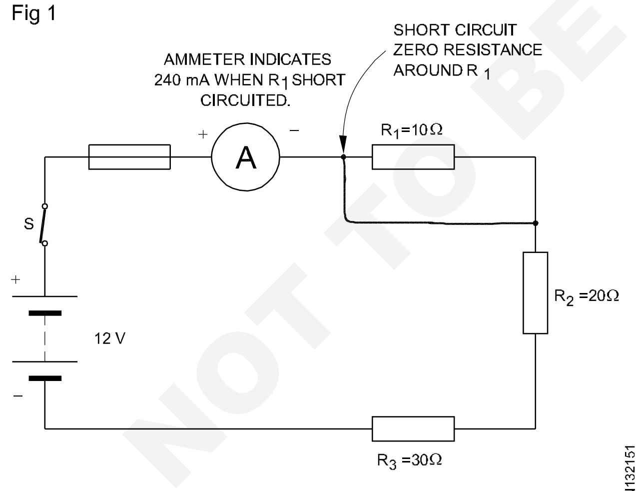
Short circuits

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.

Short circuits cause an increase in current that may or damage the series circuit.

Fig 1



PARTIAL SHORT AT R_1

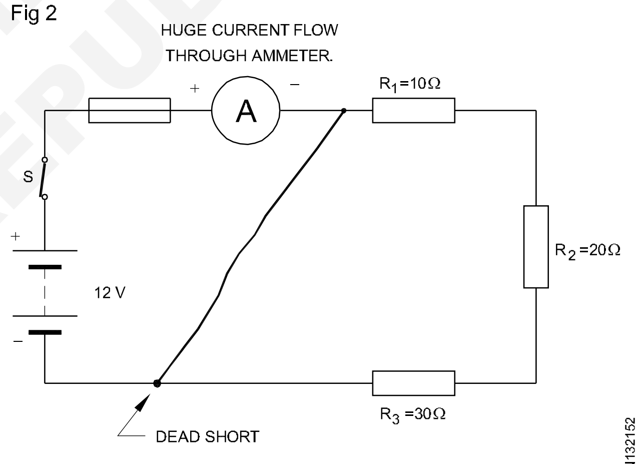
Effects due to short circuit

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.

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.

Fig 2



DEAD SHORT ACROSS 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 3.

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.

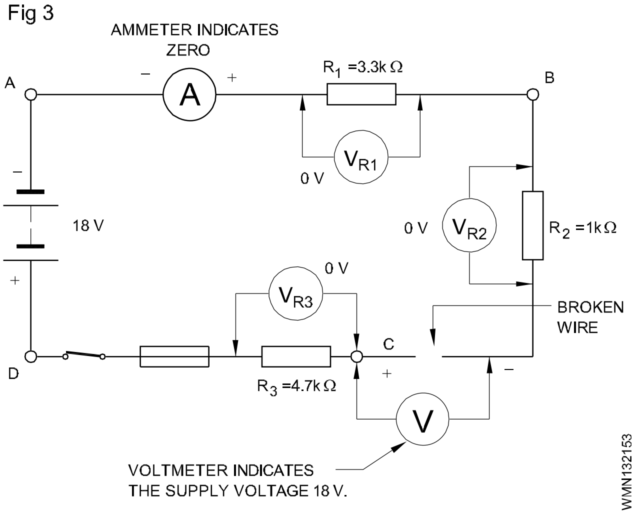
Effect of open in series circuit

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.

Fig 3



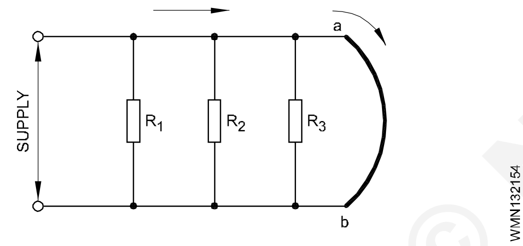
Shorts and opens in parallel circuits: The two possible defects that can occur in an electrical circuit they are;

- Short circuit
- Open circuit

Shorts in parallel circuit:

Fig 4 shows a parallel circuit with short between points 'a' and 'b'.

Fig 4



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.

Short circuit may cause burning of the circuit elements like cables, switches etc.

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 5

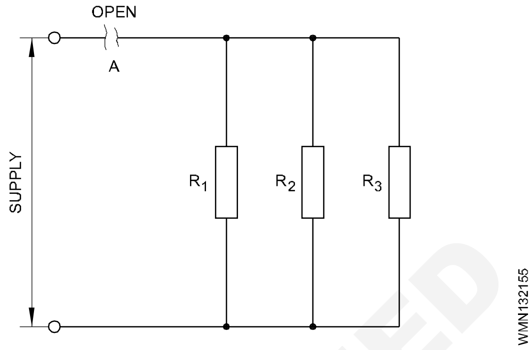
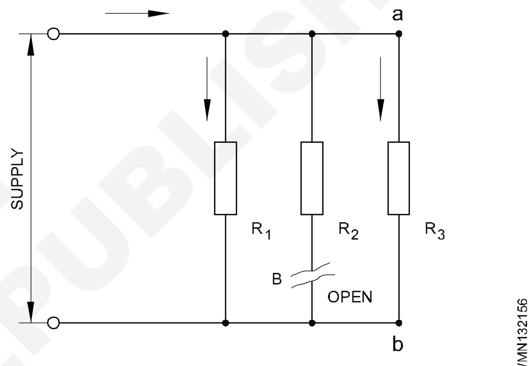


Fig 6



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.

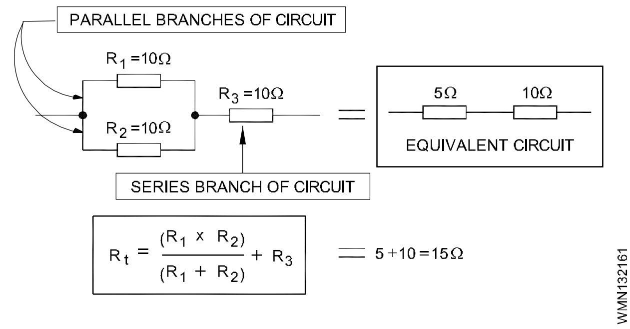
Series and parallel combination circuit

Objectives: At the end of this lesson you shall be able to
- **explain series and parallel circuits.**

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)

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.

Fig 1

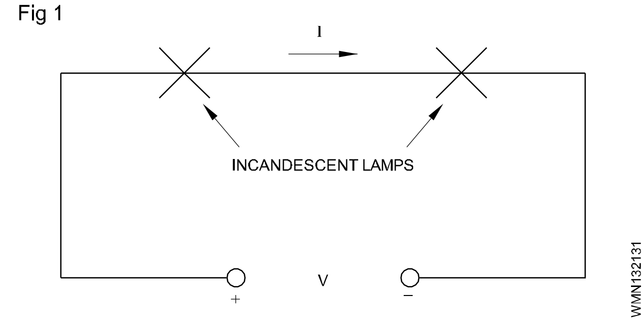


DC series circuit

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**
- **state the relation between EMF potential difference and terminal voltage.**

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



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 2(a) and 2(b). The ammeters will show the same reading.

The current relationship in a series circuit is

$$I = I_{R1} = I_{R2} = I_{R3}.$$

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.

Total resistance in series circuit

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.

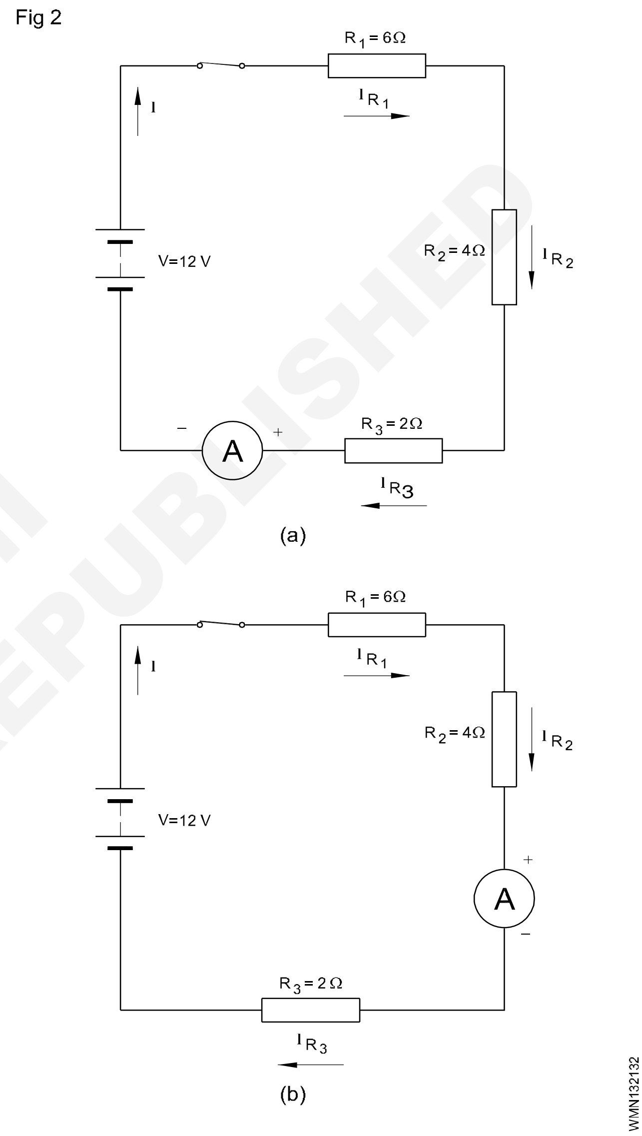
Voltage in series circuits

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.

As the source voltage divides/drops across the series resistance depending upon the value of the resistances

$$V = V_{R1} + V_{R2} + V_{R3} + ...V_{RH}$$

Fig 2



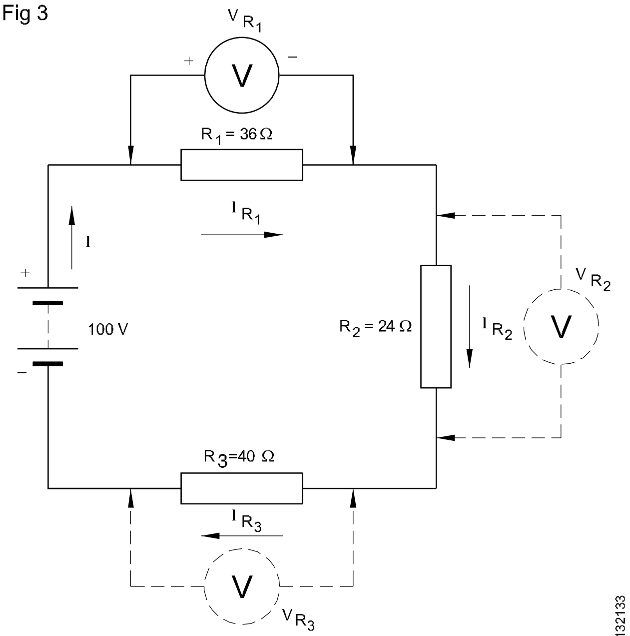
Voltages across the series resistors could be measured using one voltmeter at different positions as illustrated in Fig 3.

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 4.

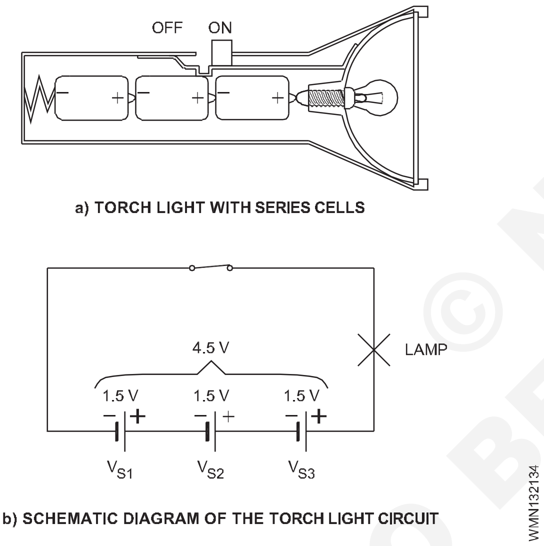
$$V_{Total} = V_{S1} + V_{S2} + V_{S3}$$
$$= 1.5\ V + 1.5\ V + 1.5\ V$$
$$= 4.5\ V$$

Fig 3



VOLTAGE DROP IN A SERIES CIRCUIT

Fig 4



a) TORCH LIGHT WITH SERIES CELLS

b) SCHEMATIC DIAGRAM OF THE TORCH LIGHT CIRCUIT

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.

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 = emf – IR

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.

DC parallel circuit

Objectives: At the end of this lesson you shall be able to
- **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.**

Voltage in parallel circuit

When 3 lamps are connected as shown (Fig 1) 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.

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

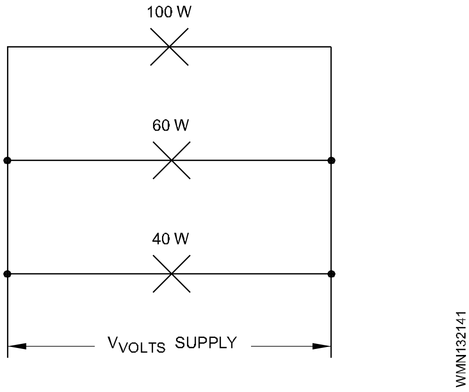
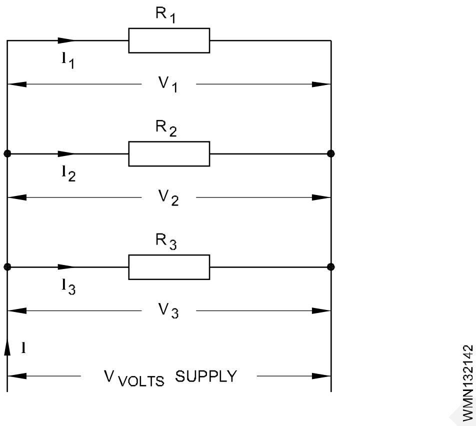


Fig 2



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 3 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.

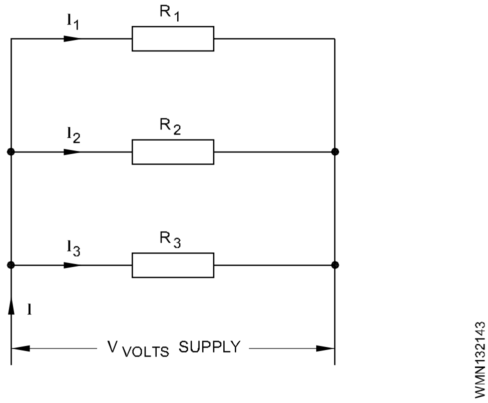
The total current I in the parallel circuit is the sum of the individual branch currents.

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.

Fig 3



Let the total resistance in the parallel circuit be R ohms.

By the application of Ohm's law

we can write

$$R = \frac{V}{I} \text{ ohms or } I = \frac{V}{R} \text{ amps.}$$

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

$I = I_1 + I_2 + I_3$

$$\text{or } \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

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.

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.

Magnetic term 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 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.

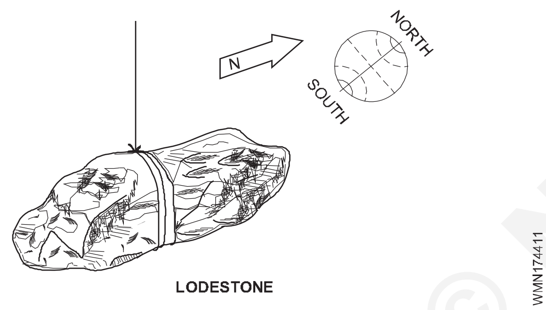
Classification of magnets

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.

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.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 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.

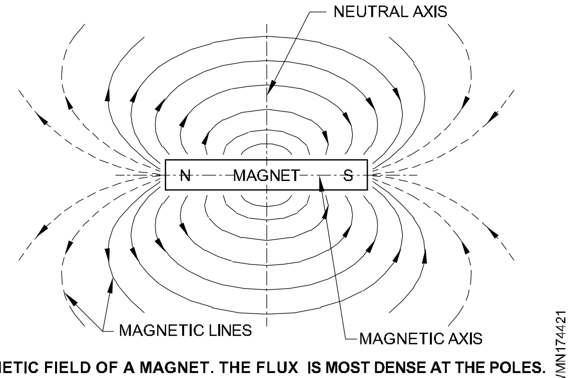
The space around a magnet in which the influence of the magnet can be detected is called the magnetic field.

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.

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.

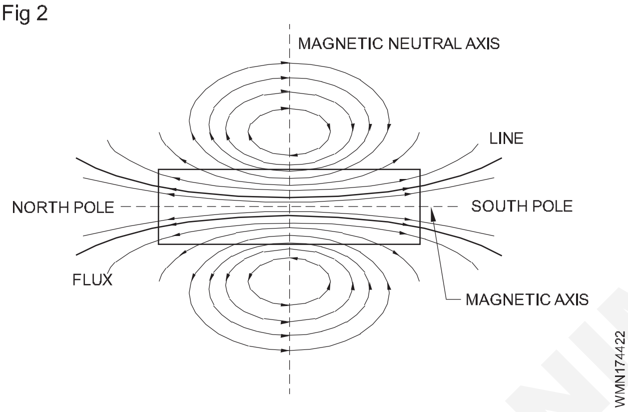
Fig 1



MAGNETIC FIELD OF A MAGNET. THE FLUX IS MOST DENSE AT THE POLES.

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

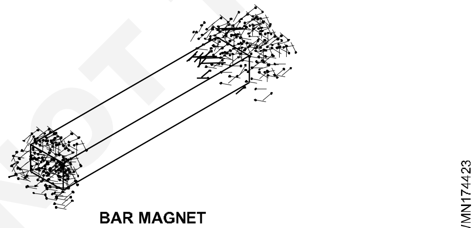


Unit pole: A unit pole may be defined as that pole which, when placed one metre apart from an equal and similar pole, repels it with a force of 10 newtons.

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

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)

Induction property: A magnet has the property of producing magnetism in a nearby magnetic substance by induction. (Fig 5)

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 4

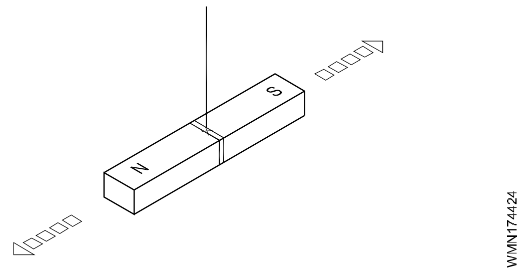
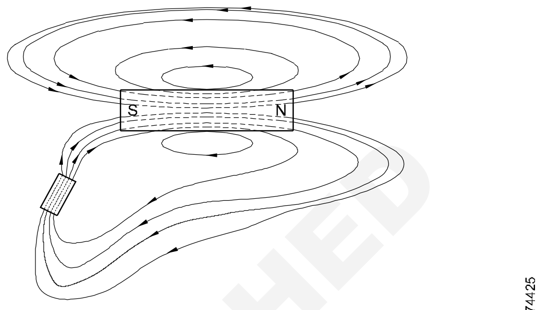
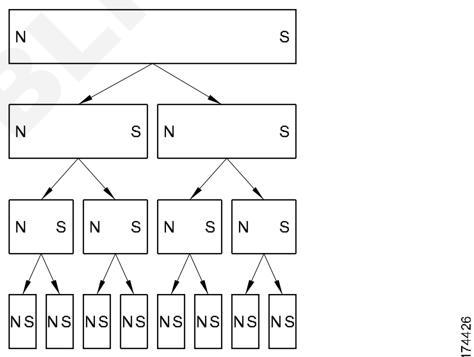


Fig 5



SOFT IRON PROVIDES A PATH FOR MAGNETIC LINES OF FORCE.

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.

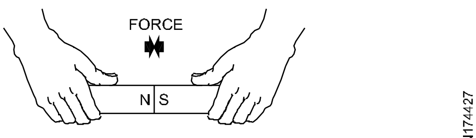
Saturation property: If a magnet of higher strength is further subjected to magnetization, it will never acquire more magnetization due to its being already saturated.

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)

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.

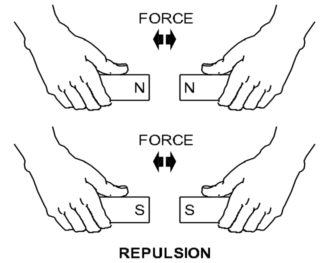
All the magnetic lines of force complete their circuit (form a loop).

Fig 7



ATTRACTION

Fig 8



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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.

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

Methods of magnetizing: There are three principal methods of magnetizing a material.

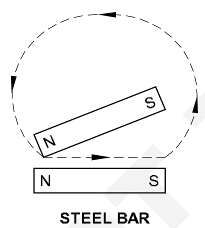
- Touch method
- By means of electric current
- Induction method.

Touch method: This method can be further divided into;

- single touch method
- double touch method
- 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 9. The process should be repeated many times for inducing magnetization of the bar.

Fig 9



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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 10. They are never lifted off the surface of the steel bar, but rubbed again and again from 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 11.

Fig 10

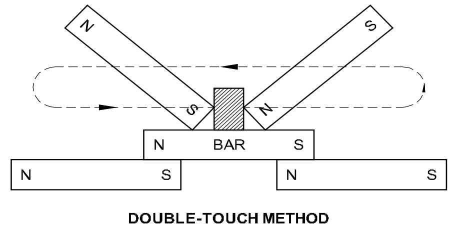

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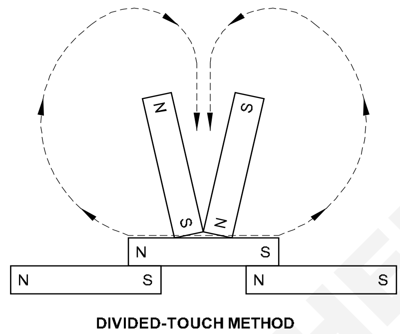
Fig 11



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The steel bar thus magnetized becomes a permanent magnet but the degree of magnetization is very low.

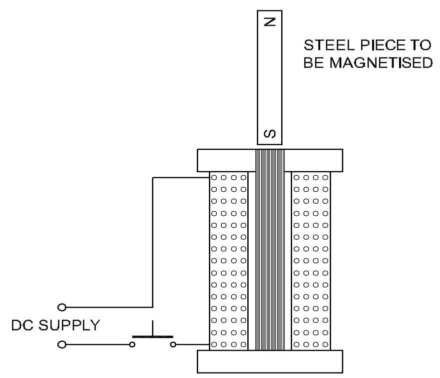
By electric current: The bar to be magnetized is wound with an insulated copper wire, and then a strong electric current (DC) from a battery is passed through the wire for some time. The steel bar then becomes highly magnetized. If the bar is of soft iron, the magnetism remains as long as the current 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.

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 12. 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 12



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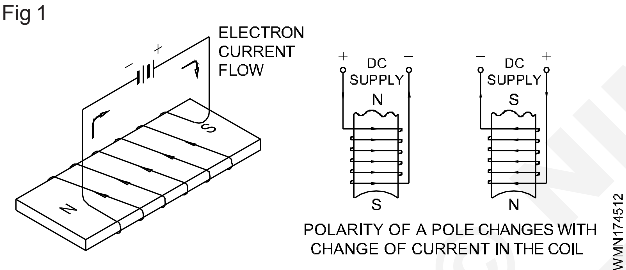
Principle of electro magnet - Right hand grip rule

Objectives: At the end of this lesson you shall be able to
- **explain what is meant by electromagnetism**
- **describe the magnetic field in current-carrying conductors, loop, coil, magnetic core -**
- **state right Hand Grip rule, Corkscrew rule Flemings left and right hand rule and right hand palm rule**
- **state the interaction of the magnetic field**
- **state the magnetic materials for a temporary magnet.**

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.

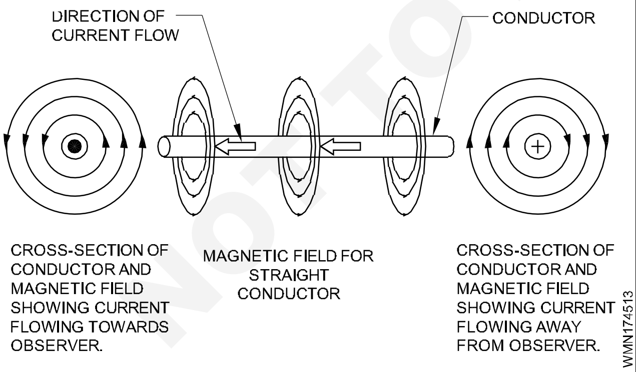
The polarity of this electromagnet depends upon the direction of the current flowing through it. If the direction of the current is altered, the polarity of the magnetic field will also be changed as shown in Fig 1.

Fig 1



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 2)

Fig 2

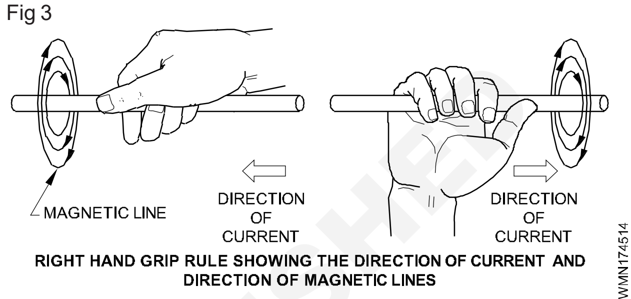


The direction of the magnetic field depends on the direction of the current flow. A compass moved around the wire will align itself with the flux lines.

Right hand grip rule

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 3.

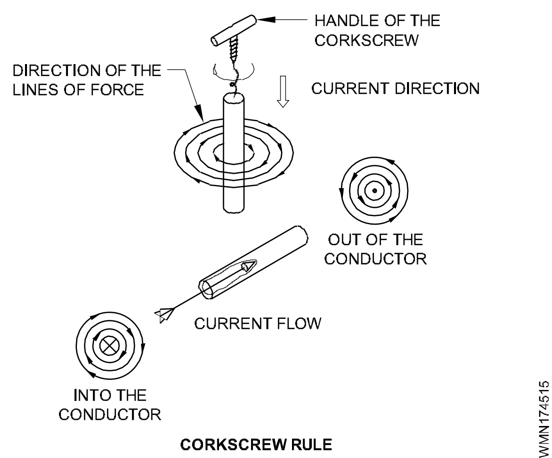
Fig 3



Cork screw rule

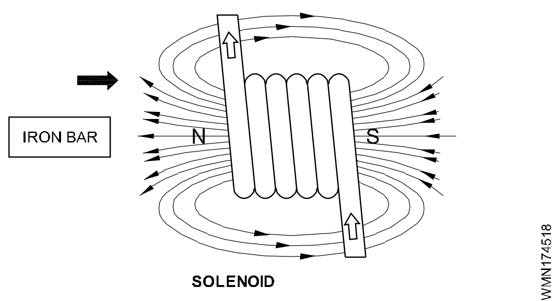
Assume a right handed corkscrew to be along the wire so as to advance in the direction of the current. The motion of the handle gives the direction of magnetic lines of force around the conductor (Fig 4)

Fig 4



Solenoid: 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 5)

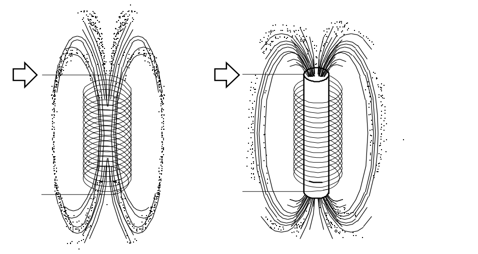
Fig 5



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 6)

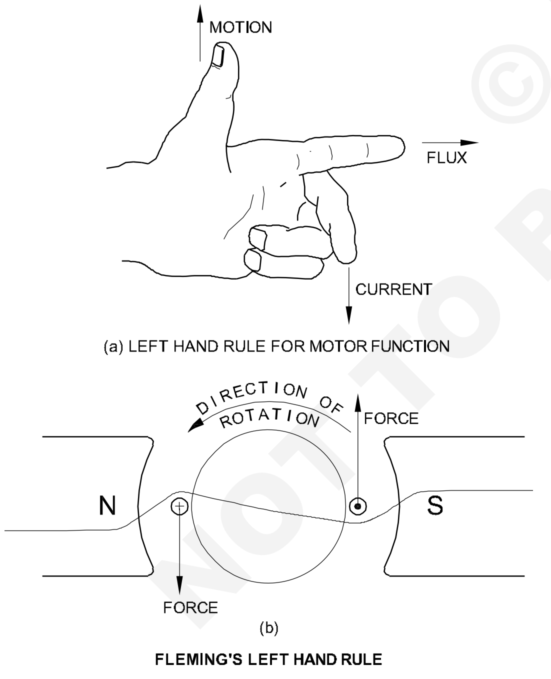
Soft iron is used as a core in an electromagnet because hard steel would become permanently magnetized.

Fig 6



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 7a hold thumb, forefinger and middle finger of the left hand mutuaaly 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 7b rotates in an anticlockwise direction.

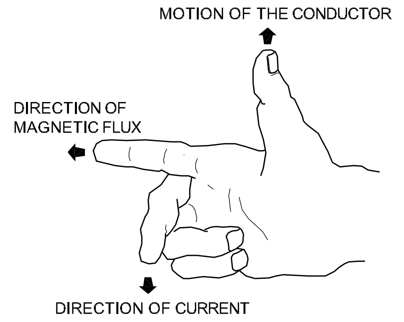
Fig 7



FLEMING'S LEFT HAND RULE

Fleming's right of hand rule: The direction dynamically induced emf can be identified by this rule. Hold the thumb, forefinger and middle finger of the right hand at right angles to each other as shown in Fig 8 such that the forefinger is in the direction of flux and the thumb is in the direction of the motion of the conductor, then the middle finger indicates the direction of emf induced, i.e towards the observe or away from the observer.

Fig 8

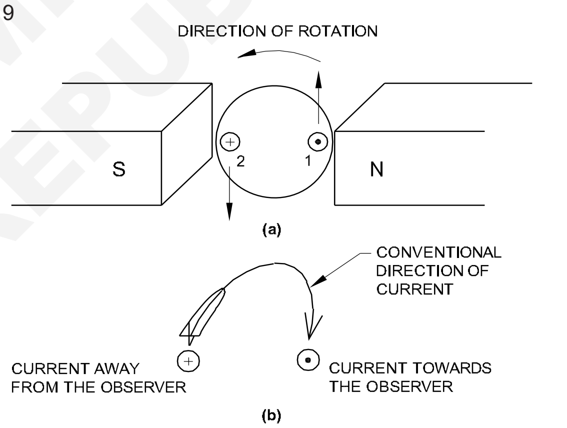


Imagine a conductor moving in between north and south poles in an anticlockwise direction as shown in Fig 9a.

Applying Fleming's right hand rule, we find that the conductor (1) which is moving upwards under the north pole will induce an emf in the direction towards the observe indicated by the dot sign and the conductor (2) which is moving down under the south pole will induce an emf in the direction away from the observe indicated by the plus sign.

Fig 9b indicates the current direction in the form of an arrow. The dot indicates the pointed head of the arrow showing the current direction towards the observer and the plus sign indicates the cross-feather of the arrow showing the current direction away from the observer.

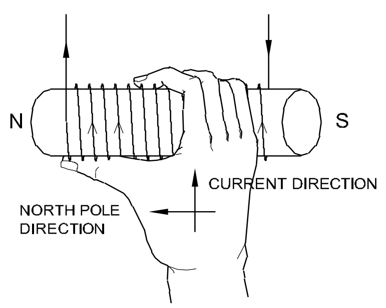
Fig 9



DIRECTION OF THE INDUCED CURRENT

The direction of the magnetic field can be found from palm rule right hand palm rule. (Fig 10)

Fig 10



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 11a)

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.

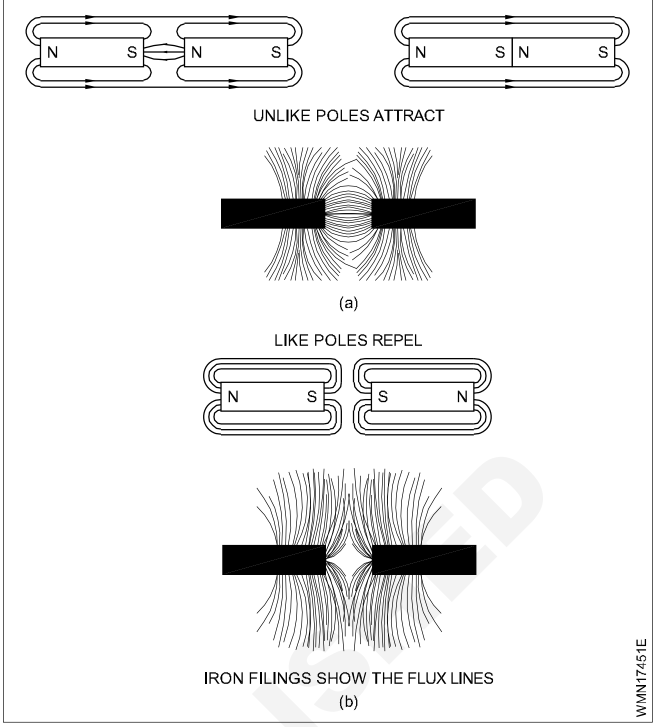
The interaction of the flux lines can also be shown with iron filings. (Fig 11b)

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.

Fig 11



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)**
- **state hysterisis and explain hysterisis loop.**

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).

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

$\phi = \frac{NI}{S}$ Where ϕ is flux and reluctances $S = \frac{\ell}{\mu_o \mu_r a}$

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.

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.

$$H = \frac{M.M.F}{\text{Length of coil in meters}} = \frac{NI}{\ell}$$

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).

$$B = \frac{\phi}{A} \text{ Weber/ } m^2$$

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

μ = B/H

where B is the flux density

H is the magnetising force.

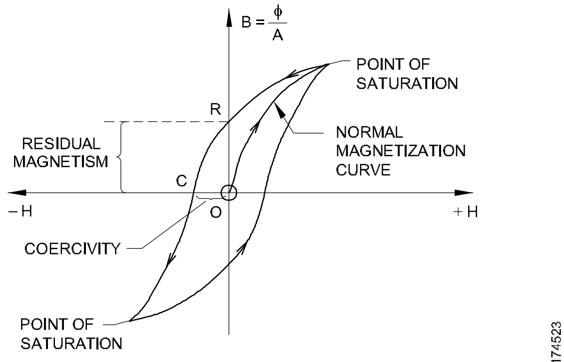
Hysteresis: Consider the graphical relation between B and H for a magnetic material. Since μ = B/H, the graphical relationship shows how the permeability of a material varies with the magnetizing intensity H.

Assume that the magnetic core is initially completely demagnetised. As we increase the current, $H = \frac{NI}{\ell}$ 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 1.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.**

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.

Fig 3



HYSTERESIS LOOP FOR MATERIAL USED IN AN AC CIRCUIT

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.

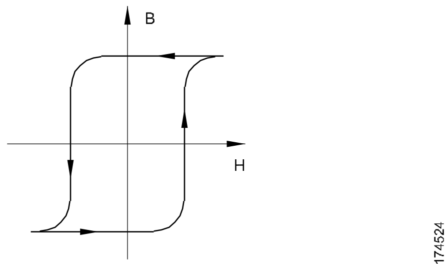
The shape of a B-H loop is an indication of the magnetic properties of the material. (Fig 2)

Hysteresis results in the dissipation of energy which appears in the form of heat.

Mutual Induction

When two or more coils one magnetically linked together by a common magnetic flux, they are said to have the property of mutual induction. It is the basic operating

Fig 4



HYSTERSIS LOOP FOR PERMANENT MAGNET

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.

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.

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.

Principle of electro magnetic induction

Objectives: At the end of this lesson you shall be able to
- **state the principle of electro magnetic induction**
- **state the Faraday's of electro magnetic induction.**

Principle of electro magnetic induction

Faraday's laws of electro magnetic induction are also applicable for conductors ccarrying alternating current.

What are Faraday's law of electro magnetic 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 magnetic of the induced emf is equal to the rate of change of flux linkage.

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.

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 electromagnetism, the induced emf is called as statically induced emf.

There are two types statically induced emf as stated below;

1 Self induced emf produced with in thte same coil.

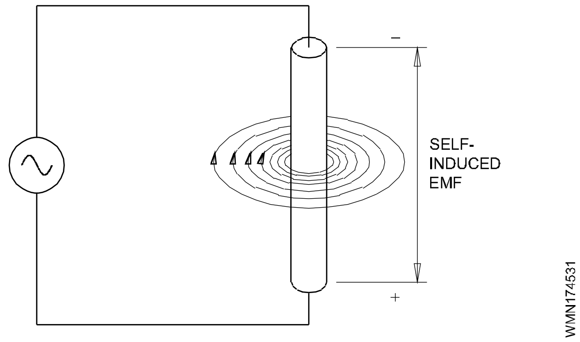
2 Mutually induced emf produced in the neighbouring coil

Self induction: When an alternating current flows in a conductor and the current periodically changes the direction, the magnetic field it produces also reverses the direction. 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. Then it 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 cut through the conductor.

According 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 called self-inductance. (Fig 1)

Fig 1



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 current.

Devices which are used to provide inductance in a circuit are called inductors. Inductors are also known as chokes, coil and reactors. Inductors are usually coils of wire.

Factors determining inductance: The inductance of an inductor is primarily determined by four factors.

- Types of core permeability of the core μ_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'.

Counter EMF

Objectives: At the end of this lesson you shall be able to
- **explain the term counter EMF (CEMF) and Lenz's law.**

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).

Lenz's law states that a cemf always has a polarity which opposes the force that created it.

Eddy currents are caused by voltages induced into the conductors and other surrounding metal parts. They are directly proportional to the frequency of the supply. The heat produced by these currents tends to increase the effective resistance of the circuit.

As the alternating voltage varies in strength, the stress on the conductor insulation increases and decreases. This variation in electric stress also produces heat which increases the circuit resistance.

Capacitors - types - functions and uses

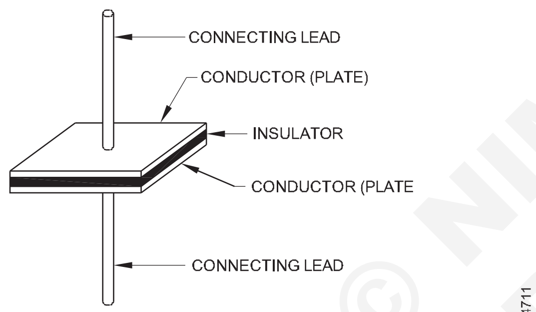
Objectives: At the end of this lesson you shall be able to
- **describe capacitor its construction and charging**
- **explain capacitance and the factors determining**
- **state the different types and application of capacitors.**

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. The unit of charge is coulomb and it is denoted by the letter `C'.

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**.

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

$$\text{as } C = \frac{Q}{V}$$

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. Capacitive reactance Xc expressed in Ohms just like a resistance in limiting the AC current flow.

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 Fig (2a) and (b).

Mica capacitors: There are two types of mica capacitors, stacked foil as shown in Fig 2(c) and Fig 2(d).

Mica capacitors are available with capacitance values ranging from 1 pF to 0.1 pF and voltgage ratings from 100 to 2500 V DC.

Electroly capacitors: Electrolytic capacitors are polarised so that one plate is positive and the other negative.

The basic construction of an electrolytic capacitor is shown in Fig 2 (e) and (f).

Paper/plastic capacitors: There are several types of plastic-film capacitors and the older paper dielectric capacitors.

Fig 3a show a common basic construction used in many plastic-film and paper capacitors. Fig 3b shows a construction view of one type of plastic film capacitor.

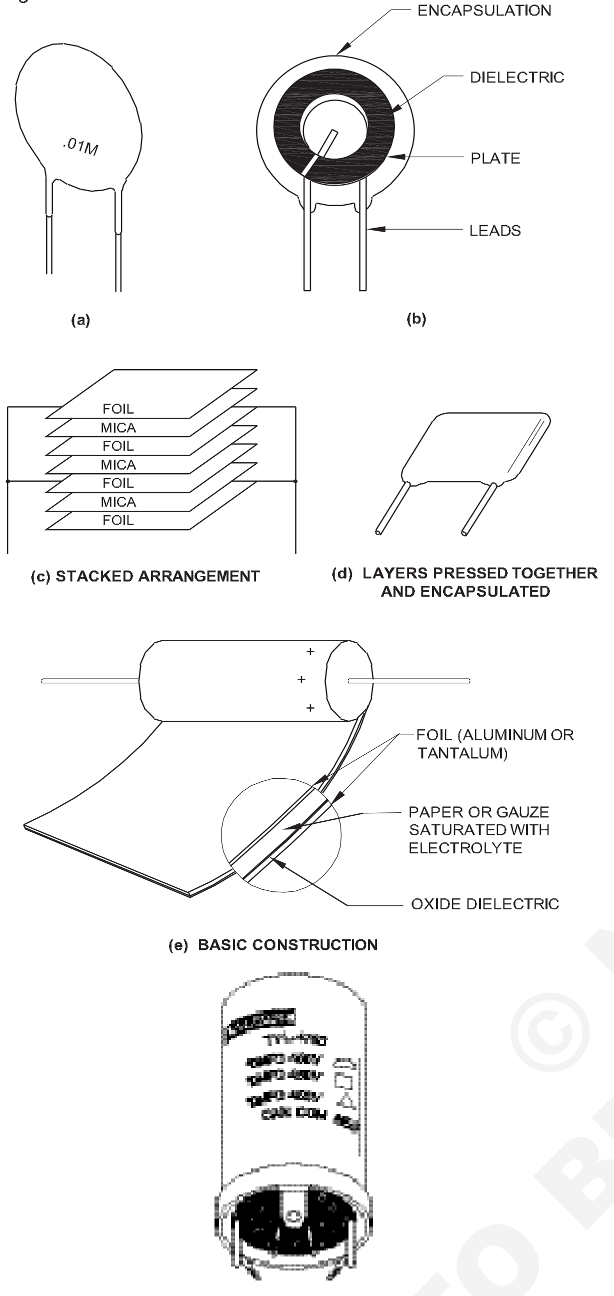
Variable capacitors

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 4(b), are sometimes used as tuning capacitors in applications requiring frequency selection.

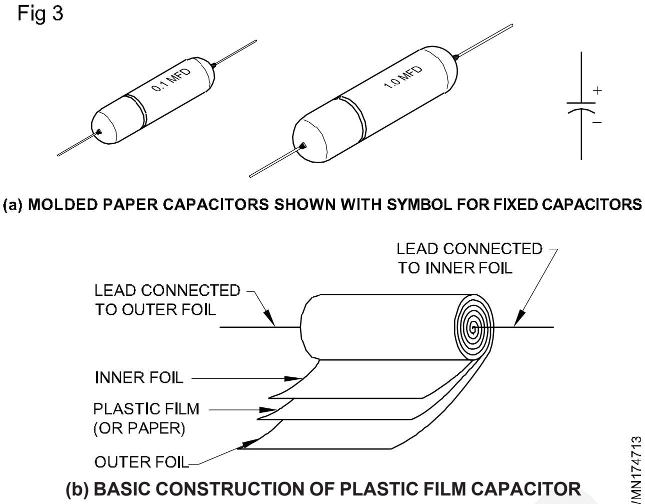
The schematic symbol for a variable capacitor is shown in Fig 4(a).

Fig 2



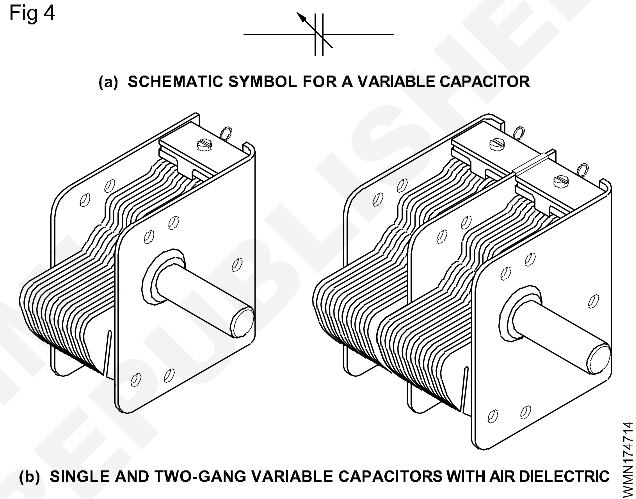
(f) ELECTROLYTIC CAPACITOR AND SYMBOL

Fig 3



(b) BASIC CONSTRUCTION OF PLASTIC FILM CAPACITOR

Fig 4



(b) SINGLE AND TWO-GANG VARIABLE CAPACITORS WITH AIR DIELECTRIC

Application of capacitors with type and ratings - Chart I

Type	Capacitance	Voltage WVDC (Working voltage DC)	Applications
Paper	0.001-1µF	200-1600	Motors, power supplies.
Electrolytic-aluminum	1-500,000µF	50-500	Power supplies, filters.
Mica	330pF-0.05µF	50-100	High frequency.
Variable-ceramic	1-5 to 16-100pF	200	Radio, TV, communications.
Air	10-365pF	50	Broadcast receivers.

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

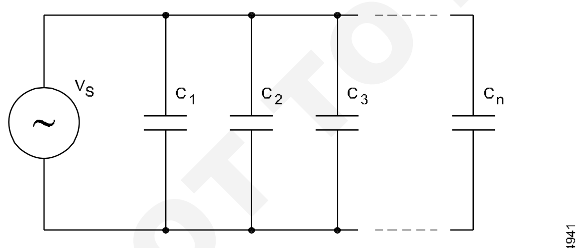
- Voltage rating of capacitors should be higher than the supply voltage Vs.
- Polarity should be maintained in the case of polarised capacitors (electrolytic capacitors).

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 capacitances. The calculation of total parallel capacitance is analogous to the calculation of total resistance of a series circuit.

Fig 1



CAPACITORS IN PARALLEL

By comparing Figs 2a and 2b, you can understand that connecting capacitors in parallel effectively increases the plate area.

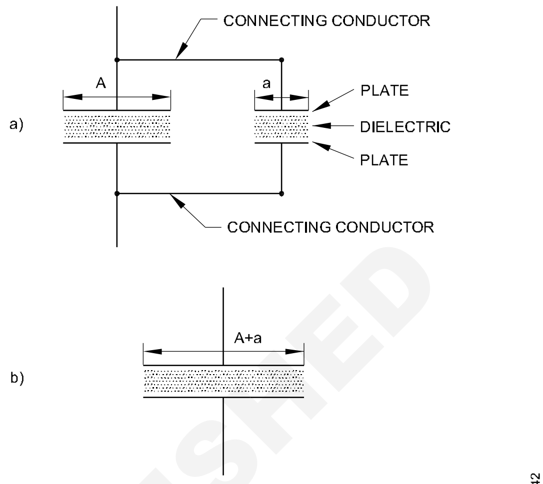
General formula for parallel capacitance: The total capacitance of parallel capacitors is found by adding the individual capacitances.

$C_T = C_1 + C_2 + C_3 + \ldots\ldots\ldots\ldots + C_n$

where C_T is the total capacitance,

C_1, C_2, C_3 etc. are the parallel capacitors.

Fig 2



CAPACITORS IN PARALLEL. THE EQUIVALENT CAPACITANCE IN (b) IS EQUAL TO THE SUM OF THE CAPACITANCES IN (a).

Charge stored in parallel grouping: 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.

$Q_T = Q_1 + Q_2 + Q_3 + \ldots.. + Q_n$

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, $C_T = C_1 + C_2 + C_3$

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.

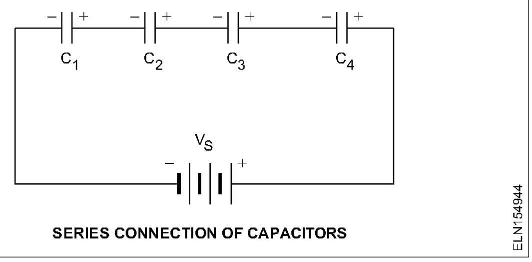
Conditions for series grouping

– 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 3 is analogous to the connection of resistances in series or cells in series.

Fig 3



SERIES CONNECTION OF CAPACITORS

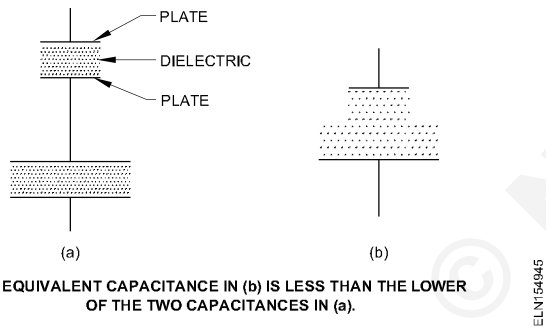
Total capacitance: When capacitors are connected in series, the total capacitance is less than the smallest capacitance value, because

- the effective plate separation thickness increases
- and the effective plate area is limited by the smaller plate.

The calcualtion of total series capacitance is analogous to the calculation of total resistance of parallel resistors.

By comparing Figs 4a and 4b 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 4



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

$$C_T = \frac{C_1 C_2 C_3}{(C_1 C_2) + (C_2 C_3) + (C_3 C_1)}$$

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.

Alternating current - terms - vector diagrams - AC circuits

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**
- **state the advantages of AC over DC.**

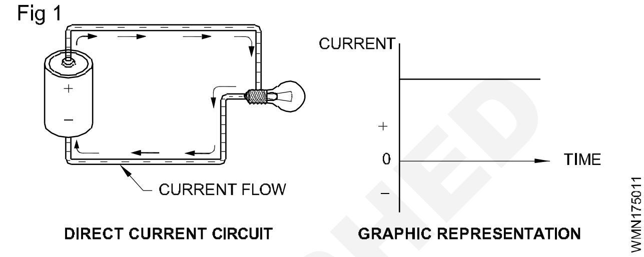
Direct current (DC)

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.

Dry cells are commonly used as a DC voltage source.

Fig 1



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.

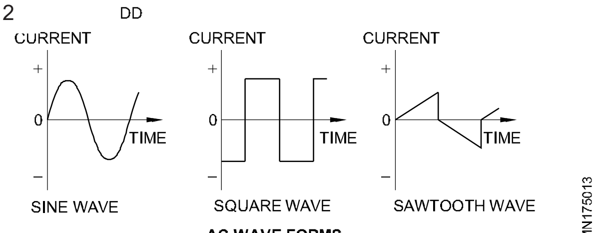
Comparison of AC and DC

	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.
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.	Nil
Types	Sinusoidal, trapezoidal, triangular, square	Pure

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 2)

Fig 2



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.

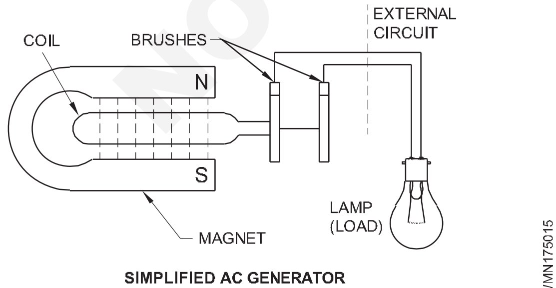
AC voltage is used because it is much easier and cheaper to generate, and when transmitted over long distances, the power loss is low.

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. 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.

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 3)

Fig 3



SIMPLIFIED AC GENERATOR

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.

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 4. 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.

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 5)

Fig 5

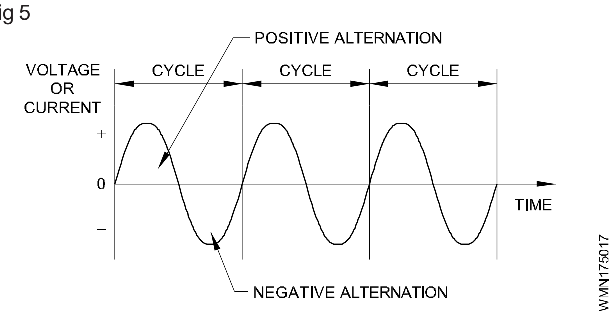
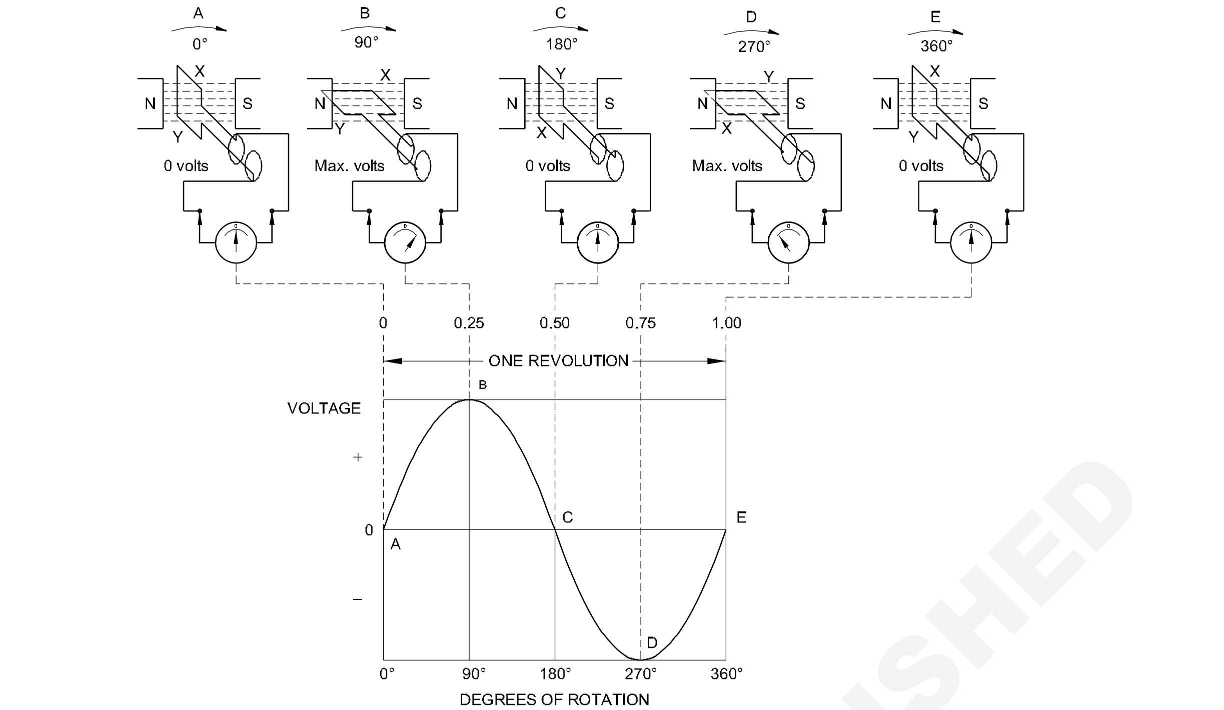


Fig 4



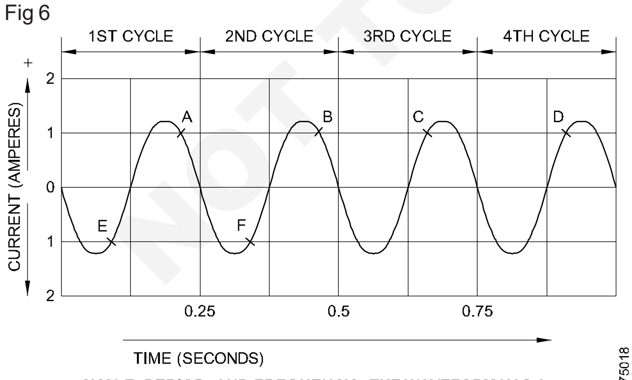
GENERATION OF AN ALTERNATING VOLTAGE: AS THE LOOP ROTATES THROUGH THE MAGNETIC FIELD. THE AMOUNT AND POLARITY OFTHE VOLTAGE CHANGES WITH ANGLE AND DIRECTION OF MOTION.

Period: The time required to produce one complete cycle is called the period of the wave-form. In Fig 6, 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 6-AB, CD or EF.)

Frequency: The frequency of an AC sine wave is the number of cycles produced per second.(Fig 6) The SI unit of frequency is the hertz (Hz). For example, the 240V AC at your home has a frequency of 50 Hz.

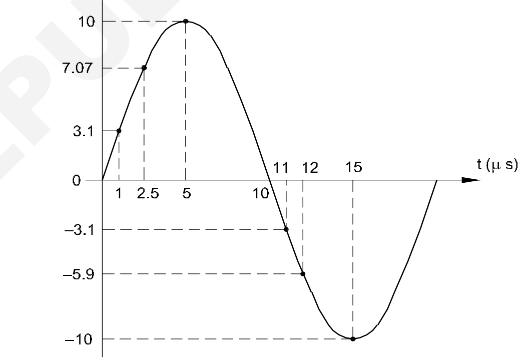
Fig 6



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 7. 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 7

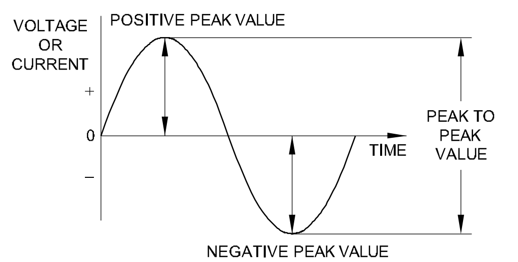


EXAMPLE OF INSANTANEOUS VALUES OF A SINE WAVE VOLTAGE

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 8)

Fig 8



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.

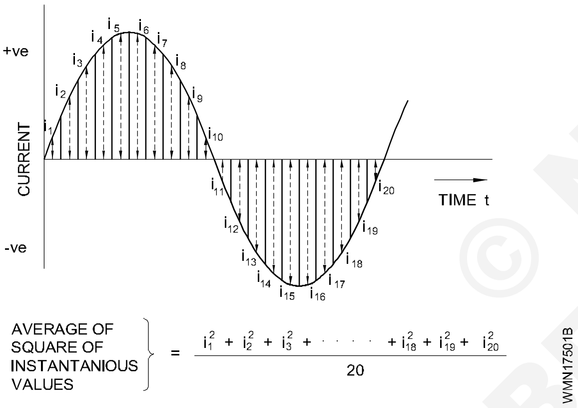
Peak-to-peak value: The peak-to-peak value of a sine wave refers to its total overall value from one peak to the other. (Fig 8) It is equal to two times the peak value.

Effective value (RMS 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 9)

Fig 9



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, $V = 0.707\ V_m$

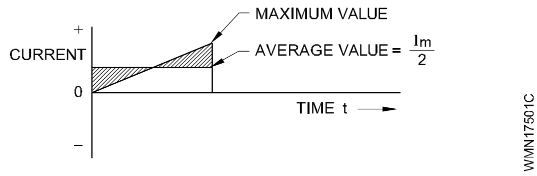
for current, $I = 0.707\ I_m$

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 10, the average value would be one half of the maximum value.

Fig 10



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.

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.

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.

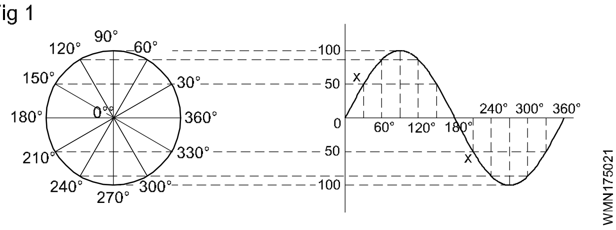
Phasor: Phasor is a vector that is rotating at a constant angular velocity. A straight line with an arrow head is used to represent graphically the magnitude and phase of a sinusoidal alternating quantity (i.e. current, voltage and power) is called phasor.

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.

Using the same scale as used for the radius of the circle, the vlaue of voltage can be measured. This value is the emf

Fig 1



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.

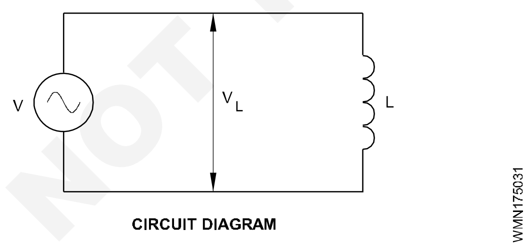
Scalar quantity	Vector quantity
1 Scalar quantity can be presented by magnitude only, for example - energy, volume etc.	Vector quantity must represent magnitude and direction also, for example - force velocity etc.
2 Addition and substraction of scalar quantities can be done algebraically	Addition and subtraction of vector quantities cannot be done algebracially but by vector summation.

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.**

Circuit with pure inductance only: 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



Phase: Phase can be an express on relative displacement between two corresponding features of two wave forms having the some frequency.

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 2&3)

Fig 2

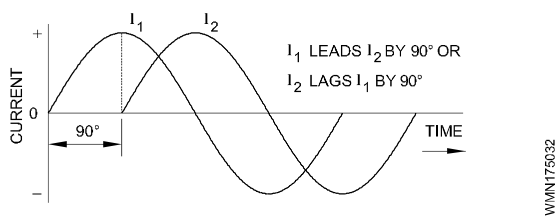
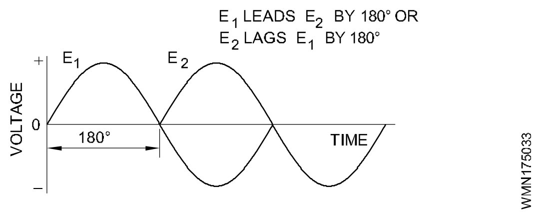


Fig 3



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.

Inductive reactance: The cemf acts just like a resistance to limit the current flow. 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.

In a circuit containing only inductance, Ohm's Law can be used to find the current and voltage by substituting X_L for R.

$$I_L = \frac{V_L}{X_L}$$

$$X_L = \frac{V_L}{I_L}$$

$$V_L = I_L X_L$$

where I_L = current through the inductance, in amperes

V_L = voltage across the inductance, in volts

X_L = inductive reactance in ohms

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 diagram in Fig 4.

The average true power, P, is zero, in a pure inductance. In AC circuits,

Power = VI Cos ϕ watts

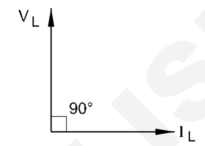
where ϕ is the phase angle between voltage and current.

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'.

Fig 4



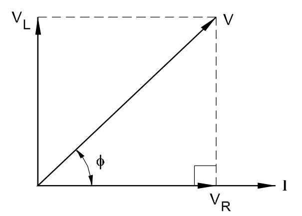
(a) PHASOR DIAGRAM

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°.

Fig 1



PHASOR DIAGRAM OF R & L SERIES CIRCUIT

Impedance of a series RL circuit: The total opposition to current in a series, RL circuit, is called the impedance Z. Impedance is measured in ohms as are resistance and inductive reactance. Impedance is the vector sum of resistance and reactance.

Consider the `voltage triangle' for a series, RL circuit, as shown in Fig 2. This is similar to the phasor diagram in Fig 1 with V_L transferred to make a closed triangle.

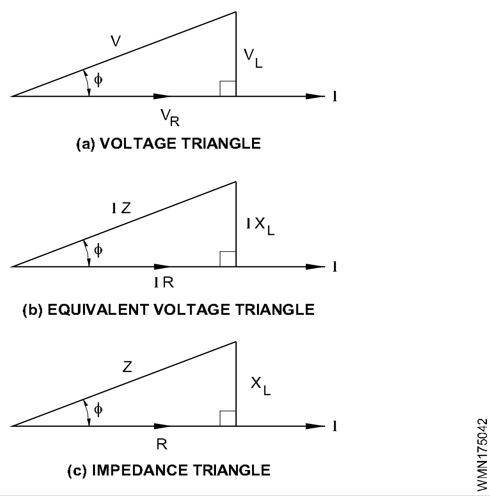
where Z is the impedance in ohms

R is the resistance in ohms

X_L is the inductive reactance in ohms

and $I = \frac{V}{Z}$ amperes (A).

Fig 2



Given $V^2 = V_R^2 + V_L^2$ and $V_R = IR$ and $V_L = IX_L$

then $V = \sqrt{(IR)^2 + (IX_L)^2}$

$$= \sqrt{I^2R^2 + (I^2X_L)^2}$$

$$= \sqrt{I^2(R^2 + X_L^2)}$$

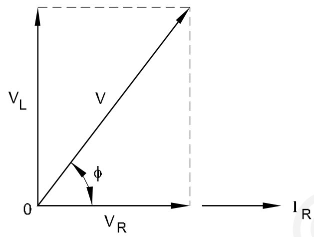
$$= I\sqrt{R^2 + X_L^2} \text{ and } \frac{V}{I} = \sqrt{R^2 + X_L^2}$$

But $\frac{V}{I}$ is the impedance Z.

Therefore, $Z = \sqrt{R^2 + X_L^2}$ ohms

Power in a series RL circuit: We have seen that inductance is always accompanied by resistance. 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 3.

Fig 3



CURRENT REFERENCE VECTOR

WMN175043

This means, unlike pure resistance and pure reactance, the product of the voltmeter and ammeter readings is a combination of the true and (quadrature) reactive power. We call the product of total V and total **I** apparent power. 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.

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 $VA = \sqrt{(W^2) + (VAR^2)}$

This relation can be represented in a power triangle, as in Fig 4.

Fig 4 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.

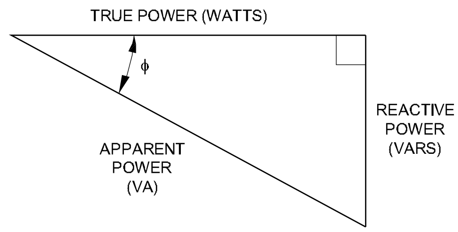
W = VA Cos ϕ

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 4, we see that the ratio of the true power to the apparent power is cosine of the angle Ø.

Fig 4



POWER TRIANGLE

POWER TRIANGLE RELATIONS FOR A SERIES RL CIRCUIT

WMN175045

Power factor = $\frac{W}{VA}$ = Cos ϕ

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 $\frac{R}{Z}$

$$\text{Power factor (PF)} = \frac{W}{VA} = \frac{V_R}{V} = \frac{R}{Z} \cos\phi$$

What should be the power factor for a circuit containing pure resistance only?

As the phase angle Ø between current and voltages is ϕ = 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.

AC Simple circuit - with capacitor only

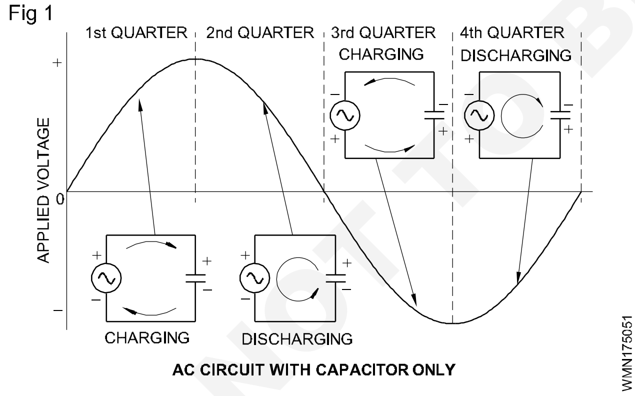
Objectives: At the end of this lesson you shall be able to
- **explain AC circuit with capacitor only**
- **state phase relation between V and I**
- **state power in pure capacitance only.**

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.

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.

Fig 1



AC CIRCUIT WITH CAPACITOR ONLY

It can be said, then, that although a capacitor blocks DC it passes AC.

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 inductive reactance, capacitive reactance is expressed in ohms. Ohm's Law can also be applied to a circuit containing capacitive reactance only.

$$I_c = \frac{V_c}{X_c}$$

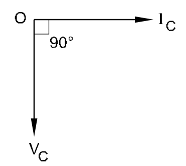
where, I_c is current through capacitor in amps

V_C is the voltage across the capacitor in volts

X_C is the capacitive reactance in ohms.

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 2.

Fig 2



(a) VECTOR DIAGRAM OF CURRENT & VOLTAGE.

The average true power, P, is zero in a pure capacitance.

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.

As in the case of pure inductive circuit, the power factor of the pure capacitive circuit is also zero.

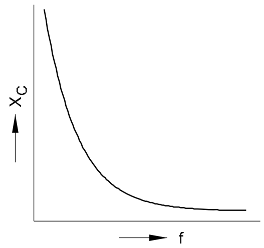
This is because the angle between the current and voltage in a capacitive circuit is 90°. Result cos ϕ = 0.

R - C Series circuit

Objectives: At the end of this lesson you shall be able to
- **state the effect of frequency on capacitive reactance in R-C series circuit**
- **calculate power factor**
- **determine the power factor and phase angle.**

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

$$X_C \propto \frac{1}{f}$$

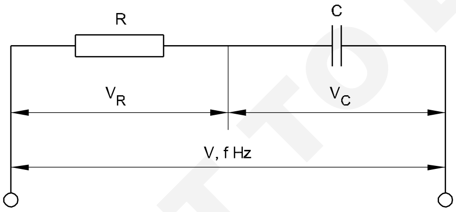
When the capacitive reactance X_C increases the circuit current decreases.

$$I \propto \frac{1}{X_C}$$

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 θ can be determined as follows. (Fig 2)

$$X_C = \frac{1}{2\pi fC}$$

Fig 2

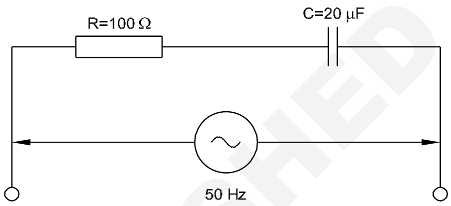


$$Z = \sqrt{R^2 + X_C^2}$$

$$\text{Power factor, } \cos\theta = \frac{R}{Z}$$

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.

$$Z = \sqrt{R^2 + X_C^2}$$

$$= \sqrt{10000 + 25600}$$

$$= \sqrt{36600} = 191.3\Omega$$

$$P.F. = \frac{R}{Z} = \frac{100}{191.3} = 0.522$$

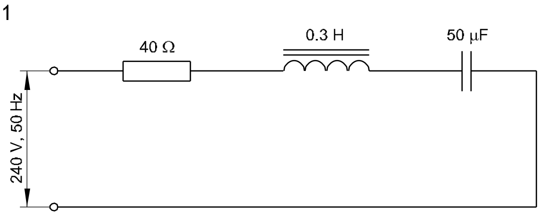
RLC series circuit

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.

Fig 1



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.

Calculate the resultant reactance in RLC circuit : Inductance and capacitance have directly opposite effects in an AC circuit. To calculate the net reactance in the above example:

Inductive reactance

$X = 2\pi fL = 314 \times 0.3 = 94.2\Omega$

Capacitive reactance

$$X = \frac{1}{2\pi fC} = \frac{1}{314 \times 0.00005} = \frac{1}{0.0157} = 63.69\ \Omega$$

Net reactance $X_L - X_C = 94.2 - 63.69 = 30.51\Omega$

Calculate the impedance: 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.

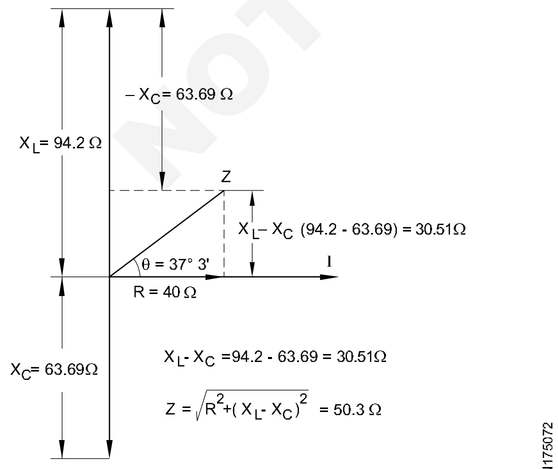
Draw along with current vector the value of R to a suitable scale i.e. 1cm = y ohm.

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.

Current in given RLC series circuit: Current in this series circuit is I = E/Z = 240/50.3 = 4.77 amps.

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.

Calculate the power factor: Power factor of the RLC series circuit can be found from the impedance triangle or voltage triangle as shown below

$$\text{Power factor} = \text{Cos}\ \theta = \frac{R}{Z} \text{ or } \frac{E_R}{V}$$

$$\text{Power factor} = \frac{R}{Z} = \frac{40}{50.3} = 0.795$$

$$= \frac{E_R}{V} = \frac{190.8}{240} = 0.795$$

Calculate the active power (R_A): Active power can be calculated by using any one of the formulae given below

P = EI Cos θ = I^2R

= EI Cos θ = 240 x 4.77 x 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 θ Vars

= 240 x 6.77 x 0.6074

= 695 Vars

Cos θ = 0.795

θ = 37°3'

Sin θ = 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 x 4.77

= 1145 Volt-amperes.

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 $X_C = X_L$

$$2\pi fL = \frac{1}{2\pi fC}$$

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.

Application

These AC circuits 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.

R-L parallel circuits

Objectives: At the end of this lesson you shall be able to
- **explain the admittance triangle and the relationship between conductance, susceptance and admittance**
- **explain susceptance, conductance and admittance by symbols.**

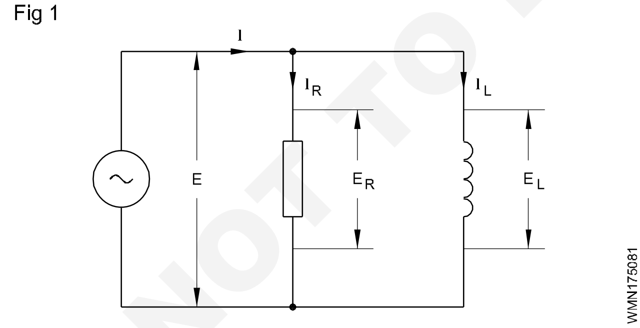
R-L Parallel circuit

When a number of impedances are connected in parallel across an AC voltage, the total current taken by the circuit is the phasor sum of the branch currents (Fig 1).

There are two methods for finding the total current.

- Admittance method
- Phasor method

Fig 1



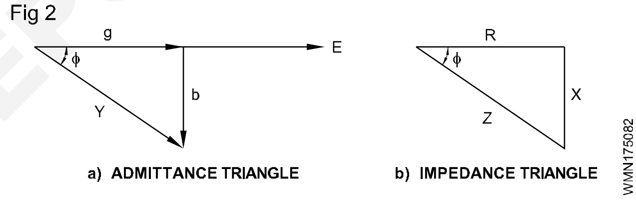
Admittance method

The current in any branch $I = \frac{E}{Z}$

$$= E \times \left|\frac{1}{Z}\right| \text{ where } \left|\frac{1}{Z}\right|$$

is called the **admittance** of the circuit i.e. admittance is the reciprocal of impedance. Admittance is denoted by 'Y' (Fig 2).

Fig 2



$$I = E \times \left|\frac{1}{Z}\right| = EY \quad \text{or} \quad Y = \frac{I}{E}$$

$$\therefore \text{Total admittance } (Y_T) = \frac{\text{total current}}{\text{common applied voltage}}$$

$$= \frac{\text{phasor sum of branch currents}}{\text{common applied voltage}}$$

= phase sum of separate admittance

Note: Supply voltage is referred as V or E interchangeably.

An admittance may be resolved into two components

- A component in phase with the applied voltage called the conductance denoted by g.
- A component in quadrature (at right angle) with the applied voltage called **susceptance,** denoted by b.

$$g = Y \cos\phi = \frac{1}{Z} \times \frac{R}{Z}$$

$$= \frac{R}{Z^2} = \frac{R}{R^2 + Z^2}$$

$$b = Y \sin\phi = \frac{1}{Z} \times \frac{X}{Z} = \frac{X}{Z^2}$$

$$= \frac{X}{R^2 + X^2}$$

The unit of admittance, conductance and susceptance is called the mho symbol ℧

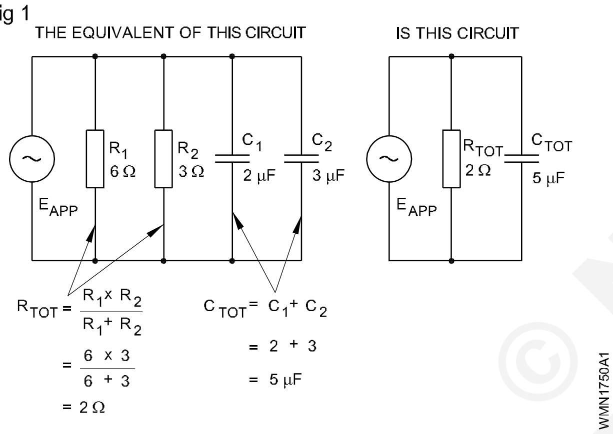
RC Parallel circuit

Objectives: At the end of this lesson you shall be able to

- **state the relationship between branch current, voltage in a parallel circuit.**

Parallel RC circuits: In a parallel RC circuit, one or more resistive loads and one or more capacitive loads are connected in parallel across a voltage source. (Fig 1) The current that leaves the voltage source divides among the branches; so there are different currents in different branches. The current is, therefore, not a common quantity, as it is in the series RC circuits.

Fig 1



Voltage: In a parallel RC circuit, as in any other parallel circuit, the applied voltage is directly across each branch. The branch voltages are, therefore, equal to each other as well as to the applied voltage, and all three are in phase. (Fig 2) So if you know any one of the circuit voltages, you know all of them.

Since the voltage is common throughout the circuit, it serves as the common quantity in any vector representation of the parallel RC circuits. This means that on any vector diagram, the reference vector will have the same direction, or phase relationship, as the circuit voltage.

Branch current: The current in each branch of a parallel RC circuit is independent of the current in the other branches. The current within a branch depends only on the voltage across the branch. (Fig 3)

The current in the resistive branch is calculated from the equation: $I_R = E_{APP}/R$.

The current in the capacitive branch is found with the equation: $I_C = E_{APP}/X_C$.

Fig 2

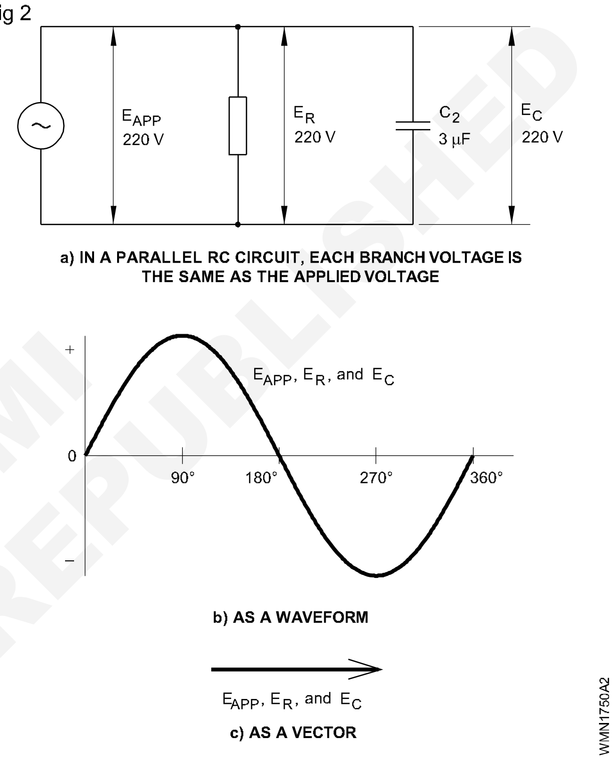
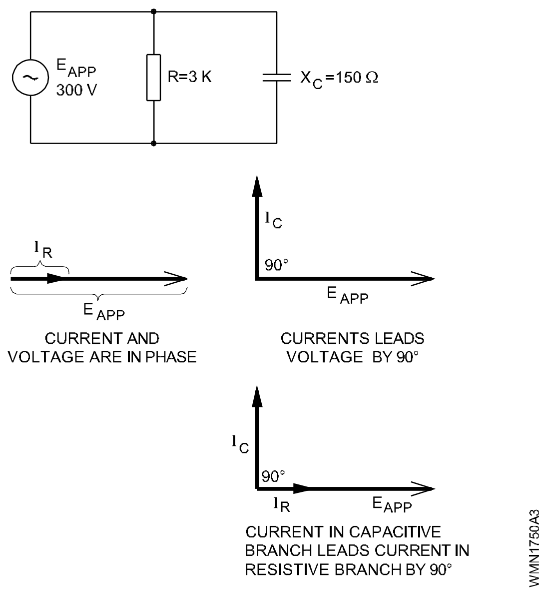
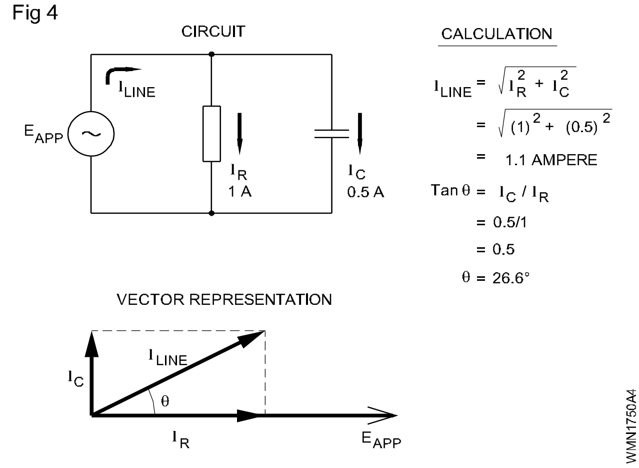


Fig 3



The current in the resistive branch is in phase with the branch voltage, while the current in the capacitive branch leads the branch voltage by 90 degrees. Since the two branch voltages are the same, the current in the capacitive branch (I_C) must lead the current in the resistive branch (I_R) by 90 degrees. (Fig 4)

Fig 4



Line current: Since the branch currents in a parallel RC circuit are out of phase with each other, they have to be added vectorially to find the line current.

The two branch currents are 90 degrees out of phase, so their vectors form a right triangle, whose hypotenuse is the line current. The equation for calculating the line current, I_{LINE}, is

$$I_{LINE} = \sqrt{I_R^2 + I_C^2}$$

If the impedance of the circuit and the applied voltage are known, the line current can also be calculated from Ohm's Law.

$$I_{LINE} = \frac{E}{Z}$$

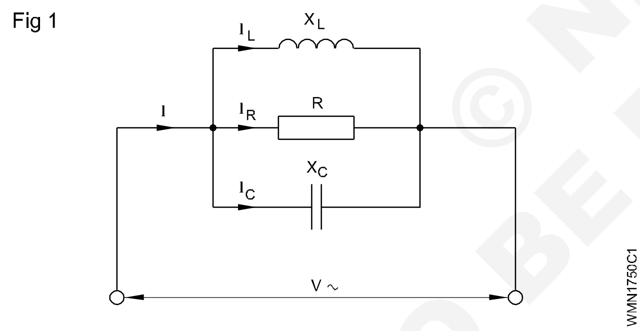
R, L and C Parallel circuit

Objectives: At the end of this lesson you shall be able to

- **explain RLC parallel circuit.**

Parallel connection of R, X_L and X_C: X_L and X_C oppose each other, that is to say, I_L and I_C are in opposition, and partly oppose one another (Fig 1).

Fig 1



$I_X = I_C - I_L$ or $I_L - I_C$, depending on whether the capacitive or inductive current dominates.

Graphic solution: when $I_L > I_C$

1 V as common value

2 I_R in phase with V

3 I_C leads by 90°

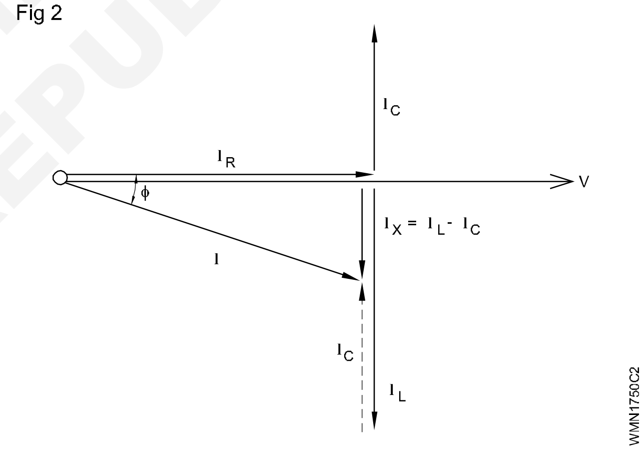
4 I_L lags by 90°

5 $I_X = I_L - I_C$

6 I as resultant

ϕ in this case inductive, I lags (Fig 2)

Fig 2



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.

Power factor - improvement of power factor

Objectives: At the end of this lesson you shall be able to
- **define power factor - explain the causes of low power factor**
- **list out disadvantage of low power factor and advantage of higher power factor in a circuit**
- **explain the methods to improve the power factor in an AC circuit**
- **illustrate the importance of power factor improvement in industries**
- **distinguish between leading, lagging and zero PF**
- **state the recommended power factor as per ISI 7752 (Part I) 1975 for electrical equipment.**

Power Factor (P.F.)

The power factor is defined as the ratio of true power to apparent power and it is denoted by Cos θ.

$$\text{i. e. Power Factor} = \frac{\text{True Power } (W_T)}{\text{Apparent Power} (W_a)} = \text{Cos } \theta$$

$$\text{or Cos } \theta = \frac{W_T}{V \text{ x } I}$$

Where W_T is the real power (true power) and is measured in watts or some times in kilowatts (kW). Similarly the product VI is known as the apparent power measured in volt amperes or sometimes in kilo-volt amperes written as kVA.

The majority of AC electrical machines and equipment draw from the supply the apparent power (kVA) which exceeds the required useful power (KW). This is due to the reactive power (kVAR) necessary to produce the alternating magnetic field in motors and transformers.

The ratio of useful power (kW) to apparent power (kVA) is termed the PF of the load. The reactive power is indispensable and constitutes an additional demand on the system.

The principal cause of a low power factor is due to the reactive power flowing in the circuit. The reactive power mostly due to inductive load rather than capacitive load.

Variation in power factor and the type of circuits

The following are the different conditions of the power factor in different circuits.

Unity power factor

A circuit with a unity power factor will have equal real and apparent power, so that the current remains in phase with the voltage, and hence, some useful work can be done. (Fig 1a)

Leading power factor

A circuit will have a leading power factor if the current leads voltage by an angle of φ electrical degrees and the true power will be less than the apparent power. Mostly capacitive circuits and synchronous motors operated at over excitation contribute for leading power factor. (Fig 1b)

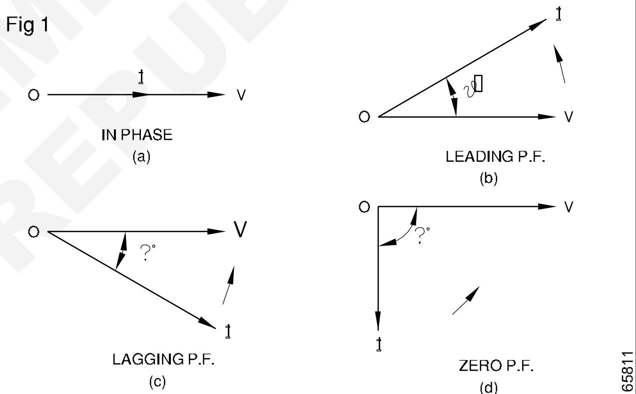
Lagging power factor

In such a circuit the true power is less than the apparent power and current lags behind the voltage by an angle, in electrical degrees. Mostly inductive loads like induction motors and induction furnaces account for lagging power factor. (Fig 1c)

Zero power factor

When there is a phase difference of 90° between the current and voltage, the circuit will have zero power factor and no useful work can be done. Pure inductive or pure capacitive circuits account for zero power factor. (Fig 1d)

Fig 1



PHASE RELATIONSHIP BETWEEN V AND I

The power factor can be one or less than one but can never be greater than one.

Table 1 shows the most common electrical appliances used, the power in watts and the average power factor.

TABLE 2 shows the power factor of the various installations used in the industries.

Causes of low power factor

The following are the reasons.

i In industrial and domestic fields, the induction motors are widely used. The induction motors always take lagging current which results in low power factor.

ii The industrial induction furnaces have low power factor.

iii The transformers at substations have lagging power factor because of inductive load and magnetising currents.

iv Inductive load in houses like fluorescent tubes, mixers, fans etc.

Table 1

Power factor for single phase electrical appliances and equipment (Reference IS 7752 (Part I) - 1975)

Sl.No.	Appliance/Equipment	Power output		Average
		Min.(W)	Max.(W)	power factor
1	Neon sign	500	5000	0.5 to 0.55
2	Window type air- conditioners	750	2000	0.75 to 0.85
				0.68 to 0.82
				0.62 to 0.65
3	Mixer	150	450	0.8
4	Refrigerator	200	800	0.65
5	Table fan	25	120	0.5 to 0.6
6	Ceiling fan	60	100	0.5 to 0.7
7	Sewing machine	80	120	0.7 to 0.8
8	Washing machine	300	450	0.6 to 0.7
9	Vacuum cleaner	200	450	0.7
10	Tube light	40	100	0.5

Table 2

Power factor for three-phase electrical installations (Reference IS 7752 (Part I) - 1975)

Sl.No.	Type of installation	Power factor
1	Cinemas	0.78 to 0.80
2	Dyeing and printing (Textile)	0.60 to 0.87
3	Plastic moulding	0.57 to 0.73
4	Film studios	0.65 to 0.74
5	Heavy engineering works	0.48 to 0.75
6	Oil and paint manufacturing	0.51 to 0.69
7	Printing press	0.65 to 0.75
8	Flour mill	0.61
9	Textile mills	0.86
10	Oil mill	0.51 to 0.59
11	Foundries	0.59 to 0.87
12	Rolling mills	0.72 to 0.60
13	Irrigation pumps	0.50 to 0.70

The disadvantages of low power factor are as follows.

a For a given true power, a low power factor causes increased current, thereby, overloading of the cables, generators, transmission and distribution lines and transformers.

b Decreased line voltage at the point of application (voltage drop at consumer end) due to voltage drop and power losses in the supply system.

c Inefficient operation of plant and machine (efficiency drops due to low voltage).

d Penal power rates (increased electricity bills).

The advantages of high power factor are as follows.

As the higher PF for a given load, reduces the current, there will be:

a a possibility of connecting extra load on existing generators and transmit additional power through the same lines

b lesser losses and voltage drop in lines; thereby, transmission efficiency is high and the voltage at the point of application will be normal without much drop

c normal voltage improves the efficiency of operation of plants and machinery

d reduction in electricity bills for the given load during the given time.

Method of improving the power factor

To improve the power factor of a circuit, two methods are used:

i to run a lightly loaded synchronous motor with over-excitation on that line in which the PF is to be improved

ii to connect capacitors in parallel with the load.

Usually the capacitor method is used in Indian factories.

Synchronous condenser method

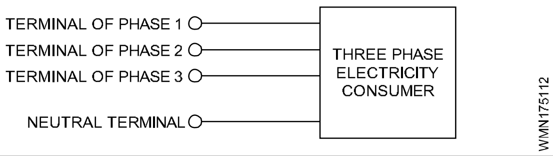
The synchronous motor is used in certain industries as well as in receiving end substations to drive a mechanical load and also to correct the power factor. An over-excited synchronous motor draws leading current to compensate the lagging current taken by the other loads.

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.**

A three-phase power consumer is provided with the terminals of three phases. (Fig 1)

Fig 1



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.

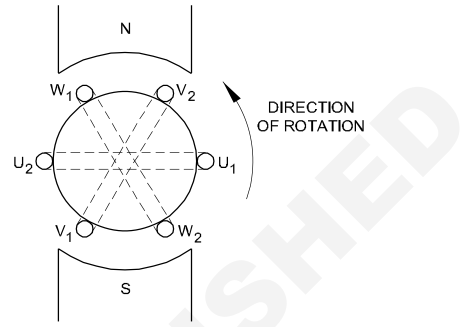
Further, lighting loads can be connected between any one of the three phases and neutral.

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.

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 2)

Fig 2

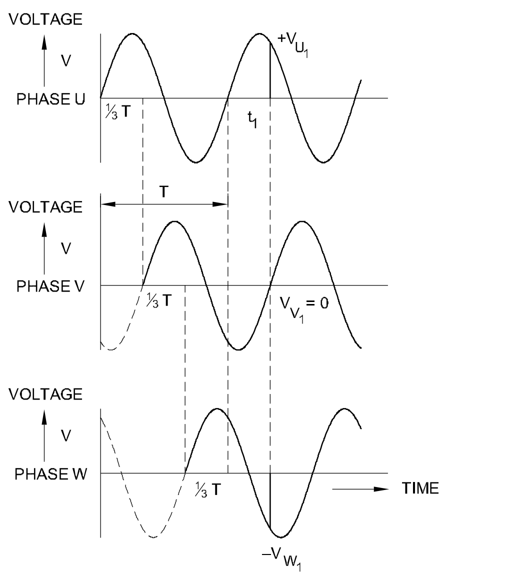


SIMPLIFIED THREE – PHASE ALTERNATOR

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 3)

Fig 3



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 3a) V follows with its zero crossing 1/3 of the period later (Fig 3b), and the same applies to W with respect to V. (Fig 3c)

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

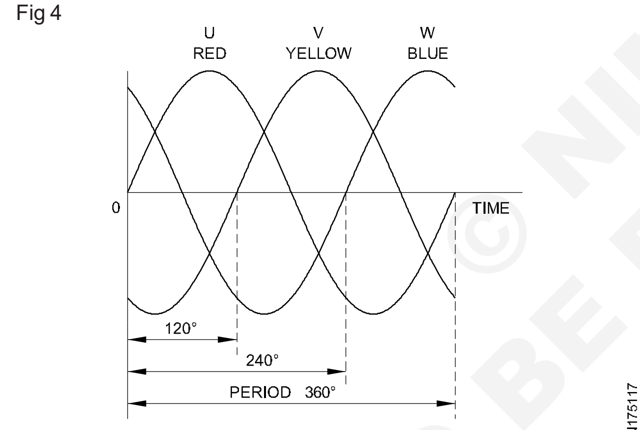
$$V_U + V_V + V_W = 0.$$

The fact that the sum of the instantaneous voltages is zero is illustrated in Fig 4. 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 4.

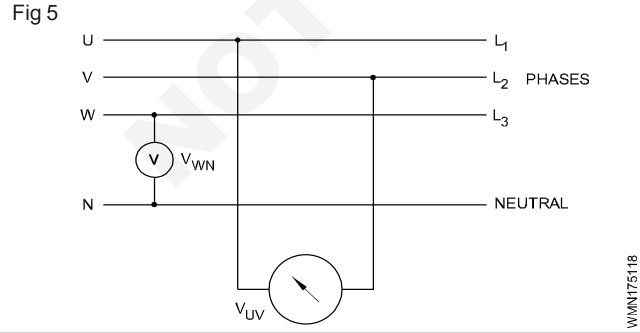
Fig 4



COMBINED WAVE - FORMS OF THREE PHASE SUPPLY

Three-phase network: A three-phase network consists of three lines or phases. In Fig 5, these are indicated by the capital letters U, V and W.

Fig 5

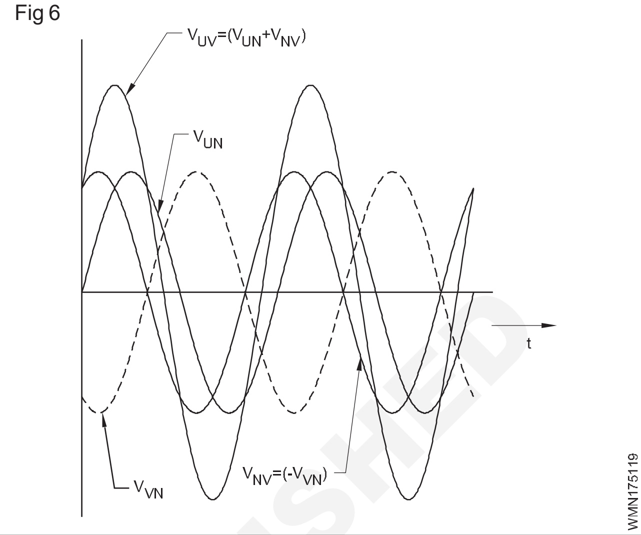


The return lead of the individual phases consists of a common neutral conductor N, which is described later in more detail. Voltmeters are connected between each of the lines U, V and W, and the neutral line N. They indicate the RMS (effective) values of the voltages between each of the three phases 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 6)

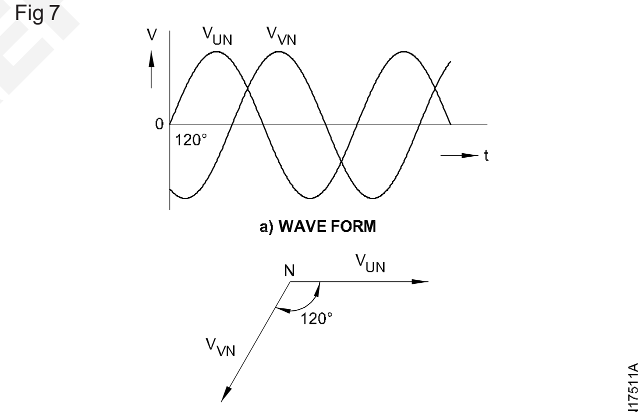
Fig 6



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 7), the RMS value of the voltage V_{UV} is measured, and this is different from any of the three phase voltages.

Fig 7



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° between the two phasors. (Fig 7)

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 $V_{UV} = V_{UN} + V_{NV}$.

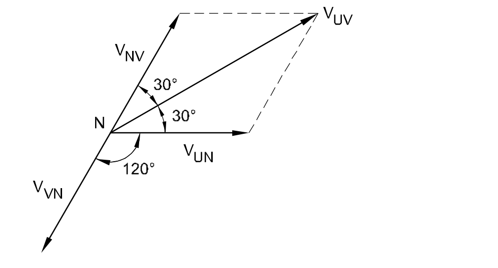
Note that to obtain the line voltage V_{UV} the measurement is made from the U terminal through the common point N to the V terminal, for a star connection.

This fact is illustrated in Fig 8. Starting with the phasors V_{UN} and V_{VN} (Fig 7), 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}.

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

$V_L = \sqrt{3} \times V_P$

Fig 8



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

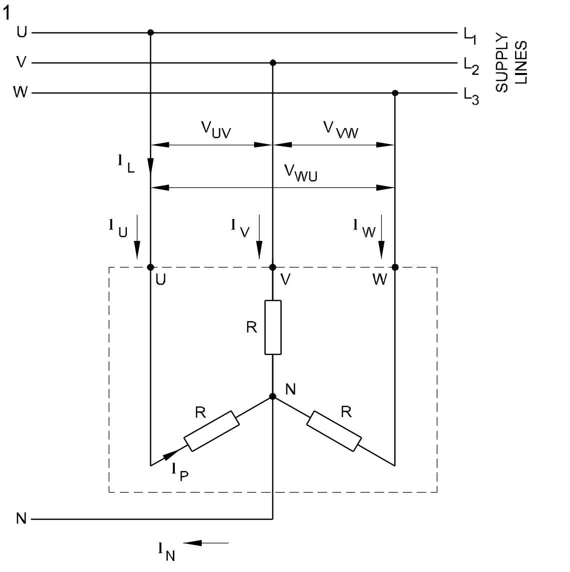
Objectives: At the end of this lesson you shall be able to
- **explain the star and delta systems of connection**
- **state phase relationship between line and phase voltages and current in a star connection delta connection**
- **state the relationship between phase and the voltage and current in star 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

Fig 1



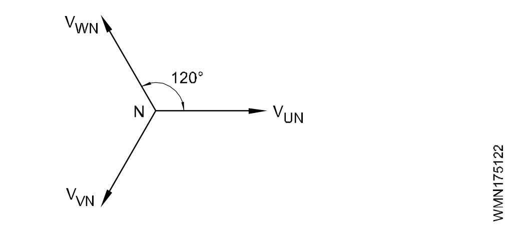
phase voltage and the negative value of the other phase voltage that exist across the two lines (Fig 2).

Thus

$V_L = V_{UV} = (\text{phasor } V_{UN}) - (\text{phasor } V_{VN})$

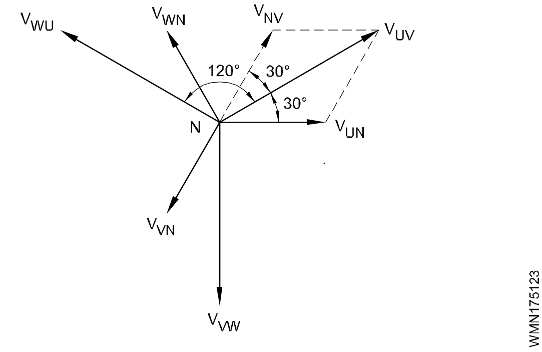
$= \text{phasor } V_{UN} + V_{VN}.$

Fig 2



In the phasor diagram (Fig 3)

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 $V_{UN} = V_{VN} = V_P$

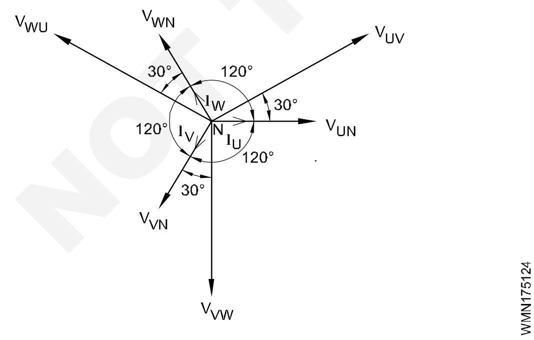
$V_L = \sqrt{3}\ V_P$.

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.

Fig 4



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?

$V_L = \sqrt{3}\,V_P = \sqrt{3} \times 240$

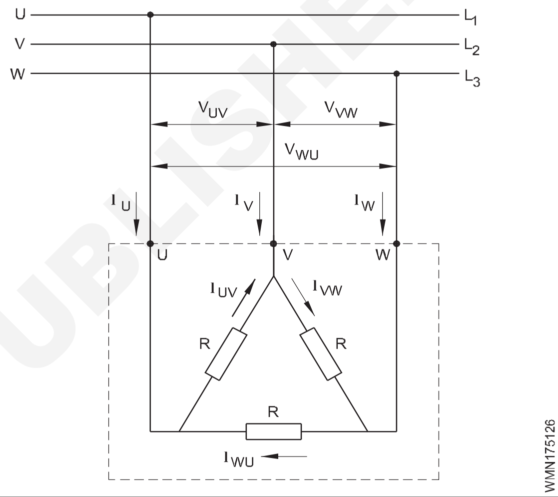
$= 415.7V$

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 5)

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.

> **In contrast to a star connection, in a delta connection the line voltage appears across each of the load phases.**

Fig 5



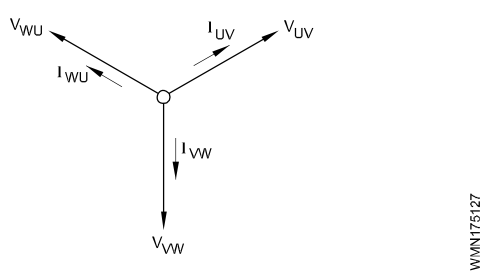
The voltages, with symbols V_{UV}, V_{VW} and V_{WU} are, therefore, the line voltages.

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 6)

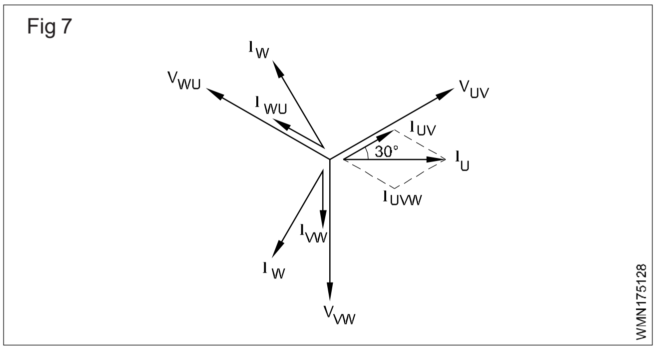
Fig 6



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 7. The line current I_U is the phasor sum of the phase currents I_{UV} and I_{UW}. (See also Fig 7)

Fig 7



Hence, $I_U = I_{UV}\cos 30° + I_{UW}\cos 30°$

But $\cos 30° = \frac{\sqrt{3}}{2}$.

Thus $I_L = \sqrt{3}\ I_{ph}$

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.

Application of star and delta connection with balanced loads

An important application is the `star-delta change over switch' or star-delta starter.

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.

Assignment: 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.

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**
- **explain the effect of broken natural wire.**

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 $V_P = V_L$ ÷ $\sqrt{3}$ and $I_p = I_L$)

Since $3 = \sqrt{3} \times \sqrt{3}$, this equation can be simplified to the form

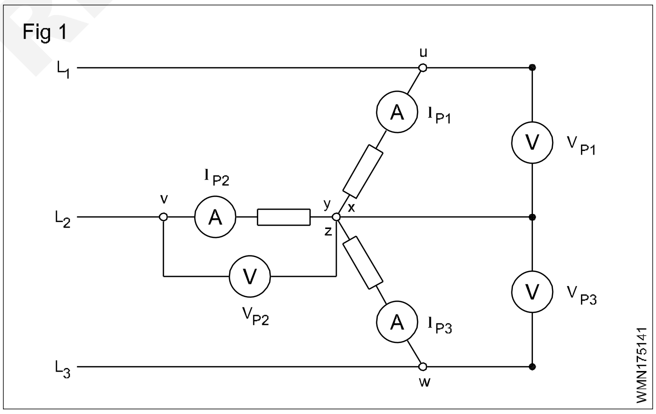
$P = \sqrt{3}\ V_L I_L$

Note that power factor in resistance circuit is unity. Hence power factor is not taken into account.

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.

Fig 1



$P = \sqrt{3} \times V \times I$ (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.

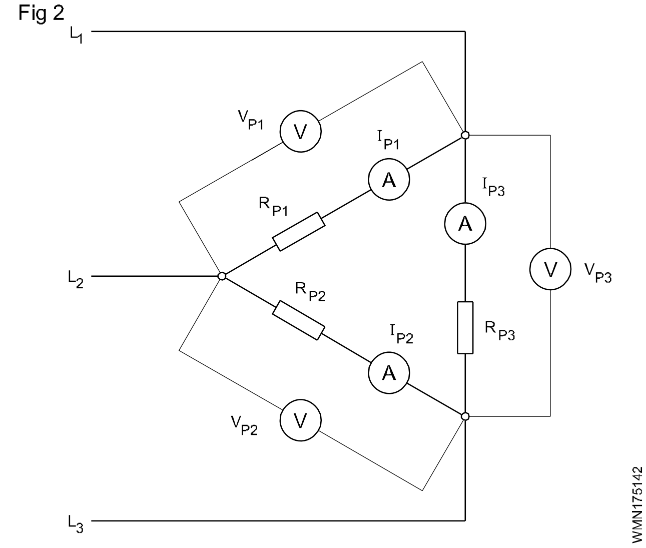
Three-phase power with a delta-connected load: Fig 2 shows the load of three resistances connected in delta. Three times the phase power will be dissipated.

$P = 3P_P = 3V_PI_P$

If the quantities V_P and I_P are replaced by the corresponding line quantities V_L and I_L, we obtain:

Since, $V_L = V_P$

Fig 2



$$I_L = \sqrt{3}\, I_P \text{ and } I_P = \frac{I_L}{\sqrt{3}}$$

but since 3 = $\sqrt{3}$ x $\sqrt{3}$, this equation can be simplified to the form:

$P = \sqrt{3}\ V_L I_L$.(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 Cosϕ	$P = \sqrt{3}\ V_L I_L \cos$	W
Reactive power	Q=VI sinϕ	$Q = \sqrt{3}\, V_L I_L \sin$	var

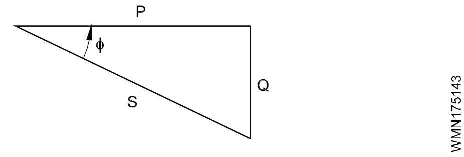
Finally, the well known relationships found in single-phase AC circuits apply also to three-phase circuits.

$$\cos\phi = \frac{\text{activepower}}{\text{apparentpower}} = \frac{P}{S}$$

$$\sin\phi = \frac{\text{reactivepower}}{\text{apparentpower}} = \frac{Q}{S}$$

This can also be seen from Fig 3.

Fig 3

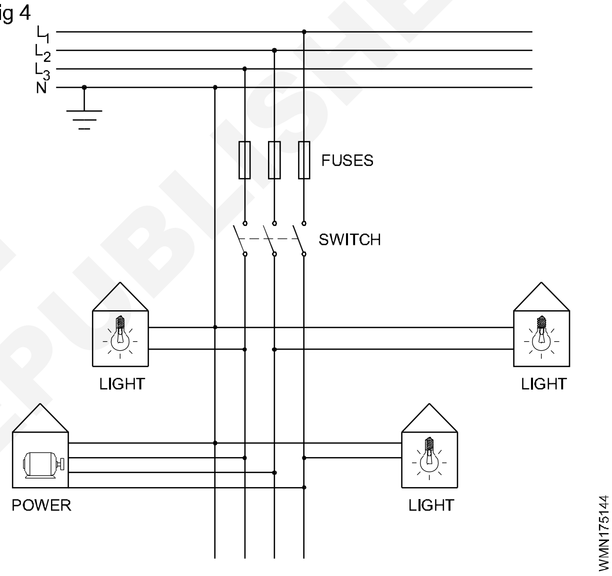


Cos ϕ is called the power factor, while sin ϕ is sometimes called the reactive power factor.

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)

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).

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.

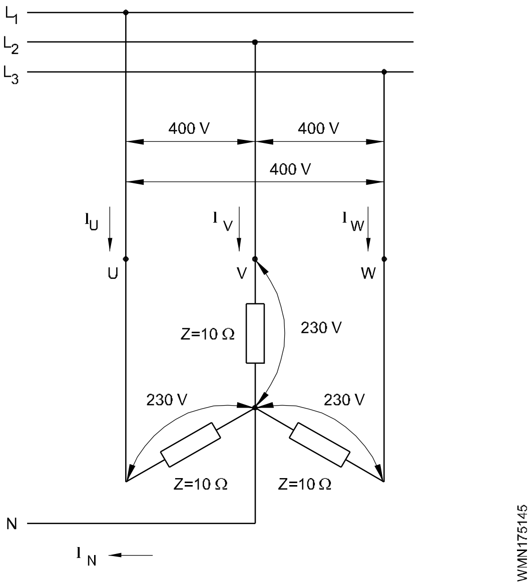
Balanced load in a star connection: In a star connection, each phase current is determined by the ratio of phase voltage and load impedance `Z'.

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/ $\sqrt{3}$).

Fig 5



The three load currents taken froms supply have the same magnitude since the star-connected load is balanced, and they are given by

$$I_U = I_V = I_W = V_P \div Z.$$

Effect of broken neutral wire in three phase four wire systems: A broken Neutral on Three phases Transformer will cause the voltage float up to line voltage depending upon the load balancing of the system. This type of Neutral Floating may damage the customer equipment connected to the Supply.

Floating neutral: If the Star Point of Unbalanced Load is not joined to the Star Point of its Power Source (Distribution Transformer or Generator) then Phase voltage do not remain same across each phase but its vary according to the Unbalanced of the load.

As the Potential of such an isolated Star Point or Neutral Point is always changing and not fixed so it's called Floating Neutral.

Floating neutral condition (Fig 6)

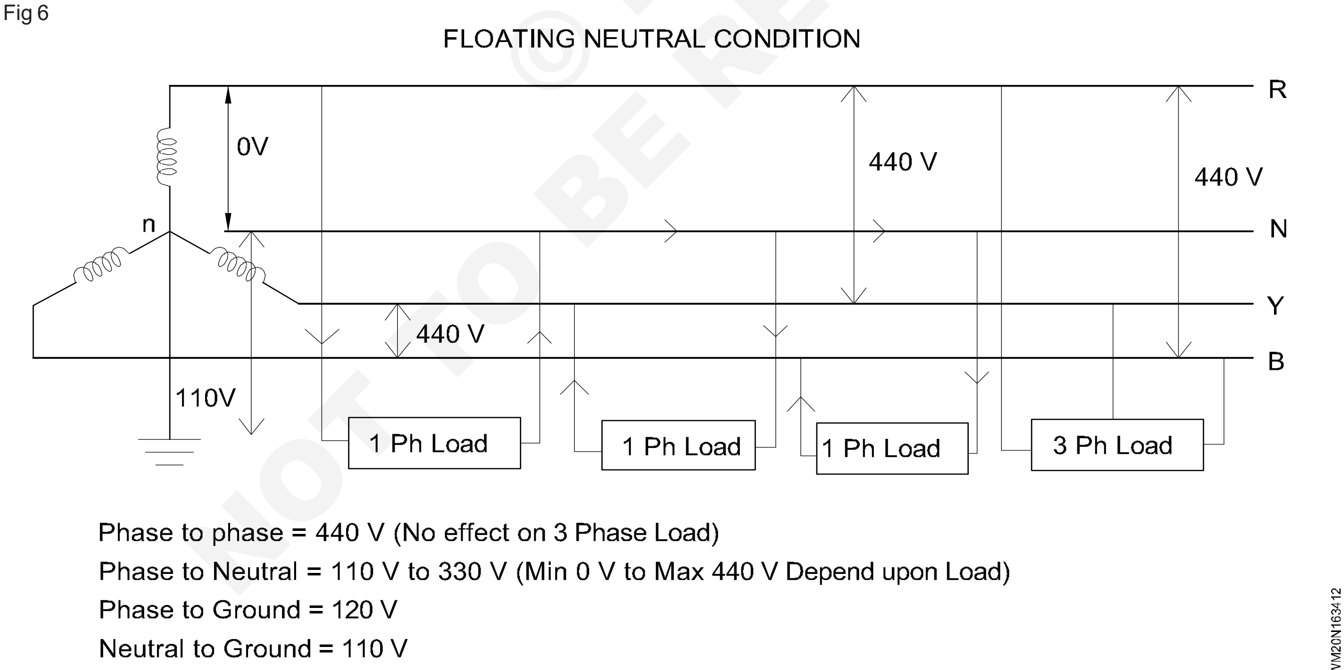
Power flows in and out of customers' premises from the distribution network, entering via the Phase and leaving via the neutral. If there is a break in the neutral return path electricity may then travel by a different path. Power flow entering in one Phase returns through remaining two phases. Neutral Point is not at ground Level but it Float up to Line Voltage.

This situation can be very dangerous and customers may suffer serious electric shocks if they touch something where electricity is present.

Broken neutrals can be difficult to detect and in some instances may not be easily identified. Sometimes broken neutrals can be indicated by flickering lights or tingling taps.

Note: If you have flickering lights or tingly taps in your home, you may be at risk of serious injury or even death.

Fig 6



Instruments - Scales - Classfication - Forces - MC and MI meter

Objectives: At the end of this lesson you shall be able to
- **state the instrument, range, position, types**
- **state the terminal markings in instrument**
- **state the instrument scales type.**

Electrical Measuring Instrument

Electrical measuring instruments (meters) is an apparatus, used for measuring the electrical quantities like current, voltage, resistance power and energy etc.

Identification of instrument

Identification of the instrument for any particular measurement is very important. By wrong identification not only the instrument may be damaged but also we may not get the result that we want.

The instrument should be identified for the quantity to be measured, the range, suitability for a particular type of supply etc. by carefully going through the data available on the dial.

Types of current: The types of supply on which the instrument is suitable for measurement is indicated by symbols as follows.

—	Direct current
~	Alternating current
⎓ ~	Direct and alternating current

Testing potential (voltage): The star mark on the dial indicates the voltage to which the instrument is subjected for test.

☆	Testing potential 500V
☆ 2	Testing potential over 500V eg, 2000V(2KV)

Using position: Instruments must be used as per the specified position mentioned on the dial.

⊥	Vertical using position.
⊓	Horizontal using position.
∠60°	Angle of usage eg. 60^0 tilt angle.

Instruments used in any position other than the one specified may cause error in reading.

Measuring instrument types

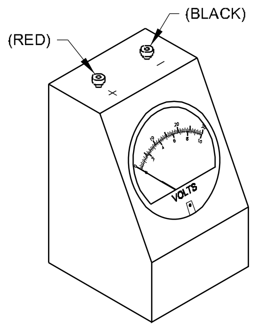
	Moving coil instrument
	Moving iron instrument
	Electrodynamic quotient instrument
	Moving coil instrument with rectifier

Indication error: Instruments are manufactured to read within certain accuracy. This is indicated on the dial by a number close to the other symbols.

1	Indication error ± 1%
2.5	Indication error ± 2.5%
3.5	Indication error ± 3.5%

Terminal markings: In a moving coil type of instrument, the terminals are marked with + and – . The positive (+) terminal is red in colour and the negative(–) terminal is black in colour (Fig 1). This type of instrument must be connected in the circuit with correct polarity. i.e. the +ve of supply to the +ve of instrument and the –ve of supply to the –ve of the instrument.

Fig 1

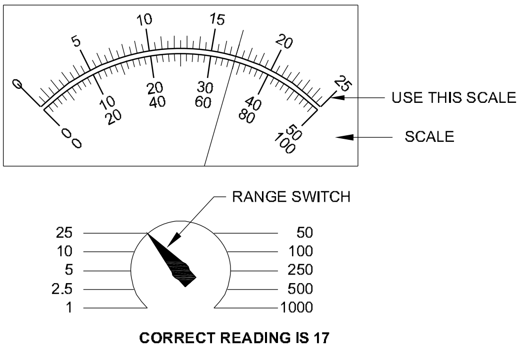


In the moving iron type there is no polarity marking on the terminals. Both the terminals are of the same colour. The instrument can be connected in the circuit without identifying the line and neutral of the supply.

In ohmmeters the terminals are marked in the same way as in the case of the moving coil meters.

A range selector switch is used in some meters (Fig 2). While reading such meters, care should be taken to keep in mind the position of the range selector switch, and read the scale reading corresponding to that selected range.

Fig 2



Classification of electrical instruments - Essential forces, MC and MI meter

Objectives: At the end of this lesson you shall be able to
- **classify electrical instruments with respect to standard, function and operation by the effect of electric current**
- **explain the type of forces required for the proper functioning of an electrical indicating instrument.**

Electrical instruments may be classified based on the following.

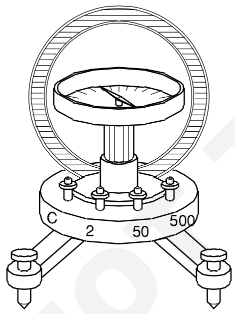
- Manufacturing standards
- Function
- Effects of electric current on the instruments.

Manufacturing standards: The electrical instruments may, in a broad sense, be classified according to the manufacturing standards into absolute instruments and secondary instruments.

Absolute instruments: These instruments give the value of quantity to be measured in terms of deflection and instrument constants. A good example of an absolute instrument is the tangent galvanometer (Fig 1).

These instruments are used only in standard laboratories.

Fig 1

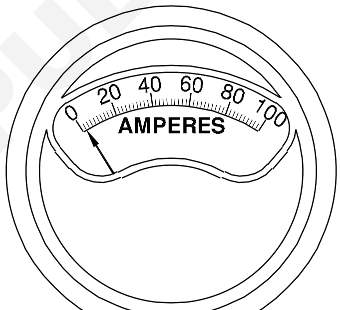


Secondary instruments: In these instruments the value of electrical quantity (voltage, current, power, etc.) to be measured can be determined from the deflection of the instruments on the calibrated dial. These instruments should be calibrated in comparision with either an absolute instrument or with one which has already been caliberated. All the instruments used commercially are secondary instruments.

Functions: Secondary instruments are further classified according to their functions, that is, whether the instrument indicates, or records the quantity to be measured. Accordingly, we have indicating, integrating and recording instruments.

Indicating instruments: These instruments (Figs 2) indicate the value of voltage, current power etc., directly on a graduated dial. Ammeters, voltmeters and wattmeters belong to this class.

Fig 2



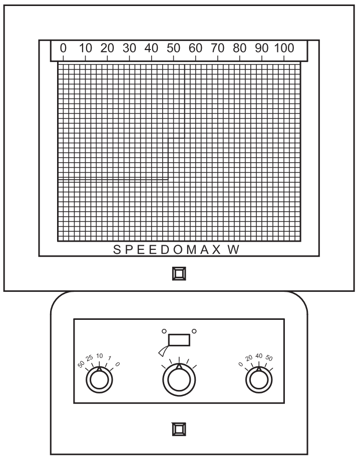
Integrating instruments: These instruments measure the total amount, either the quantity of electricity or the electrical energy, supplied to a circuit over a period of time. Ampere hour meters and energy meters belong to this class. Fig 3 shows the Kilowatt hour/energy meter.

Fig 3

Energy meter

Recording instruments: These instruments register the quantity to be measured in a given time, and are provided with a pen which moves over a graph paper. With this instrument, the quantity can be checked for any particular date and time. Recording voltmeters,ammeters and power factor meters belong to this class. Fig 4 shows such a recording instrument.

Fig 4



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Effects of electric current used on electrical instruments: Secondary instruments may also be classified according to the various effects of electricity upon which their operation depends. The effects utilised are as follows.

- Magnetic effect
- Heating effect
- Chemical effect
- Electrostatic effect
- Electromagnetic induction effect

Essential forces required for an indicating instrument: The following three forces are essential requirements of an indicating instrument for its satisfactory operation. They are

- deflecting force
- controlling force
- damping force.

Deflecting force or operating force: This causes the moving system of the instrument to move from its `zero' position, when the instrument is connected to the supply. To obtain this force in an instrument, different effects of electric current, such as magnetic effect, heating effect, chemical effect etc. are employed.

Controlling force: This force is essential to control the movement of the moving system and to ensure that the magnitude of the deflction of the pointer is always the same for a given value of the quantity to be measured. As such, the controlling force always acts opposite to the deflecting force, and also brings the pointer to zero position when the instrument is disconnected from the supply.

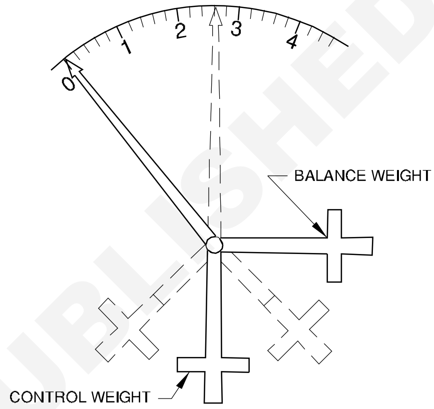
The controlling force could be produced by any one of the following ways.

- Gravity control
- Spring control

Gravity control: In this method, small adjustable weights are attached to the opposite extension of the pointer (Fig 5). These weights are attracted by the earth's gravitational pull, and thereby, produce the required controlling force(torque). The instruments with gravity control are to be used in the vertical position only.

When the instrument is not connected to the supply, the control weight and the balance weight attached to the opposite end of the pointer make the pointer to be at zero position (Fig 5). When the instrument is connected to the supply, the pointer moves in a clockwise direction, thereby displacing the weights (Fig 5). Due to the gravitational pull, the weights will try to come to their original vertical position, thereby exerting a controlling force on the movement of the moving system.

Fig 5



GRAVITY CONTROL

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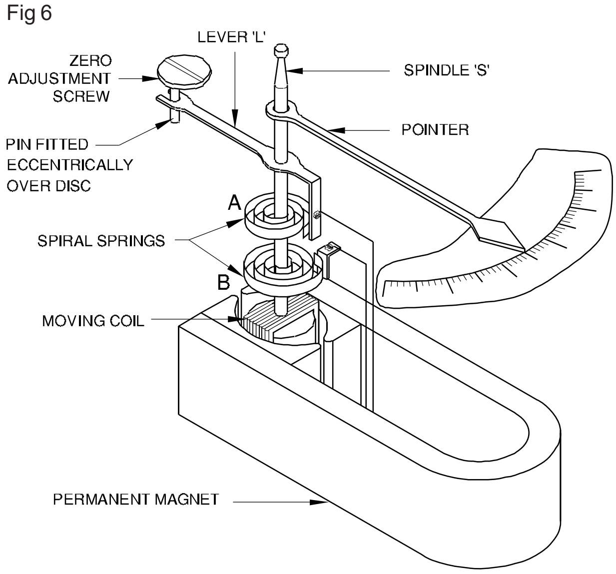
Spring control: The most common arrangement of spring control utilises two phosphor-bronze or beryllium-copper spiral hair-springs A and B, the inner ends of which are attached to the spindle S (Fig 6). The outer end of the spring B is fixed, whereas that of A is attached to the end of a lever `L' pivoted at P, thereby enabling the zero adjustment to be easily effected when needed.

Fig 6



SPRING CONTROLLED MOVING COIL INSTRUMENT

ELN259236

The two springs A and B are wound in opposite directions so that when the moving system is deflected, one spring winds up while the other unwinds, and the controlling force is due to the combined torsions of the springs.

These springs are made from such alloys that they have:

- non-magnetic properties (should not get affected by external magnetism)
- low temperature cofficient (do not elongate due to temperature)
- low specific resistance (can be used for leading current `in' and `out' of the moving system).

Spring controlled instruments have the following advantages over the gravity controlled instruments.

They are:

- the instruments can be used in any position
- the control springs help in leading in and out the current to the moving coil of the instruments.

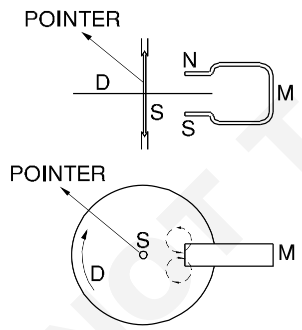
Damping force: This force is necessary to bring the moving system to rest in its final deflected position quickly.Without such damping, the combination of the inertia of the moving system and the controlling force makes the pointer (moving system) to oscillate about its final deflected position for some time before coming to rest, resulting in a waste of time in taking the reading.

The two methods of damping, commonly employed are:

- eddy current damping
- air friction damping.

Eddy current damping: Fig 7 shows one form of eddy current damping. A copper or aluminium disc D,is attached tothe spindle 'S'. When the pointer moves, the disc also moves.

Fig 7



ELN259237

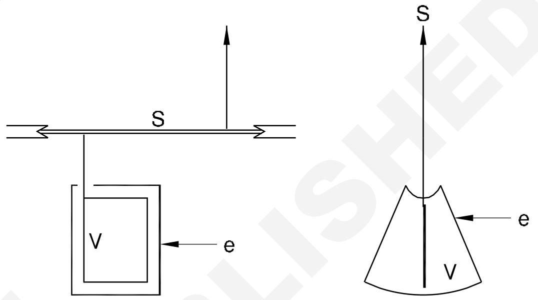
EDDY CURRENT DAMPING

The disc is made to move in the air gap between the poles of a permanent magnet M. The moving disc cuts the flux, thereby inducing eddy currents in the disc. According to Lenz's law, the flux produced by the eddy current opposes the movement of the disc, thereby effecting the damping force.

In the case of moving coil instruments, the moving coil is wound on a thin aluminium former. The eddy currents induced in the former produces the damping force.

Air friction damping: Fig 8 shows the method of obtaining air friction damping. Accordingly a thin metal vane V is attached to the spindle S, and the vane is made to move inside a sector shaped box ‘e’ while the pointer moves on the graduated scale.

Fig 8



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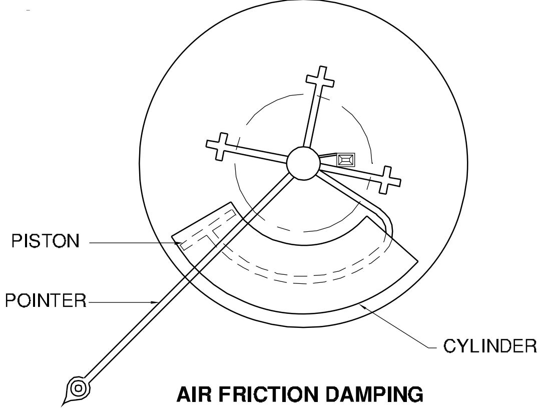
AIR FRICTION DAMPING

Alternatively, the vane in the form of a piston could be arranged to move inside an air chamber (cylinder) as shown in Fig 9. In the above two cases, the air inside the air chamber opposes the movement of the vane/piston, and, thereby, the damping force is created.

Fig 9



ELN259239

AIR FRICTION DAMPING

Permanent magnet moving coil (PMMC) instruments

Objectives: At the end of this lesson you shall be able to
- **state the principle of a permanent magnet moving coil (P.M.M.C) instrument**
- **describe the construction and operation of a P.M.M.C instrument**
- **state the uses, advantages and disadvantages of a P.M.M.C instrument.**

Moving Coil and Moving Iron Instruments :

Instruments are classified based on their moving system They are :

(i) Moving Coil Instruments (MC)

Permanent Magnet Moving Coil Instrument (PMMC)

Dynamo meter type instruments

(ii) Moving Iron Instruments (MI)

Attraction type

Repulsion type

Permanent magnet moving coil (PMMC) instruments

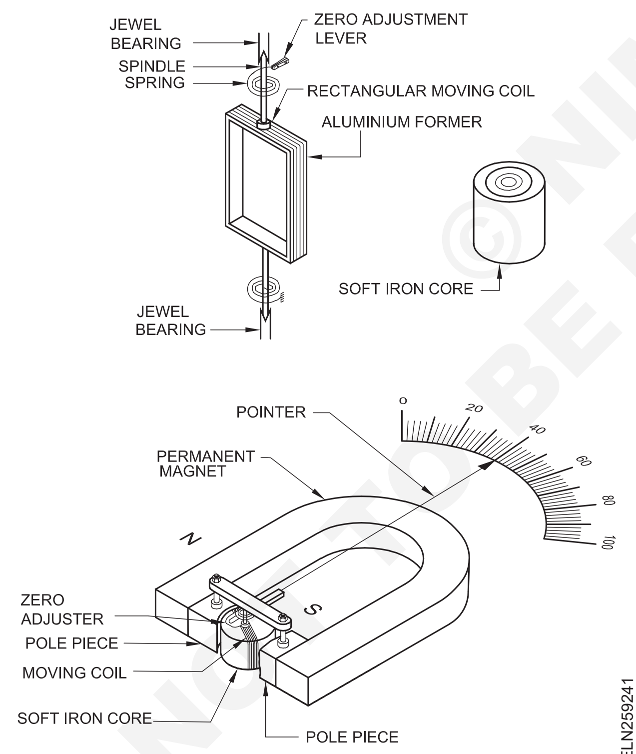
The most commonly used instrument to measure DC quantities like voltage and current, is the permanent magnet moving coil (PMMC) instrument.

Principle: The working of the PMMC instrument is based on the principle that when a current-carrying conductor is placed in a magnetic field, it is acted upon by a force which tends to move the conductor. The DC motor also works on this principle.

Construction: The PMMC instrument consists of a permanent magnet and a rectangular coil wound with a very fine gauge insulated copper wire on a thin light aluminium former.

The aluminium former not only supports the coil, but also produces eddy current for damping. The coil and the former are attached with spindles on either side, and supported by jewelled bearings so as to make the assembly move freely in the air gap (Fig 1).

Fig 1



The two ends of the coil are connected to two phosphor-bronze springs, fixed one on each spindle to lead in and lead out the current. The springs are spiralled in the opposite direction in order to neutralize the effect of temperature changes.

The horseshoe shaped permanent magnet is made of an alloy called 'Alnico' and it has soft iron pole pieces which are shaped to distribute uniform flux in the air gap.

A soft iron core is fixed in such a way that the moving coil can move within the gap, between the soft iron core and the pole pieces. The function of the soft iron core is (i) to decrease the reluctance of the magnetic path between the poles and thereby increase the magnetic flux and (ii) to make the flux uniformly distributed in the air gap.

The pointer is attached to one of the spindles, and it moves on a graduated scale when the coil is deflected by the quantity to be measured.

Operation: When the current is passed through the coil, the coil experiences a force due to the interaction of the magnetic fluxes, produced by the permanent magnet and the current in the moving coil.

We have the force 'F' in the coil equal to BLIN Newtons Fig 2

where

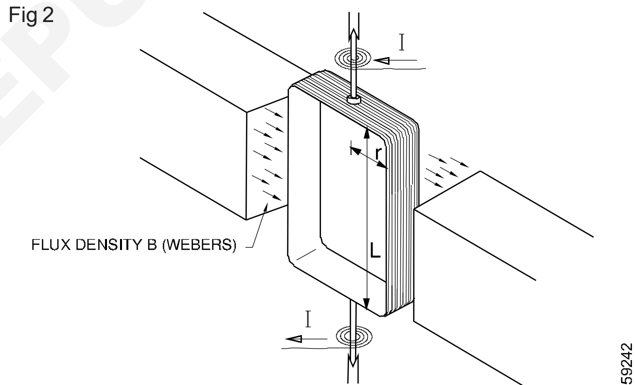
B	-	The flux density in the air gap in Webers/ square metre,
L	-	The active length of one conductor in the air gap in metres
I	-	The current in amperes passing through the coil and N is the number of turns.

But B,L,N and r are constants for a particular instrument and can be denoted by a letter 'K'. As such

Torque = KI

Torque proportional to I

Fig 2



PRINCIPLE OF THE MOVING COIL INSTRUMENT

From the above equation we can infer that the deflecting torque of a PMMC instrument is directly proportional to the current, and, therefore, the scale of the PMMC instrument is uniform that is the scale in which the space between numbers are equal.

Hence, while connecting the instrument in DC the polarity should be correctly observed. Further the instrument will not deflect when connected to an AC supply.

Uses: As a PMMC instrument is a polarized instrument, it could be used only in DC.

The PMMC instrument could be directly used to measure milli or micro amperes as the moving coil can carry a low current only. With proper shunts, this instrument could be used to measure large currents, and with proper series resistors, called multipliers, it could be converted into a voltmeter.

Advantages: The PMMC instrument

- consumes less power
- has uniform scale and can cover an arc up to 270°
- has high torque/weight ratio
- can be modified as voltmeter or ammeter with suitable resistors

Disadvantages: The PMMC instrument

- can be used only in DC
- is very delicate
- is costly when compared to a moving iron instrument

Uses :

- It can be used as volt meter and Ammeter

Moving-iron instruments

Objectives: At the end of this lesson you shall be able to

- **state the principle of moving-iron instruments - attraction and repulsion type**
- **describe the construction and working of a moving-iron Instrument**
- **state the use, advantages and disadvantages of moving-iron instruments.**

Moving-iron instruments: This instrument derives its name from the fact that a piece of soft iron which is attached to the spindle and needle moves in a magnetic field, produced by the current or by a current proportional to the quantity of electricity being measured.

There are two types of this instrument which are used either as voltmeter or ammeter.

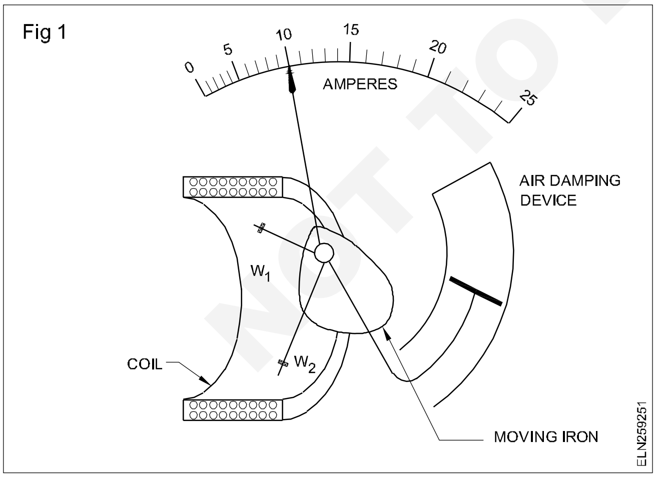
They are:

- attraction type
- repulsion type.

Principle of operation: The attraction type instrument works on the principle of magnetic attraction, and the repulsion type instrument works on the principle of magnetic repulsion between two adjacent pieces of soft iron, magnetised by the same magnetic field.

Construction and working of attraction type moving-iron instrument: This instrument consists of an electromagnetic coil having an air core (Fig 1). Just in front of the air core, an oval shaped soft iron piece is eccentrically pivoted in a spindle (Fig 1).

Fig 1



The spindle is free to move with the help of the jewelled bearings, and the pointer, which is attached to the spindle, could thus move over the graduated scale. When the electromagnetic coil is not connected to the circuit, the soft iron piece hangs vertically down, due to gravitational force and the pointer shows zero reading.

When the electromagnetic coil is connected to the supply, the magnetic field created in the coil attracts the soft iron piece (Fig 1). Due to the eccentricity of pivoting of the iron piece, the enlarged portion of the iron piece is pulled towards the coil. This in turn moves the spindle and makes the pointer to deflect.

The amount of deflection of the pointer will be greater when the current producing the magnetic field is greater. Further the attraction of the soft iron piece is independent on the current direction in the coil. This characteristic enables the instrument to be used both in DC and AC.

Construction and working of repulsion type moving-iron instrument: This instrument consists of a coil wound on a brass bobbin B, inside which two strips of soft iron M and F are set axially (Fig 2a). Strip F is fixed whereas the iron strip M is attached to the spindle S, which also carries the pointer P.

Spring control is used, and the instrument is designed such that when no current is flowing through W, the pointer is at zero position and the soft iron strips M and F are almost touching. (Fig 2a & 2b)

When the instrument is connected to the supply, the coil W carries current which in turn produces a magnetic field. This field makes the fixed and moving-iron F and M respectively to produce similar poles in the ends. Therefore, the two strips repel each other.

The torque set up produces a deflection of the moving system end. Therefore it brings into play a controling torque due to torsion of the control springs or weights. The moving system comes to rest in such a position that the deflecting and controlling torques are equal.

In this type of instrument, air damping is used commonly which is provided by the movement of a piston P_N in a cylindrical air chamber C (Fig 2a).

Deflecting torque and graduation of scale: However, in the moving-iron instruments, the deflecting torque is proportional to the square of the current passing through the coil. As such the scale of this instrument will be uneven. It is cramped at the beginning and open at the end (Fig 3).

Fig 2a

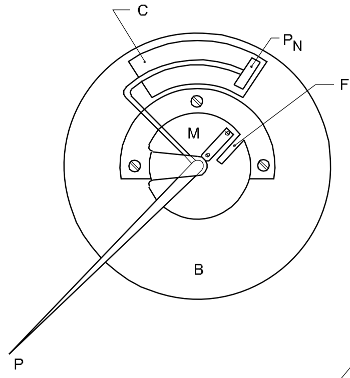


Fig 2b

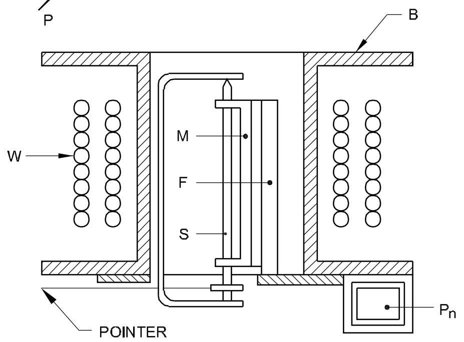
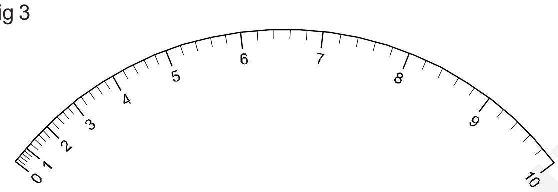


Fig 3



In order to achieve uniformity of scale, some manufacturers have designed tongue shaped strip as fixed soft iron (Fig 4a).

The fixed iron consists of a tongue-shaped soft iron sheet bent into a cylindrical form, while the moving iron is made of another soft iron sheet, and is so mounted as to move parallel to the fixed iron and towards its narrower end (Fig 4b).

The torque, which is proportional to the square of the current, is proportionally reduced by the narrow portion of the fixed iron, resulting in more or less even torque and thereby uniform scale.

These instruments are either gravity or spring controlled, and the damping is achieved by the air friction method

Uses, advantages and disadvantages of Moving-iron instruments

Uses: They are used as voltmeters and ammeters.

Fig 4a

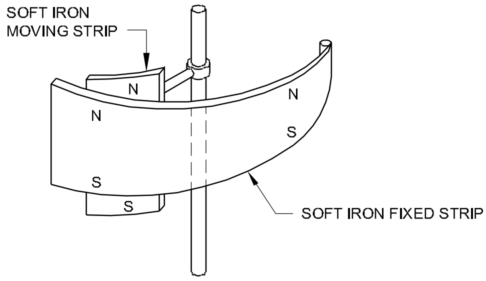
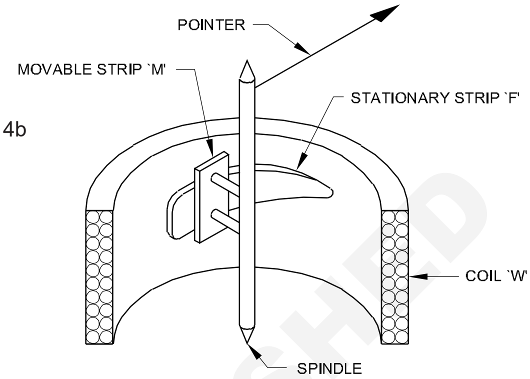


Fig 4b



The coil W is wound with thick conductor of less number of turns for ammeters and is wound with thin conductors of large number of turns for voltmeter.

Advantages

- They can be used for both AC and DC, and are hence called unpolorized instruments.
- They have a small value of friction errors as the torque/weight ratio is high.
- They are less costly when compared to the moving coil instruments.
- They are robust owing to their simple construction.
- They have satisfactory accuracy levels within the limits of both precision and industrial grades.
- They have scales covering 240°.

Disadvantages

- They have errors due to hysteresis, frequency changes, wave-form and stray magnetic fields.
- They have non-uniform scales commonly. However, special manufacturing designs are utilized to get more or less uniform scales.

Dynamometer type instrument

Objectives: At the end of this lesson you shall be able to
- **state the principle of dynamometer type instrument**
- **describe the construction, and working of the dynamometer type instruments**
- **explain the internal connections of a dynamometer instrument when used as a voltmeter, ammeter and wattmeter**
- **state the advantages and disadvantages of using the dynamometer instruments.**

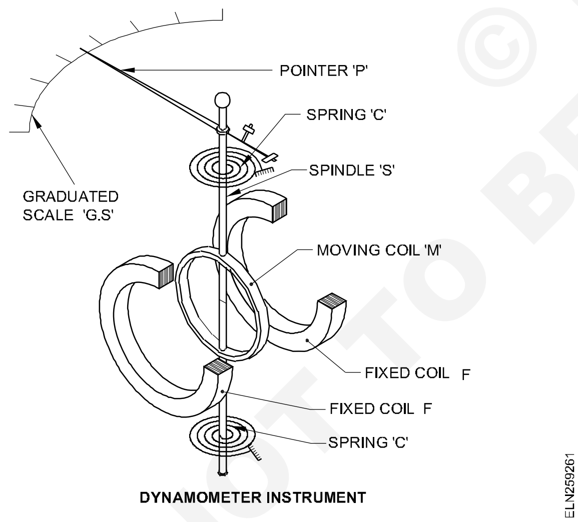
Electro-dynamic or Dynamo-meter type Instruments

Working principle: This Instrument works on the principle of DC motor. That is, whenever a current-carrying conductor is kept in a magnetic field, a force is created and it tends to move the conductor away from the magnetic field. In a dynamo-meter instrument, the magnetic field is produced by an electromagnet named as fixed coils.

The moving coil, either connected in series or parallel with the fixed coil, carries a proportionate current. Operation of this instrument in both AC and DC is possible due to the fact that when ever the current reverses in AC, the direction of flux in the fixed coils as well as the direction of flux produced by moving coil, reverses at the same time resulting in the same direction of torque.

Construction: A general arrangement of the instrument is shown in Fig 1. The main magnetic field is produced by the fixed/stationary coil. This coil is divided into two sections to give a uniform field in the centre and also to allow the moving coil mechanism to be placed in between them.

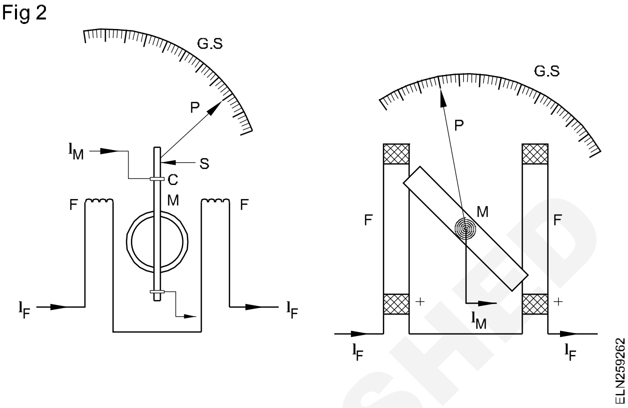
Fig 1



The fixed coils F and F are placed close together and parallel to each other (Fig 2). The air core section removes hysteresis effects when used in AC circuits. The moving coil `M' is mounted on a spindle `S' and the spindle is free to move in the air gap with the help of jewelled bearings.

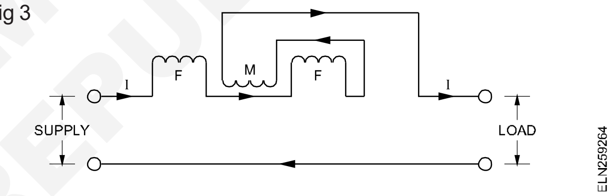
The pointer `P' is attached to one end of the spindle and the spindle end made to move on a graduated scale `G S'. The controlling torque is provided by two phosphor-bronze springs `C' attached to the spindle. Further the springs are used to allow the current `in' and `out' from the moving coil.

Fig 2



Working: As shown in Fig 3, let the current passing through the fixed coils be I_F, and the current passing through the moving coil be I_M. The field strength will be proportional to the current I_F.

Fig 3



The deflecting torque is produced due to the interactions of the magnetic fields produced by the fixed and moving coils and will be proportional to the current carried by them.

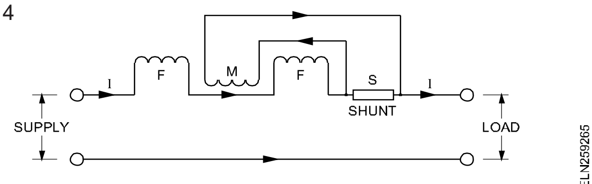
The deflecting torque T_d is proportional to I_F and I_M where I_F is the current in the fixed coil and I_M is the current in the moving coil.

From the above torque equation, it is clear that the instrument when used as voltmeter or ammeter will have ununiform scale due to the square law response.

Connection of this instrument requires modification depending up on the usage viz, ammeter, voltmeter or wattmeter as explained below.

Dynamometer instrument as an ammeter: This instrument could be used as milli or micro ammeter by connecting the fixed and moving coils in series (Fig 4).

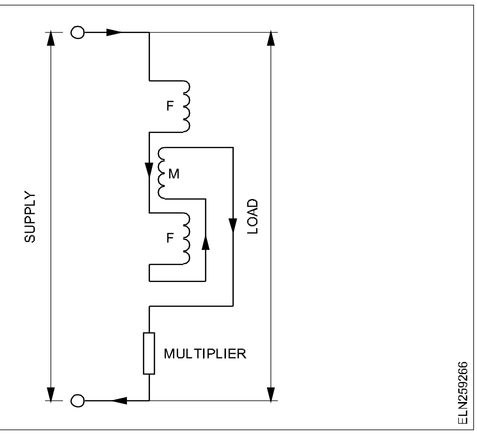
Fig 4



When the instrument is to be converted as an ammeter to measure large currents, the moving coil is connected across a shunt (Fig 4). Both AC and DC, measurements are possible.

Dynamometer instrument as a voltmeter: When this instrument is used as voltmeter, the fixed and moving coils are joined in series along with a high resistance (multiplier) (Fig 5). This voltmeter could be used both in AC and DC.

Fig 5



Dynanometer used as a Wattmeter: The dynamometer is commonly used as a wattmeter to measure power in both AC and DC circuits and will have uniform scale.

Advantages

- This instrument can be used both in AC and DC.
- As this is an air cored instrument, the hysteresis and eddy current losses are eliminated. .
- When used as wattmeter, the scale is uniform.

Disadvantages :

- It is more expensive than PMMC and moving iron instruments.
- When used as voltmeter or ammeter the scale will not be uniform.
- It consumes more power than PMMC meters.

Digital Ammeter

Objectives: At the end of this lesson you shall be able to
- **state the features of digital ammeter**
- **state the movements, special operation and standard.**

Digital Ammeter

Digital Ammeters are instruments that measure the current in ampere and display it in digital. These instruments provide information about current drawn and current continuty to help users troubleshoot electric loads.

They have both positive and negative leads and low internal resistance. Digital ammeters are connected in series with a circuit so that current flow passes through the meter.

High current flow may indicate short circuit (or) defective component. Low current flow may indicate high resistance. It can be used to measure the A.C and D.C. Many digital ammeters include a current sensor built in the meter or that is clamped around the wire.

Features:

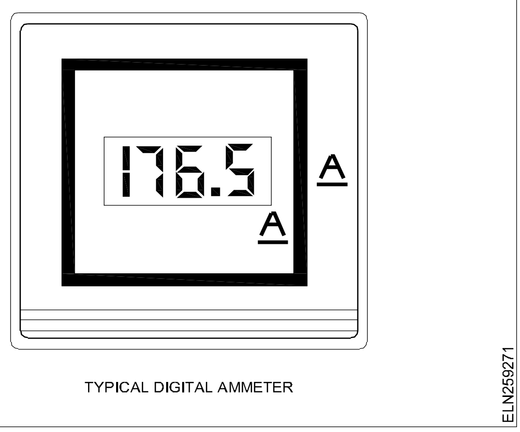
Different types of digital ammeters can measure different ranges of A.C current and D.C current and also A.C frequency.

Batteries are provided in it to operate without plug-in-power and suitable for cutdoor use Fig 1 shows a typical digital ammeter.

Standards :

Digital ammeters must have a certain standards and specifications to ensure proper design and functionality refer IEC 600 51 - 2.

Fig 1



TYPICAL DIGITAL AMMETER

Digital Volt Meter (DVM)

Objectives: At the end of this lesson you shall be able to
- **distinguish between analogue and digital voltmeter**
- **list out the advantage of DVM**
- **explain the working principle of DVM.**

Digital Volt Meter (DVM) : The Digital Volt Meter(DVM) is an electrical measureing instrument which is used to measure line potential difference (P.D) between two points. The voltage to be measured may be AC or DC.

Digital voltmeters display the value of AC or DC voltage being measured directly as discrete numerical instead of a pointer deflection on a continuous scale as in analog instruments.

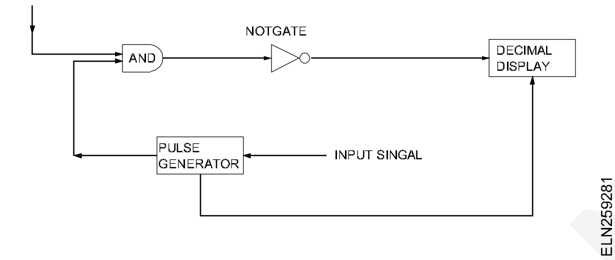
Advantages of Digital Voltmeters:

- Read out of DVMs is easy as it eliminates observational errors in measurement
- Parallax error is eliminated
- Reading can be taken very fast
- Output can be fed to memory devices for storage and future computations
- More versatile and accurate
- Compact portable and cheap
- Requires low power

Working Principle of Digital Voltmeter:

The block diagram of a simple digital voltmeter is shown in the Fig 1 It consists the following blocks

Fig 1



1 Input signal

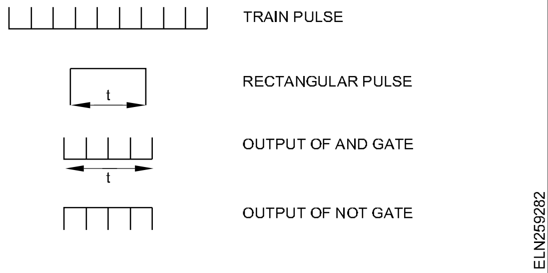
2 Pulse generator

3 AND gate:

4 Decimal Display

Working (Fig 2)

Fig 2

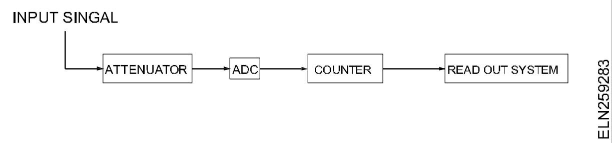


- Unknown voltage signal is fed to the pulse generator which generates a pulse whose width is proportional to the input signal.
- Output of pulse generator is fed to one leg of the AND gate.
- The input signal to the other leg of the AND gate is a train of pulses.
- Output of AND gate is positive triggered train of duration same as the width of the pulse generated by the pulse generator.
- This postitive triggered train is fed to the inverter which converts it into a negative triggered train.
- Output of the inverter is fed to a counter which counts the number of triggers in the duration which isproportional to the input signal i.e. voltage under measurement

This counter can be calibrated to indicate voltage in volts converts an analog signal into a train of pulses, the number is proportional to the input signal. So a digital voltmeter can be made by using any one of the A/D conversion methods (Fig 3)

Now-a- days digital voltmeters are also replaced by digital multi meters due to its multitasking feature.

Fig 3



Wattmeters

Objectives: At the end of this lesson you shall be able to
- **state the advantages of measuring power directly**
- **state the types of single phase wattmeters**
- **explain the construction and working of the induction type single phase wattmeter.**

Advantages of measuring power supply

Power in a single phase AC circuit can be calculated by using an ammeter, a voltmeter and a power factor meter with the help of the formula

Power in a single phase circuit = $EI \cos \phi$ watts.

In the same way power in a 3-phase balanced circuit can be measured by using one ammeter, one voltmeter and one power factor meter with the help of the formula

Power in a balanced 3 - phase circuit = $3E_P I_P \cos\phi$

$$\text{or } \sqrt{3}\, E_L I_L \cos\phi$$

where $E_P I_P$ are the phase values and

$E_L I_L$ are the line values

To get an on the spot true power reading, a wattmeter is used. The power dissipated in the circuit can be read directly from the scale of the meter. The wattmeter takes the power factor of the circuit into account and always indicates the true power.

Types of wattmeters

There are three types of wattmeters in use as stated below.

- Dynamometer wattmeter
- Induction wattmeter
- Electrostatic wattmeter

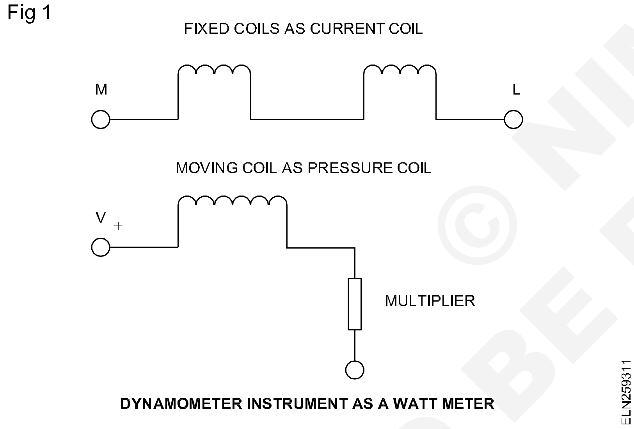
Among the three, the electrostatic type is very rarely used. Information given here is for the other two types only.

Dynamometer type, single phase wattmeter: This type is commonly used as a wattmeter.

Dynanometer used as a Wattmeter: The dynamometer is commonly used as a wattmeter to measure power in both AC and DC circuits and will have uniform scale.

When this instrument is used as a wattmeter, the fixed coils are treated as current coil, and the moving coil is made as pressure coil with necessary multiplier resistance (Fig 1).

Fig 1



DYNAMOMETER INSTRUMENT AS A WATT METER

Induction type single phase wattmeter: This type of wattmeters could be used only in AC circuits whereas a dynamometer type wattmeter could be used in both AC and DC circuits.

Induction type wattmeters are useful only when the supply voltage and frequency are almost constant.

Construction: Induction wattmeters having two different types of magnetic cores (Figs 2a and 2b).

Both the types have one pressure coil magnet and one current coil magnet. The pressure coil carries a current proportional to the voltage whereas the current coil carries the load current.

A thin aluminium disc is mounted on a spindle in between the space of the magnets and its movement is controlled by springs. The spindle carries a weightless pointer at one end.

Fig 2(a)

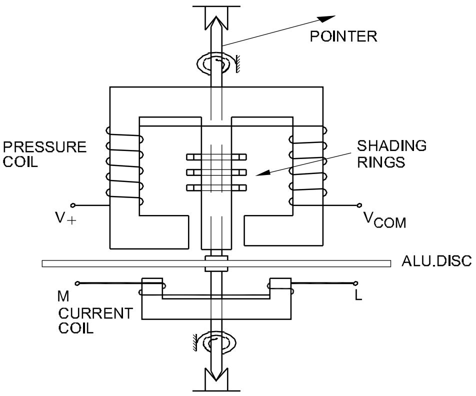
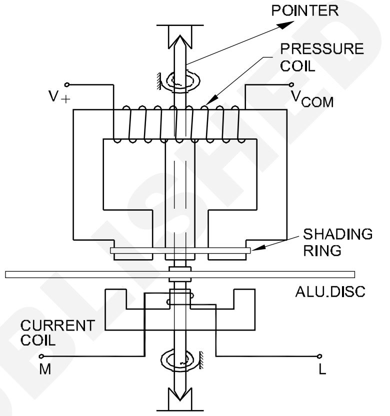


Fig 2(b)



Working: The alternating magnetic fluxes produced by the pressure and current coils cut the aluminium disc and produce eddy currents in the disc. Due to the interaction between the fluxes and the eddy currents a deflecting torque is produced in the disc and the disc tries to move. Control springs attached to the two ends of the spindle control the deflection and the pointer shows the power in watts on a graduated scale.

Shaded rings provided in the pressure coil (shunt) magnet could be adjusted in order to cause the resultant flux in the magnet to lag in phase by exactly 90^o behind the applied voltage.

Method of connecting wattmeter in single phase circuits - pressure coil connection to reduce erroneous measurement.

There are two ways of connecting the pressure coil of the wattmeter (Fig 3).

Both the methods shown in Figs 3a & b need correction in power measurement due to the reasons stated below.

In the method of connection shown in Fig 3a, the pressure coil is connected on the 'supply' side of the current coil, and hence, the error in power measurement is due to the fact that the voltage applied to the voltage coil is higher than that of the load on account of the voltage drop in the current coil. As such the wattmeter measures the load power in addition to the power lost in the current coil.

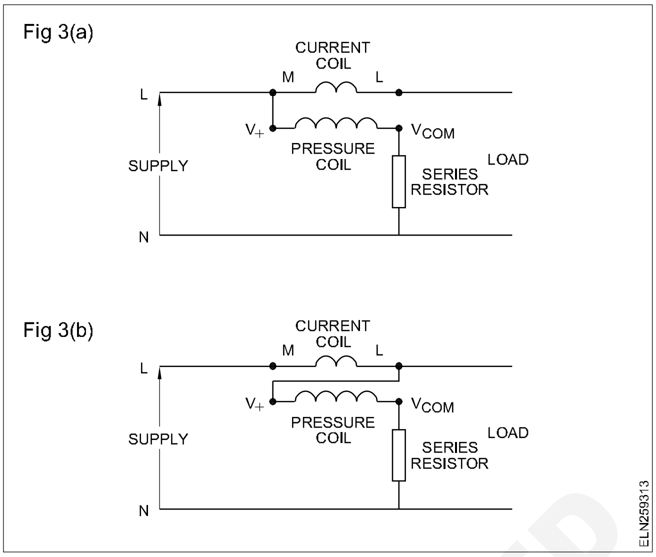
On the other hand, in the method of connection shown in Fig 3b, the current coil carries the small current taken by the voltage coil, in addition to the load current, thereby introducing errors in power measurement. As such the wattmeter measures the load power in addition to the power lost in the pressure coil.

If the load current is small, the voltage drops in the current coill will be small, so that the method of connection, shown in Fig 3a, introduces a very small error and, hence, preferable.

On the other hand, if the load current is large the power lost in the pressure coil will be negligible when compared to the load power in the method of connection shown in Fig 3b, and, hence, a very small error is introduced resulting in the preference of this connection.

Fig 3(a)

Fig 3(b)



3-phase Wattmeter

Objectives: At the end of this lesson you shall be able to
- **describe the various types of 3-phase wattmeters, their connections**
- **state how to connect different types of 3 phase watt meter.**

In single-phase wattmeters there will be one set of pressure and current coils driving a single aluminium disc, whereas in 2-element, three phase wattmeters there will be two sets of pressure and current coils driving a single aluminium disc (Fig 1a) or driving two aluminium discs mounted on the same shaft (Fig 1b) thereby providing a torque proportional to the 3-phase power.

On the other hand a 3-element, 3-phase wattmeter will have three sets of pressure and current coils kept at 120° to each other but driving a single aluminium disc (Fig 2) or alternatively 3 sets of pressure and current coils driving three discs one over the other but mounted on the same single spindle (Fig 3).

The principle and working of an induction type wattmeter are similar to the induction type energy meter. The only difference in construction between the energy meter and wattmeter is that the spindle of the wattmeter is spring-controlled, has a pointer but no train of gears.

However to summarise what has been learnt earlier the following table 1 is provided with connection diagram of 3-phase wattmeter Fig 4, Fig 5 & Fig 6

Fig 1(a)

Fig 1(b)

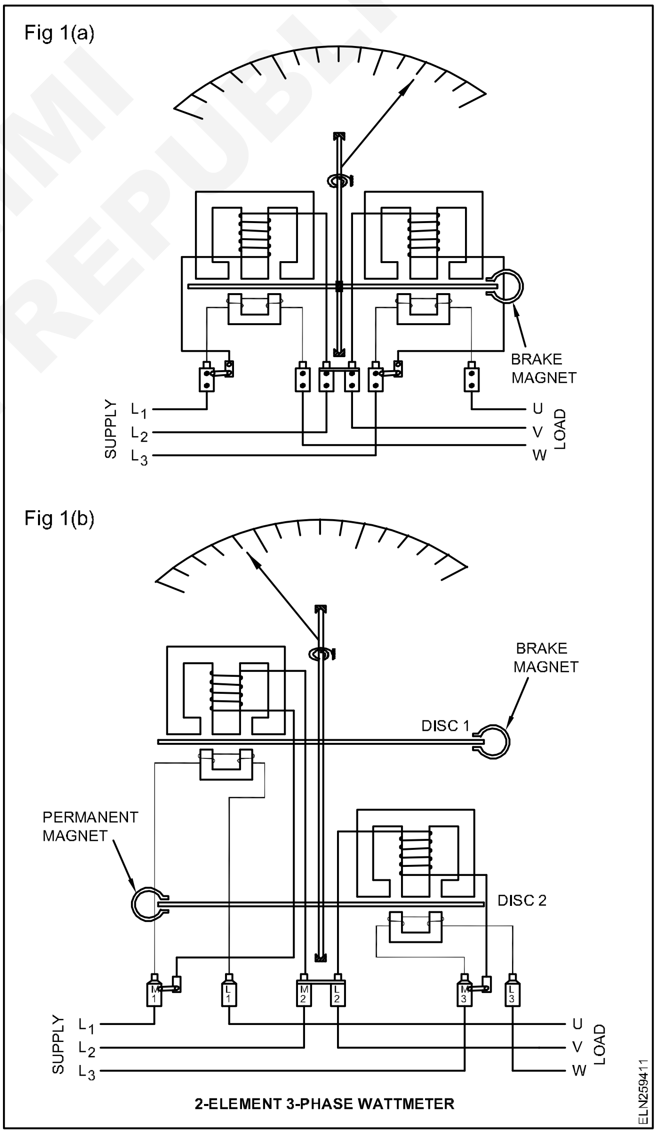


Fig 2

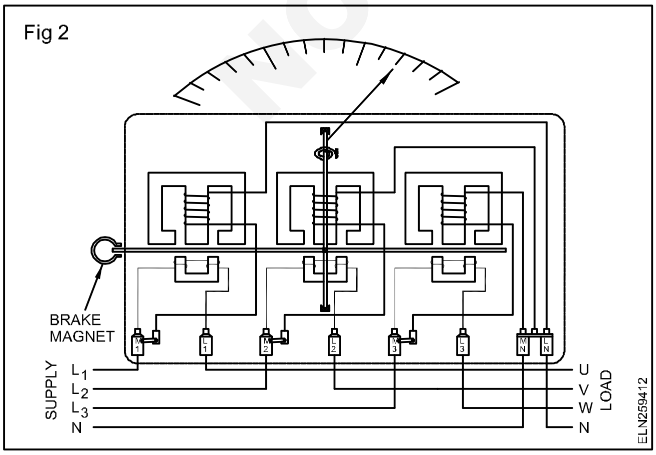


Fig 3

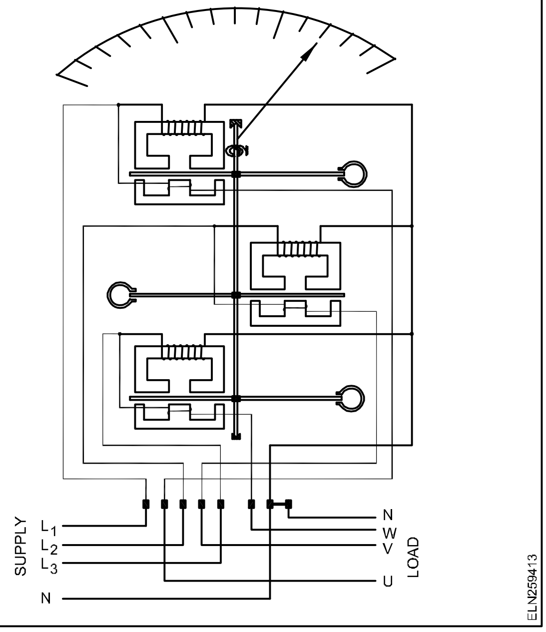
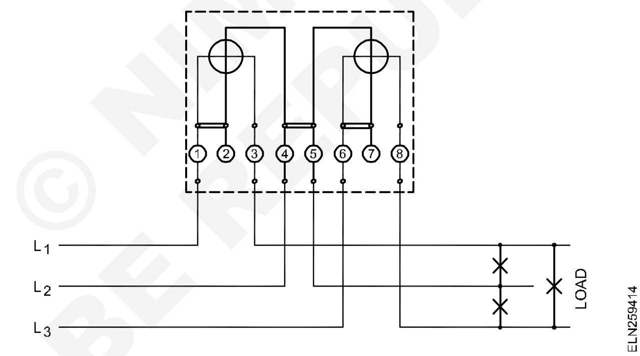
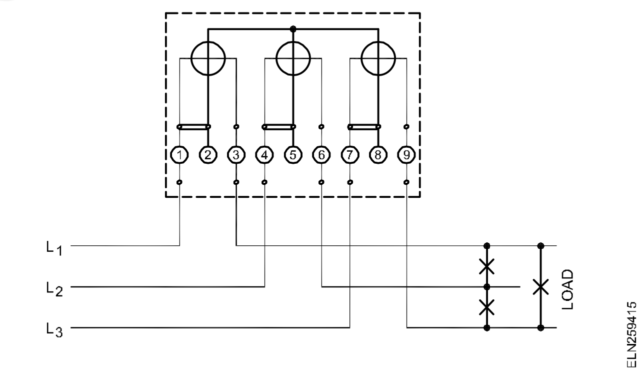
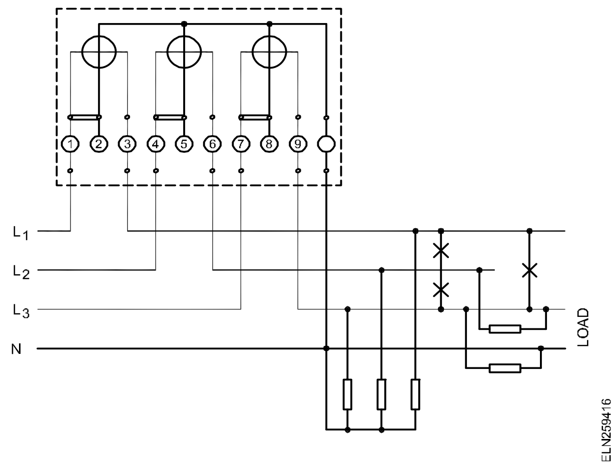


Table 1

Sl.No.	Types of 3-phase wattmeter	Circuit diagram	Application
1	2-element 3-wire type	Fig 4 	Balanced and unbalanced loads.
2	3-element 3-wire type	Fig 5 	Balanced loads.

Sl.No.	Types of 3-phase wattmeter	Circuit diagram	Application
3	3-element 4-wire type	Fig 6 	Un balanced loads.

Digital Wattmeter

Objectives: At the end of this lesson you shall be able to

- **describe the block diagram**
- **compare between analog and digital wattmeter.**

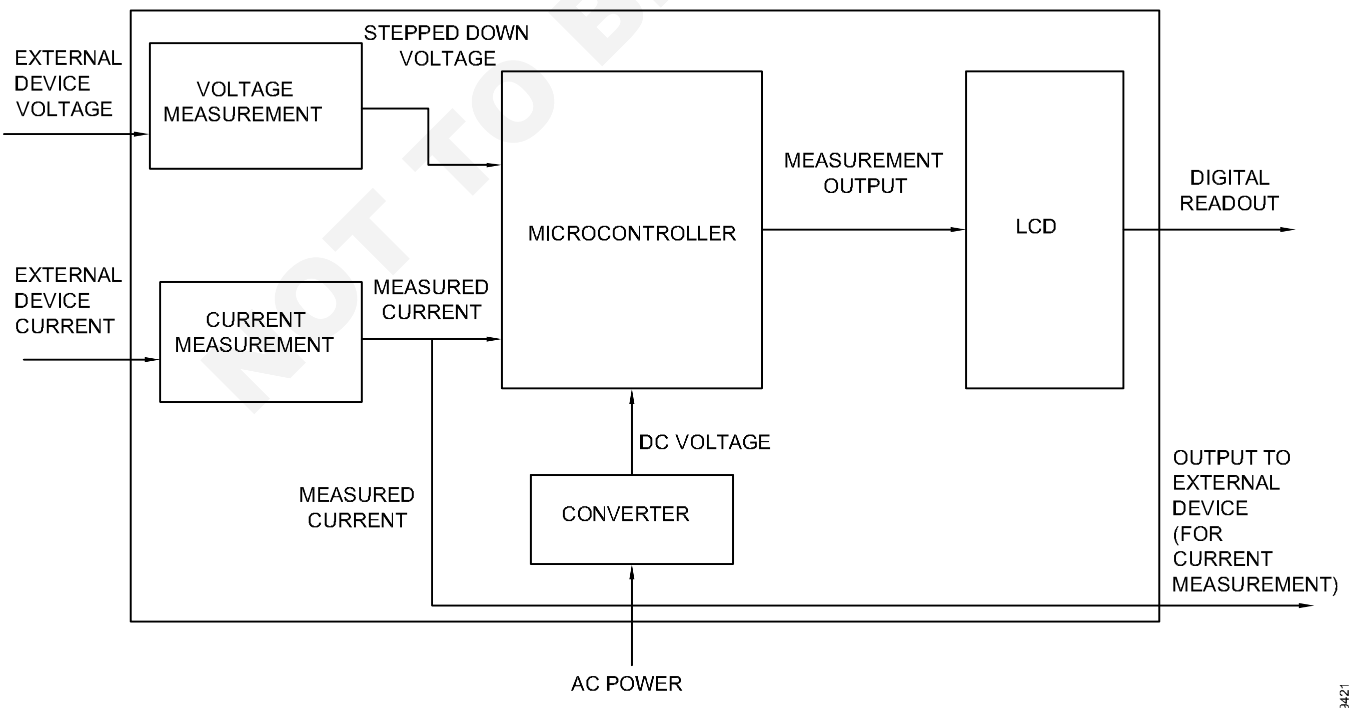
Digital wattmeter

The wattmeter is an instrument for measuring the electric power in watts of any given circuit. Electromagnetic wattmeters are used for measurment of utility frequency and audio frequency and audio frequency power; other types are required for radio frequency.

Fig 1 shows the block diagram of digital wattmeter.

Digital wattmeters measure current and voltage electronically thousands of times a second, multiplying the results in a computer microcontroller chip to determine watts. The computer can also perform statistics such as peak, average, low watts consumed. They can monitor the power line for voltage surges and outages. Digital electronic wattmeter, have become popular for conveniently measuring power consumption in household appliances with saving energy and money.

Fig 1



BLOCK DIAGRAM OF DIGITAL WATTMETER

Energy meter (analog)

Objectives: At the end of this lesson you shall be able to
- **describe the construction and working principle of single phase energy meters**
- **state and explain creeping error in energy meter.**

Necessity of energy meter: The electrical energy supplied by the Electricity board should be billed, based on the actual amount of energy consumed. We need a device to measure the energy supplied to a consumer. Electrical energy is measured in kilowatt hours in practice. The meter used for this is an energy meter.

Principle of a single phase induction type energy meter: The operation of this meter depends on the induction principle. Two alternating magnetic fields produced by two coils induce current in a disc and produce a torque to rotate it (disc). One coil (potential coil) carries current proportional to the voltage of the supply and the other (current coil) carries the load current. (Fig 1) Torque is proportional to the power as in wattmeter.

Fig 1

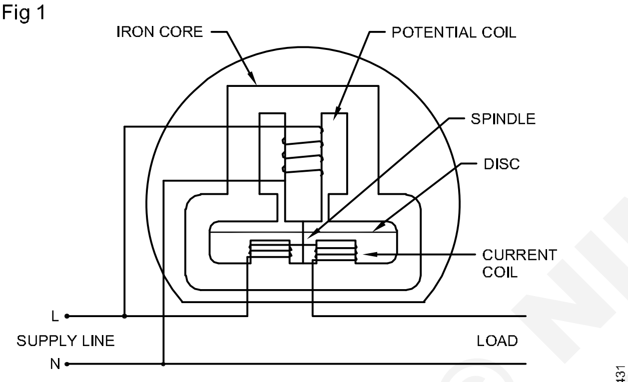


DIAGRAM OF AN INDUCTION TYPE WATT-HOUR METER

The watt-hour meter must take both power and time into consideration. The instantaneous speed is proportional to the power passing through it.

The total number of revolutions in a given time is proportional to the total energy that passes through the meter during that period of time.

Parts and functions of an energy meter: The parts of the induction type single phase energy meter are (Fig 1).

Iron core: It is specially shaped to direct the magnetic flux in the desired path. It directs the magnetic lines of force, reduces leakage flux and also reduces magnetic reluctance.

Potential coil (voltage coil): The potential coil is connected across the load and is wound with many turns of fine wire. It induces eddy current in the aluminium disc.

Current coil: The current coils, connected in series with load, are wound with a few turns of thick wire, since they must carry the full load current.

Disc: The disc is the rotating element in the meter, and is mounted on a vertical spindle which has a worm gear at one end. The disc is made of aluminium and is positioned in the air gap between the potential and current coil magnets.

Spindle: The spindle ends have hardened steel pivots. The pivot is supported by a jewel bearing. There is a worm gear at one end of the spindle. As the gear turns the dials, they indicate the amount of energy passing through the meter.

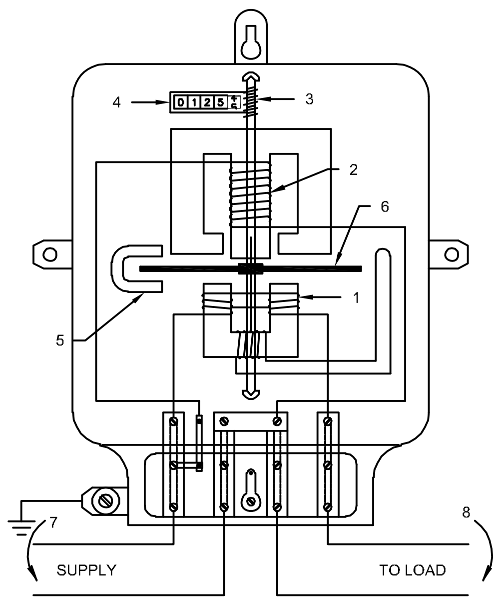
Permanent magnet/brake magnet: The permanent magnet restrains the aluminium disc from racing at a high speed. It produces an opposing torque that acts against the turning torque of the aluminium disc.

Functioning of energy meters: The rotation of the aluminium disc (Fig 2) is accomplished by an electromagnet, which consists of a potential coil and current coils. The potential coil is connected across the load. It induces an eddy current in the aluminium disc. The eddy current produces a magnetic field which reacts with the magnetic field produced by the current coils to produce a driving torque on the disc.

The speed of rotation of the aluminium disc is proportional to the product of the amperes (in the current coils) and the volts (across the potential coil). The total electrical energy that is consumed by the load is proportional to the number of revolutions made by the disc during a given period of time.

A small copper ring(shading ring) or coil (shading coil) is placed in the air gap under the potential coil, to produce a forward torque, large enough to counteract any friction produced by the rotating aluminium disc.

Fig 2



1. CURRENT COIL
2. VOLTAGE COIL
3. WORM GEAR
4. REGISTERING MECHANISM
5. PERMANENT MAGNET
6. ALUMINIUM DISC
7. SUPPLY TERMINALS
8. LOAD TERMINALS

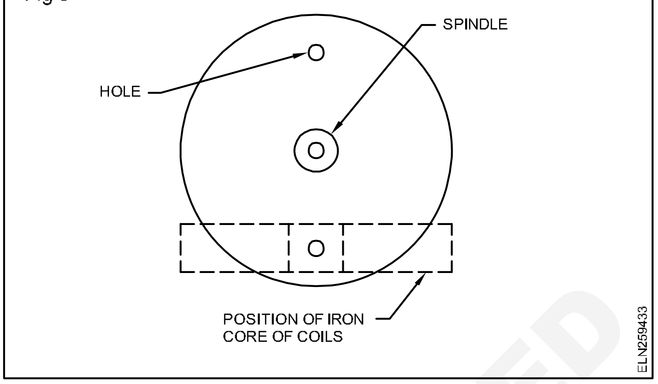
INDUCTION TYPE ENERGY METER

This counter torque is produced when the aluminium disc rotates in the magnetic field established by the permanent magnet. The eddy currents, in turn, produce a magnetic field that reacts with the field of the permanent magnet, causing a restraining action that is proportional to the speed of the disc.

Creeping error and adjustment: In some meters the disc rotates continuously even when there is no current flow through the current coil i.e. when only the pressure coil is energised. This is called creeping. The major cause for creeping is over-compensation for friction. The other causes for creeping are excessive voltage across the pressure coil, vibrations and stray magnetic fields.

In order to prevent creeping, two diameterically opposite holes are drilled in the disc (Fig 3). The disc will come to rest with one of the holes under the edge of a pole of the potential coil magnet, the rotation being thus limited to a maximum of half a revolution.

Fig 3



Digital Energy meters

Objectives: At the end of this lesson you shall be able to
- **describe the functional operation of digital type energymeter from block diagram.**

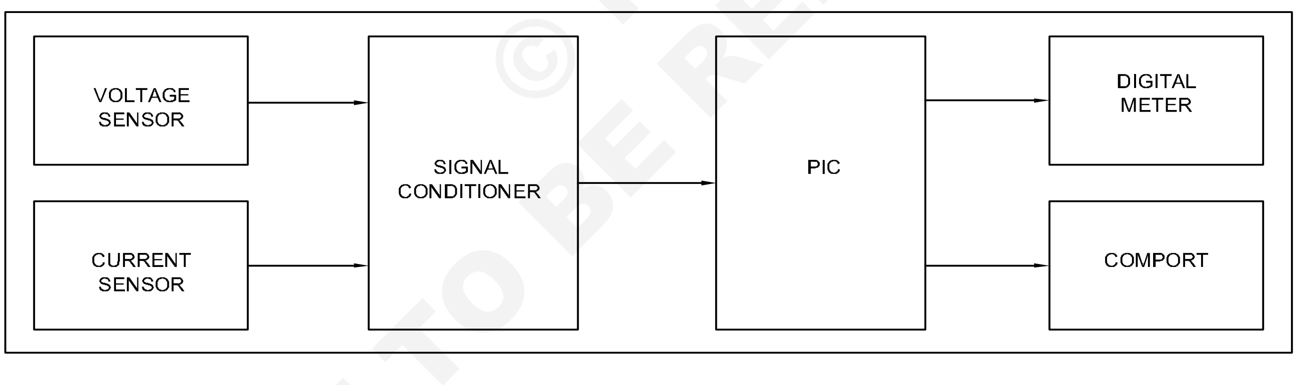
Electronic (Digital energy meter) (Fig 1)

This meters measure the energy using highly integrated components and it digitizs the instantaneous voltage and current in a high-resolution sigma-delta analogue to digital converter (ADC), gives the instantaneous power in watts.

The voltage sensor built around a step down element and potential divider network sensors both the phase voltage and load voltage.

The second sensor is a current sensor, which senses the current drawn by the load at any point in time.

Fig 1



The control circuit centred on a PIC integrated circuit. It contains ten bit analogue to digital converter (ADC), flexible to program and good for peripheral interfacing.

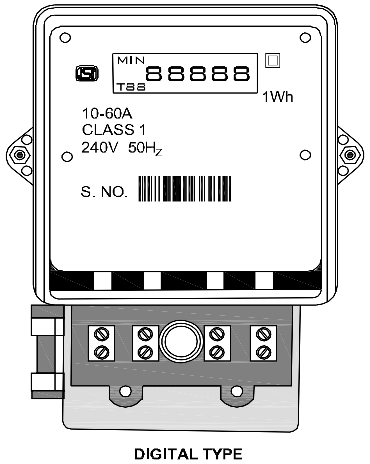
The ADC converts the analogue signals to its digital equivalent, both signals from the voltage and current sensors are then multiplied by the means of embedded software in the PIC.

The error correction is taken as the offset correction by determining the value of the input quality in the short circuited input and storing this value in the memory for use as the correction value device calibration.

The PIC is programmed in 'C' language. It stimulates to use the received data to calculate power consumption per hour, as well as the expected charges. These are displayed on the liquid crystal display (LCD) attached to the circuit.

Fig 2 shows the image of a digital energy meter.

Fig 2



Advantages

DIGITAL electronic meters are much more accurate than electromechanical meters. There are no moving parts and hence, mechanical defects like friction are absent.

3-phase energy meter

Objectives: At the end of this lesson you shall be able to
- **list the various types of 3-phase energy meters**
- **describe the construction and working of a 3-phase 3-wire induction type energy meter**
- **describe the construction and working of a 3-phase 4-wire induction type energy meter**
- **state the application of a 3-phase 3-wire and 3-phase 4-wire energy meter.**

3-phase energy meters: Even though different types of energy meters are available, the induction type energy meter is most commonly used because it is simple in construction, less in cost and requires less maintenance.

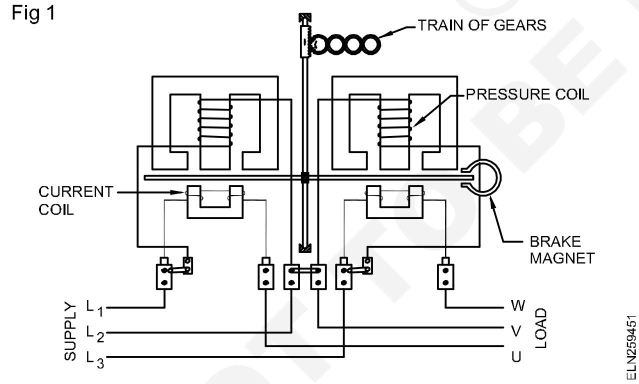
Types of 3-phase energy meters

There are two types of 3-phase energy meters mainly.

- Three phase 3-wire energy meters (3-phase 2- element energy meter)
- Three phase 4-wire energy meters (3-phase 3- element energy meter)

Two element 3-phase energy meters: This energy meter works on the principle of measurement of power by the two wattmeter method. Two elements of a current coil and two elements of a potential coil are used in this energy meter. These assemblies can be arranged on the different sectors in a horizontal position (Fig 1) with a single aluminium disc which rotates between the poles of a single braking magnet.

Fig 1

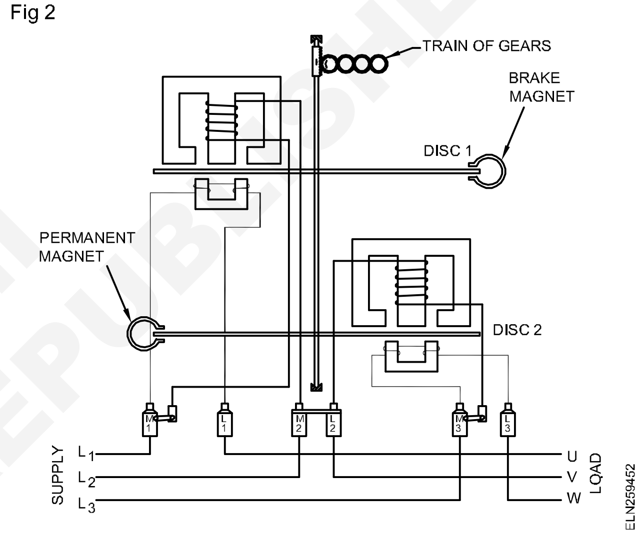


The two elements can also have individual driving discs on a common spindle. In this case they will have individual braking magnets (Fig 2). The second type usually preferred by the manufacturers due to the construction simplicity.

In both the cases the driving torque produced by individual elements are summed up. The recording mechanism which is attached to the train of gears i.e., cyclometer or counter type dial shows the sum of the energies that has passed through the elements. The two element energy meter is only suitable for a 3-phase 3-wire system but can be used for both balanced and unbalanced loads.

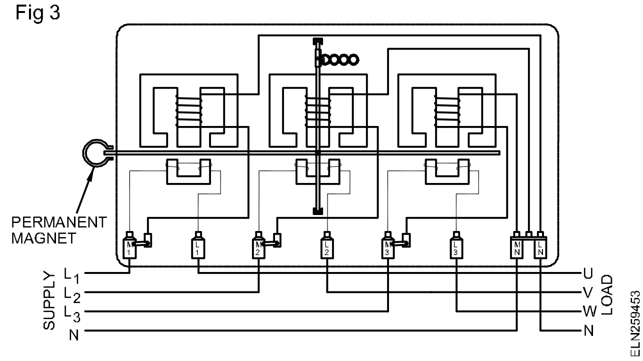
3-element 3-phase energy meter: This works on the same principle as that of the 3 wattmeter method of power measurement with a 3-phase load. Here 3 units, each with a current coil and a potential coil, are used. The potential coils of the 3 elements are connected in star to the supply lines with their common point connected to the neutral line of power supply.

Fig 2



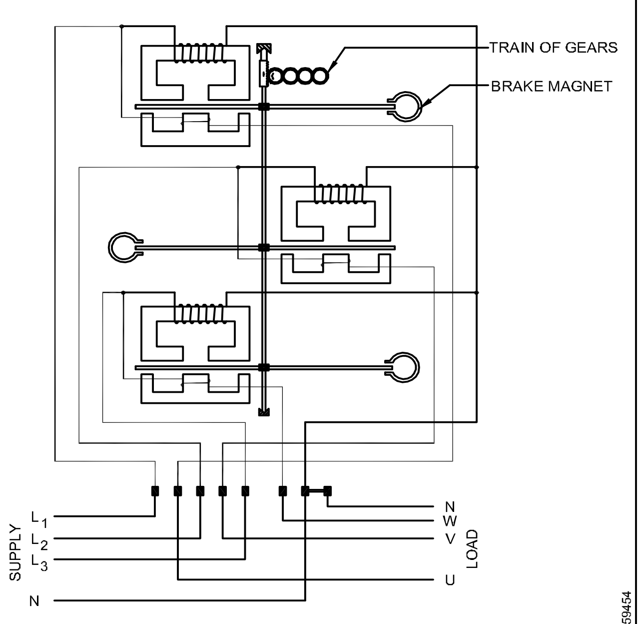
The current coils are connected in series to the individual lines. As is the case with the two element energy meter, these three elements can be arranged in the different sectors of a common single aluminium disc which serves as a rotating part connected to driving dial (Fig 3).

Fig 3



The three elements can also have a common spindle with three individual discs and braking magnets (Fig 4). Here also the 2nd type is usually preferred by manufacturers due to the easiness in construction. The driving torque produced by the three individual elements are summed up and the recording mechanism shows the sum of energies that has passed through the individual elements. This energy meter is suitable for the 3-phase 4-wire system.

Fig 4



3-ELEMENT 3-PHASE ENERGY METER

Application of 3-phase energy meter: A two element 3-phase energy meter is used with three phase loads in which a neutral is not used such as for an industry or irrigation pumpset motors etc. having three phase loads only or with an 11kV 3-phase 3-wire supply to an industry.

A 3-phase 4-wire element energy meter is used with three phase load in which balanced or unbalanced loads are connected with individual phases and neutral such as for a large domestic consumer or for an industry having lighting loads also.

Errors in energy meter

Objectives: At the end of this lesson you shall be able to

- **explain the errors caused by the driving system and the braking system in energy meters**
- **explain the different adjustments provided for correcting the errors in energy meters**
- **explain the method of determining the percentage error in the single phase energy meter**
- **state the recommendations of IS regarding percentage errors, load percentage and the power factor.**

Errors caused by the driving system.

Incorrect magnitude of fluxes: This may be due to abnormal values of current or voltage. The shunt magnet flux may be in error due to changes in resistance of coil or due to abnormal frequencies.

Incorrect phase angles: There may not be a proper relationship between the various phasors. This may be due to improper lag adjustment, abnormal frequencies, change in resistance with temperature etc.

Lack of symmetry in magnetic circuit: If the magnetic circuit is not symmetrical, a driving torque is produced which makes the meter creep.

Error caused by the braking system

They are:

- changes in the strength of the brake magnet
- changes in the disc resistance
- self-braking effect of series magnet flux
- abnormal friction of the moving parts.

Adjustments are provided for correcting the errors in the energy meters so that they read correctly and their errors are within acceptable limits.

Preliminary light load adjustment: The rated voltage is applied to the potential coil with no current through the current coil and the light load device is adjusted until the disc just fails to start. The electromagnet is slightly adjusted to make the holes in the disc to take a position in between the poles of the electromagnets.

Full load unity power factor adjustment: The pressure coil is connected across the rated supply voltage and the rated full load current at unity power factor is passed through the current coils. The position of the brake magnet is adjusted to vary the braking torque so that the meter revolves at the correct speed within the required limits of error.

LAG adjustments (Low power factor adjustments): The pressure coil is connected across the rated supply voltage and the rated full load current is passed through the current coil at 0.5 P.F. lagging. The lag device is adjusted till the meter runs at the correct speed.

Rated supply voltage: By adjusting the rated supply voltage, with the rated full load current and unity power factor, the speed of the meter is checked and the full load unity power factor and low power factor adjustments are repeated until the desired accuracy limits are reached for both the conditions.

Light load adjustment: The rated supply voltage is applied across the pressure coil and a very low current (about 5% of full load current) is passed through the meter at unity power factor. Light load adjustment is done so that the meter runs at the correct speed.

Full load unity power factor: Light load adjustments are again done until the speed is correct for both loads i.e. full load as well as light loads.

Creep adjustment: As a final check on the light load adjustment, the pressure coil is excited by 110 percent of the rated voltage with zero load current. If the light load adjustment is correct, the meter should not creep under these conditions.

Multimeters

Objectives: At the end of this lesson you shall be able to
- **explain the construction of multimeter**
- **explain the working priniciple of analog multimeter**
- **explain the method of measuring direct / alternating voltages and current with a multimeter**
- **explain the method of measuring resistance by a multimeter**
- **explain the precautions to be observed while measuring voltage, current and resistance in the circuit.**

A single instrument used for measuring current, voltage and resistance is known as a multimeter. It is a portable, multi range instrument.

It has a full scale deflection accuracy of ±1.5 %. The lowest sensitivity of multimeters for AC voltage range is 5 K ohms/volts and for the DC voltage range it is 20 K ohms/volts. The lowest range of DC is more sensitive than the other ranges.

Fig 1 show typical multimeters.

Construction of a multimeter

A multimeter uses a single meter movement with a scale calibrated in volts, ohms and milliamperes. The necessary multiplier resistors and shunt resistors are all contained within the case. Front panel selector switches are provided to select a particular meter function and a particular range for that function.

On some multimeters, two switches are used, one to select a function, and the other the range. Some multimeters do not have switches for this purpose; instead, they have separate jacks for each function and range.

Batteries/cells fixed inside the meter case provide the power supply for the resistance measurement.

The meter movement is that of the moving coil system as used in DC ammeters and voltmeters.

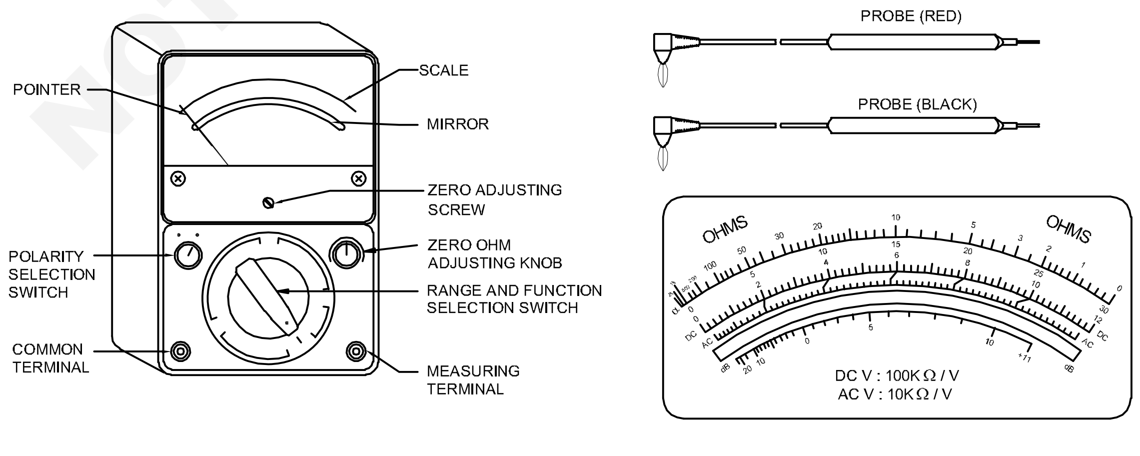
Rectifiers are provided inside the meter to convert AC to DC in the AC measurement circuit.

Fig 1

Parts of a multimeter

A standard multimeter consists of the main parts and controls. (Fig 2)

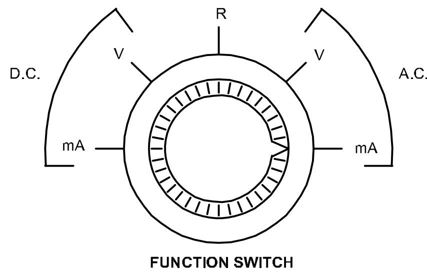
Fig 2



Controls

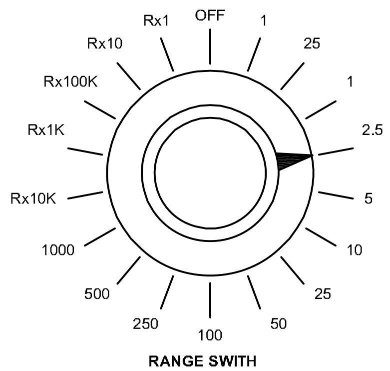
The meter is set to measure the current, voltage (AC and DC) or resistance by means of the FUNCTION switch. In the example given in Fig 3 the switch is set to mA, AC.

Fig 3



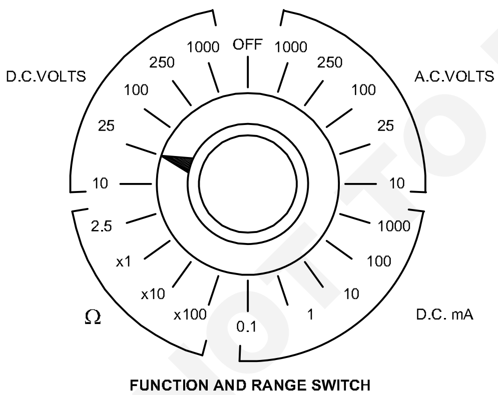
The meter is set to the required current, voltage or resistance range - by means of the RANGE switch. In Fig 4, the switch is set to 2.5 volts or mA, depending on the setting of the FUNCTION switch.

Fig 4



The example in Fig 5 shows the switch set to 25V DC of a meter having the function and the range selected by a single switch.

Fig 5



Scale of multimeter

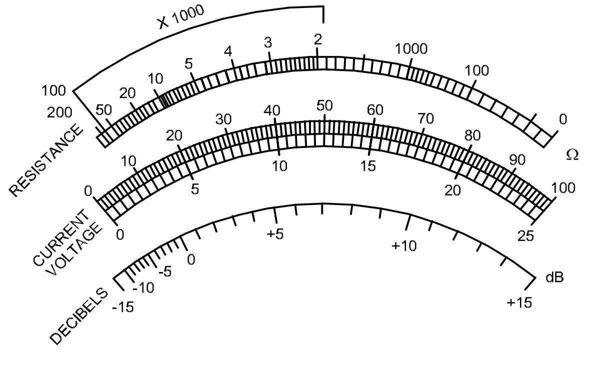
Separate scales are provided for:

- resistance
- voltage and current.(Fig 6)

The scale of current and voltage is uniformly graduated.

The scale of the ohmmeter is non-linear. That is, the divisions between zero and infinity (¥) are not equally spaced. As you move from zero to the left across the scale, the divisions become closer together.

Fig 6



The scale is usually 'backward', with zero at the right.

Principle of working

A circuitry when working as an ammeter is shown in Fig 7.

Shunt resistors across the meter movement bypass current in excess of 0.05 mA at fsd. A suitable value of shunt resistor is selected through the range switch for the required range of current measurement.

A circuitry when working as a voltmeter is shown in Fig 8.

The voltage drop across the meter coil is dependent on the current and the coil resistance. To indicate voltages greater than 50 mV at fsd as per the circuit, multiplier resistances of different values are connected in series with the meter movement through the range switch for the required range of measurement.

A circuitry when working as an ohmmeter is shown in Fig 9.

To measure resistance, the leads are connected across the external resistor to be measured (Fig 9). This connection completes the circuit, allowing the internal battery to produce current through the meter coil, causing deflection of the pointer, proportional to the value of the external resistance being measured.

Zero adjustment

When the ohmmeter leads are open, the pointer is at full left scale, indicating infinite (¥) resistance (open circuit). When the leads are shorted, the pointer is at full right scale, indicating zero resistance.

The purpose of the variable resistor is to adjust the current so that the pointer is at exactly zero when the leads are shorted. It is used to compensate for changes in the internal battery voltage due to aging.

Multiple range

Shunt (parallel) resistors are used to provide multiple ranges so that the meter can measure resistance values from very small to very large ones. The reading on the ohmmeter scale is multiplied by the factor indicated by the range setting.

Remember, an ohmmeter must not be connected to a circuit when the circuit's power is on. Always turn the power off before connecting the ohmmeter.

Fig 7

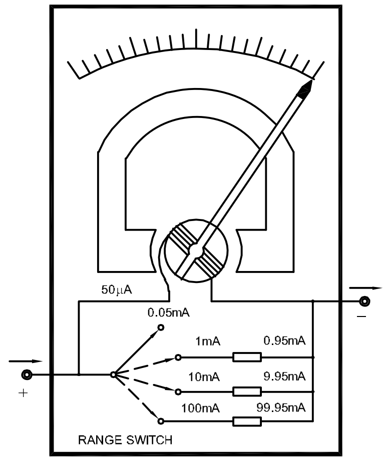


Fig 8

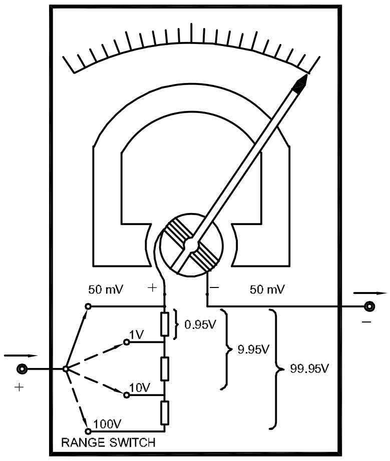
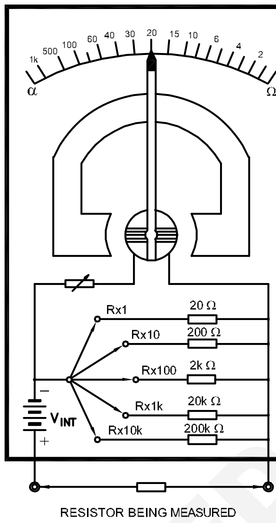


Fig 9



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Digital multimeters

Objectives: At the end of this lesson you shall be able to
- **explain the method of measurement of voltage by using digital multimeter**
- **list and explain the types of digital multimeter**
- **state the application of digital multimeters**

In a digital multimeter the meter movement is replaced by a digital read out (Fig 1 and 2). This readout is similar to that used in electronic calculators. The internal circuitry of the digital multimeter is made up of digital, integrated circuits. Like the analog-type multimeter, the digital multimeter has a front panel switching arrangement.

The quantity measured is displayed in the form of a four digit number with a properly placed decimal point. When DC quantities are measured the polarity is identified by '+ve' or '-ve' sign displayed to the left of the number indicating the probes are connected correctly by +ve sign and probes are reversely connected by -ve sign.

DMM functions: The basic functions found on most DMMs are the same as those on analouge multimeters. That is it can measure:-

Fig 1

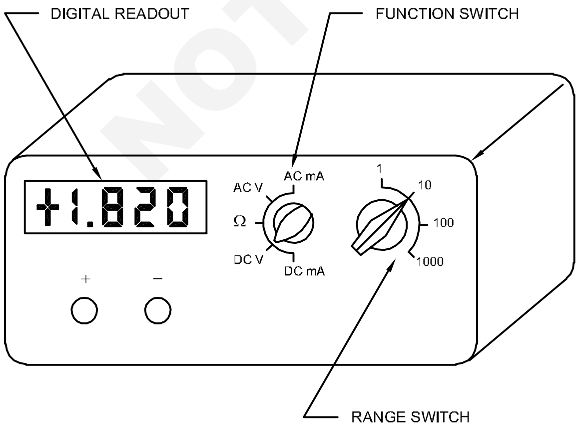

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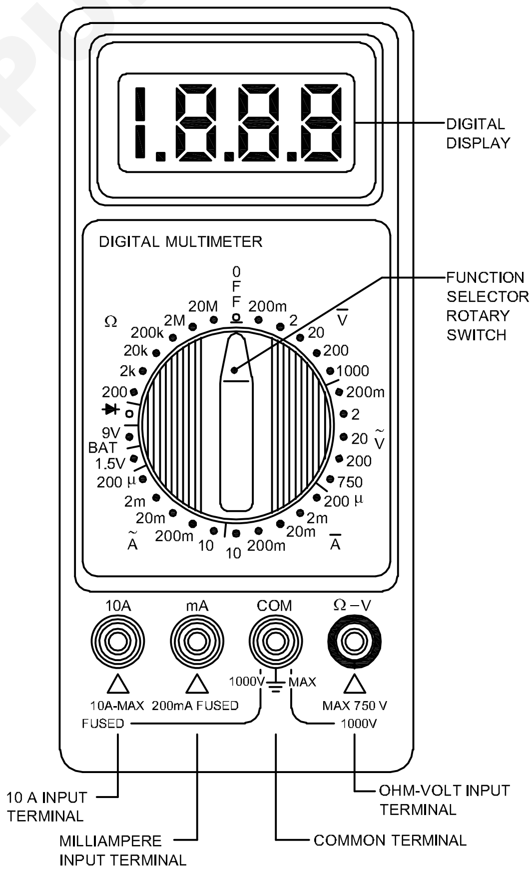
Fig 2



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- ohms
- DC voltage and current
- AC voltage and current

Some DMMs provide special functions such as transistor or diode test, power measurement, and decibel measurement for audio amplifier tests.

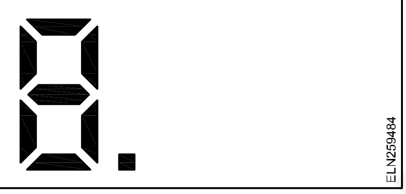
DMM displays: DMMs are available with either LCD (liquid -crystal display) or LED (light-emitting diode) read-outs. The LCD is the most commonly used read-out in battery-powered instruments due to the fact that it draws very small amount of current.

A typical battery-powered DMM with an LCD read-out operates on a 9V battery that will last from a few hundred hours to 2000 hours and more. The disadvantages of LCD read-outs are that (a) they are difficult or impossible to see in poor light conditions, and (b) they are relatively slow response to measurement changes.

LEDs, on the other hand, can be seen in the dark, and respond quickly to changes in measured values. LED displays require much more current than LCDs, and, therefore, battery life is shortened when they are used in portable equipment.

Both LCD and LED-DMM displays are in a seven segment format (Fig 3).

Fig 3



The following safety precautions should always be taken.

- Never use the ohmmeter section on a live circuit.
- Never connect the ammeter section in parallel with a voltage source.
- Never overload the ammeter or voltmeter sections by attempting to measure currents or voltages far in excess of the range switch setting.
- Check the meter test leads for frayed or broken insulation before working with them. If damaged insulation is found the test leads should be replaced.
- Avoid touching the bare metal clips or tips of the test probes.
- Whenever possible, remove the supply before connecting the meter test leads into the circuit.

Applications of Digital multimeter: A multimeter is used for testing and fault finding in electrical/electronic circuits, electrical appliances and machines. A multimeter is a portable handy instrument used for

- checking continuity of circuit, appliances and devices.
- measuring/checking the supply presence at the source
- for testing components like capacitors, diodes, and transistors for checking their condition.
- measuring the current drawn by the circuit to infer its condition
- measuring resistance of the electrical appliances and devices for checking their condition.

Note: Some meters have provision also for temperature measurement with suitable sensing probes.

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.**

Phase sequence

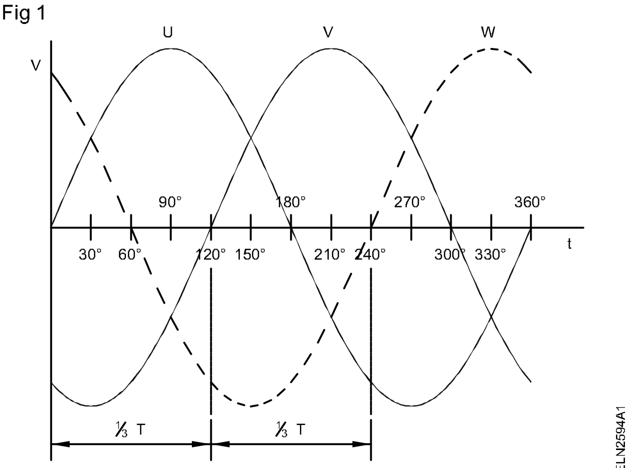
A three-phase alternator contains three sets of coils positioned 120° apart and its output is a three-phase voltage as shown in Fig 1. A three-phase voltage consists of three voltage waves, 120 electrical degrees apart.

At a time 0, phase U is passing through zero volts with positively increasing voltage. (Fig 1) V follows with its zero crossing $\frac{1}{3}$ 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.

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.

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.

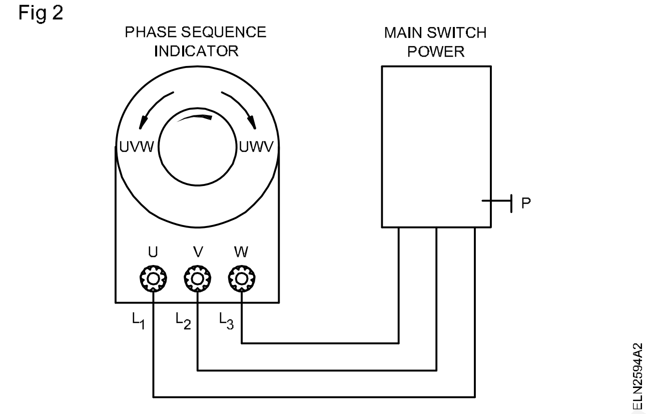
Fig 1



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.

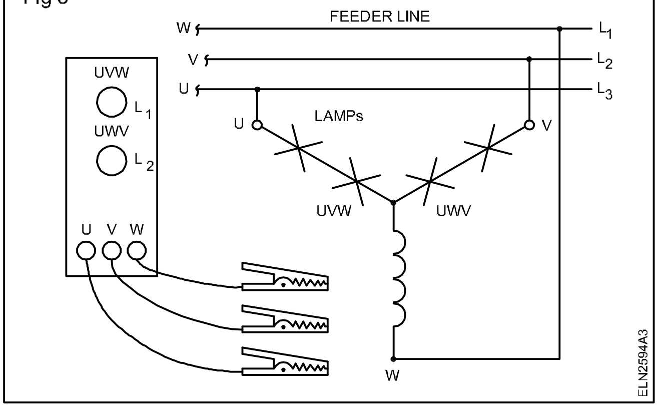
The direction of the disc movement is marked with an arrowhead on the indicator. Below the arrowhead the correct sequence is marked (Fig 2). The phase sequence of the three-phase system may be reversed by interchanging the connections of any two of the three phases.

Fig 2



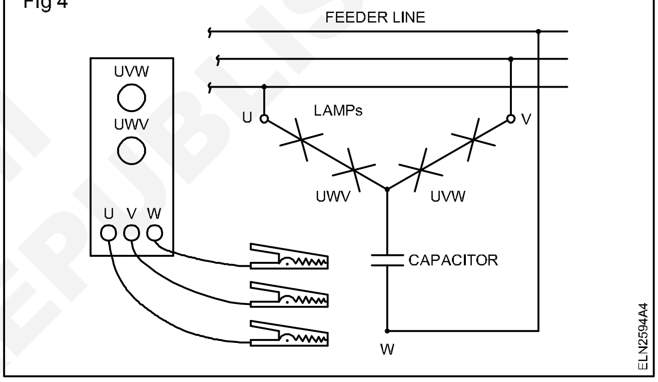
Phase-sequence indicator using choke and lamps: The phase-sequence indicator consists of four lamps and an inductor connected in a star formation (Y). A test lead is connected to each leg of the `Y'. One lamp is labelled U-V-W, and the other is labelled U-W-V. When the three leads are connected to a three-phase line, the brighter lamp indicates the phase sequence (Fig 3).

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 4



Frequency meter

Objectives: At the end of this lesson you shall be able to
- **state the types of frequency meters**
- **describe the principle, construction and working of a mechanical resonance (vibrating reed) type frequency meter.**

The following types of frequency meters are used for measuring power frequencies.

- Mechanical resonance type
- Electrical resonance type
- Electro-dynamic type
- Electro-dynamometer type
- Weston type
- Ratiometer type
- Saturable core type

The explanation given here is for mechanical resonance type frequency meters only as indicated below.

The trainees are advised to refer to books on electrical measuring instruments for learning about the other types of frequency meters.

Mechanical resonance type frequency meter (vibration reed type)

Principle: The vibration reed type frequency meter shown in Fig 1 works on the principle of natural frequency. Every object in the world has its natural frequency, depending upon its weight and dimensions. When an object is kept in a vibrating medium, it starts vibrating, if the frequency of the medium attains the natural frequency of the object.

If the vibrations are not controlled, the object may even get totally destroyed. A good example of this phenomenon is the shattering of window glass panes due to the vibration caused by low flying aircraft.

Construction: Mechanical resonance type frequency meters consist of an eletromagnet and a set of metallic reeds arranged in front of the electromagnet. The frequency meter is connected across the supply like a voltmeter, taking care about the voltage rating (Fig 2) .

Fig 1

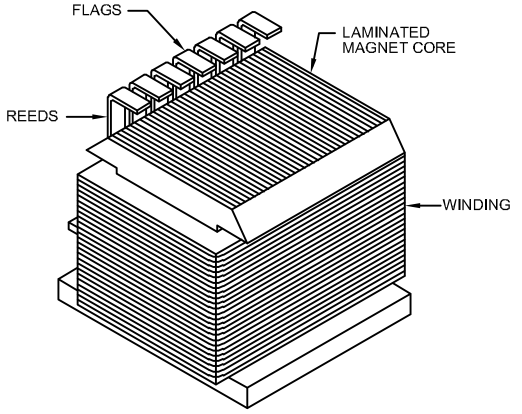


Fig 2(a)

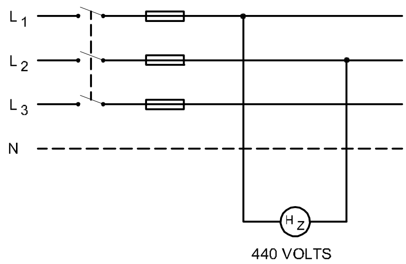


Fig 2(b)

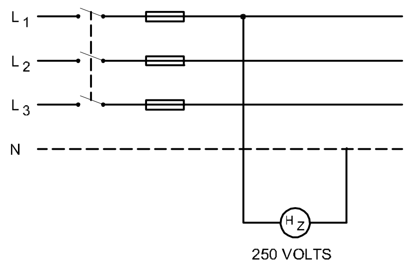
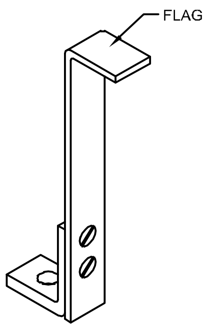


Fig 3 shows the shape of the reed and these reeds are of about 4mm wide and 0.5 mm thick. One end of the reed is fitted on a base, and the other overhanging end carries a white painted surface as the indicator and sometimes referred to as flag.

The reeds are arranged in a row and the natural frequency of the reeds differs by 1/2 cycle. This 1/2 cycle difference is possible between the reeds due to the difference in the weights of the reeds. The reeds are arranged in an ascending order (Fig 4a), and generally the natural frequency of the centre reed is the same as that of the supply frequency (50Hz).

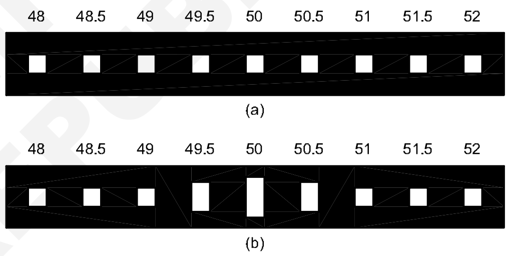
Fig 3



Working: When the frequency meter is connected to the supply, the electromagnet produces a magnetic field which alternates at the rate of the supply frequency. The reed, which has its natural frequency coincident with that of the alternating magnetic field, vibrates more than the adjacent reeds Fig 4(b).

The flag of this vibrating reed makes it possible to note the frequency of the supply from the scale marking of the frequency meter. Though the other reeds also vibrate, Fig 4(b), their magnitude will be much less than the reed whose natural frequency is exactly in coincidence with the supply frequency.

Fig 4



Advantages and disadvantages

The reed type frequency meter has the following advantages.

The indications are independent of i) the wave form of the applied voltage and ii) magnitude of the applied voltage, provided that the voltage is not too low. At a low voltage the flag indication of the reed will not be reliable.

The disadvantages are the meter cannot read closer than half the cycle frequency difference between adjacent reeds and the accuracy greatly depends upon the proper tuning of the reeds.

Digital Frequency Meter

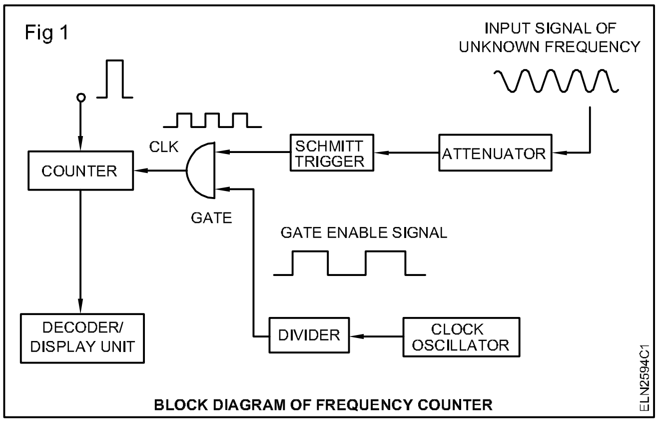
Objectives: At the end of this lesson you shall be able to
- **state the function of digital frequency meter**
- **describe the block diagram of digital frequency meters.**

A frequency counter is a digital instrument that can measure and display the frequency of any periodic waveform. It operates on the principle of gating the unknown input signal into the counter for a predetermined time.

If the unknown input signal were gated into the counter for exactly 1 second, the number of counts allowed into the counter would be the frequency of the input signal. The term gated comes from the fact that an AND or an OR gate is employed for allowing the unknown input signal into the counter to be accumulated. Fig 1

Discription of block diagram:

The simplified form of block diagram of frequency counter is in Fig 1. It consists of a counter with its associated display/decoder circuitry, clock oscillator, a divider and an AND gate. The counter is usually made up of cascaded Binary Coded Decimal(BCD) counters and the display/ decoder unit converts the BCD outputs into a decimal display for easy monitoring.



BLOCK DIAGRAM OF FREQUENCY COUNTER

Power factor meter

Objectives: At the end of this lesson you shall be able to
- **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

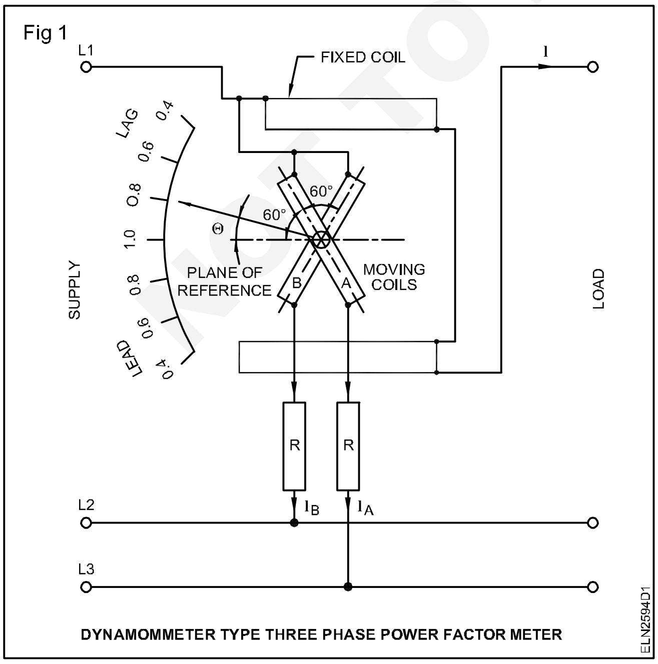
$$P.F. = \frac{Power}{EI}$$

On the other hand, for measuring power factor in a balanced 3-phase circuit we have to use the formula

$$P.F. = \frac{3\text{-phase power}}{3E_{PH}I_{PH}} \text{ or } \frac{3\text{-phase power}}{\sqrt{3}E_L I_L}$$

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.



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.

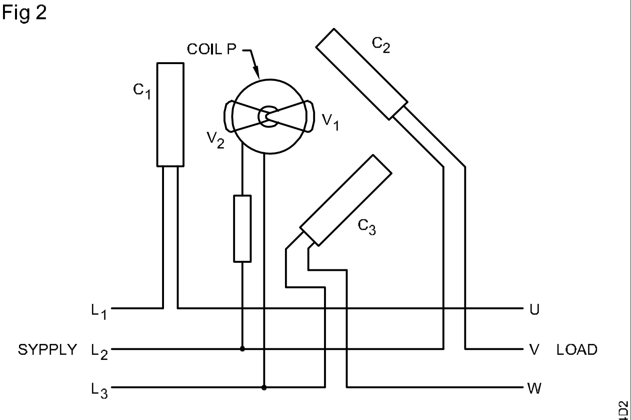
Moving iron power factor meters: This type of power factor meter is more popular than the dynamometer type due to the following advantages.

- 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.

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 2

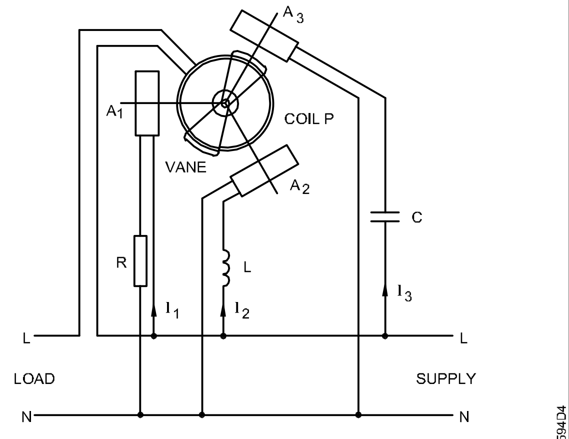


MOVING IRON TYPE POWER-FACTOR METER
FOR A BALANCED 3-PHASE LOAD

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 3) uses a phase splitting network comprising of a capacitor, an inductor and a resistor.

Fig 3



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.

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.**

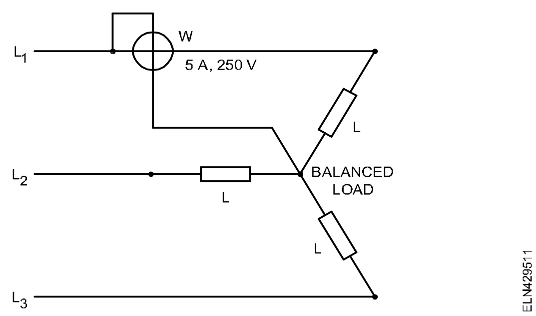
The measurement of power: The number of wattmeters used to obtain power in a three-phase system depends on whether the load is balanced or not, and whether the neutral point, if there is one, is accessible

- 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.

$P = 3E_P I_P \cos\varphi = 3P = 3W$

Fig 1



The two wattmeter method of measuring power

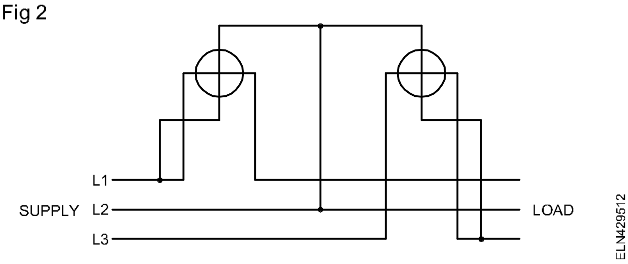
Power in a three-phase, three-wire system is normally measured by the `two-wattmeter' method. It may be used with balanced or unbalanced loads, and separate connections to the phases are not required. This method is not, however, used in four-wire systems because current may flow in the fourth wire, 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.

Fig 2



$P_T = V_{UN}\, i_U + V_{VN}\, i_V + V_{WN}\, I_W$

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.

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

Assignment 1: 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.

Assignment 2: 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.

Assignment 3: 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.

Tong - tester (clamp - on ammeter)

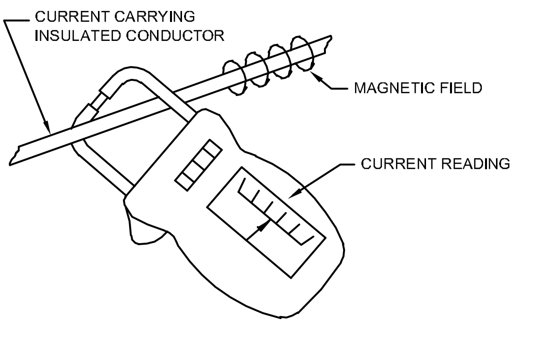
Objectives: At the end of this lesson you shall be able to
- **state the necessity of tong-testers**
- **state the construction and working of a tong-tester**
- **state the precautions to be observed while using a tong-tester.**

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).

Working principle

The instrument can function only when current passes through its deflecting system. It works under the mutual induction principle.

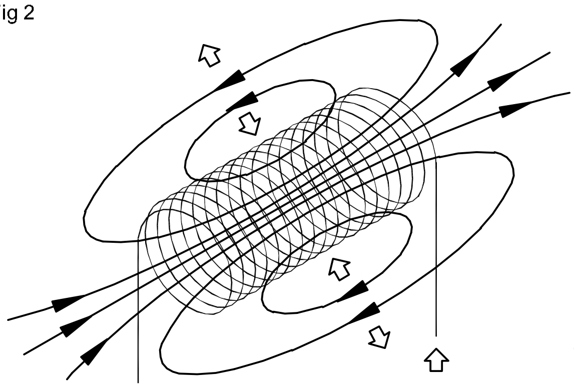
Fig 1



TONG-TESTER

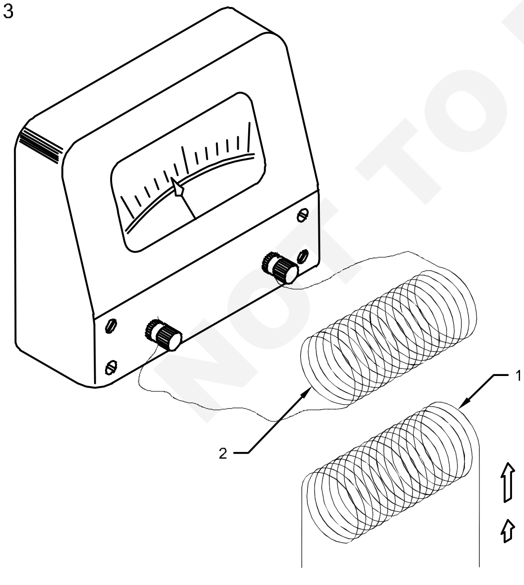
Electromagnetic induction: When a changing flux is linked with the coil, an emf is induced in the coil. The current in a coil so produced changes as that of the changing magnetic flux. If an alternating current is flowing through the coil, the magnetic flux produced is also alternative i.e. changing continuously.(Fig 2)

Fig 2



Placing another coil (2) in the changing flux of coil (1), an emf will be induced. (Fig 3)

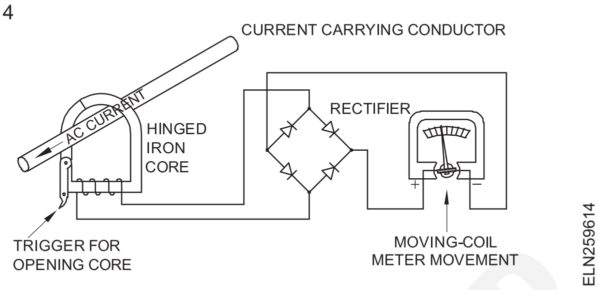
Fig 3



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



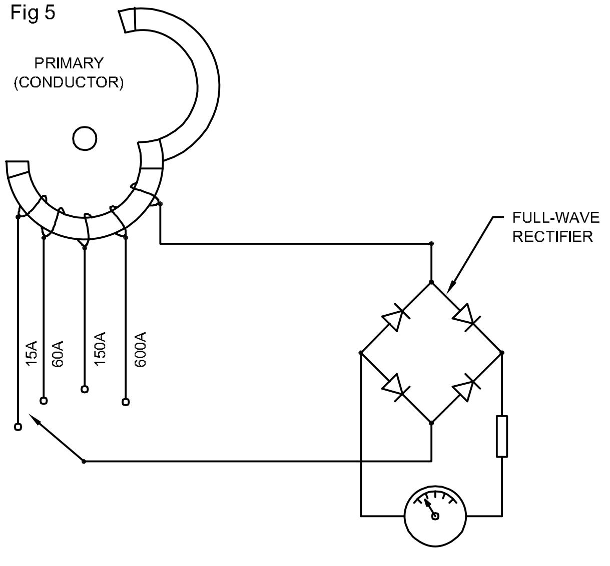
The core is so designed that there is only one break in the magnetic path. The hinge and the opening both fit tightly when the instrument closes around the conductor. The tight fit of the instrument ensures minimum variation in the response of the magnetic circuit.

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



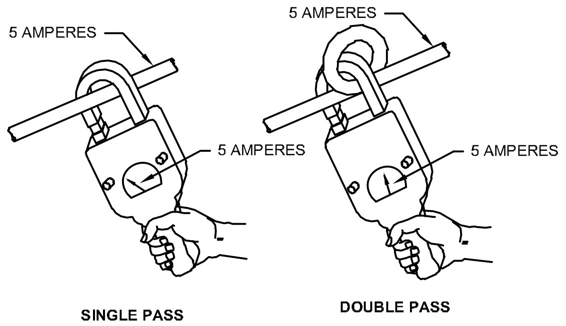
TAPPED-SECONDARY CIRCUIT

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).

Fig 6



Application

1 For measuring the incoming current in the main panel board.

2 Primary current of AC welding generators.

3 Newly rewinded AC motor phase current and line current.

4 Starting current of all AC machines.

5 For measuring the unbalanced or balanced loads.

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.

Extension of range of MC voltmeters - loading effect - voltage drop effect

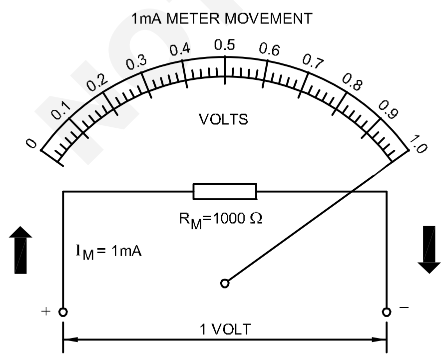
Objectives: At the end of this lesson you shall be able to

- **state the function of the additional series resistance in a voltmeter**
- **calculate the value of the total resistance of the meter with respect to voltage and full scale deflection of current**
- **determine the resistance of a multiplier.**

Meter movement: A basic current meter movement by itself can be used to measure voltage. You know that every meter coil has a fixed resistance, and, therefore, when current flows through the coil, a voltage drop will be developed across this resistance. According to Ohm's Law, the voltage drop (E) will be proportional to the current flowing through the coil of resistance R ($E = IR$).

For example, in Fig 1 you have a 0-1 milliampere meter movement with a coil resistance of 1000 ohms. When 1 milliampere is flowing through the meter coil and is causing f.s.d. the voltage developed across the coil resistance will be:

Fig 1



SINCE THE VOLTAGE ACROSS THE METER COIL RESISTANCE IS PROPORTIONAL TO THE CURRENT FLOWING THROUGH THE COIL, THE 1MA CURRENT METER MOVEMENT CAN MEASURE VOLTAGE DIRECTLY IN UNITS OF VOLTAGE.

$E = I_M R_M = 0.001 \times 1000 = 1\text{Volt}$

$E = I_M R_M = 0.001 \times 1000 = 1$ volt.

If only half that current (0.5 milliampere) was flowing through the coil, then the voltage across the coil would be:

$E = I_M R_M = 0.0005 \times 1000 = 0.5$ volt.

It can be seen that the voltage developed across the coil is proportional to the current flowing through the coil. Also, the current that flows through the coil is proportional to the voltage applied to the coil. Therefore, by calibrating the meter scale in units of voltage instead of in units of current, the voltage in various parts of a circuit can be measured.

Although a current meter movement inherently can measure voltage, its usefulness is limited because the current that the meter coil can handle, as well as its coil resistance, are very low. For example, the maximum voltage you could measure with the 1 milliampere meter movement in the above example is 1 volt. In actual practice, voltage measurements higher than 1 volt will be required.

Multiplier resistors: Since a basic current meter movement can only measure very small voltages, The voltage range of a meter movement can be extended by adding a resistor, in series. The value of this resistor must be such that, when added to the meter coil resistance, the total resistance limits the current to the full-scale current rating of the meter for any applied voltage.

For example, suppose one wanted to use the 1-milliampere, 1000-ohms meter movement to measure voltages up to 10 volts. From Ohm's Law, it can be seen that, if the movement is connected across a 10-volt source, 10 milliamperes would flow through the movement and would probably ruin the meter ($I = E/R = 10/1000 = 10$ milliamperes).

But the meter current can be limited to 1 milliampere if a multiplier resistor (R_{MULT}) is added in series with the meter resistance (R_M). Since a maximum of only 1 milliampere can flow through the meter, the total resistance of the multiplier resistor and the meter ($R_{TOT} = R_{MULT} + R_M$) must limit the meter current to one milliampere. By Ohm's Law, the total resistance is

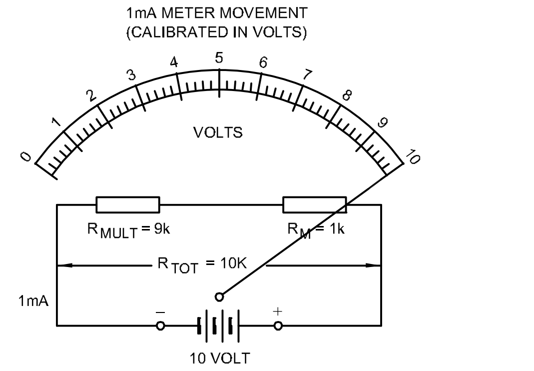
$$R_{TOT} = E_{MAX}/I_M = 10 \text{ volts}/0.001 \text{ ampere}$$
$$= 10{,}000 \text{ ohms.}$$

But this is the total resistance needed. Therefore, the multiplier resistance is

$$R_{MULT} = R_{TOT} - R_M = 10000 - 1000 = 9000 \text{ ohms.}$$

The basic 1-milliampere, 1000-ohms meter movement can now measure 0-10 volts, because 10 volts must be applied to cause a full-scale deflection. However, the meter scale must now be re-calibrated from 0-10 volts, or, if the previous scale is used all the reading should be multiplied by 10 (Fig 2).

Fig 2



BY CONNECTING A MULTIPLIER RESISTOR IN SERIES WITH THE METER RESISTANCE, THE RANGE OF A BASIC METER MOVEMENT CAN BE EXTENDED TO MEASURE VOLTAGES HIGHER THAN THE $I_M R_M$ VOLTAGE DROP ACROSS THE METER COIL.

Multiplying factor (M.F)

$$MF = \frac{\text{Proposed voltmeter range (V)}}{\text{Voltage drop across MC at FSD}} = \frac{V}{v}$$

Calculating the multiplier resistance using M F

$$R_{MULT} = (MF - 1)\, R_M$$

where

R_{MULT} = Multiplier resistance

M F = Multiplying factor

R_M = Meter resistance

A 1 mA meter has a coil resistance of 1000 ohms. What value of multiplier resistor is needed to measure 100V?

$$MF = \frac{V}{v}$$
$$v = I_M \times R_M$$
$$= 1 \times 10^{-3} \times 1000 = 1V$$
$$MF = \frac{V}{v} = \frac{100}{1} = 100$$
$$R_{MULT} = (MF - 1)R_M = (100 - 1)1000$$
$$= 99{,}000 \text{ ohms.}$$

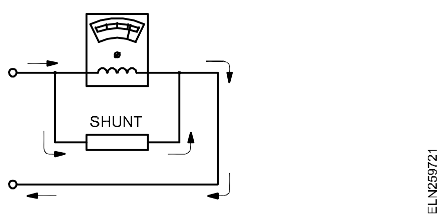
Extension of range of MC ammeters

Objectives: At the end of this lesson you shall be able to
- **define shunt used in ammeter**
- **calculate a shunt resistance to extend the range of an ammeter**
- **name the material used for shunt**
- **apply the use of terminals in standard shunts.**

Shunts: Moving coils of basic meters by themselves cannot carry large currents, since they are made of fine wire. To measure a current greater than that which the moving coil can carry, a low resistance, called a SHUNT, is connected across the instrument terminals (Fig 1).

The shunt, therefore, makes it possible to measure currents much greater than that could be measured by the basic meter alone.

Fig 1



The shunt equation: A meter and shunt combination is identical to the parallel circuit shown in Fig 2. Instead of labelling the top resistor R_2, it can be labeled R_M, which represents the resistance of the moving coil. Resistor R_1 can be labelled R_{SH} to represent the resistance of the shunt. I_{R1} and I_{R2} then become I_{SH} and I_M to indicate the current flow through the shunt and through the meter. This means that the equation $I_{R1}R_1 = I_{R2}R_2$ can now be written as $I_{SH}R_{SH} = I_M R_M$.

Therefore, if three of these values are known, the fourth can be calculated. Since the shunt resistance R_{SH} is always the unknown quantity, the basic equation

$$I_{SH}R_{SH} = I_M R_M \text{ becomes } R_{SH} = \frac{I_M R_M}{I_{SH}}$$

From this equation, shunts can be calculated to extend the range of a current meter to any value,

where R_{SH} = shunt resistance

I_M = meter current

R_M = resistance of moving coil instrument

I_{SH} = current flow through shunt.

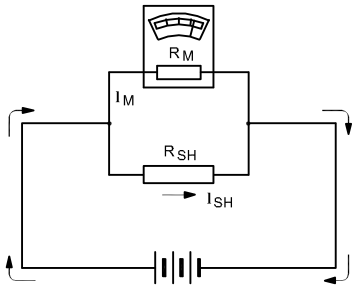
The value of current through the shunt(I_{SH}) is simply the difference between the total current you want to measure, and the actual full-scale deflection of the meter.

$I_{SH} = I - I_M$ where I = total current.

The meter and shunt act like R_1 and R_2 in parallel.

So,

Fig 4



THE METER AND SHUNT ACT LIKE R_1 AND R_2 IN PARALLEL. SO, $R_{SH} = \frac{I_M R_M}{I_{SH}}$

ELN259724

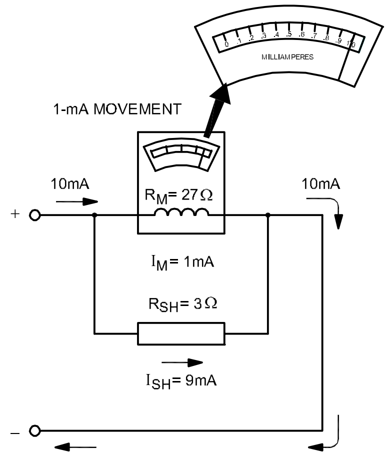
$$R_{SH} = \frac{I_M R_M}{I_{SH}}$$

Calculating shunt resistance: Assume that the range of a one milliampere meter movement is to be extended to 10 milliamperes, and the moving coil has a resistance of 27 ohms. Extending the range of the meter to 10 milliamperes means that 10 milliamperes will be flowing in the overall circuit when the pointer is deflected full scale. (Fig 3)

I_M = 1 mA (0.001 A)

I = Current to be measured = 10mA

Fig 5



THE RANGE OF THIS 1-MILLIAMPERE METER MOVEMENT WAS EXTENDED TO 10 MILLIAMPERES BY USING THE SHUNT EQUATION $R_{SH} = \frac{I_M R_M}{I_{SH}}$

ELN259725

R_M = 27 Ohms

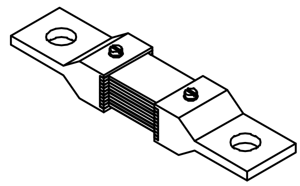
$I_{SH} = I - I_M$ = 10 mA – 1 mA

= 9 mA (0.009 A)

$$R_{SH} = \frac{I_M R_M}{I_{SH}} = \frac{0.001 \times 27}{0.009} = 3 \text{ ohms.}$$

Shunt material: The resistance of shunt should not vary due to the temperature. The shunt is usually made of Manganin which has negligible temperature coefficient of resistance. A high current shunt of a switch board instrument is shown in Fig 4.

Fig 6



HIGH CURRENT SHUNT FOR A SWITCHBOARD INSTRUMENT

ELN259726

Calibration of MI Ammeter and Voltmeter

Objectives: At the end of this lesson you shall be able to
- **define the term 'calibration' and standards accuracy precision,resolution and sensitivity**
- **explain the calibration of voltmeter and ammeter.**

Calibration: In many industrial operations, measurement instruments must be trusted to provide the accuracy stipulated by the original design to assure a satisfactory product. This confidence is provided by a periodic testing and adjustment of the instrument to verify the required performance. This type of maintenance is called calibration.

Standards

Before calibration can begin, you must have the accurately known values of the measured quantities against which to compare the measurements made by the instrument being calibrated. Thus, for an instrument that is supposed to measure current of 1 milli ampere, you must have, for comparison, a source of current that is known to within at least that range or better. Only then you can say whether the instrument performs satisfactorily.

A very accurately known quantity used for calibration of instruments is known as a standard.

Calibration standards

Quantity	Standard
Voltage	Standard cell, high precision source
Current	Voltage standard and standard resistance standard milli volt source, gas filled/ mercury filled thermometers.

Calibrating DC and AC Meters (Ammeter & Voltmeter)

Both DC and AC meters are calibrated in essentially the same way. To calibrate a DC meter, a very accurate DC current source is connected to the meter. The output of the current source must be variable, and some means must be available to monitor the output current of the source. Many sources have built-in meter for this purpose.

The output of the current source is varied in very small steps, and at each step the scale of the meter being calibrated is marked to correspond to the reading on the monitoring device. This procedure is continued until the entire scale of the meter is calibrated.

Same procedure is used to calibrate an AC meter, except that a 50/60 cps sine wave is used mostly. Also, you know that an a-c meter reads the average value of a sine wave, but it is desirable for the meter to indicate rms values. Therefore the rms equivalent are calculated and marked on the scale.

METER ACCURACY

Meter	Typical accuracy
Moving coil	0.1 to 2%
Moving iron	5%
Rectifier type moving coil	5%
Thermocouple	1 to 3%

Precautions to be observed when using an ammeter in measurement work

1 Never connect an ammeter across a source of EMF. Because of its low resistance it would draw damaging high currents and damage the delicate movement. Always connect an ammeter in series with a load capable of limiting the current.

2 When using a multi range meter, first use the highest current range, then decrease the current range until substantial deflection is obtained. To increase the accuracy of the observation, use the range that will give a reading as near to full scale as possible.

The following general precautions should be observed when using a Voltmeter

1 Observe the correct polarity. Wrong polarity causes the meter to deflect against the mechanical stop and this may damage the pointer.

2 Place the voltmeter across the circuit or component whose voltage is to be measured.

3 When using a multi range voltmeter, always use the highest voltage range and then decrease the range until a good up scale reading is obtained.

4 Always be aware of the loading effect. The effect can be minimised by using the high voltage range (and highest sensitivity) as possible. The precision of measurement decreases if the indication is at the low end of the scale.

Instrument transformers - current transformer

Objectives: At the end of this lesson you shall be able to

- **state the necessity, types and principle of the instrument transformer**
- **explain the construction and connection of the current transformer**
- **state the general terms like accuracy, phase displacement, burden and output with respect to the current transformer**
- **identify the I.S. symbols and markings used in the current transformer**
- **state the precautions to be followed while using the current transformer**
- **specify the current transformer.**

Necessity of instrument transformers: Transformers used in conjunction with measuring instruments for measurement purposes are called **'instrument transformers'**. the actual measurements are done by the measuring instruments only.

Where the current and voltage are very high, direct measurements are not possible as, these current and voltage are too large for reasonably sized instruments and the cost of the meter will be high.

The solution is to step-down the current and voltage with instrument transformers, so that, they could be metered with instruments of moderate size.

Type of instrument transformers: Three are two types of instrument transformers.

- Current transformer
- Potential transformer

The transformer used for measurement of high current is called 'current transformer' or simply 'CT'

The transformer used for high voltage measurement is called 'voltage transformer or potential transformer' or simply 'PT' in short.nt but high reliability and ruggedness are essential.

Principle: Instrument transformers work on the principle of mutual induction similar to the two winding transformers.

In the case of an instrument transformer, the following design features are to be considered.

Core: In order to minimise the error, the magnetizing current must be kept low. This means the cores should have low reactance and low core losses.

Winding: The winding should be close together to reduce the secondary leakage reactance; otherwise the ratio error will increase. In the case of a current transformer the winding must be so designed as to withstand the large short circuit current without damage.

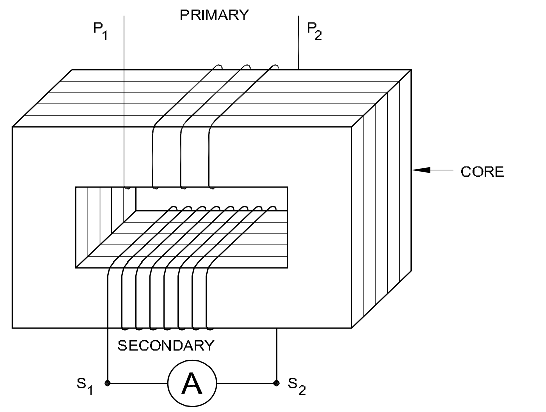
Current transformers - types of construction and connection

The following are the different types of current transformers.

Wound type current transformer: This is one in which the primary winding is having more than one full turn wound on the core (Fig 1)

Fig 1 shows the connections of a wound type current transformer having a rectangular type of core. In general the ammeter is arranged to give full scale deflection with 5A or 1A when connected to the secondary of the current transformer.

Fig 1



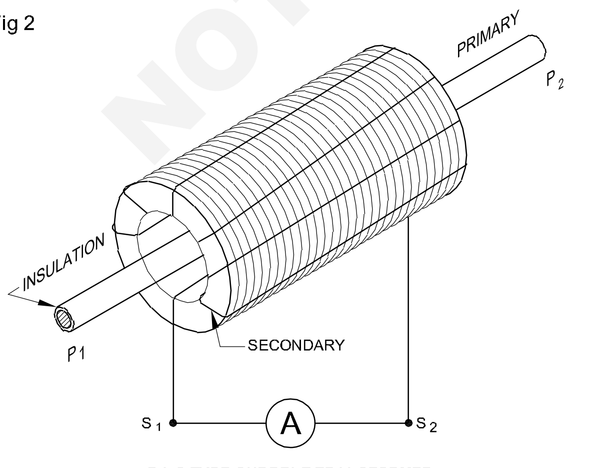
WOUND TYPE CURRENT TRANSFORMER

The ratio between the primary and secondary turns of the current transformer decides the primary current which could be measured with fixed secondary current rating of 5 or 1 amp.

For example if the primary current is 100 amps and there are two turns in the primary, then the full load primary ampere turns is 200. Consequently, to circulate 5 amps in the secondary, the number of secondary turns must be 200/5, that is 40 turns.

Ring type current transformer: This has an opening in the centre to accommodate a primary winding through it Fig 2 shows a ring type current transformer with single turn primary. In this current transformer, the insulated conductor that carries the current to be measured passes directly through an opening in the transformer assembly.

Fig 2



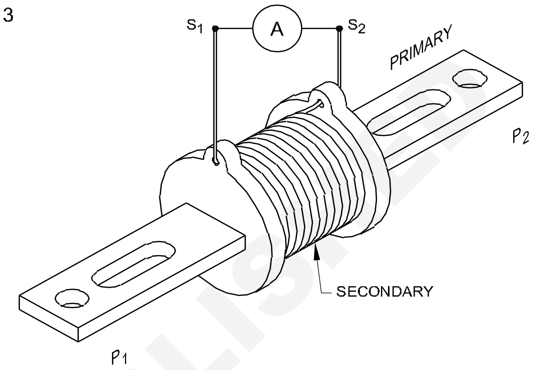
RING TYPE CURRENT TRANSFORMER

If there are 20 turns in the secondary having a current range of 5 amps, this current transformer according to the transformation ratio, could measure a primary current of 100 amps.

Clamp on or clip on ammeters work on this principle only but the core is made such that it can open to pass the insulated conductor and then get closed to complete the magnetic circuit.

Bar type current transformer: This is one in which the primary winding consists of a bar of suitable size and secondary winding and core assembly material forming an integral part of the current transformer (Fig 3).

Fig 3



BAR TYPE CURRENT TRANSFORMER

Dry type current transformer :This is one which does not require the use of any liquid or semi-liquid material for the purpose of cooling.

Oil immersed current transformer: This is one which requires the use of an oil of suitable characteristic as insulating and cooling medium.

General terms used

Accuracy class: Accuracy class is a designation assigned to a current transformer the errors of which remain within the specified limits under prescribed conditions of use. The standard accuracy classes for measuring current transformers shall be 0.1, 0.2, 0.5, 1.0, 3.0 and 5.0.

Rated output: The standard values of rated outputs are 2.5, 5.0, 7.5, 10, 15 and 30 VA.

Precautions while using the current transformer: In a current transformer the secondary current depends upon the primary current. Futher the secondary of the current transformer could be assumed to be almost short circuited as the ammeter resistance is extremely low.

In any case, the secondary winding of the current transformer should not be open circuited. This may happen when the ammeter become open circuited or when the ammeter is removed from the secondary.

In such cases the secondary should be short circuited. If the secondary is not short circuited, in the absence of secondary ampere-turns, the primary current will produce abnormally high flux in the core thereby heating up the core and resulting in burning out the transformer.

Further secondary will produce a high voltage across its open terminals endangering safety. In addition to earthing non-current carrying metal parts of the current transformer, we have to earth one end of the secondary of the current transformer to prevent a high static potential difference in case of open circuit. It also serves as a safeguard in case of insulation failure.

Specification of a current transformer: While purchasing a current transformer, the following specifications need to be checked.

- Rated voltage, type of supply and earthing conditions (for example, 7.2 kV, three phase, whether earthed through a resistor or solidly earthed).
- Insulation level
- Frequency
- Transformation ratio
- Rated output
- Class of accuracy

Standard values of rated primary current: The standard values in amperes of rated frequency are 10, 15, 20, 30, 50, 75 amperes and their decimal multiples.

Standard values of rated secondary current: The standard values of rated secondary current shall be either 1 ampere or 5 amperes.

Potential transformer

Objectives: At the end of this lesson you shall be able to
- **explain the construction and connection of the potential transformer**
- **state the potential transformer.**

Potential transformer

Construction and connection: The construction of a potential transformer is essentially the same as that of a power transformer. The main difference is that the volt-ampere rating of a potential transformer is very small.

To reduce the error in a potential transformer, it is required to provide a short magnetic path, good quality of core materials, low flux density and proper assembling and interlaying of cores.

To reduce resistance and leakage reactance, thick conductors are used and the two windings are kept as close as possible.

The primary and secondary windings are coaxial to reduce the leakage reactance to the minimum. In order to simplify the insulation problem, generally a low voltage winding (secondary) is put next to the core.

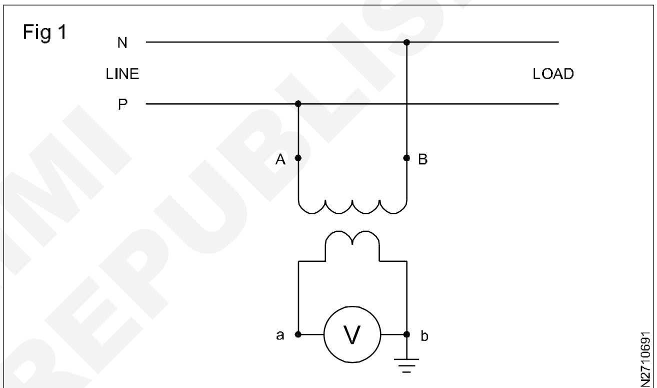
The primary winding may be of a single coil in the case of low voltage transformers but in the case of high voltage transformers the winding is divided into a number of short coils.

Fig 1 shows the connections of a potential transformer. In general, the voltmeter connected to the secondary of the potential transformer is arranged to give full scale deflection at 110 volts.

The ratio between the primary and secondary turns of the potential transformers decides the primary voltage which could be measured with the fixed secondary voltage rating of 110 volts (Fig 1).

If the primary turns are four, the secondary turns are two and the primary is connected to a voltage source of magnitude 220 volts, the secondary voltage will be 110 volts according to the transformation ratio.

Fig 1



CONNETION OF POTENTIAL TRANSFORMER

Precautions to be followed while using a potential transformer: The assembly comprising of the chasis frame work and the fixed part of the metal casing of the voltage transformer shall be provided with two separate, readily accessible, corrosion-free terminals marked legibly as earth terminals.

Specification of a potential transformer: While purchasing a potential transformer, the following specifications need to be checked.

- Rated voltage, type of supply and earthing conditions (for example 6.6 KV, 3 phase solid earthed)
- Insulation level
- Frequency
- Transformation ratio
- Rated output
- Accuracy class
- Winding connection
- Rated voltage factor
- Service conditions including whether voltage transformers are for indoor or outdoor use, whether for use at unsually low temperatures, altitudes (if over

1000 metres), humidity and any special conditions likely to exist or arise, such as exposure to steam or vapour, fumes, explosive gases, excessive dust, vibrations etc.

- Whether the voltage transformer is required for connection between the star point of the generator and earth.
- Whether the installation is electrically exposed or not.

Standard rating of potential transformer

Rated frequency: The rated frequency shall be 50 Hz.

Rated primary voltage: The rated primary nominal system voltage of a 3-phase transformer. 0.6, 3.3, 6.6, 11, 15, 22, 33, 47, 66, 110, 220, 400, and 500 KV.

The standard value of primary voltage of a single phase transformer connected between one line of a 3-phase system and neutral point shall be $\frac{1}{\sqrt{3}}$ times of the above values of the nominal system voltages.

The rated secondary voltage: The rated value of secondary voltage for a single phase transformer or for a 3-phase transformer shall be either 100 and 110V.

NE code of practice and IE Rules for energy meter installation

Objectives: At the end of this lesson you shall be able to
- **state IE rules for energy meter installation.**

NE code of practice and IE rules for energy meter installation

Energy meters shall be installed at such as place which is readily accessible to both the owner of the building and the authorise 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 the 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 the 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 metes 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 consists 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.

Energy Meters are an integral part of electricity revenue generation system.

Meter Reading Instrument (MRI) as a two-way communicating interface between various makes of static electrical energy meters and a base computer station for the purpose of exchange of data (uploading & downloading)

Importance of metering

- Energy meter is the cash register of the utility.
- Energy meters form vital instruments of revenue realization for a utility.
- Inaccurate/ defective metering is catastrophe (hard ship) both for Consumer & the utility.

Purpose of metering

- Workout line losses between sending end to s/s ,
- Workout losses in between DTR and consumers
- Recording consumptions in consumers meters (consumed by the users)
- Obtain data for analyzing system for load pattern/ power quality/ system strengthening.

Make of MRI available in our system

1 Analogic make MRI
2 Sands make MRI

Before operation of MRI following should be ensured

1 Battery of MRI should be charge up to the mark.
2 Sufficient space should be available in MRI memory.
3 Battery charger , connecting leads should be in healthy condition.

Information retrived by MRI from meter memory

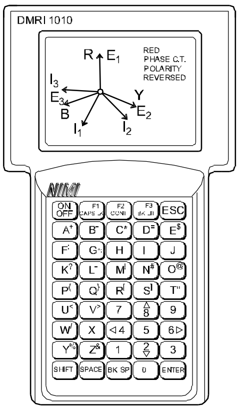
1 Instant parameters like voltages. Phases current, power factors, Active power, Apparent power, Reactive Power, system Frequency, Phase sequence etc.
2 Energy Values like Active/apparent/reactive energy & demand , average power factor, mid night data, power on/off position etc. meter CT/PT ratio, meter tarrif program, flag position of meter

3 Load survey data like daily load data of energy & demand for last 30 days at every 15 minutes interval.

4 Events & temper data like PT missing, CT short, CT open, load unbalance, magnet temper, Over load, neutral disturbance conditions etc.

5 Transactions record : Any changes in meter display or programming or temper reset with date & time

Fig 5



CMRI-1010

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Base computer application software

A BCS play vital role to read the meter remotely and for efficient and speedy recovery of data read through CMRI/ HHU and also to view the downloaded information in different formats & graphs.

The general specifications of the Base Computer Application Software is as below:

The BCS software shall be user friendly. Windows based Base computer software shall be supplied. Base Computer software shall give all details adequate for analysis and load surveys parameters. The software shall have the facility to convert all the consolidated information / data of selectable parameters into ASCII and XML format. EDP department of purchaser can generate its own DBF (data base files) to downloaded all the required information into it.

i **Platform:** The BCS shall be executable on all WINDOWS system. The BCS shall be suitable to run on IBM compatible PC hardware platform.

ii **Meter Data Display:** The software shall show electrical condition existing at the time of reading the meter in tabular forms as well as graphical format (Phase diagram)

All the information about energy, maximum demand and their respective TOD register reading, billing register readings shall be shown in a manner which user can easily understand.

All the load survey data shall be available in numerical as well as graphical format. It shall be possible to view this data daily, weekly, and monthly format. The load survey graph will show values where the cursor is placed for the selected or for all parameter.

All the information about abnormality events shall be accompanied with date and time stamping along with 'snap-shot' of respective electrical conditions. This information shall be displayed in the sequence in which it happened in cumulative format as well as summary format.

The software shall be capable of preparing CMRI to read the meter information or time setting of the meter.

iii **Support Display:** There shall be "user friendly" approach for viewing meter data for the reading collected now or for the reading collected in the past. All information about a particular consumer will be sorted out and available at one place so that locating any consumer's past data is easy. It shall be possible to retrieve/locate data on the basis of either one of the following particulars:

a Consumer's ID/Numbers.

b Meter Sr. No.

c Date of meter reading.

d Location.

iv **The Data Transfer:** It shall be possible to transfer data to and fro from CMRI through serial interface.

v **Remote Meter Reading option:** It should be possible to read remote end meter using GSM/ GPRS infrastructure with configurable auto reading mode and manual mode. The auto dialling and reading mode shall have enough flexibility to define different groups and their priority orders to read the meter etc.

vi **Configurability:** It shall be possible to have selective printing of all available data of the meter. Print out shall not include anything and everything available with the BCS. The software shall support "print wizard" whereby user can decide what to print out. The use of the software need not revert back to the supplier of the software for modifying the software just to print what he desires.

BCS shall have facility to export data to ASCII or spreadsheet format for integrating with the purchaser's billing system. Here again an "Export wizard" or similar utility shall be available whereby user can select file format, what data to export, the field width selection etc.

vii **Security:** The BCS shall have multilevel password for data protection and security. The first level shall allow the user to enter the system. The different software features shall be protecting by different passwords. The configurable of passwords shall be user definable.

Sources of energy - Thermal power generation

Objectives: At the end of this lesson you shall be able to
- **explain conventional and non-conventional energy source**
- **state the various source of energy**
- **state the type of fuels used for power generation**
- **explain the working principle of thermal power station**
- **explain schematic arrangement and constituents of thermal, power plants.**

Introduction of power generation

Energy is the basic necessity for the economic development of a country and it exists in different forms in nature. But the most important form is the electrical energy . The modern society is fully depend on the electrical energy and it has close relationship with standard of living. The per capita consumption of energy is the measure of standard of living of people.

Sources of electrical energy

Since electrical energy is produced from energy available in various forms in nature, it is desirable to look into the various sources of energy. The natural sources of energy which are used to generate the electricity are :

i Sun

ii Wind

iii Water

iv Fuels

v Nuclear energy

vi Tidal

Out of these sources, the energy due to Sun and wind has not been utilized on large scale due to a number of limitations. At present, the other three sources viz, water, fuels and nuclear energy are primarily used for the generation of electrical energy.

Comparison of energy sources

The main sources of energy used for the generation of electrical energy are water, fuels and nuclear energy. Their comparison is given in a tabular form in Table 1.

Table 1

Sl.No	Terms	Water	Fuels	Nuclear Energy
1	Initial cost	High	Low	Highest
2	Running cost	Less	High	Least
3	Reserves	Permanent	Exhaustible	Inexhaustible
4	Cleanliness	Cleanest	Dirtiest	Clean
5	Simplicity	Simplest	Complex	Most complex
6	Reliability	Most reliable	Less reliable	More reliable

Types of fuels used for power generations

Fuels are categorized into Three; They are

1 Solid fuels

2 Liquid fuels

3 Gaseous fuels

Types of electrical power generation

Basically power generation are of two types

a **Conventional power generation:** Power generations by using non- renewable sources of energy through various methods such as hydro, thermal and nuclear etc is called conventional power generation. It contributes to the major power requirement.

b **Non conventional power generation:**Power generation by using renewable energy sources such as wind, Tide and sun etc, is called non- conventional power generation. They are small scale power generation used for specific purpose.

Generating stations

Bulk electric power is produced by special plants known as generating station or power plants. A generating station employs a prime mover coupled with an alternator or generator for the production of electric power. The generated power is further transmitted and distributed to the customers.

Depending upon the form of energy converted into electrical energy the generating station are classified into,

1 Steam power stations /Thermal power stations

2 Hydro - electric power stations

3 Diesel power stations

4 Nuclear power stations

5 Gas - turbine power stations

Non conventional energy: It is evident that all energy resources based on fossil fuels has limitations in availability and will soon exhaust. Hence the long term option for energy supply lies only with non-conventional energy sources. These resources are in-exhaustible/do not deplete for the next hundreds of thousands of years.

For example electrical energy from solar energy, Bio-energy, Wind energy, Geothermal energy, Wave, Tidal and Micro-hydro.

Steam power stations

Choice of site for steam power stations: In order to achieve overall economy, the following points should be considered while selecting a site for a steam power station.

i Supply of fuel

ii Availability of water

iii Transportation facilities

iv Cost and type of land

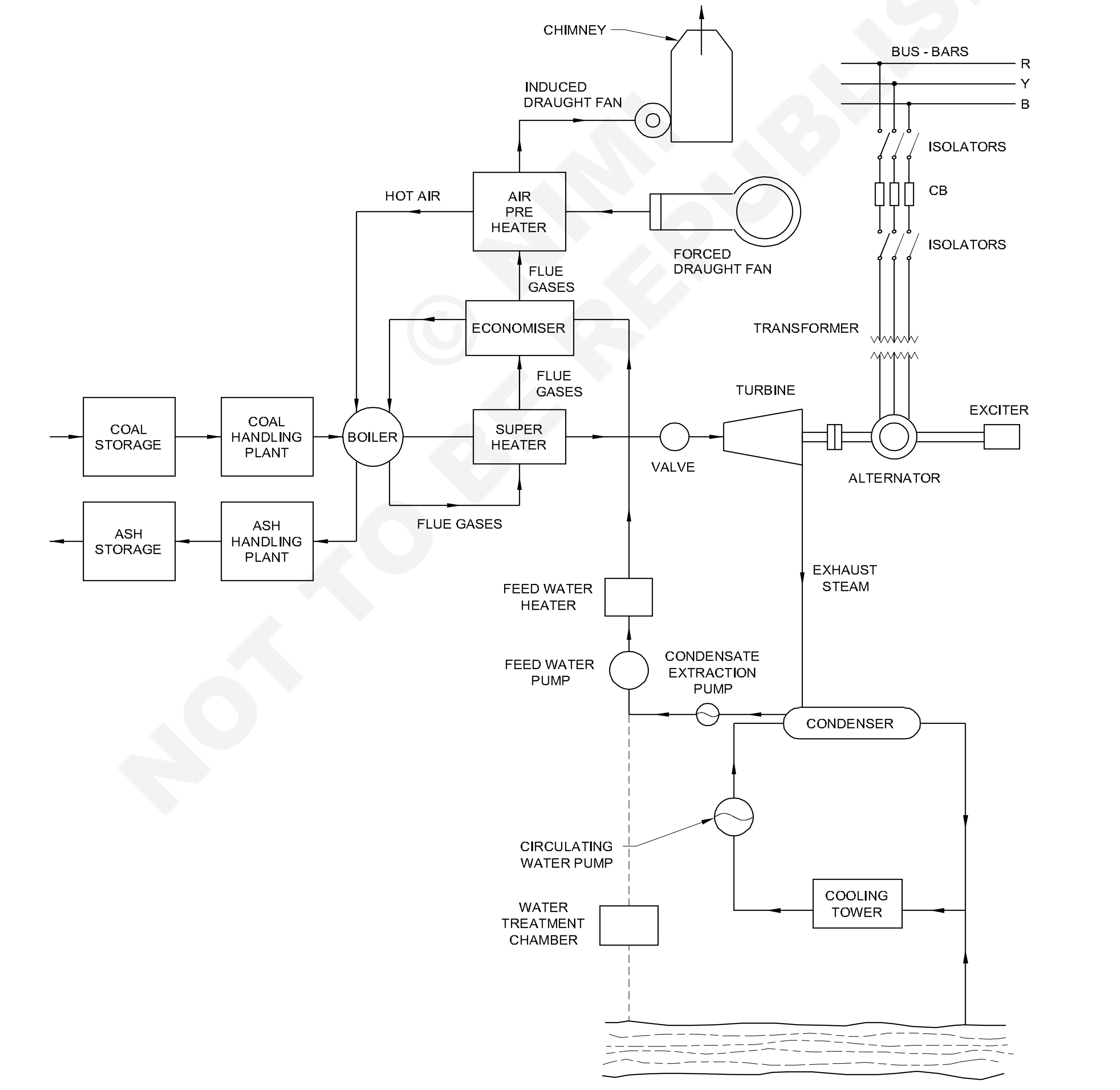
v Nearness to load centers

vi Distance from populated area

Conclusion : It is clear that all the above factors cannot be favorable at one place. However, keeping in view the fact that now- a -days the supply system in AC and more importance is being given to generation than transmission, a site away from the towns may be selected. In particular, a site by river side where sufficient water is available and fuel can be transported economically, may perhaps be an ideal choice.

Schematic arrangement of steam power station: Although steam power station simply involves the conversion of heat of coal combustion into electrical energy, yet it embraces many arrangements for proper working and efficiency. The schematic arrangement of a modern steam power station is in Fig.1. The whole arrangement can be divided into the following stages for the sake of simplicity.

Fig 1



SCHEMATIC ARRANGEMENT OF STEAM POWER STATION

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1 Coal and ash handling arrangement

2 Steam generating plant

3 Steam turbine

4 Alternator

5 Feed water

6 Cooling arrangement

Constituents in steam power station

A modern steam power station is highly complex and has numerous equipment and auxiliaries. However, the most important constituents of a steam power station are :

1 Steam generating equipment

2 Condenser

3 Prime mover

4 Water treatment plant

5 Electrical equipment

1 Steam generating equipment

This is an important part of steam power station. It is concerned with the generation of superheated steam and includes such items as boiler, boiler furnace, super heater, economizer, air pre-heater and other heat reclaiming devices.

i Boiler : A boiler is closed vessel in which water is converted into steam by utilizing the heat of coal combustion. Steam boilers are broadly classified into the following two types.

a Water tube boilers

b Fire tube boilers

ii Boiler furnace : A boiler furnace is a chamber in which fuel is burnt to liberate the heat energy. In addition, it provides support and enclosure for the combustion equipment i.e burners.

iii Super heater : A super heater is a device which super heats the steam (i.e) it further raises the temperature of steam. This increases the overall efficiency of the plant. A super heater consists of a group of tubes made of special alloy steels such as chromium-molybdenum. The steam produced in the boiler is led through the super heater where it is superheated by the heat of flue gases. Super heaters are mainly classified into two types according to the system of heat transfer from flue gases of steam viz.

a Radiant super heater

b Convection super heater

iv Economiser : It is a device which heats the feed water on its way to boiler by deriving heat from the flue gases. This results in raising boiler efficiency, saving in fuel and reduces stresses in the boiler due to high temperature of feed water.

v Air Pre-heater : Super heaters and economizers generally cannot fully extract the heat from flue gases. Therefore, pre - heaters are employed which recover some of the heat in the escaping gases. The function of an air pre-heater is to extract heat from the flue gases and give it to the air being supplied to furnace for coal combustion. This raises the furnace temperature and increases the thermal efficiency of the plant. Depending upon the method of transfer of heat from flue gases to air, air pre-heaters are divided into the following classes.

a Recuperative type

b Regenerative type

2 Condensers

A condenser is a device which condenses the steam and the exhaust of turbine. It serves two important functions. Firstly, it creates a very low pressure at the exhaust of turbine, thus permitting expansion of the steam in the prime mover to a very low pressure. This helps in Converting heat energy of steam into mechanical energy in the prime mover. Secondly, the condensed steam can be used as feed water to the boiler. There are two types of condensers, namely

a Jet condenser

b Surface condenser

3 Prime movers

The prime mover converts steam energy into mechanical energy. There are two types of steam prime mover viz., steam engines and steam turbines. Therefore, all modern steam power stations employ steam turbines as prime movers.

Steam turbines are generally classified into two types according to the action of steam on moving blades viz.

a Impulse turbines

b Reaction turbines

4 Water treatment plant

Boilers require clean and soft water for longer life and better efficiency. However, the source of boiler feed water is generally a river or lake which may contain suspended and dissolved impurities, dissolved gases etc. Therefore, it is very important that water is first purified and softened by chemical treatment and then delivered to the boiler

Nuclear power station

A generating station in which nuclear energy is converted into electrical energy is known as a Nuclear power station.

In nuclear power station, heavy elements such as Uranium (U^{235}) or Thorium (Th^{232}) are subjected to nuclear fission in a special apparatus known as a reactor. The heat energy thus released is utilized in raising steam at high temperature and pressure. The steam runs into the steam turbine which converts steam energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

The most important features of a nuclear power station is that huge amount of electrical energy can be produced from a relatively small amount of nuclear fuel as compared to other conventional types of power station.

Advantages

i The amount of fuel required is quite small. Therefore, there is a considerable saving in the cost of fuel transportation.

ii A nuclear power plant requires less space as compared to any other type of the same size.

iii This type of plant is very economical for producing bulk electric power.

iv It can be located near the load centers because it does not requires large quantities of water and need not be near coal mines.

v It ensures reliability of operation.

Disadvantages

i The fuel used is expensive and is difficult to extract.

ii The capital cost on a nuclear plant is very high as compared to other types of plants.

iii The erection and commissioning of the requires greater technical know - how.

iv The fission by products are generally radio - active and may cause a dangerous amount of radioactive pollution.

v Maintenance charges are high due to lack of standardization.

vi The disposal of the waste, which are radioactive, is a big problem. They should either be disposed off in a deep trench or in the sea away from the sea- shore.

Schematic arrangement of nuclear power station

The schematic arrangement of a nuclear power station is in Fig 2. The whole arrangement can be divided into the following main stages.

i Nuclear reactor

ii Heat exchanger

iii Steam turbine

iv Alternator

i Nuclear reactor : It is an apparatus in which nuclear fuel (U^{235}) is subjected to nuclear fission. It controls the chain reaction that starts once the fission is done. If the chain reaction is not controlled, the result will be an explosion due to the fast increase in the energy released.

A nuclear reactor is a cylindrical stout pressure vessel and houses fuel rods of Uranium, moderator and control rods (Fig 3).

The fuel rods constitute the fission material and release huge amount of energy when bombarded with slow moving neutrons. The moderator consists of graphite rods which enclose the fuel rods. The moderator slows down the neutrons before they bombard the fuel rods. The control rods are of cadmium and are inserted into the reactor. Cadmium is strong neutron absorber and thus regulates the supply of neutrons for fission.

When the control rods are pushed in deep enough, they absorb most of fission neutrons and hence few are available for chain reaction which, therefore, stops. However, as they are being withdrawn, more and more of these fission neutrons cause fission and hence the intensity of chain reaction (or heat produced) is increased. Therefore, by pulling out the control rods, power of the nuclear reactor is increased whereas by pushing them in, it is reduced.

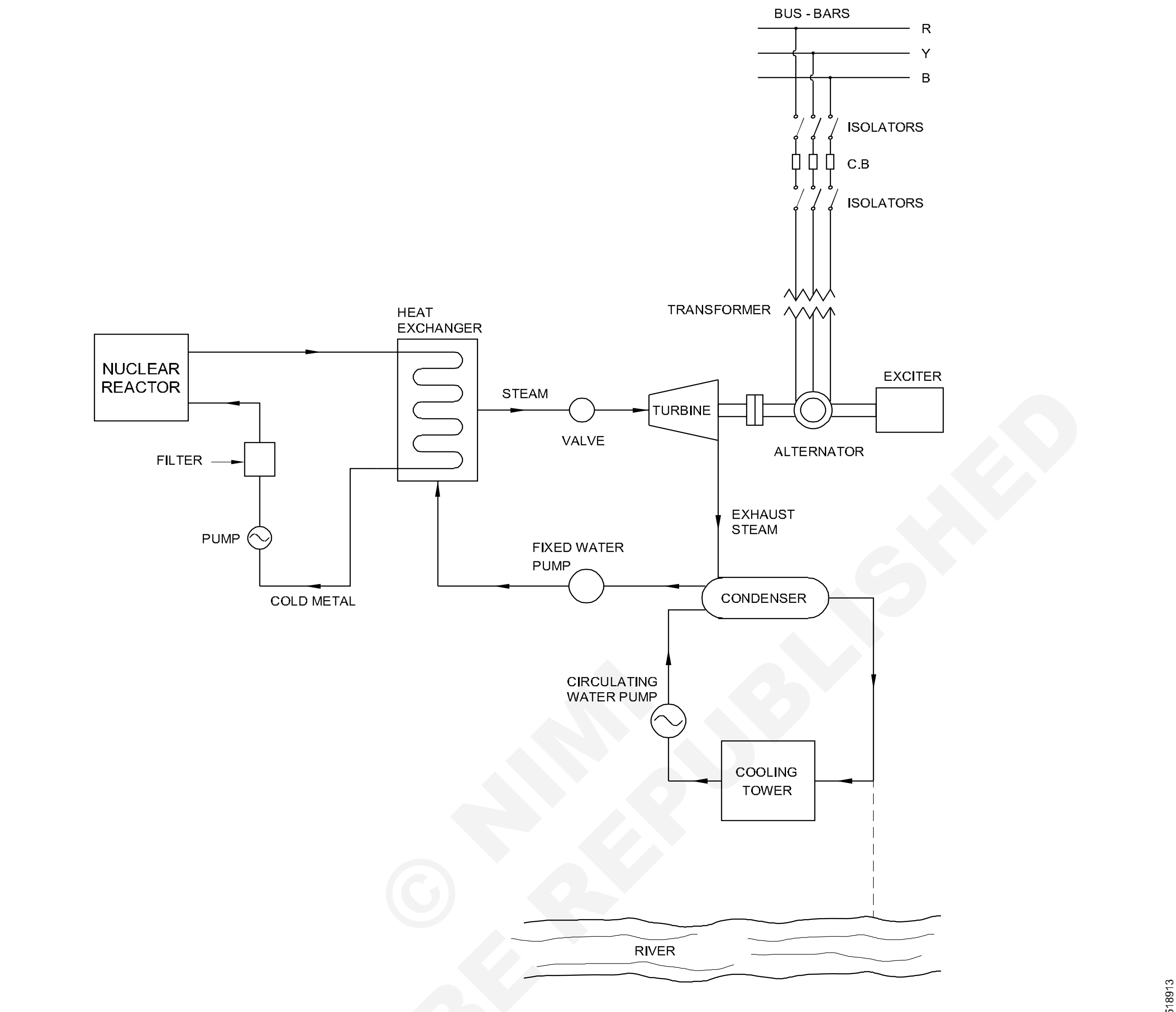
In actual practice, the lowering or raising of central rods is accomplished automatically according to the requirement of rod. The heat produced in the reactor is removed by the coolant, generally in a sodium metal. The coolant carries the heat to the heat exchanger.

ii Heat exchanger : The coolant gives up heat to the heat exchanger which is utilized in raising the steam. After giving up heat, the coolant is again fed to the reactor.

iii Steam turbine : The steam produced in the heat exchanger is led to the steam turbine through a valve. After doing a useful work in the turbine, the steam is exhausted to condenser. The condenser condenses the steam which is fed to the heat exchanger through feed water pump.

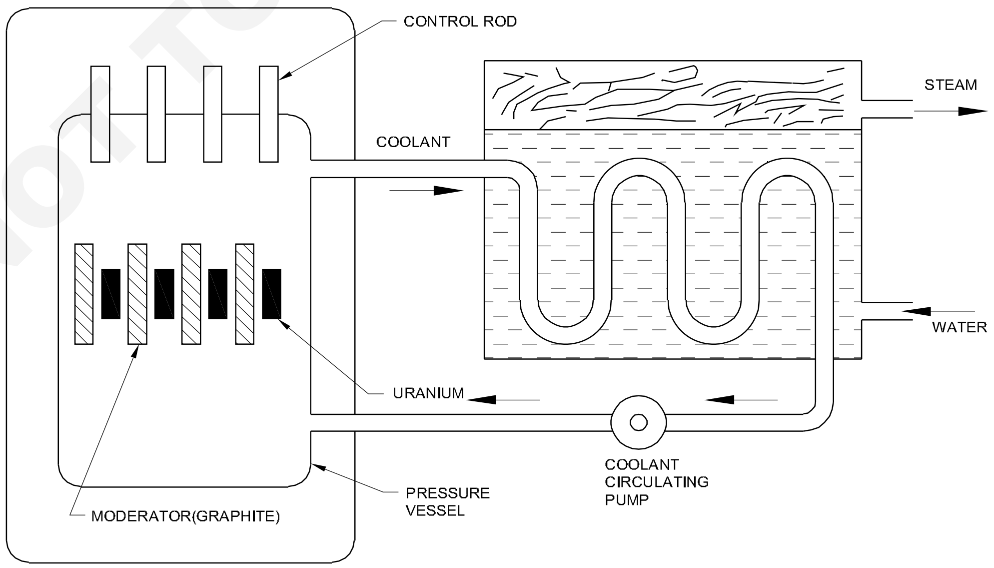
iv Alternator : The steam turbine drives the alternator which converts mechanical energy into electrical energy. The output from the alternator is delivered to the bus- bars through transformer, circuit breaker and isolators.

Fig 2



SCHEMATIC ARRANGEMENT OF NUCLEAR POWER PLANT

Fig 3



NUCLEAR REACTOR

Hydel power plants

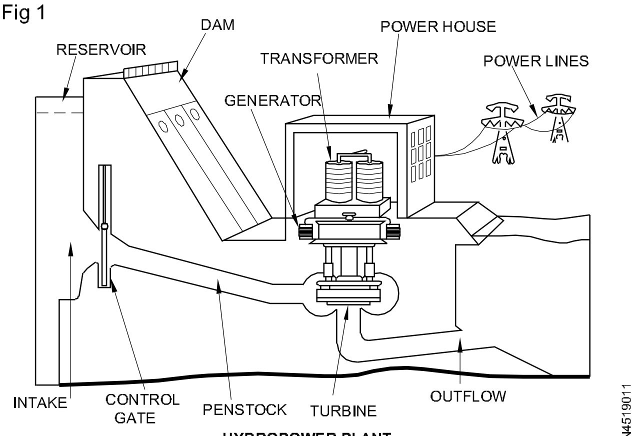
Objectives: At the end of this lesson you shall be able to
- **state the advantage & disadvantage of hydro electric power station over thermal power station**
- **explain the schematic arrangement of hydro electric power station**
- **state the turbines used in hydro electric power station with suitable reasons.**

Hydro - electric power stations

A generating station which utilizes the potential energy of water at a high level for the generation of electrical energy is known as "Hydro-electric power station".

A basic model of a H.P.P generation is illustrated in Fig 1 is known as hydro - electric power station.

Fig 1



HYDROPOWER PLANT

Hydro - electric power stations are generally located in hilly areas where dams can be built conveniently and large water reservoirs can be obtained. From the dam, water is led to a water turbine. The water turbine captures the energy in the falling water and changes the hydraulic energy (i.e product of head and flow of water) into mechanical energy at the turbine shaft.

The turbine drives the alternator which converts mechanical energy into electrical energy. Hydro electric power stations are becoming very popular because the reserves of fuels (i.e coal and oil) are depleting day by day.

Advantages

i It is quite neat and clean as no smoke or ash is produced

ii It requires very small running charges because water is the source of energy which is available free cost.

iii It is comparatively simple in construction and requires less maintenance.

iv It is robust and has a longer life.

v Such plants serve many purposes. In addition to the generation of electrical energy, they also help in irrigation and controlling floods.

Disadvantages

i It involves high capital cost due to construction of dam

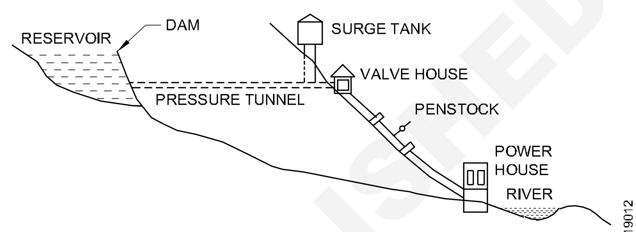
ii There is uncertainly about the availability of huge amount of water due to dependence on weather conditions.

iii Skilled and experienced hands are required to build the plant

iv It requires high cost of transmission lines as the plant is located in hilly areas which are away from the consumers.

Schematic arrangement of hydro - electric power station : (Fig 2)

Fig 2



SCHEMATIC ARRANGEMENT OF A HYDRO - ELECTRIC PLANT

The schematic arrangement of a modern hydro - electric plant is shown in Fig. 2. The dam is constructed across a river or lake and water from the catchment area collects at the back of the dam to form a reservoir. A pressure tunnel is taken off from the reservoir and water brought to the valve house at the start of the Penstock.

The valve house contains main sluice valves and automatic isolating valves. The former controls the water flow to the power house and the latter cuts of supply of water flow to the power house when the penstock bursts. From the valve house, water is taken to water turbine through a huge steel pipe known as penstock . The water turbine converts hydraulic energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

Constituents of Hydro - Electric Plant

The constituents of hydro - electric plant are (1) hydraulic structures (2) water turbines and (3) electrical equipment.

1 Hydraulic Structures

Hydraulic structures in a hydro electric power station include dam, spillways, headworks, surge tank, penstock and accessory works.

i Dam : A dam is a higher barrier which stores water and creates water head.

ii Spillways : To discharge the surplus water from the storage reservoir into the river on the down - stream side of the dam, spillways are used.

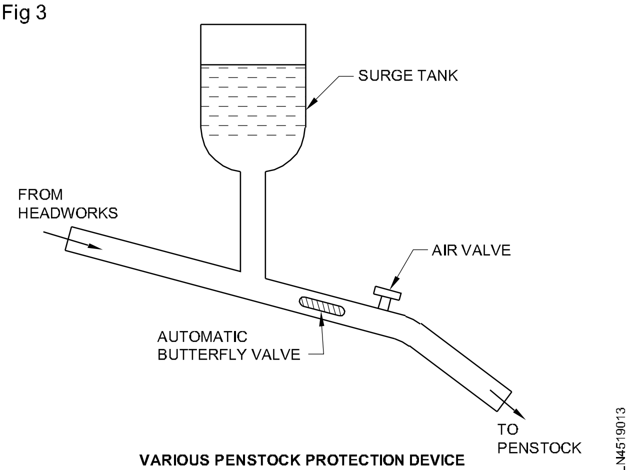
iii Headworks : The headworks consists of the diversion structures at the head of an intake. The flow of water into and through head works should be as smooth as possible to avoid the head loss and cavitation.

iv **Surge tank :** Surge tank is a small reservoir or tank (open at the top) in which water level rises or fails to reduce the pressures swings in the conduit.

v **Penstocks :** Penstocks are open or closed conduits which carry water to the turbines. They are generally made of reinforced concrete or steel. The thickness of the Penstock increases with the head or working pressure.

A typical penstock protective device is in Fig 3.

Fig 3



VARIOUS PENSTOCK PROTECTION DEVICE

vi **Tail race** : The tail race is the channel which carries water (known as tail water) away from the power house after it has passed through the turbine.

2 Water turbine

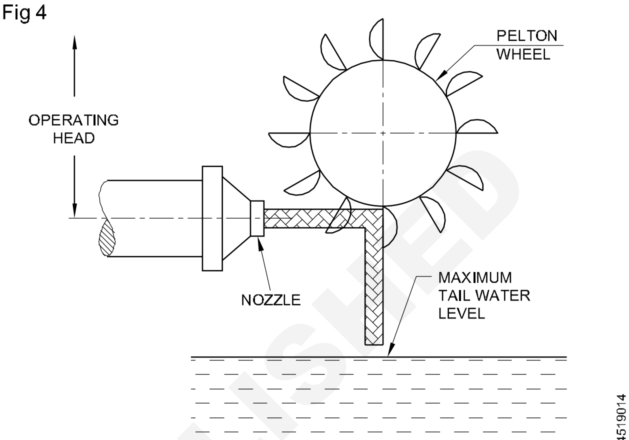
Water turbines are used to convert the energy of falling water into mechanical energy. The principal types of water turbines are :

i Impulse turbines

ii Reaction turbines

i **Impulse turbines :** Such turbines are used for high heads. In an impulse turbines, the entire pressure of water is converted into kinetic energy in a nozzle and the velocity of the jet drives the wheel i.e, pelton wheel as in Fig 4. It consists of a wheel fitted with elliptical buckets along it periphery. The force of water jet striking the bucket on the wheel drives the turbine. The quantity of water jet falling on the turbine is controlled by means of needle or spear (not shown in the figure) placed in the tip of the nozzle.

Fig 4



PELTON WHEEL

The movement of the needle is controlled by the governor. If the load on the turbine decreases the governor pushes the needle into the nozzle, there reducing the quantity of water striking the bucket. Reverse action takes place if the load on the turbine increases.

3 Electrical equipment

The electrical equipment of a hydro - electric power includes alternators, transformers, circuit breaker and switching and protective devices.

Electrical power generation by non conventional methods

Objectives: At the end of this lesson you shall be able to
- **state the non - conventional energy**
- **explain the methods of generators power from, micro-hydel**
- **list out the merits and demerits of non-conventional power generation.**

Non - conventional energy

Energy generated by using wind, tides, solar, geothermal heat and biomass including farm and animal waste is known as non-conventional energy. All these sources are renewable or inexhaustible and do not cause environmental pollution.

Mertis of non - coneventional over conventional sources of energy

1 Provide more energy

2 Reduce security risk associated with the use of nuclear energy.

3 Reduce pollutants

4 Less running and maintenance cost

5 Despite the high initial investment and several limitations, use of solar energy to meet our ever increasing energy demand seems to be the only answer.

6 Green house effect and global warming is avoided

Demerits of non conventional over conventional sources of energy

1 High initial cost

2 Less reliable and efficiency

3 Can not be used for base load demand.

Micro hydel power generation

Micro-Hydel Power (MHP)

The method of generating electrical power by using low head or small flow rate of water is termed as micro hydel power generation.

Small -scale micro hydro power is both an efficient and reliable form of energy, most of time. However, there are certain disadvantages that should be considered before construction a small hydro power system. With the right research and skills, micro hydro can be excellent method of harnessing renewable energy from small streams.

Advantages

a Efficient energy source

b Reliable electricity source

c No reservoir required

d Cost effective energy solution

e Power for developing countries

f Integrate with the local power grid

g Suitable site characteristic required

Disadvantages

a Energy expansion not possible

b Low - power in the summer months

c Environmental impact

Micro-hydel electric system basic components

Here are some brief descriptions of the common equipment used in grid- intertied and off- grid micro hydro electric systems. The basic components of the systems may vary, where all the following equipment is not necessary for every system.

- Intake
- Pipe line
- Turbine
- Controls
- Dump load
- Battery bank
- Metering
- Main DC disconnect
- Inverter
- AC breaker panel

Intake: Intakes can be as simple as a screened box submerged in the water course, or they can involve a complete damming of the stream. The goal is to divert derbis and air-free water into a pipe line.

Pipe line: Most hydro turbines require at least a short run of pipe to bring the water to the machine, and some turbines require piping to move water away from it. The length can vary widely depending on the distance between source and the turbine.

Turbine/: The turbine converts the energy in the water into electricity.

Controls: The function of a charge controller in a hydro system is equivalent to turning on a load to absorb excess energy. Battery-based micro hydro systems require charges controllers to prevent the overcharging of the batteries.

Dump load: A dump load is an electrical resistance heater that must be sized to handle the full generating capacity of the micro hydro turbine. Dump loads can be air or water heaters, and are activated by the charge controller whenever the batteries or the grid cannot accept the energy being produced, to prevent damage to the system. Excess energy is “shunted” to the dump load when necessary.

Battery Bank: By using reversible chemical reactions, a battery bank provides a way to store the surplus energy when more is being produced than consumed.

Metering: System meters measure and display several different aspects of microhydro - electric system’s performance and status - tracking the condition of battery, amount of electricity produced and used / consumed.

Main DC disconnect: In battery-based systems, a disconnect between the batteries and inverter is required. This disconnect is a DC- rated breaker mounted in a sheet-metal enclosures. It allows the inverter to be disconnected from the batteries for services and protects the inverter to battery wiring against the electrical faults.

Inverter: Inverter transform the DC electricity stored in battery into AC electricity for powering household appliance. Grid tied inverters synchronize the system’s output with the utility’s AC electricity, allowing the system to feed hydro electricity to the utility grid.

Micro hydel power working principle: Hydro power is based on simple concepts. Moving water turns a turbine, the turbine spins a generator, and electricity is produced. Many other component’s may be in a system, but it all begins with the energy already within the moving water.

Water power is the combination of head and flow. Both must be present to produce electricity. Consider a typical hydro system. Water is diverted from a stream into a pipeline, where it is directed downhill and flow through the turbine. The vertical drop (head) creates pressure at the bottom end of the pipeline. The pressurized water drives the turbine. More flow or more head produces more electricity. Electrical power output will always be slightly less than water power input due to the turbine and system efficiencies.

Flow is water quantity, and is expressed as “volume per time”. such as gallons per minute (gpm), cubic feet per second (cfs) or litres per minute (lpm). Design flow is the maximum flow for which your hydro system is designed. It will likely be less than the maximum flow of your stream (especially during the rainy season), more than your minimum flow, and a compromise between potential electrical output and system cost.

Power generation by solar

Objectives: At the end of this lesson you shall be able to
- **explain the basic principle and construction of the solar cell**
- **explain the features of solar power generation system.**

Solar energy generation

Solar energy is very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8 x 1011 MW, which is many thousands of time large than the present consumption rate on the earth of all commercial energy sources. Thus, in principle, solar energy could supply all the present and future energy needs of the world on a continuous basis. This makes it one of the most promising of the non conventional energy sources.

Solar electricity

When sunlight strikes on photovoltaic (PV) solar panel, the electricity is produced. The method of generating the electrical energy from the solar panel (cells) is termed as solar energy generation.

Generation of electricity by using solar energy depends up on the photovoltaic effect in some specific materials. There are certain materials that produce electric current when these are exposed to direct sun light. This effect is seen in combination of two thin layers of semiconductor materials. One layer of this combination will have a depleted number of electrons. When sunlight strikes on this layer, it absorbs the photons of sun light ray and consequently the electrons are excited and jump to the other layer. This phenomenon creates a charge difference between the layer and resulting to a tiny potential difference between them.

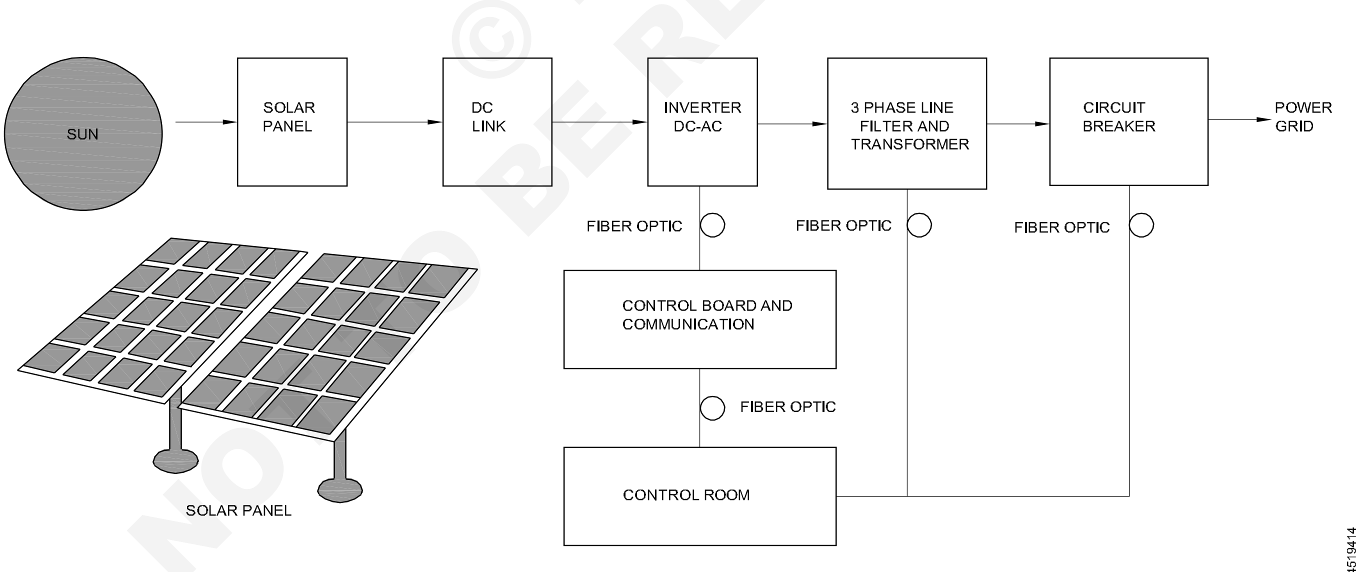
The unit of such combination of two layers of semi conductor materials, for producing electric potential difference in sunlight is called solar cell. Silicon is normally used as solar cell. For building cell, silicon material is cut into very thin wafers. Some of these wafers are doped with impurities. Then both doped and undoped wafers are sandwiched together to build solar cell. A metallic strip is attached to two extreme layers to collect current.

A desired number of solar cell are connected together in both parallel and series to form a solar module for producing desired electricity.

The solar cell can also work in cloudy weather as well as is moon light but the rate of production of electricity low as and it depends up on intensity of incident light ray.

Fig 1 describes the typical system of solar panels, controller, energy storage, inverter for converting DC into AC and how the system is connected to power grid.

Fig 1



SOLAR POWER PLANT

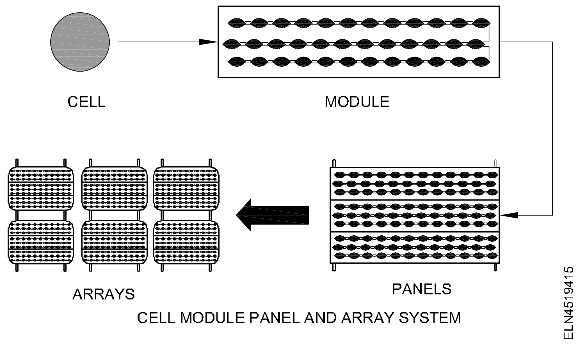
Basic idea of a solar module, array and balance of system (BOS)

Module

Solar cells are made in various shapes and sizes. The smallest of the cells can be seen in devices like an ordinary calculator, these type of devices are very little amount of power used in home lighting system needs more power to run on. The number of cells are put together to produce more power. The group of cells is packaged together in an enclosed space is called as a **module**.

It helps to give higher voltage, high power and protects the panel from rain, snow and wind etc. voltage and power output of module depend on the size and number of cells used. So, more number of modules are to be connected in a simple assembly of modules is known as **array.** (Fig 2)

Fig 2

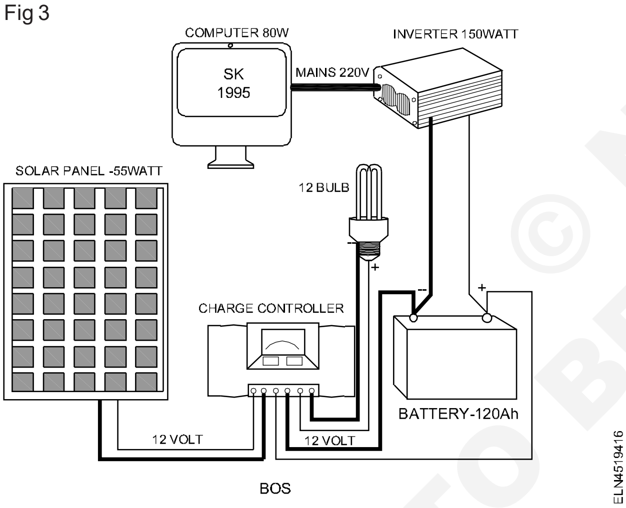


Balance of system (BOS)

The cells modules and arrays are the power producing part, a small devices like radio, needs a small amount of power, can be directly connected to a small module. But most of the devices appliances need more power at night. The assembly of module, battery and an appliance is simple form a P.V system.

A module cannot be connected directly to a battery, so, a charge controller ON charge regulator is used in between module and battery and inverter are required to operate AC appliances. So, the whole system excepts the module is known as balance of system (BOS). (Fig 3)

Fig 3



The main components is BOS assembly are:

- Storage battery
- Charge controller
- Inverter
- Support structure
- Junction boxes
- Wire, cables and fuses
- Connections and switches

(Fig 4a & 4b) shows the installed solar panel with mid clamp and with frame mounted installation are illustrated.

Fig 4a

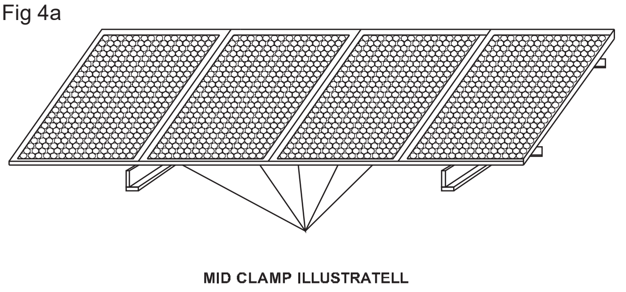
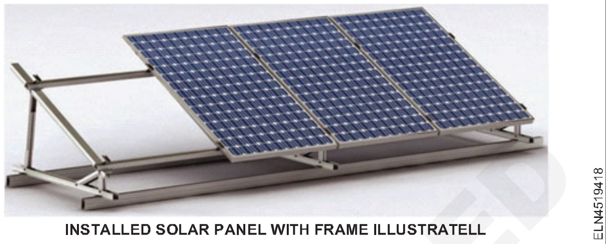


Fig 4b



Functionality of solar panel: Sunlight is the basic fuel for a solar panel. Sunshine is the cause to keep the panel for normal functioning. But the environment around the modules will affect it's working.

The following few factors will affect it's normal working cause for power loss.

- Tilt angle
- Dust
- Temperature
- Cabling losses
- Improper connections

Tilt angle

The solar module must be installed in the proper path of sun and it is tilted properly at an angle, equal to the latitude of the place. If any error in the tilt angle will lead to same amount of power loss.

Dust

If the modules is not cleaned properly, dust will form on the modules surface in the dry season, and it may cause for high energy loss 5-10%.

Temperature

The higher the temperature the output power is reduced from a module, due to power loss.

Cabling loss

The cables are also cause for power loss, It can be minimized by choosing a large diameter of wire size.

Improper connection

If the electrical connections are not made properly, it results in less power is fed to the battery. It can be reduced by keeping clean, and tight connections.

Wind power generation

Objectives: At the end of this lesson you shall be able to
- **explain the features of wind power generation**
- **state the advantages and disadvantages of wind power generation.**

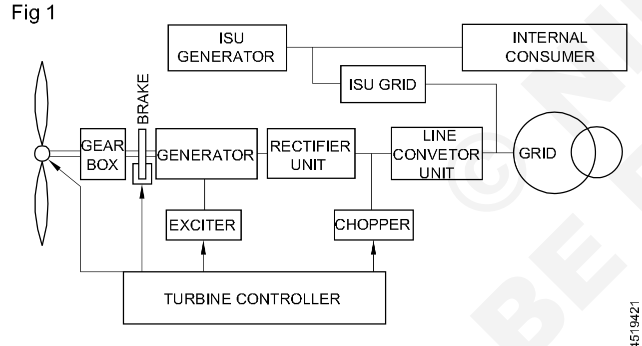
The method of generating the electrical energy by using the wind is termed as wind power generation. Since the wind has velocity and kinetic energy, it can be used to produce electricity. For that, we can use windmills. The important part of a windmill is a structure with large leaves, fixed at the top of a high tower. The speed of leaves changes with the speed of the wind. If the rotation of the windmill is given to the rotor of a generator, then the electricity will be obtained from the generator.

Wind power can be usefully exploited for the generation of electricity as there are large, coastal, hill and desert areas. Wind turbines comprising of machines with blade diameter of 17 m, which can generate about 100 kilowatts. A strike of blowing wind on specially designed blades of a windmill's rotor causes both to rotate. This rotation, which is the mechanical energy, when coupled to a turbine, drive the power generator.

Operation

The schematic arrangement of wind power station is given in Fig 1.

Fig 1



WIND POWER GENERATION

When the wind strikes the rotor blades, blades start rotating. Rotor is directly connected to high speed gear box. Gear box converts the rotor rotation into high speed which rotates the electrical generator. An exciter is needed to give the required excitation to the coil so that it can generate required voltage. The exciter current is controlled by a turbine controller which senses the wind speed based on that it calculate the power what we can achieve at that particular wind speed.

The output voltage of electrical generator is given to a rectifier and rectifier output is given to line converter unit to stabilise the output AC that is fed to the grid by a high voltage transformer. An extra units is used to give the power to internal auxiliaries of wind turbine (like motor, battery etc), this is called **internal supply unit**. ISU can take the power from grid as well as from wind. Chopper is used to dissipate extra energy from the Rectifier Unit (RU) for safety purpose.

Advantages

1 The wind energy is free, inexhaustible and does not need transportation.

2 Wind power plant on the other hand does not take long time to construct.

3 It is non polluting

4 It does not require high technology.

5 Electricity can be produced at a lower cost after installation.

Disadvantages

1 The major disadvantage associated in the wind power is that it is not constant and steady, which make the complications in designing the whole plant.

2 The rotor blades of wind turbine generators must sweep out large areas to produce worthwhile amount of power.

3 The wind is a very dangerous such storms can cause tremendous shear stresses which may spoil the whole plant within no time.

4 Among all the disadvantages mentioned above, the cost factor is the major which has restricted the development of wind power on large scale for feeding to the existing grid.

The wind energy is utilized by means of a wind mill or a series of wind mills. A wind mill consists of few vanes (normally 3 to 6) which rotate about their axis, when the wind blows against them. The rotational motion (i.e. mechanical energy) thus created is utilized for various applications, such as,

1 Lifting water from the well

2 Battery charging

3 Water pumping

4 Operating a simple machine

5 Wind energy is used for agricultural& rural applications such as grinding flour mills, wood cutting saw, stone crushers, mixers, water pumps and irrigation facility etc.

Overhead transmission

Objectives: At the end of this lesson you shall be able to
- **state the power transmission by O.H lines**
- **list out the main components and explain each of them**
- **explain the line supports used in transmission lines**
- **state the types of power lines with respect to the classification of voltage**
- **state about corona effect, sag and skin effect in O.H lines.**

Overhead lines

Electric power, which is generated from generating plant / station to the consumer end is transmitted and distributed either by means of overhead lines (O.H) or by under ground cables (U.G. cables).

Electrical power transmission is the bulk movement of electrical energy from generated power plant to electrical substation. This inter connected lines are known as **transmission network.** The electrical link from substations to customer is typically referred as electrical power **distribution.** The combined transmission and distribution network is known as the **'Power Grid'.**

Electricity is transmitted at high voltages (11, 33, 66, 230, 400, and 500 Kv) to reduce the energy loss which occurs in long distance transmission. The power is actually transmitted through O.H lines (or) underground cables.

The O.H lines are high voltage three phase alternating current, and also single phase A.C sometimes used in Railway Electrification system. High voltage Direct-Current (HVDC) is used for greater efficiency even for very long distances, used in submarine power cables and to stabilize large power distribution network.

Main components used in O.H lines: An overhead line may be used to transmit or distribute electric power. The successful operation of an overhead line depends to a great extent upon the mechanical design of the line. In general, the main components of an overhead line are,

i Conductors which carry electric power from the sending end station to the receiving end station.

ii Supports which may be poles or towers and keep the conductors at a suitable level above the ground.

iii Insulators which are attached to supports and insulate the conductors from the ground.

iv Cross arms which provide support to the insulators.

v Miscellaneous items such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

Conductor materials

The conductor is one of the important items as most of the capital outlay is invested for it. Therefore, proper choice of material and size of the conductor is of considerable importance. The conductor material used for transmission and distribution of electrical power should have the following properties.

i High electrical conductivity

ii High tensile strength in order to withstand mechanical stresses.

iii Low cost so that it can be used for long distances.

iv Low specific gravity so that weight per unit volume is small.

Commonly used conductor materials

The most commonly used conductor material for overhead lines are copper, aluminium, steel reinforced aluminium, galvanized steel and cadmium copper.

Line Supports

The supporting structures for overhead line conductors are various types of poles and towers called line supports. In general, the line supports should have the following properties:

i High mechanical strength to withstand the weight of conductors and wind loads etc.

ii Light in weight without the loss of mechanical strength

iii Cheap in cost and economical to maintain.

iv Longer life

v Easy accessibility of conductors for maintenance

The line supports used for transmission and distribution of electric power are of various types including wooden, poles, steel poles, R.C.C poles and lattice steel towers. The choice of supporting structures for a particular case depends upon the line span, cross sectional area, line voltage, cost and local conditions.

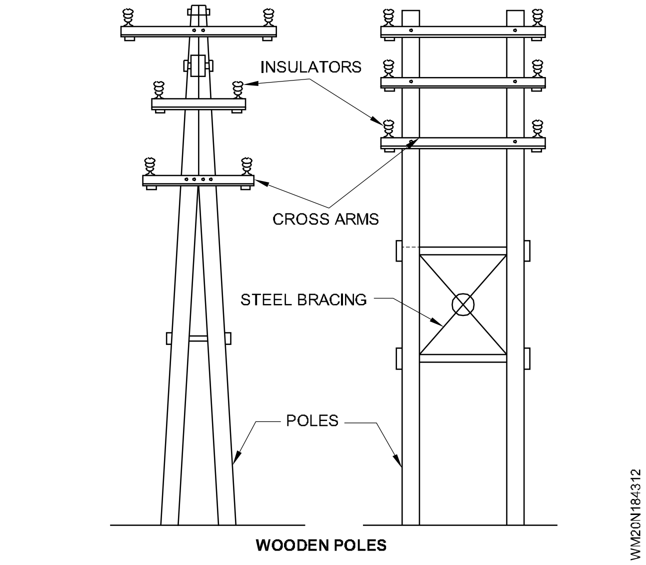
Wooden poles: Double pole structures of the 'A' or 'H' type are often used (see Fig 1) to obtain a higher transverse strength than could be economically provided by means of single poles.

The main objections to wooden supports are: (i) tendency to rot below the ground level (ii) comparatively smaller life (20 – 25 years) (iii) cannot be used for voltage higher than 20 kV (iv) less mechanical strength and (v) require periodical inspection.

Steel poles

The steel poles are often used as a substitute for wooden poles. The steel poles are of three types viz (i) rail poles (ii) tubular poles and (iii) rolled steel joints.

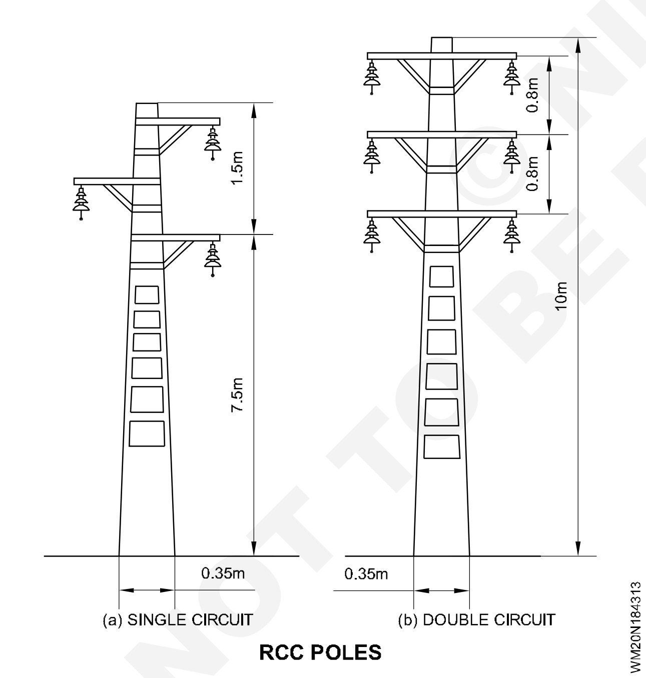
Fig 1



WOODEN POLES

RCC Poles: The reinforced cement concrete (RCC) poles have become very popular as line supports in recent years. They have greater mechanical strength, longer life and permit longer spans than steel poles. Fig 2 shows R.C.C poles for single and double circuit. The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line supports.

Fig 2



RCC POLES

Steel towers: For long distance transmission at higher voltage, steel towers are invariably employed. Steel towers have greater mechanical strength, longer life, can withstand more severe climatic conditions and permit the use of longer spans.

Fig 3a shows a single circuit tower. However, at a moderate additional cost, double circuit tower can be provided as shown in Fig 3b. The double circuit has the advantage that it ensures continuity of supply. In case there is breakdown of one circuit, the continuity of supply can be maintained by the other circuit.

The electric supply is transmitted at different voltages through over head lines and the types of power lines are furnished below:

a. Low voltage line (should not exceed 250V)

b. Medium voltage line (should not exceed 650V)

c. High voltage line (should not exceed 33000V (33 KV)

d. Extra high voltage line (above 33KV)

Voltage standard

The voltage standard of above types have been defined in I E Rules 2

Low where the voltage does not exceed 250 volts

Medium where the voltage does not exceed 650 volts

High where the voltage does not exceed 33,000 volts

"Extra high" where the voltage exceeds 33,000 volts

The nominal system voltage generally used is given below:

a	240 V	b	415 V
c	650 V	d	11 kV
e	33 kV	f	66 kV
g	110 kV	h	132 kV
i	220 kV	j	400 kV
k	800 kV		

Corona: The phenomenon of violet glow, hissing noise and production of ozone gas around an overhead transmission line is known as **corona.**

When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent change in the condition of atmospheric air surrounding the wires if the applied voltage is low. However, when the applied voltage exceeds a certain value, called critical disruptive voltage, the conductors are surrounded by a faint violet glow called **corona.**

Sag in Overhead Lines

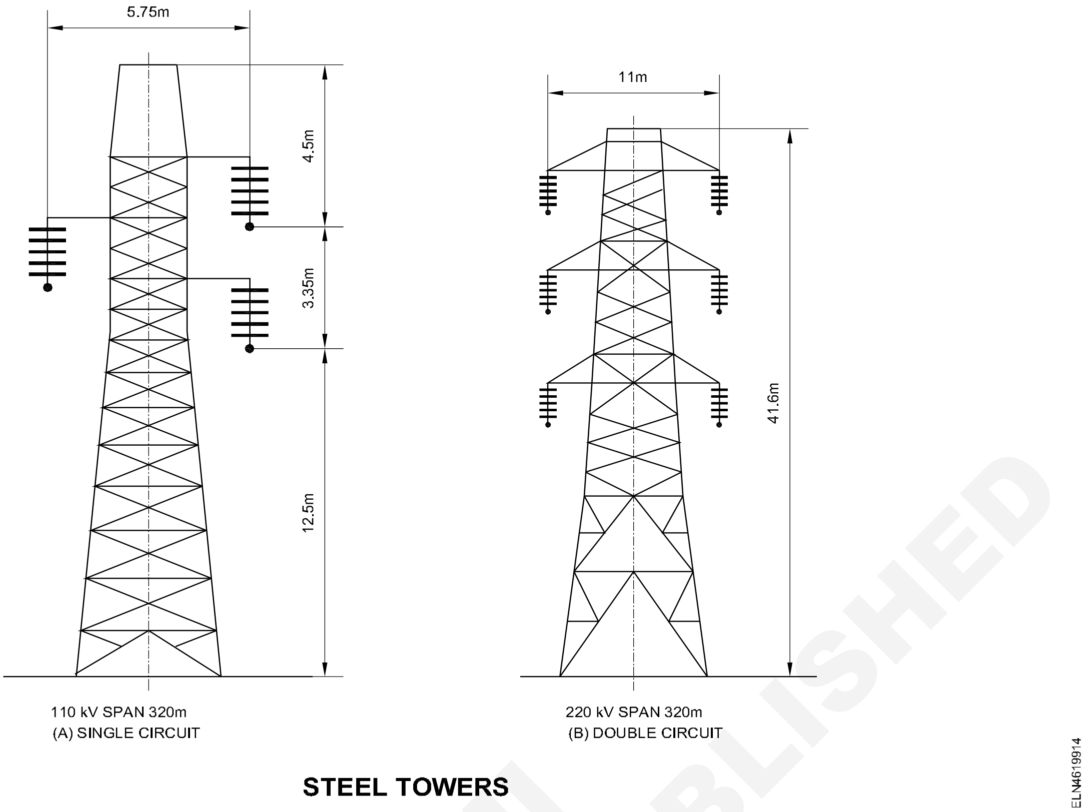
The difference in level between points of supports and the lowers point on the conductor is called **'Sag'.**

Fig 4a shows a conductor suspended between two equal level supports A and B. The conductor is not fully stretched but is allowed to have a dip. The lowest point of the conductor is O and the sag is S. Fig 4b shows unequal level supports.

Classification of Overhead Transmission Lines

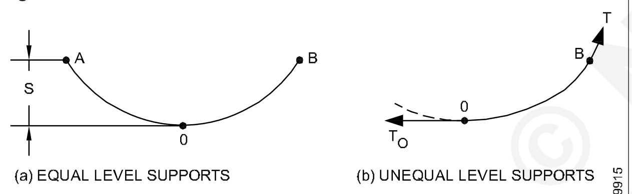
The capacitance effect introduces complications in transmission line calculations. Depending upon the manner in which capacitance is taken into account, the overhead transmission lines are classified as:.

Fig 3



STEEL TOWERS

Fig 4



SAG

i Short transmission lines: When the length of an overhead transmission line is up to about 50 km and the line voltage is comparatively low (<20 KV), it is usually considered as a short transmission line. Due to smaller length and lower voltage, capacitance effects are small and hence can be neglected.

ii Medium transmission lines : When the length of an over-head transmission line is about 50 – 150 km and the line voltage is moderately high (20 KV - 100 KV), it is considered as a medium transmission line. Due to sufficient length and voltage of the line, the capacitance effects are taken into account.

iii Long transmission lines: When the length of an over-head transmission line is more than 150 km and line voltage is very high (>100 KV), it is considered as a long transmission line. For the treatment of such a line, the line constants are considered uniformly distributed over the whole length of the line.

Power distribution network

Objectives: At the end of this lesson you shall be able to
- **state the features of distribution power systems**
- **classify and state various distribution systems**
- **explain the schematic diagram of AC distribution system.**

Distribution power system

The part of electrical power system, which distributes electrical power for load area is called as "Distribution system".

The distribution system is the electrical system between the substation fed by the transmission system and the consumer's meter. It consists of

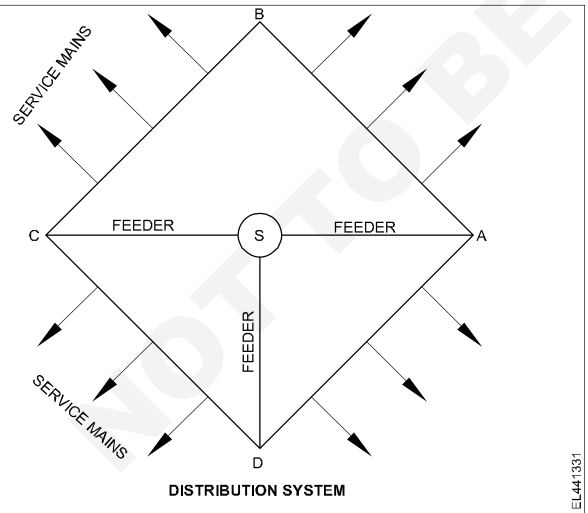
(i) Feeders, (ii) Distributors (iii) Service mains.

i **Feeders :** A feeder is a conductor which connects the sub-station to the area where power is to be distributed. The current remains the same throughout the feeder line, if there is no tappings are taken from it. The main consideration is the current carrying capacity.

ii **Distributors :** It is a conductor, from which tappings are taken for supply to the consumers. In the Fig.AB, BC, CD and DA are the distributors (Fig 1). The current through the distributor is not constant, because tappings are taken to various places. While designing distribution voltage drop along its length, is the main consideration.

i **Service mains** : A service main is generally a small cable which contacts the distribution to the consumer's terminals.

Fig 1



Classification of distribution system

The distribution system may be classified according to

i **Nature of current :** According to the nature of current distribution system may be classified as.

a DC distribution system

b AC distribution system

AC distribution system is adopted elsewhere more than DC distribution, because it is simple and more economical.

ii **Type of construction** : According to type of construction. It may be classfied as.

a Over head system (O.H)

b Underground system (U.G)

O.H system is 5 to 10 times cheaper than the equivalent underground system. The underground system is preferred, where O.H system is prohibited by the local law.

iii **Scheme of connection :** According to scheme of connection, the distribution system may be classifed as

a Radial system

b Ring main system

c Interconnected system

Each system has advantages and disadvantages

Radial electrical power distribution system

In distribution system, different feeders radially come out from substation and are connected to the primary of distribution transformer directly in early days. In this system separate feeders receive from a single substation and feed the distributors at one end only. Fig 2(a) shows distribution where a feeder DC supplies a distributor AB at point A. The distributor is fed at one end only.

Fig 2(b) shows a single line diagram of radial system for AC distribution. It is only possible when power is generated of low voltage, the substation is at the centre of the load.

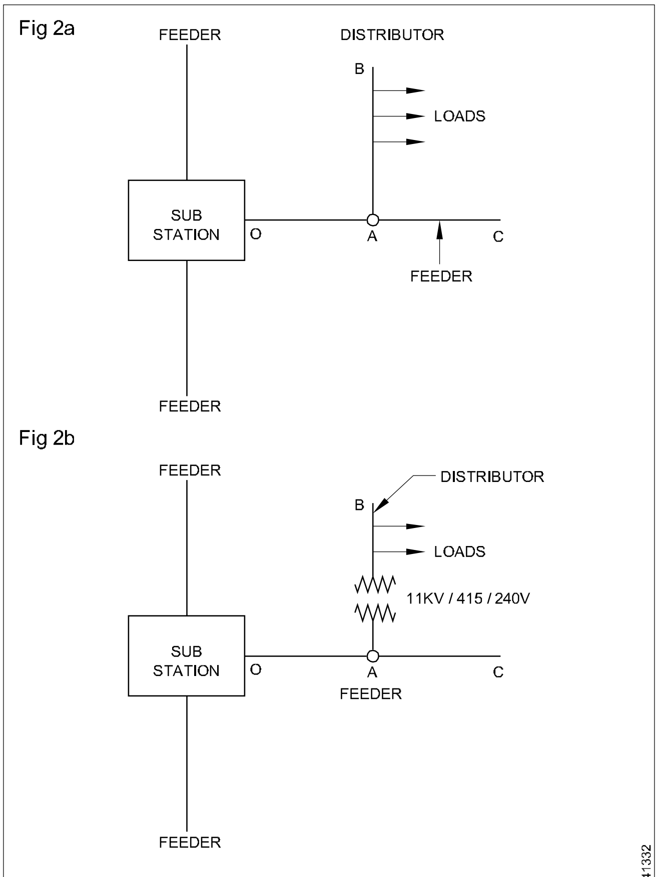
Some draw backs of the radial distribution system as

i The end of the distributors nearest to the feeding point will be loaded heavily.

ii If any fault occurs in the feeder or distributor, it disconnects supply to the consumer on the side of the fault away from the substation.

iii The distant consumer will be subjected to serious voltage fluctuation on load.

iv In the case of any feeder failure, the consumer will not get any power as there is no alternative path. Hence, this sytem is used for short distance only.



RADIAL SYSTEM FOR D.C.DISTRIBUTION

This draw back can be over come by ring main distribution.

Ring main distribution: In this system the primary distribution transformer form a loop. This loop starts from the substation bus bars, makes a loop through the area to be served and returns to the substation.

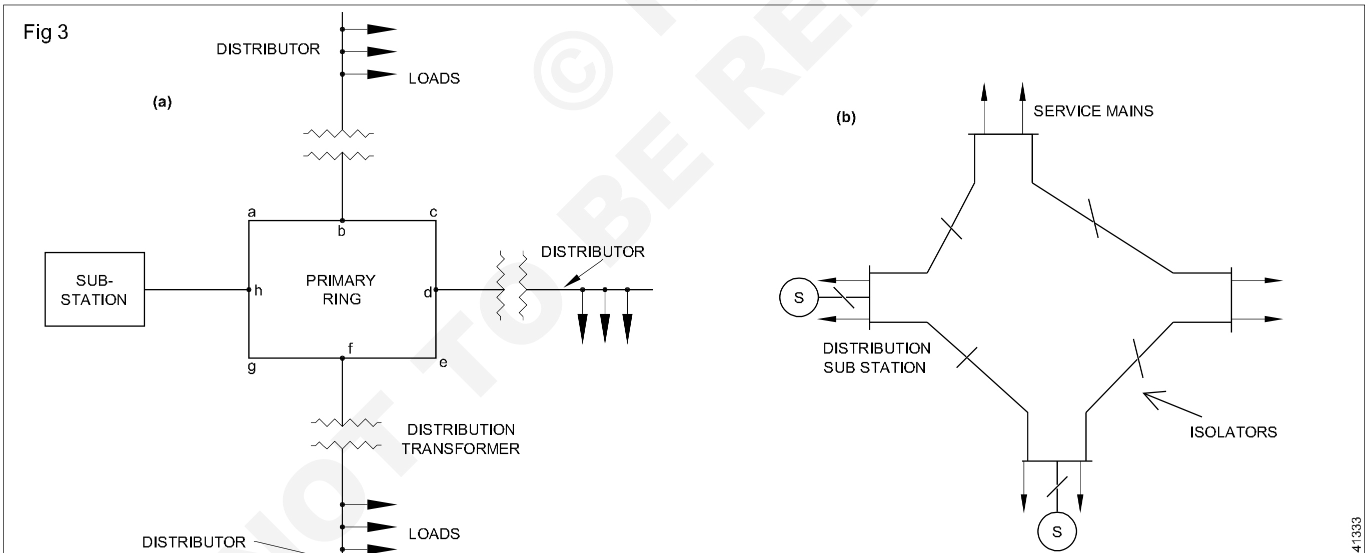
Fig 3 (a) & 3 (b) show the single line diagram of ring mainsystem for AC distribution to the closed feeder loop "abcdefgh". The distributors are tapped from different points 'b,d and f' of the feeder through distribution transformers.

Advantages of ring main distribution

- Less voltage fluctuation at consumer's terminals.
- This system is very reliable as each distributor is fed through two feeders.
- In the case of any fault on any section of the feeder the continuity of the supply is maintained.
- One ring main network distributor can be fed by more than one feeder.
- It is also provided with different section and isolates at different points.

Disadvantage

In this system, sub distributor are also used to feed a group mains where direct access of distributor is not possible. The number of feeders connected to the ring main electrical power distribution system depends upon the the following factors.



RING MAIN DISTRIBUTION

Interconnected system

If the feeder ring is energized by two or more generating stations or substations are called as **interconnected system.** The Fig 4 shows the single line diagram of interconnected system, where the closed feeder ring 'ABCD' is supplied by two substatinos S1 & S2 at points D and C respectively. The points O, P, Q and R are connected with distributors through distribution transformer.

Advantages of interconnected system

1 It increases the service reliability

2 Any area fed from one generating station during peak load hours can be fed from the other generating station.

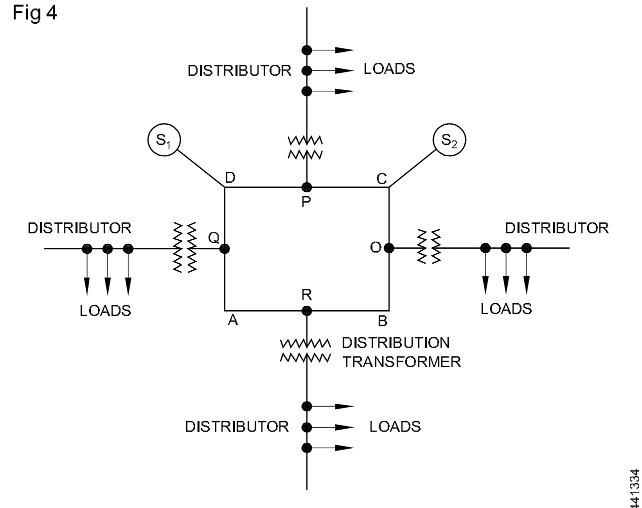
3 It reduces reserve power capacity and increases efficiency of the system.

Disadvantages

- Proper voltage with permissible voltage drop

- Availability of power on demand
- Design of feeders and distributors require careful consideratino to maintain good service to the customer.

Fig 4



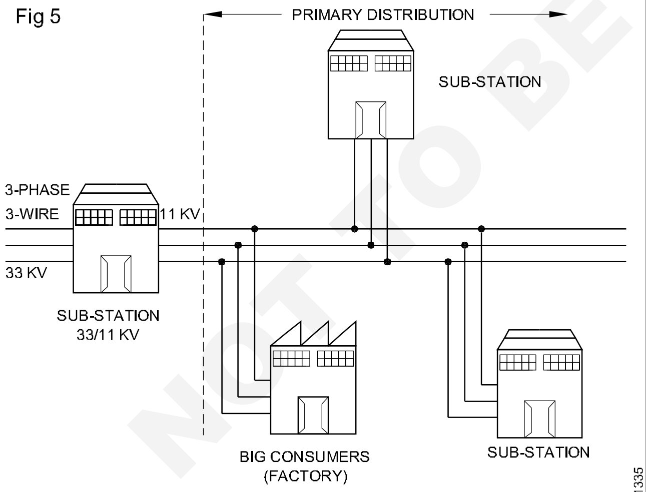
INTERCONNECTED SYSTEM.

AC distribution

The electrical energy is generated, transmitted and distributed in the form of alternating current, due to the wide spread use of AC, which is flexible and moreover the voltage can be changed conveniently by means of transformers. Transformer transmits AC power at high voltage and uitilze it at a safe potential. High transmission and distribution voltages reduce the current in the conductors and minimize the line losses.

In general, the AC distribution system is the electrical system between the step-down substation fed by the transmission system and the consumer's meter.

Fig 5



PRIMARY DISTRIBUTION

The AC distribution sytem is classified into

i Primary distribution

ii Secondary distribution

i Primary distribution system

It is the part of AC distribution operates at voltages higher than general utilization and blocks of electrical energy thanthe average low voltage consumer use. The voltage used for primary distribution depends upon the power and the distance of the substation requried. The primary distribution voltages are, 11KV, 6.6 KV and 3.3 KV. Due to economical consideration, primary distribution is carried out by 3 phase, 3 wire system.

Fig 5 shows the typical primary distribution system. Electric power from generating station is transmitted at high voltage to the substation here the voltage is stepped down to 11KV by step-down transformer.

This forms the high voltage distribution (or) primary distribution.

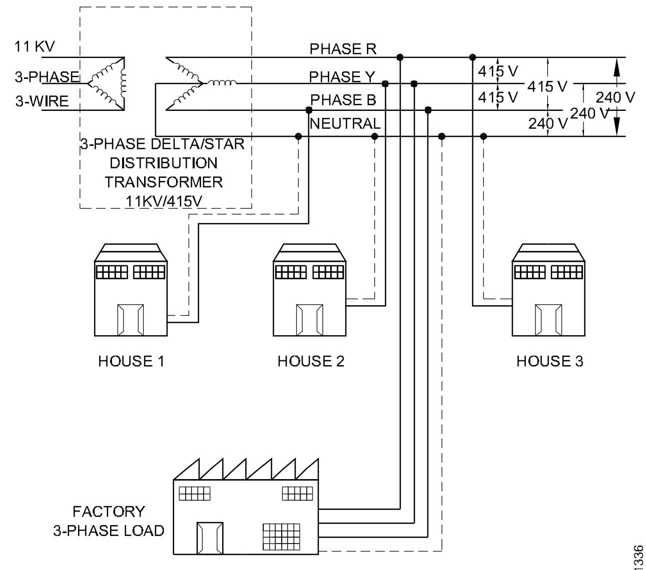
ii Secondary distribution system

It is the part of a AC distribution system employs 415V/240V, 3phase, 4 wire system.

Fig 6 shows secondary distribution system.

The secondary distribution delivers power to various substations, which are near the consumers area and contain step-down transformers. The single phase domestic loads are connected between any one phase and neutral, and the motor loads are connected across 3 phase lines directly.

Fig 6



SECONDARY DISTRIBUTION

Line insulators

Objectives: At the end of this lesson you shall be able to
- **explain the types of insulators and their uses**
- **explain the method of binding of the insulators.**

Line insulators

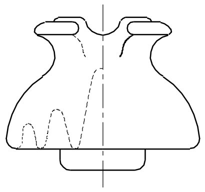
The aim of using a line insulator in an overhead line is to hold the live conductor to prevent leakage of current from the conductor to the pole. These are made of porcelain clay and are thoroughly glazed to avoid the absorption of moisture from the atmosphere.

The following are the common types of insulators in use.

- Pin type insulator
- Shackle insulator
- Suspension insulator
- Strain insulator
- Post insulator
- Stay insulator
- Disc insulator

Pin Insulators : Pin insulators are used for holding the line conductors on straight running of poles. Pin insulators are three types. i.e single shed (Fig 1) double shed (Fig 2) and triple shed (Fig 3) The single -shed pin insulators are used for low and medium voltage lines. The double and triple shed pin insulators are used for over 3000V. These sheds are used to drip off the rain water.

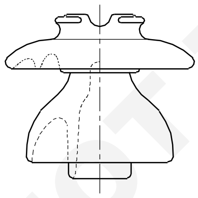
Fig 1



SINGLE SHED TYPE OF PIN INSULATOR

ELN4619621

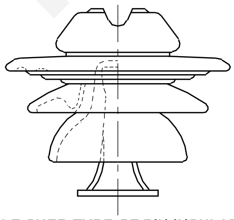
Fig 2



DOUBLE SHED TYPE OF PIN INSULATOR

ELN4619622

Fig 3

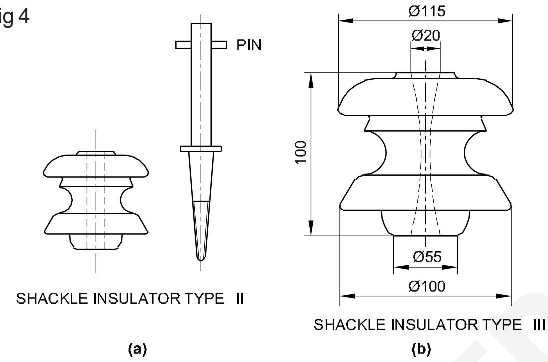


TRIPLE SHED TYPE OF PIN INSULATOR

ELN4619623

Shackle insulators : Shackle insulators are generally used for terminating on corner poles. These insulators are used for medium voltage line only. (Fig 4a & 4b)

Fig 4



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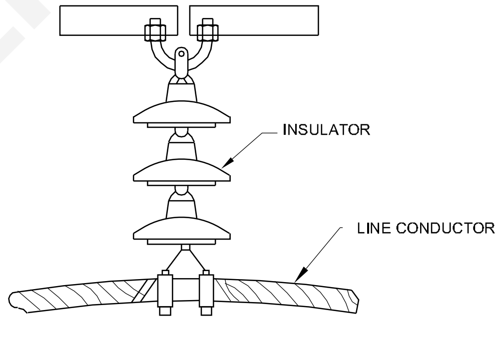
Suspension type insulators: For high voltage (>33KV), it is a usual practice to use suspension type insulators as in Fig 5. They consist of a number of porcelain discs connected in series by metal links in the form of a string. The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross- arm of the tower. Each unit or disc is designed for low voltage, say 11KV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66KV, then six discs in series will be provided on the string.

Fig 5



SUSPENSION INSULATOR

ELN4619627

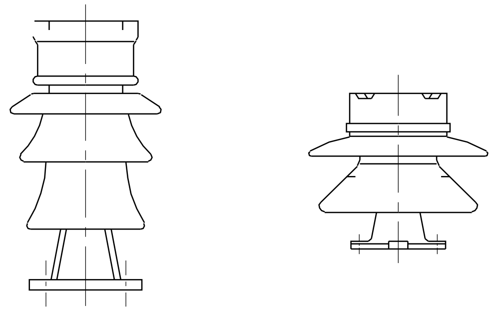
Strain insulators

When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, the strain insulators are used.

Post insulators

Cap and pin type (Fig 6a & 6b) : Such insulators can be used for mounting of buses, dropout fuses, line conductors, G.O.A.B (Gang Operated Air Break) switches. These are of outdoor type and are available in 11, 22 and 33KV ranges.

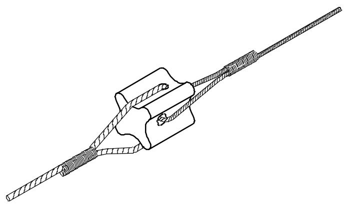
Fig 6



a) CAP AND PIN INSULATOR FOR GOAB SWITCH   b) ANOTHER DESIGN OF CAP AND PIN INSULATOR FOR GOAB SWITCH

Stay insulators (Fig 7) : Stay insulators are also known as strain insulators and are generally used up to 33 KV line. These insulators should not be fixed below three metres from the ground level. These insulators are also used where the lines are strained.

Fig 7

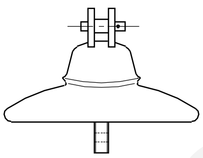


STAY INSULATOR

Disc insulators : Disc insulators are made of glazed porcelain or tough glass and are used as insulators at dead ends, or on straight lines as suspension type for voltages 3.3 kV and above. (Fig 8)

Tongue and clevis type (Fig 8): A round pin with a cotter pin is used to hold the tongue of one unit in the clevis of the other.

Fig 8



DISC INSULATOR TONGUE AND CLEVIS TYPE

Classification of Distribution System

The power system network is divided into three parts; Generation, Transmission, and Distribution. The power generated from the power plant is supplied to the load via transmission and distribution system.

According to the shape of the system, the distribution network is classified into three types.

- Radial Distribution System
- Ring or Loop Distribution System
- Grid or Interconnected Distribution System

Radial Distribution System

In this system, separate feeders radiate from a single substation and feed the distributor at one end only.

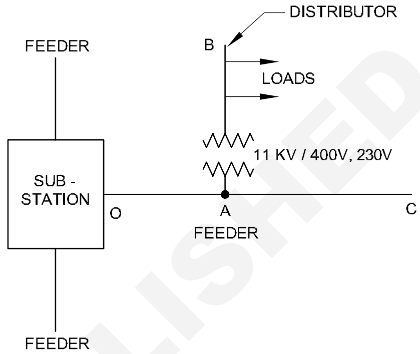
Fig 9 shows a single line diagram of a radial system for AC Distribution.

In a radial system, only one path is connected between each consumer and the substation. The electrical power flows from the substation to the consumer along a single path.

Thus, if a fault occurs in the system, it results in a complete loss of power to the consumer. The initial cost of this system is low compared to other systems.

Simple in planning, design, and operation. The reliability of the radial distribution system is less. The distributor nearer to the feeding end is heavily loaded. Consumers at the far end would be subjected to voltage fluctuations with variations in load.

Fig 9

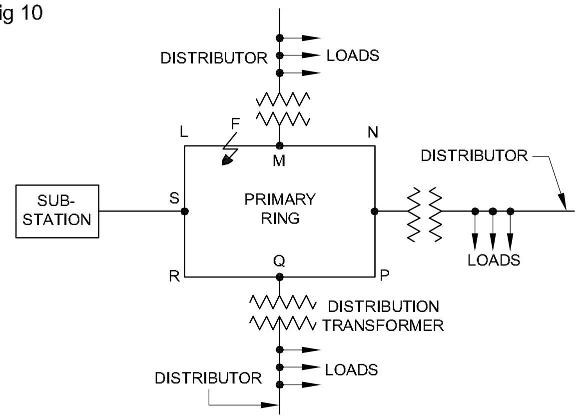


Ring or Loop Distribution System

The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation.

Fig 10 shows the single line diagram of the ring main network for AC distribution.

Fig 10



The distributors are tapped from different points M, O, and Q of the feeder through distribution transformers.

It is selected to carry its normal load plus the load of the other half of the loop also. The size of the feeder conductor in a loop distribution network is the same throughout the loop.

Less conductor material is required as each part of the ring carries less current in the radial system.

Fewer voltage fluctuations It is more reliable. It is difficult to design when compared to the designing of a radial system.

Grid or Interconnected Distribution System

When the feeder ring is energized by two or more than two generating stations or substations, it is called an interconnected system.

Fig 11 shows the single line diagram of the interconnected system where the feeder ring ABCD is supplied by two substations S1 and S2 at points D and C respectively.

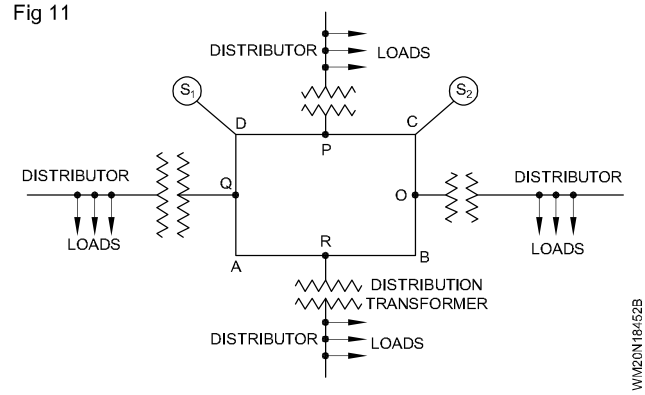
Distributors are connected to points O, P, Q, and R of the ring through distribution transformers.

The reliability and quality of the service of the interconnected type distribution arrangement are much higher than the radial and loop arrangements.

It is more difficult to design and operate than radial or loop systems. It increases the reliability of supply. Losses are less and efficiency is more.

The quality of service is improved. The initial cost is more. Difficult in planning, design, and operation.

Fig 11



Line protecting devices

Objectives: At the end of this lesson you shall be able to
- **explain various types of line protective devices.**

Fatal accident may happen if an overhead line snaps and, while falling on the ground, comes in contact with a man or an animal. In order to assure safety against chances of such accidents, safety devices are used in medium and low voltage overhead lines.

A safety device is usually made of galvanised iron wire. One end of this wire is directly tied up with the earth wire of the line, while its other end is tied up with the neutral wire through a reel insulator or an egg-type insulator. As soon as the live conductor of an overhead line snaps, it comes into contact with the safety device before falling on the ground. This contact causes short-circuit between live wire and earth.

As a result either the line fuse burns out or the circuit breaker trips, and the flow of current through the live line is at once stopped, i.e. the live line is disconnected from the source. Hence, even if the wire falls on the ground, there is no risk of any fatal accident.

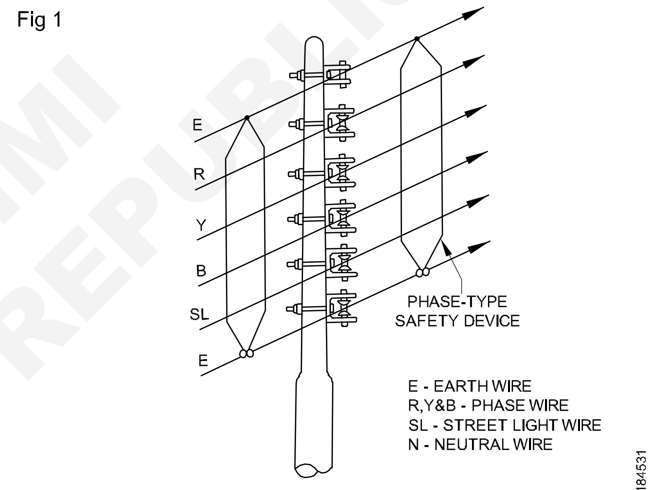
Some safety devices are given below:

Phase-Type or Box-Type Safety Device (Fig 1)

A phase type or box type safety device is used in cases where overhead lines are drawn in vertical configuration, i.e. one line is drawn vertically above or below the other. The connection of such a safety device is shown in Fig 1. The top most wire of the line is the earth wire and the neutral wire is drawn at the bottom of the configuration.

The phase wires or live wires are drawn in between these two wires. Safety devices are tied up with the lines about 60 cm to 75 cm away from the poles. Two devices are used on both sides of an intermediate pole, but one device is enough for a terminal pole, as overhead line is drawn on one side only of this pole.

Fig 1



CONNECTIONS OF PHASE-TYPE SAFETY DEVICE

Advertisments

At the lower end the wire of a safety device is passed through the hole in the reel insulator and the two ends of this wire are drawn up to top most position and tied up with the earth wire. The neutral wire is placed in the groove of the reel insulator and tightly bound with it with the help of binding wire.

Ring-Type Safety Device (Fig 2&3)

A ring type safety device can be conveniently used irrespective of whether a line has been drawn in vertical or in horizontal configuration. But it is not usually found to be used in overhead lines drawn in vertical configuration.

Fig 2

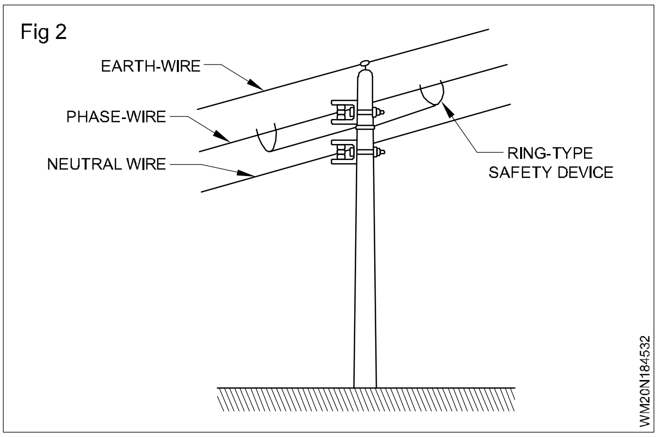
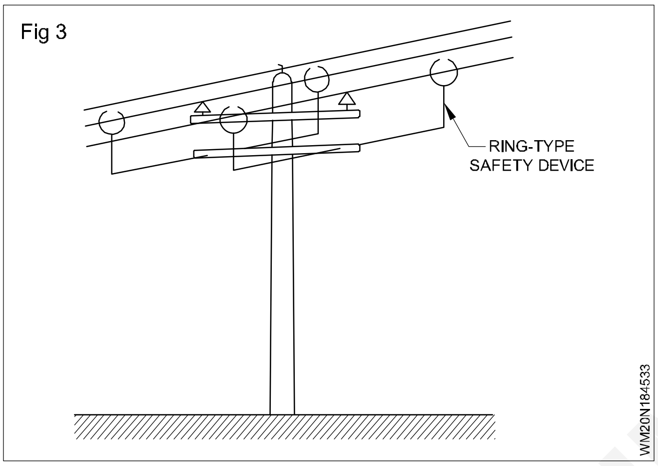


Fig 3



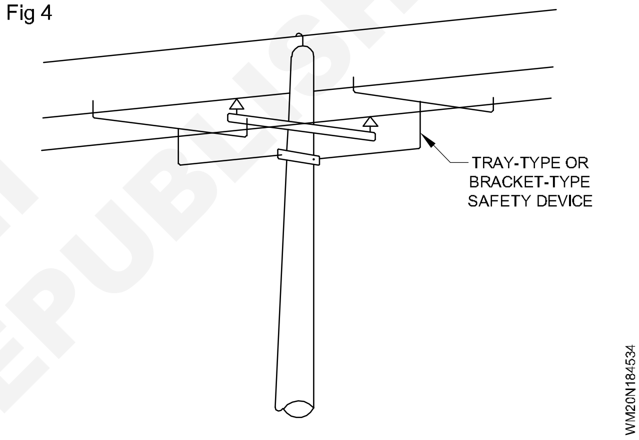
A galvanised iron ring with bracket remains fixed to the pole. Each ring and its bracket must have good electrical connection with earth wire. Every live conductor of the line is drawn through a ring so that in the event of snapping, it comes in contact with the ring and hence becomes electrically connected with the earth wire. This causes the line fuse to be burnt out immediately as a result of which flow of current through the live wire is stopped. The distance maintained between a ring and the corresponding pole is about 60 cm to 90 cm.

Tray-Type or Bracket-Type Safety Device

This type of safety device is specially suitable for an overhead line drawn in horizontal configuration. All live wires drawn parallel to one another horizontally on a cross-arm are covered by a single tray type safety device. (Fig 4)

A tray made of galvanised iron flat with bracket remains fixed to a pole. Tray and bracket must have good electrical connection with earth wire. As the phase wires or live conductors of an overhead line are drawn over the tray in horizontal configuration, as soon as a conductor snaps, it falls into the tray and thus becomes electrically connected with the earth wire. A tray is kept at a distance of 60 cm to 75 cm (2 to 2.5 feet) away from the respective pole.

Fig 4



Electrical substations

Objectives: At the end of this lesson you shall be able to
- **state the functions and purpose of electrical substations**
- **classify the different types of substation**
- **list out the equipment and components used in substation**
- **state the single line diagram of electrical substation with symbols.**

Substations

Electric power is produced at the power generating stations, which are generally located far away from the load centers. Between the power generating station and consumers a number of transformations and switching stations are required. These are generally known as substations.

Substations are important part of power system and form a link between generating stations, transmission systems and distribution systems. It is an assembly of electrical components such as bus-bars, switch gear apparatus, power transformers etc.

Function

Their main functions are to receive power transmitted at high voltage from the generating stations and reduce voltage for switching operations of transmission lines. Substations are provided with safety devices to disconnect equipment or circuit at the time of faults.

Classification of substation

The substations may be classified in according to service requirements and constructional features. According to service requirements they are classified in to transformer substations, switching substations and converting substations.

1 **Transformer substations :** Majority of the substations in the power system are in this type. They are used to transform the power from one voltage level to another voltage level. Transformer is the main component in such substation.

   a **Step - up substations :** These substations are usually located at the generating stations. Generating voltage of the order of 11KV needs to be stepped up to a primary transmission voltage level of the order of 220KV or 400KV.

   b **Primary grid substations :** These substations are located at the end of primary transmission lines and the primary voltage is stepped down to suitable secondary voltages of the order of 66KV or 33KV.

   c **Secondary substations :** The voltage is further stepped down to 11KV. Large consumers ar supplied with power at 11KV.

   d **Distribution substations :** These substations are located near the consumer localities to supply power at 415V three phase or 240V single phase to the consumers.

2 **Converting substation :** Such substations are meant for either converting AC to DC or vice versa. Some are used to change the frequency from higher to lower or vice versa for industry utilizations.

According to constructional features substations are classified into indoor substations, outdoor substations, under ground substations and pole mounted substations.

1 **Indoor substations :** All equipment of the substation are installed within the station buildings.

2 **Outdoor substations :** All equipments such as transformers, circuit breakers, isolators, etc, are installed outdoors.

3 **Underground substations :** In thickly populated areas where the space is the major constraint, and cost of land is higher, under such situation the substations are laid underground.

4 **Pole mounted substations :** This is an outdoor substation with equipment installed overhead of a H pole or 4 pole structure.

The substations can also be classified in several ways including the following.

1 **Classification based on application**

- **Primary Grid substation :** Created at suitable load centre along primary transmission lines. It receive the power from EHV lines at 400KV, 220 KV, 132KV and transform the voltage to 66KV, 33KV or 22KV (22KV is uncommon) to suit the local requirements in respect of both load and distance of ultimate consumers. These are also referred to EHV substations.
- **Secondary substation :** Along secondary transmission line. It receive the power at 66/33KV which is stepped down usually to 11KV.
- **Mobile substation :** For emergency replacement of transformer etc.
- **Distribution substations :** It receive power at 11KV, 6.6 KV and step down to a volt suitable for LV distribution purposes, normally at 415 volts.

The parts, equipment and components installed in substation

Each substation has the following parts and equipment.

1 Outdoor switchyard

- Incoming lines
- Outgoing lines
- Busbar
- Transformers
- Bus post insulator & string insulators
- Substation equipment such as circuit-breakers, isolators, earthing switches, surge arresters, CTs, PTs neutral grounding equipment
- Station earthing system comprising ground mat, risers, auxiliary mat, earthing strips, earthing spikes & earth electrodes.
- Overhead earthwise shielding against lightning strokes.
- Galvanized steel structures for lower equipment supports.
- PLCC equipment including line trap, tuning unit, coupling capacitor, etc.
- Power cables
- Control cables for protection and control
- Road, cable trenches
- Station illumination system

2 Switchgear and control panel building

- Low voltage AC switchgear
- Control panels, protection panels

3 Battery room and DC distribution system

- DC battery system and charging equipment
- DC distribution system

4 Mechanical, electrical and other auxiliaries

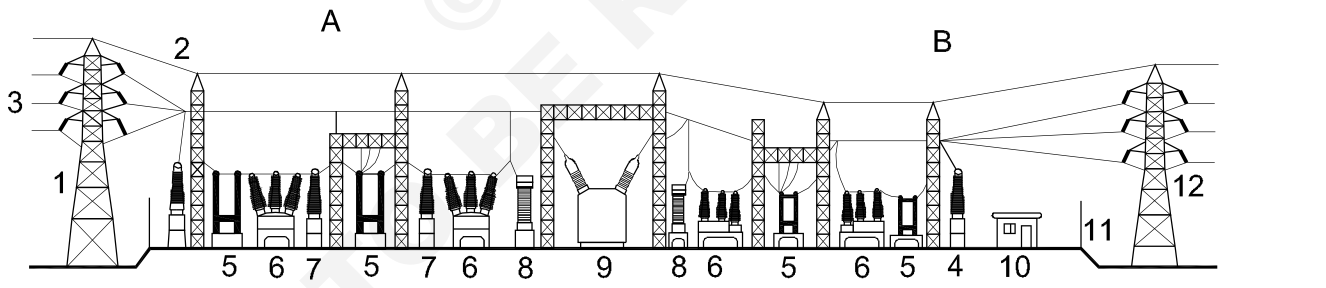
- Fire fighting system
- D.G (Diesel Generator) set
- Oil purification system

An important function performed by a substation is switching, which is the connecting and disconnecting of transmission lines or other components to and from the system. A transmission line or other component may need to be de-energized for maintenance or for new construction, for adding or removing a transmission line or a transformer. All work to be performed, from routine testing to adding new substations, must be done while keeping the whole system running.

Substation layout and their components

Fig 1 shows the typical substation layout.

Fig 1



A:PRIMARY POWER LINES' SIDE
1.PRIMARY POWER LINES
2.GROUND WIRE
3.OVERHEAD LINES
4.POTENTIAL TRANSFORMER
5.DISCONNECT SWITCH
6.CIRCUIT BREAKER
7.CURRENT TRANSFORMER
8.LIGHTNING ARRESTER
B:SECONDARY POWER LINES' SIDE
7.CURRENT TRANSFORMER
8.LIGHTNING ARRESTER
9.MAIN TRANSFORMER
10.CONTROL BUILDING
11.SECURITY FENCE

SUB STATION LAYOUT

Fig 2 show as single line layout diagram of a transmission and distribution substation.

Fig 2

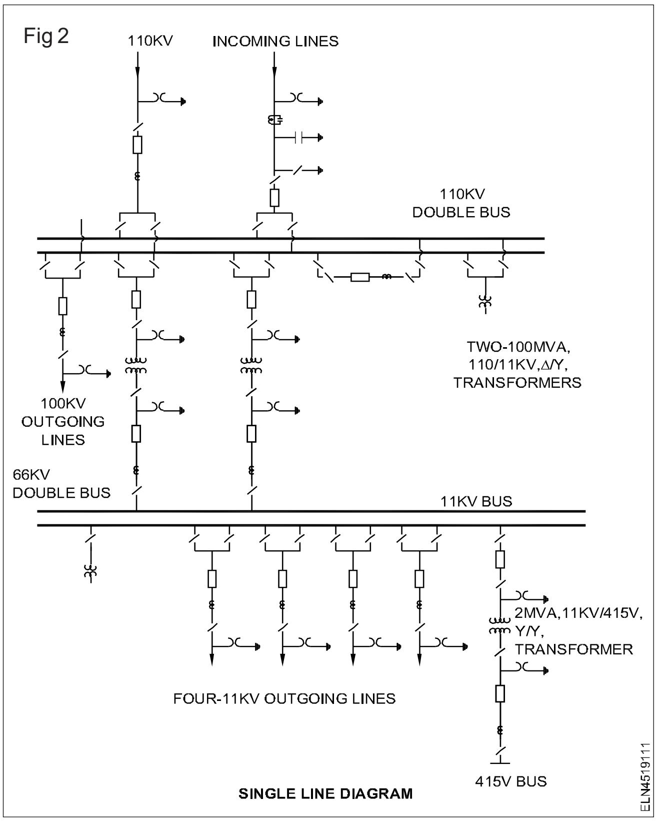


Fig 3 shows pole mounted substation.

Fig 4 shows indoor substation.

Fig 4

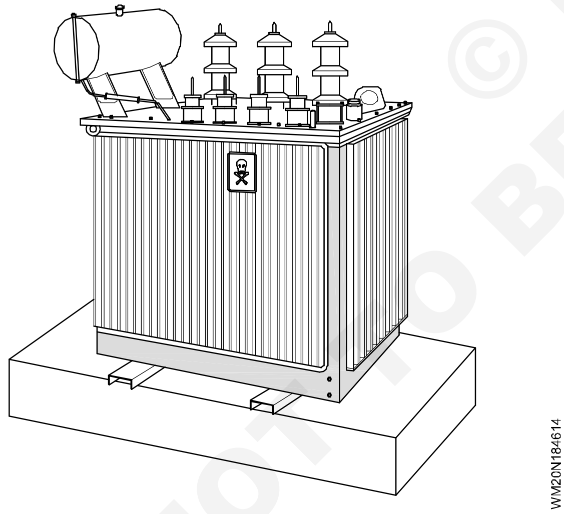


Fig 3

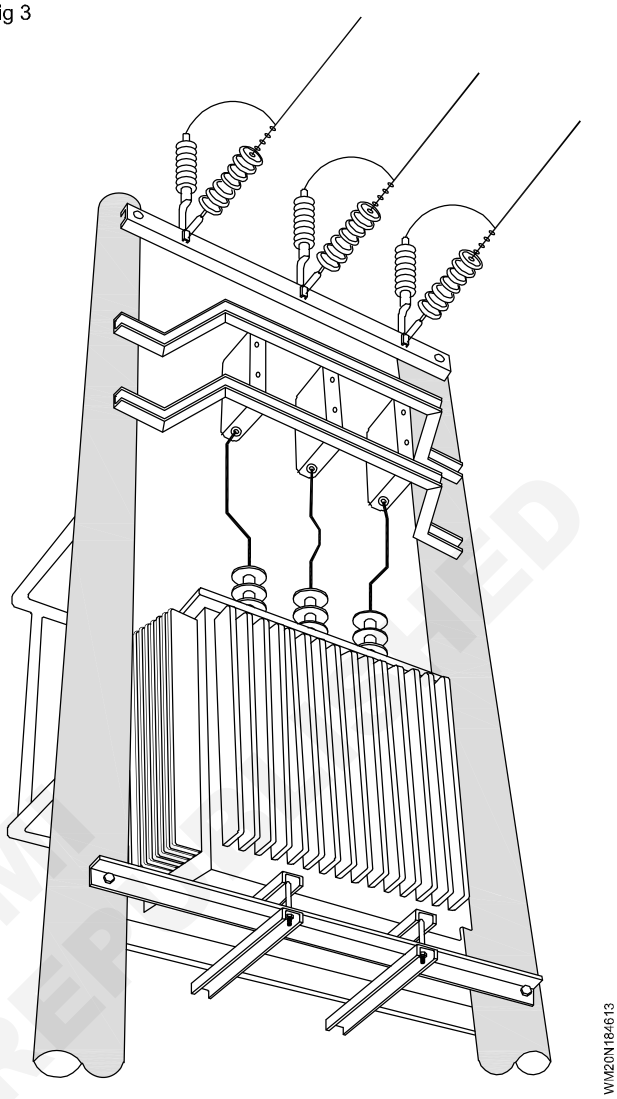
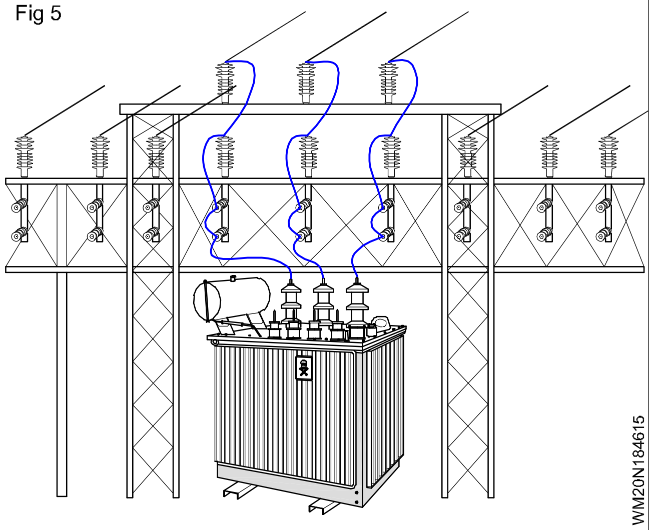


Fig 5 shows outdoor substation

Fig 5



Circuit breakers - parts - functions- tripping mechanism

Objectives: At the end of this lesson you shall be able to
- **explain circuit breaker**
- **list the various types of circuit breakers**
- **explain the parts of each circuit breakers**
- **explain the principle of operation of circuit breaker**
- **explain the application and uses of circuit breaker.**

Circuit breaker

Circuit breakers are the electrical device (or) equipment, which makes or breaks the electrical circuit. In a 240 volt single phase system a low rated single pole switch can use the circuit to break or make.

But in the case of heavy loads; say some hundreds, of ampere are flowing in a circuit the resultant spark at contact are heavy and this leads to electrical fire. To overcome this problem the sparks at the contacts are to be controlled or quenched, when any load makes or breaks. The equipment or device used to make or break a circuit under control at the same time it prevents or quenching the resultant fire is called as a circuit breaker.

Air circuit breaker (ACB)

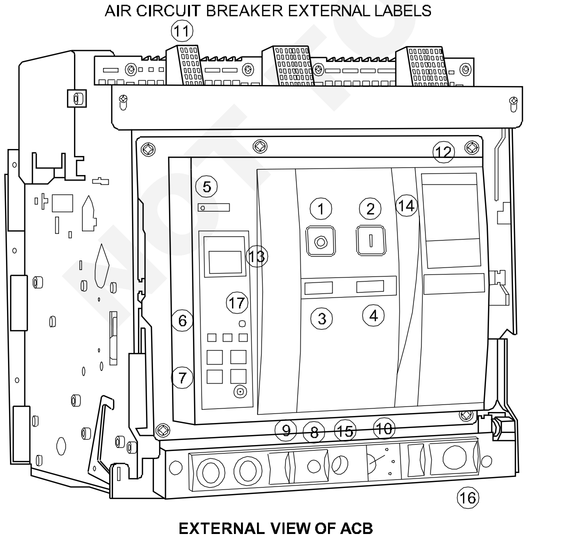
A circuit breaker which uses the either natural air or blast air as an Arc quenching medium is termed as Air-circuit breakers.

Air- Circuit breakers are widely used in industries as well as power system for controlling and protection of different section of the circuit like, Transformers, Motors, Generators / Alternator etc and leads the system stable and reliable.

Construction of air - circuit breaker

External lables / parts of ACB in Fig 1

Fig 1 AIR CIRCUIT BREAKER EXTERNAL LABELS



EXTERNAL VIEW OF ACB

1 OFF button (O)

2 ON button (I)

3 Main contact position indicator

4 Energy storage mechanism status indicator

5 Reset button

6 LED indicators

7 Controller

8 "Connection" "Test" and "isolated" position latching / locking mechanism

9 User padlock

10 Connection, "Test", and isolated position indication

11 Connection test and isolated position indication contacts

12 Name plate

13 Digital displays

14 Energy storage handle

15 Draw out /in hole

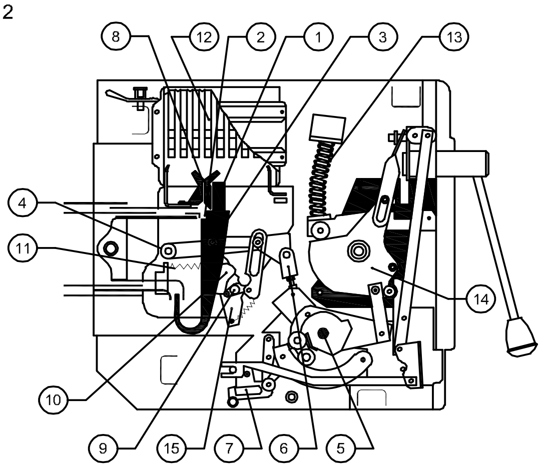
16 Rocker repository

17 Trip reset button

Internal construction of air circuit breaker

The internal parts of an ACB in Fig 2

Fig 2



INTERNAL VIEW OF CIRCUIT BREAKER

1 Sheet steel supporting structure

2 Current transformer for protection trip unit

3 Pole group insulating box

4 Horizontal rare terminals

5 Plate for fixed main contacts

6 Plates for fixed arcing contacts

7 Plate for main moving contacts

8 Plates for moving arcing contacts

9 Arcing chamber

10 Terminal box for fixed version - sliding contacts for withdrawable version

11 Protection trip unit

12 Circuit breaker closing and opening control

13 Closing springs

14 Spring loading arrangement

15 Manual releasing lever

Principle of operation of air circuit breaker

- When the circuit breaker opens the circuit either under the normal condition or in the fault condition, some Arc is produced between the main contacts and some current flows to the load, called **transition current** through the arc.
- This Arc and the current should be suppressed / eliminated especially during the fault condition otherwise the severity of the fault level will be more and damages the circuit which leads to the electric fire.
- During the period of Arc some voltage appears across the main contacts called **transition voltage**, which will be more than the rated system / supply voltage.
- To quench the Arc, this transition voltage should be reduced or the Arc voltage to be increased. The minimum voltage required to maintain the arc is called as **Arc voltage**. In ACB, the Arc voltage is increased in the following three ways.
- Arc voltage can be increased by cooling arc plasma by air. The temperature of arc plasma is reduced, more voltage will be required to maintain the arc.
- By splitting the arc into a number of series in Arc chute will increases the arc voltage.
- Arc voltage can be increased by lengthening the arc path. As length of arc path is increased its resistance of the arc path will increase hence the arc voltage is increased.

Some ACB contains two pairs of contact . The main pair carries the current and the made of copper. An additional pair of contact (Arc contact) is made of carbon. When the breaker is opened, the main contact opens first. and the arc contact remains in touch. The arcing gets initiated when arc contacts are separated. Hence transition voltage will be reduced.

Application and uses of air circuit breaker

- It is used for protection of plants
- It is used for common protection of electrical machines
- Air circuit breaker is also used in electricity sharing system upto 15KV
- Also used in low as well as high voltage and current applications.
- It is used for protection of transformers, capacitors and generators.

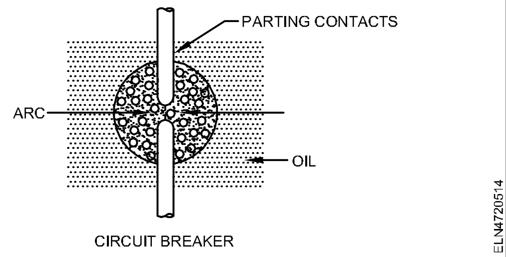
Oil circuit breakers (OCB)

Circuit breakers which uses the insulating oil (e.g transformer oil) as an arc quenching medium is called as oil circuit breaker. The main contacts of the OCB are opened under the oil and an arc is struck between them. The heat of the arc evaporates the surrounding oil and dissociates it into gaseous of hydrogen at high pressure.

The hydrogen gas occupies a volume about one thousand times that of the oil decomposed. The oil is, therefore, pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region of the contacts. The arc extinction is completed by two processes. Firstly, the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionization of the medium between the contacts.

Secondly, the gas sets up turbulence in the oil and forces it into the space between contacts, thus eliminating the arc as in Fig 3. The result is that arc is extinguished and circuit current is interrupted.

Fig 3



The advantages of oil as an arc quenching medium

i It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.

ii It acts as an insulator and permits smaller clearance between main contacts.

iii The surrounding oil presents the cooling surface in close proximity to the arc.

Types of oil circuit breakers

a Plain break oil circuit breakers

b Arc control oil circuit breakers.

c Low oil circuit breakers

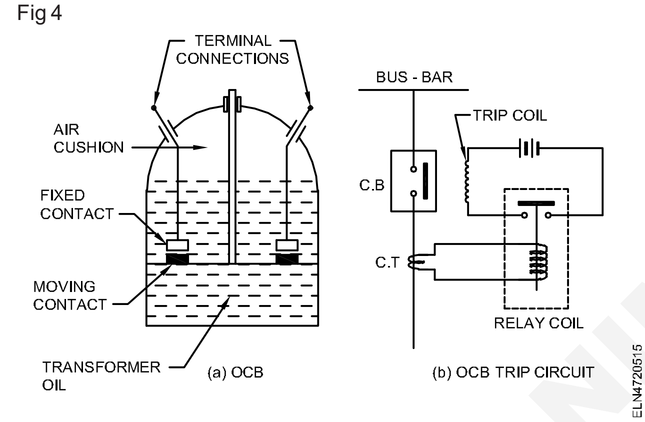
Plain break oil circuit breakers

In plain- break oil circuit breaker the main contacts are placed under the whole oil in the tank. There is no special system for arc control other than the increase in length of separation of the contacts. The arc extinction occurs when a critical gas is reached between the contacts.

The plain - break oil circuit breaker is the oldest type and has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather- tight earthed tank containing transformer oil upto a certain level and an air cushion above the oil level.

The air cushion provides sufficient room to arc gases without the generation of unsafe pressure in the circuit breaker. It also absorbs the upward oil movement. Fig 4 shows a double break plain oil circuit breaker. It is called a double break because it provides two breaks in series.

Fig 4



Principle of working

Under normal operating conditions, the fixed and moving contacts remain closed and carries the normal circuit current. When a fault occurs, the moving contacts are pulled down by the tripping mechanism and an arc is produced which vaporizes the oil into hydrogen gas. The arc extinction is completed by the following processes.

i The hydrogen gas bubble generated around the arc, cools the arc.

ii The gas sets up turbulence in the oil and helps in eliminating the arc.

iii As the arc lengthens due to the separation of contacts, the Arc voltage is increased.

The result is at some critical gap, the arc is extinguished and the circuit current is interrupted.

Vacuum circuit breaker (VCB)

Circuit breaker which uses vacuum as an arc quenching medium is called as vacuum circuit breaker.

Vacuum offers the highest insulating strength and have the superior arc quenching properties than any other medium. When the contacts of a breaker are opened in vacuum, the interruption occurs instantly as the dielectric strength between the contacts are many times higher than the other circuit breakers.

For higher voltage application, the vacuum technology has been developed.

Principle of vacuum circuit breaker

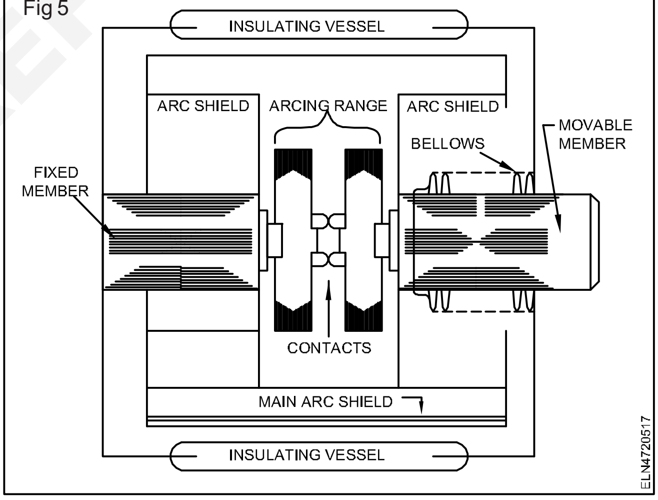
- When the contacts of the breaker are opened in vacuum (10^{7} to 10^{5} torr), an arc is produced between the contacts by the ionisation of metal vapours i.e, combination of electrons and ions of contacts. However, the arc is quickly extinguished because the metallic vapours, rapidly cools resulting quick recovery of dielectric strength.
- The salient feature of vacuum is, as soon as the arc is produced in vacuum, it is quickly extinguished due to the rapid recovery of dielectric strength of vacuum.

Construction of vacuum circuit breaker

Fig 5 shows the typical parts of vacuum circuit breaker

- It consists of the fixed contact, moving contact and arc shield mounted inside a vacuum chamber.
- The movable member is sealed by a stainless steel bellows, is connected to the control mechanism . This enables the permanent sealing of the vacuum chamber, to eliminate the possibility of leak.
- A glass vessel or ceramic vessel is used as the outer insulating body.
- The arc shield prevents the metallic vapours falling on the inside surface of the outer insulating cover.

Fig 5



Working of vacuum circuit breaker

- When the breaker opens, the moving contact is separated from the fixed contact and an arc is produced between the contacts. The production of arc is due to the ionisation of metal ions and depends upon the material of contacts.
- The arc is quickly extinguished because the metallic vapours , are diffused in a short time and condensed on the surfaces of moving and fixed members and arc shields.
- Since vacuum has rapid Arc recovery rate of dielectric strength, the arc extinction in a vacuum breaker occurs with a short separation (say 0.625 cm) of contacts.

Application of VCB

- Vacuum circuit breakers are employed for outdoor applications ranging from 22KV to 66KV.
- They are suitable for majority of applications in rural areas.

Sulphur hexafluoride (SF_6) circuit breaker

Circuit breakers which uses the sulphur hexafluoride gas (SF_6) as an arc quenching medium is called as SF_6 circuit breaker.

The sulphur hexafluoride gas (SF_6) is an electronegative gas and has a strong tendency to absorb the free electrons. When the contacts of the breaker are opened in a high pressure sulphur hexafluoride (SF_6) gas medium and an arc is struck between them.

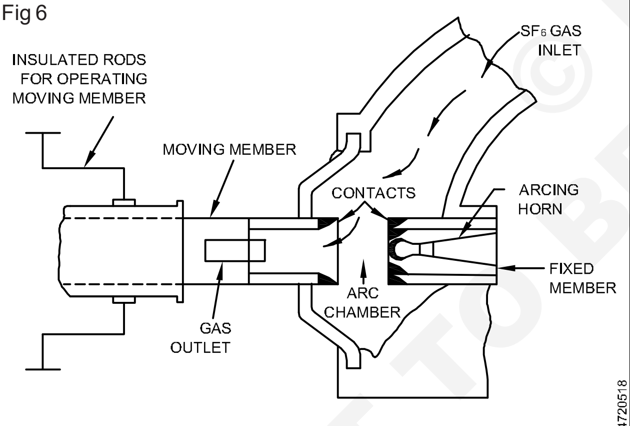
The SF_6 gas capture the conducting free electrons in the arc and form immovable negative ions. This loss of conducting electrons in the arc quickly improve the insulation strength to extinguish the arc.

The sulphur hexafluoride (SF_6) circuit breakers are very effective for high power and high voltage applications.

Construction of SF6 circuit breaker

A sulphur hexafluoride (SF_6) circuit breaker consists of fixed and moving contacts enclosed in a chamber as in Fig 6. The chamber is called arc interruption chamber which contains the sulphur hexafluoride (SF_6) gas and it is connected to sulphur hexafluoride (SF_6) gas reservoir.

Fig 6



TYPICAL INTERNAL VIEW OF SF_6 - CB

When the contacts of breaker are opened, the valve mechanism permits a high pressure sulphur hexafluoride (SF_6) gas from the reservoir to flow towards the arc interruption chamber.

The fixed contact is a hollow cylindrical contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides. The holes permit the sulphur hexafluoride gas (SF_6) to let out through them after flowing along and across the arc.

The tips of fixed contact, moving contact and arcing horn are coated with copper - tungsten arc resistant material. Since sulphur hexafluoride gas is costly, it is reconditioned and reclaimed using suitable auxiliary system after each operation of breaker.

Working of SF_6 circuit breaker

In the closed position of the breaker, the contacts remain surrounded by SF_6 gas at a pressure of about 2.8 kg/cm^2. When the breaker opens, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronized with the opening of a valve which permits SF_6 gas at 14kg /cm^2 pressure from the reservoir to the arc interruption chamber.

The high pressure flow of SF_6 gas rapidly absorbs the free electrons in the arc path to form immovable negative ions which are ineffective as charge carriers. The result is that the medium between the contacts rapidly improve the dielectric strength and causes the extinction of the arc. After the breaker operation (i.e. after arc extinction), the valve mechanism is closed by a set of springs.

Advantage of SF_6 circuit breaker

Due to the superior arc quenching properties of SF_6 gas, the sulphur hexafluoride gas circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below.

1 Such circuit breakers have very short arcing time.

2 Since the dielectric strength of SF_6 gas is 2 to 3 times more than the air, such breakers can interrupt much larger currents.

3 SF_6 circuit breaker gives noiseless operation due to its closed gas circuit and no exhaust to the atmosphere unlike the air blast circuit breaker.

Protective relays

Objectives: At the end of this lesson you shall be able to
- **state the classification of relays**
- **list the types of relays and their uses**
- **explain the principle of operation of over current, differential and distance relays**
- **explain the principle of operation of a over voltage end under voltage relay**
- **state the necessity of time multiplier setting of relay.**

Introduction

The relays is the element that senses as abnormal condition in the circuit and commands the operation of the breaker. It interpret the fault quantities ie, CT output current and PT output voltage and sending the command to the tripping circuits of breaker for operation in accordance with the characteristic set in the relay and the value of the time multiplier setting.

Classification of Relays

Relays are classified mainly in three categories; they are according to:

1 **Quantity sensed :** Current, Voltage, active power, reactive power & impedance

2 **Tripping :** Instantaneous trip, delayed trip inverse time response and definite time

3 **Operating principle:** Electro magnetic relays, Induction relays, Thermal relays and static or digital relays

Types or relays : Various types of relays are used as per the requirement; they are:

1 Over current relay, 2 Over voltage relay, 3 Under voltage relay, 4 Differential relay, 5 Earth fault relay, 6 Distance relay, 7 Impedance relay, 8 Admittance relay, 9 Reactance relay

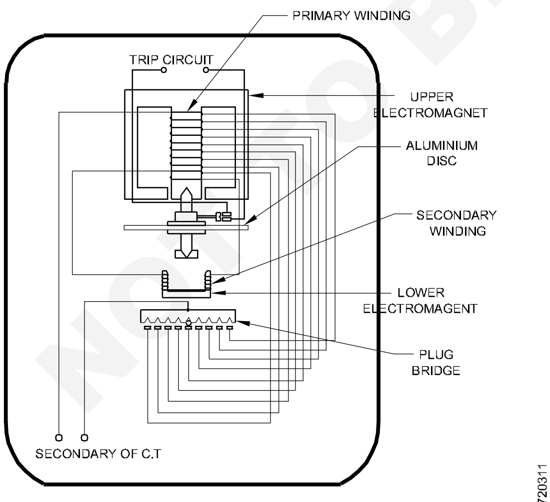
Relay is one of the main device used for switch gear protection networks to protect the transmission lines, transmission equipments and sub station equipments. The equipments used for transmission and in substation for distribution such as transformers, lightening arrestors,earth switches, isolators, CTs & PTs etc; are very costly and needs continuous protection from damage.

Reasons for over current, Over voltage and under voltage fault:

Working principle of current relay

The electro magnetic relay widely using in the substation and transmission lines are serves the protection from the disaster conditions. The latest version of modern static or digital relays are now a days out dated the conventional electro magnetic relays, because of their many of advancements compare to electro magnetic relay. (Fig 1)

Fig 1



INDUCTION TYPE NON-DIRECTIONAL OVERCURRENT RELAY

Over voltage and under voltage relays

This electromagnetic relays are working on the same principle of induction type disc type relays. The sensor used in this relay input is from PT (potential transformer) where output generally kept on 110v AC.

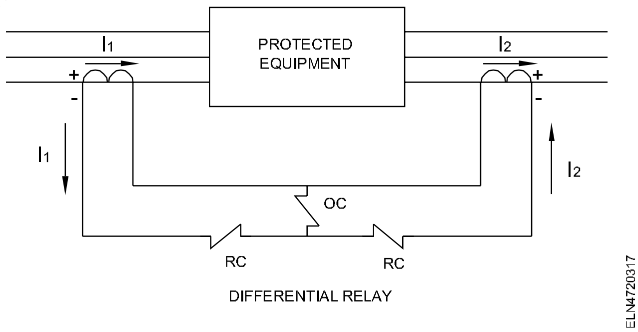
When the fault occurs the PT output produces a voltage which in turn energise the disc mechanism to rotate. As the fault continue to represent; and the trip time settled, the relay disc rotates and make the trip coil to activate in the trip mechanism in the breakers. The tripping time settled as per the characteristics selected. The pick up voltage has to be verified with the plug setting value of fault voltage which can be selected in different fault voltages in both over/ under voltage relay. Time Multiplier Setting (TMS) shorten the trip time if necessary on the fault quantity is more as the case may be.

Time multiplier setting: This setting is helps the relay to shorten the time selected without change of any other settings made in the relay. Time multiplier helps the relay to activate fast the breaker in case the fault quantity is more than 50% of the fault quantity selected by the tap setting.

Differential protection relay: Differential protection is a very reliable method of protecting generators, transformers, busbar and transmission lines from the effects of internal faults. In normal operating conditions the current through the CTs is the same. So the relay sense no differential current. This is also the case for external faults. Differential protection can be used for protecting generators from faults to ground. Differential protection of busbars in substations uses one CT for each incoming line. All incoming currents are added up and compared to the sum of all out going currents.

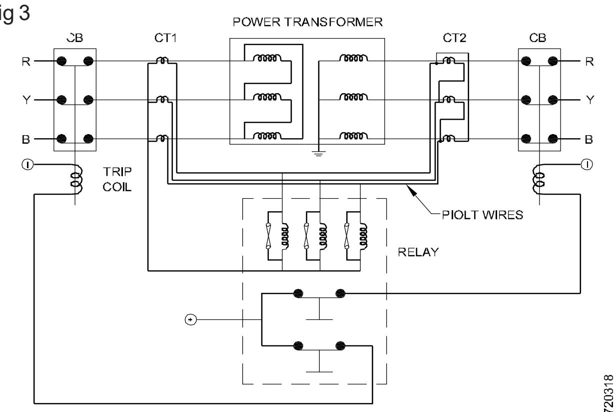
General schematic diagram of differential protection relay is in Fig 2.

Fig 2



The installation of differential relay for protection of power transformers used in transmission line is in Fig 3.

Fig 3



DIFFERENTIAL PROTECTION IN TRANSFORMERS

Distance relays / Admittance relay

The impedance of a transmission line is proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring the impedance of a line up to a predetermined point (the reach point) Such a relay is described as a distance relay and is designed to operate only for faults occurring between the relay location and the selected reach point thus giving discrimination for faults that may occur in different line sections.

'Potective devices'

1 Circuit breakers, 2 Current transformers, 3 Potential (voltage) transformers, 4 Protection relays, 5 Measuring instruments, 6 Electrical fuses, 7 Lightning arresters (or) surge arresters, 8 Electrical switches / Isolators etc.

Lightning arrester

Objectives: At the end of this lesson you shall be able to
- **state about the lightning arresters**
- **describe different types of lightning arresters used for outdoor applications.**

Lightning arrester

It is a protective device which protect the equipment or line from the lightning and high surge / transient voltage. Generally there are connected parallel to either at the beginning or at end of the power line or equipment which are to be protected.

The lightning arrester provides a low impedance path to ground for the a ligtning strike or transient or surge or over voltage and then restores to a normal operating conditions.

Cause of surge/ transient /over voltages

1 **Direct lightning stroke:** In direct stroke, the lightning discharge is directly from the cloud to the equipment line. The magnitude of lightning stroke in the order of several lakh of voltage.

2 **Indirect lightning stroke:** Indirect stroke results from the electro statically induced charges on the conductors due to the presence of charge clouds.

Effects of lightning stroke in line / Equipment

- The travelling waves produced due to lightning will damage the insulators appratus/ appliances connected with it.
- If the travelling waves hit the windings of a transformer or generator it may damage or burn the winding.

Type of lightning arrester (LA) for outdoor applications

There are several types of lightning arresters in general use. They differ only in constructional details but operate on the same principle, providing low resistance path for the surges to the ground.

1 Rod arrester

2 Horn gap arrester

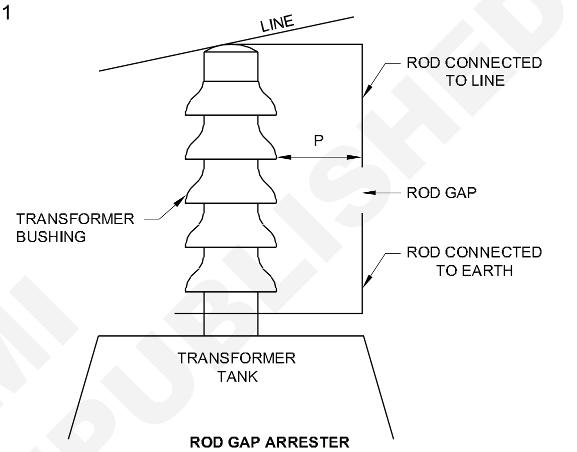
3 Multi gap arrester

4 Expulsion type lightning arrester

5 Valve type lightning arrester

Rod gap arrester: It is a very simple type of diverter and consists of two 1.5 cm rods, which are bent at right angles with a gap in between as shown in Fig 1.

Fig 1



ROD GAP ARRESTER

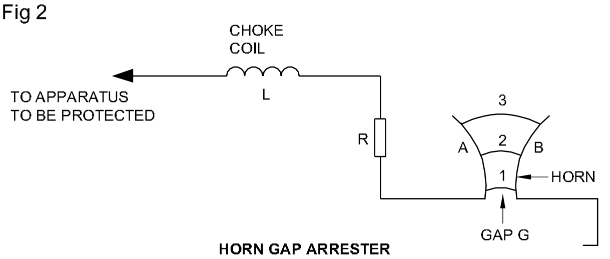
One rod is connected to the line circuit and the other rod is connected to earth. The distance between gap and insulator (i.e. distance P) must not be less than one third of the gap length so that the arc may not reach the insulator and damage it.

Under normal operating conditions, the gap remains non - conducting. On the occurence of a high voltage surge on the line, the gap sparks over and the surge current is conducted to earth. In this way excess charge in the line due to the surge harmlessly conducted to earth.

2 Horn gap arrester

- Fig.2. shows the horn gap arrester : It consits of a horn shaped metal rods. A and B separated by a small air gap. The horns are so constructed that distance between them gradually increases towards the top as shown Fig 2

Fig 2



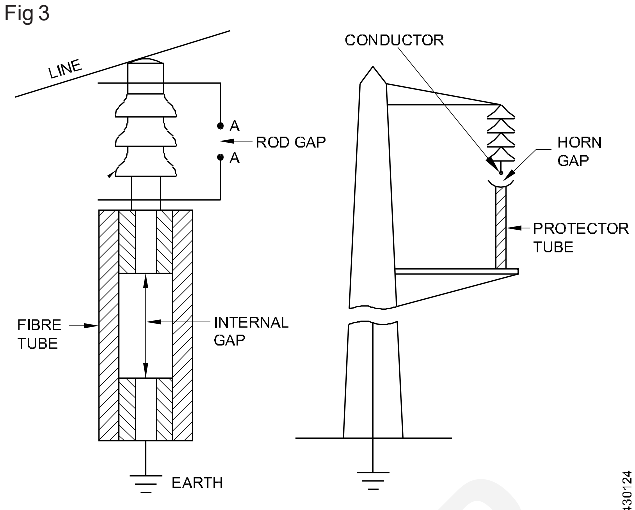
HORN GAP ARRESTER

- The horns are mounted on porcelian insulators. One end of horn is connected to the line through a resistor and choke coil L while the other end is effectively grounded.
- Under normal conditions the gap is non conducting i.e normal supply voltage is insufficient to initiate the arc between the gap. On the occurrence of an over voltage, spark - over takes place across the small gap G. The heated air around the arc and the magnetic effect cause the arc to travel up the gap. The arc moves progressively into positions 1, 2 and 3.
- At some position of the arc (Position 3) the distacne may be too great for the voltage to maintain the arc, consequently, the arc is extinguished. The excess charge on the line is thus conducted through the arrester to the ground.

Expulsion type arrester

- This type of arrester is also called **"protector tube"** and is commonly used on system operating at voltages up to 33KV. Fig 3 shows the essential parts of an **expulsion type lightning arrester.**
- It essentially consists of a rod gap AA in series with a second gap enclosed within the fiber tube. The gap in the fiber tube is formed by two electrodes. The upper electrode is connected to rod gap and the lower electrode to the earth. One expulsion arrester is placed under each line conductor. Fig 3 shows the installation of expulsion arrester on an overhead line.

Fig 3



EXPULSION TYPE ARRESTER

- Once over voltage occurs on the line, the series gap AA sparked and an arc is stuck between the electrodes in the tube. The heat of the arc vaporizes some of the fiber of tube walls resulting in the production of neutral gas. This de-ionizing effect is generally so strong that the arc goes out at of a current zero and will not be re-established.

Advantages

1 They are not very expensive

2 They are improved form of rod gap arresters as they block the flow of power frequency currents.

3 They can be easily installed.

Protection schemes

Objectives: At the end of this lesson you shall be able to
- **state about protection schemes**
- **explain briefly about micro processor based digital protective relay**
- **state about earth fault relay.**

Introduction of protection systems

The protection of the power system especially for the generation, transmission and distribution is very important to have a normal operation without any electrical fault or failures. When a fault occurs on any part of the power system, it must be quickly detected and disconnected from the rest of the system.

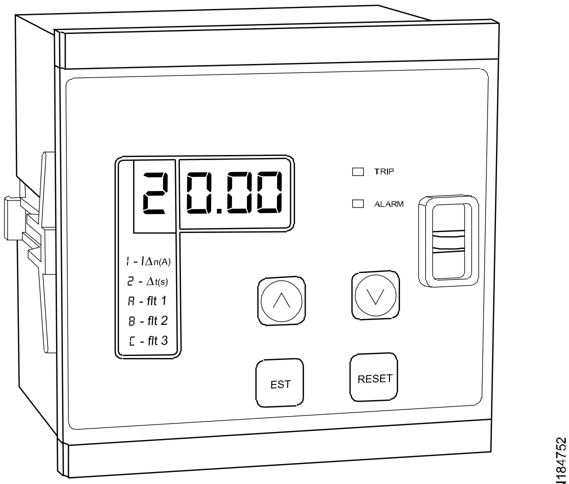
The important functions of the protection system are

- Rapidly disconnect the faulty line or circuit from the system and thus limits the amount of damages. Consequently it,
- Prevents the spreading of fault into the system
- Avoid the unnecessary interruption of service to the customers connected in the healthy section.

Micro processor - based digital protective relay

Now a days the microprocessor - based digital protective relays (Fig 1) are used instead of electro mechanical relays. In many cases a single microprocessor relay will do the functions of two or more electro mechanic relays.

Fig 1



MICRO - PROCESSOR BASED DIGITAL RELAY

Advantages of micro-processor based relays.

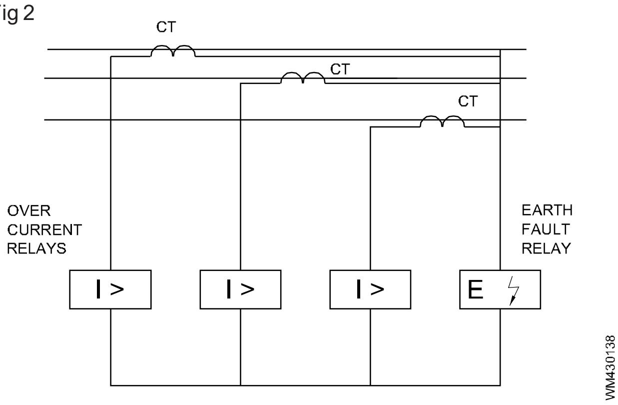
- It provides function of two or more electro mechanical relay in a single case or enclosure.
- It occupy only less space
- It save the capital cost and maintenance cost
- It have very long life span because of no - moving part.
- Attractive design and good looking and colour

Earth fault relay

A protective relay which detects the earth fault of the power system and initiate the trip signal can be called as the earth fault relay. This relay will operates or pick up only when the earth fault current in the connected power system exceeds the pre determined setting value.

The connection of the typical earth fault relay along with three over current relays is shown in Fig 2

Fig 2



Rotary, multi range and power circuit switches

Objectives: At the end of this lesson you shall be able to
- **state about rotary switch**
- **state the application and types of rotary switches**
- **brief about the multi circuit (range) switch**
- **state briefly about power circuit switches.**

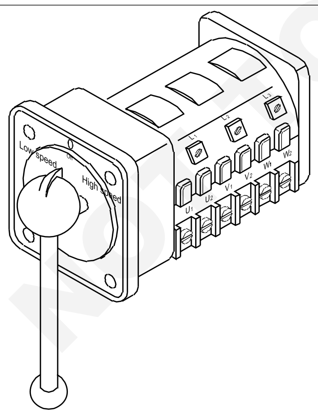
Rotary switches

Rotary switch is an electrical switch operated by rotation, move in a circle or to a certain angles and stop in several position.

Rotary switches have a rotating spindle consists of number of rotor which has a contact arm projected from its surface like a cam.

It has a detent mechanism to move from one active position to another and does not stall in an intermediate position when the turning the spindle. Thus the rotary switch have capabilities of providing greater number of position, poles and throw than the simple switch as shown in Fig 1

Fig 1



TYPICAL ROTARY SWITCH

Application

1 Used as ammeter and voltage selector switches in the panel boards of generating station, transmission and distribution substation, etc.

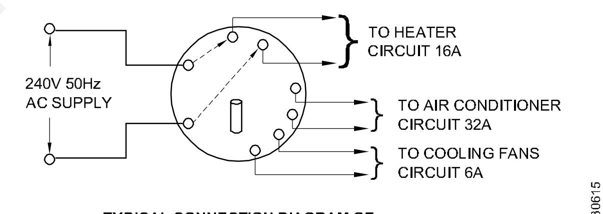
2 Used in the motor circuit to change poles and speed as well as to charge the star and connection.

3 Used as the change over switch in 3 phase power system.

Multi circuit (range) switches

It is a type of the rotary switch used to control the different circuit or different range circuit through the single switch by turning its knob. The typical connection diagram of the multi circuit switch is shown in Fig 2.

Fig 2



TYPICAL CONNECTION DIAGRAM OF MULTI RANGE / CIRCUIT SWITCH

This typical switch used to connect the heater or air-condition or cooling fans circuit at a time depends on the requirement by simply rotating its knob. The current rating (range) of the each circuit is different.

They are used in the thermal control panel to control the substation temperature and panel boards to connect the current or voltage instruments alternatively.

Power circuit switches

It is the type of the rotary switches, generally turn or rotates to only certain angles (not move in a circle) and used to control power and motor circuit breakers.

Generally it have three different position on which one is stable neutral position i.e, the knob of switch will always return or stay in this position and other two position are spring return position.

In addition, the lost motion contact is also provided in the switches to indicate the last operated position of the breaker. This spring return switches prevent any two successive operation, generally successive closing operation, ensuring the tripping of fault circuit from the successive closing.

Mercury switches

Objectives: At the end of this lesson you shall be able to
- **state about mercury switches and its construction and working**
- **state about advantages, disadvantages and application of the mercury switches.**

A **mercury switch** is an electrical switch which opens or closes an electrical circuit under the pre-determined condition through the small amount of mercury along with metal electrodes (contacts).

They are generally available is three different designs such as

1 Tilt type mercury switch

2 Displacement type mercury switch

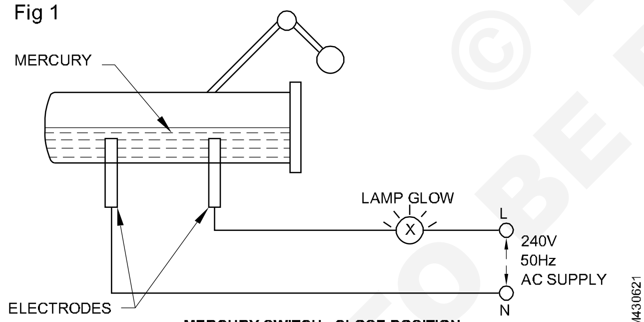
3 Radial type mercury switch

Construction and working

Mercury switches may have one or more sets of electrical contacts sealed in a glass envelope which contains a small quantity of mercury. The envelope may contain air or an inert gas or vacuum. The gravity force of earth will pull the mercury constantly to the lowest point of the envelope.

When the mercury switch is tilted in a particular direction, the mercury touches a set of contacts and completes the electrical circuit as shown in Fig 1.

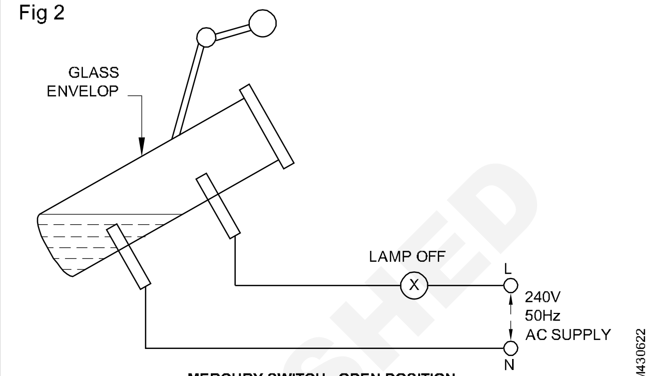
Fig 1



MERCURY SWITCH - CLOSE POSITION

If the mercury switch is tilted in the opposite direction, the mercury moves away from the set of contacts thus breaks the circuit as shown in Fig 2.

Fig 2



MERCURY SWITCH - OPEN POSITION

Advantages

1 The contacts are enclosed in a sealed envelope hence oxidation of the contact points does not happen.

2 The interruption of the circuit will not emit spark hence can be used in fire or gas hazardous location.

3 Contact points will not wear out and stay clear always.

4 Welding or pitting or chattering of the contact does not arise.

Application

1 They are used in construction equipment and lift vehicles used in rugged off- highway terrains.

2 They are used in automobiles for lighting control, ride control and anti-lock braking system.

3 Used where the work performed inside a vessel for worker safety to make an alarm circuit .

4 Used in an electrically driven attitude indicators .

5 They are used in Buchholz relay of the transformer to give alarm and trip signals.

6 They are used as alarm and trip switches in the temperature monitoring instruments of the transformers windings and transformer oil.

Thermostats and control panel

Objectives: At the end of this lesson you shall be able to
- **state about thermostat and its types**
- **state briefly about different types of thermostat.**

Thermostat

A thermostat is a device which senses the temperature and act as an electrical switch which closes or opens a circuit at the predetermined temperature. Thermostat are used in many devices or systems to control and regulate the heats and cooling thus maintain the temperature at the set values.

Types of thermostats

1 Bimetallic - mechanical thermostat

2 Expanding wax thermostat (pellets)

3 Electrical thermostat

4 Digital electronic thermostat

Bi-metallic mechanical thermostat

It is a traditional thermostat which has two different metals strips bolted together and has an electrical contact to act as switch to open or close the circuit to regulate or control or maintain the temperature.

It is generally used in automatic electric iron, ovens, geysers and cooking ranges etc.,

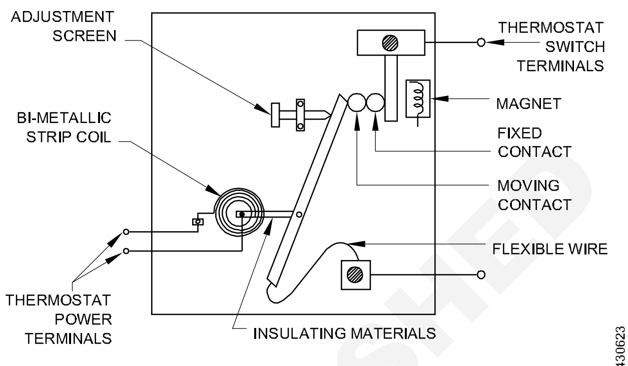
Electric thermo-stat

It is a type of thermostat which uses the power the heating device to control the temperature. It uses the power, ranging from few milli volts to 240 volts and control the heating system either directly (electric base board heaters) and indirectly (gas, oil and forced hot water systems).

They are generally used in oil furnaces, boilers, boiler valves, electric furnace, electric base board heater and domestic appliances. Fig 1 shows the internal arrangement of common two wire domestic thermostat.

A magnet is used in this thermostat ensures the good contact when the contacts closes, allows the temperature of the system be raised several degree before the contacts open and prevent the short heating cycles.

Fig 1



ELECTRICAL THERMOSTAT

Cooker control panel

Objectives: At the end of this lesson you shall be able to
- **explain briefly cooker control panel.**

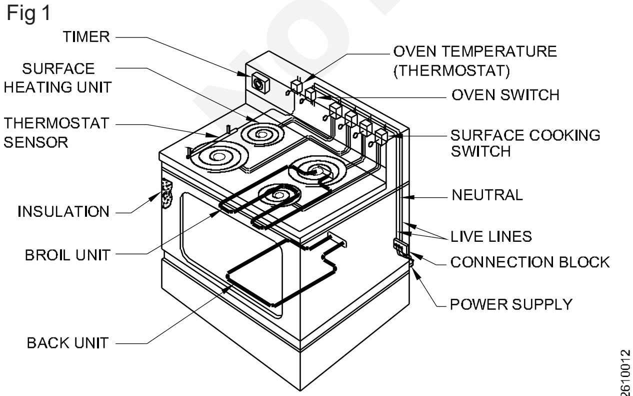
Cooker control panel: Electric cooking range is the combination of an oven and hot plate. The electric range consist of highly efficient heating elements, it gives better cooking control, has shelf oven, fingertip controls and designs to fit almost every possible kitchen need.

The surface heating units are set in the top of the range, the electric connections for these units are carried in the space between the top of the range (Fig 1). Oven controls are also kept in the top but in separate elevated pedestal.

The parts of a cooking range

Surface heating elements: In present day cooking range the nichrome element is encased in a metal tube with magnesium oxide insulation. This enclosed surface heating element (Fig 1) more efficient, more durable and safe to handle.

Fig 1



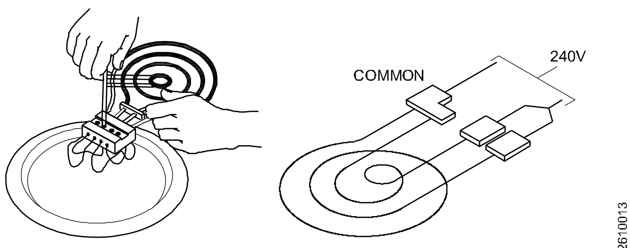
ELECTRIC COOKING RANGE

Step/Selector switches: A step switch is simply a rotary switch, which can select four or six different heats (wattages) Fig 2 and 3.

The step switch connected to two or three elements to 240 volts. The total circuit resistance or the voltage is changed to provide different heats.

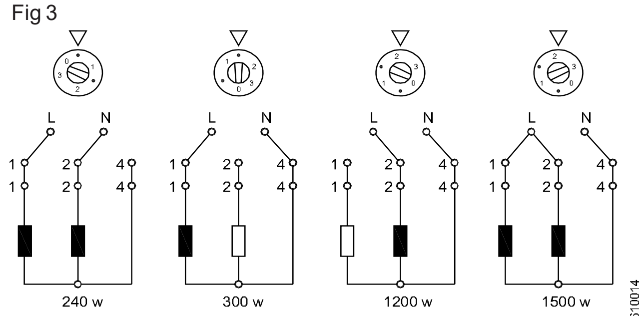
High heat is obtained by connecting total elements in parallel. For low heat all the coils are connected in series (Figs 2 & 3).

Fig 2



HEATING ELEMENTS

Fig 3



STEP/SELECTOR SWITCH-4 POSITION

Oven unit: The oven unit consists of two heating elements, an upper element and a lower element.

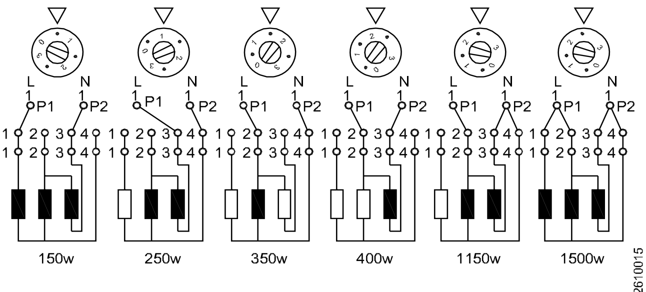
The oven heat is normally controlled by thermostat and timing device.

In a oven electric circuit, the broil unit is constructed by stringing the element through the frame in two separate coils, whereas the bake unit is strung with only one coil.

Now-a-days instead of thermostat switch, the typical infinite-heat switches are used (Fig 4). This switch operates the internal heater causes the bimetal to open and close the switch that controls the range heater element. This bimetal heater is series the cooking range and must have the correct resistance for the element being controlled.

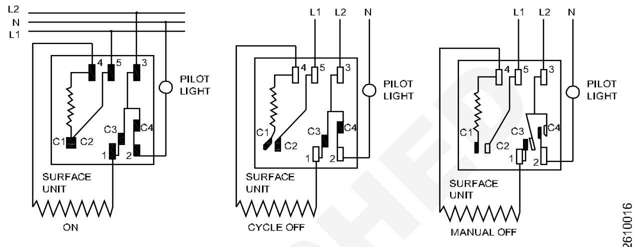
A schematic diagram of a typical electric range is given in Fig 5.

Fig 4



STEP/SELECTOR SWITCH-6 POSITION

Fig 5



TYPICAL INFINITE-HEAT SWITCHES

Earthing

Objectives: At the end of this lesson you shall be able to
- **explain the reasons for system and equipment earthing**
- **define the terminology related to earthing**
- **state and explain the methods of preparing pipe earthing and plate earthing, and mesh earthing recommendations**
- **explain the procedure for reducing the resistance of earth electrodes to an acceptable value.**

Earthing of an electrical installation can be brought under two major categories.

- System earthing
- Equipment earthing

System earthing: Earthing associated with current-carrying conductors is normally essential to the security of the system, and is generally known as system earthing.

Equipment earthing: Earthing of non-current carrying metal work and conductor which is essential for the safety of human life, animals and property is generally known as equipment earthing.

Earth-continuity conductor (ECC): The conductor which connect the non-conductive metal part/body of an electrical system/equipment to the earth electrode is called as earth contained conductor.

Earth electrode: A metal plate, pipe or other conductor electrically connected to the general mass of the earth.

Earth fault: Live portion of an electrical system getting accidentally connected to earth.

Leakage current: A current of relatively small value, which passes through the insulation of conductive parts/ wire.

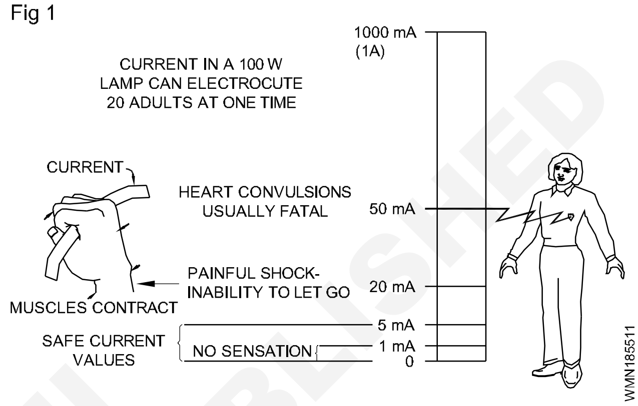
Step potential: The maximum value of the potential difference possible of being shunted by a human body between two accessible points on the ground separated by the distance of one step, which may be assumed to be one metre.

Touch potential: The maximum value of potential difference between a point on the ground and a point touched by a person.

Reasons for earthing: The basic reason for earthing is to prevent or minimize the risk of shock to human beings and livestock. The reason for having a properly earthed metal part in an electrical installation is to provide a low resistance discharge path for earth leakage currents which would otherwise prove injurious or fatal to a person or animal touching the metal part.

An electric shock is dangerous only when the current through the body exceeds beyond a certain milliampere value. In general, any current flow through the body beyond 5 milliamperes is considered dangerous. Fig 1 shows the magnitude of current and its effect.

Fig 1



However, the degree of danger is also dependent on the time during which it flows, and resistance of the body. In human beings, the resistance between hand and hand or between hand and foot can easily be as low as 400 ohms under certain conditions. Table 1 shows the body resistance at specified areas of contact.

Table 1

Skin conditon or area	Resistance value
Dry skin	100,000 to 600,000 ohms
Wet skin	1,000 ohms
Internal body-hand	400 to 600 ohms to foot
Ear to ear	about 100 ohms

CASE 1: **Metal body of apparatus when it is not earthed**

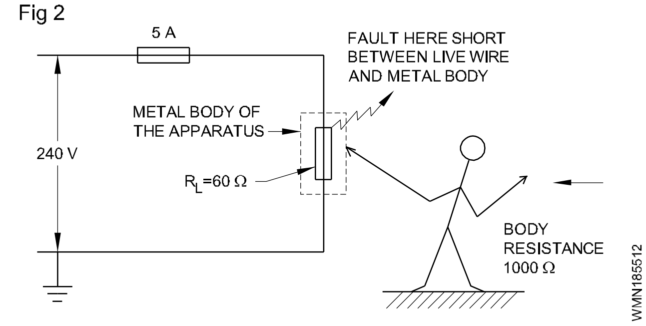
Let us consider a 240V AC circuit connected to an apparatus having a load resistance of 60 ohms. Assume that the defective insulation of cable makes the metal body live and the metal body is not earthed.

When a person, whose body resistance is 1000 ohms, comes in contact with the metal body of the apparatus which is at 240V, a leakage current may pass through the body of the person (Fig 2).

$$\text{The value of current through the body} = \frac{V}{R_{Body}}$$

$$= \frac{240}{1000} = 0.24 \text{ amps or 240 milliamps.}$$

Fig 2



This current, as can be judged from Table 1, is highly dangerous, and might prove to be fatal. On the other hand, the 5 amps fuse in the circuit will not blow for this additional leakage current of 240 milliamperes. As such the metal body will have 240V supply and may electrocute any person touching it.

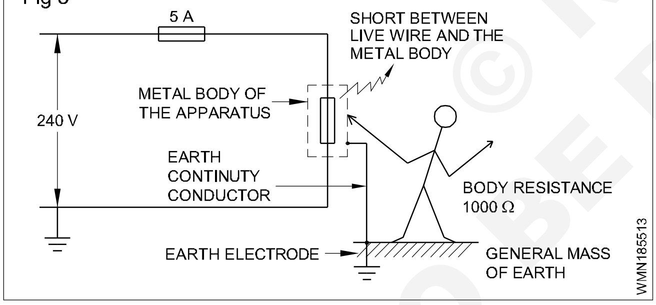
CASE 2: Metal body of apparatus when earthed.

In case the metal body of the apparatus is earthed (Fig 3), the moment the metal body comes in contact with the live wire, a higher amount of leakage current will flow through the metal body to earth.

Assuming that the sum of the resistace of the main cable, metal body, earth continuity conductor and the general mass of earth is to the tune of 10 ohms

$$\text{the leakage current} = \frac{V}{R_{Total}} = 240/10 = 24 \text{ amps.}$$

Fig 3



This leakage current is 4.8 times higher than the fuse rating, and, hence, the fuse will blow and disconnect the supply from the mains. The person will not get a shock due to two reasons. Before the fuse operates, the metal body and earth are in the same zero potential, and across the person, there is no difference of potential. Within a short (milli-seconds) time the fuse blows to open the defective circuit, provided the earth circuit resistance is sufficiently low.

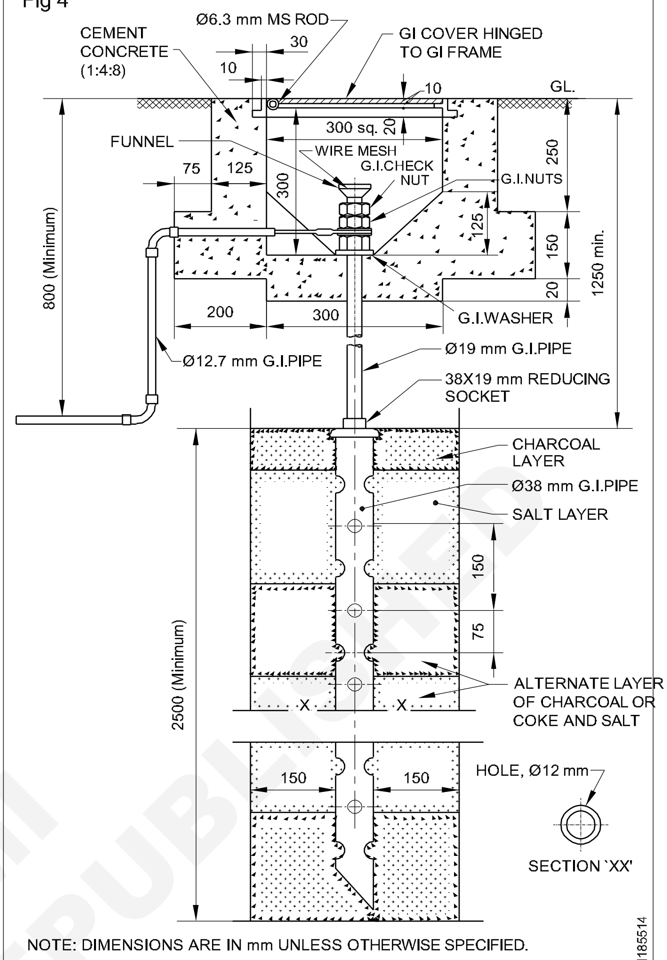
By studying the above two cases, it is clear that a properly earthed metal body eliminates the shock hazards to persons and also avoids fire hazards in the system by blowing the fuse quickly in case of ground faults.

Types of earth electrodes

Rod and pipe electrodes (Fig 4)

These electrodes shall be made of metal rod or pipe having a clean surface not covered by paint, enamel or other poorly conducting material.

Fig 4



PIPE EARTHING

Rod electrodes of steel or galvanised iron shall be at least 19 mm in diameter, and those of copper shall be at least 12.5 mm in diameter.

Pipe electrodes shall not be smaller than 38 mm internal diameter, if made of galvanised iron or steel, and 100 mm internal diameter if made of cast iron.

Electrodes shall, as far as practicable, be embedded in earth below the permanent moisture level.

The length of the rod and pipe electrodes shall not be less than 2.5 m.

Except where rock is encountered, pipes and rods shall be driven to a depth of atleast 2.5 m. Where rock is encountered at a depth of less than 2.5 m, the electrodes may be buried, inclined to the vertical. In this case too, the length of the electrodes shall be atleast 2.5 m, and the inclination not more than 30^0 from the vertical.

Deeply driven pipes and rods are, however, effective where the soil resistivity decreases with depth or where a sub-stratum of low resistivity occurs at a depth greater than those to which rods and pipes are normally driven.

Pipes or rods, as far as possible, shall be of one piece.

For deeply driven rods, joints between sections shall be made by means of a screwed coupling,which should not be of a greater diameter than that of the rods which it connects together.

Plate electrodes (Fig 5): Plate electrodes,when made of galvanised iron or steel,shall not be less than 6.3 mm in thickness. Plate electrodes of copper shall be not less than 3.15 mm in thickness. Plate electrodes shall be of a size, at least 60 cm by 60 cm.

Fig 5

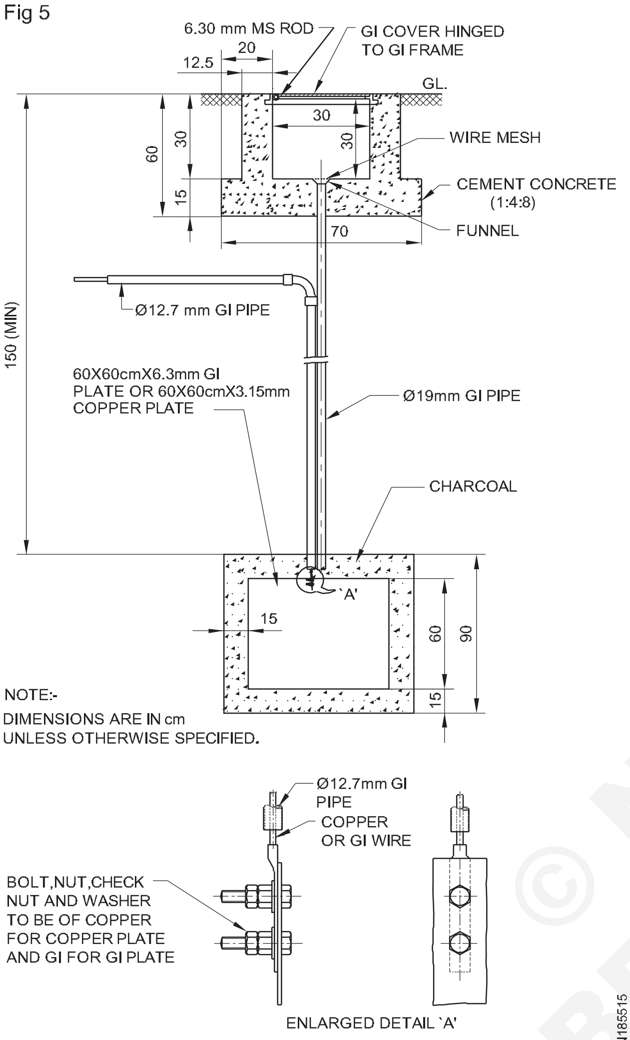


PLATE EARTHING

Plate electrodes shall be buried such that the top edge is at a depth not less than 1.5 m from the surface of the ground.

Where the resistance of one plate electrode is higher than the required value, two or more plates shall be used in parallel. In such a case, the two plates shall be separated from each other by not less than 8.0 m.

Plates shall preferably be set vertically.

Use of plate electrodes is recommended only where the current-carrying capacity is the prime consideration; for example, in generating stations and substations.

If necessary, plate electrodes shall have a galvanized iron water pipe buried vertically and adjacent to the electrode. One end of the pipe shall be atleast 5 cm above the surface of the ground, and it need not be more than 10 cm. The internal diameter of the pipe shall be atleast 5 cm and need not be more than 10 cm. The length of pipe, if under the earth's surface, shall be such that it should be able to reach the centre of the plate. In no case, however, shall it be more than the depth of the bottom edge of the plate.

Methods of improving earth by reducing the resistance of an earth electrode to an acceptable value

To achieve efficient operation of the protective devices, under fault condition the earth electrode resistance should be lower than an acceptable value which could be calculated from circuit details.

However, the earth electrode resistance is found higher in rocky or sandy areas where moisture is very low.

The following methods are suggested to bring down the earth electrode resistance to an acceptable value.

1 After installing the rod or pipe or plate in earth, the earth pit (the area surrounding the rod / pipe / plate) should be treated with layers of coke and common salt to get a lower value of earth resistance.

2 Pouring water in the earth pit at repeated intervals lowers the earth electrode resistance.

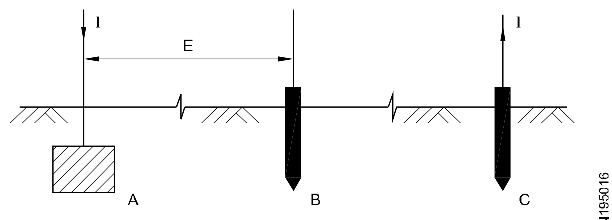
3 Connecting a number of earth electrodes in parallel reduces the earth electrode resistance. (Distance between two adjacent electrodes shall be not less than twice the length of the electrodes.)

4 Soldering the earth connections or using non-ferrous clamps lowers the earth electrode resistance.

5 Avoiding rust in the earth electrode connections lowers the earth electrode resistance.

Method of earth resistance measurement: To measure the earth electrode resistance, the earth electrode is preferably disconnected from the installation. Then two spikes (the current and pressure spikes) are to be driven into the ground at a straight line at a distance of 25 metres and 12.5 metres respectively from the main electrode under test. The pressure and current spikes and the main electrode need to be connected to the instrument (Fig 6)

Fig 6



FALL OF POTENTIAL METHOD

The earth tester has to be placed horizontally and is rotated at a rated speed (normally 160 r.p.m). The resistance of the electrode under test is directly read on the calibrated dial. To ensure correct measurement, the spikes are placed at a different position around the electrode under test, keeping the distance the same as in the first reading. The average of these readings is the earth resistance of the electrode.

<u>I.E. Rules pertaining to earthing</u>

Earthing shall generally be carried out in accordance with the requirements of Indian Electricity Rules 1956, as amended from time to time, and the relevant regulations of the electricity supply authority concerned. The following

Indian Electricity Rules are particularly applicable to both system and equipment earthing: 32,51,61,62,67,69,88(2) and 90.

Extracts from Indian Electricity Rules, 1956

Rule no. 32: **Identification of earthed and earthed neutral conductors and position of switches and cut-outs therein.**

Rule no.51: **Provisions applicable to medium, high or extra high voltage installations**

Rule no.61: **Connection with earth**

1 The following provisions shall apply to the connection with earth of systems at low voltage in cases where the voltage between phases or outers normally exceeds 125 volts and of systems at medium voltage.

Rule no.62: **Systems at medium voltage**

Where a medium voltage supply system is employed, the voltage between earth and any conductor forming part of the same system shall not, under normal conditions, exceed low voltage.

Rule no.67: **Connection with earth**

1 The following provisions shall apply to the connection with earth of three-phase systems for use at high or extra-high voltages:-

In the case of star-connected with earthed neutrals or delta-connected systems with earthed artificial neutral point

Rule no.69: **Pole type substations**

1 Where platform type construction is used for a pole type substation and sufficient space for a person to stand on the platform is provided, a substantial hand rail shall be built around the said platform, and if the hand rail is of metal, it shall be connected with earth:

Provided that in the case of pole type substation on wooden support and wooden platform the metal hand-rail shall not be connected with earth.

Rule no.88: **Guarding**

1 Every guard-wire shall be connected with earth at each point at which its electrical continuity is broken.

Rule no.90: **Earthing**

1 All metal support of overhead line and metallic fittings attached thereto, shall be permanently and efficiently earthed. For this purpose a continuous earth wire shall be provided and securely fastened to each pole and connected ordinarily at four points in every mile or 1.601 km, the spacing between the points being as nearly equidistant as possible. Alternatively, each support and metallic fitting attached thereto shall be efficiently earthed.

2 Each stay-wire shall be similarly earthed unless an insulator has been placed in at a height not less than 10 ft. from the ground.

Grid/Mesh earthing (Fig 7): The substation earthing system comprises of a grid (earth mat) formed by a horizontal buried conductors.

Fig 7

The grounding system in substation is very important. The functions of grounding systems or earth mat in include:

- Ensure safety to personnel in substations against electrical shocks.
- Provide the ground connection for connecting the neutrals of stat connected transformer winding to earth (neutral earthing).
- Discharge the overvoltages from overhead ground wires or the lightning masts to earth. To provide ground path for surge arresters.
- Provide a path for discharging the charge between phase and ground by means of earthing switches.
- To provide earth connections to structures and other non-current carrying metallic objects in the sub-station (equipment earthing).

In addition to such a grid below ground level, earthing spikes (electrodes) are driven into the ground. They are connected electrically to the earth grid, equipment bodies, structures, neutrals, etc. All these are connected to the station earthing system by earthing strips.

If the switchyards have a soil of low resistivity, earth resistance of the earthing system would be low. If the soil resistivity is high, the mesh rods are laid at closer spacing. More electrodes are inserted in the ground.

Earth Mat in 110kV side of a 220/110 kV Substation. (Fig 8)

The fence, equipment body, tanks, support, structures, towers, structural steelworks, water pipes, etc. should be earthed.

Fig 8

DC generator - principle - parts - types - function - e.m.f. equation

Objectives: At the end of this lesson you shall be able to
- **state the general concepts of rotating electrical machine**
- **state the principle of the DC generator**
- **explain the faraday's of laws of electro magnetic induction**
- **explain the production of dynamically induced e.m.f., its magnitude and direction**
- **describe the parts of a DC generator and their function**
- **classify and identify the different type of generators and their terminal markings**
- **explain the armature circuit resistance and its relation**
- **derive the emf equation and calculation of a DC generator**
- **explain about separately excited DC generator with different types of windings.**

General concept of rotating electrical machine

In rotating machines, there are two parts, the stator and rotor. Rotating Power machines are also of two types - DC and AC machines. Power machines are widely used. In DC machines the stator is used as a field and the rotor is used as an armature, while reverse is the case for AC machines. That is synchronous generators and synchronous motors. The induction motor is another kind of AC machine, which is singly excited; that is AC supply voltage is only given to the stator and no supply is given to the rotor. In DC machines and synchronous machines, the field is always excited.

Generator:An Power generator is a machine which converts mechanical energy into Power energy.

Principle of the generator:To facilitate this energy conversion, the generator works on the principle of Faraday's Laws of Electromagnetic Induction.

Faraday's Laws of Electromagnetic Induction: There are two laws.

The first law states:

First law: Whenever the flux linking to a conductor or circuit changes, an emf will be induced.

The second law states: The magnitude of such induced emf depends upon the rate of change of the flux linkage.

$$\text{emf} \propto \frac{\text{Change of flux}}{\text{Time taken for change}}.$$

Types of emf: According to Faraday's Laws, an emf can be induced, either by the relative movement of the conductor and the magnetic field or by the change of flux linking on a stationary conductor.

Production of dynamically induced emf: Whenever a conductor cuts the magnetic flux, a dynamically induced emf is produced in it. This emf causes a current to flow if the circuit of the conductor is closed.

For producing dynamically induced emf, the requirements are:

- magnetic field
- conductor
- relative motion between the conductor and the magnetic field.

If the conductor moves with a relative velocity 'v' with respect to the field, then the induced emf `E' will be

E = BLV Sinθ Volts

where

B = magnetic flux density, measured in tesla

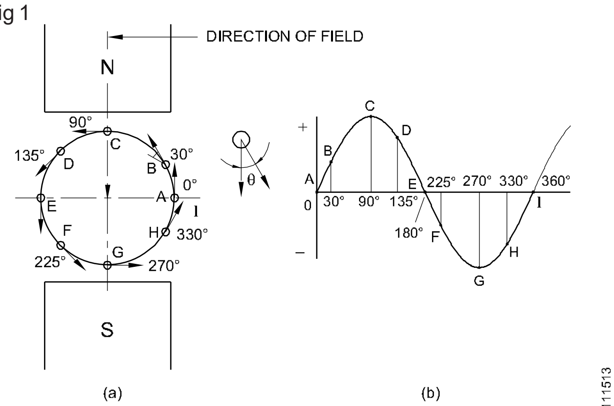
L = effective length of the conductor in the field in metres

V = relative velocity between field and conductor in metre/second

θ = the angle at which the conductor cuts the magnetic field.

Let us consider Fig 1a in which conductors A to I are placed on the periphery of the armature under magnetic poles. Assume for this particular generator shown in Fig 1a, the value of BLV = 100V.

Fig 1



PRODUCTION OF THE SINEWAVE

Accordingly the conductor A induces an emf

= BLV Sin θ where θ = zero and Sin zero is equal to zero

= 100 x 0 = zero.

emf induced in

Conductor B = BLV Sin 30°

= 100 x 0.50

= 50 volts.

emf induced in

Conductor C = BLV Sin 90°

= 100 x 1

= 100 V.

emf induced in

Conductor D = BLV Sin 135°

= BLV Sin 45°

= 100 x 0.707

= 70.7 volts.

emf induced in

Conductor E = BLV Sin 180°

= Sin 180°= 0

= 100 x 0

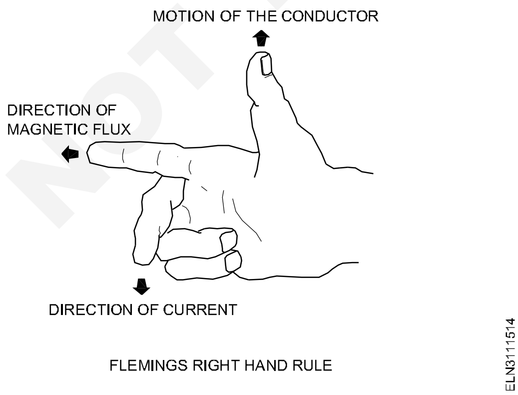
= zero.

Likewise for every position of the remaining conductors in the periphery, the emf induced could be calculated. If these values are plotted on a graph, it will represent the sine wave pattern of induced emf in a conductor when it rotates under N and S poles of uniform magnetic field.

As in Fig 1b the emf induced by this process is basically alternating in nature, and this alternating current is converted into direct current in a DC generator by the commutator.

Fleming's right hand rule: The direction of dynamically induced emf can be identified by this rule. Hold the thumb, forefinger and middle finger of the right hand at right angles to each other as shown in Fig 2 such that the forefinger is in the direction of flux and the thumb is in the direction of the motion of the conductor, then the middle finger indicates the direction of emf induced, i.e. towards the observer or away from the observer.

Fig 2

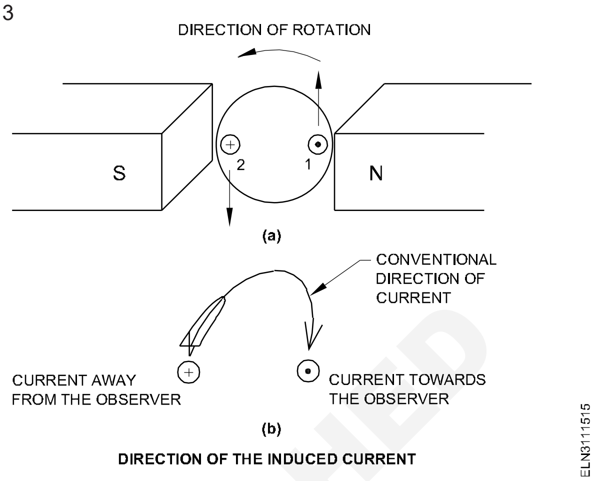


FLEMINGS RIGHT HAND RULE

Imagine a conductor moving in between north and south poles in an anticlockwise direction as shown in Fig 3a.

Applying Fleming's right hand rule, we find that the conductor 1 which is moving upwards under the north pole will induce an emf in the direction towards the observer indicated by the dot sign and the conductor 2 which is moving down under the south pole will induce an emf in the direction away from the observer indicated by the plus sign.

Fig 3



DIRECTION OF THE INDUCED CURRENT

Fig 3b indicates the current direction in the form of an arrow. The dot sign indicates the pointed head of the arrow showing the current direction towards the observer and the plus sign indicates the cross-feather of the arrow showing the current direction away from the observer.

Parts of DC generator

A DC generator consists of the following essential parts as shown in Fig 6.

1 Frame or yoke

2 Field poles and pole-shoes

3 Field coils or field winding

4 Armature core

5 Armature windings or armature conductors

6 Commutator

7 Brushes

8 Bearings and end plates

9 Air filter for fan

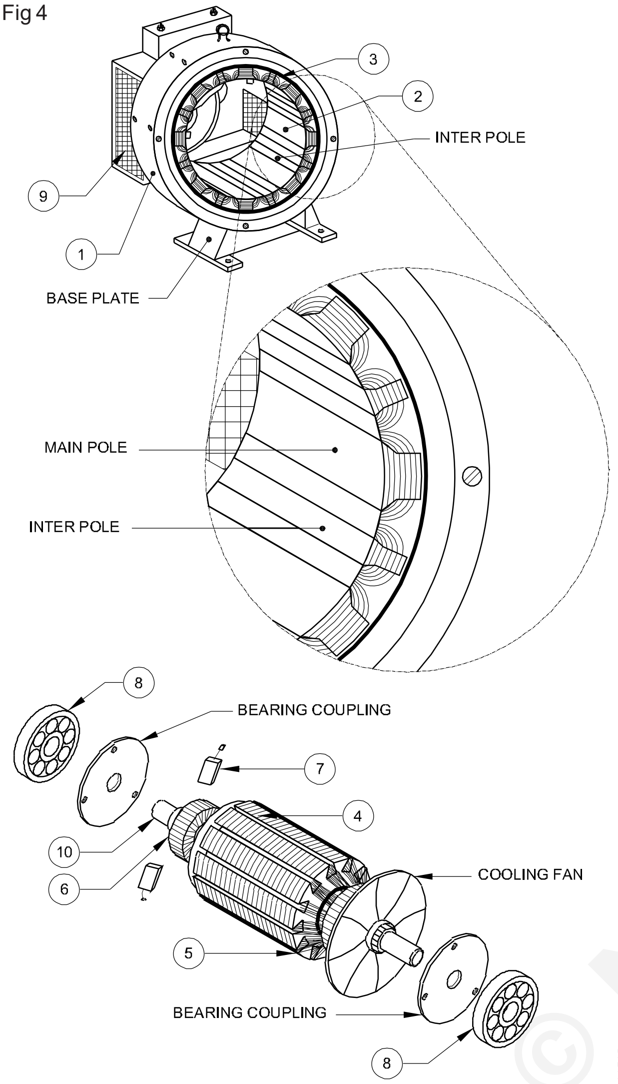
10 Shaft

The yoke, the pole cores, the armature core and the air gaps between the poles and the armature core form the magnetic circuit, whereas the armature conductors, field coils, commutators, and brushes form the Power circuit.

Yoke: The outer frame or yoke serves a dual purpose. Firstly, it provides mechanical support for the poles and acts as a protecting cover for the whole machine as shown in Fig 4. Secondly, it allows the magnetic circuit to complete through it.

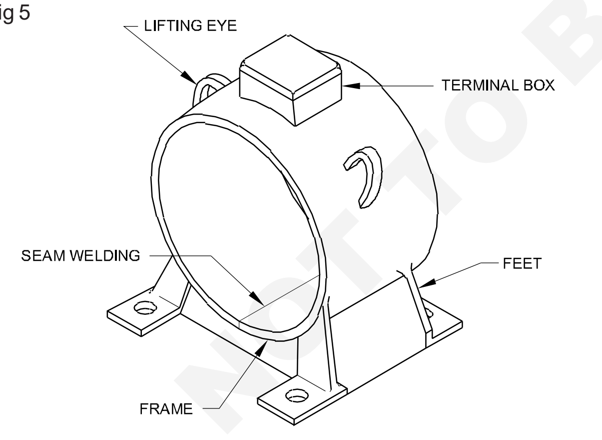
The feet, the terminal box etc. are welded to the frame afterwards as shown in Fig 5. Such yokes possess sufficient mechanical strength and have high permeability.

Fig 4



PARTS OF A DC MACHINE

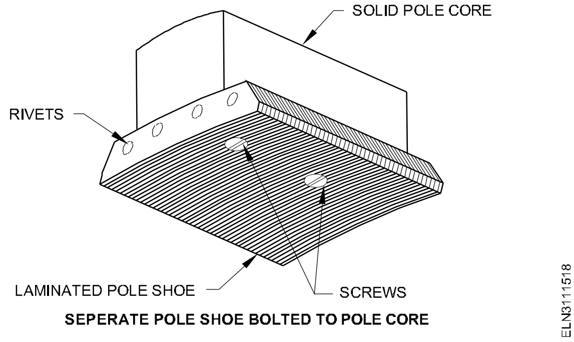
Fig 5



YOKE

Poles cores and pole shoes (Fig 6): The field magnets consist of pole cores and pole shoes. The pole shoes serve two purposes; (i) they spread out the flux in the air gap uniformly and also, being of a larger cross-section, reduce the reluctance of the magnetic path, and (ii) they also support the field coils.

Fig 6

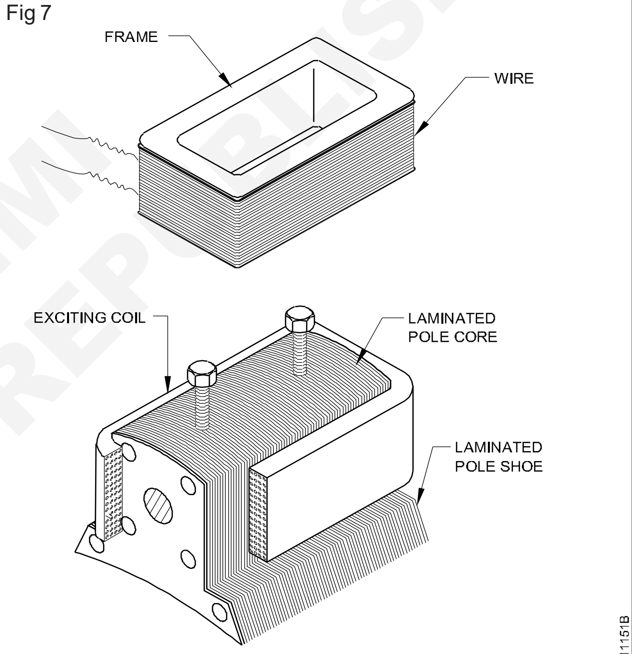


SEPERATE POLE SHOE BOLTED TO POLE CORE

Pole coils (Field coils): The field coils or pole coils, which consist of copper wire or strip are former-wound for the correct dimension. Then the former is removed and the wound coils are put into place over the core as shown in Fig 7.

When a current is passed through the coils, they magnetise the poles which produce the necessary flux that is cut by revolving armature conductors.

Fig 7



POLE ASSEMBLY

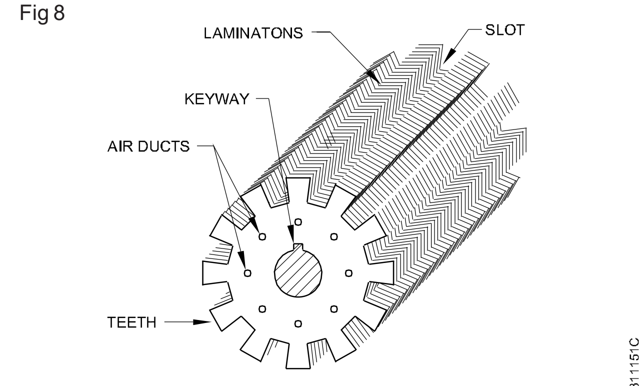
Armature core: The armature core houses the armature conductors and rotate in the magnetic field so as to make the conductors to cut the magnetic flux.

The armature core is cylindrical or drum-shaped as shown in Fig 8, and build up of circular sheet steel discs or laminations approximately 0.5mm thick as shown in Fig 9.

The slots are either die-cut or punched on the outer periphery of the disc and the keyway is located on the inner diameter as shown. In small machines, the armature stampings are keyed directly to the shaft.

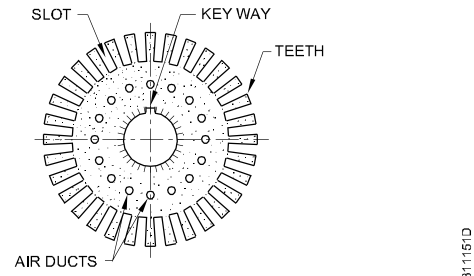
The purpose of using lamination is to reduce the loss due to eddy currents. Thinner the laminations are, greater the resistance offered against eddy current loss.

Fig 8



ARMATURE CORE MADE OF LAMINATION

Fig 9



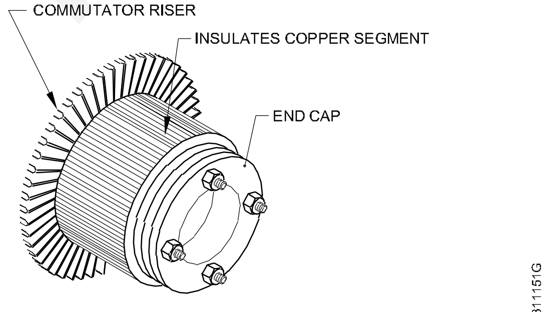
ARMATURE CORE LAMINATIONS

Armature windings: The armature windings are usually former-wound. These are first wound in the form of flat rectangular coils and are then pulled into their proper shape with a coil puller. Various conductors of the coils are insulated from each other. The conductors are placed in the armature slots which are lined with tough insulating material. After placing the conductors in the slot, this slot insulation is folded over the armature conductors, and is secured in place by special, hard, wooden or fibre wedges.

Commutator: The function of the commutator is to facilitate collection of current from the armature conductors. It rectifies i.e. converts the alternating current induced in the armature conductors into uni-directional current for the external load circuit. It is of cylindrical structure and is built up of wedge-shaped segments of high conductivity, hard-drawn or drop-forged copper. These segments are insulated from each other by thin layers of mica. The number of segments is equal to the number of armature coils. (Fig 10)

Brushes: The brushes whose function is to collect current from the commutator are usually made of carbon and graphite and are in the shape of a rectangular block.

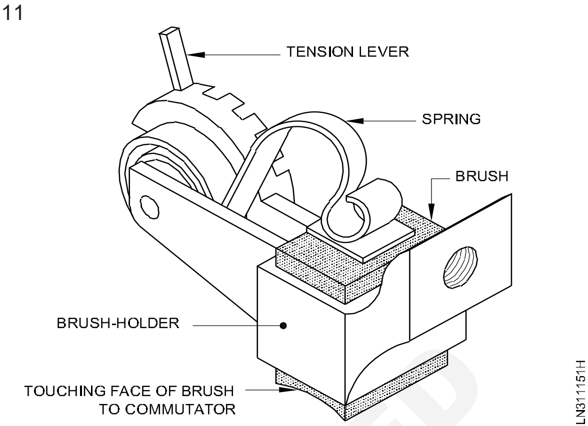
Fig 10



COMPLETE ASSEMBLY OF COMMUTATOR

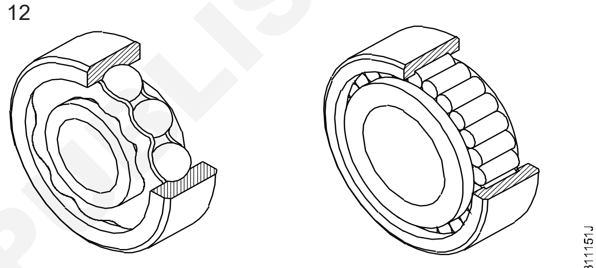
These brushes are housed in brush-holders, shown in Fig 11, which have a box-holder for the brush, a spring to maintain the brush tension and a hole to fix the holder to the rocker arm.

Fig 11



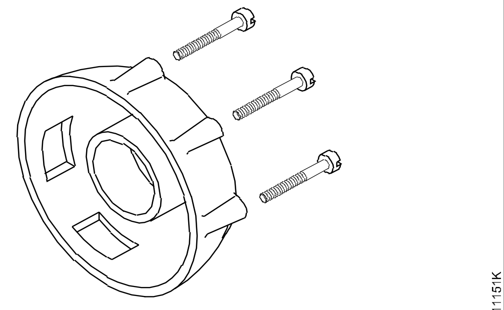
Bearings (Fig 12): The ball and rollers are generally filled with hard oil for quieter operation and for reduced bearing wear. .

Fig 12



End plates (Fig 13): The bearings are housed in these end plates, and they are fixed to the yoke. They help the armature for frictionless rotation and to position the armature in the air gap of the field poles.

Fig 13



END PLATE 2-OFF

Cooling fan: In most cases, heat dissipation is achieved through a cooling fan fitted on the DC Machine shaft.

Types of DC generators: The type of a DC generator is determined by the manner in which the field excitation is provided. In general, the methods employed to connect the field and armature windings, fall into the following groups.(Fig 14)

Separately excited generator: The field excitation for a separately excited generator, shown in Fig 15, is supplied from an independent source, such as storage battery, separate DC generator or rectified DC supply from an AC source.

Fig 14

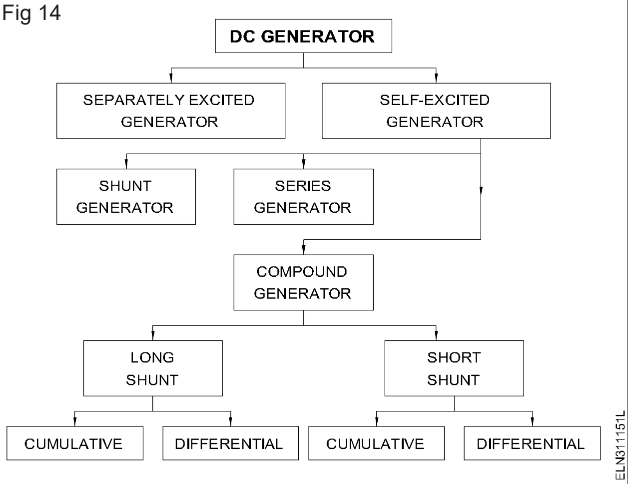
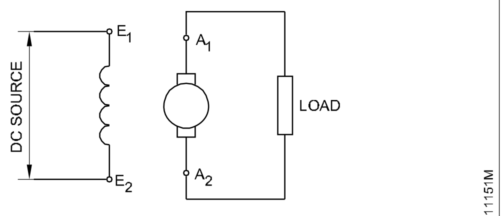


Fig 15

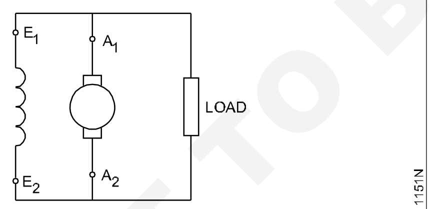


CONNECTION DIAGRAM OF SEPARATELY EXCITED DC GENERATOR

Self-excited generator: The field excitation is provided by its own armature. In this type of generators, initially the voltage is built up by residual magnetism retained in the field poles. Self-excited generators may be further classified as shunt, series and compound generators.

Shunt generator: The field winding is connected to the armature terminals as shown in Fig 16. (i.e. shunt field winding is connected in parallel with armature winding). The shunt field contains many turns of relatively fine wire and carries a comparatively small current only which is a small percentage of the rated current of the generator.

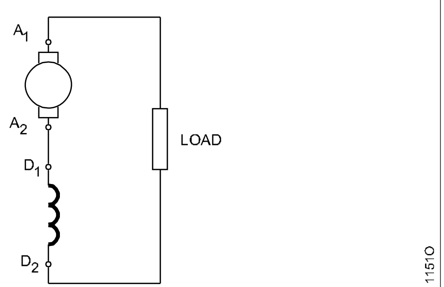
Fig 16



SHUNT GENERATOR

Series generator: The field winding is connected in series with the armature winding as shown in Fig 17. The series field winding has a few turns of heavy wire. Since it is in series with the armature it carries the load current.

Fig 17

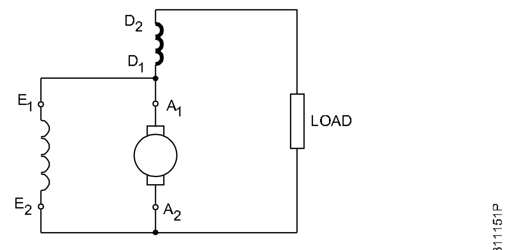


SERIES GENERATOR

Compound generator: The field excitation is provided by a combination of shunt and series field windings.

Short-shunt compound generator: This is a generator in which the shunt field is directly across the armature as shown in Fig 18.

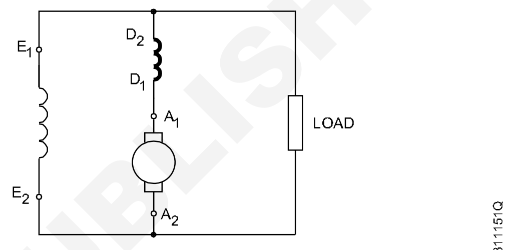
Fig 18



SHORT SHUNT COMPOUND GENERATOR

Long-shunt compound generator: This is a generator in which the shunt field is connected after the series field as shown in Fig 19.

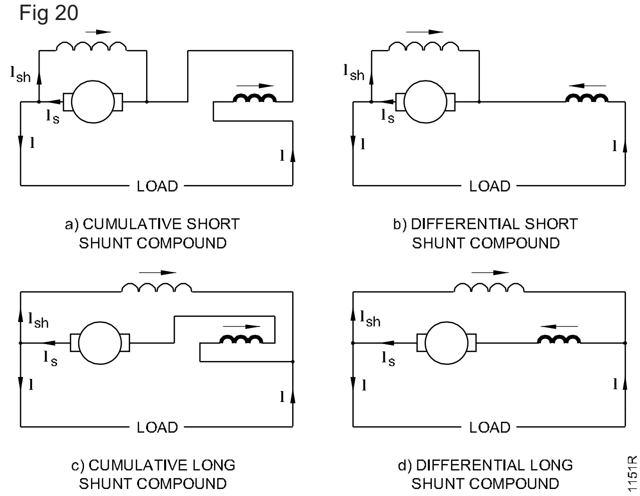
Fig 19



LONG SHUNT COMPOUND GENERATOR

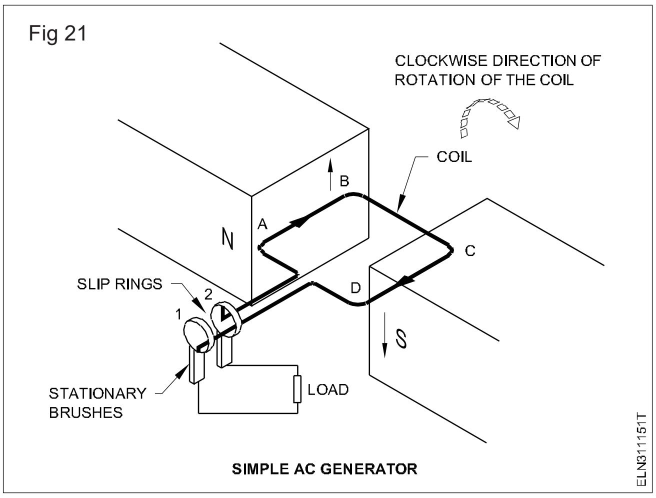
Differential and cumulative compound generator: The compound generators can also be further classified as cumulative and differential. In cumulative compound generators the magnetising forces of the shunt and the series field ampere-turns are cumulative, i.e. they both tend to set up flux in the air gap in the same direction. However, in case the ampere turns of the shunt widning oppose those of the series winding, the machine is said to be differentially compound wound generator. Both the types are shown in Fig 20.

Fig 20



TYPES OF DC COMPOUND GENERATORS

Slip rings: Let us consider a simple AC generator having a single loop of wire and rotated within a fixed magnetic field, as shown in Fig 21.



SIMPLE AC GENERATOR

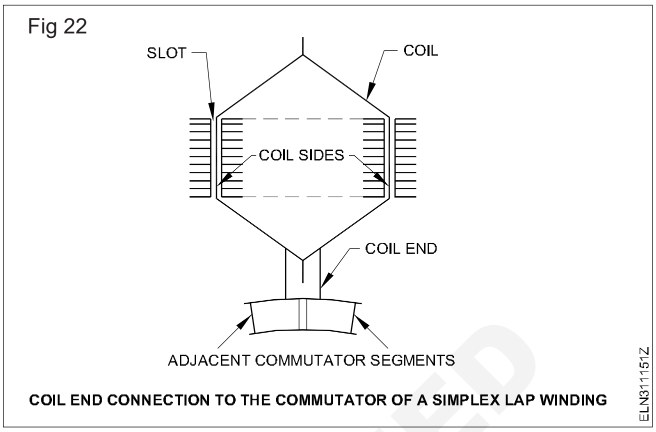
The current in the externally connected load resistor via the stationary brushes in contact with the pair of **slip rings** `1'and `2' will be alternating (AC) in nature.

Armature windings (Fig 22 Lap winding, Fig 23 wave winding): There are several coils in the armature, each with a large number of turns laid in the slots of the armature core. This arrangement of the coil is called armature winding. The ends of the coils are soldered to the commutator raisers, depending on the kind of winding i.e. lap or wave, which decides the number of parallel paths in the armature.

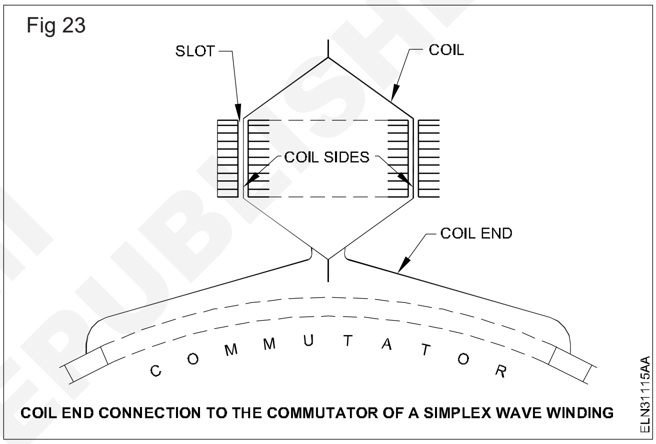
i.e. lap or wave, which decides the numbers of parallel paths in the armature.

A preliminary knowledge about the different types of winding is essential to tackle problems related to the calculation of induced voltage in various types of generators.

As shown in Fig 22, in a simplex lap winding, the ends of a coil are connected to adjacent commutator segments. Fig 23 shows the simplex wave winding in which the coil ends are connected to the commutator segments almost equal to the distance between poles of the same polarity.



COIL END CONNECTION TO THE COMMUTATOR OF A SIMPLEX LAP WINDING



COIL END CONNECTION TO THE COMMUTATOR OF A SIMPLEX WAVE WINDING

Table 1 shows the main differences between lap and wave winding.

Table 1

Lap winding	Wave winding
The two ends of each armature coil are connected to adjacent commutator segments in the case of simplex, two segments apart in duplex and three segments apart in triplex.	The two ends of each coil connect to the commutator segments placed between adjacent poles of the same polarity.
There are many parallel paths for current as there are field poles in the case of lap winding	There are two parallel paths regardless of the number of field poles in the case of simplex wave winding.
No. of parallel paths = Number of poles x plex of the winding	Number of parallel paths in wave windings = 2 x plex of the winding where plex for-simplex is 1, duplex is 2 and triplex is 3.
The number of brush positions is equal to the number of poles.	Only two brush positions are required regardless of the number of field poles.
Used for machines having low voltage and high current capacity.	Used in machines having low current and high voltage capacity.

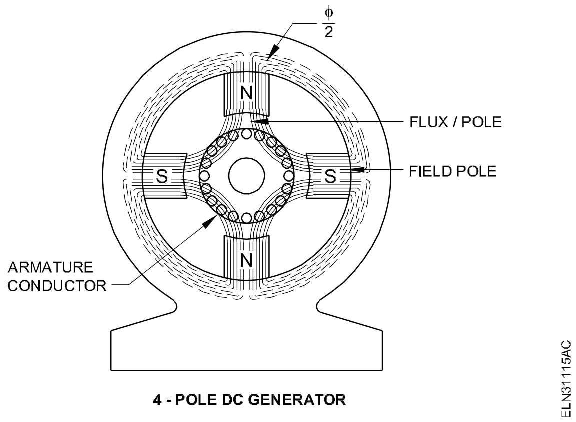
EMF equation of DC generator

When the armature of a DC generator, containing a number of conductors in the form of a winding, rotates at a specific speed in the magnetic field, emf is induced in the armature winding and is available across the brushes. The equation and the numerical problems given as examples will help an electrician to better his understanding about the construction of a DC machine.

Induced emf in a DC generator can be calculated as explained below.

Figure 24 is given for your reference.

Fig 24



Let $Ø$ = flux/pole in weber

Z = total number of armature conductors = No. of slots x No.of conductors/slot

P = No. of poles in the generator

A = No. of parallel paths in armature

N = armature revolution per minute (r.p.m.)

E = emf induced in the generator.

Average emf generated per conductor in one revolution = Rate of change of flux (Faraday's Laws of Electromagnetic induction

$$\frac{dØ}{dt} \text{ volt (since N = 1)}$$

Now, flux cut/conductor in one revolution, (dØ) = PØ Wb

No. of revolutions/second = N/60

Time for one revolution, (dt) = 60/N second

According to Faraday's Laws of Electromagnetic Induction, we have emf generated/conductor/second

$$= \frac{dØ}{dt} = \frac{PØN}{60} \text{ volts}$$

emf generated in `Z'conductors in the armature assuming they are all in series $= \frac{PØZN}{60}$ volts.

The emf generated in the armature of the DC generator when there are `A' parallel paths in the armature

$$= \frac{PØZN}{60\,A} \text{ volts.}$$

Could be written as $= \frac{ØZN}{60} \times \frac{P}{A}$ volts.

A = 2 - for simplex wave winding

= P - for simplex lap winding.

Example: An 8-pole DC generator has 960 armature conductors and a flux per pole of 20mWb running at 500 r.p.m. Calculate the emf generated when the armature is connected as (i) a simplex lap-winding, (ii) a simplex wave winding.

Solution

(i) Simplex lap winding

$$E = \frac{ØZN}{60} \times \frac{P}{A}$$

$$E = \frac{20 \times 10^{-3} \times 960 \times 500}{60} \times \frac{8}{8} = 160V.$$

(ii) Simplex wave winding

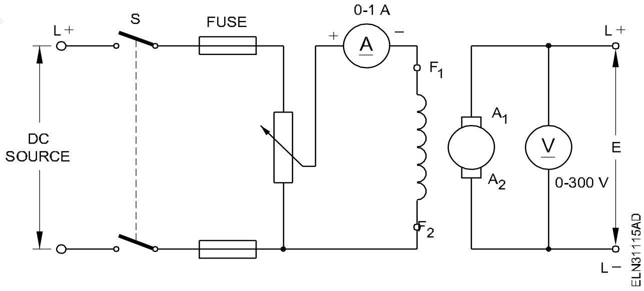
$$E = \frac{20 \times 10^{-3} \times 960 \times 500}{60} \times \frac{8}{2} = 640V.$$

Separately excited DC generator

Introduction: A DC generator is the most commonly used separately excited generator, used for electroplating and battery charging. A separately excited generator is one in which the magnetic field is excited from an external DC source. The DC source may be a DC generator or a battery or a metal rectifier connected to an AC supply. Generally a potential divider is connected across the DC source, and the required DC voltage is supplied to the field as shown in Fig 25.

An ammeter is connected in the field circuit to measure the field current. The shaft of the generator is coupled to a prime mover. (Not shown in Fig 25)

Fig 25



Advantages of a separately excited generator: The terminal voltage remains almost stable when compared to the self-excited generators because the field circuit is independent of the induced voltage.

As the field is independent, the I_aR_a drop in the armature will not affect the field flux.

This generator can be used where a wide range of terminal voltage is required.

Disadvantage

1 The disadvantage of a separately excited generator is the inconvenience of providing a separate DC source for excitation.

2 Besides it is expensive.

Building up of a DC shunt generator

Objectives: At the end of this lesson you shall be able to
- **explain the conditions and method of building up of voltage in a DC shunt generator**
- **explain the method of creating residual magnetism in the poles of a DC generator**
- **determine the magnetization characteristic of a DC shunt generator**
- **estimate the value of field critical resistance in the DC shunt generator.**

Condition for a self-excited DC generator to build up voltage: For a self-excited DC generator to build up voltage, the following conditions should be fulfilled, assuming the generator is in sound condition.

- There must be residual magnetism in the field cores.
- The field resistance should be below the field critical resistance value.
- The generator should run at the rated speed.
- There must be a proper relation between the direction of rotation and the direction of field current. It could be explained as stated below.

The polarity of the induced voltage must be in such a direction as to produce the field current to assist the residual magnetism.

The polarity of the induced emf depends upon the direction of rotation and the polarity of the field poles depends upon the field current direction.

Even after fulfilling the above conditions, if the self-excited DC shunt generator fails to build up voltage, there may be other reasons as listed in Table 1.

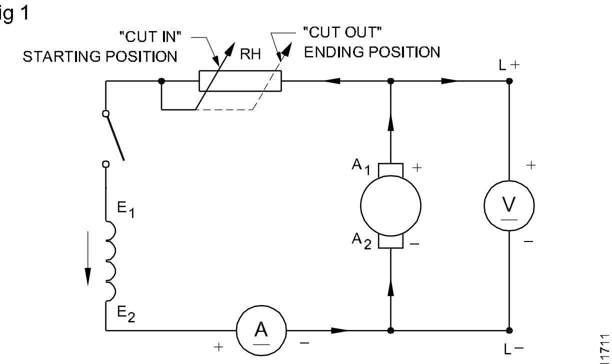
Table 1

Sl.No.	Causes	Reasons	Remedies
1	A break or opening in the field or armature circuit.	Break or loose connection in the field or in the armature winding/circuit.	Locate the open circuit and rectify.
		High resistance in the field circuit beyond the field critical resistance value.	Reduce the resistance of the field regulator.
2	Loose brush connections or contacts.	Improper brush contact/loose brush connections.	Check the brushes for excessive wear, and replace them, if necessary. Check the commutator for pitting. If necessary, turn down the commutator. Always clean the commutator when poor brush contact is discovered. Check the brush tension and readjust it, if necessary Tighten any loose connections.
3	A dirty or severely pitted commutator.	Severe sparking due to overload.	In this case, follow the same procedure as outlined above.
4	A short circuit in the armature or field	Overload or excess heating.	Do a resistance check, ascertain, locate and remove the fault.

Method of building up voltage in a DC shunt generator: Fig 1 shows the circuit diagram for building up voltage in a DC shunt generator. When the generator is made to run at its rated speed initially, the voltmeter reads a small amount of voltage say, 4 to 10 volts. It is due to the residual magnetism. Since the field coils are connected across the armature terminals, this voltage causes a small amount of current to flow through the field coil. If the current flow in the field coils is in the correct direction, it will strengthen the residual magnetism and induce more voltage.

As such, the generated voltage will rise marginally. This rise in voltage, in turn, will further strengthen the increasing field current and induce more voltage. This cumulative action will build up voltage until saturation is reached.

Fig 1



DC SHUNT GENERATOR

After saturation, any increase in the field current will not increase the induced voltage. However, the whole procedure of building up of voltage takes a few seconds only.

Method of creating residual magnetism: Without residual magnetism, a self-excited generator will not build up its voltage. A generator may lose its residual magnetism due to any one of the following reasons.

– The generator is kept idle for a long time.

– Heavy short circuit.

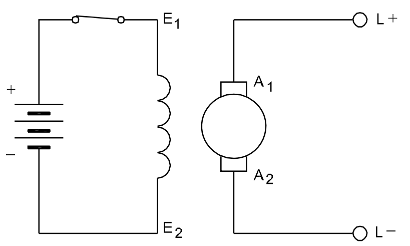
– Heavy overloading.

– The generator is subjected to too much heat.

When the generator loses its residual magnetism, it can be re-created as stated below.

Flashing of field: One of the methods to create residual magnetism is called the flashing of the `field'. This can be done by connecting the shunt field across a battery or any DC source for a few minutes as shown in Fig 2.

Fig 2



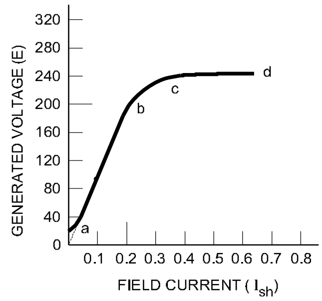
FLASHING OF THE FIELD

While flashing the field, the polarity of the magnetic field, now created, should be the same as that of the residual magnetic field it lost earlier.

In practice, this checking may not be possible. Alternatively note the polarity of the DC supply used for flashing the field and the corresponding field terminals. Run the generator in the specified direction at its rated speed. Measure the residual voltage induced and its polarity. Check whether the polarity of the residual voltage is the same as that of the DC generator. If found reversed, flash the field again by connecting the supply voltage in reverse polarity.

Magnetisation characteristic of a DC shunt generator: The magnetisation characteristic curve shown in Fig 3 gives the relation between the field current and the induced voltage. Referring to the emf equation, the induced emf in a generator is proportional to the flux per pole and the revolutions per minute of the generator. At a constant speed, the generated emf becomes directly proportional to the field flux. In a given machine, the flux depends upon the field current. The graph (Fig 3) illustrates this feature. Because of the residual magnetism, the curved part below point `a' does not start at zero. Between the points `ab', the curve is in almost a straight line indicating that the voltage in the area is proportional to the field current. Between points `b' and `c' a large increase in field current causes only a slight increase in the voltage. It indicates that the field cores are reaching saturation and this part of the curve is called the `knee' of the curve. Between points `c' and `d', the curve is flat indicating that the increased field current is not able to increase the induced voltage. This is due to saturation of the field cores. Because of saturation, the field flux becomes constant, and the induced voltage will not be in a position to increase further. This curve is also called a no-load or open-circuit characteristic curve.

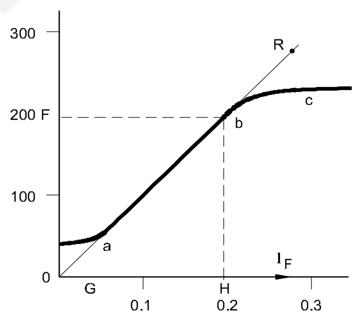
Fig 3



MAGNETISATON CHARACTERISTIC OF A DC SHUNT GENERATOR

Critical resistance: If the shunt field circuit resistance is too large, it does not allow sufficient current to flow into the field to build up its voltage. In other words, it acts like an open field. Therefore, the field circuit resistance should be smaller than a value called critical field resistance. Critical field resistance is the highest value of resistance of the shunt field circuit with which a DC shunt generator can build up voltage. Beyond this value of resistance, the generator fails to build up voltage. The value of the critical resistance can be determined by drawing a tangential line to the open circuit characteristic curve. (Fig 4)

Fig 4



FIELD CRITICAL RESISTANCE

For example, by drawing the tangent on the open-circuit characteristic curve as shown by line OR of Fig 4, we find the tangent is parting at point `b' from the curve. By drawing ordinates from point `b' to x and y axis, the value of critical resistance (R_c) can be determined as below.

R_c = Field critical resistance

$$= \frac{\text{voltage represented by the tangent}}{\text{current represented by the tangent}}$$

$$= \frac{OF}{OH} = \frac{200\ V}{0.2\ A} = 1000\ \text{ohms.}$$

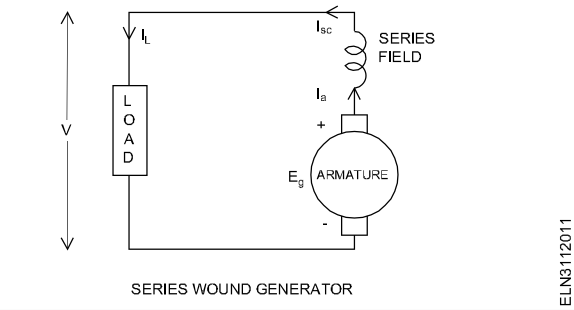
Field circuit resistance is the sum of the field resistance and field rheostat resistance. This value should be less than, say 1000 ohms (field circuit resistance) to enable the generator to build up voltage, if the generator is intended to self-excite. Normally this happens when the field regulator resistance is set at a high value.

Characteristics of DC generator

Objectives: At the end of this lesson you shall be able to
- **explain the characteristic of DC series generator, DC shunt generator, DC compound generator**
- **explain the operation of paralleling of DC shunt generators**
- **explain the effect of armature reaction and remedies**
- **explain losses and efficiency of DC generators**
- **explain the routine and maintenance of DC generator.**

Characteristics of series generator: In these types of generators the field windings, armature windings and external load circuit all are connected in series as shown in Fig 1.

Fig 1



SERIES WOUND GENERATOR

Therefore, the same current flows through armature winding, field winding and the load. Let, $I = I_a = I_{sc} = I_L$ Here, I_a = armature current I_{sc} = series field current I_L = load current There are generally three most important characteristics of series wound DC generator which show the relation between various quantities such as series field current or excitation current, generated voltage, terminal voltage and load current.

Magentic or open circuit characteristic of series wound DC generator

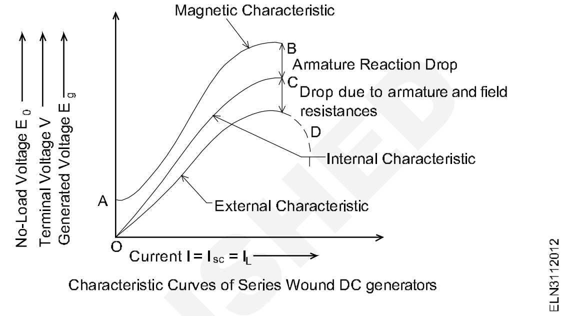
The curve which shows the relation between no load voltage and the field excitation current is called magnetic or open circuit characteristic curve. As during no load, the load terminals are open circuited, there will be no field current in the field since, the armature, field and load are series conected and these three make a closed loop of circuit. So, this curve can be obtained practically by separating the field winding and exciting the DC generator by an external source.

Here in the diagram below AB curve is showing the magnetic characteristic of sereis wound DC generator. The linearity of the curve will continue till the saturation of the poles. After that there will be no further significant change of terminal voltage of DC generator for increasing field current. Due to residual magnetism there will be a small initial voltage across the armature that is why the curve started from a point A which is a little above the origin O.

Internal characteristic of series wound DC generator

The internal characteristic curve gives the relation between voltage generated in the armature and the load current. This curve is obtained by subtracting the drop due to the demagnetizing effect of armature reaction from the no load voltage. So, the actual generated voltage (E_g) will be less than the no load voltage (E_0). That is why the curve is slightly dropping from the open circuit characteristic curve. Here in the diagram below OC curve is showing the internal characteristic or total characteristic of the series wound DC generator. (Fig 2)

Fig 2



Characteristic Curves of Series Wound DC generators

External characteristic of series wound DC generator: The external characteristic curve shows the variation of terminal voltage (V) with the load current (I_L). Terminal voltage of this type of generator is obtained by subtracting ohmic drop due to armature resistance (R_a) and series field resistance (R_{sc}) from the actually generated voltage (E_g). Terminal voltage $V = E_g - I(R_a + R_{sc})$ The external characteristic curve lies below the internal characeristic curve because the value of terminal voltage is less than the generated voltage. Here in the Figure 2 OD curve is showing the external characteristic of the series wound DC generator

The external/load characteristic of a shunt generator: The external/load characteristic is important for judging the suitability of a generator for a particular purpose. When the DC shunt generator is loaded, it is found that the terminal voltage drops with increase in the load current. In a shunt generator, the field current appears to be constant, and, hence, `V' also should remain constant and be independent of the load. But, it is not so practically. There are two main reasons for the drop in terminal voltage. They are :

- armature resistance drop (directly)
- armature reaction drop (indirectly).

Because of the above two reasons, the terminal voltage is reduced. This in turn affects the field current also. The decreased field current reduces the field flux which further reduces the induced emf.

Armature resistance drop: According to formula

Terminal voltage = Induced emf – armature voltage drop

$V = E - I_a R_a$

where I_a is the armature current

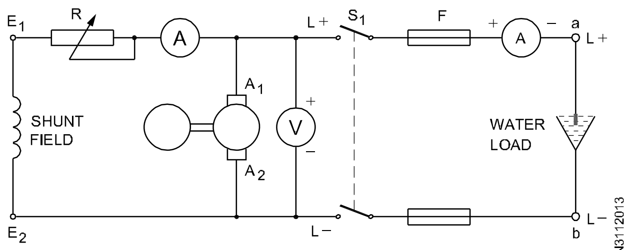
and R_a is the armature circuit resistance.

As such, when the load current is increased, more voltage is dropped in the armature circuit. Hence, the terminal voltage `V' decreases, under load condition.

Armature reaction drop: Due to the demagnetising effect of armature reaction, the main pole flux is weakened, and the induced emf (E) will be reduced in its magnitude.

The external characteristic gives the relation between terminal voltage and load current. Fig 3 gives the circuit diagram to determine this characteristic. The generator is first built up to its rated voltage. Then it is loaded in suitable steps up to full load. The terminal voltage and the corresponding load currents are noted for each step.

Fig 3



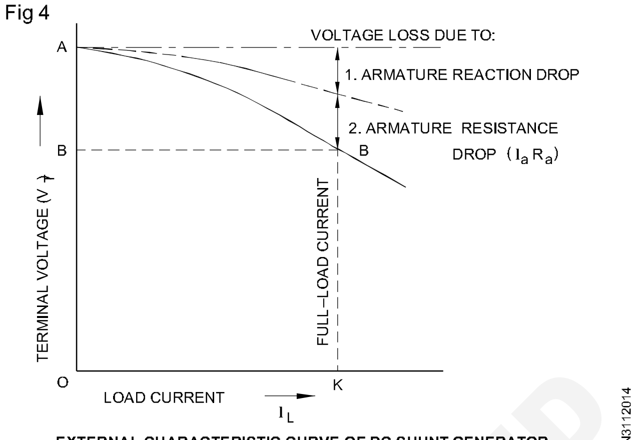
DC SHUNT GENERATOR

In this experiment, the field current has to be kept constant. This is due to the fact that when terminal potential decreases on load, the field which is connected across the armature will have a decreased current. This effect, if allowed, will reduce the field flux, thereby, decreasing the induced voltage. This effect cumulatively reduces the terminal voltage further. From the obtained values of the terminal voltage V_T and load current IL, the external characteristic curve is plotted as shown in Fig 4, keeping in V_T on `Y' axis and I_L on X axis. From the curve it will be observed that the no-load voltage OA is maximum, and it falls to OB when loaded, to indicate that the full load current value is OK as noted in the name-plate of the generator.

Fall of voltage from no load to full load, which is due to armature reaction, and the armature voltage drop are found to be not appreciable. Normally the generators are designed to deliver full load current I_L, and the fall of voltage will be about 5 to 8 percent of the no-load voltage which can be regarded as negligible. If the load current is further increased by decreasing the load resistance, the curve reaches a point `C' as shown in Fig 5. At this point, the terminal voltage falls to OC which will be an appreciable fall when compared to the no-load terminal voltage. At this point `C', though the load current is maximum (OK), the terminal voltage will be much less than the no-load voltage.

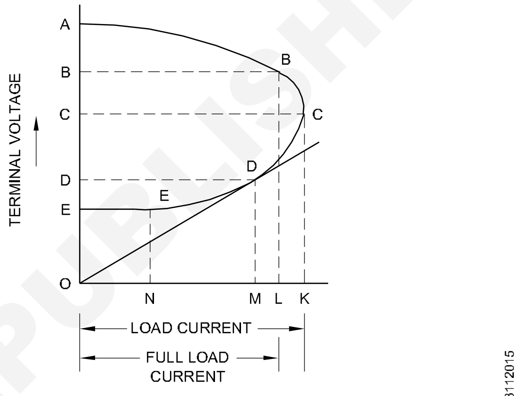
However, when the load resistance is further decreased the load current decreases to OM and V_T is reduced to `OD', that means the load current cannot be increased beyond OK and the point `C' is called the breakdown point. It is the maximum possible current that a generator can supply. Beyond this point `C', the curve drops rapidly with decrease in the load resistance, indicating that the load current is also decreasing, instead of increasing. At point `E' the generator is virtually short-circuited, and all the voltage induced is dropped to near zero due to IaRa drop and armature reaction. Rather, we can say OE is the residual voltage of the generator. Practically all the generators operate only on the portion `AB' of the curve

Fig 4



EXTERNAL CHARACTERISTIC CURVE OF DC SHUNT GENERATOR

Fig 5



EXTERNAL CHARACTERISTIC CURVE (FULL CURVE)

where the efficiency of the generator is maximum.

Internal characteristic: The internal characteristic gives the relation between induced voltage and the armature current. In a shunt generator,

$Ia = I_L + I_{sh}$ $\qquad$ $E = V_T + I_a R_a$

$$I_{sh} = \frac{V_T}{R_{sh}}$$

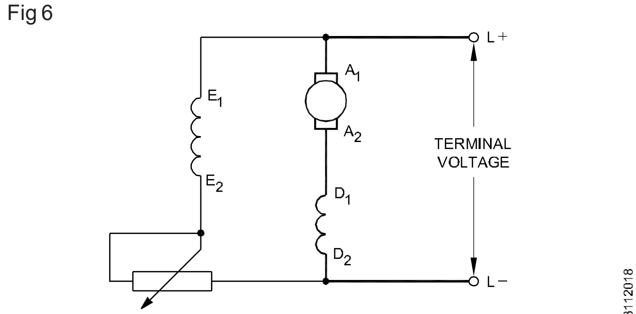
Applications of DC shunt generator: According to the load characteristic of the DC shunt generator, the drop in voltage from no load to full load is not appreciable, up to its rated value of load current. Hence, it can be called a constant voltage generator. Therefore, it can be used for constant loads like:

- centrifugal pump
- lighting load
- fans
- battery charging and electroplating.

Compound generator: Combination of shunt field and series field within one generator provides two sources of excitation, and such a generator is called a compound generator.

Long shunt compound generator: When the shunt field is connected in parallel with the series combination of the armature and the series field, the generator is said to be connected as a long shunt compound generator which is shown in Fig 6.

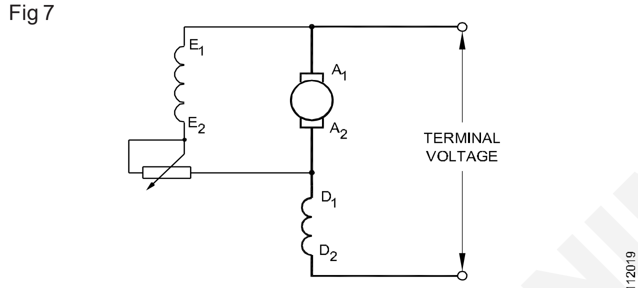
Fig 6



LONG SHUNT COMPOUND GENERATOR

Short shunt compound generator: When the shunt field is connected in parallel with only the armature, the generator is said to be connected as a short shunt compound generator which is shown in Fig 7.

Fig 7

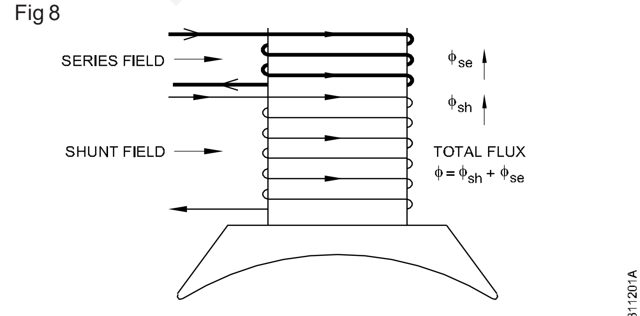


SHORT SHUNT COMPOUND GENERATOR

Cumulative compound generator: The shunt field excitation flux is usually more or less steady, and is affected only slightly as the terminal voltage fluctuates. The flux of the series field is quite variable because its ampere-turns depend upon the load current. When the load current is zero, it produces less flux (long shunt) or no flux (short shunt) and when the load current is high, it creates a good amount of flux. How much flux it must develop depends upon the extent to which it must compensate for the voltage drop. In a compound machine, the series field is wound directly over the shunt field with proper separation by insulations.

The series field coils may be connected to `assist' or `aid' the shunt field, as shown in Fig 8. Then this machine is said to be a cumulative (increasing by successive additions) compound generator. The ampere turns of the series field determines the amount of compounding.

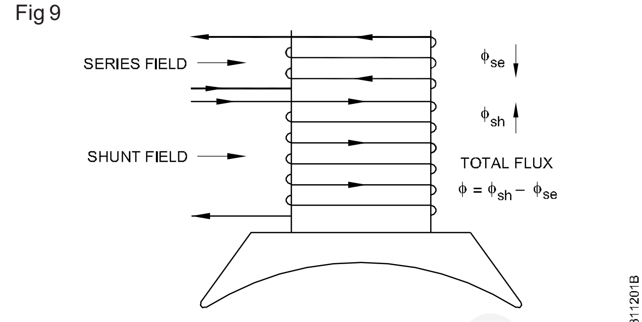
Fig 8



CUMULATIVE COMPOUNDING

Differentially compounded generator: If the flux produced by the series field opposes the shunt field flux as shown in Fig 9, then the action is called `bucking' and the machine is said to be a differential (decreasing by successive subtractions) compound generator.

Fig 9

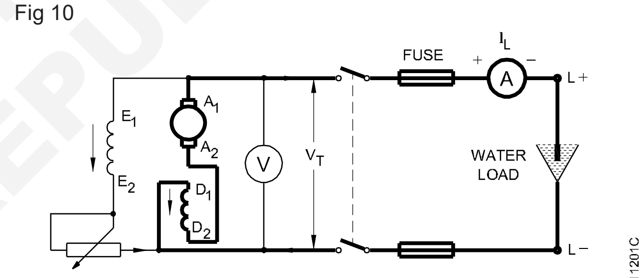


DIFFERENTIAL COMPOUNDING

External characteristics of DC compound generator

Cumulative compound generator: Fig 10 shows the connection diagram for a long shunt cumulative compound generator. In such a connection, the series field aids the shunt field and the total flux is equal to the sum of both the fluxes. By taking a set of readings for different load currents I_L and the corresponding terminal voltage V_T, we can draw a graph showing the relation between V_T and I_L. This curve is called the external characteristic curve.

Fig 10

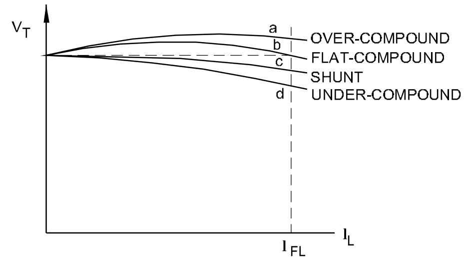


LONG SHUNT CUMULATIVE COMPOUND GENERATOR CONNECTION DIAGRAM

If the shape of the curve is as shown in curve `C' of Fig 11, then it will be the same as the curve shown for the shunt generator, and this generator could be used for constant voltage loads. If the shape of the curve is as shown in curve `a' of Fig 11, it shows that the terminal voltage goes on increasing with an increase of the load current. It is due to the reason that the series ampere-turns produce more flux than the flux required to over come the IaRa drop and the armature reaction. Such a machine is called an over-compounded generator, and this generator could be used for supplying load to long distance distribution lines so that the voltage drop in the line could be compensated by increased voltage.

If the shape of the curve is as shown in curve `b' of Fig 11, it shows that the series ampere-turns at light load are producing more flux than required to overcome the I_aR_a drop but at full load the series field flux is just sufficient to overcome the I_aR_a drop and armature reaction. Such a machine is called a flat (level) compounded generator, and this generator could be used for supplying power to constant loads requiring specified terminal voltage.

Fig 11



EXTERNAL CHARACTERISTICS OF COMULATIVE COMPOUND DC GENERATORS

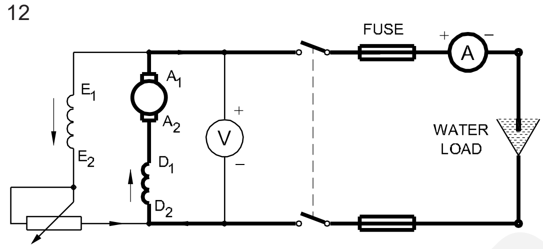
ELN311201D

If the shape of the curve is as shown in curve `D', it shows that the series ampere-turns are not sufficient to overcome the drop in the terminal voltage due to the I_aR_a drop and the armature reaction but still they are aiding the shunt field. Such a machine is called an under-compounded generator, and this generator may be used for electroplating or lighting.

Differential compound generator: If the series field terminals are interchanged as shown in Fig 12, then the curve obtained may be as shown in Fig 13. In such a connection, the series field opposes the shunt field, and the generator becomes a differential compound generator. The total flux produced will be equal to the shunt field flux minus the series field flux. From the curve, it is clear that the terminal voltage drastically reduces with increase in the load current. It is due to the reason that series ampere-turns produce flux which are opposing or bucking the shunt field flux. This characteristic may be used in welding work, where the potential difference between the electrode and the job before striking an arc is in the order of, say 100V, and when the arc strikes it falls to, say 40 to 50 V, to maintain the flow of current.

Application of a compound generator: Table 1 gives the different types of compound generators and their application in industry.

Fig 12



CUMULATIVE COMPOUND GENERATOR CIRCUIT

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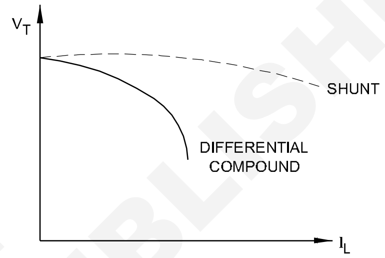
Fig 13



EXTERNAL CHARACTERISTIC OF DIFFERENTIAL COMPOUND DC GENERATOR

ELN311201G

Table 1

Sl.No.	Type of compound generator	Uses
1	Cumulative compound generator	
	a. Over-compounded	Used where the load is at a considerable distance from the generator as in railways, street lights etc.
	b. Flat or level compound	Used where the load is nearby, such as lighting loads and power loads of small buildings or lathes which require constant voltage.
	c. Under-compounded	Used for electroplating, lighting, etc.
2	Differential compound generator	Used for arc welding generators.

Numerical problems pertaining to DC generator: When the generator is loaded, there will be voltage drops in the armature resistance and series field resistance. To calculate the induced emf from the available data, the following steps should be adopted.

$Eg = V + I_aR_a + I_{se}R_{se}$

In the case of a short shunt compound generator

shown in Fig 14, $I_{se} = I_L$ and $I_a = I_L + I_{sh}$.

In the case of a long shunt compound generator shown in Fig 15 $I_{se} = I_a$ and $Ia = I_L + I_{sh} = I_{se}$

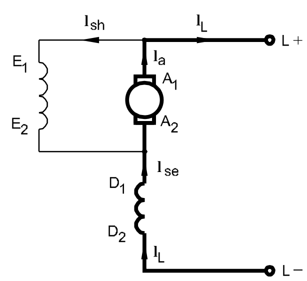
where I_a = armature current in amps

I_{sh} = shunt field current in amps

I_{se} = series field current in amps

I_L = load current in amps.

Fig 14

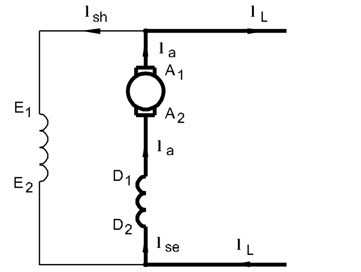


SHORT SHUNT COMPOUND GENERATOR

ELN311201H

Assignment: A 10 kW compound generator works on full load with a terminal voltage of 220 V. The armature, series and shunt windings have resistances of 0.05 ohm, 0.025 ohm and 440 ohms respectively. Calculate the total emf generated in the armature when the machine is connected as short shunt.

Fig 15



LONG SHUNT COMPOUND GENERATOR

Parallel operation of DC generators

Parallel Operation of DC Generators: In a dc power plant, power is usually supplied from several generators of small ratings connected in parallel instead of from one large generator.

The necessity of parallel operation

1 **Continuity of service:** If a single large generator is used in the power plant, then in case of its breakdown, the whole plant will be shut down.

The supply can be obtained from a number of small units operating in parallel, then in case of failure of one unit, the continuity of supply can be maintained by other healthy units.

2 **Efficiency:** Generators run most efficiently when load demand on power plant decreases, one or more generators can be shut down and the remaining units can be efficiently loaded.

3 **Maintenance and repair:** If generators are operated in parallel, the routine or emergency operations can be performed by isolating the affected generator while load is being supplied by other units. This leads to both safety and economy.

4 **Increasing plant capacity:** When added capacity is required, the new unit can be simply paralleled with the old units to increase the plant capacity.

Conditions for paralleling of DC Generators

1 Output voltage must be same

2 Polarities must be same

Connecting Shunt Generators in Parallel: The generators in a power plant are connected in parallel through bus-bars. The bus-bars are heavy thick copper bars and they act as +ve and -ve terminals. The positive terminals of the generators are .connected to the +ve side of bus-bars and negative terminals to the negative side of bus-bars. Fig 16 shows shunt generator 1 connected to the bus-bars and supplying load. When the load on the power plant increases beyond the capacity of this generator, the second shunt generator 2 is connected in parallel with the first to meet the increased load demand.

Operation of paralleling of DC Generator

1 The prime mover of generator 2 is brought up to the rated speed. Now switch S_4 in the field circuit of the generator 2 is closed.

2 Next circuit breaker CB_2 is closed and the excitation of generator 2 is adjusted till it generates voltage equal to the bus-bars voltage. This is indicated by voltmeter V_2.

3 Now the generator 2 is ready to be paralleled with generator 1. The main switch S_3 is closed, thus putting generator 2 in parallel with generator 1. Note the generator 2 is not suplying any load because its generated emf is equal to bus-bars voltage. The generator is said to be "floating" (i.e. not supplying any load) on the bus-bars (Fig 16).

4 If generator 2 is to deliver any current then its generated voltage E should be greater than the bus-bars voltage V. In that case, current supplied by it I = (E-V)/Ra is the resistance of the armature circuit. By increasing the field current (and hence induced emf E), the generator 2 can be made to supply proper amount of load.

5 The load may be shifted from one shunt generator to another merely by adjusting the field excitation. Thus if generator 1 is to be shut down, the whole load can be shifted onto generator 2 provided it has the generator 1 to zero (This will be indicated by ammeter A_1) open CB_1 and then open the main switch S_1

Load Sharing: The load may be shifted from one generator to another merely by adjusting the field excitation. The load sharing of two generators which have unequal no-load voltages. Let E_1, E_2 = no-load voltages of the two generators R_1, R_2 = their armature resistances

Thus current output of the generators depends upon the values of E_1 and E_2. These values may be changed by field rheostats. The common terminal voltage (or bus-bars voltage) will depend upon (i) the emfs of individual generators and (ii) the total load current supplied. It is generally desired to keep the busbars voltage constant. This can be achieved by adjusting the field excitations of the generators operating in parallel.

Armature reaction

When armature conductors carry a lower load current, the mmf set up by the armature conductors interact with the main field flux in such a way that the field of the main field flux gets distorted and this is called cross-magnetizing effect.

However, the effect could be nullified by shifting the brush position of the generator by a small angle in the direction of rotation.

When the generator is loaded further, the pole tips get saturated which results in demagnetising the main field flux, thereby reducing the induced emf. This effect is called demagnetising effect, and can be explained further.

Fig 16

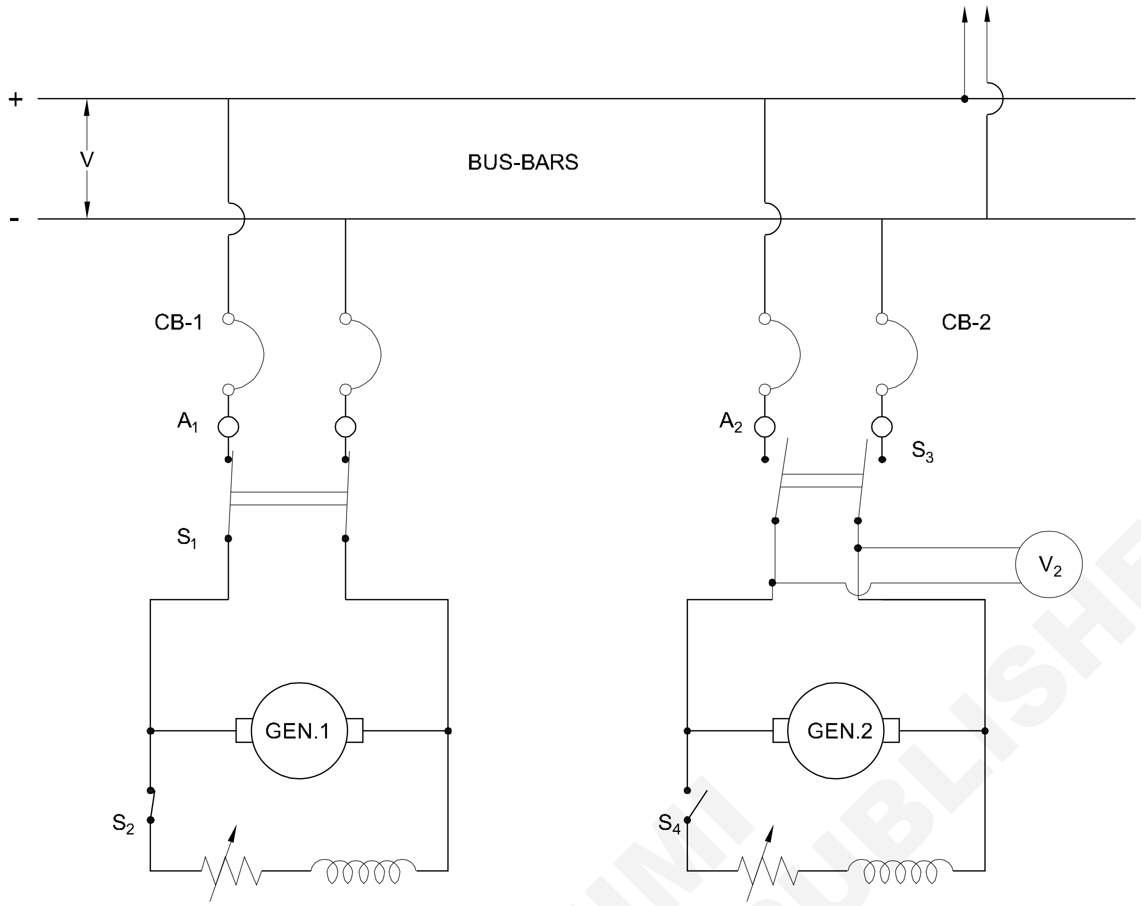


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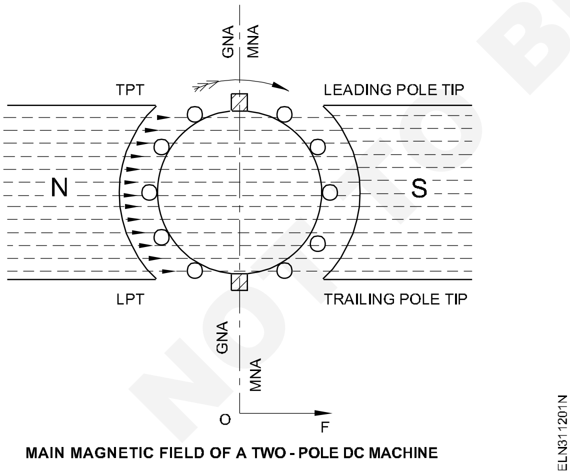
Fig 17 shows the flux distribution by the main field flux only. Since there is no current in the armature conductors, the flux is uniform. The GNA (Geometrical Neutral Axis) and MNA (Magnetic Neutral Axis) are coincident with each other.

Fig 17

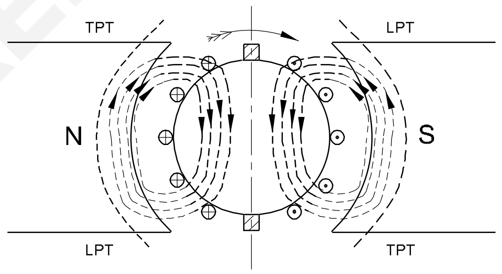


MAIN MAGNETIC FIELD OF A TWO - POLE DC MACHINE

ELN311201N

Fig 18 shows the flux set up by the armature conductors alone. The current direction is marked as a plus sign(+), under the N.pole and dot (•) under the south pole as shown in the figure. The strength of this armature field (mmf) depends upon the armature current which, in turn, depends upon the load current.

Fig 18



FLUX CREATED BY THE ARMATURE CURRENT

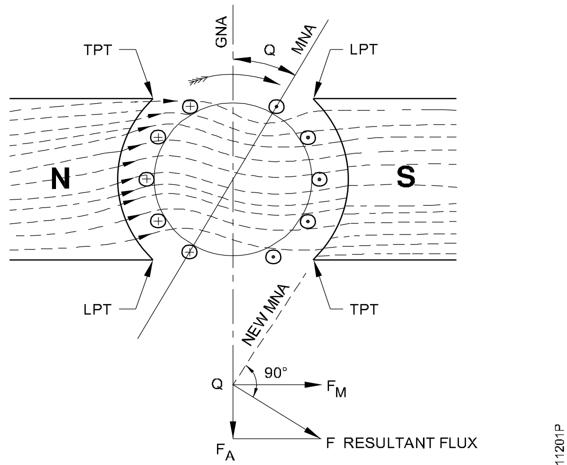
ELN311201O

Cross-magnetising effect: Fig 19 shows the flux distribution by the combined effect of the main field and the armature mmf. The resulting field is found to have strengthened at the trailing pole tips and weakened at the leading pole tips. Due to this cross-magnetizing effect, the magnetic neutral axis (MNA) is shifted from the geometrical neutral axis (GNA) by an angle Q in the direction of rotation.

The effect of the main field flux (FF) and the armature flux (F_A) are shown by vectors in Fig 19. The magnetic neutral axis (MNA) should be at right angle to the resultant flux (F).

Remedy: The effect of the cross-magnetisation can be neutralized by shifting the brushes from GNA to MNA with the help of the rocker arm. Of course the amount of shifting depends upon the magnitude of the armature current. At the correct position of the brush, the induced emf will be maximum and the spark at the sides of brushes will be minimum.

Fig 19



CROSS - MAGNETISING EFFECT

Demagnetising effect: The uneven distribution of magnetic flux at heavy armature current results in a demagnetizing effect because strengthening on the trailing pole tip is only up to saturation of that tip. After saturation the flux cannot increase at the trailing tips equally with the decrease in flux at the leading pole tips which causes the demagnetising effect, and hence, the induced emf reduces under heavy load condition.

Remedy: To compensate the demagnetizing effect of the reduced induced emf, the ampere-turns are increased in the field winding itself to strengthen the main field for small machines. But, for large machines, the demagnetizing effect can be neutralized by providing compensating winding in the main pole-faces as shown in Fig 20, and connecting this compensating winding in series with armature as shown in Fig 21, which is for a compound machine.

Fig 20

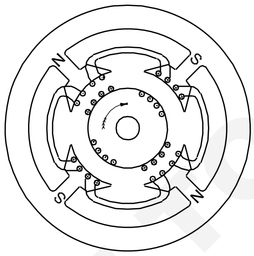
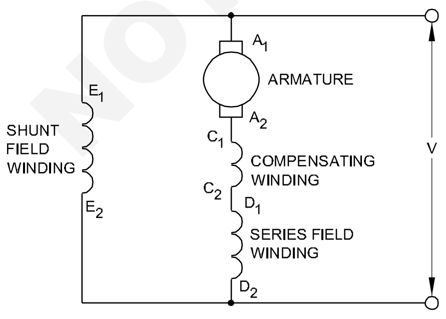


Fig 21

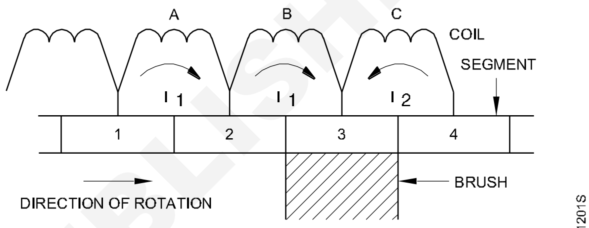


Commutation: When a DC generator is loaded, the current flows through the armature winding, commutator and brushes to the external circuit. During this process, whenever a brush spans the two commutator segments, the winding element connected to those commutator segments is short-circuited. The changes in current direction, which take place in the winding element, just before, during and after the short circuit is called commutation.

If the change in the current direction is gradual, then a smooth commutation takes place. On the other hand a sudden change in current in the winding element is called rough commutation which results in heavy sparking at the sides of brushes. If rough commutation is allowed to continue, the brushes and commutator get spoiled ultimately due to the excess heat produced by the sparks.

These changes in current are explained through the following figures. Fig 22 shows the current in the coil B flows in a clockwise direction, and the brush collects I_1 amps from the left side winding and I_2 amps from the right side winding.

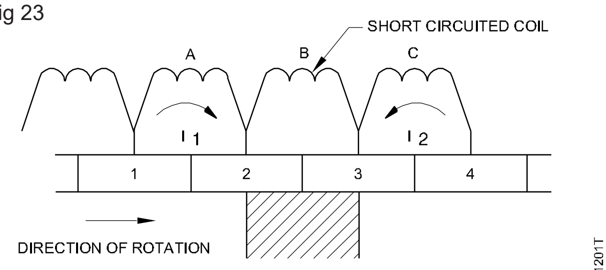
Fig 22



CURRENT COLLECTION - SEGMENT 3 IN CONTACT WITH THE BRUSH

Fig 23 shows that the brush short-circuits segments 2 and 3, and hence, coil B is short-circuited. Current I_1 in the left side winding passes to the brush through coil A, and the right side winding current passes through coil C. No current is in coil B as it is short-circuited.

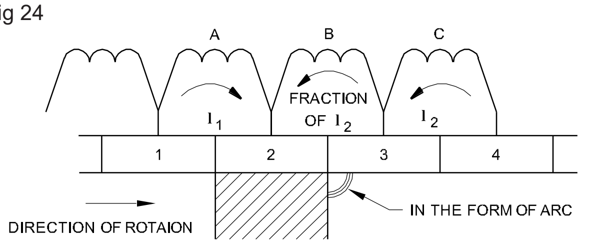
Fig 23



CURRENT COLLECTION-SEGMENTS 2 & 3 ARE IN CONTACT WITH THE BRUSH

Fig 24 shows that the brush contacts segment 2 only, and the current in the left side winding passes to the brush through coil A. On the other hand the current in the right hand side (I_2) should now pass through coil B via segment 2 to the brush.

Fig 24



CURRENT COLLECTION - SEGMENT 2 IN CONTACT WITH THE BRUSH

At this instant, the current in coil B, has to change its direction from clockwise to anticlockwise, but even though it changes it would not attain the full value of current after the short circuit. Therefore, a major portion of current I_2 from the right side passes to the brush through an arc from segment 3. This is due to the fact that the sudden change of current direction in coil B induces a statically induced (reactance) emf equal to $\frac{\varnothing}{t}$ or $\frac{I}{t}$

where Ø is the flux created by the current I in amps, and 't' represents the time of short circuit in seconds.

Further, the induced emf can also be calculated by knowing the reactance of the coil under commutation which depends upon the self-inductance of the coil, and the mutual inductance of the neighbouring coils.

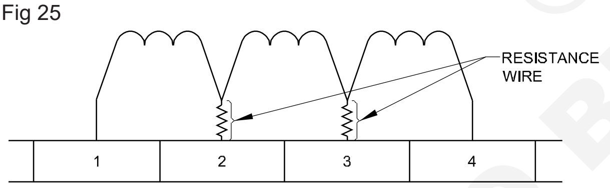
This induced emf will obey Lenz's law, and oppose the change in the current. Hence the current from the right hand side as shown in Fig 24 would not be able to pass through coil B, and hence it jumps to the brush in the form of an arc. This is called rough commutation.

Remedies for rough commutation by providing interpoles

To avoid sparks in the brush position, the following methods are used which effectively change the rough commutation to smooth commutation.

- Resistance wires are introduced between the end connection of the coil to the commutator, as shown in Fig 25. This increased resistance helps the current to change its direction smoothly, increasing the timing and reducing the statically induced emf.

Fig 25



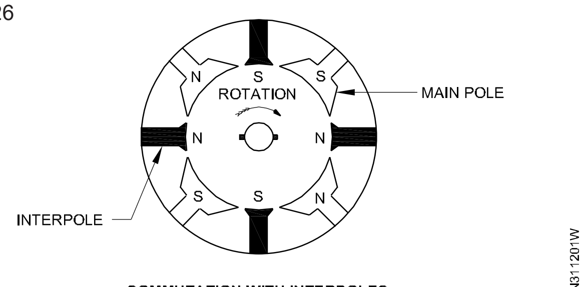
COMMUTATION WITH RESISTANCE WIRES

- High resistance brushes are used. Hence the contact resistance variation allows the current to change its direction smoothly, thereby reducing the statically induced emf.
- Small field poles called inter-poles are provided in between the main poles as shown in Fig 26. These inter-poles have their polarity the same as the next pole ahead in the direction of rotation of the, generators. Further, their winding is connected in series with the armature so that they carry the same current as that of the armature.

These inter-poles produce an emf opposite in direction to the statically induced emf, and have a magnitude depending upon the current. Thereby, the effect of statically induced emf is nullified.

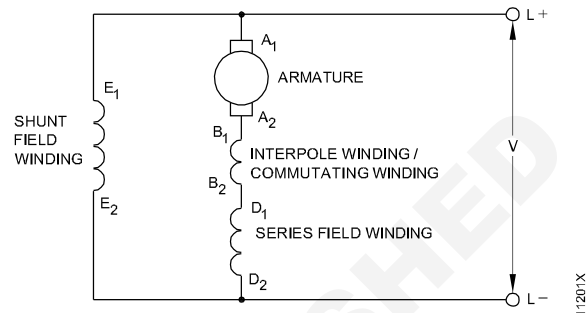
These inter-poles are wound with less number of turns having thick gauge wire. Fig 27 shows the connection of inter-pole winding in a DC compound machine.

Fig 26



COMMUTATION WITH INTERPOLES

Fig 27



CONNECTION OF INTERPOLE WINDING IN A DC MACHINE

Losses and efficiency of DC machines

It is convenient to determine the efficiency of a rotating machine by determining the losses than by direct loading. Further it is not possible to arrange actual load for large and medium sized machines. By knowing the losses, the machine efficiency can be found by

$$\eta = \frac{\text{output}}{\text{output} + \text{losses}} \left(\text{For generators}\right)$$

$$\eta = \frac{\text{input - losses}}{\text{input}} \left(\text{For motors}\right)$$

In the process of energy conversion in rotating machines - current, flux and rotation are involved which cause losses in conductors, ferromagnetic materials and mechanical losses respectively. Various losses occurring in a DC machine are listed below (FIg 28 shows losses of DC machine.

Total losses can be broadly divided into two types

1 Constant losses   2 Variable losses

These losses can be further divided as

1 Constant losses - i) Core loss or iron loss

a Hysteresis loss   b Eddy current loss

ii Mechanical loss

a Windage loss

b Friction loss - brush friction loss and Bearing friction loss.

2 Variable losses - i) copper loss (I^2R)

a Armature copper loss

b Field copper loss

c Brush contact loss

ii Stray load loss

a Copper stray load loss

b Core stray load loss

Efficiency of a DC generator

Power flow in a DC generator is shown in Figure 29.

$$= \frac{\text{output}}{\text{output} + \text{losses}} = \frac{VI}{VI + I_a^2 r_a + W_e}$$

where w_e is constant loss

Condition for maximum efficiency

Generator output = VI

Generator input = output+losses

$= VI + I^2 a R_a + W_e$

$= VI + (I + I_{sh})^2 R_a + W_e \setminus I_a = (I + I_{sh})$

However, if I_{sh} is negligible as compared to load current I_a=I (approx.)

$$\because \eta = \frac{\text{output}}{\text{input}} = \frac{VI}{VI + I^2 a R_a + W_e} = \frac{VI}{VI + I^2 R_a + W_e}$$

Efficiency is maximum when variable loss = constant loss.

Fig 28

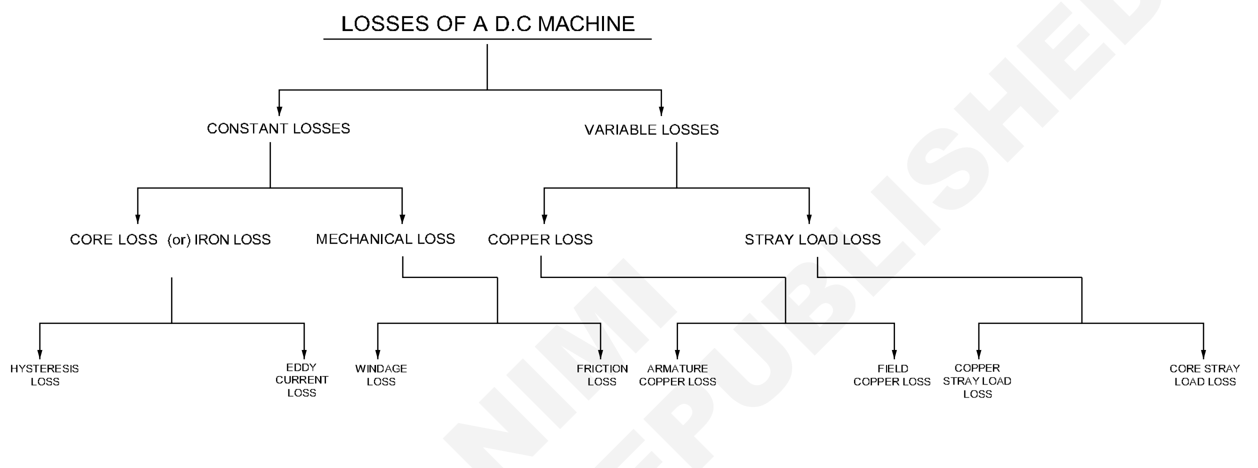
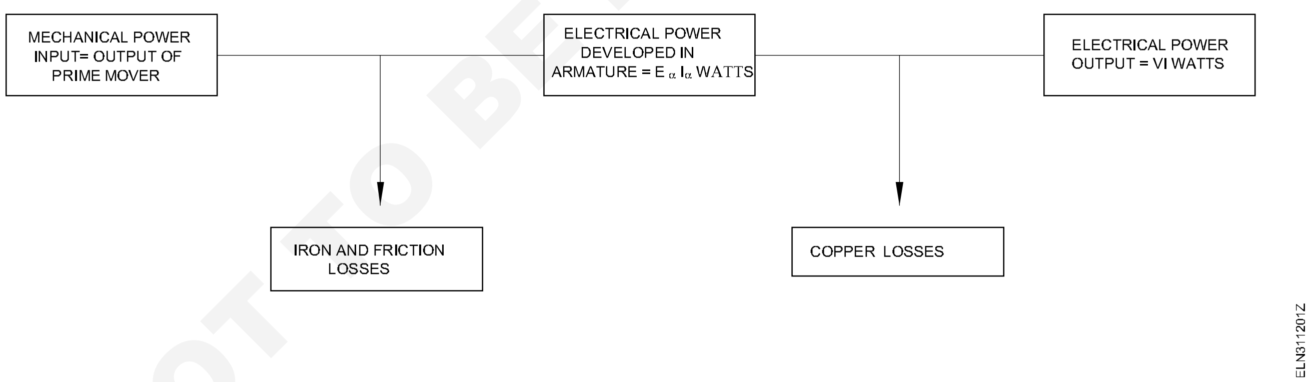


Fig 29



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.

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.

Fig 1

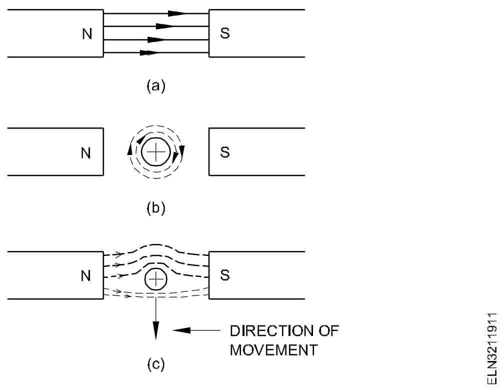
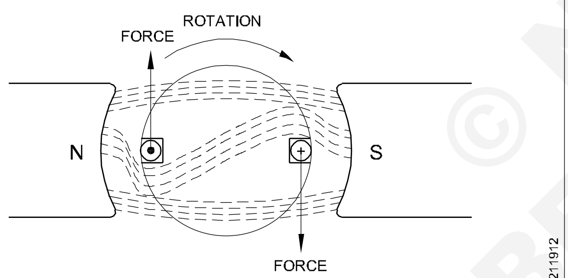
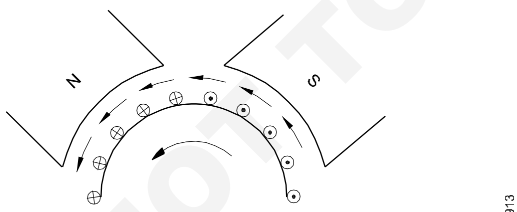


Fig 2



REACTION OVER A CURRENT CARRYING LOOP BY THE MAGNETIC FIELD

Fig 3

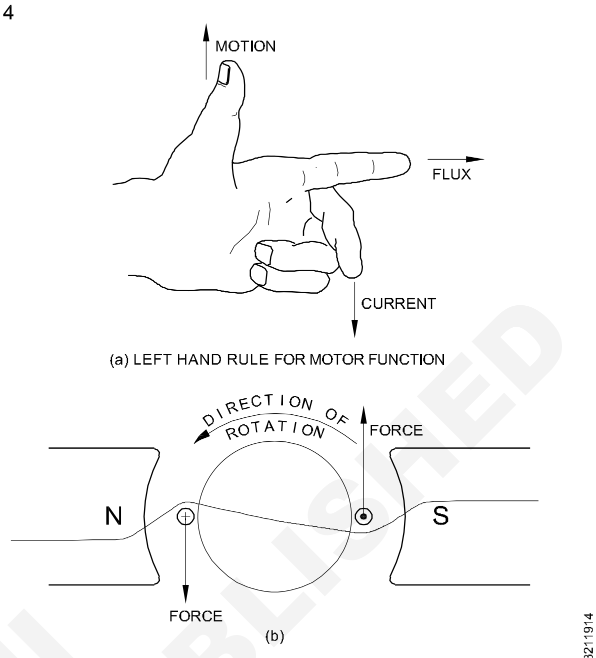


REACTION OVER THE ARMATURE CURRENT CARRYING CONDUCTORS BY THE MAGNETIC FIELD

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.

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.

Fig 4

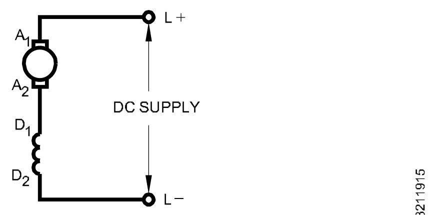


FLEMING'S LEFT HAND RULE

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.

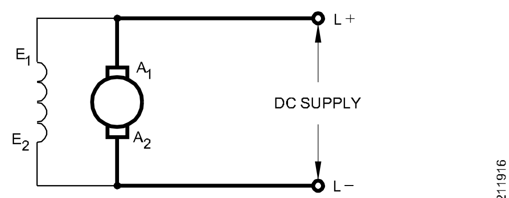
Fig 5



SERIES MOTOR

When the armature and field are connected in parallel across supply, as shown in Fig 6, it is called a shunt motor.

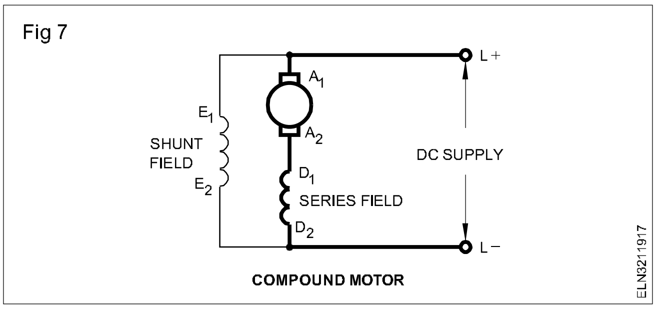
Fig 6



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 7



COMPOUND MOTOR

The relation between applied voltage, 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 E_b. Its value is the same as that found in the generator. It could be written as

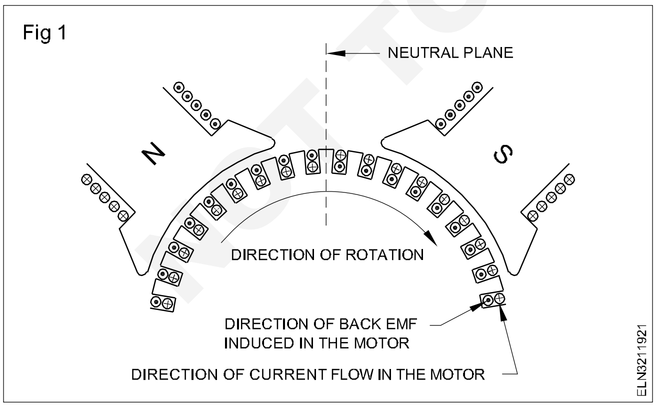
$$E_b = \frac{\varnothing ZNP}{60A} \text{ volts}$$

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 I_aR_a drop because it is proportional to the product of the armature current I_a and armature resistance R_a. It has a definite relation with the applied voltage and back emf as shown by the formula

Fig 1



$V = E_b + I_aR_a$.

Alternatively, $I_aR_a = V - E_b$.

Further the back or counter emf E_b 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.

$$E_b = V - I_aR_a$$

$$\frac{\varnothing ZNP}{60A} = V - I_aR_a$$

$$\therefore\ N = \frac{(V - I_aR_a) \times 60A}{\varnothing ZP} \text{ rpm}$$

For a given motor ZPA and 60 are constants and can be denoted by a single letter K

$$\text{where } K = \frac{60A}{ZP}$$

Therefore $N = K E_b/Ø$.

It shows that the speed of a DC motor is directly proportional to E_b 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

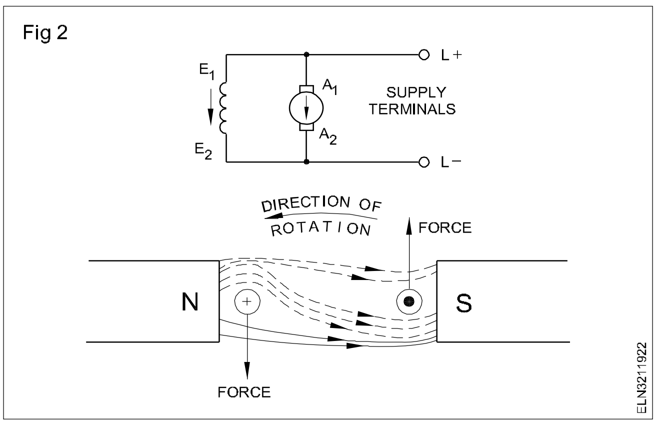
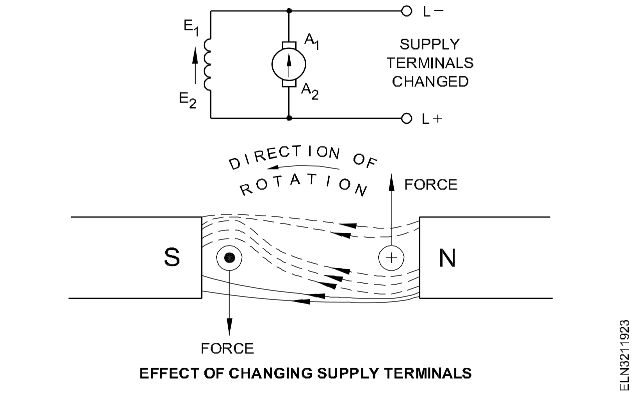
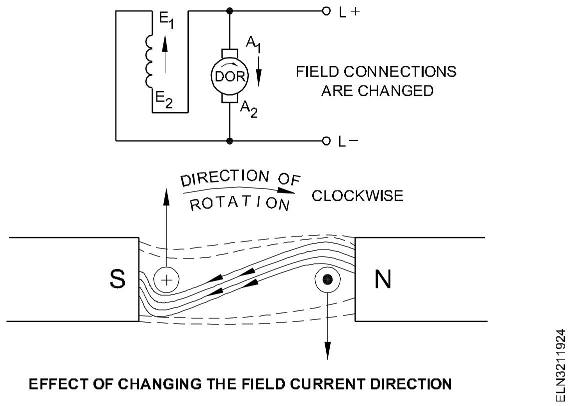


Fig 3



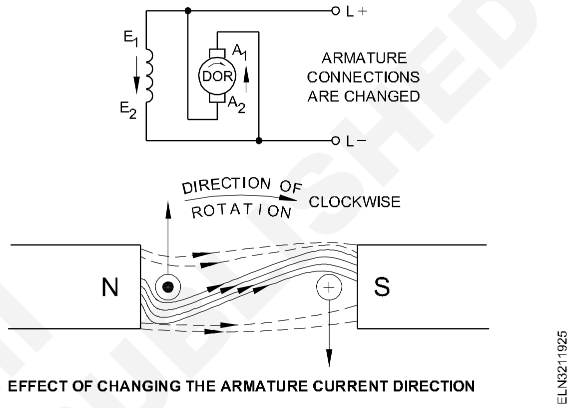
EFFECT OF CHANGING SUPPLY TERMINALS

Fig 4



EFFECT OF CHANGING THE FIELD CURRENT DIRECTION

Fig 5



EFFECT OF CHANGING THE ARMATURE CURRENT DIRECTION

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.

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.**

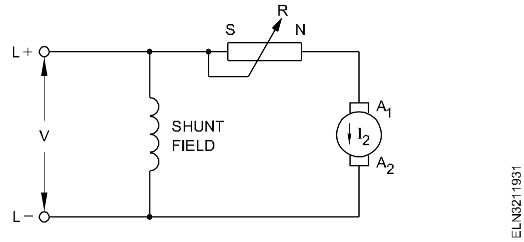
Necessity of starters: Since the armature is stationary before starting, the back emf which is proportional to speed is zero. As the armature resistance is very small, if the rated voltage is applied to the armature, it will draw many times the full load current, and thereby, there is every possibility 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



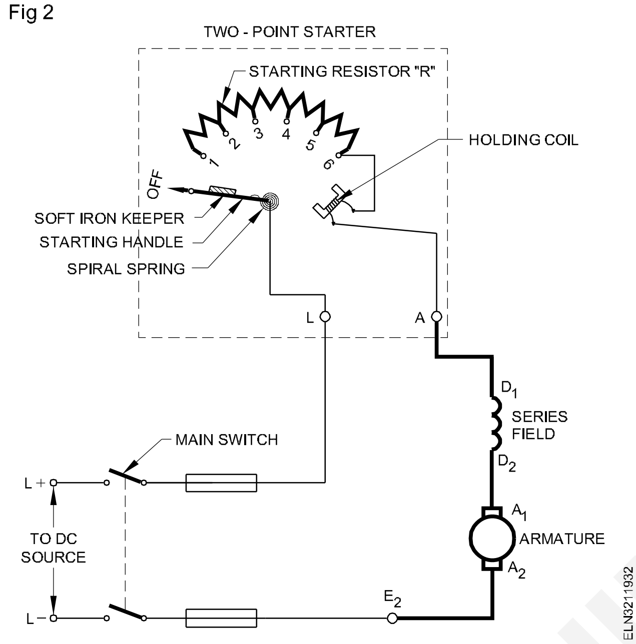
Two-point starter: This contains the following components.

- 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.

Fig 2

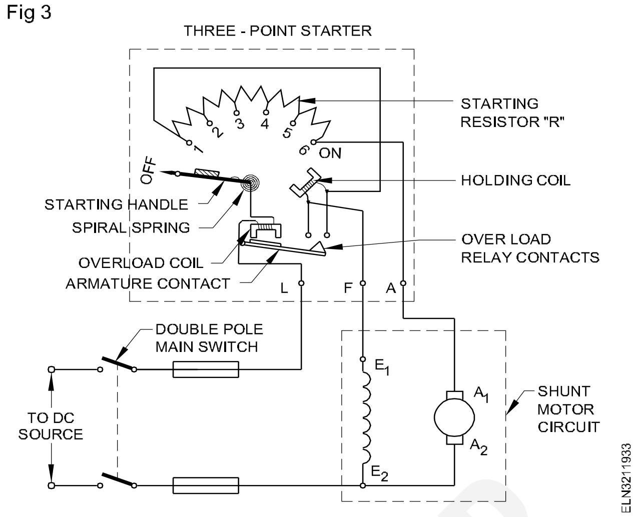


Three-point starter: Fig 3 shows the internal diagram of a three(terminal) point starter connected to a DC shunt motor. The direct current supply is connected to the starter, the motor circuit through a double pole switch and suitable fuses. The starter has an insulated handle or knob for the operator's 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.

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

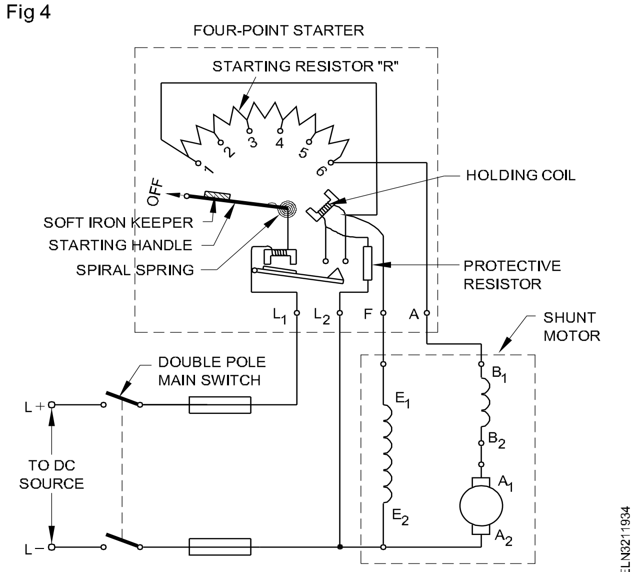


An overload coil is provided to prevent damage to the motor from overload. Under normal load condition, the flux produced by the O/L coil will not be in a position to attract the armature contact. When the load current increases beyond a certain specified value, the flux of the O/L coil will attract 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

$V = E_b + I_aR_a$.

Hence $E_b = V - I_aR_a$ and also

the back emf $E_b = \frac{P\varnothing N}{60} \times \frac{Z}{A} = K\varnothing N$

where K is a constant.

Therefore $N = \frac{E_b}{k\varnothing} = \frac{V - I_aR_a}{k\varnothing}$ Eqn.1

From the above expression, it is clear that the speed of a DC motor is directly proportional to the back emf E_b, and inversely proportional to flux (Ø). Thus the speed of the DC motor can be varied by changing either the back emf E_b 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 = $V - I_aR_a$, 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 N_1 and N_2, and the back emf be E_{b1} and E_{b2} respectively,

Then $N1 = \frac{E_{b1}}{k}$ .....Eqn.2.

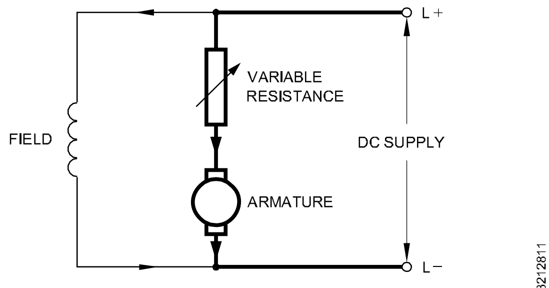
$N2 = \frac{E_{b2}}{k}$ .....Eqn.3.

By dividing Eqn.3 by Eqn.2 we have

$N_2 = \frac{E_{b2}N_1}{E_{b1}}$.

By varying the controller resistance value in the armature circuit, the back emf can be varied from E_{b1} to E_{b2}, thereby, the speed can be varied from N_1 to N_2.

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.

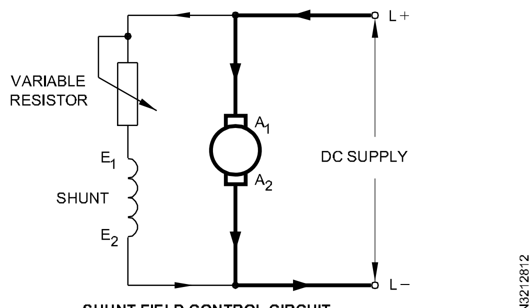
Disadvantages

- 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

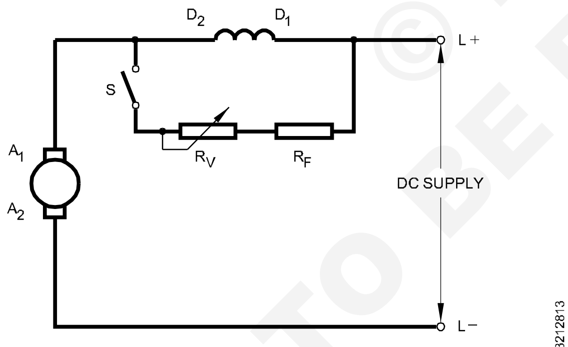
- Owing to the very weak field, a reduced torque is obtained at top speeds.
- The operation at high speeds with a weak field leads to commutation difficulties unless inter-poles are used.

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. R_V represents the variable portion of the divertor and R_F the fixed portion. The function of R_F is to prevent the series winding being short-circuited, when the diverter is operated.

Fig 3



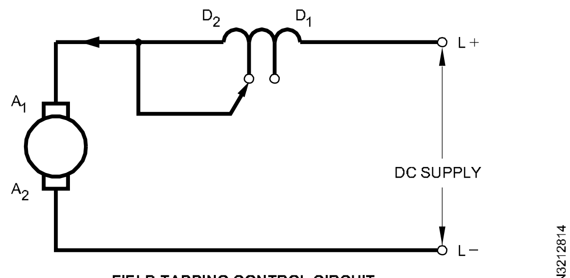
FIELD DIVERTER CONTROL CIRCUIT

The smaller the value of $R_V + R_F$, 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



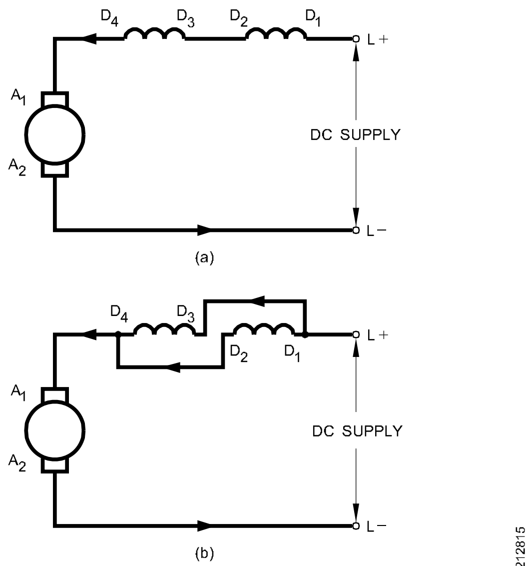
FIELD TAPPING CONTROL CIRCUIT

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

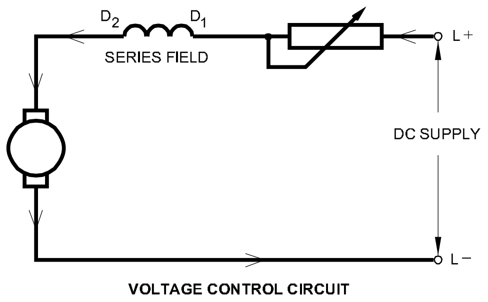


SERIES-PARALLEL METHOD OF CONTROL

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.

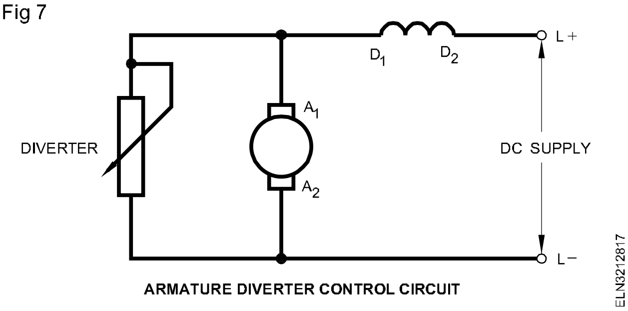
The disadvantage in this method is that there is loss of energy in the control resistance in the form of heat. But with the introduction of SCR based control circuit, obtaining a variable supply voltage to motor is achieved with the least power loss. This method is widely used in larger modern machines where power loss is a major concern.

Fig 6



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.

Fig 7



Maintenance procedure for DC machines

Objectives: At the end of this lesson you shall be able to
- **state what is meant by preventive maintenance and its importance**
- **describe the recommended maintenance schedule for DC motors**
- **explain how to maintain the maintenance record.**

Preventive maintenance: Preventive maintenance of Power machines consists of routinely scheduled periodical inspections, tests, planned minor maintenance repairs and a system of maintaining inspection records for future reference. Preventive maintenance is a combination of routine and planned operations.

Necessity of preventive maintenance: By carrying out an effective preventive maintenance programme on Power machines, we can eliminate major failures of the machines, accidents, heavy repair costs and loss of production time. Proper preventive maintenance will lead to economy of operation, less down-time, dependable machine operation, longer machine life and lower overall cost of maintenance and repair.

Scheduling of preventive maintenance: Routine periodical inspection and tests may be scheduled to be carried out daily, weekly, monthly, half-yearly and annualy depending upon the following factors.

- The importance of the motor/generator in the production
- The duty cycle of the machine
- The age of the machine
- The earlier history of the machine
- The environment in which the machine operates
- The recommendations of the manufacturer.

Recommended maintenance schedule for machines: While carrying out routine periodical maintenance, an electrician will make full use of his senses to diagnose and locate problems in Power machines. The sense of smell directs attention to burning insulation: the sense of feel detects excessive heating in winding or bearing; the sense of hearing detects excessive noise, speed or vibration and the sense of sight detects excessive sparking and many other mechanical faults.

Sensory impressions must also be supplemented by various testing procedures to localize the trouble. A thorough understanding of Power principles and the efficient use of test equipment are important to an electrician during this phase of operation.

Machine details **Page 1**

Manufacturer, Trade Mark ____________________

Type, Model or Serial number ____________________

Type of connection ____________ Sep/Shunt/Series/Compound

Rated voltage ____________ volts   Rated current ____________ amps

Rated power ____________ K.W.   Rated speed ____________ r.p.m.

Rating class ____________   Directon of rotation ____________

Insulation class ____________   Protection class ____________

The following maintenance schedule is recommended for DC machines.

1 Daily maintenance

- Examine visually earth connections and machine leads.
- Check the sparking at the commutator.
- Check the motor windings for overheating. (The permissible maximum temperature is near about that which can be comfortably felt by hand.)
- Examine the control equipment.
- In the case of oil-ring lubricated machines
  - a examine the bearings to see that the oil rings are working
  - b note the temperature of the bearings
  - c add oil, if necessary
  - d check end play.
- Check for unusual noise at the machine while running.

2 Weekly maintenance

- Examine the commutator and brushes.
- Check belt tension. In cases where this is excessive it should immediately be reduced.
- Blow out air through the windings of protected type machines situated in dusty locations.
- Examine oil in the case of oil-ring lubricated bearings for contamination by dust, grit, etc.(This can be roughly judged from the colour of the oil.)
- Check foundation bolts and other fasteners.

3 Monthly maintenance

- Inspect and clean the oil circuit breakers.
- Renew the oil in high- speed bearings which are in damp and dusty locations.
- Wipe the brush-holders and check the bedding of brushes of DC machines.
- Test the insulation of windings.

4 Half-yearly maintenance

- Check the brushes and replace, if necessary.
- Check the windings of machines subjected to corrosive and other elements. If necessary, bake the windings and varnish.
- Check the brush tension and adjust, if necessary.
- Check the grease in the ball and roller bearings, and make it up, where necessary, taking care to avoid overfilling.
- Check the current input to the motor or the output of the generator and compare it with normal values.

5 Annual maintenance

- Check all the high speed bearings, and renew, if necessary.
- Blow out all the machine winding thoroughly with clean dry air.
- Clean and varnish the oily windings.
- Overhaul the motors which have been subjected to severe operating conditions.
- Renew the switch and fuse contacts, if damaged.
- Check the oil in the starter and the grease/oil in the bearings.
- Check the switch conditions, resistance to earth between motor/generator windings, control gear and wiring.
- Check the resistance of earth connections.
- Test the insulation of windings before and after overhauling the motors/generators.

6 Records

- Maintain a register giving one or more pages for each machine, and record therein all important inspections and maintenance works carried out from time to time. These records should show past performance, normal insulation level, air gap measurements, nature of repairs and interval between previous repairs and other important information which would be of help for good performance and maintenance.

While routine maintenance could be done either during the working of the machine or during short interval `down' periods, the planned maintenance requires to be done during holidays or by taking shut-downs of small duration.

Planned maintenance schedule needs to be decided, based on the routine maintenance reports entered in the maintenance card.

Details of inner parts	**Page 1**
Bearing	**Particulars of supply order**
Sleeve ball roller	Supply order No: ____________
Front end No. ____________	Year of purchase ____________
Pulley end No. ____________	Date of first inspection and test ____________
Grease type ____________	Date of installation ____________
Coupling type ____________	Location ____________
Brush grade ____________	
Brush No. as per manufacturer ____________	

Initial test results	Page 1

Resistance value of shunt winding ____________

Resistance value of series winding ____________

Resistance value of armature ____________

Insulation resistance value between

armature and shunt field ____________

armature and series field ____________

series field and shunt field ____________

armature and frame ____________

shunt field and frame ____________

series field and frame ____________

The 2^{nd} page gives the record of maintenance carried out, and, in particular the defects noted therein.

Maintenance record: Maintaining a system of inspection records is a must in preventive maintenance schedule. This system uses a register as stated above or cards as shown below which are kept in the master file. By referring to these maintenance cards, the foreman can schedule the planned maintenance.

Maintenance card: The 1st page gives the details of name-plate, location, year of purchase, initial test results etc pertaining to the machine.

A careful study of the maintenance card helps the foreman to plan the shut-down date to facilitate early overhauling or planned maintenance schedule to prevent a major breakdown.

Method of maintenance: During the routine maintenance inspection, the investigations and adjustment to be carried out for the parts and accessories of the motors/generators are given below to improve the efficiency of preventive maintenance.

- Clean daily the motor/generator, switch gear and associated cables free from dirt, dust and grease.
- Check the bearing daily for excessive noise and temperature. If required, re-grease or re-oil the bearing with the same grade of grease/oil as in original.
- Check the machine daily against strains of water or oil or grease which may leak from the surroundings.
- Check daily the belts, gears and coupling for looseness, vibration and noise.
- Check weekly the brushes and the commutator for sparking and wear.
- Check weekly the bearing for proper lubrication.
- Check weekly the terminals and switch contacts.
- Inspect the brushes and the commutator once in a month for excessive wear, chatter and sparking. Worn-out brushes need to be replaced with the same grade brushes. Check spring tension on the brushes, and adjust, if necessary.
- Check monthly the brushes for proper seating.
- Check monthly the end plates and the shaft for excessive end play.
- Check monthly the main and auxiliary contact points of the switch gear for wear, pitting and burns.
- Test monthly once the field windings and armature for insulation and ground faults.
- Check monthly once the foundation bolt and other fasteners for tightness.
- Once a year undercut the mica in between the commutator bars. Test the commutator and armature for shorts, open and ground faults.

Maintenance card

Report on routine maintenance **Page 2**

Date of maintenance	Scheduled maintenance carried out	Defects noted	Attended by (Signature)	Reported to (Signature)	Remarks

The 3rd page gives the details of the test carried out in the motor at intervals with corresponding readings

Maintenance card

Report on test details **Page 3**

Date of Test	Schedule	Test particulars	Test results	Tested by (Signature)	Reported to (Signature)	Remarks

From the above it is clear that atleast once in a year, the motor/generator needs a thorough overhauling in addition to frequent routine maintenance.

The 4th page gives the details of the defects,causes and repair carried out

Motor service card **Page 4**

Date of repair	Repair and parts replaced	Cause	Repaired by (Signature)	Supervised by (Signature)	Remarks

Transformer - Principle - Classification - EMF Equation

Objectives: At the end of this lesson you shall be able to
- **define a transformer**
- **explain the construction of two winding transformer**
- **state the reasons for laminated silicon steel being used as core material.**

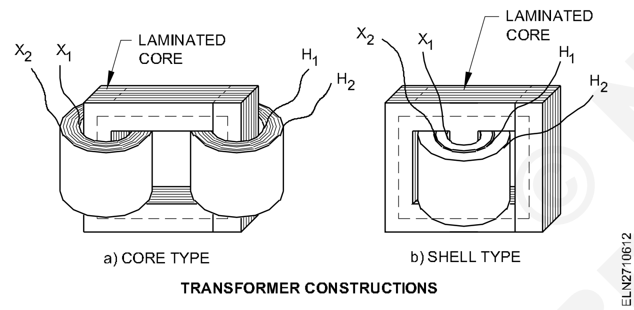
Transformer

Transformer is a static electric device which transfer the electric energy from one circuit to other without changing the frequency and power.

Construction: There are basically two types of iron-core construction. Fig 1a shows core type transformer. It consists of two separate coils, one on each of the two opposite legs of a rectangular core.

Normally, this is not a desirable design. Its disadvantage is the large leakage fluxes associated with it. The large leakage fluxes cause poor voltage regulation. Therefore, to ensure that most of the flux set by the primary will link the secondary, the construction Fig 1b is employed. This is called shell type construction.

Fig 1



TRANSFORMER CONSTRUCTIONS

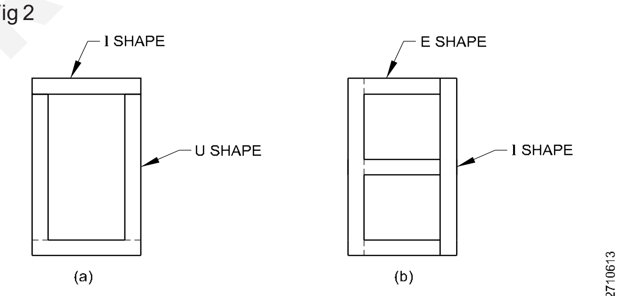
Here the two windings are wound concentrically. The higher voltage winding is wound on top of the lower voltage winding. The low-voltage winding is then located closer to the steel. This arrangement is preferable from an electrical insulating point of view. From the electrical viewpoint there is not much difference between the two constructions.

Cores may be built up of lamination silicon steel sheet. Most laminating materials have an approximate alloy content of 3% silicon and 97% iron. The silicon content reduces the magnetizing losses. Particularly, the loss due to hysteresis is reduced. The silicon makes the material brittle. The brittleness causes problems in stamping operation.

Most laminated materials are cold-rolled and often specially annealed to orient the grain or iron crystals. This provides very high permeability and low hysteresis to the flux in the direction of rolling. Transformer laminations are usually 0.25 to 0.27 mm thick for 50 Hz. operation. The laminations are coated on one side by a thin layer of varnish or paper to insulate them from each other.

Coils are pre-wound, and the core design must be such that it permits placing the coil on the core. Ofcourse, the core must then be made in atleast two sections. The laminations for the core-type transformer of Fig 1a may be made up of (U and I) shaped laminations, as shown in Fig 2a. The core for the shell type transformer of Fig 1b is normally made up of E and I shaped laminations Fig 2b.

Fig 2



CORE CONSTRUCTION BUILT OF SEPARATE LAMINATIONS

Transformer principle

Objectives: At the end of this lesson you shall be able to
- **explain the principle of the operation of a transformer**
- **derive the EMFequation of a two-winding transformer**
- **derive the transformation ratio of a transformer.**

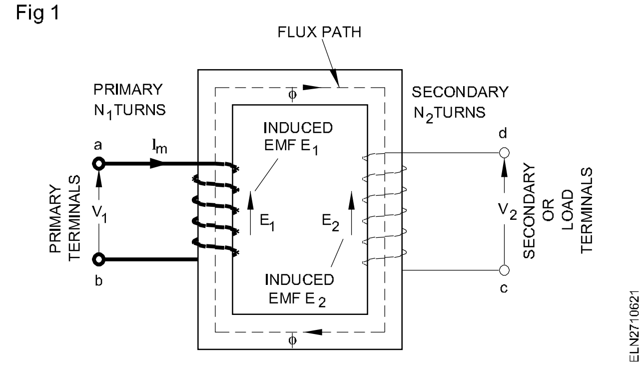
Let us consider an ideal transformer (Fig 1) whose secondary is open and whose primary is connected to a sinusoidal voltage V_1.

Working principle: The transformers work on the principle of mutual induction of Faraday's law of electro - magenetic induction.

The applied voltage causes a small current to flow in the primary winding. This no-load current is meant to build up a counter-electromotive force equal and opposite to the applied voltage.

Since the primary winding is purely inductive and there is no output, the primary draws the magnetizing current I_m only. The function of this current is merely to magnetise the core. The I_m is small in magnitude and lags V_1 by 90°. This alternating current I_m produces an alternating flux f which is proportional to the current and hence is in phase with it (I_m). This changing flux is linked with both the windings. Therefore, it produces self-induced EMF (E_1) in the primary which lags the flux 'f' by 90^0. This is shown in vector diagram Fig 2.

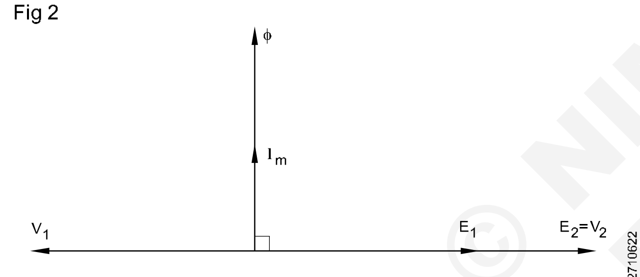
Fig 1



The flux 'ø' produced by the primary links with the secondary winding and induces an EMF (E_2) by mutual induction which lags behind the flux 'ø' by 90° Fig 2. As the EMF induced in primary or secondary per turn is same the secondary EMFwill depend on the number of turns of the secondary.

When secondary is open circuit, its terminal voltage 'V_2' is the same as the induced EMF (E_2). On the other hand, the primary current at no load is very small, hence the applied voltage 'V_1' is practically equal and opposite to the primary induced EMF (E_1). The relationship between primary and secondary voltages Fig 2.

Fig 2



VECTOR DIAGRAM OF AN IDEAL TRANSFORMER

Hence we can say that

$$\frac{\text{Total emf indued in seconday' } E_2}{\text{Total emf induced in primary' } E_1\text{'}}$$

$$= \frac{N_2 \times \text{emf per turn}}{N_1 \times \text{emf per turn}} \quad \text{OR}$$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

$$\text{as } E_1 = V_1 \text{ and } E_2 = V_2$$

$$\text{We have } \frac{V_2}{V_1} = \frac{N_2}{N_1}$$

Ideal Transformer on Load: When the secondary is connected to a load, secondary current flows this in turn makes the primary current to increase. How this happens is explained below.

The relationship between primary and secondary currents is based upon a comparison of the primary and secondary ampere turns.

When the secondary is open circuit, the primary current is such that the primary ampere turns are just sufficient to produce the flux 'ø' necessary to induce an EMF (E_1) that is practically equal and opposite to the applied voltage 'V_1'. The magnetising current is usually about 2 to 5 percent of the full load primary current.

When a load is connected across the secondary terminals, the secondary current - by **Lenz's law** - produces demagnetising effect. Consequently the flux and the EMFinduced in the primary are reduced slightly.

But this small change may increase the difference between applied voltage 'V_1' and the induced EMF (E_1) by say 1 percent in which case the new primary current would be 20 times the no load current.

The demagnetising ampere turns of the secondary are thus nearly neutralized by the increase in the primary ampere turns and since the primary ampere turns on no load are very small compared with the full load ampere turns.

Therefore Full load primary ampere turns $\simeq$ full load secondary ampere turns

i.e $I_1N_1 \simeq I_2N_2$

$$\text{so that } \frac{I_1}{I_2} \simeq \frac{N_2}{N_1} \simeq \frac{V_2}{V_1} \text{ Transformation ratio}$$

From the above statement, it is clear that the magnetic flux forms the connecting link between the primary and secondary circuits and that any variation of the secondary current is accompanied by a small variation of the flux and therefore of the EMFinduced in the primary, thereby enabling the primary current to vary approximately, proportional to the secondary current.

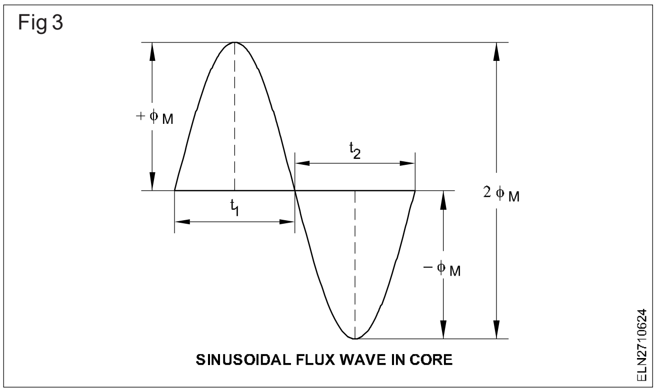
EMF equation of a transformer: Since the magnetic flux set up by the primary winding links the secondary winding, an EMF will be an induced E_2, in the secondary, in accordance with Faraday's law, namely, E = N (dø/dt). The same flux also links the primary itself, inducing in it an emf, E_1. The induced voltage must lag the flux by 90°, therefore, they are 180° out of phase with the applied voltage V_1.

Since there is no current in the secondary winding, $E_2 = V_2$. The primary voltage and the resulting flux are sinusoidal; thus the induced quantities E_1 and E_2 vary as a sine function. The average value of the induced voltage is given by

$$E_{avg} = \text{turns} \times \frac{\text{change in flux in a given time}}{\text{given time}} \quad ...(1)$$

Referring to Fig 3, it is seen that the flux change in time interval t_1 to t_2 is $2f_m$ where f_m is the maximum value of the flux, in webers. The time interval represents the time in which this flux change occurs and equals one-half cycle

Fig 3



SINUSOIDAL FLUX WAVE IN CORE

of ($\frac{1}{2f}$) seconds, where f is the supply frequency, in hertz. It follows that

$$E_{avg} = N \times \frac{2\phi_m}{\frac{1}{2f}} = 4fN\phi_m \qquad ...(2)$$

where N is the number of turns on the winding.

The effective or rms voltage for a sine wave is 1.11 times the average voltage, thus

$$E = 4.44\ f\ Nf_m \qquad ...(3)$$

Since the flux links with the primary and secondary windings, the voltage per turn in each winding is the same. Hence

$$E_1 = 4.44\ f\ N_1 f_m \qquad ...(4)$$

and

$$E_2 = 4.44\ f\ N_2 f_m \qquad ...(5)$$

where N_1 and N_2 are the number of turns in the primary and secondary windings respectively.

Voltage Transformation Ratio (K): From the equations 4 and 5, we get

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K \text{ (Constant)} \qquad ...(6)$$

This constant is known as voltage transformation ratio. Although the true transformation ratio is constant, the ratio of terminal voltages varies somewhat depending on the load and its power factor. In practice, the transformation ratio is obtained from the name plate data refers the voltages of primary and secondary on full load condition.

When the secondary voltage V_2 is less compared to the primary voltage, the transformer is said to be step down transformer. If the secondary voltage is higher it is called a step-up transformer. In other words

(a) $N_2 < N_1$ i.e $K<1$, then the transformer is called a step-down transformer

(b) $N_2 > N_1$ i.e $K>1$, then the transformer is called a step-up transformer

Assume that the power output of a transformer is equal to its input i.e we are dealing with an ideal transformer.

Thus $P_{in} = P_{out}$ (or)

$V_1 I_1$ x primary PF = $V_2 I_2$ x secondary PF

where PF is the power factor. For the above stated assumption it means that the power factor on primary and secondary sides are equal. (It is possible when I_o is neglected). Therefore,

$V_1 I_1 = V_2 I_2$ (or)

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = K \qquad ...(7)$$

Equation 7 shows that as an approximation the terminal voltage ratio equals the turns ratio.

Transformer - simple calculations

Objective: At the end of this lesson you shall be able to
- **define the rating of transformer**
- **calculate the voltage, current and turns of primary from the secondary data and vice versa.**

Rating of transformer

The capacity of the transformers are always rated by its apparent power (volt amp - VA (or KVA), not by its true power (watt (or) KW) (ie.) KW = KVA x Cosϕ . The transformer can be loaded with either resistive, inductive, capacitive (or) combined. The power factor (Cosϕ) depends on the load of the transformer. If the transformer rating is in KVA the load current can be determined directly by knowing its voltage.

Example 1: A 100 KVA 2400/240V, 50 Hz. transformer has 300 turns on the secondary winding. Calculate (a) the approximate value of primary and secondary currents (b) the number of primary turns and (c) the maximum flux ϕ_m in the core.

Data given : Transformer rating 100 KVA

Frequency f = 50 Hz

Primary voltage V_P = 2400 V

Secondary voltage V_S = 240 V

Secondary turns N_S = 300

Known: $E_P = (4.44 \times f \times N_P \times \phi_m)$ volts

$$\frac{V_P}{V_S} = \frac{I_S}{I_P} \cong \frac{E_P}{E_S} \cong \frac{N_P}{N_S}$$

$V_P I_P = V_S I_S = KVA$

Find: Primary current I_P

Secondary current I_P

Primary turns N_P

Maximum flux Φ_m

Solution

(a) $I_P \text{ (full load)} = \frac{KVA \times 1000}{V_p} = \frac{100000}{2400} = 41.7A$

and $I_S = \frac{100000}{240} = 417A$

(b) $\frac{V_P}{V_S} = \frac{2400}{240} = 10 = \frac{N_P}{N_S}$

Therefore, $N_P = 10 \times N_S$

$= 10 \times 300 = 3000$ turns.

(c) $4.44 \times f \times N_P \times \phi_m = E_P$

$$\Phi_m = \frac{2400}{4.44 \times 50 \times 3000} = 0.0036 \text{ Wb.}$$

Example 2: In a transformer the number of turns per volt (i.e N/V) is 8. The primary voltage is 110V. Find the primary and secondary turns of wire if V_2 is to be 25 volts.

Data given: $V_1 = 110V$

$$\frac{\text{Primary turns}}{\text{Primary volts}} = \frac{N_1}{V_1} = 8$$

$V_2 = 25$

Known: $\frac{V_1}{V_2} = \frac{N_1}{N_2}$ or $\frac{N_1}{V_1} = \frac{N_2}{V_2}$

Find: N_1 and N_2

Solution: Primary turns $\frac{N_1}{V_1} = 8$

$N_1 = 8 \times 110 = 880$ turns

Secondary turns $N_2 = 8 \times 25 = 200$ turns

Classification of transformers

Objectives : At the end of this exercise you shall be able to
- **state the classification of transformers based on various factors**
- **state about the dry type transformers.**

Classification of Transformers

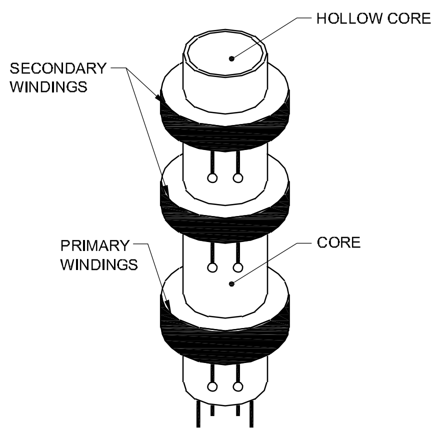
1 Classification based on the type of Core Material used

- **Air core transformers** : Fig 1, air core transformers consists of a hollow non magnetic core, made of paper or plastic over which the primary and secondary windings are wound. These transformers will have values of k less than 1. Air core transformers are generally used in high frequency applications because these will have no iron-loss as there is no magnetic core material.

2 Classification based on the shape of core

- **Core type transformers**: In Core type of transformer, the primary and secondary windings are on two separate sections/limb of core. (Fig 1 in chart 1)
- **Shell type transformers**: In this type, both the primary and the secondary windings are wound on the same section/limb of the core.These are widely used as voltage and power transformers. (Fig 2 in chart 1)
- **Ring type transformers**: In this, the core is made up of circular or semicircular laminations (Fig 2). These are stacked and clamped together to form a ring. The primary and secondary windings are then wound on the ring. The disadvantage of this type of construction is the difficulty involved in winding the primary and secondary coils. Ring type transformers are generally used as instrument transformers for measurement of high voltage and current. (Fig 3 in chart 1)

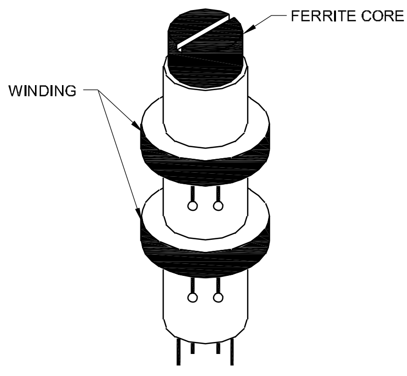
Fig 1



AIR CORE TRANSFORMER

ELN2710631

Fig 2



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4 Single phase and three phase transformers

Transformers Fig 4 of Chart 1 are designed for use with single phase AC mains supply. Such transformers are known as single phase transformers. Transformers are also available for 3 phase AC mains supply. These are known as poly-phase transformers. Refer Fig 5 in Chart 1. Three phase transformers are used in electrical distribution and for industrial applications.

5 Classification based on application

Transformers can also be classified depending upon their application for a specialized work. There are innumerable number of applications, However a few of these are listed below:

Instrument Transformers - used in clip - on current meters, overload trip circuits etc.,

Constant voltage transformers - used to obtain stabilized voltage supply for sensitive equipments

Ignition transformers - used in automobiles

Welding transformers - used in welding equipments

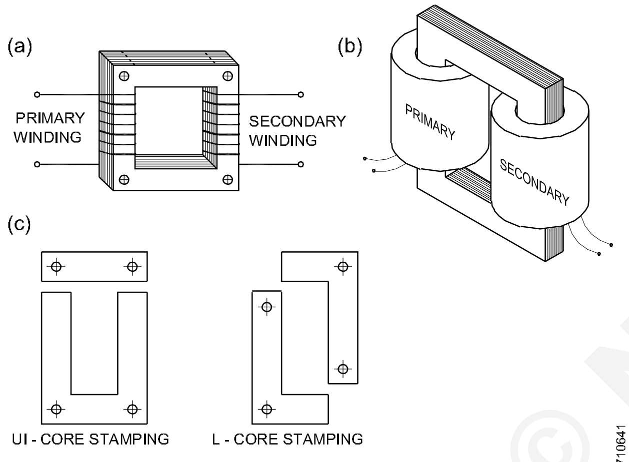
Pulse transformers - used in electronic circuits

Dry Type Transfomers

Dry type, or air-cooled, transformers are commonly used for indoor applications where other transformer types are considered too risky.

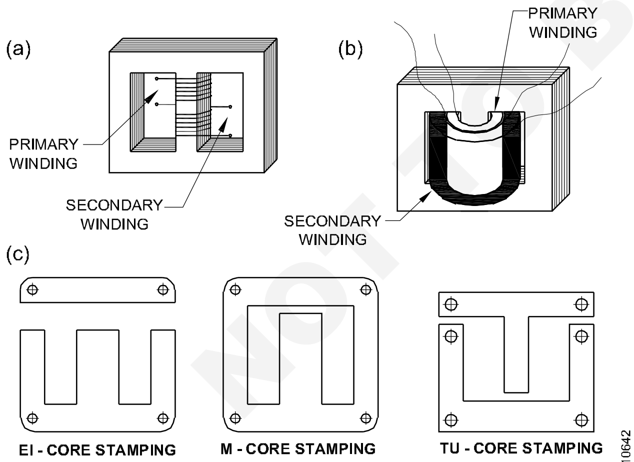
Chart - 1
Types of transformers

Fig 1 **CORE - TYPE TRANSFORMER**



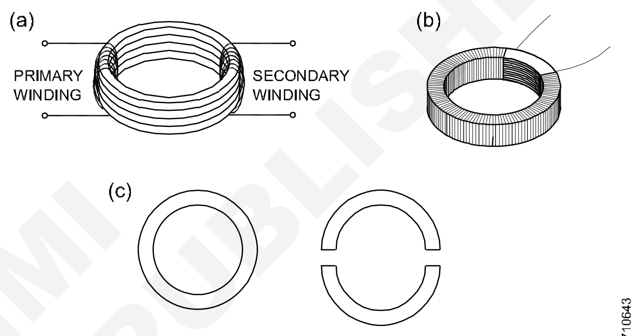
CORE-TYPE TRANSFORMER

Fig 2 **SHELL - TYPE TRANSFORMER**



SHELL-TYPE TRANSFORMER

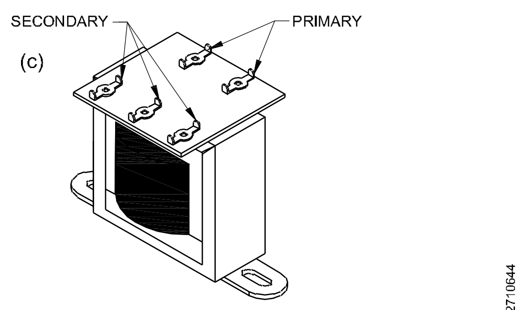
Fig 3 **RING - TYPE TRANSFORMER**



RING - TYPE TRANSFORMER

SINGLE PHASE TRANSFORMER

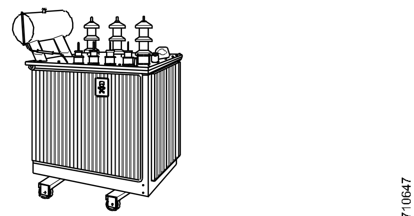
Fig 4



MAINS FREQUENCY TRANSFORMER

POLY - PHASE TRANSFORMER

Fig 5



POLY - PHASE TRANSFORMER

Parts and their functions of transformer

Objectives: At the end of this lesson you shall be able to
- **list out the mainparts of transformer**
- **explain the parts of a distribution transformer.**

Distribution transformer: Fig 1 shows the essential parts of a distribution transformer.

The important components of a distribution transformer are briefly described below:-

The important components of transformer are : -

1 Steel tank

2 Conservation tank

3 Temperature gauge

4 Explosion vent

5 Cooling tubes

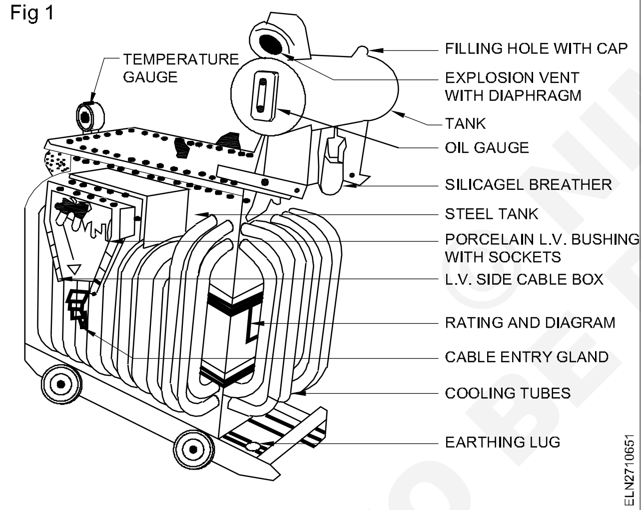
6 Tap changer

7 Bushing termination

8 Silical gel breather

9 Buchholz relay

Fig 1



1 Steel tank

It is a fabricated M.S plate tank used for housing the core, winding and for mounting various accessories required for the operation of a transformer. Core is built from cold rolled grain oriented silicon steel lamination. The L.V winding is normally close to the core and the H.V winding is kept around the L.V winding.

2 Conservator tank

It is in the shape of a drum, mounted on the top of the transformer. An oil level indicator is fitted to the conservator tank. Conservator is connected to the transformer tank through a pipe. The conservator carries the transformer oil to a specified level. When transformer is heated up due to normal load operation, the oil expands and the level of oil in conservator tank is increased or vice versa. A pipe connected to the top of the conservator tank allows the internal air to go out or get in through the breather.

It reduces the oxidation of oil when it get contact with air.

3 Temperature gauge

It is fitted to the transformer which indicates the temperature of the transformer oil.

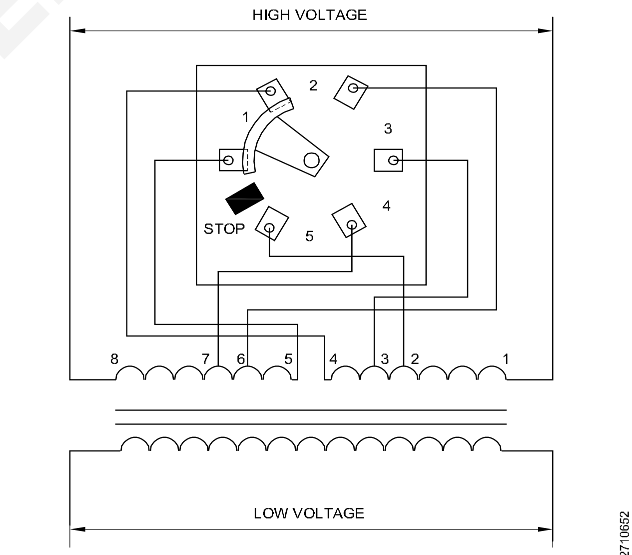
4 Cooling tubes

In earlier discussions, we found that the transformer is heated up, when the transformer is connected to the supply is due to iron loss and copper loss. To keep down the temperature of the windings, when the transformer is put on load, the heat generated inside the transformer should be radiated to the atmosphere. To dissipate the heat produced inside the winding and core, the transformer tank is filled with an insulating oil. The oil carries the heat to the cooling pipes where the heat is dissipated to atmosphere due to surface contact with air.

5 Tap changer

When voltages are transmitted over long distances there will be voltage drop in the conductors, resulting in lower voltage at the receiving end. To compensate this line voltage drops in the conductors, it is customary to increase the sending end voltage by tap changing transformers. These transformers may have several winding taps in their primary winding (Fig 2).

Fig 2



MANUALLY OPERATED TAP - CHANGING

6 Porcelain bushing of transformer

This type of Transformer Bushings are used in several power industries for their robustness and they are also very cheap. Porcelain offers very good and reliable electrical insulation for a wide range of voltages as well as they have high dielectric strength too.

A porcelain bushing is a hollow cylindrical shaped arrangement made by porcelain discs which is fitted to the top portion of the transformer. And the energised conductors are passed through the centre portion of the bushings.

After inserting the conductor, the ends of the porcelain bushings are tightly sealed with glaze and this arrangement ensures a prevention from any type of moisture.

The entire bushing arrangement is checked and it should not contain any leakage paths. If the operating voltage level is very high then the vacuum space of the Transformer Bushing is filled with insulating oil.

7 Protective - devices / parts of transformers:

1 Breather

Transformer oil deterioration takes place due to moisture. Moisture can appear in a transformer from three sources, viz. by leakage through gasket, by absorption from air in contact with the oil surface or by its formation within the transformer as a product of deterioration as insulation ages at high temperature.

The effect of moisture in oil is to reduce the di-electric strength, especially if loose fibres or dust particles are present.

Methods available to reduce oil contamination from moisture are:

- by the use of silica gel breather
- by the use of rubber diaphragm
- by using sealed conservator tank
- by using gas cushion
- by using thermosyphon filter

Silica gel breather: Silica gel breather is a protective device fitted to the conservator through a pipe and allows the moisture free air to and fro into the conservator when the transformer oil get heated and cools down.

As the load and heat on a transformer reduces, air is drawn in to the conservator through a cartridge pakced with **silica gel crystals**.

The silica gel effectively dries the air and thus prevent the moistured dust entering into transformer oil. The fresh silica gel is available in blue colour. The colour of the silica gel changes to pure white or light pink colour as it absorbs moisture from air.

To recondition silica gel either it can be dried in sun or it could be dry roasted on a frying pan kept over a stove.Fig 3 & 4 show a cross-sectional view of such a silica gel breather.

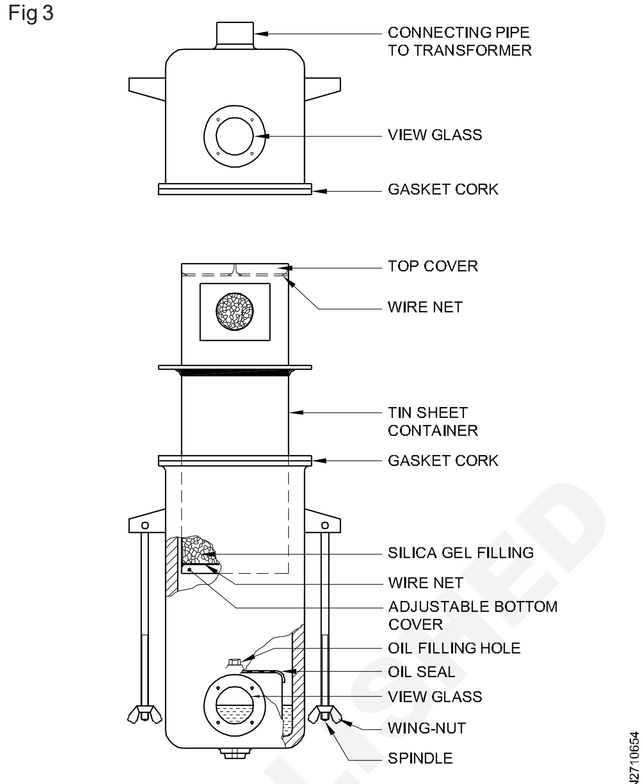
The oil seal at the bottom of the breather absorbs the dust particles that are present in the air entering the conservator.

2 Buchholz relay

Buchholz relay is a gas operated - protective device which is connected between the transformer oil tank and the conservator tank.

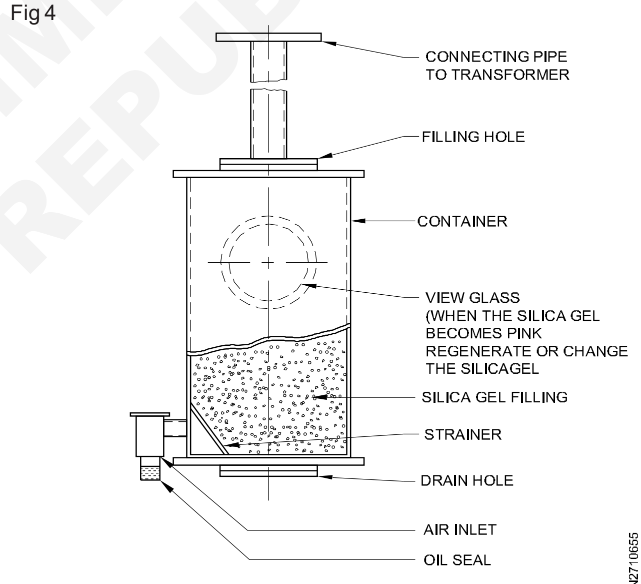
If a fault is present inside a transformer, it may be indicated by the presence of bubbles (gas) in the transformer oil. Presence of gas could be viewed from class in window of by the Buchholz relay.

Fig 3



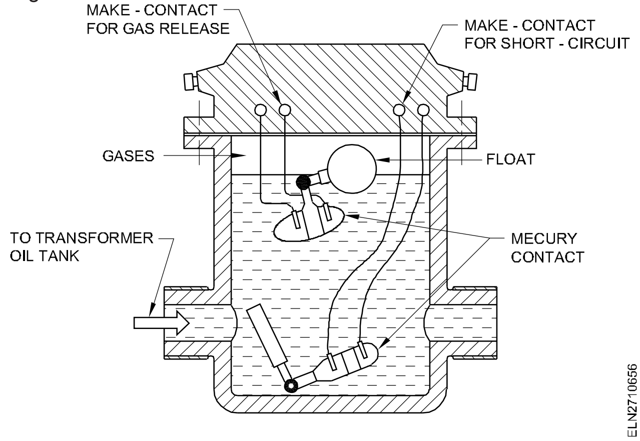
SILICA GEL BREATHER

Fig 4



SILICAL GEL BREATHER

Fig 5



The relay comprises of a cast iron chamber which have two floats. Top float assembly operates during initial stages of gas/air bubble formation due to minor fault in the transformer.

When sufficient gas bubbles formed around the top float, the float operates in pneumatic pressure principle to close an electric circuit through mercury switch which causes the siren or alarm bell to operate to caution the operator.

On hearing the alarm sound the operator takes necessary preventive steps to safeguard the transformer.

If any major fault like earth, fault etc, occurs in the transformer then the production of gas bubbles are more severe and hence the bottom float activates the mercury switch and closes the relay contacts.

Closing of the bottom relay contacts trips the transformer circuit breaker and opens the transformer from main line to protect the transformer from further damage.

3 Explosion vent

It is a pressure release device fitted to the transformer. The mouth of the explosion pipe is tightly closed using either a thin glass or laminated sheet.

If, by any, chance the transformer is overheated either due to short circuited or sustained overload, the gases produced inside the transformer tank creates tremendous pressure which may damage the tank.

On the other hand the pressure built inside the transformer may break the glass/laminated diaphragm of the explosion pipe and thereby the tank can be saved from total damage.

Autotransformer - principle - construction - advantages - applications

Objectives: At the end of this lesson you shall be able to
- **state the principle of auto-transformer**
- **describe the construction of auto-transformer**
- **state the advantages, disadvantages and appliations of auto-transformer.**

Auto transformer

- The auto transformer is a transformer having single winding which acts as primary as well as secondary winding.
- The auto transformer works on the principle of self inductance of Faraday's Law of electro - magnetic induction.

It may be recalled that in the discussion of transformer operation a counter emf was induced in the winding which acted as primary.

The induced voltage per turn was the same in each and every turn linking with the common flux in the core.

Therefore, fundamentally it makes no difference in the operation whether the secondary induced voltage is obtained from a separate winding linked with the core, or from a portion of the primary turns. The same voltage transformation results in both the situations.

Construction: An ordinary two winding transformer may also be used as an auto-transformer by connecting the two windings in series and applying the voltage across the two, or merely to one of the windings.

It depends on whether it is desired to keep the voltage down or up, respectively.

Figs 1 and 2 show these connections.

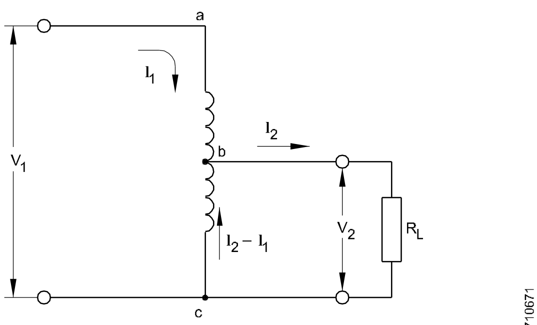
Advantages : Auto-transformers:

- less cost
- have better voltage regulation
- are smaller
- are lighter in weight
- are more efficient when compared with two winding transformers of the same capacity.

Disadvantages: Auto-transformers have two disadvantages.

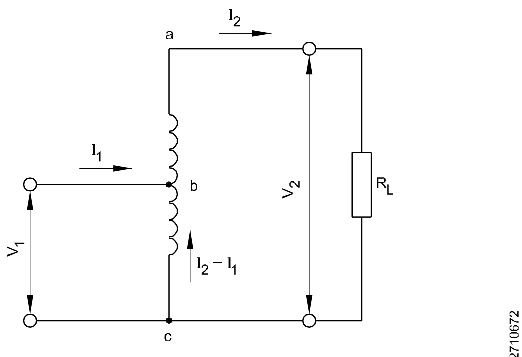
- An auto-transformer does not isolate the secondary from the primary circuit.
- If the common winding bc becomes open circuit, referring to Fig 1 or 2, the primary voltage can still feed the load. With a step-down auto-transformer this could result in burnt out secondary load and/or a serious shock hazard, particularly if the step down ratio is high.

Fig 1



AUTOTRANSFORMER STEP-DOWN

Fig 2

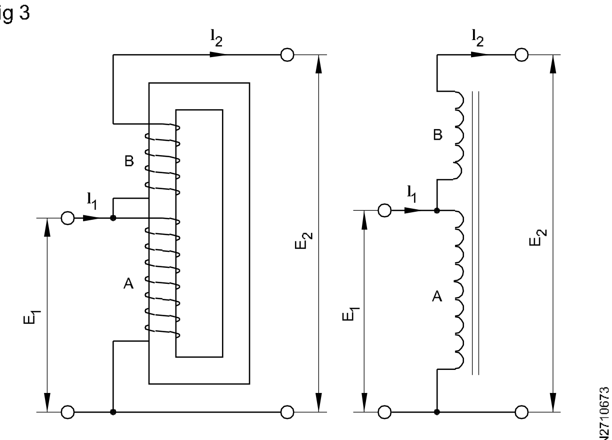


AUTOTRANSFORMER STEP-UP

Application: The common applications are:

- fluorescent lamps (where supply voltage is less than the rated voltage)
- reduced voltage motor starter
- series line boosters for fixed adjustment of line voltage (Fig 3)
- servo-line voltage correctors.

Fig 3



BOOSTER CIRCUIT

Transformer losses - OC and SC test - efficiency - Voltage Regulation

Objectives: At the end of this lesson you shall be able to
- **state the type of losses occured in transformer**
- **explain Iron (No - load) losses and copper (load) losses in transformer.**

Losses

There are two type of losses occured in the transformer such as iron (core) loss (Hysterisis + eddy current) and copper (Ohmic) or load loss

Iron (or) No-load losses: The no load losses consist of two components i.e hysteresis and eddy current loss.The hysteresis loss due to the cyclic variation of the magnetic flux in the ferrous metal.

The eddy current occurs because of the changing flux in the core,(according to Lenz's law) inducing a voltage in the core. As a result, circulating eddy currents set up in the core with subsequent I^2R loss. This is also called as **iron loss (or) core loss (or) constant losses**.

As the core flux in a transformer remains practically constant at all loads, the core-loss is also constant at all loads. This is also known as no-load losses.

Hysteresis loss W_h = $K_h B_m^{1.6}$ watts
Eddy current loss W_e = $K_e f^2 K_f B_m^2$
where K_h = the hysteresis constant
K_f = the form factor
K_e = the eddy current constant

These losses are minimised by using steel of high silicon content (from 1.0 to 4.0 percent) for the core and by using very thin laminations.

Silicon steel has a high saturation point, good permeability at high flux density, and moderate losses. Silicon steel is widely used in power transformers, audio output transformers and many other applications.

The input power of a transformer, when on no-load, measures the core-loss.

Copper (or) Load losses: This loss is mainly due to the ohmic resistance of the transformer windings. The load current through the resistances of the primary and secondary windings creates I^2R losses that heat up the copper wires and causes voltage drops. This loss is also called **copper losses (or) variable losses**. Copper losses are measured by the short circuit test.

The core loss in a transformer is a constant loss for all load conditions. The copper loss varies proportionally to the square of the current.

Open Circuit (O.C) test of a transformer

Objective: At the end of this lesson you shall be able to
- **explain the method of conducting an open circuit test**
- **calculate the exact iron loss.**

The open circuit

The open circuit test is performed to determine the no-load losses or the core losses.

In this test, a rated voltage is applied to one winding, usually the low-voltage winding for safety reasons, while the other is left open-circuited. The input power supplied to the transformer represents mainly core losses. Since the no-load current is relatively small the copper loss may be neglected during this test.

The circuit instruments are shown in Fig 1. The wattmeter indicates the core loss. The voltmeter will register the rated voltage. The ammeter reading in conjunction with voltage will provide the necessary data to obtain information about the magnetizing branch.

The core loss can be measured on either side of the transformer. For instance, if a 3300/240V transformer were to be tested the voltage would be applied to the secondary side, since 240V is more readily available.

The core loss measured on either side of the transformer would be the same, because 240V is applied to a winding that has fewer turns than the high voltage side. Thus the volt/turn ratio is the same. This implies that the value of the maximum flux in the core is the same in either case. The core loss depends on the maximum flux.

The frequency of the o.c. test supply should be equal to the rated frequency of the transformer.

The actual (exact) iron loss (W_i) can be calculated by the formula

Iron loss $= W_i = W_0$ - no load copper loss

$W_i = W_o - (I_0)^2 R$

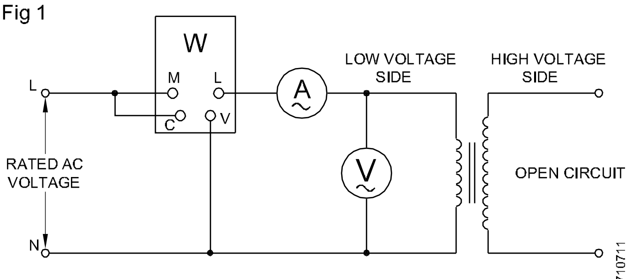
W0 = Wattmeter reading on no load

No Load copper loss = $(I_0)^2$ R

R = Resistance of winding in which the OC test calculated

I_0 = No - load current

Fig 1



OPEN CIRCUIT TEST CONNECTIONS

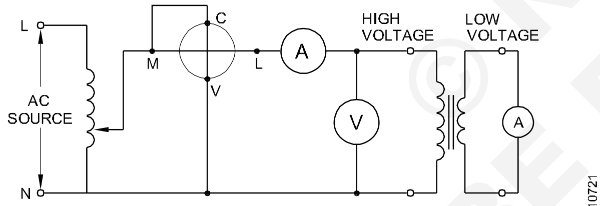
Short circuit (S.C) test of a transformer

Objectives: At the end of this lesson you shall be able to
- **explain the method of conducting the short circuit test on a single phase transformer**
- **calculate the equivalent resistance and equivalent reactance of the transformer, with respect to high voltage circuit**
- **calculate the copper loss.**

Short circuit test:

A short circuit test is required to determine the transformer equivalent circuit parameters and copper losses. The connected diagram for the short circuit test is shown in Fig 1.

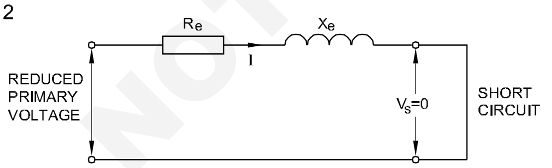
Fig 1



CONNECTION DIAGRAM

The low voltage side of the transformer is short circuited. A reduced voltage applied on the high voltage winding of the transformer such that the rated current flows through the ammeter. In this condition the impedance of the transformer is merely as equivalent impedence (Fig 2).

Fig 2



EQUIVALENT CIRCUIT

The test is performed on the high voltage side because it is convenient to apply a small percentage of the rated voltage. In the case of a 3300V/240V transformer, it is easier and more accurate to deal with 5% of 3300V than with 5% of 240V.

With the primary voltage greatly reduced, the flux will be reduced to the same extent. Since the core loss is somewhat proportional to the square of the flux, it is practically zero.

Thus a wattmeter used to measure the input power will indicate the copper losses only; the output power is zero. From the input data obtained from the instruments, the equivalent reactance, can be calculated. All the values calculated are in terms of high voltage side.

R_e is equivalent resistance

X_e is equivalent reactance

R_{eH} is equivalent resistance on high voltage side

X_{eH} is equivalent reactance on high voltage side

Z_{eH} is equivalent impedance on high voltage side

$$R_{eH} = \frac{P_{SC}}{I^2_{SC}} \text{ ohms}$$

$$Z_{eH} = \frac{V_{SC}}{I_{SC}} \text{ ohms}$$

$$\text{and } X_{eH} = \sqrt{Z^2_{eH} - R^2_{eH}} \text{ ohms}$$

where I_{sc}, V_{SC} and P_{SC} are the short circuit amperes, volts and watts respectively, and R_{eH}, Z_{eH} and X_{eH} are equivalent Resistance, Impedance and Reactance respectively in terms of high voltage side.

Efficiency of transformer

In general, the efficiency of any electrical apparatus is

$$\eta = \frac{\text{output power}}{\text{input power}} = \left|\frac{\text{output power}}{\text{output power} + \text{losses}}\right| \text{.....x } 100$$

Condition for maximum efficiency:

The efficiency of a transformer is at a maximum when the fixed losses are equal to the variable losses. In other words, when the copper losses is equal to the iron losses, the efficiency is maximum.

Voltage regulation

The voltage regulation of a transformer is the difference between the no-load and full load secondary voltage expressed as a percentage of the full load voltage. The primary or applied voltage must remain constant.

This is an additional condition that must be fulfilled in the case of transformers.

Also, the power factor of the load must be stated since the voltage regulation does depend on the load power factor.

In general,

$$\text{Voltage regulation} = \frac{V_{noload} - V_{load}}{V_{load}} \times 100\%$$

Let V_0 = Secondary terminal voltage at no-load
V_S = Secondary terminal voltage at load.

$$\text{Then \% regulation} = \frac{V_o - V_S}{V_S} \times 100$$

The numerical values employed in the calculations depend on which winding is used as a reference for the equivalent circuit. Similar results are obtained whether all impedance values are transferred to the primary or to the secondary side of the transformer.

Assignment

The secondary voltage of 11KV/440V, 100KVA transformer is 426 V at no-load. Under the full load condition, the same is 410V at 0.92 Power factor. Calculate the percentage voltage regulation of the transformer.

Three Phase transformer - Connections

Objectives: At the end of this lesson you shall be able to
- **state the transformer connections, of the 3 phase transformers.**

The high voltage and low voltage winding terminals of a three-phase transformer are connected either in star or in delta for connections to a three-phase system.

When the primary high voltage winding terminals are connected in, say, star and the secondary low voltage winding terminals are connected in, say, delta, it is said that the transformer windings are connected in star-delta (Y – Δ or Y – d). Similarly

star-star (Yy)

delta-delta (Dd)

and, delta-star (Dy) connections can be used.

Type of connection	High voltage side	Low voltage side
Delta	D	d
Star	Y	y

Fig 1 shows the high voltage side and low voltage side windings are connected in star-star

Fig 1

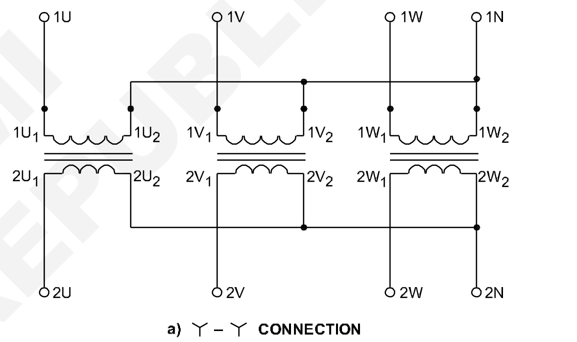
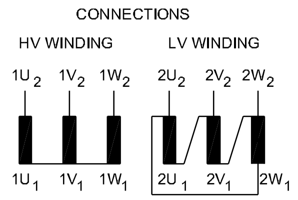


Fig 2 shows the primary high voltage and secondary low voltage side windings are connected in Yd (Star-delta).

Fig 2



Three single phase transformers for three phase operation

Objectives: At the end of this lesson you shall be able to
- **list and interpret the four types of connections of primary and secondary windings**
- **state the phase and line values of current and voltage.**

There are various methods available for transforming 3-phase voltages, that is for handling a considerable amount of power. There are four possible ways in which the primary and secondary windings of a group of three transformers may be connected together to transfer energy from one 3-phase circuit to another. They are:

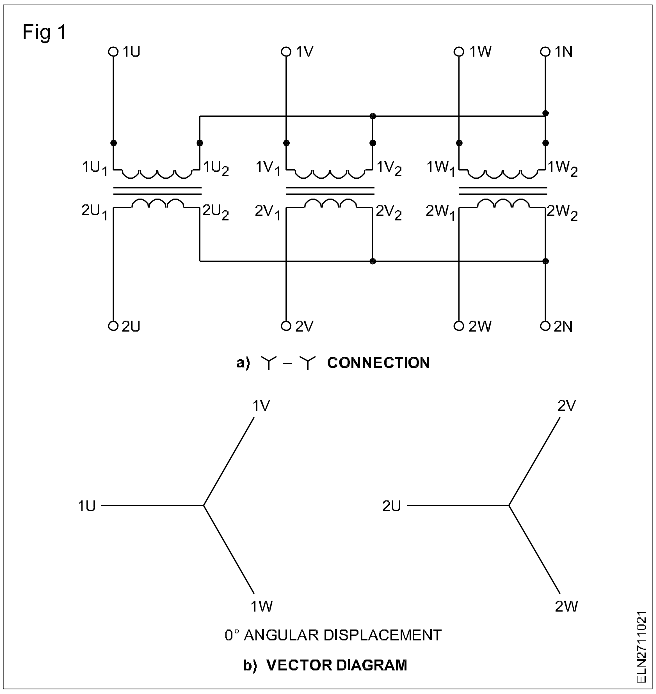
Primaries in Y, Secondaries in Y

Primaries in Y, Secondaries in Δ

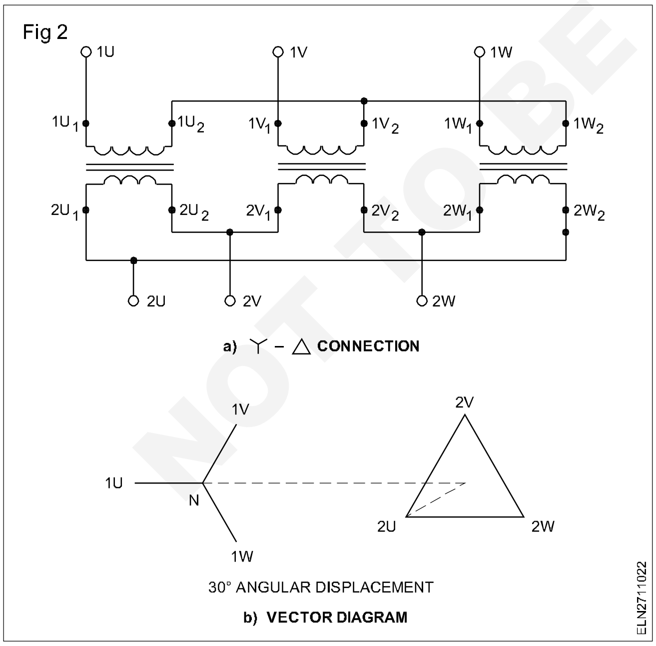
Primaries in Δ, Secondaries in Δ

Primaries in Δ, Secondaries in Y.

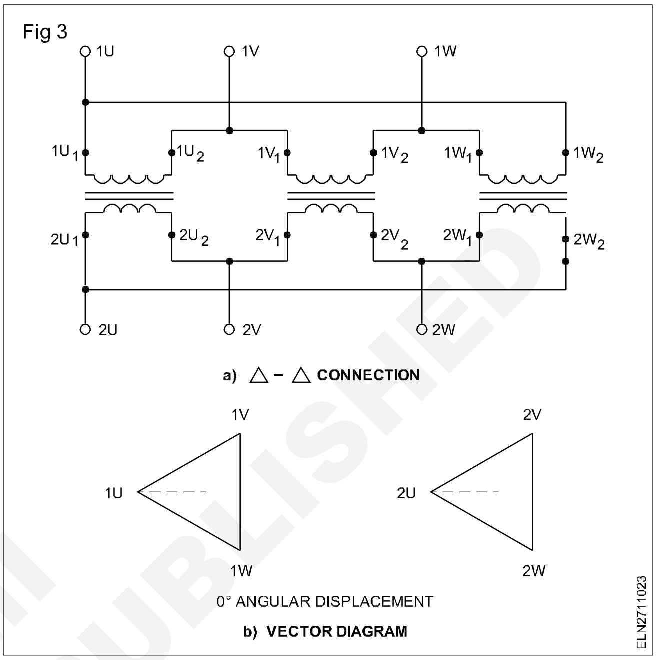
Star/Star or Y/Y connection: Fig 1 shows the connection of a bank of 3 trans-formers in a star-star. This connection is most economical for small, high voltage transformers because the number of turns per phase and the amount of insulation required is minimum. This connection works satisfactorily only if the load is balanced. For a given voltage V between lines, the voltage across the terminals of a Y connected transformer is $V/\sqrt{3}$; the coil current is equal to the line current I.



Star - Delta or Y/Δ connection: In primary side 3 transformers are connected in star and the secondary consist of their secondary connected in delta as shown in Fig 2. The ratio between the secondary and primary line voltage is $1/\sqrt{3}$ times the transformation ratio of each transformer. There is a 30° shift between the primary and secondary line voltages. The main use of this connection is at the substation end of the transmission line.

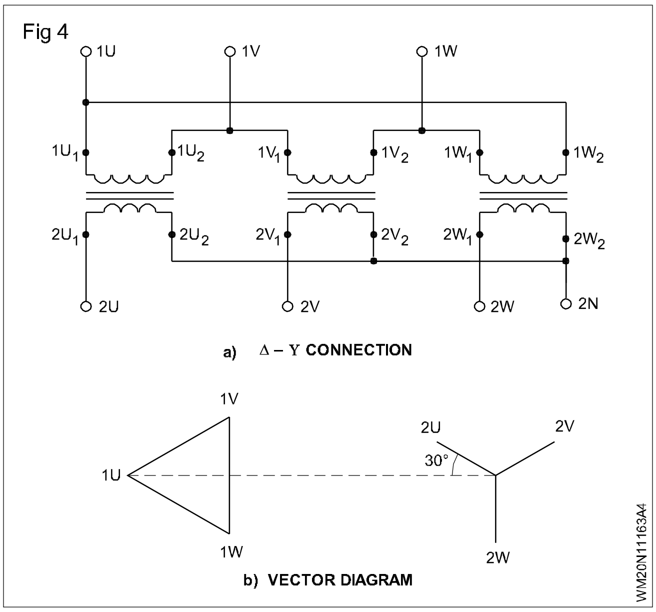


Delta - Delta or Δ/Δ connection: Fig 3 shows three transformers, connected in Δ on both primary and secondary sides. There is no angular displacement between the primary and secondary line voltages. An added advantage of this connection is that if one transformer becomes disabled, the system can continue to operate in open-delta or in V-V. In V-V it can be operated with a reduced capacity of 58% and not 66.6% of the normal value.



Delta - Star or Δ/Y connection: (Fig 4) This connection is generally employed where it is necessary to step up the voltage, as for example, at the beginning of high tension transmission system.

The primary and secondary line voltages and line currents are out of phase with each other by 30°. The ratio of secondary to primary voltage is $\sqrt{3}$ times the transformation ratio of each transformer.



Single phase motors

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.**

Introduction: 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. Most single phase motors fall into this category. Single phase motors are also manufactured in 1.5,2,3 and up to 10 H.P. as a special requirement.

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.

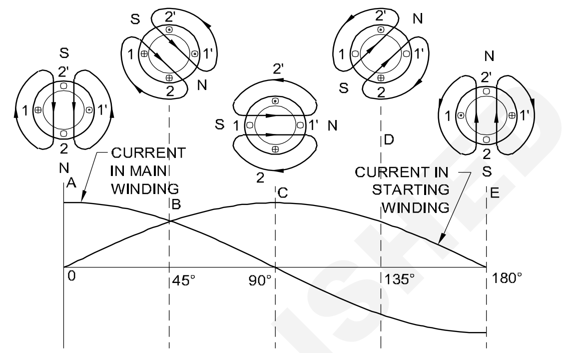
The basic principle of operation of a split-phase induction motor is similar to that of a polyphase induction motor. The main difference is that the single phase motor does not produce a rotating magnetic field but produces only a pulsating field. Hence to produce the rotating magnetic field, phase-spliting 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 Powerdegrees 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 as stated below.

Fig 1 shows that the main (1,1') and starting (2,2') windings are kept in the stator at 90° to each other. For consideration, only, one half cycle is shown with the effects at 45^0 increments.

Fig 1



PRODUCING ROTATING FIELD FROM TWO 90° OUT-OF-PHASE FIELDS

At position `A', only the main winding is producing flux, and the net flux will be in a vertical direction, as shown in the stator diagram. At instant `B', 45° later, both windings are producing flux, and the net flux direction will also have rotated 45°. At position `C', the maximum flux is now in a horizontal direction because only the starting winding is producing flux. At instant `D', the current from the main winding is building up again, but in a new direction, while that from starting winding is now decreasing. Therefore, the net flux at this instant will be as shown in position D. At position `E', the maximum flux is just the opposite of what it was at instant `A'. It should now be evident that the two out-of-phase fields are combining to produce a net rotating field effect.

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.

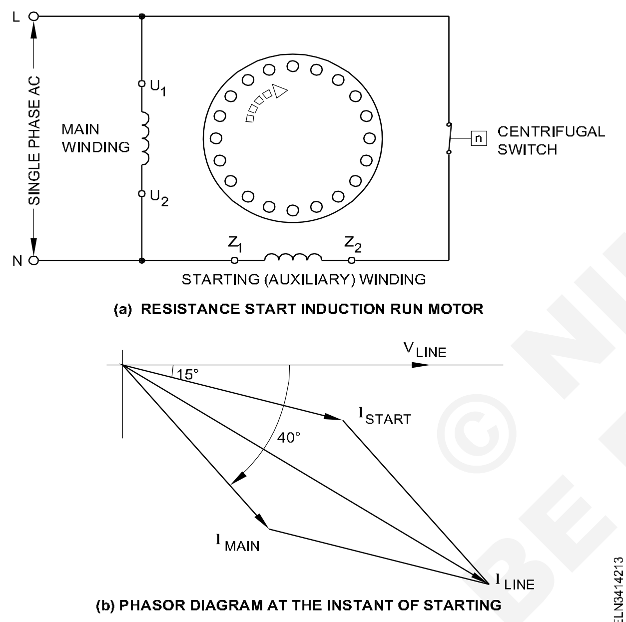
Resistance-start, induction-run motor: As the starting torque of this type of motor is relatively small and its starting current is high, these motors are most commonly used for rating up to 0.5 HP where the load could be started easily.

The essential parts are as shown in Fig 2a.

- 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 2b. 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.

Fig 2



(a) RESISTANCE START INDUCTION RUN MOTOR

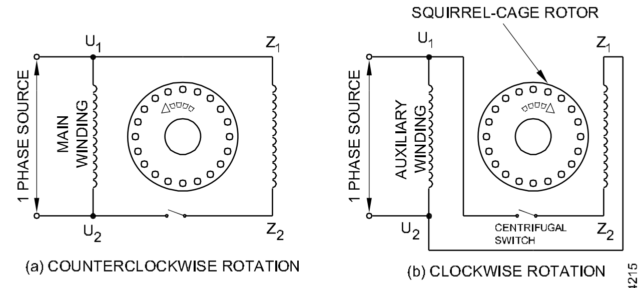
(b) PHASOR DIAGRAM AT THE INSTANT OF STARTING

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.

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.

Fig 3



(a) COUNTERCLOCKWISE ROTATION (b) CLOCKWISE ROTATION

METHOD OF CHANGING THE DIRECTION OF ROTATION OF RESISTANCE START INDUCTION RUN MOTOR

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 4, and a rotating part as shown in Fig 5. 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.

Fig 4

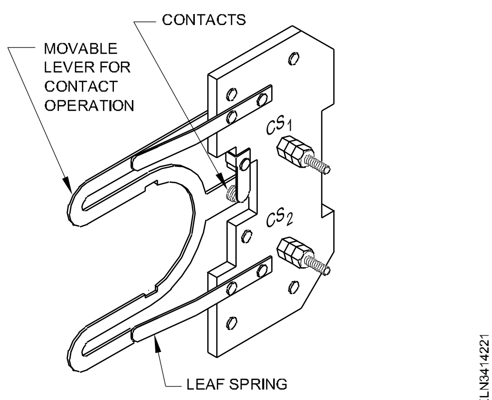
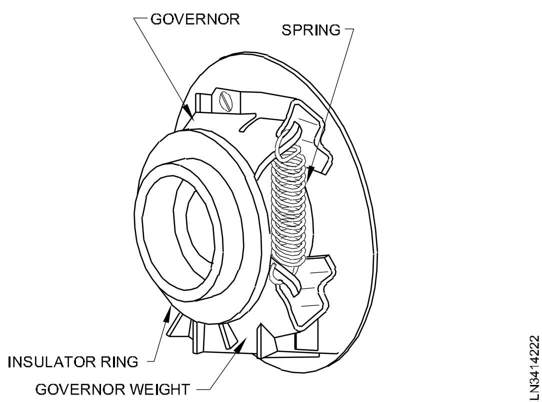


Fig 5



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.

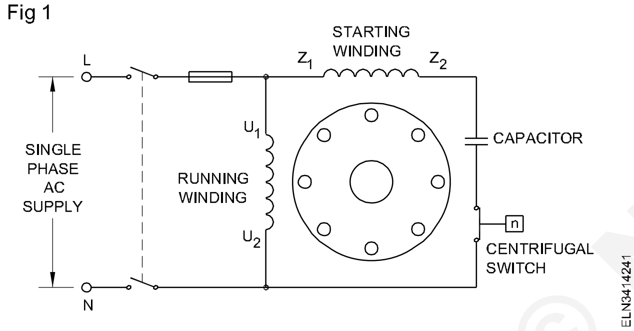
Capacitor - start, induction - run motor

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° Powerdegrees apart, and a squirrel cage type rotor is used.

Fig 1



At the time of starting, the current in the main winding lags the supply voltages by about 70° 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° degrees.

Hence, the phase difference between the main and starting winding becomes near to 90 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.

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.

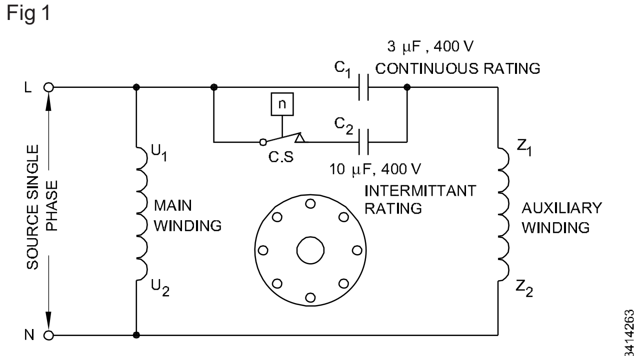
Capacitor-start, capacitor-run motor and shaded pole motor

Objectives: At the end of this lesson you shall be able to
- **explain the working of a capacitor-start, capacitor-run motor, state its characteristic and use.**

Capacitor-start, capacitor-run motors: 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 1. A general view of such a two-value capacitor motor is shown in Fig2. 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.

Fig 1



SCHEMATIC DIAGRAM OF A CAPACITOR-START CAPACITOR-RUN MOTOR

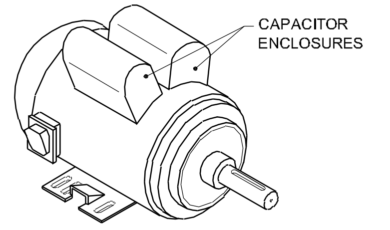


Fig 2

CAPACITOR-START CAPACITOR-RUN MOTOR

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.

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

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 characteristic of the shaded pole motor and its application.**

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 1.

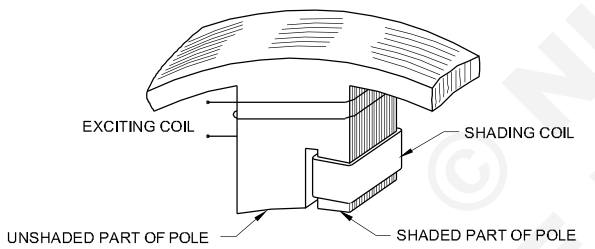


Fig 1

A TYPICAL SHADED-POLE CONSTRUCTION

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.

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 2. 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 electro-magnetic 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 2 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 2. On the other hand as shown in Part 2 of Fig 2 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 2.

In the next instant, as shown in part 3 of Fig 2, 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 2.

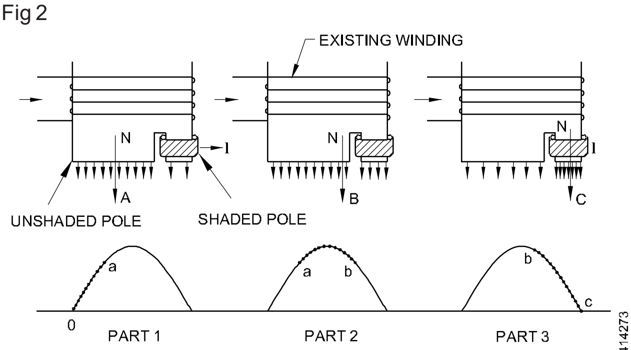


Fig 2

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.

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.

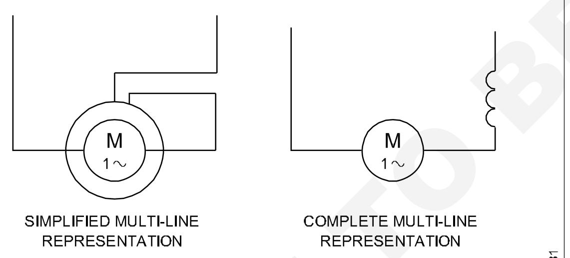
The efficiency varies from 5% to 35% only in these motors.

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 (or) 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 sparkless 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 3 shows the multi-line representation according to B.I.S. 2032, Part IV.

Fig 3



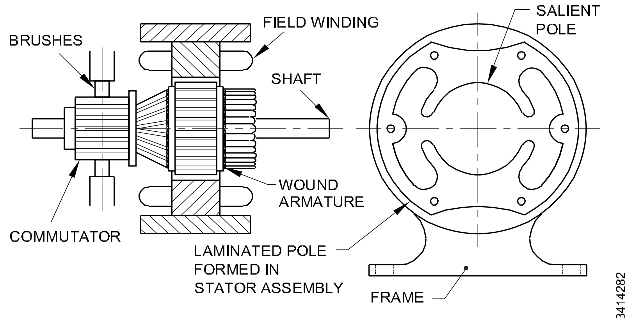
MULTILINE REPRESENTATION OF AC SINGLE PHASE SERIES MOTOR (BIS 2032-PART IV.)

The main parts of a universal motor are an armature, field winding, stator stampings, frame, end plates and brushes as shown in Fig 4.

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.

Fig 4

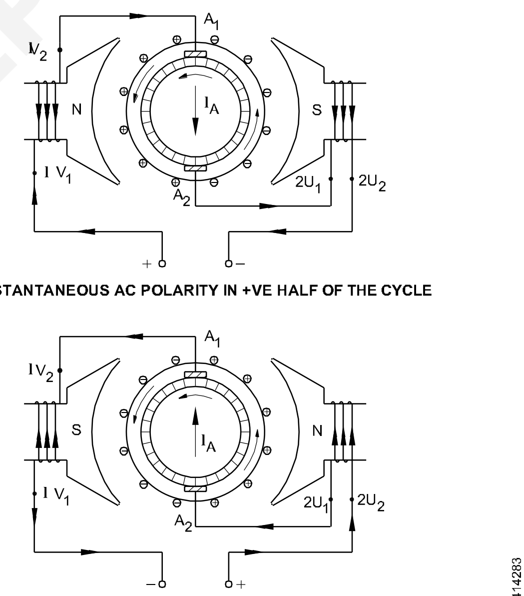


PARTS OF A UNIVERSAL MOTOR

- 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.

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 5 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 5



a) INSTANTANEOUS AC POLARITY IN +VE HALF OF THE CYCLE

b) INSTANTANEOUS AC POLARITY IN -VE HALF OF THE CYCLE

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**
- **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.

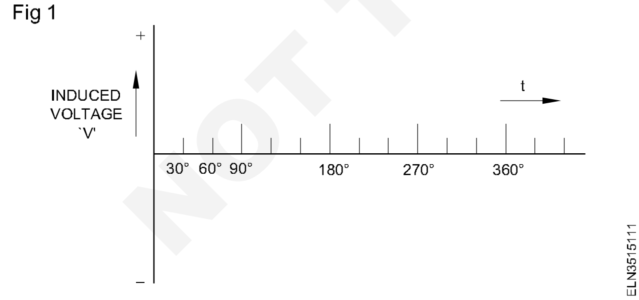
In the case of DC generators, we have seen that the alternating current produced inside the rotating armature coils has to be rectified to DC for the external circuit through the help of a commutator. But in the case of alternators, the alternating current produced in the armatrue coils can be brought 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 Powerdegrees of displacement of the loop are kept in the `X' axis as shown in Fig 1 through 30 Powerdegrees. 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.

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

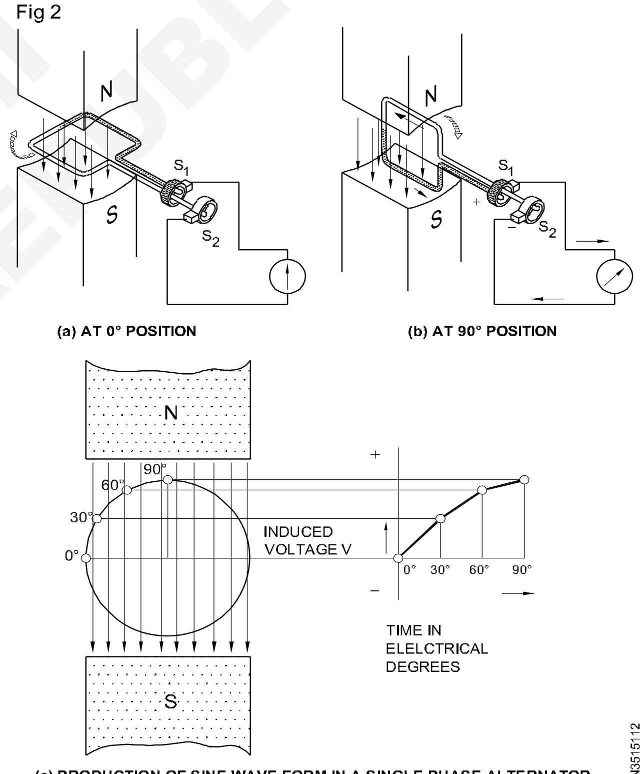
θ is the angle at which the conductor cuts the line of force.

As sin θ = 0

E at 0 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 (E_{30}) in the loop whose magnitude will be equal to BLV Sinq where θ 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 2



(a) AT 0° POSITION (b) AT 90° POSITION

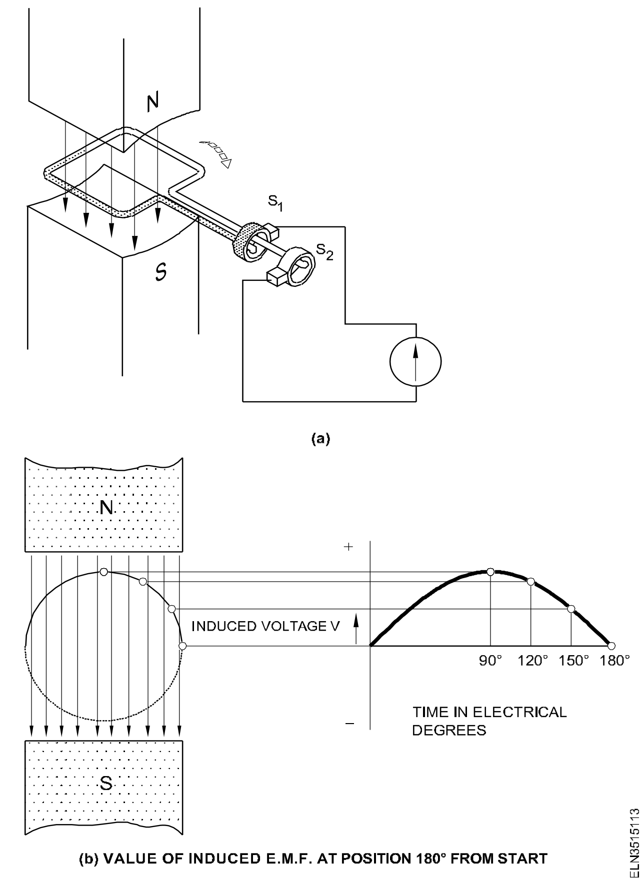
(c) PRODUCTION OF SINE WAVE FORM IN A SINGLE PHASE ALTERNATOR

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 0 to 180°, the slip ring S_1 will be positive and S_2 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.

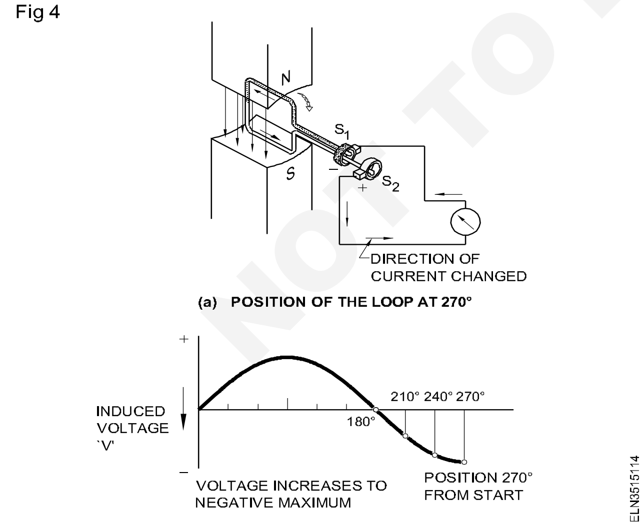
Fig 3



(b) VALUE OF INDUCED E.M.F. AT POSITION 180° FROM START

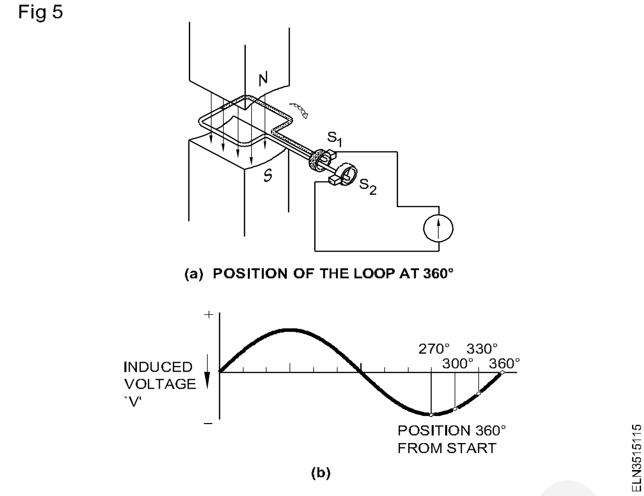
Further during the turn of the loop from the position 180° to 270°, the voltage increases again but the polarity is reversed as shown in Fig 4b. During the movement of the loop from 180 to 360°, the slip ring S_2 will be positive and S_1 will be negative as shown in Fig 4a. However, at 270° the voltage induced will be the maximum and will decrease to zero at 360°. Fig 5b shows the variation of the induced voltage in both magnitude and direction during one complete revolution of the loop. This is called a cycle.

Fig 4



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 number 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.

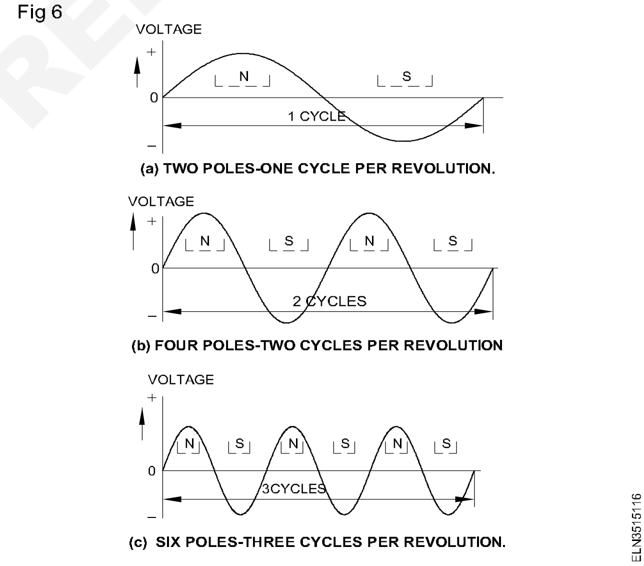
Fig 5



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.

Fig 6



Therefore frequency $F = \frac{P}{2} \times 'n'$

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 $F = \frac{PN}{2 \times 60} = \frac{PN}{120}$

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

Types and construction of alternators

Objective: 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 generator sends out the Powerenergy in the same form of alternating emf to the external load with the help of slip rings.

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 a 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.

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.

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.

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,W and 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.

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 be of cast iron or 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 1

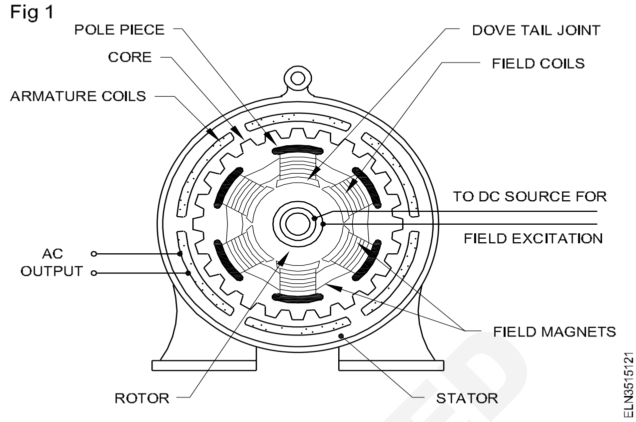
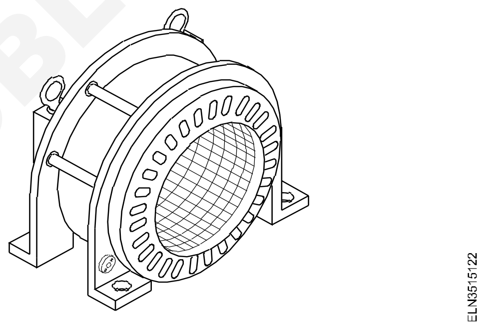
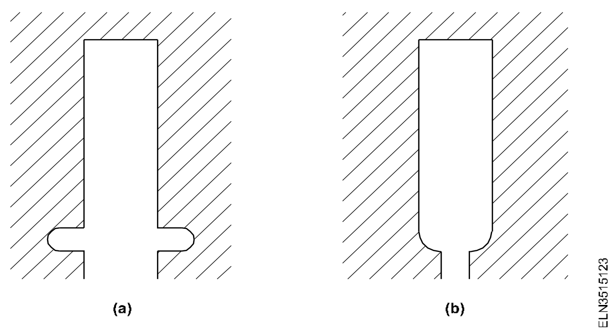


Fig 2



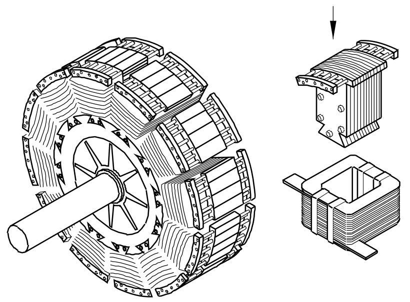
Slots provided on the stator core to house the armature coils are mainly of two types, (i) open and (ii) semi-closed slots, as shown in Fig 3a and b respectively.

Fig 3



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, thereby 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.

Fig 4



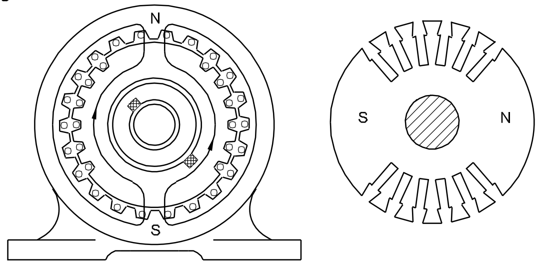
SALIENT POLE FIELD STRUCTURE

ELN3515124

Rotor: This forms the field system, and is similar to DC generators. Normally the field system is excited from a separate source of low voltage DC supply. The excitation source is usually a DC shunt or compound generator, known as an exciter, mounted to the same alternator shaft. The exiting current is supplied to the rotor with the 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, as shown in Fig 5.

Fig 5



NON-SALIENT POLE TYPE FIELD STRUCTURE

ELN3515125

Emf equation of the alternator

Objective: At the end of this lesson you shall be able to
- **explain 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

Ø = flux per pole in webers

k_f = form factor = 1.11 - if emf is assumed to be sinusoidal

N = 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 PØ webers.

Hence the change of total flux = dØ = PØ and the time duration in which the flux changes takes place

= dt = 60/N seconds.

Hence the average emf induced in a conductor

$$= \frac{d\varnothing}{dt} = \frac{P\varnothing}{\frac{60}{N}} \text{ volts} \qquad \text{-------- Eq 1}$$

Substituting the value for $N = \frac{120F}{P}$ in eqn 1

we have the average emf induced in a conductor =

$$= \frac{P\varnothing 120F}{P60} \text{ volts} = 2\varnothing F \text{ volts} \qquad \text{------ Eq. 2}$$

If there are Z conductors in series per phase we have the average emf per phase = 2ØFZ volts.

Then r.m.s. value of emf per phase = average value x form factor

$= V_{AV} \times K_F$

$= V_{AV} \times 1.11$

= 2ØFZ x 1.11

= 2.22ØFZ volts.

Alternatively r.m.s. value of emf per phase = 2.22ØF2T volts

= 4.44ØFT 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 directly; occasionally this value needs to be calculated by a formula $K_p = K_c = \cos a/2$

where a is the Powerangle by which the coil span falls short of full pitch.

Principle of 3-phase induction motor

Objectives: At the end of this lesson you shall be able to
- **state the principle of a 3-phase induction motor**
- **explain briefly the method of producing a rotating magnetic field.**

The three-phase induction motor is used more extensively than any other form of Powermotor, 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 conductors kept in a magnetic field will tend to create a force. However, the induction motor differs from the DC 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 stator magnetic 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 . The rotor 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.

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 Powerdegrees apart from each other. These windings are placed on the stator core to form non-salient stator field poles. When the stator is energized from a three-phase voltage supply, in each phase 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 rotating magnetic field could be produced by a set of 3-phase stationary windings, placed at 120° Powerdegrees 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.

$$= \frac{120F}{P} \text{ rpm}$$

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 rotor with short-circuited bars whereas slip ring motors have wound rotors having three windings, either connected in star or delta. The terminals of the rotor windings of the slip ring motors are brought out through slip-rings which are in contact with stationary brushes.

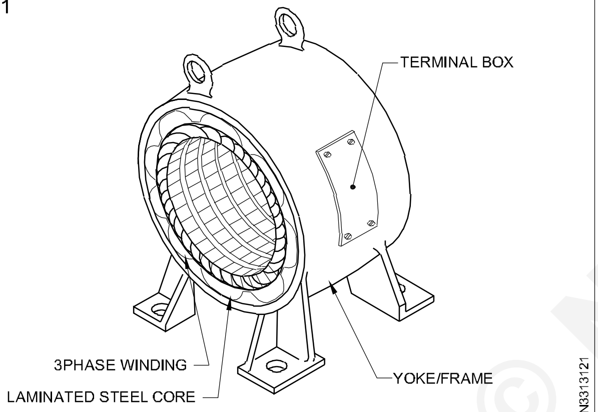
Development of these two types of induction motors is due to the fact that the torque of the induction motor depends upon the rotor resistance. Higher rotor resistance offers higher starting torque but the running torque will be low with increased losses and poor efficiency. For certain applications of loads where high starting torque and sufficient running torque are the only requirements, the rotor resistance 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. As this 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.

Stator of an induction motor: There is no difference between squirrel cage and slip-ring motor stators.

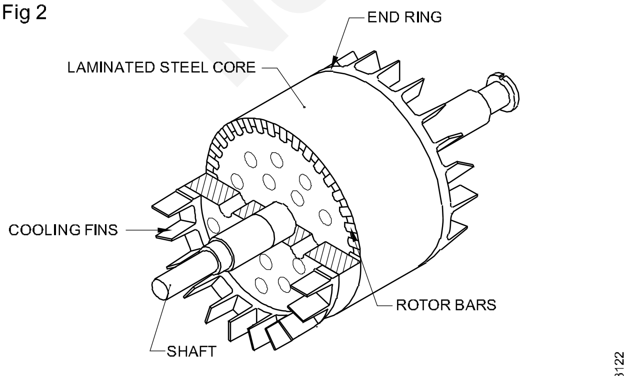
The induction motor stator resembles the stator of a revolving field, three-phase alternator. The stator or the stationary part consists of three-phase winding held in place in the slots of a laminated steel core which is enclosed and supported by a cast iron or a steel frame as shown in Fig 1. The phase windings are placed 120 Powerdegrees apart, and may be connected in either star or delta externally, for which 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.

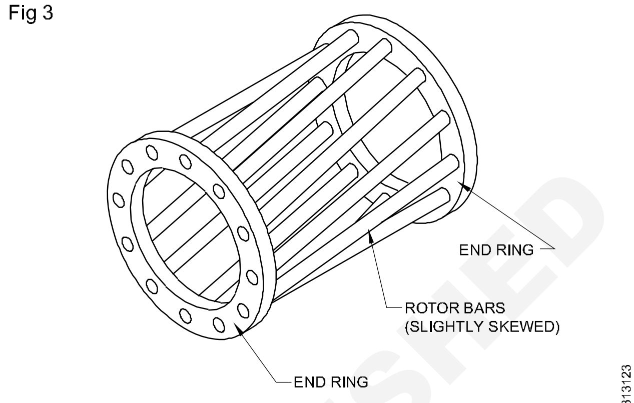
Fig 2



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 the bars and end-rings resembles a squirrel cage, the name squirrel cage induction motor is used. (Fig 3)

Fig 3



DETATCHED VIEW OF THE SQUIRREL CAGE MOTOR ROTOR BARS

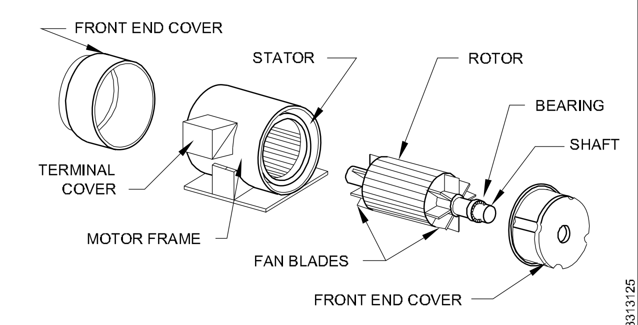
The rotor bars are not insulated from the rotor core because they are made of metals having less resistance than the core. The induced current will flow mainly in them. Also, the bars are usually not quite parallel to the rotor shaft but are mounted in a slightly skewed position. This feature tends to produce a more uniform rotor field and torque; also it helps to reduce some of the internal magnetic noise when the motor is running.

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.

Fig 4 shows the exploded view of 3 phase squirrel cage induction motor

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.

Fig 4



PARTS OF 3 PHASE SQUIRREL CAGE INDUCTION MOTOR

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

$$= \frac{N_s - N_r}{N_s}$$

Then percentage slip (% slip)

$$= \frac{N_s - N_r}{N_s} \times 100$$

where N_s = synchronous speed of the stator magnetic field

N_r = Actual rotating speed of the rotor in r.p.m.

Most squirrel cage induction motors will have a percentage slip of 2 to 5 percent of the rated load.

Insulation test on 3 phase induction motors

Objectives: At the end of this lesson you shall be able to

- **state the necessity for and the method of testing continuity and insulation resistance in a 3-phase induction motor**
- **state the necessity of continuity test before insulation test.**

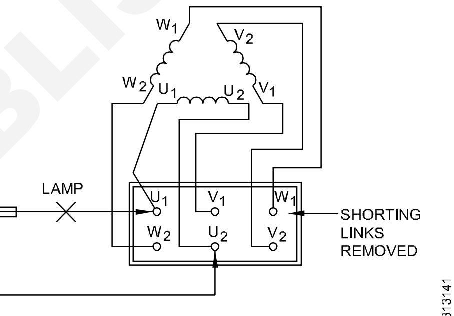
Necessity of continuity test before insulation test: While testing the insulation resistance between the winding and the frame, it is the usual practice to connect one prod of the Megger to the frame and the other prod to any one of the terminals of the winding. Likewise, when testing insulation resistance between windings, it is the usual practice to connect the two prods of the Megger to any two ends of a different winding. In all the cases it is assumed that the windings are in sound condition and the two ends of the same winding will be having continuity. However, it is possible the winding may have a break, and part of the winding may have a higher insulation resistance and the other part might have been grounded. Hence, to increase the reliability of the insulation resistance test, it is recommended that continuity test may be conducted in the motor before the insulation test, to be sure, that the winding is sound and the insulation resistance includes the entire winding.

Continuity test: The continuity of the winding is checked by using a test lamp in the following method as shown in Fig 1. First the links between the terminals should be removed.

The test lamp is connected in series with a fuse and a switch to the phase wire and the other end is connected to one of the terminals (say U_1 in Fig 1). The neutral of the supply wire is touched to the other terminals one by one. The terminal in which the lamp lights is the other end of the winding connected to the phase wire (say U_2 in Fig 1). The pairs are to be found in a similar manner. Lighting of the lamp between two terminals shows continuity of the winding. Lighting of the lamp between more than two terminals shows short between the windings.

Limitations of lamp continuity test: However, this test only shows the continuity but will not indicate any short between the turns of the same winding. A better test would be to use an ohmmeter having an accurate low resistance range to measure the resistance of the individual windings. In a 3-phase induction motor, the resistance of the three windings should be the same, or more or less equal. If the reading is less in one winding, it shows that the winding is shorted.

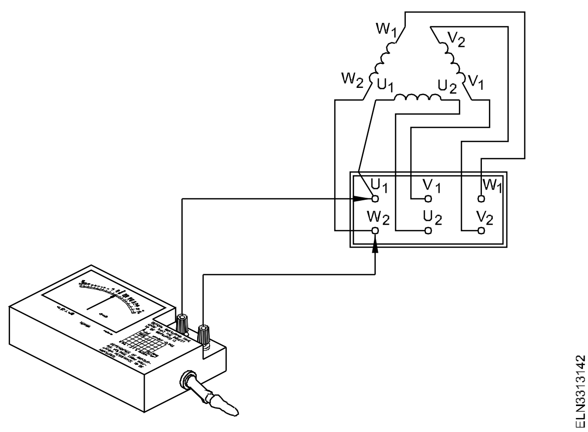
Fig 1



CONTINUITY TEST CIRCUIT

Insulation test between windings: As shown in Fig 2, one of the Megger terminals is connected to one terminal of any one winding (say U_1 in Fig 2) and the other terminal of the Megger is connected to one terminal of the other windings (say W_2 in Fig 2).

Fig 2

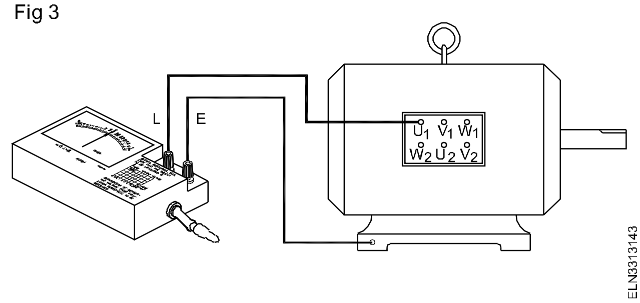


When the Megger handle is rotated at its rated speed, the reading should be more than one megohm. A lower reading than one megohm shows weak insulation between the windings, and needs to be improved. Likewise the insulation resistance between the other windings is tested.

Insulation resistance between windings and frame: As shown in Fig 3, one terminal of the Megger is connected to one of the phase windings, and the other terminal of the Megger is connected to the earthing terminal of the frame. When the Megger handle is rotated at the rated speed, the reading obtained should be more than one megohm. A lower reading than one megohm indicates poor insulation between the winding and the frame and needs to be improved by drying and varnishing the windings.

Likewise the other windings are tested.

Fig 3



Starter for 3-phase induction motor - power control circuits - D.O.L starter

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**
- **explain the basic contactor circuit with a single push-button station for start and stop.**

Necessity of starter: A squirrel cage induction motor just before starting is similar to 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 will produce large line voltage drop, which in turn will affect the operation of other Power 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, and then 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 and low voltages, a starter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to the motor at the time of starting.

Types of starters: Following are the different types of starters used for starting squirrel cage induction motors.

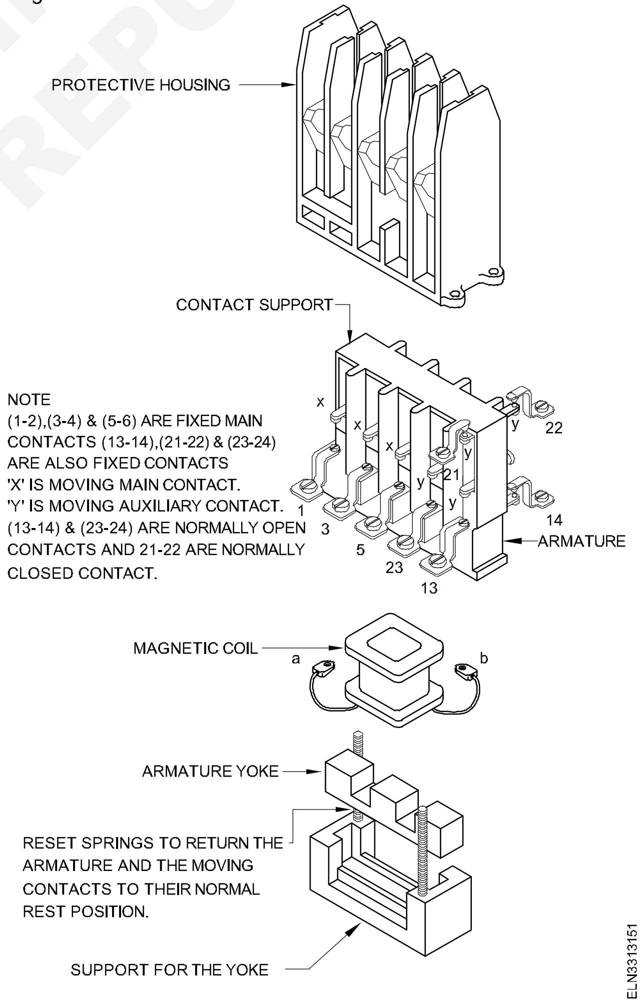
- Direct on-line starter
- Star-delta starter
- Step-down transformer starter
- Auto-transformer starter

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.

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, pneumatic or electro-pneumatic relays.

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 contacts carry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an integrated part, but will have to be used as separate accessories along with the contactor to form the starter function.

Fig 1

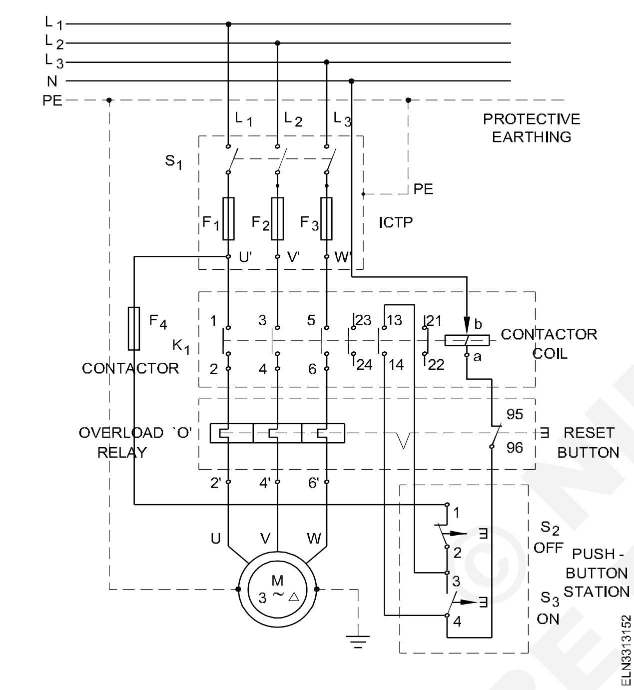


The main parts of a magnetic contactor are shown in Fig 1, and Fig 2 shows the schematic diagram of the contactor when used along with fused switches (ICTP), push-button stations and OL relay for connecting a squirrel cage motor for starting directly from the main supply. In the same way the direct on-line 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 U V & W of the motor are connected to the supply terminals R Y B via the ICTP switch, contactor and OL relay.

Fig 2



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.

Control circuits

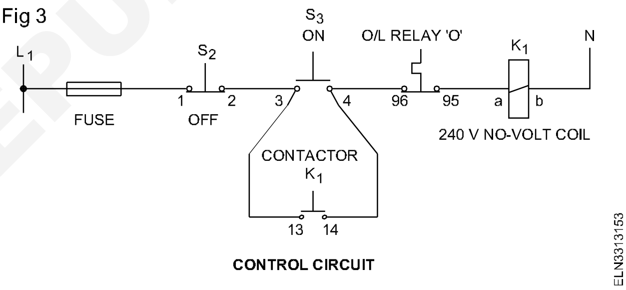
Push-button actuation from one operating location: As shown in the complete circuit Fig 2, and the control circuit Fig 3, when the `ON' push-button S_3 is pressed, the control circuit closes, the contactor coil is energised and the contactor K_1 closes. An auxiliary, a normally open contact 13,14 is also 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.

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 the power 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. (Fig 3)

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'.

Fig 3



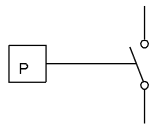
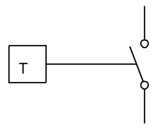
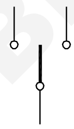
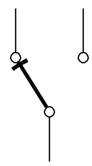
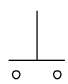
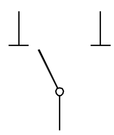
B.I.S. symbols pertaining to contactor and machines

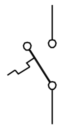
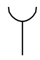
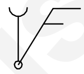
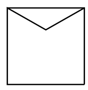
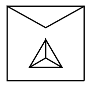
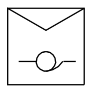
Objective: At the end of this lesson you shall be able to
- **identify B.I.S. symbols pertaining to rotating machines and transformers (BIS 2032 Part IV), contactors, switch, gear and mechanical controls (BIS 2032 Part VII, 2032 Part XXV and XXVII).**

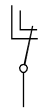
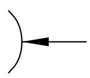
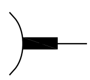
The table given below contains most of the important symbols used by an electrician. However, you are advised to refer to the quoted B.I.S. standards for further additional information.

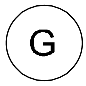
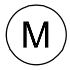
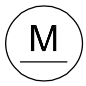
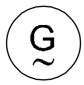
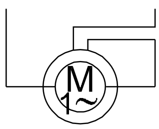
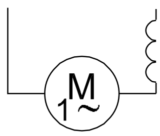
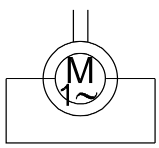
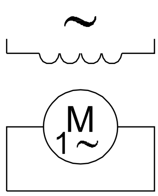
Table

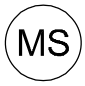
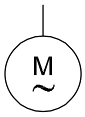
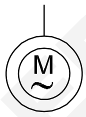
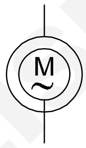
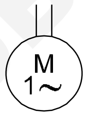
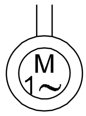
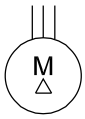
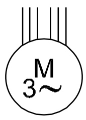
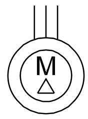
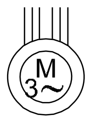
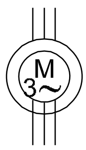
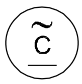
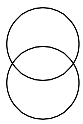
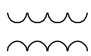
S.No.	BIS Code No.	Description	Symbol	Remarks
	BIS 2032 (Part XXV)-1980			
	9	**Switch gear, accessories**		
1	9.1	Switch, general symbol		

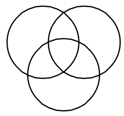
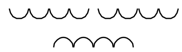
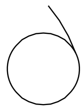
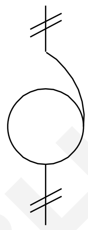
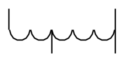
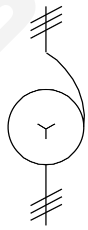
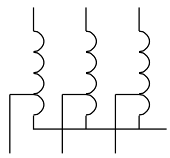
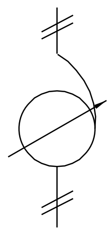
S.No.	BIS Code No.	Description	Symbol	Remarks
2	9.2	Three-pole switch, single line representation.		
3	9.3	Pressure switch		
4	9.4	Thermostat		
5	9.5	Circuit-breaker		
6	9.7	Two-way contact with neutral position		
7	9.8	Make-before-break contact.		
8	9.9	Contactor, normally open.		
9	9.9.1	Contactor, normally closed.		
10	9.10	Push-button with normally open contact.		
11	9.11	Isolator.		
12	9.12	Two-way isolator with interruption of circuit.		

S.No.	BIS Code No.	Description	Symbol	Remarks
13	9.14	Make contact, general symbol.		
14	9.15	Break-contact, general symbol.		
15	9.16	Thermal overload contact.		
16	9.17	Socket (female).		
17	9.17.2	Socket with switch.		
18	9.18	Plug (male).		
19	9.19	Plug and socket (male and female).		
20	9.20	Starter, general symbol.		
21	9.22	Star-delta starter.		
22	9.23	Auto-transformer starter.		
23	9.24	Pole-changing starter (Example, 8/4 poles).		
24	9.26	Direct on-line starter.		
25	9.29	Fuse.		

S.No.	BIS Code No.	Description	Symbol	Remarks
	BIS 2032 Part(XXV11) 1932	**Contactors**		
	3.2	**Qualifying symbols**		
26	3.3.7	Contact with two makes.		
27	3.3.8	Contact with two breaks.e symbols have been specified. In the case of transformers, symbols for single line and multi-line representation have been given separately.		
	BIS:2032 (Part IV) 1964	**Classification**		
		In this standard, more than one symbol have been used to designate the same type of rotating machine or transformer depending on the type and class of drawing involved. For the same type of rotating machines, in simplified as well as in the complete, multi-line symbols have been specified. In the case of transformers, symbols for single line and multi-line representation have been given separately. Wherever single line representation is required for rotating machines, reference may be made to IS:2032(Part II)-1962. Elements of symbols		
28	3.14	Winding Note: The number of half circles is not fixed, but if desired a distinction might be made for the different windings of a machine as specified in 3.2,3.3 and 3.4.		
29	3.34	Series winding.		
30	3.44	Shunt winding or separate winding.		
31	3.54	Brush or slip-ring.		
32	3.64	Brush on commutator.		

S.No.	BIS Code No.	Description	Symbol	Remarks
33	3.74	**Supplementary indications, numerical data.**		
		Supplementary indications (method of connecting windings, letter M, G or C and numerical data) are shown only on one symbol for each class of machine, as an example.		
	4	**Rotating machines**		
	4.1	**General symbols**		
34	4.1.14	Generator		
35	4.1.2	Motor		
		Note: Other special types of coupling, that is, monobloc construction, shall be suitably indicated wherever necessary.		
	4.2	**Direct current machine**		
36	4.2.1	Direct current generator, general symbol.		
37	4.2.2	Direct current motor, general symbol.		
	4.3	**Alternating current machines**		
38	4.3.1	AC generator, general symbol.		
39	4.3.2	AC motor, general symbol.		
	4.4	**Alternating current Commutator machines.**	**Simplified multiline representation**	**Complete multiline representation**
40	4.4.1	AC series motor, single phase.		
41	4.4.2	Repulsion motor, single phase.		

S.No.	BIS Code No.	Description	Symbol	Remarks
	4.5	**Synchronous machines**		
42	4.5.1	Synchronous generator, general symbol.		
43	4.5.2	Synchronous motor - general symbol.		
	4.6	**Induction Machines**		
		Note : In symbols 4.6.1 to 4.6.9 groups of conductors may be placed in another manner than generally shown below. For example, symbol 4.6.6.		
44	4.6.1	Induction motor, with short-circuited rotor, general symbol.		
45	4.6.2	Induction motor, with wound rotor, general symbol.		
46	4.6.3	Induction motor, single phase, squirrel-cage.	 **Simplified multiline representation**	 **Complete multiline representation**
47	4.6.5	Induction motor, three-phase, squirrel-cage.	 	 
48	4.6.7	Induction motor, three-phase, with wound rotor.		
	4.7	**Synchronous converters.**		
49	4.7.1	Synchronous converter, general symbol.		
	5	**Transformers**		
	5.1	**General symbols**		
50	5.1.1	Transformer with two separate windings.		

S.No.	BIS Code No.	Description	Symbol	Remarks
			Simplified multiline representation	**Complete multiline representation**
51	5.1.2	Transformer with three separate windings.		
52	5.1.3	Auto-transformers		
	5.3	**Auto-transformers**		
53	5.3.1	Auto-transformer, single-phase.		
54	5.3.2	Auto-transformer, three-phase. Connection:star.		
55	5.3.3	Single-phase auto-transformer with continuous voltage regulation.		

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 construction, operation and application.**

A D.O.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated 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 is a simple starter which is inexpensive and easy to install and maintain.

The D.O.L. starter is enclosed in a metal or PVC 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. Further the 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 D.O.L. starter on their own

Specification of D.O.L. starters: While giving specification, the following data are to be given.

D.O.L. STARTER

Phases - single or three.

Voltage 240 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 or 400/440 volts.

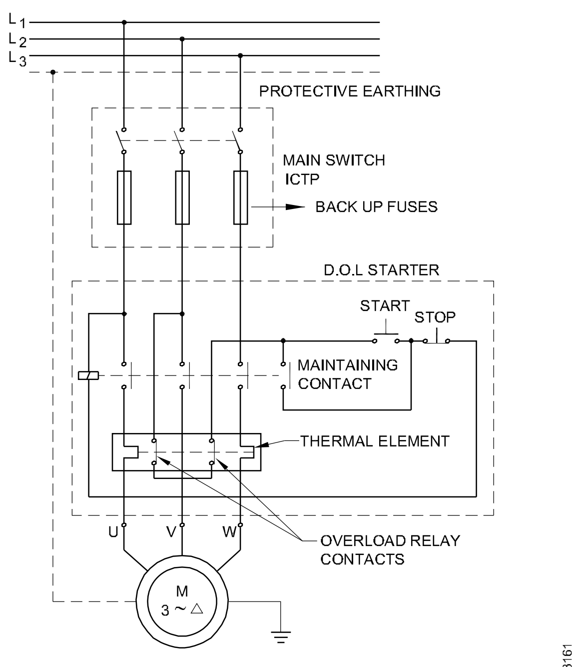
Number of main contacts 2, 3 or 4 which are normally open.

Number of auxiliary contacts 2 or 3. 1 NC + 1 NO or 2 NC + 1 NO respectively.

Push-button - one `ON' and one `OFF' buttons.

Overload from setting – amp-to-amp. Enclosure - metal sheet or PVC.

Fig 1



WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES

Applications: In an induction motor with a D.O.L. starter, the starting current will be about 6 to 7 times the full load current. As such, D.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.

Problems 1

A 3-phase, 400V, 50 HZ, delta-connected induction motor draws a line current of 150 amps with a P.F. of 0.85 and is delivering an output of 100 (Metric) HP. Calculate the efficiency.

$$\% \text{ of efficiency} = \frac{\text{Output x 100}}{\text{Input}}$$

$$= \frac{100 \times 735.5 \times 100}{\sqrt{3} \times 400 \times 150 \times 0.85}$$

$$= 83.3\ \%$$

Problems 2

A 3-phase, 400 V, induction motor takes a line current of 30 amperes with a power factor of 0.9. The efficiency of the motor is 80%. Calculate the output in metric horsepower.

$$\text{Output in watts} = \text{Input x Efficiency}$$

$$= \frac{\sqrt{3} \times 400 \times 30 \times 0.9 \times 80}{100}$$

$$\text{Output in metric HP} = \frac{\text{Output in watts}}{735.5}$$

$$= \frac{\sqrt{3} \times 400 \times 30 \times 0.9 \times 80}{100 \times 735.5}$$

= 20.3 HP.

Manual star-delta 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**
- **explain the construction, connection and working of a star-delta switch and starter.**

Necessity of star-delta starter for 3-phase squirrel cage motor: If a 3-phase squirrel cage motor is started directly, it takes about 5-6 times the full load current for a few seconds, and then the current reduces to normal value once the speed accelerates to its rated value. As the motor is of rugged construction and the starting current remains for a few seconds, the squirrel cage induction motor will 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 motor needs to be reduced during the starting periods, and regular supply could be given when the motor picks up its speed.

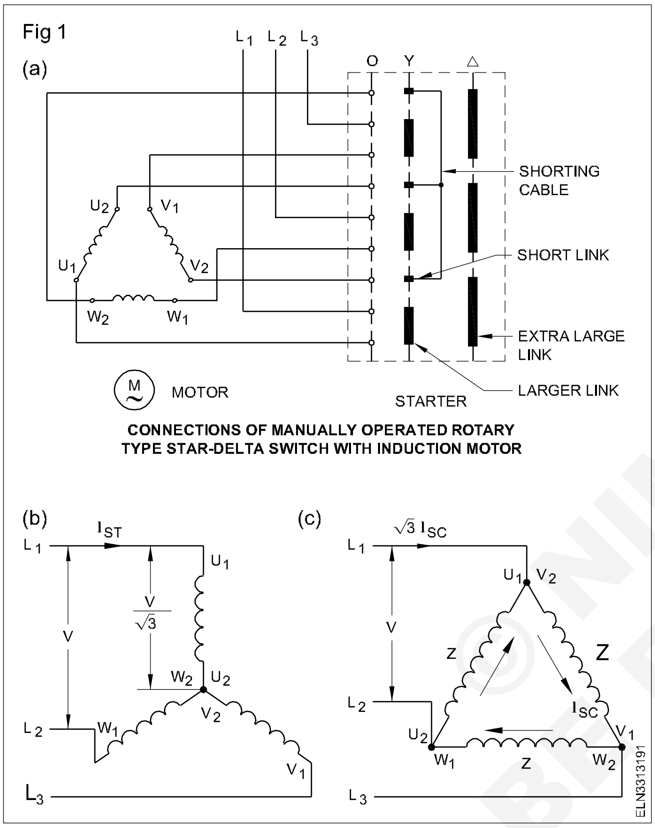
Following are the methods of reducing the applied voltage to the squirrel cage motor at the start.

- Star-delta switch or starter
- Auto-transformer starter

Star-delta starter: A star-delta switch is a simple arrangement 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 $1/\sqrt{3}$ 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/starter to a 3-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 in star, and then in delta. In star position, 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 links, 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)

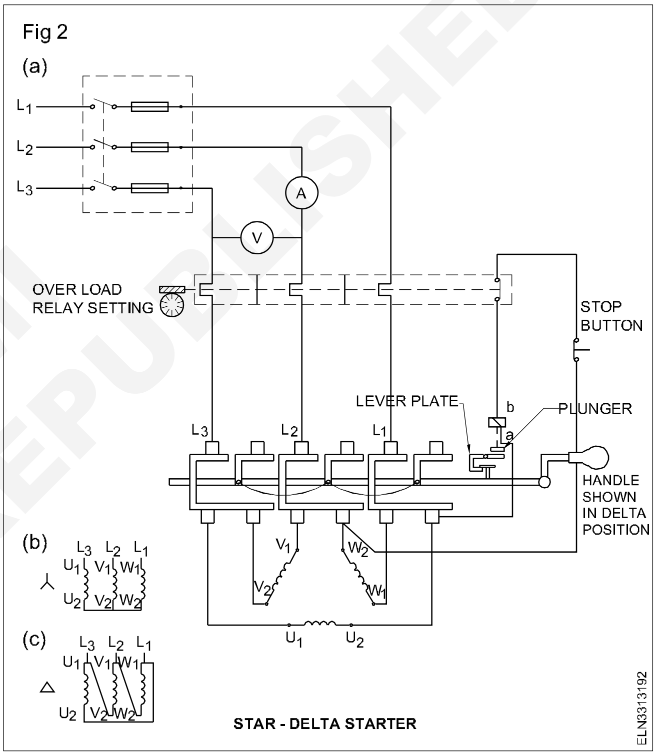
When the switch handle is changed over to delta position, the line supply L_1, L_2 and L_3 are connected to terminals U_1 V_2, W_1 U_2 and V_1 W_2 respectively by the extra large links to form a delta connection. (Fig 1c)



Manual star-delta starter: Fig 2a 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 is energised and 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 falls and operates the lever plate mechanism so as 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 for the operator to put the handle in delta position in the first moment. It is only 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 thrown to star position, the baffles connect the supply lines L_1, L_2 and L_3 to beginning of the 3-phase winding W_1, V_1 and U1 respectively. At the same time the small baffles connect V_2, W_2 and U_2 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 L_1, L_2 and L_3 to the winding terminals W_1U_2, V_1W_2 and U_1V_2 respectively to form the delta connection. (Fig 2c)



The overload relay current setting could be adjusted by the worm gear mechanism of the insulated rod. When the load current exceeds a stipulated value, the heat developed in the relay 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.

Automatic star-delta starter

Objectives: At the end of this lesson you shall be able to
- **describe the operations of automatic star-delta starter.**

Operations of automatic star-delta starter: 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 K_3. (Current flows through K_4T NC terminals 15 & 16 and K_2 NC terminals 11 & 12). Once K_3 energises the K_3 NO contact closes (terminals 23 & 24) and provide path for the current to close the contactor K_1. The closing of contactor K_1 establishes a parallel path to start button via K_1 NO terminals 23 & 24.

Fig 1

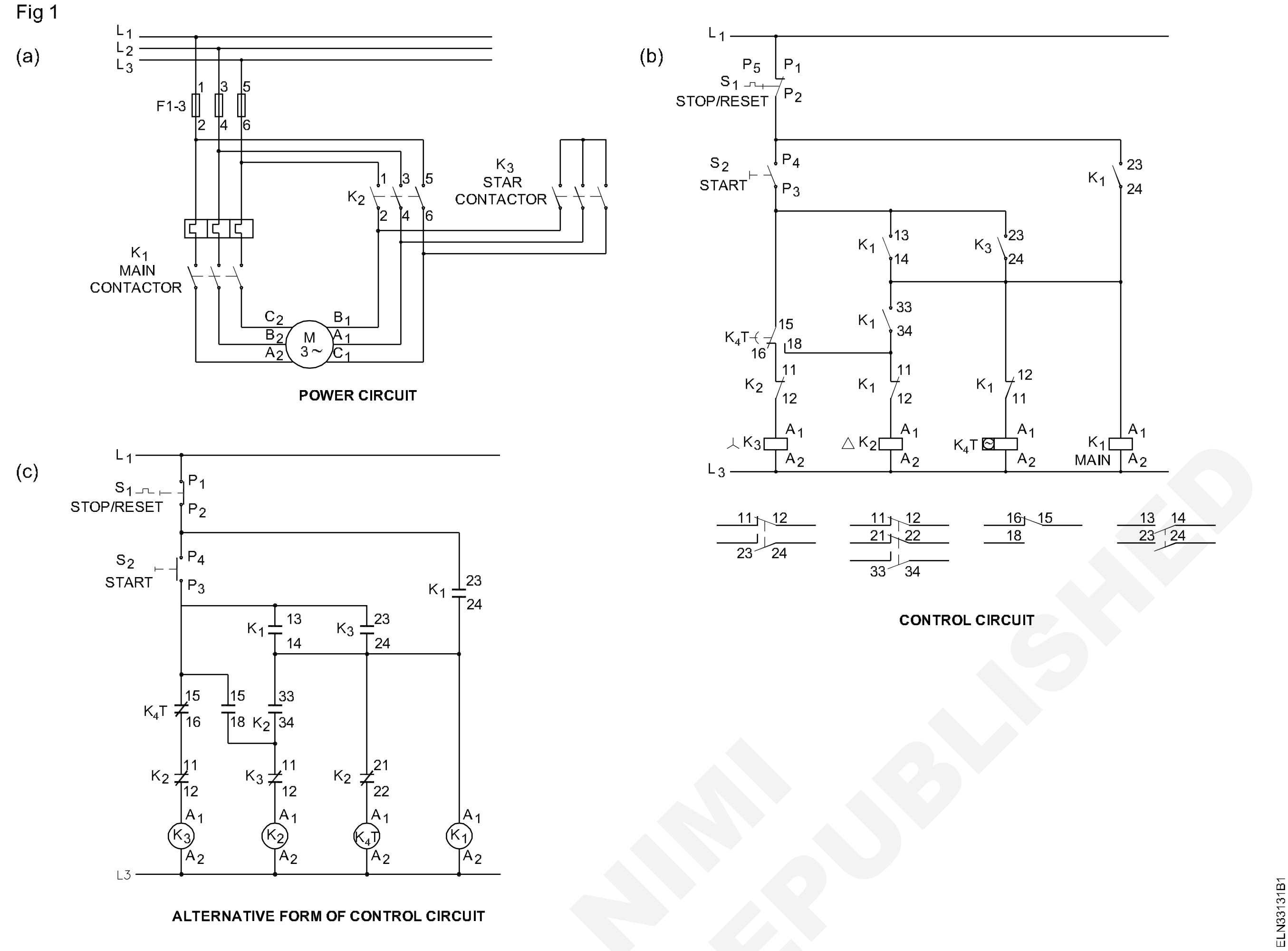


Fig 2 shows the current direction and closing of contacts as explained above.

Similarly Fig 3 shows the action taking place after the timer relay operating the contact K_4T.

Fig 2

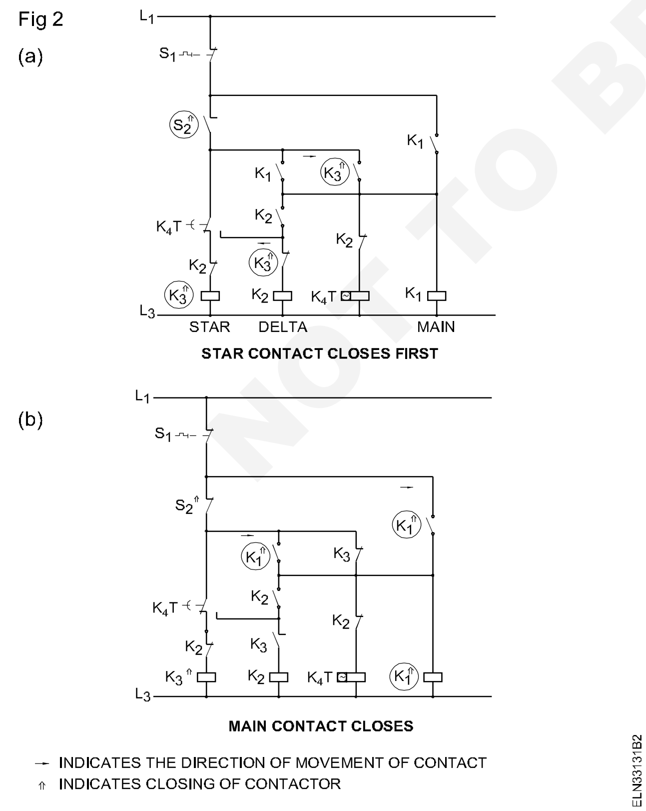
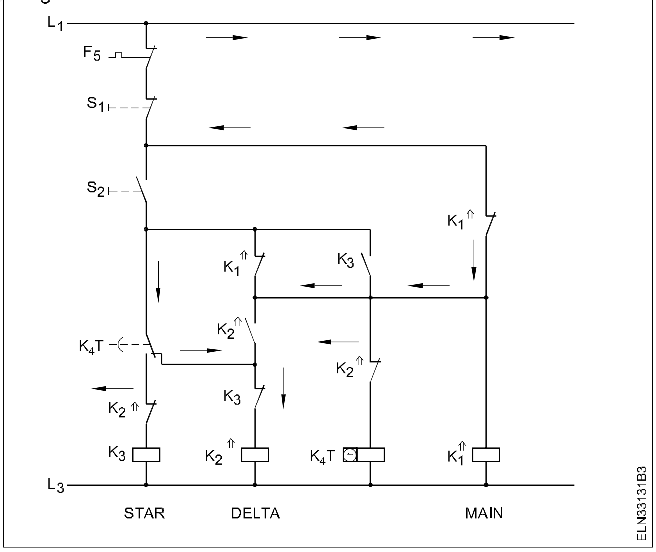


Fig 3

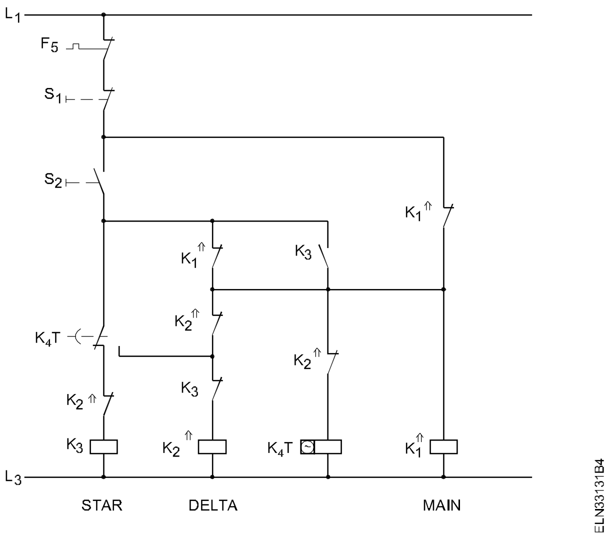


Time delay contact changes opening star contact.

Fig 4 shows the connections established while the motor is running in delta with the contactors K_1 and K_2 closed.

Delta contact closes.

Fig 4

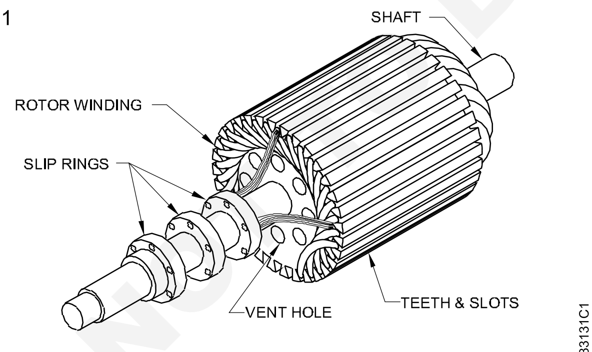


Three-phase, slip-ring induction motor

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**
- **state the characteristic of the slip-ring induction motor.**

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.

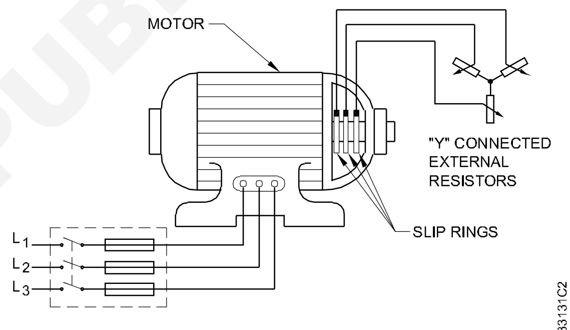
Fig 1



WOUND ROTOR FOR SLIP RING INDUCTION MOTOR

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.

Fig 2



CIRCUIT FOR A WOUND - ROTOR INDUCTION MOTOR

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 I^2R losses in the rotor due to increased resistance is inevitable.

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 betweeen 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 Powerfaults

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	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.
3	Overload.	Measure the starting torque required by load.	Reduce load, raise tapping on auto-transformer, install a motor of a higher output.
4	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.
5	Open circuit in stator or rotor.	Check visually and then with multimeter/megger.	Rectify the defect or wind.
6	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.
7	Winding is grounded.	Test with a Megger or test lamp.	If the fault is found, repair or rewind.
8	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	Low 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, like loose or bad contacts in starter, switches, distribution box,etc.
2	Too low or high tension on driving belt.	Measure the tension and verify it with the instruction of the manufacturer.	Adjust the belt tension.
3	Faulty stator winding.	Check for continuity, short circuit and leakage.	Repair the circuit if possible or rewind the stator.
4	Defective bearings.	Examine bearings for play.	Replace the bearings.
5	Excessively loaded.	Measure the line current of the motor and compare it with its rated current.	Reduce the mechanical load on the motor.
6	Low frequency.	Measure the line frequency with a frequency meter.	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	Low voltage	Measure the line voltage.	Remove the cause of low voltage.
2	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.
3	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.
4	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.
5	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	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.
3	Dirt in ventilation ducts.	Inspect ventilation ducts for any dust or dirt in them.	Reduce the load or loosen the belt. Rectify the single phasing defect.
4	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.
5	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.
6	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.

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.

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 1

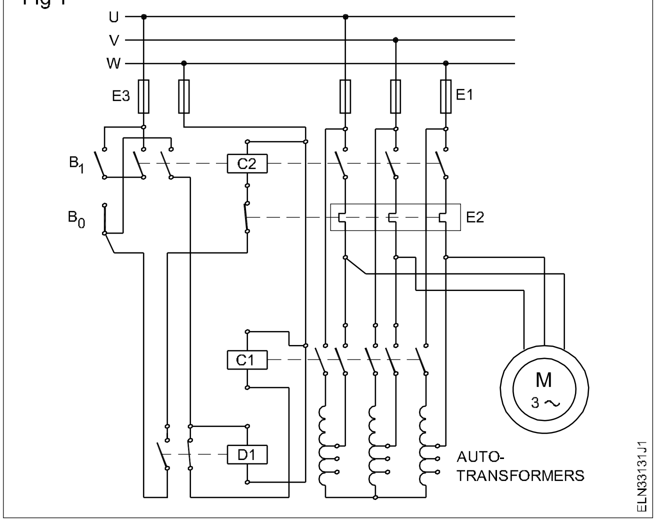


Fig 2

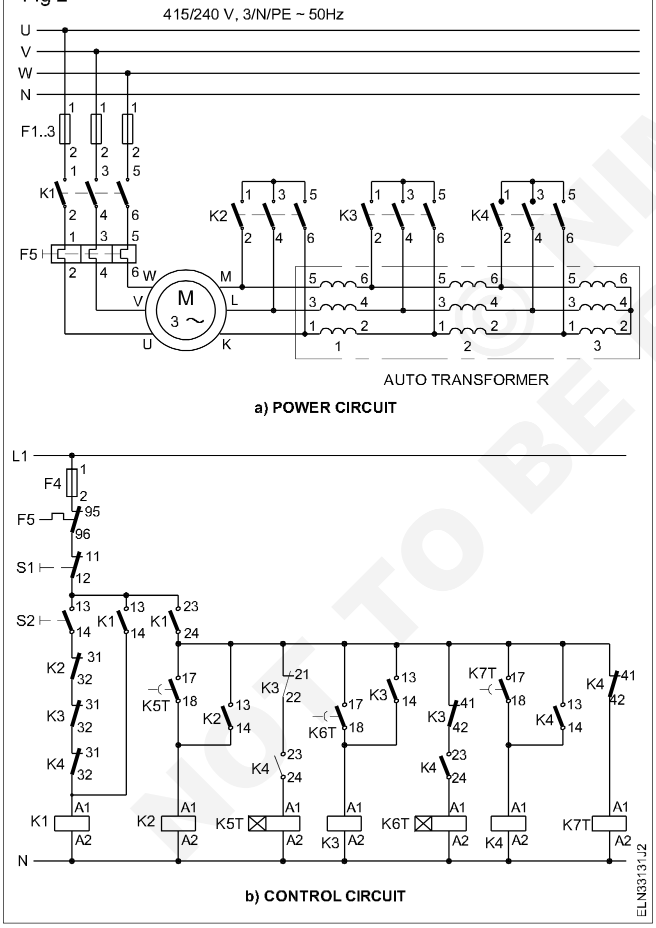
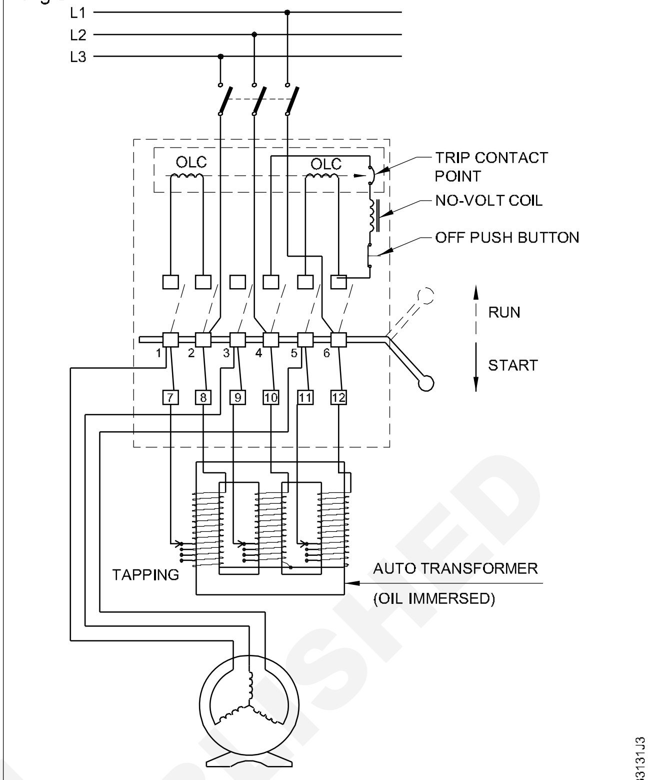


Fig 3 shows the connection of an auto-transformer starter. To start the motor the handle of the starter is turned downward and the motor gets a reduced voltage from the auto-transformer tappings. When the motor attains about 75% of its rated speed the starter handle is moved upward and the motor gets full voltage. The auto-transformer gets disconnected from the motor circuit.

Fig 3



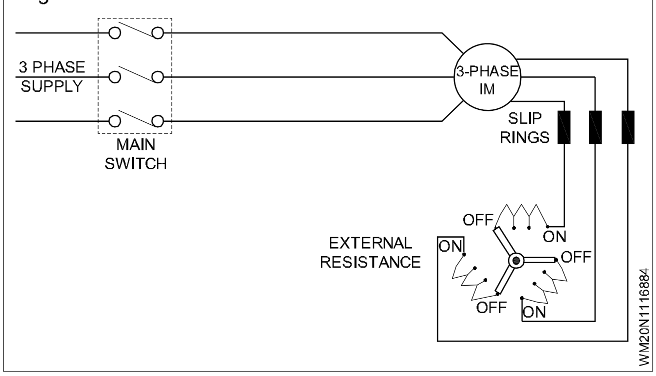
CONNECTION DIAGRAM OF AUTO-TRANSFORMER STARTER

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.

Rotor Resistance Starting (Fig 4)

In this method, a star connected variable resistance is connected in the rotor circuit through slip-rings. The full voltage is applied to the stator windings.

Fig 4



At the instant of starting, the handle of variable resistance (rheostat) is set to 'OFF' position. This inserts maximum resistance in series with the each phase of the rotor circuit. This reduces the starting current and at the same time starting torque is increased due to external rotor resistance.

As the motor accelerates, the external resistance is gradually removed from the rotor circuit. When the motor attains rated speed, the handle is switched in the 'ON' position, this removes the whole external resistance from the rotor circuit.

Soft starter

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.

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. (Fig 5)

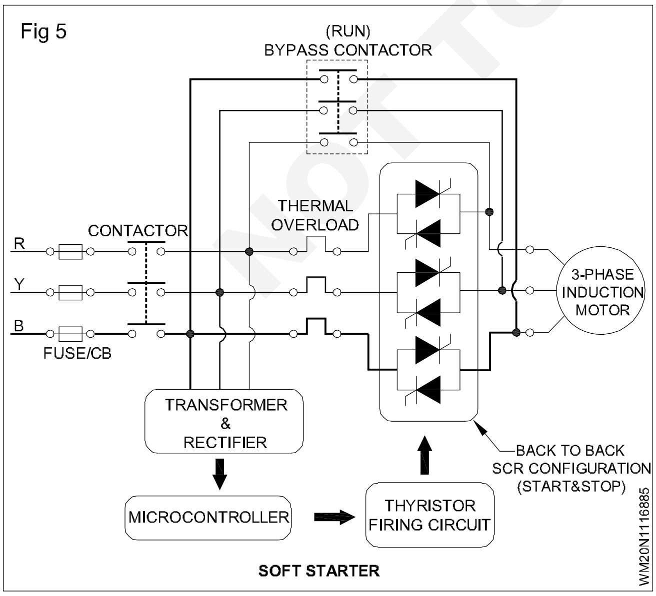


Fig 5

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 6)

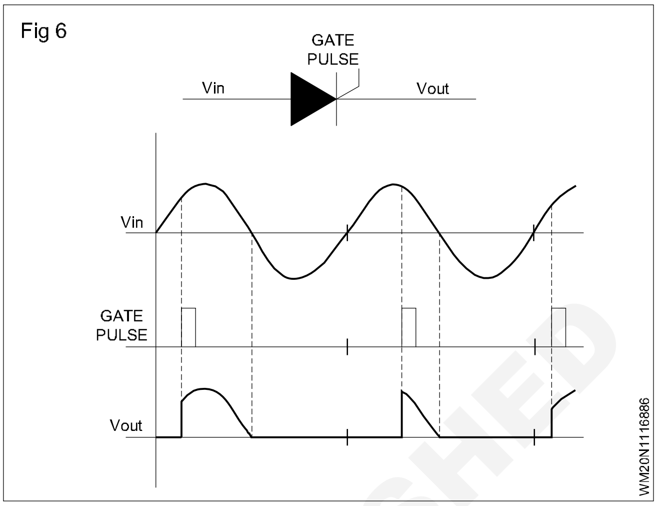


Fig 6

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.

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 7)

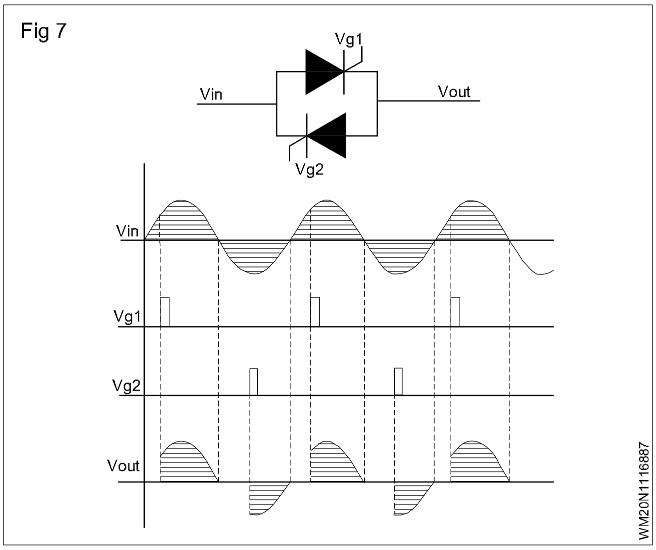


Fig 7

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.

Relay and control panel wiring

Objectives: At the end of this lesson you shall be able to
- **explain the layout marking methods and necessity**
- **explain the methods of mounting and equipments**
- **state the various control elements used for control panel board**
- **list the different wiring accessories used in control panel wiring.**

Layout marking

Wiring diagrams for power and control circuit should be developed for sequence of operation of automatic star - delta starter with forward and reverse. Types of protection, control, indication and measuring accessories needed should be finalized.

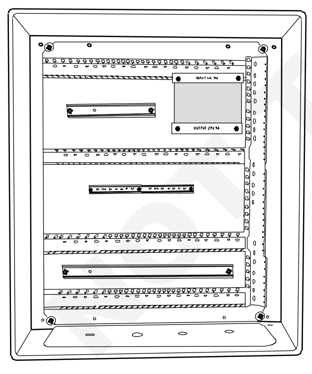
To wire up the above starter in a control panel the well designed and easily understandable layout should be finalized. Layout of the finalized wiring diagram should developed keeping important features of the control panel in mind. While designing the control panel the outside dimensions, the swing area of cabinet doors and area required for maintenance and tools kit have to be considered.

While selecting the control and protective accessories of the control panel the full load current of the individual load, total load and duty cycle, simultaneous operation of the load and 25% additional load capacity of the motors have to be considered.

The finalized layout of accessories can be marked in the control panel using suitable marking device.

DIN rail being fixed to the chassis before fitted the contactors and other accessories using screwsas shown in FIg 1.

Fig 1

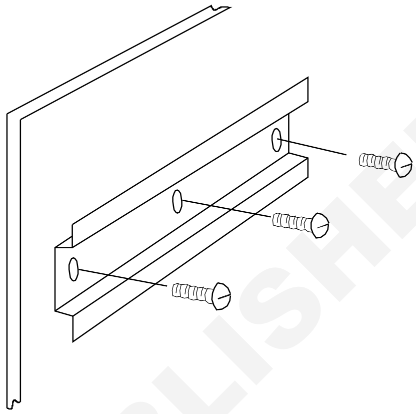


CONTROL PANEL WITH RACEWAYS / DIN RAILS

Din rail can be cut in to the required length and then screwed or bolted inside the panel before mounting any accessories and wiring begins as in Fig 2.

Race way is one form of cable ducting used to carry the wiring between components and keeping the wires neat. The leads wires and cables are laid inside the raceways brought out through the holes / slots in the sides and can be inspected by removing the cover of the raceways.

Fig 2



FIXING OF DIN RAIL

The minimum spacing between components and raceways should be 100 mm for 415V systems and 50 to 75 mm for less than 415V system. The next stage is to clip the accessories to the rail and wire them.

Mounting and wiring the accessories in control panel

The accessories can be mounted on the DIN rails allowing sufficient space for easy maintenance, wiring and troubleshooting. The mounting should not move or lean in the DIN rail due to vibration or strain due to cables.

Contactor can be either flush mounted to the chassis or DIN rail - mounted . Contactor mounting type over load relay which have three pin connectors engage into the contactor terminals may be used to reduce the mounting and wiring time and labour.

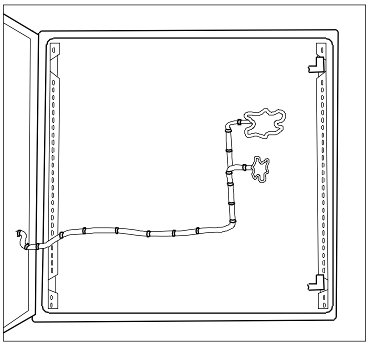
To mount the contactor on rail first place the back top groove on the top of rail and turn it downwards against the lower rail which will cause the spring of the contactor to retract and snap into place behind the rail. There is a slot in the spring clip of the contactor so that the clip can be retracted using small screw driver or connector to remove the contactor if required. To avoid fouling the underneath of the accessories use screws with low profile heads.

All the internal wiring should be terminated in the top and external wiring in the bottom of the connectors to avoid the crossover of both wirings. Flexible conduit and cables have to be installed in such a way that the liquid or water if any can drain away from the fitting and grommets.

An earth terminal usually green or green yellow to be clamped to the rail and ensure the cabinet and door are earthed properly.

U loops of the cables as long as possible facing down and anchored on each side of the hinged doors and panel with screws or bolts and do not use adhesive. Place the sleeve and spiral flexible conduits of suitable size over the cables running between the hinged doors and panel as in Fig 3.

Fig 3



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U LOOP OF CABLES

The care to be given to the bundle of wires which is mounted on the hinged doors should not restrict the opening and closing of the door or the doors should not damage the wires.

Minimize the use of cable ties if the raceways are used. They may be cut OFF during troubleshooting and rarely replaced.

Routing and bunching

Routing

Conductors and cables should run from terminal to terminal without any intervening joins and cross over. Extra length should be left at connector / terminals where assembly needs to be disconnected for maintenance and servicing. Multi core cable terminations have to be adequately supported to avoid undue strain on the terminals.

Different colour may be used to aid identification of group of controls and functions.

Bunching and tying

Run the wires in horizontal and vertical lines avoid diagonal runs as possible. Do not run the wire over the other devices or race ways.

The wires should be neatly bundled, run in the race ways and routed with smooth radius bends.

Where the multiple earths are used it is necessary to use a common earth terminal or connectors as in Fig 3.

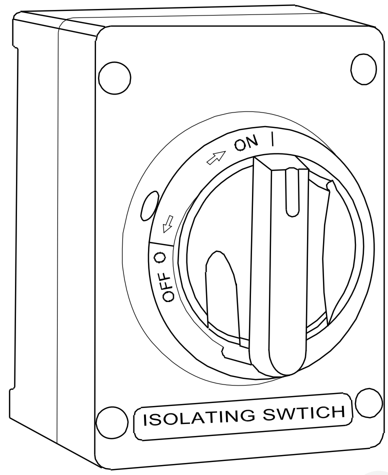
Control elements and equipments for control panel

1 Isolating switch (Fig 4)

Isolating switch (Isolator) is a manually operated mechanical switch which isolates/disconnects the circuit which are connected with it from the supply system as and when required. It should be normally operated at "OFF" load condition.

It is available in different current, voltage rating and size.

Fig 4



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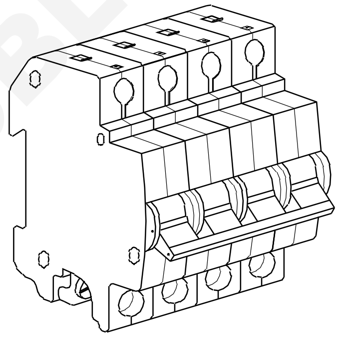
ISOLATING SWITCH

2 MCB (Fig 5)

Miniature circuit breaker (MCB) is an electro mechanical protective device which protect an electrical circuit from short circuit and over load . It automatically turns off, when the current flowing through it exceeds the maximum allowable limit.

Fig 5



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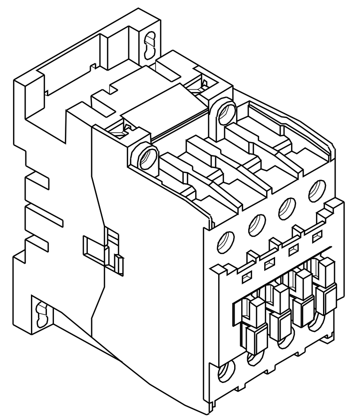
MINIATURE CIRCUIT BREAKER

3 Contactors (Fig 6)

A contactor is an electrically controlled double break switch used for switching ON / switching OFF the electrical circuit, similar to a relay with higher current ratings. It is controlled by a circuit which has a much lower power level than the switched circuit.

Fig 6



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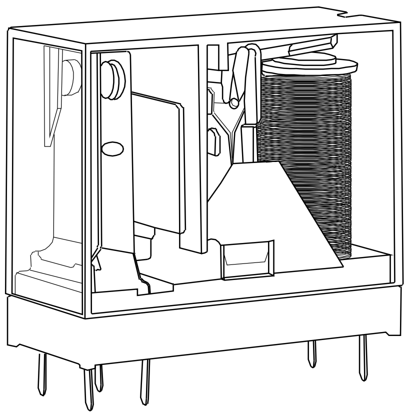
CONTACTOR

4 Electro mechanical relays (Fig 7)

Electromechanical relays are electrically operated switches used to control a high powered circuit accessories using low power signal. When an electric current passes through its coil it produces a magnetic field that activates the armature to make or break a connection.

Fig 7

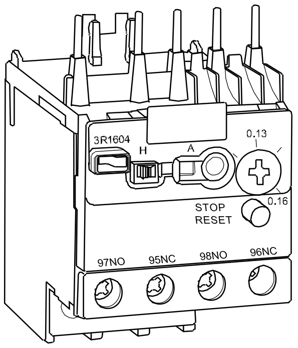


ELECTRO MECHANICAL RELAY

5 Thermal overload relays (Fig 8)

It is a thermally operated electromechanical device that protects motors from over heating and loading.

Fig 8

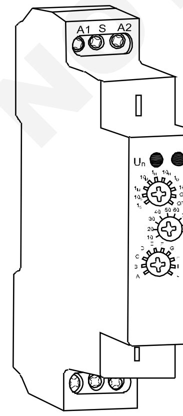


THERMAL OVERLOADED RELAYS

6 Time delay relay (timers) (Fig 9)

Time delay relays are simply the control relays in - built with a time delay mechanism to control the circuit based an time delay.

Fig 9



TIMER

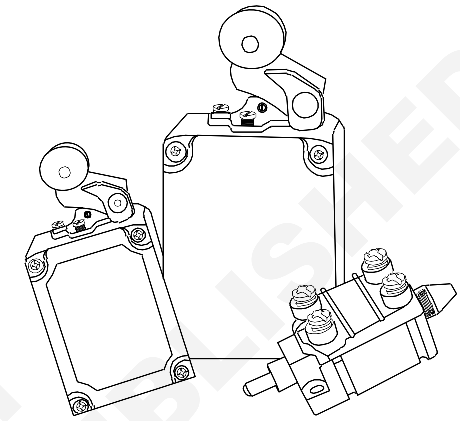
In time delay relays its contact will open or close after the pre-determined time delay either on energising or on de-energising its no volt coil. It can be classified into two types as ON delay timer and OFF delay timer.

7 Limit switches (Fig 10)

Limit switch is a switch with an actuator which is operated by the motion of a machine part or an object.

When an object or parts comes into contact with actuator, it operates the contacts of the switch to make or break an electrical connection. They are used to control the distance or angles of movement of any machine parts or axis or objects.

Fig 10



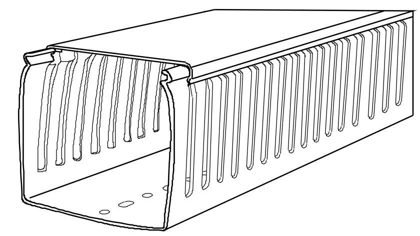
LIMIT SWITCHES

Wiring accessories for control panel wiring

1 PVC channel / Race ways (Fig 11)

It is an inspection type PVC enclosed channel which provides a pathway for electrical wiring inside the control panel. It has the opening slots on both sides to facilitate the good ventilation and visual inspection.

Fig 11

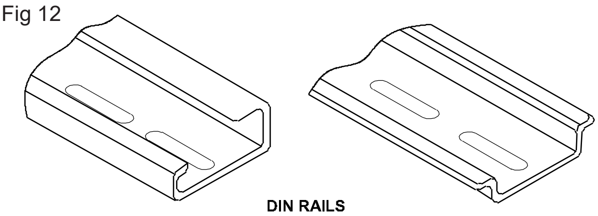


PVC CHANNEL

2 DIN rail (Fig 12)

It is a zinc - plated or chromated metal rail which is used for mounting the control accessories like MCB, contactors and OLR etc, with out using screws inside the control panel.

Fig 12

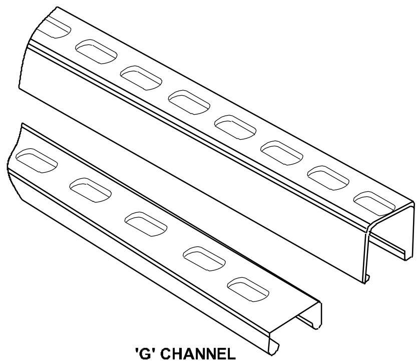


DIN RAILS

3 G Channel (Fig 13)

It is a zinc - coated metal channel which is especially used for mounting the feed through or spring load or double deck terminal connectors without using screw inside the control panel.

Fig 13

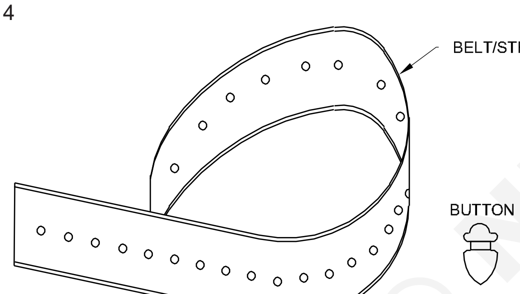


'G' CHANNEL

4 Cable binding straps and button (Fig 14)

It is made up of PVC or polymer belt with a small holes at regular intervals, used to tie up, bunching, binding and dressing the cable / wires with help of buttons.

Fig 14



CABLE BINDING STRAPS AND BUTTON

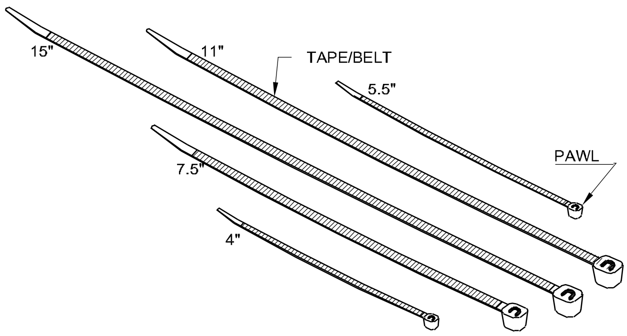
5 Nylon cable ties (Fig 15)

- It is a type of fastener used to hold or tie or bunch the wires / cable or group of cables.

6 Grommets (Fig 16)

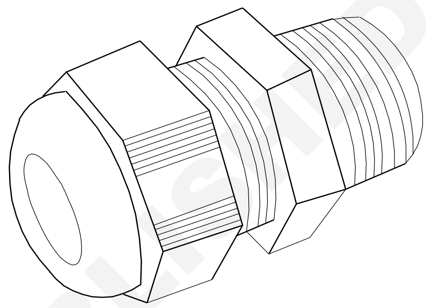
It is a type of bushing which is used to insulate and hold the cables when they pass through a punched / drilled holes of panels or enclosures.

Fig 15



NYLON CABLE TIES

Fig 16



GROMMETS

Relay Ladder Logic: Ladder diagrams, or Relay Ladder Logic (RLL), are the primary programming language for programmable logic controllers (PLCs). Ladder logic programming is a graphical representation of the program designed to look like relay logic. This convention goes back to the early days of PLCs when electricians and technicians were trained in relay logic and expected to troubleshoot these new devices...

The relay logic drawing shows switches electrically connected to coils-solenoids, pilot lights, etc. The ladder diagram uses contacts to represent the switches, or any input, and the coil symbol to represent an output. A line showing an input or several inputs and an output is known as a rung.

The relay diagram used electrical continuity to show a rung as electrically closed. Ladder logic programming shows the results of a status check of the inputs and outputs where the conditions are true or not true. The original intent of RLL was to provide a way for the controller to solve logic sequences involving discrete signals.

Power and control circuits for three phase motors

Objectives: At the end of this lesson you shall be able to
- **explain the basic power and control circuit**
- **explain the sequential control of motors.**

Power circuit: As in Fig 1, when the main ICTP switch is closed and the contactor K_1 is operated, all the three windings U V & W of the motor are connected to the supply terminals R Y 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.

Control circuits

Push-button actuation from one operating location: As shown in the complete circuit Fig 1, and the control circuit Fig 2, when the `ON' push-button S_3 is pressed, the control circuit closes, the contactor coil is energised and the contactor K_1 closes. An auxiliary, a normally open contact 13,14 is also 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 1

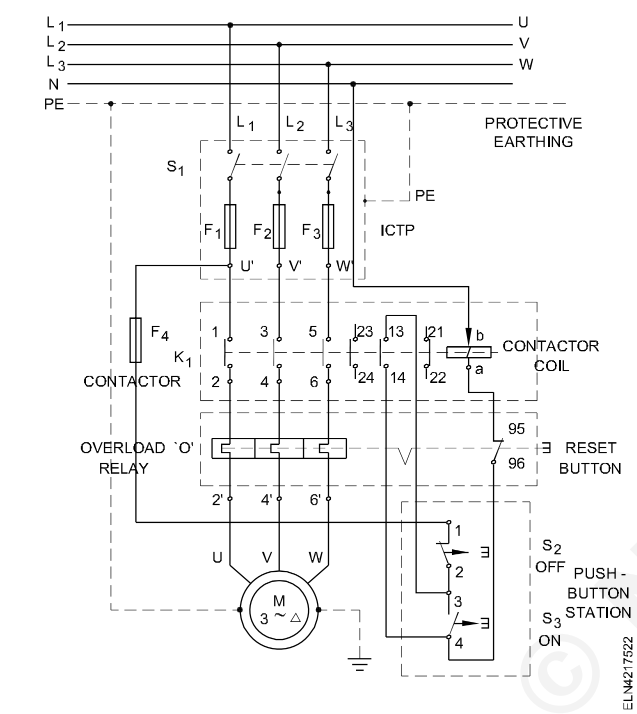
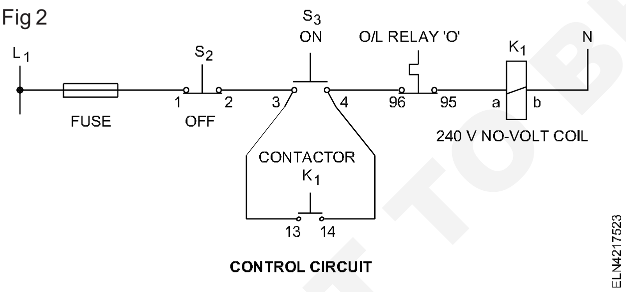


Fig 2



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 the power 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'.

Sequential control of motors: It is a kind of multiple motor's control in a specified manner by means of timer or limit switches or sensor depend the requirements of industries or application.

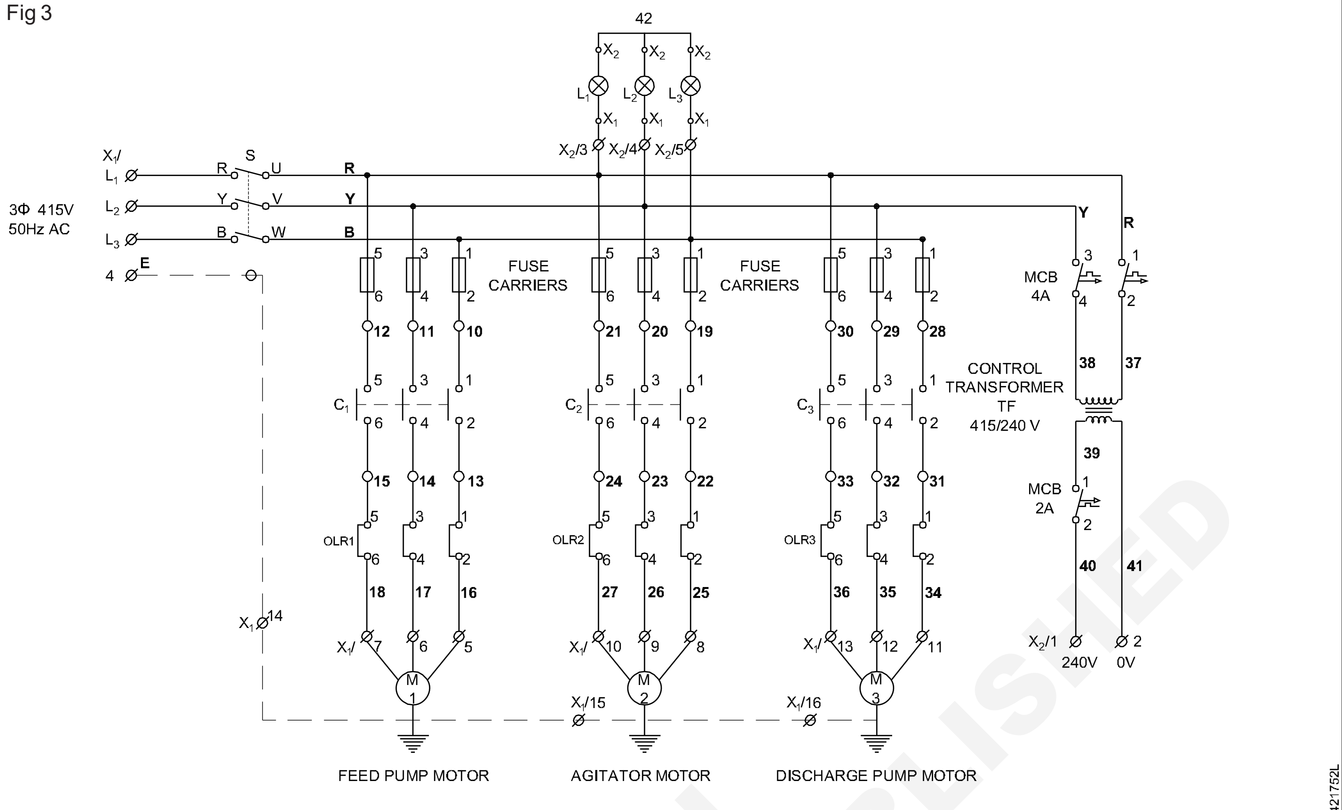
In this method generally the operation of two or more individual motors are controlled with respect to the specified time lapse or reaching of the specified level or completion of the specified operation. The operation of first motor will control the operation of the second or other motors and operation of second motor will control the operation of other motors and so on.

This type of the control system reduce the error due to human and man power, increase the accuracy of the operation cycle, minimize the ideal time of the machines and increase the efficiency and production of the industries.

The example of such sequential control system might be found in some of the industrial agitator system.

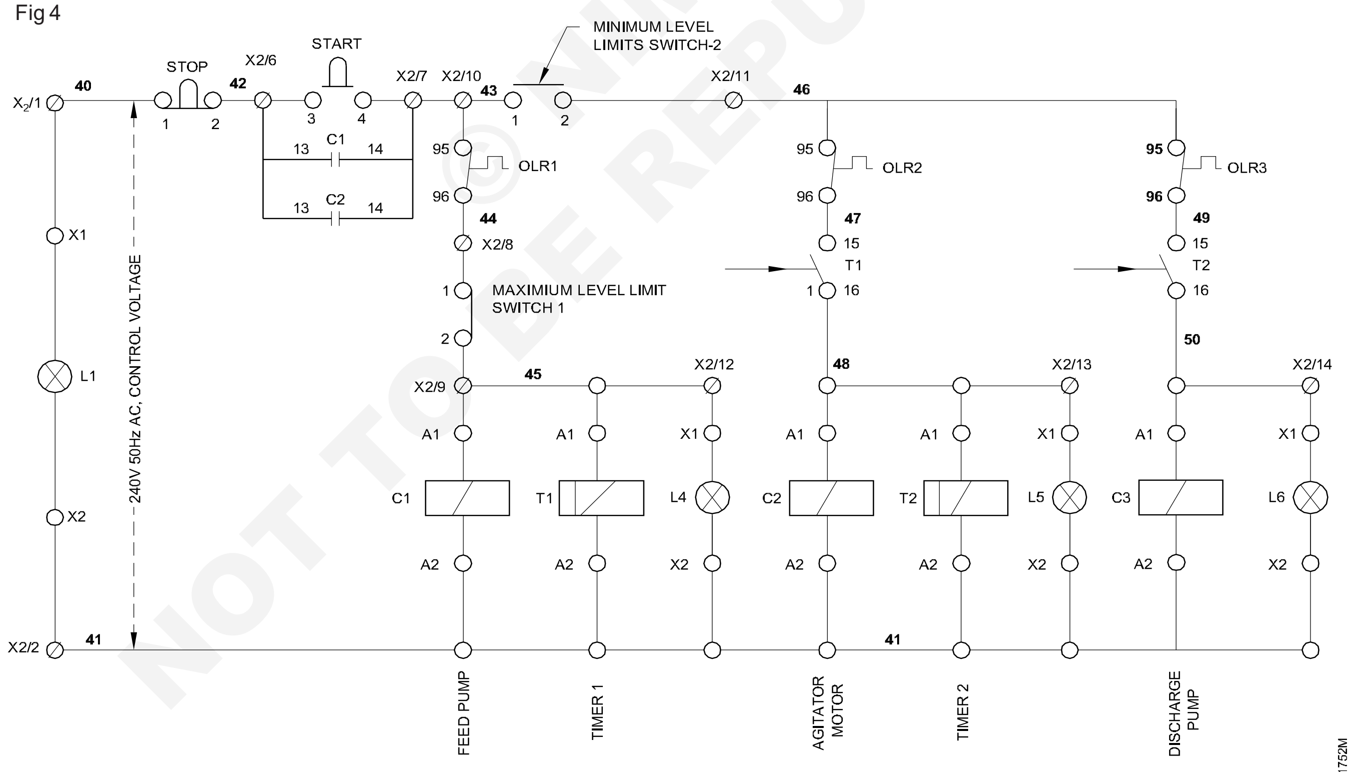
The Fig 3 and 4 show the power and control circuit of the sequential control of the typical agitator system with three motors.

Fig 3



POWER CIRCUIT FOR SEQUENTIAL CONTROL OF THREE MOTORS

Fig 4



CONTROL CIRCUIT OF SEQUENTIAL CONTROL OF AGITATOR SYSTEM WITH THREE MOTORS

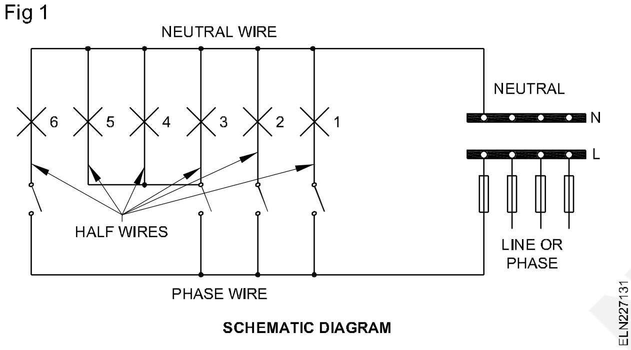
Methods of layout of domestic wiring installations

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



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 3 shows the same circuit suitable for practical work.

Fig 2

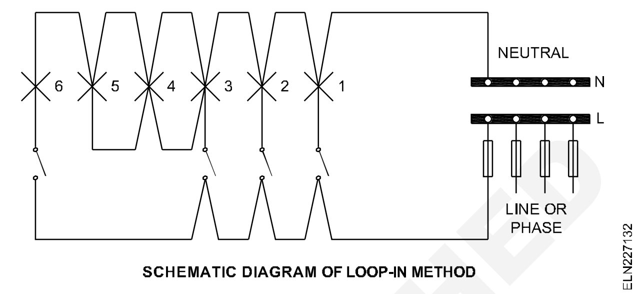
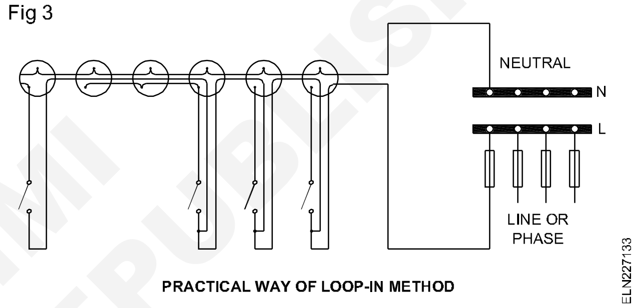
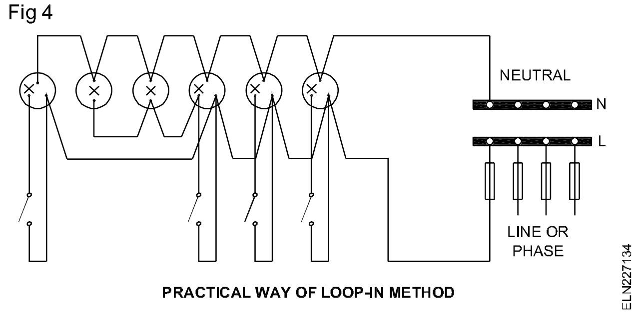


Fig 3



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.

Fig 4



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.

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).

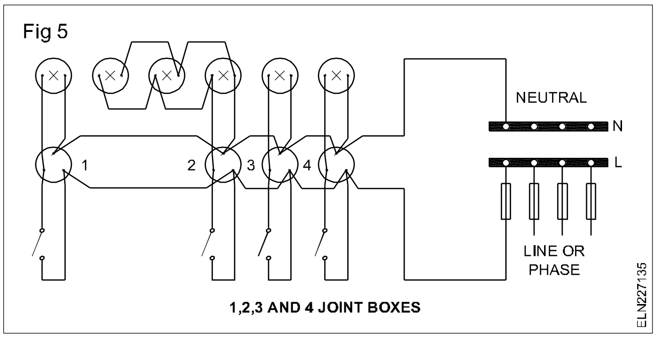


Fig 5

Voltage drop concept - diversity factor

Objectives: At the end of this lesson you will be able to
- **state the voltage drop concept**
- **explain diversity factor.**

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).

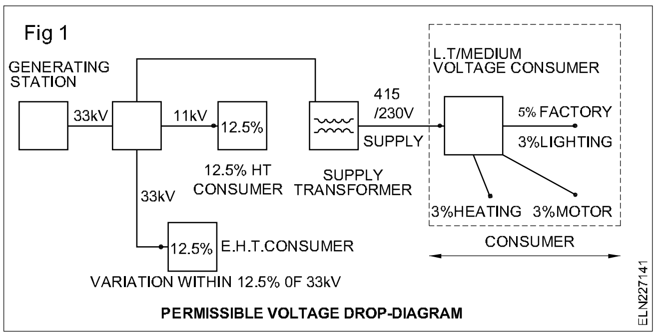


Fig 1

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.

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%

$$= \frac{3 \text{ x } 240}{100} = 7.2 \text{ Volts}$$

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

$$= \frac{50 \text{ x } 65}{7.2 \text{ x } 69} = 6.54 \text{ Volts}$$

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.

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	30	100%	30 } 72.00
	ii	30	80%	24
	iii	30	60%	18
3	Water heaters (inst)	29.2	100%	29.2
4	Water heaters (thermo)	25.00	100%	25.00
5	Cooker i	12.5	80%	10.00
	ii	44.5	100%	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.

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 deman
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.

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

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.

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. volts
mm	inch	approx. area in mm	amp	230V watts	250 V watts	
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

Rules for wiring

The following regulations are to be followed during installation of wiring as per Bureau of Indian Standard (BIS), IS 732-1963, IS 4648 - 1968. All these are recommended by the National Electrical Code.

1 Only the electrical license holders approved by the competent authority are eligible to carry out the erection and maintenance of electrical works.

2 AC and DC circuits must be wired separately. In DC circuit, the positive wire should be in red colour and negative wire in black colour. The three phases of AC should be in red, yellow and blue colours. Neutral should be in black colour. Earth should be in green with yellow colour.

3 In and electrical circuit, if the operating voltage is above 250 volt, 'Danger' warning sign must be displayed.

4 Electrical sub-circuits are divided into two. They are

   i Lighting and fan sub-cirucit

   ii Power sub-circuit

i Lighting and Fan Sub-Circuit

Each lighting sub-circuit is designated to have a maximum of 10 number electrical points (lights, fans and 6 A socket outlets), at the same time, maximum load is restricted to 800 watt. 3-pin 6A socket outlets shall only be used in the sub-circuit.

E.g.: Lamp - 60W, fan - 60W, tube-light 4 feet - 40 W, 6A socket outlet - 100 W, etc.

ii Power sub-circuit

The maximum load on each power sub-circuit should be restricted up to 3000 watts and allowed to have not more than 2 outlets.

E.g.: 16 A Power outlet - 1000 W. All 3-pin, 16A socket outlets should be controlled by an individual switch and it should be positioned immediately next to socket.

5 Fix electrical accessories, according to its rated voltage and current.

6 In lighting sub-circuit wiring, the minimum size of conductor used in domestic wiring should not be less than 1 mm² for copper or 1.5 mm² for aluminium wire. For power wiring, the cross-sectional area of copper wire should not be less than 2.5 mm² and 4 mm² for aluminium wire. For the flexible cord a minimum 0.5 mm² copper wire is used.

7 All wiring equipment made of metal must be earthed.

8 Do not connect the switch or fuse on the earth conductor.

9 The appropriate fuse wire must be fitted in the fuse unit as per the rating of the current flowing in the circuit.

10 Each sub-circuit must be connected to a separate fuse from the distribution board.

11 All switchboards must be erected (left-hand side of the entrance) at a height of 1.5 meter from the floor.

12 Electrical points should be set to 2.75 meter above floor level for fans and 2.25 meter for lamps. (The gap between the bottom of the fan and floor level should not be less than 2.4 meter. The space between the roof ceiling and the blades of the fan should not be less than 300mm).

13 The socket outlet and switches should be installed at a height of 1.3 meter, without any obstruction.

14 The casing should run at a height of 3 meter above the floor level.

15 The light brackets should be fixed at 2 to 2.5 meter from floor level.

16 Two-way switching is recommended for stair-cases.

17 In bed rooms it is recommended that some important lightings and fans are controlled from bed location.

18 For easy operation, it is recommended to use door switch for the light fittings, fitted in deep and dark cupboards.

19 If a 6A socket outlet is installed at a height of 130 cm above the floor level, it is recommended to use shuttered or interlocked socket outlets, thereby preventing access to children.

20 The light fittings erected in kitchens should be so placed that the room is well-illuminated and no shadow falls on working surface. Depending on the size of kitchen, one or two 3-pin 16A socket outlets shall be provided to plug appliances but at the same time care should be taken that they are not fixed directly behind the appliances

21 In bathrooms, it is recommended to use ceiling lamps, and the switch for the same should be fixed outside the bathroom. Alternatively, an insulated-cord-operated switch may be used. Touching a switch with wet hand is very dangerous and lead to electric shock hazard.

22 Use waterproof light fittings and switches for outdoor lighting.

23 Flexible cords shall be used only for wiring of fixtures or pendants or portable appliances. Flexible cords should not be used for concealed wiring and attached permanently to the walls, ceilings, etc.

24 Main switch and starter for motor should be erected at the appropriate height for use. The length of flexible conduit used for connections between terminal box of motors and starters or switches shall not exceed 1.25 meter.

25 Two separate earths must be connected to machines operating at medium and high voltages.

26 All the plugs and sockets must have 3 pins and be earthed.

27 The socket outlet above 16A must be controlled by and appropriate double-pole switch.

28 Multi-pin adaptor should not be used to connect more than one appliance in a socket. Main and distribution board (DB) shall be installed so as not to exceed 2 meter above the floor level. There should also be a space of 1 meter in the front.

29 The metering board shall be fixed 1 meter above the floor level. Energy meter must be fixed first and then continuously connect the IC cutout fuse, main switch, distribution board and so on.

30 It is recommended to use single-phase supply up to 3000 watts load and beyond that, three-phase power supply should be used.

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.

Switch may be installed at any height up to 1.3m above the floor level.

Two-way switching is recommended for halls and staircases.

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 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.

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.

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.

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.

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

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.

Maximum demand and load factor

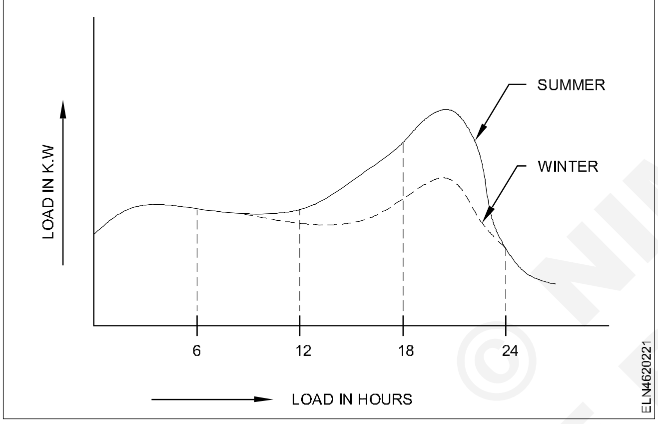
Objectives: At the end of this lesson you shall be able to
- **state the term maximum demand**
- **explain load factor.**

Maximum Demand

It is the highest level or greatest electrical demand monitored in a particular period or a month.

The maximum demand is in between 18 hours and 24 hours in the night during summer as well as in winter seasons as in Fig 1. All other times the maximum demand falls very low to the connected load. However the maximum load demand less than the connected load because all the consumers do not switch 'ON' their connected load of the system at a time.

Fig 1



The importance of the maximum demand knowledge is very important as it helps in determining the installed capacity of the stations, and the station must be capable of meeting the maximum demand.

The ratio of maximum demand as the power station to its connected load is known as demand factor; Mathematically

$$\text{Demand factor} = \frac{\text{Max. Demand}}{\text{Connected load}}$$

Usually it always less than one. The knowledge of demand factor is vital in determining the capacity of the plant equipment.

Load factor

In electrical engineering the load factor is defined as the total load divided by the peak load in specified time period. It is a measure of the utilization rate, or efficiency of electrical energy usage; a low load factor indicates that load is not putting a strain on the electric system, whereas consumers or generators that put more of a strain on the electric distribution will have a high load factor.

$$f_{Load} = \frac{\text{Total load}}{\text{Maximum load in given time period}} \text{ or } \frac{\text{Total load}}{\text{Peak load.}}$$

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.**

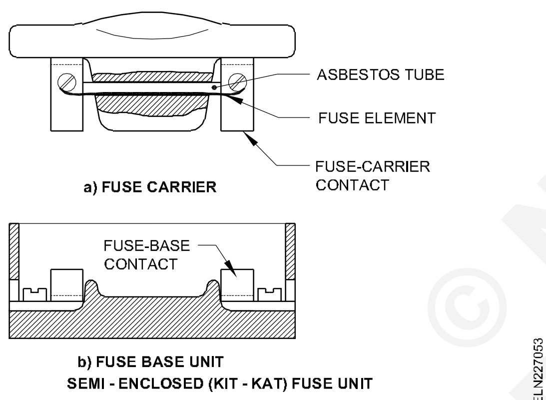
Purpose of fuses: A fuse is a safety device used for the purpose of protecting a circuit against excess current. In the event of excessive current, the fuse element melts and opens up the circuit thereby protecting it from damage.

Types of fuses used in domestic wiring:

- Re-wirable type (up to 200A)
- Cartridge type (up to 1250A)

Rewirable type fuse (Fig 1): 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.

Fig 1



The fuse elements used in this type are tinned copper wire, lead and tin alloy or aluminium wire (Table 1).

Table 1

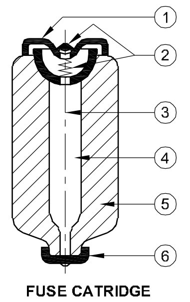
Current rating for	Approximate fusing current Amp	Tinned copper wire		Aluminium wire dia. in mm
		S.W.G.	Diameter in mm	
1.5	3	40	.12192	--
2.5	4	39	.13208	–
3.0	5	38	.1524	.195
4.0	6	37	.17272	–
5.0	8	35	.21336	–
5.5	9	34	.23368	–
6.0	10	33	.254	.307
7.0	11	32	.27432	–
8.0	12	31	.29464	–
8.5	13	30	.31496	–
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	--

The fuse element will melt after approximately 2 minutes when carrying a current equal to twice the current rating.

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.

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 2).

Fig 2

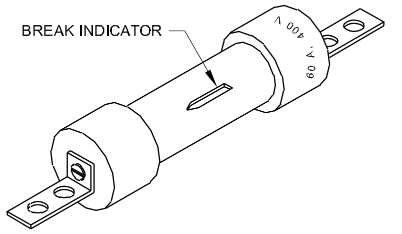


High rupturing capacity (HRC) fuses (Fig 3): They are cylindrical in shape and are made of a ceramic body filled in with a chemically treated filling powder or silica to quench the arcing quickly without any fire hazard.

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.

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.

Fig 3



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.**

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.

1 **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).

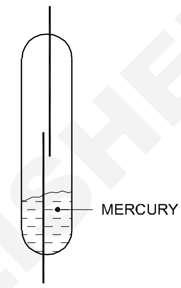
2 **Under-current relay:** Under-current relay is an alarm or protective relay. It is specifically designed to operate when the current falls below a predetermined value.

3 **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.

4 **Mercury wetted contact relay:** This relay consists of a glass enclosed reed with its base immersed in a pool of mercury (Fig 1) . When the coil surrounding the capsule is activated, mercury makes the contact between fixed and movable contacts.

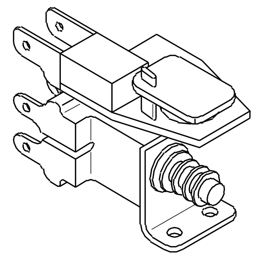
5 **Impulse relay:** The impulse relay (Fig 2) is a special single-coil relay. It has an armature-driven mechanism that alternatively assumes one of two positions as the coil is pulsed. This mechanism moves the contact from one position to the other and back again as electrical pulses are received. The relay can operate on AC or DC power.

Fig 1



MERCURY-WETTED REED RELAY

Fig 2

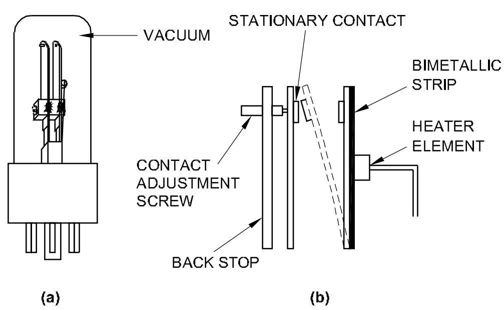


IMPULSE RELAY

6 **Thermal relay:** A thermal relay (Fig 3) 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 3



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 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

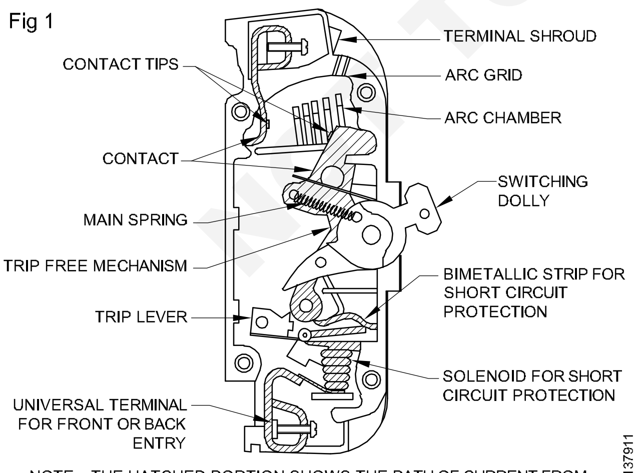
c Assisted bimetallic

In this lesson thermal magnetic MCB explained below

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

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.

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 2).

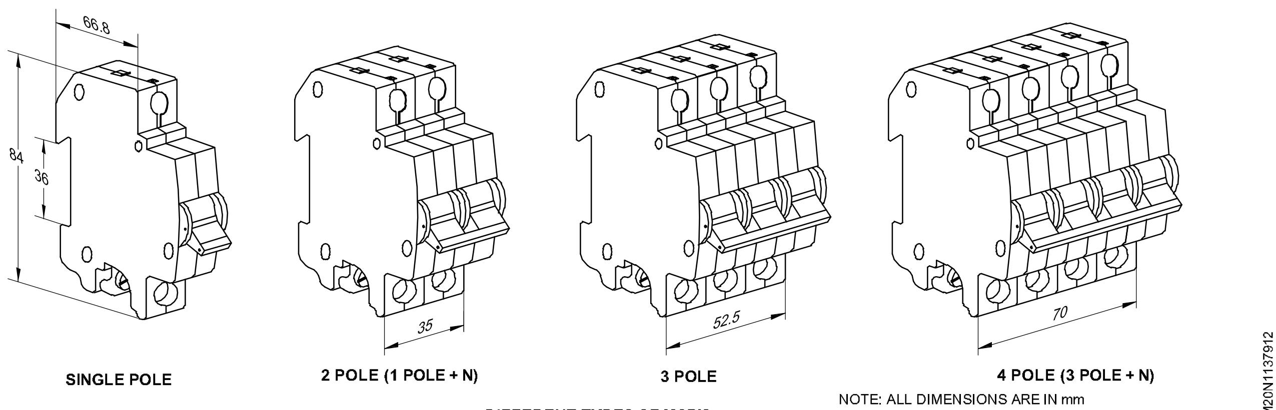
Sl.No.	No. of poles	Current
1	Single pole MCB	0.5 to 60A
2	Double pole MCB (ie. 2 MCBs with common trip bar)	5 to 60A
3	Triple pole MCB	5 to 60A
4	Four pole MCB	5 to 60A

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.

Fig 2



DIFFERENT TYPES OF MCB'S

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 agriculture pump sets.

5 Operation theatres and electrically operated medical equipment such as X-ray machines.

Moulded Case Circuit Breakers (MCCB)

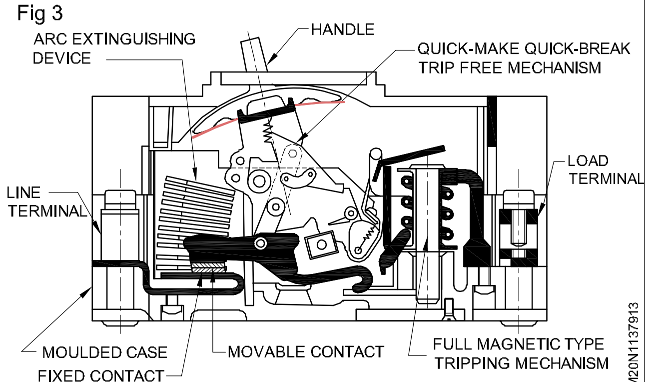
Moulded case circuit breakers are similar to thermo magnetic type MCBs except that these are available in higher ratings of 100 to 800amp at 500V 3-phase.

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 3).

Fig 3



FULLY MAGNETIC TYPE M.C.C.B

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.

ELCB - types - working principle

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).**

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.

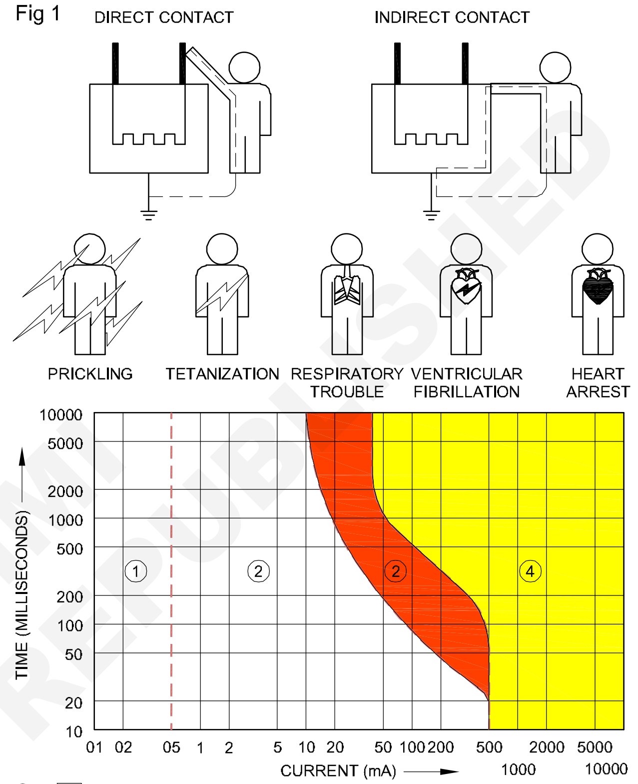
The leakage current to earth also results in the wastage of energy and excessive billing for electricity not actually used.

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.

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 1)

Fig 1



(1) USUALLY NO REACTION EFFECT

(2) USUALLY NO PATHOPYSIOLOGICALLY DANGEROUS EFFECT

(3) USUALLY NO DANGER OF FIBRILLATION

(4) FIBRALLATION DANGER (MORE THAN 50% PROBABILITY)

EFFECT OF ELECTRIC CURRENT ON HUMAN BODY

WM20N1137921

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.

Difference between Earthing and Grounding: The key difference between earthing and grounding is that the term "Earthing" means that the circuit is physically connected to the ground which is Zero Volt Potential to the Ground (Earth). Whereas in "Grounding" the circuit is not physically connected to ground, but its potential is zero with respect to other points.

Earthing: Earthing can simply be defined as the process of protecting against unwarranted spikes and bouts of electricity that can cause damage to life and property. Therefore it is important to remember these key differences between the two. One needs to understand that they both are referring to the same process.

Grounding: Grounding is similar to Earthing, by which insulation against accidental currents is achieved. The main live wire is connected to a power supply to power an appliance, however, the other portion of the wire is led under the earth. This is done in case of an accidental cut in the circuit, to avoid overloading and other dangerous side effects.

Earthing	Grounding
This method protects human beings from electric shocks.	This method protects the entire power system from malfunctioning.
The earth wire used is green in colour.	The wire used for grounding is black in colour
Earthing is primarily used to avoid shocking . the humans	Grounding is primarily used for unbalancing when the electric system overloads.
Earthing is located under the earth pit, between the equipment body underground.	It is located between the neutral of the equipment being used and the ground.

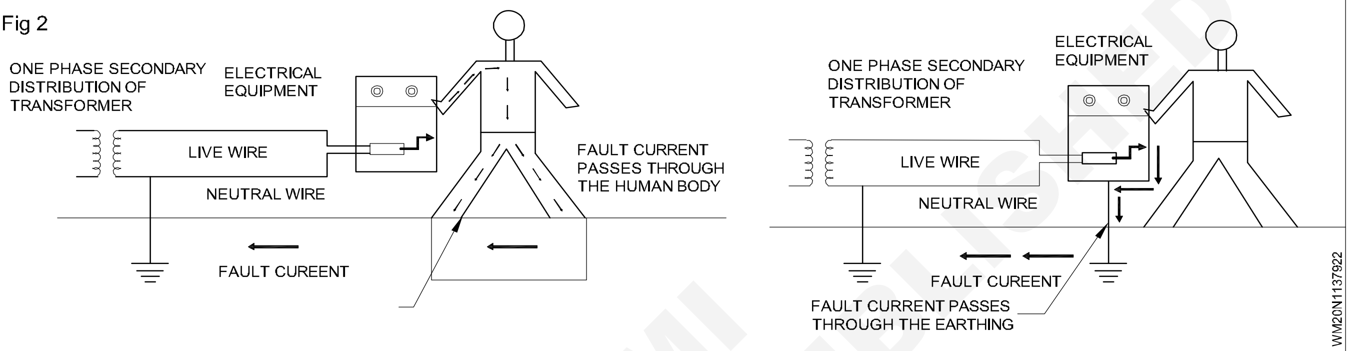
Awareness of earthing

1 Earthing is most important to save human life from the danger of electrical shock or death by blowing a fuse i.e provide an alternate path for the fault current to flow so that it does not harm the user.

2 To protect buildings, machinery, and appliances under a fault condition. (Fig 2)

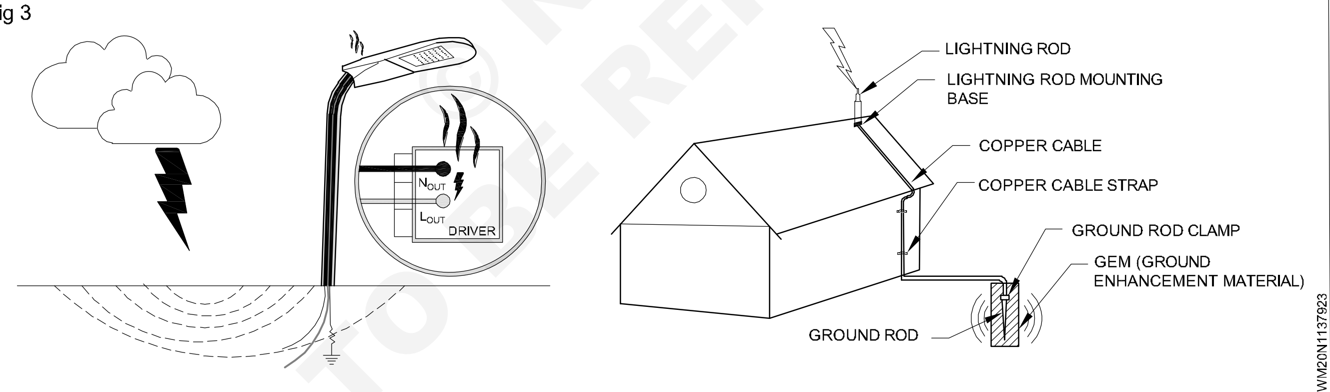
3 To ensure that all the exposed conductive parts do not reach a dangerous potential.

Fig 2



4 To provide a safe path to dissipate lightning and short circuit current. (Fig 3)

Fig 3



Portable Earthing

Short Circuiting & Earthing Kits ensure a repair operator's protection against an accidental commissioning or possible return voltage during repair operations. (Fig 4)

Portable Earthing Kits are self-contained sets consisting of portable cut-out equipment and portable line equipment. To provide a controlled path for short-circuit current, portable short-circuiting and earthing equipment is temporarily installed on isolated power circuits. (Fig 5)

Fig 4

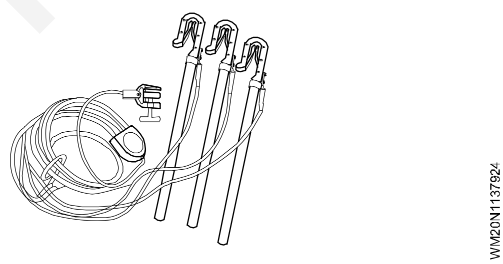
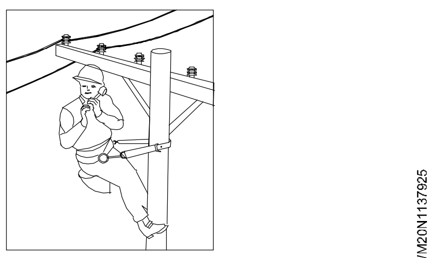


Fig 5



Voltage Regulator

Objectives : At the end of this exercise you shall be able to
- **explain voltage regulator).**

Coltage regulator: A voltage regulator is a circuit that creates and maintains a fixed output voltage, irrespective of changes to the input voltage or load conditions**.**

Voltage regulators (VRs) keep the voltages from a power supply within a range that is compatible with the other electrical components. While voltage regulators are most commonly used for DC/DC power conversion, some can perform AC/AC or AC/DC power conversion as well.

Types of Voltage Regulators: Linear vs. Switching: There are two main types of voltage regulators: linear and switching. Both types regulate a system's voltage, but linear regulators operate with low efficiency and switching regulators operate with high efficiency. In high-efficiency switching regulators, most of the input power is transferred to the output without dissipation.

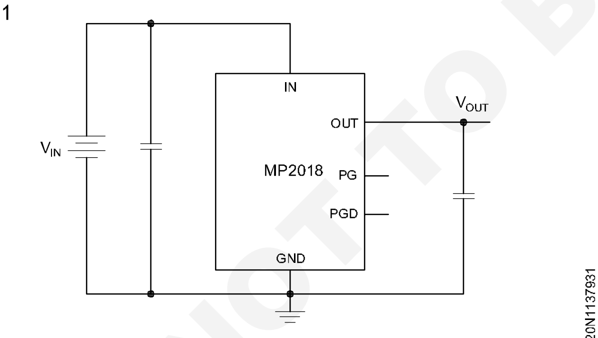
Linear Regulators: A linear voltage regulator utilizes an active pass device which is controlled by a high-gain operational amplifier. To maintain a constant output voltage, the linear regulator adjusts the pass device resistance by comparing the internal voltage reference to the sampled output voltage, and then driving the error to zero.

Linear regulators are step-down converters, so by definition the output voltage is always below the input voltage. However, these regulators offer a few advantages: they are generally easy to design, dependable, cost-efficient, and offer low noise as well as a low output voltage ripple.

Linear regulators, such as the MP2018, only require an input and output capacitor to operate Fig 1.

MP2018 Linear Regulator

Fig 1



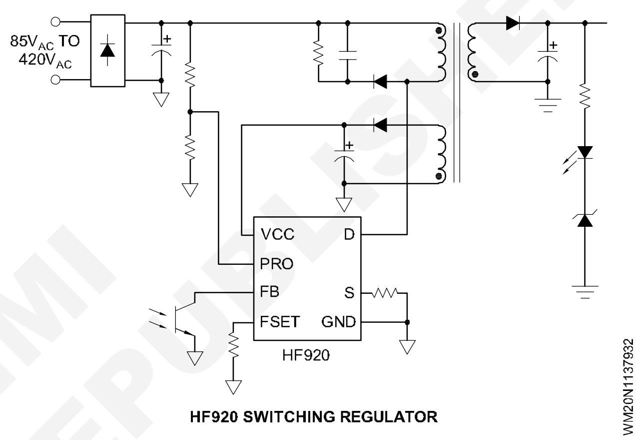
LINEAR REGULATOR

Switching Regulators: A switching regulator circuit is generally more complicated to design than a linear regulator, and requires selecting external component values, tuning control loops for stability, and careful layout design.

Switching regulators can be step-down converters, step-up converters, or a combination of the two, which makes them more versatile than a linear regulator.

Advantages of switching regulators include that they are highly efficient, have better thermal performance, and can support higher current and wider VIN / VOUT applications. Unlike linear regulators, a switching power supply system may require additional external components, such as inductors, capacitors, FETs, or feedback resistors. The HF920 is an example of a switching regulator that offers high reliability and efficient power regulation. (Fig 2)

Fig 2



HF920 SWITCHING REGULATOR

Limitations of Voltage Regulators: One of the main disadvantages for linear regulators is that they can be inefficient, as they dissipate large amounts of power in certain use cases. The voltage drop of a linear regulator is comparable to a voltage drop across a resistor. For instance, with a 5V input voltage and a 3V output voltage, there is a 2V drop between the terminals, and the efficiency is limited to 3V/5V (60%). This means linear regulators are best suited for applications with lower VIN / VOUT differentials.

Another limitation of linear voltage regulators is that they are only capable of buck (step-down) conversion, in contrast to switching regulators, which also offer boost (step-up) and buck-boost conversion.

Switching regulators are highly efficient, but some disadvantages include that they are generally less cost-effective than linear regulators, larger in size, more complex, and can create more noise. Noise can be very important for a given application, as noise can affect circuit operation and performance.

Layout of domestic 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.**

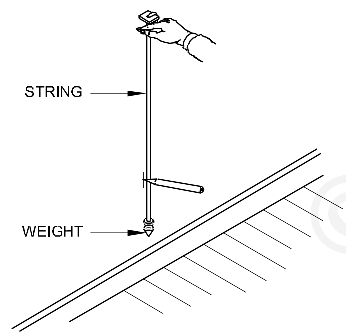
When installing electrical wiring in a building, it is necessary to mark the layout on the ceiling and walls to indicate the position of the various fittings and appliances to be installed and the routing of the cable runs.

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)

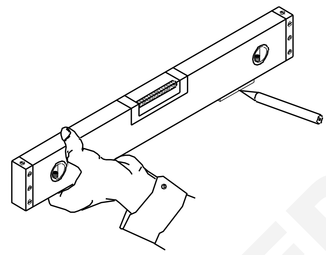
Fig 1



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)

Fig 2

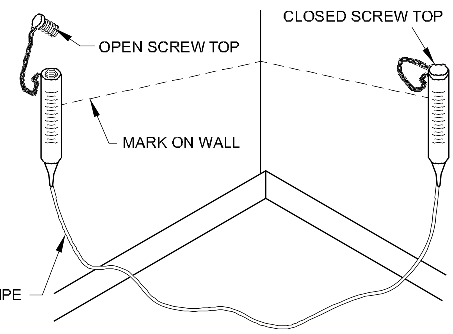


USE OF SPIRIT LEVEL

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)

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.

Fig 3



WATER LEVEL

Electrical wiring system - Cleat, batten (CTS), conduit, concealed conduit, casing and capping

Objectives: At the end of this lesson you shall be able to
- **state the types of intendent wiring used in domestic installation.**

Introduction of cleat wiring

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 internal wiring

The following are the types of internal wiring used in domestic installations.

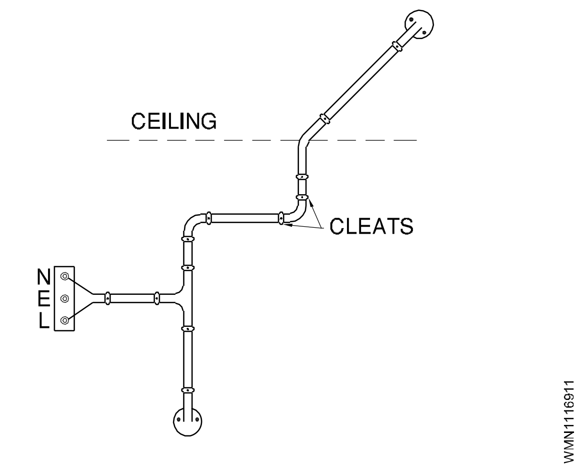
- Cleat wiring (for temporary wiring only)
- PVC casing & capping wiring

- CTS/TRS (batten) wiring
- Metal/PVC conduit wiring, either on surface or concealed in the wall.

Cleat wiring

This system shown in Fig 1 uses insulated cables supported in porcelain cleats.

Fig 1



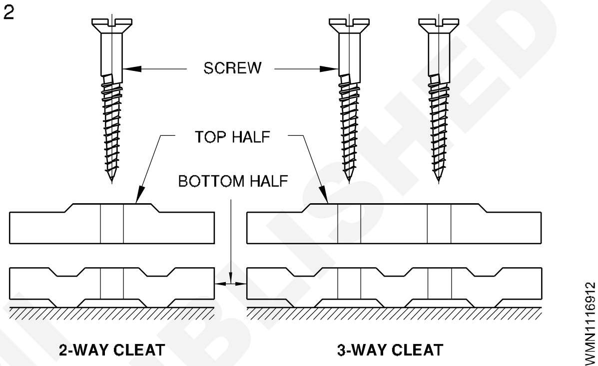
Cleat wiring is recommended only for temporary installations. These cleats are made in pairs having bottom and top halves as shown in Fig 2. Bottom half is grooved to receive the wire and the top half is for cable grip.

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. Two types of cleats are shown in Fig 2.

Cleat wiring is one of the cheapest wirings considering the initial cost and labour, and is most suitable for temporary 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.

Fig 2



Batten wiring

Objectives: At the end of this lesson you shall be able to
- **state the batten wiring installation**
- **describe the types of clips (size, material, shape)**
- **state the B I S regulation regarding spacing of clips.**

Batten wiring: Tough rubber sheathed (T R S) or PVC sheathed cables are suitable to run on the teak wood battens.

Method of securing the battens: These battens shall be secured to the walls and ceilings by flat head wood screws to wooden plugs at an interval not exceeding 75 cm. The flat head wood screws shall be countersunk within the wooden batten and smoothed down with a file.

Suitability of tough rubber sheathed cables: Wiring with tough rubber-sheathed cables is suitable for low voltage installation and shall not be used in places exposed to sun and rain nor in damp places.

Suitability of PVC - sheathed cables: Wiring with PVC sheathed cables is suitable for medium voltage installation and may be installed directly under exposed conditions of sun and rain or in damp places. This system of wiring is suitable in situations where acids and alkalies are likely to be present.

Painting: If so required, the tough rubber-sheathed wiring shall, after erection, be painted with one coat of oil-less paint or distemper and the PVC-sheathed wiring shall be painted with a synthetic enamel paint of quick drying type.

Bends in wiring: The wiring shall not in any circumstances be bend so as to form a right angle but shall be rounded off at the corners to a radius not less than six times the overall diameter of the cable.

Passing through walls: Care shall be taken to see that wires pass very freely through a protective pipe or box and that the wires pass through in a straight line without any twist or cross in the wires, on either end of such holes.

Passing through floors: All cables taken through floors shall be enclosed in an insulated heavy gauge steel conduit extending 1.5 m above the floor and flush with the ceiling below.

Stripping of outer covering: While cutting and stripping the outer covering of the cables, care shall be taken that the sharp edge of the cutting instrument does not touch the rubber or PVC-sheathed insulation of the conductors.

Link clips: Link clips are used for firmly clipping the cables in position. Link clips are of two types.

– Link clips which separate linking eye. (Fig 1)

– Joint link clips which have combined linking eye. (Fig 2)

Fig 1

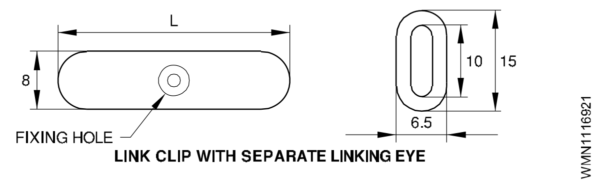
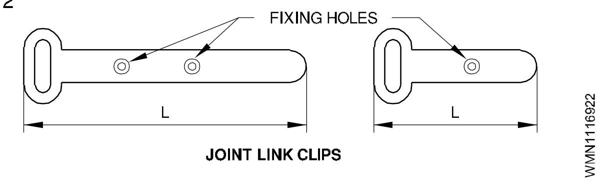


Fig 2



Link clips are made out of tin or brass or brass coated tin or aluminium.

Fixing the link clips

Link clips shall be arranged so that one single clip shall not hold more than two twin-core or three single core TRS or PVC insulated and PVC sheathed cables up to 1.5 sq. mm. above which a single clip shall hold a single twin-core or two single core cables. The clips shall be fixed on varnished wood battens with rust-resisting pins and screws and spaced at intervals of 10 cm in the case of horizontal runs and 15 cm in the case of vertical runs. For the wiring and runs of mains exposed to heat and rain, clips specially made for outdoor use from a durable metal, resistant to weather and atmosphere corrosion, shall be used.

Conduit wiring - types of conduits

Objectives: At the end of this lesson you shall be able to
- **distinguish between the different types of conduits used in wiring**
- **state the gauge, diameter and length of the metallic and non- metallic conduits available in the market**
- **state the variations in the conduit wiring system**
- **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. However, tubular conduit is the most commonly used material 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.

Rigid steel conduit

This can be further divided into a) Heavy gauge screwed conduit, and b) light gauge conduit.

a Heavy gauge screwed conduit

This can be either solid-drawn or seam - welded. Seam-welded conduit is the one, commonly used in modern domestic, commercial and industrial wirings.

b Light gauge conduit

The use of a light gauge conduit is restricted to indoor conduit wiring to have protection for inlaid cables.

Size of metal conduits

Commercially metal conduits are available in lengths of 3.00 metres and in diameters from 20 mm to 64 mm. Commercially available diameters of metal and non-metal conduits and their wall thickness are given in Table 1.

Choosing a particular diameter of conduit depends upon the size and number of cables to be drawn in.

Normally the conduit pipe size refers to the outer diameter whereas, for G I pipes sizes are referred in terms of the internal diameter.

All metallic conduits get corroded in damp and chemical environment. Hence, conduits are to be protected against corrosion by galvanising them, when used for outdoor work or where dampness is present. For dry environments, black enameling on the conduit would be sufficient.

Table 1

Nominal size of conduit in mm	Wall thickness of heavy gauge conduit in mm	Wall thickness of light gauge conduit in mm
20	1.8	1.0
25	1.8	1.2
32	1.8	1.2
38	2.0	—
51	2.24	—
64	2.5	—
Non-metal 18 to 64	2 or more than 2	Less than 1.5 mm

Non-metallic conduits: These are made of 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.

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.

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 2 will help in choosing the right type of conduit for a specific installation.

Table 2

Comparison between metal and PVC wirings

Sl.No.	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^{0}C, the conduit starts melting. At very low temperature the conduit cracks.
9	Fire resistant.	Non-fire-resistant.
10	More costly.	Less costly.

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^{o}C.
- In places where the ambient temperature is less than 5^{o}C.
- For suspension of fluorescent fittings and other fixtures
- In areas exposed to sunlight.

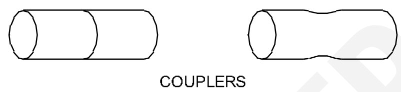
Non-metallic conduit accessories

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.

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.

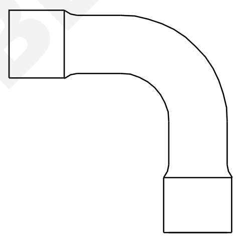
Fig 1



TYPES OF COUPLERS

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.

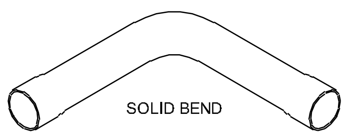
Fig 2



ELBOWS

Bends (Fig 3): A bend gives a diversion of 90^{o}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.

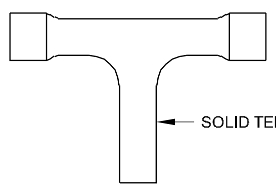
Fig 3



BENDS

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.

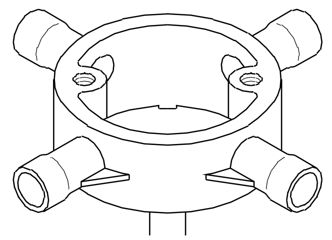
Fig 4



TEE

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.

Fig 5



CIRCULAR BOXES

WMN1116935

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.

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.

Conduit fittings should be best avoided, as far as possible, on outdoor systems.

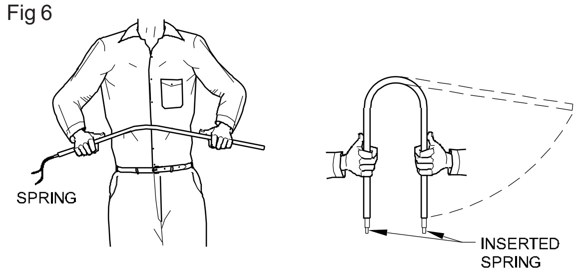
Bends in conduit: All bends in the non-metallic system shall be formed either by bending the pipes by proper heating or by inserting suitable accessories such as bends elbows or similar fittings. Solid type fittings shall be used for recessed wiring. Solid type/inspection type of fittings shall be used 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 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 6). 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.

Fig 6



BENDING OF PVC PIPE BY HAND

WMN1116938

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.

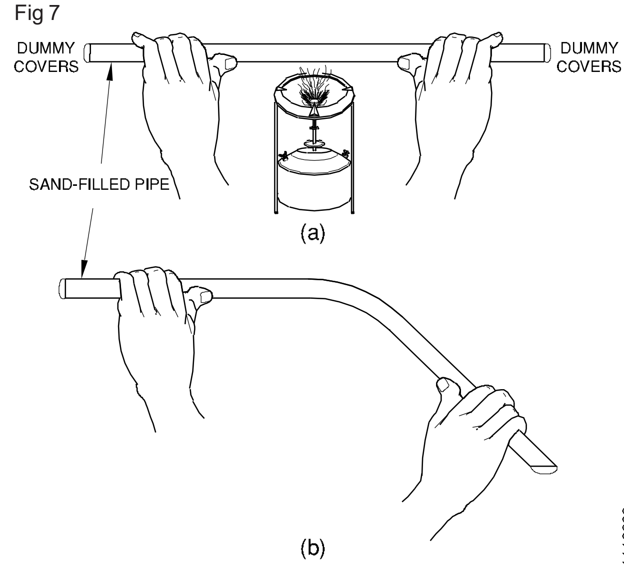
Bending PVC conduit in cold weather: In cold weather it may become necessary to warm the conduit slightly at the point where the bend is required. One of the simplest ways to do this is to rub the conduit with the hand or a cloth. The PVC will retain the heat created long enough for the bend to be made. 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 7a) 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 7b). Care shall be taken to avoid kinks on the conduits while bending.

Fig 7



HOT BENDING OF THE PVC PIPE

WMN1116939

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.

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.**

Installation of conduits

The conduit work of each circuit or section shall be completed before the cables are drawn in.

Points to be followed while drawing cables through a conduit

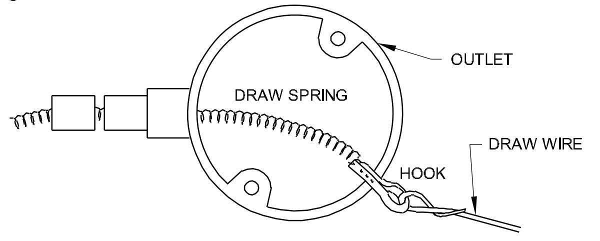
When drawing cables care shall be taken to avoid twisting of cables. If the cable available is in a drum or reel it can be mounted on a stand and drawn freely. Cables generally available in the market will be in the coil form. The cable shall be simultaneously drawn into the conduits. To draw more numbers of cables, from different coils, keep the coils side by side, then bunch the cable ends to be drawn into the conduit.

The G I fish wire or draw wire can be inserted inside the conduit to pull the cables through the conduits.

In cases where the fish wire provided is cut in between, a spring shall be pushed through from one point to the other point in the section. The spring shall have hooks to bind the draw wire at both ends. Then a draw-wire (GI/Steel) should be tied to the hook on one end of the spring as shown in Fig 1 and drawn inside the conduit. A spring wire should not be used for drawing in the cables as it may get damaged. A spring may be used to pull through a draw-wire as shown in Fig 1.

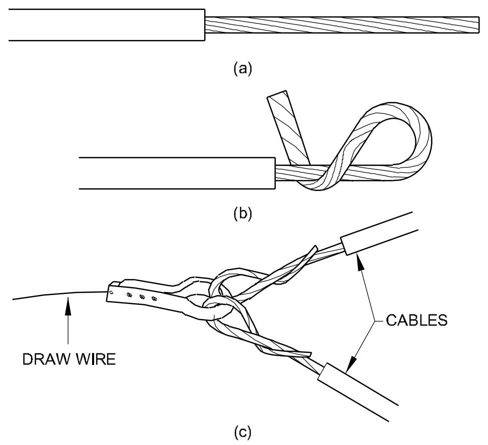
The ends of the cables must be bared for a distance of approximately 75 mm, and threaded through a loop in the draw wire as shown in the Fig 2.

Fig 1



METHOD OF DRAWING THE CABLE IN THE CONDUIT

Fig 2



METHOD OF FASTENING THE CABLES WITH DRAW SPRING

When drawing in a number of cables they must be fed in by pushing the cables in very carefully at the delivery end whilst someone pulls them at the receiving end.

This operation needs care and there must be synchronisation between the person who is feeding and the person who is pulling.

Method of drawing cables through conduit

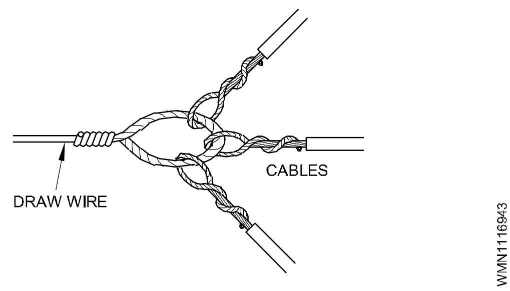
Pass the spring through the outlets as shown in Fig 1. Fasten a draw-wire securely to the spring.

Feed the draw-wire into the conduit, by pulling the spring. Ensure that the draw-wire is long enough and strong enough for the job.

Fasten the cables to the draw-wire. Atleast 75 mm (3") of insulation should be stripped away and secured as illustrated in Figs 2 and 3. Fasten each cable separately.

Rules and regulations regarding conduit wiring system with rigid non-metallic conduits as per NE code: Rigid non-metallic conduits are used for surface and concealed conduit wiring.

Fig 3



Types of PVC conduit: The conduit may be either of the threaded type or plain type and shall be used with the corresponding accessories.

For all interior electrical applications the plain PVC conduit of grip joining type shall be used.

Bunching of cables: Conductors of AC supply and DC supply shall be bunched in separate conduits. For lighting and small power outlet circuits, phase segregation in a separate circuit is recommended. The number of insulated cables that may be drawn into the conduits shall be as per Table 2.

Conduit joints: Conduits shall be joned by means of screwed or pain grip type couplers depending on weter conduits are screwed or pain. Where there are long runs of straight conduits, inspection type couplers shall be provided at intervals. A joints in conduits shall be sealed with a solvent cement/adhesive.

Fixing of conduits: Conduit pipes shall be fixed by heavy gauge non-metallic saddles with a base. Spacing between saddles or supports in recommended to be 60 cm for rigit non-metallic conduits. At either end of the fittings, saddles shall be fixed at a distance o 15 cm.

Bending in conduit: Wherever necessary bends or diversion may be achieved by bending the conduits or by employing normal bends, inspection bends, inspection boxes, elbows or similar fittings.

Fittings: Conduit fittings shall be avoided, as far as possible on outdoor systems.

Outlets: All the outlets for fittings, switches, etc. sall be boxes of substantial contruction. In order to minimise condensation or sweating and the conduit, all outlets of conduit systems, shall be property drained and ventilated, but in such a manner as to prevent the entry of insects, etc., as far as possible.

Table 2

Maximum permissible number of 250-volts grade single-core cables that may be drawn into rigid non-metallic conduits.

Size of cable		Size of conduit(mm)					
Nominal cross-sectional area mm²	**Number and diameter in mm of wires**	**16**	**19**	**25**	**32**	**38**	**51**
1.0 –	1/1.12 Cu	5	7	13	20	–	
1.5	1/1.40 Al/Cu	4	6	10	14	–	–
2.5	1/1.80 Al/Cu 3/1.06 Cu	3	5	10	14	–	–
4	1/2.24 Al/Cu	2	3	6	10	14	–
6	1/2.80 Al/Cu 7/1.06 Cu	–	2	5	8	11	–
10	1/3.55 Al 7/1.40 Cu	–	–	4	7	9	–
16	7/1.70 Al/Cu	–	–	2	4	5	12
25	7/2.24 Al/Cu	–	–	–	2	2	6
35	7/2.50 Al/Cu	–	–	–	–	2	5
50	7/3.00 Al19/1.80 Al/Cu	–	–	–	–	2	3

Cu – For copper conductors only.

Al – For aluminium conductors only.

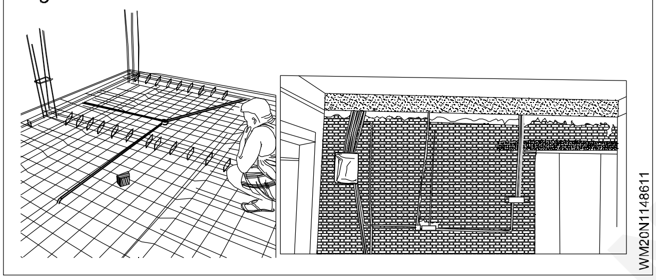
Concealed PVC conduit wiring

Objectives: At the end of this lesson you shall be able to
- **explain the method of executing concealed conduit wiring in an installation**
- **state the advantages and disadvantages of concealed conduit wiring.**

Concealed wiring is the most suitable wiring for workshop, offices, apartments and houses. The only requirement in the installation should be planned well in advance before starting of the construction work and executed while construction is in progress. As such this type of wiring is not suitable for already constructed houses.

Concealed conduit wiring is the method of installing heavy metal or PVC conduits under the plaster of walls or inside the concrete of the ceiling. Concealed wiring demands proper planning of the route of conduit in the ceiling as well as in the walls. (Fig 1)

Fig 1



Advantages of the concealed wiring

Concealed wiring when installed properly ensures

a excellent protection against mechanical damages

b good look of the electrical installation as the conduit is concealed

c protection against moisture in the atmosphere

d protection against fire

e long life of installed cables

f shock-proof installation

g the wiring can be done through the shortest route.

Disadvantages of the concealed wiring

a The cost of installation is high

b Difficult to trace the wiring routes unless conduit route plan is available

c In case of fault location, rectification of the fault is difficult

d The concealed wiring installation requires skilled technicians to carry out the job

e The wiring has to be planned and executed only during the construction of the building.

PVC Channel (casing and capping) wiring

Objectives: At the end of this lesson you shall be able to
- **state the use of channel wiring system**
- **state the limitations of channel wiring system**
- **state how to select the channel size according to size and number of cables from the chart**
- **state the rules regarding the installation of channels, floor/wall crossings and joints**
- **explain the method of fabricating neutral, bend, junction and double set in a metal channel system**
- **state the method of drawing cables and maintaining earth continuity in channel wiring system.**

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.

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.

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

Installation of PVC/Metal channel : The channel should be fixed to wall/ceiling with flat headed screws and rawl plugs. These screws shall be fixed at an interval of 60cm.

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.

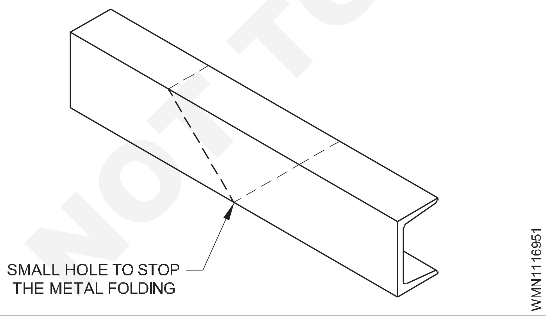
Joint in metal channel : Joint in metal channel is made by cutting the sections to required angles and then joining by rivetting, welding or with connecting with nuts and bolts.

Fabricating a right-angled vertical bend

1 Mark out the position of bend of all sides as shown in Fig 1.

2 Drill small holes in corners at point of bend to stop metal folding. (Fig 1)

Fig 1



3 Place wood blocks inside trunking for support. Cut sides of trunking as shown in Fig 2.

4 Cut, file and break-off waste as shown in Fig 3.

5 File all the edges smooth in order to bend to shape. (Fig 4)

6 Make fish plates out of scrap and drill for fixing holes. (Fig 5)

Fig 2

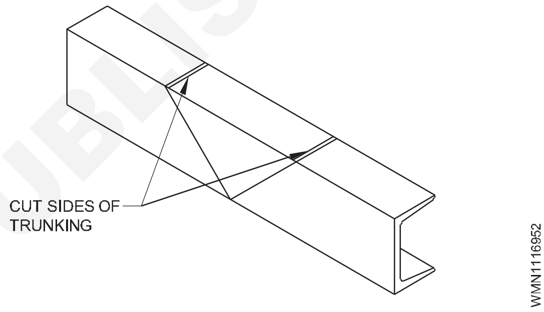


Fig 3

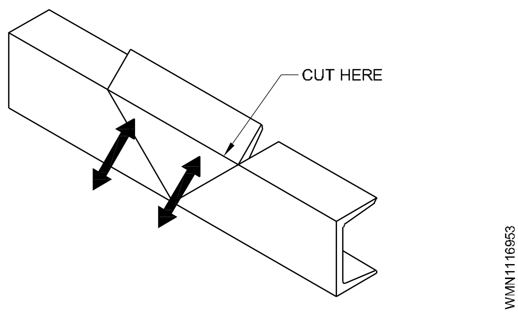


Fig 4

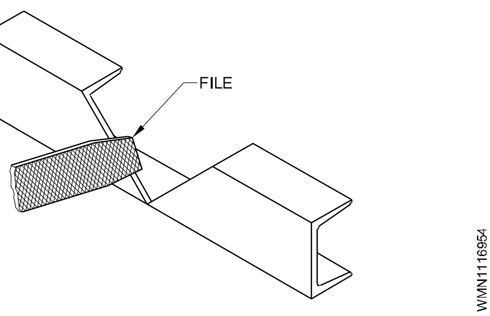
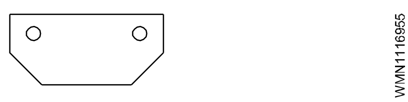


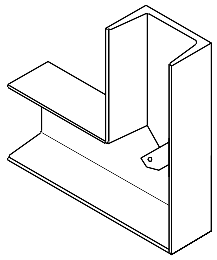
Fig 5



7 Mark out the trunking from fish plates and drill in the block.

8 Secure assembly with nuts and bolts or rivets. (Fig 6) Alternatively joints may be spot-welded.

Fig 6

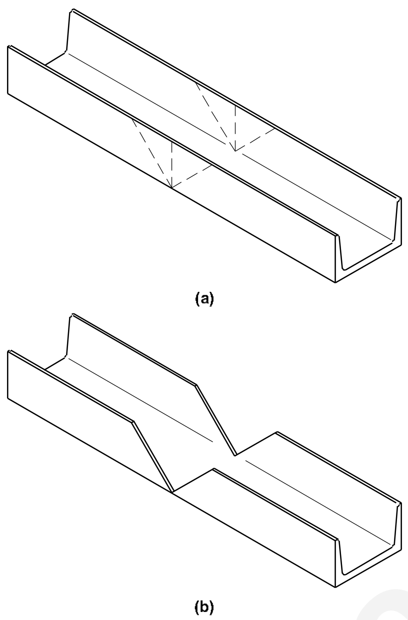


Fabricating 90° bend

1 Mark out the position of bend as shown in Fig 7a & b.

2 Place wood blocks in trunking for support and make cuts with hacksaw.

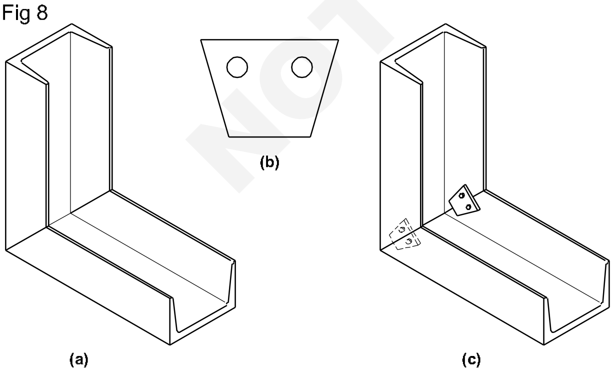
Fig 7



3 Remove sections and file smoothly.

4 Bend shape and adjust the fit as required in Fig 8a, b & c.

Fig 8



Fabricating a Tee junction

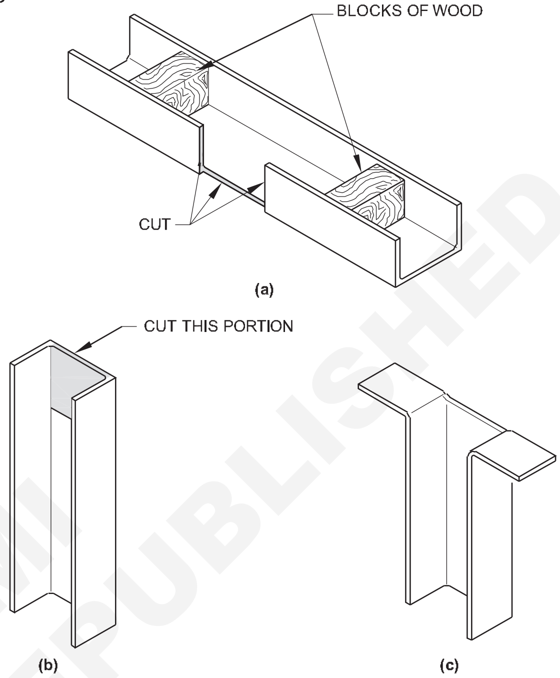
1 Mark out the position of tee using another piece of trunking to gauge width

2 Cut out the space for the tee, as shown in Fig 9a. Blocks of wood should be used to support section being cut.

3 In another piece cut away the section as shown in Fig9b to form leg. Bend in vice as shown in Fig 9c.

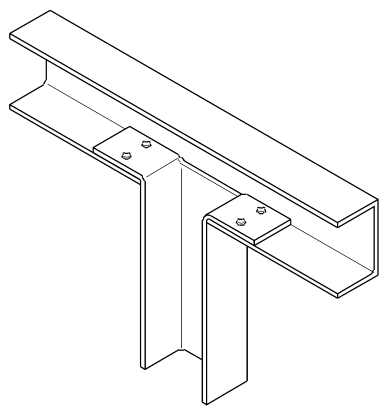
4 File edges smooth and remove burrs. Check fit and adjust as necessary.

Fig 9



5 Mark out for holes, drill and secure with nuts and bolts or rivets or (Fig 10) may be spot-welded.

Fig 10



ASSEMBLEDTEE JUNCTION

Installation of cables : Cables carrying direct current or alternate current shall always be bunched 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.

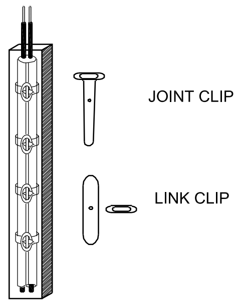
In case of metallic casing and capping channel, there shall be a metallic link between adjacent casing with screw connections, and also connections from end channel (casing) to earth terminal of metallic boxes/outlets.

Clip distance, fixing of screws and cable bending

Objectives: At the end of this lesson you shall be able to
- **state the distance requires for fixing clips**
- **state the distance requires for fixing screws**
- **state the method of fixing bends.**

Clip distance: Group of single or double or three core cables are used to be laid on teakwood batten. The cable are hold with help of tinned brass tlink clip or buckleclip. Buckle clips is fixed with brass pin on the wooden battan at an interval of 10 cm for horizontal and 15 cm for vertical runs. (Fig 1)

Fig 1



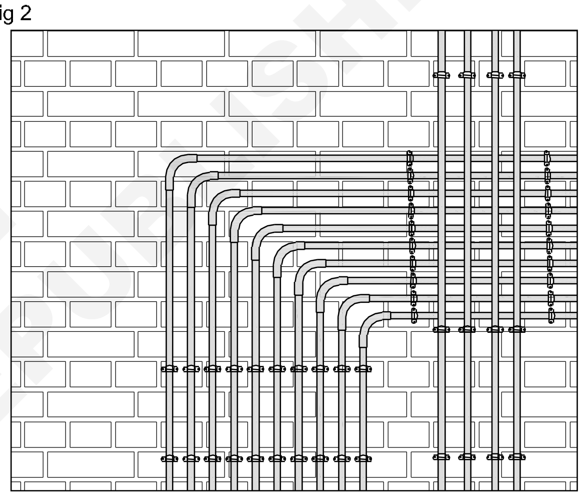
BATTEN WIRING SYSTEM

Fixing of screws

For fixing batten the distance between the fix screws should not exceed 75 cm.

Bends in wiring: The wiring shall not at any circumcumtances bent at right angle but shall be rounded off at the corners to a radius not less than six times the over all diameter of the cable. (Fig 2)

Fig 2



Estimation procedure for house wiring

Objectives: At the end of this lesson you shall be able to
- **explain estimation procedure for house wiring.**

The estimation and costing of house wiring or residential plan, materials required for wiring, estimation, and cost of the lighting circuit, and heating circuit for house wiring or residential plan.

Estimation And Costing of House: Wiring Given data: Consider a given residential plan. (Fig 1)

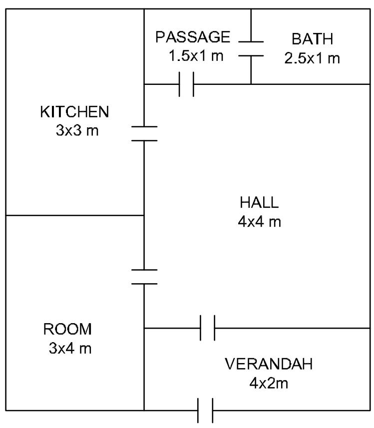
This is the plan where we should calculate everything i.e., what are the materials required for the plan and make a list of materials with costing.

All dimensions are in a meter

The following assumptions are made :

- The height of the meter board, distribution board from the floor level = 2 meters.
- Height of horizontal run and lighting fitting from floor level = 3 meters.
- Height of switchboard from floor level = 1.5 meters.

Fig 1



Step-01

Total lighting load and number of circuits.

Sl.No.	Location	Area (meter square	Wattage (10W/m sq)	Points	Points	Points	Type of Fitting
				Lights	Fans	Socket	
01	Verandah	8	80	1 * 60	–	–	Pendent
02	Room	12	120	1*40(FL) 1*60(IL)	1*80	1*60	Pendent Batten
03	Hall	16	160	2*40 1*60	1*80	1*60	Pendent Batten
04	Kitchen	9	90	1*40 1*60	– –	PS=2000	Pendent Batten
05	Passage	1.5	15	1*60	–	PS=1000	Pendent
06	Bath room	2.5	2.5	1*60	–	–	Pendent
		Total load =	480 watts	160 watts	120 watts		

- Total lighting circuit load = 480 + 160 + 120 = 760 watts
- Total heating circuit load = 3000 watts
- Total load of Installation = 760 + 3000 = 3760 watts

No of the lighting circuit

= Total lighting circuit load/800

= 760/800 = **0.95**

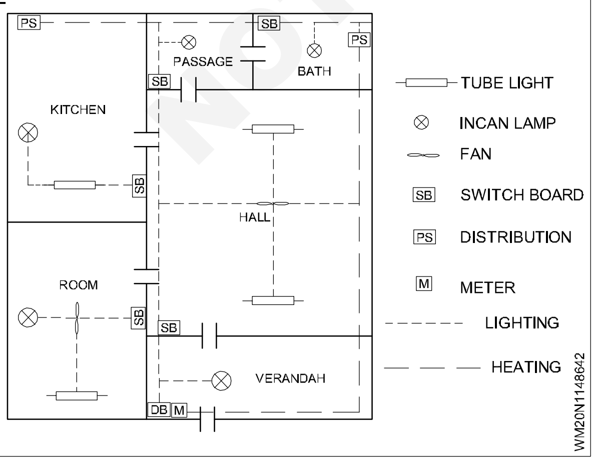
If the total lighting circuit load exceeds 800 watts then two circuits must be provided, but here total lighting circuit load is less than 800 watts.

Therefore, only one circuit is used. Hence from the Meter board, one lighting and one heating circuit are taken.

Step-02

Wiring diagram for the given plan: (Fig 2)

Fig 2



Step-03

Size of the wire

To calculate any size of the wire, first, we should calculate load current and by using a wire table size of the wire can be calculated.

Load current = Total lighting circuit load/Voltage

= 760/230 = 3.30 Amps

let, a factor of safety be 2(for future demands or load)

Current rating = load current * 2

= 3.30 * 2 = 6.6 Amps

Therefore, for lighting circuit 3/22 SWG copper wire is selected from the wire table.

Step-04

Length of Conduit required, use concealed conduit system of wiring.

Total = 37 + 1,65(wall crossing)

= 38.65 = 39 (say)

Total PVC conduit = 39 +5% wastage

= 40.95 = 41 meter (say)

Step-05

The total length of wire required

length of wire(3/22 copper wire) = 41 * 3

= 123 meter

Sl.No	Location	Horizontal run	Vertical drop to switch	Vertical rise pipe line to ceiling fan	Wall crossing	Total
01	Verandah	4+2	–	0.5		6.5
02	Room	3+2	1	0.5		6.5
03	Kitchen	3+1.5	1	0.5		6
04	Hall	4+4+4	1	0.5	0.33*5 = 1.65 (overall)	12
05	Passage	1+1.5+0.75	1	0.5		3.25
06	Bath	1.25	1	0.5		2.75
	Total				1.65	37

Step-06

Wood screws(assorted size) = 4(No of MB+SB)

= 4(1 + 4)

= 20 + 5% wastage

= 21.95 Nos

Step-07

The number of wood plugs required is 22 Nos as same as wood screws.

Step-08

Other accessories required

ICDP Switch

- load current = 3.30 * 2 = 6.6 Amps
- 16A ICDP switch is selected or 16A MCB is used.

Switches = No of lamps + fans + sockets

= 12 + 2

= 14 Nos

250 V, 6 A switches = 14Nos

250 volts, 6 A, 3-Pin socket = 2 Nos

No of fan regulators = 2 Nos

No of Pendant holder = 6 Nos

No of Angle holder = 4 Nos

No of ceiling roses = No of fan + No of pendant

= 2 + 6 = 8 Nos

Fluorescent fitting, 230 V, 6 A = 4 set

Ceiling fans, 230 V = 2 set

Incandescent fitting = 6 set

No of Tees = 4 Nos

Meter Board = 1 Nos

Switch Board = 4 Nos

Step-09

Labour Charge

The labour charge depends upon the number of points

No of point

- = (lights + fan + sockets) * 0.5 + MB + DB
- = (10 + 2 + 2) * 0.5 + 1 + 1
- = 15 Nos

Labour Cost = Cost per point * No of points

= 195 * 15 = Rs 2970.00

Step-10

Cost Of Materials

Cost depends on you which company product you are buying.

1 For heating load

load current = Total heating circuit load / Voltage

= 3000 / 230 = 13.04 Amps

Current rating = load current * Factor of safety

= 13.04 * 2 = 26.08 Amps

Therefore, 7/20 SWG copper wire is selected.

2 PVC Conduit required

Horizontal run = 4+2+4+1+2.5+1.5+3

= 18 meter

- Vertical drop = 1+1 = 2 meter
- Wall crossing = 0.33 * 4 = 1.32 meter
- Total PVC Conduit = 21.32 = 22 (25mm, 2mm thick)

Therefore, Total PVC conduit = 22 + 10% wastage

= 24.2 = 25 meter

3 Length of wire required

Length of wire = 3 * length of PVC conduit

= 3 * 25

= 75 meter

4 Wood screws (assorted size) = 4 * 2

= 8 No + 5%

= 8.4 = 9 No's

5 Wood Plugs = 9 No's

6 Other accessories required

a ICDP Switch

Load current = 13.04, FOS = 3

Current rating = 13.04 * 3 = 39.13 Amps

250 V, 50 Amps selected

b Switches - A 250 V, 16 A switches = 2 No's

c 3-Pin socket = 2 No's

d No of elbows = 2 No's

e Switch board (200*250*45 mm) = 2 No's

7 Labour Cost

No of point = 2

labour cost = 195 * 2 = 390 rupees.

National building code for house wiring, specifications, types, rating and materials

Objectives: At the end of this lesson you shall be able to
- **state the National building code for house wiring specifications**
- **state the National building code for house wiring speficification, type, rating and materials.**

National building code: For guidelines for electrical installation in residential buildings, reference may be made to good practice.

A typical distribution scheme in a residential building with separate circuits for lights and fans and for power appliances.

The important information regarding the installation of different electrical equipment, reference are given below undersection 8 - (32) code 6.

Wiring

Provision for Maximum Load

All conductors, switches and accessories shall be of such size as to be capable of carrying, without their respective ratings being exceeded, the maximum current which will normally flow through them. (Table 1)

Estimation of Load Requirements

In estimating the current to be carried by any conductor the following ratings shall be taken, unless the actual values are known or specified for these elements:

Table 1

Sl No. (1)	Element (2)	Rating (Watts) (3)
i	Incandescent lamp	60
ii	Ceiling fan	60
iii	Table fan	60
iv	6 A socket outlet	100 unless the actual value of loads are specified
v	16 A socket outlet	1 000, unless the actual value of loads are specified
vi	Fluorescent light: Length :	
	a 600 mm	25
	b 1 200 mm	50
	c 1 500 mm	90
vii	High pressure mercury vapour (HPMV) lamps, high pressure sodium vapour (HPSV) lamps	According to their capacity, control gear losses shall be also considered as applicable

viii	Compact fluorescent lamp (CFL)	20
ix	Light emitting diode (LED)	10
x	Exhaust fan	
xi	Geyser (storage type)	2,000
xii	Geyser (Instant)	3,000
xiii	Computer point	150
xiv	Computer (laptop)	50
xv	Printer, laser	1500
xvi	Printer, inkjet	70
xvii	Kitchen outlet	1500
xviii	Air conditioner:	
	1 TON	1250
	1.5 TON	1875
	2 TON	2500
	2.5 TON	3200

Selection of Size of Conductors

The size of conductors of circuits shall be so selected that the drop in voltage from consumer.s terminals in a public supply (or from the bus-bars of the main switchboard controlling the various circuits in a private generation plant) to any point on the installation does not exceed three percent of the voltage at the consumer.s terminals (or at two bus-bars as these may be) when the conductors are carrying the maximum current under the normal conditions of service. The overall voltage drop from the transformer end to consumer.s final distribution board shall not exceed six percent.

The wiring diagram for a typical distribution scheme in a residential building. (Fig 1)

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 branch switches shall be placed in the outer or live conductor of the circuit and no single phase switch or protective device shall be inserted in the middle wire, earth or earthed neutral conductor of the circuit. Single-pole switches (other than for multiple control) carrying not more than 16 A may be of tumbler type or flush type which shall be on when the handle or knob is down.

Conductors and Accessories

Conductors: Conductors for all the internal wiring shall be of copper. Conductors for power and lighting circuits shall be of adequate size to carry the designed circuit load without exceeding the permissible thermal limits for the insulation. The conductor size shall also be based on the voltage drop in the line so as to provide a terminal voltage not below the prescribed voltage requirement.

The conductor for final sub-circuit for fan and light wiring shall have a nominal cross-sectional area not less than 1.50 mm2 copper. The cross-sectional area of conductor for power wiring shall be not less than 2.5 mm2 copper. The minimum cross-sectional area of conductor of flexible cord shall be 1.50 mm^2 copper.

Flexible cables and cords shall be of copper and stranded and protected by flexible conduits or tough rubber or PVC sheath to prevent mechanical damage.

Cable Ends: When a stranded conductor having a nominal sectional area less than 6 mm^2 is not provided with cable sockets, all strands at the exposed ends of the cable shall be soldered together or crimped using suitable sleeve or ferrules.

Connection to ancillary buildings: Unless otherwise specified, electric connections to ancillary buildings, such as out-houses, garages, etc, adjacent to the main building and when no roadway intervenes shall be taken in an earthed GI pipe or heavy duty PVC or HDPE pipe of suitable size. This pipe can be taken either underground or over ground, however, in latter case, its height from the ground shall not be less than 5.8 m.

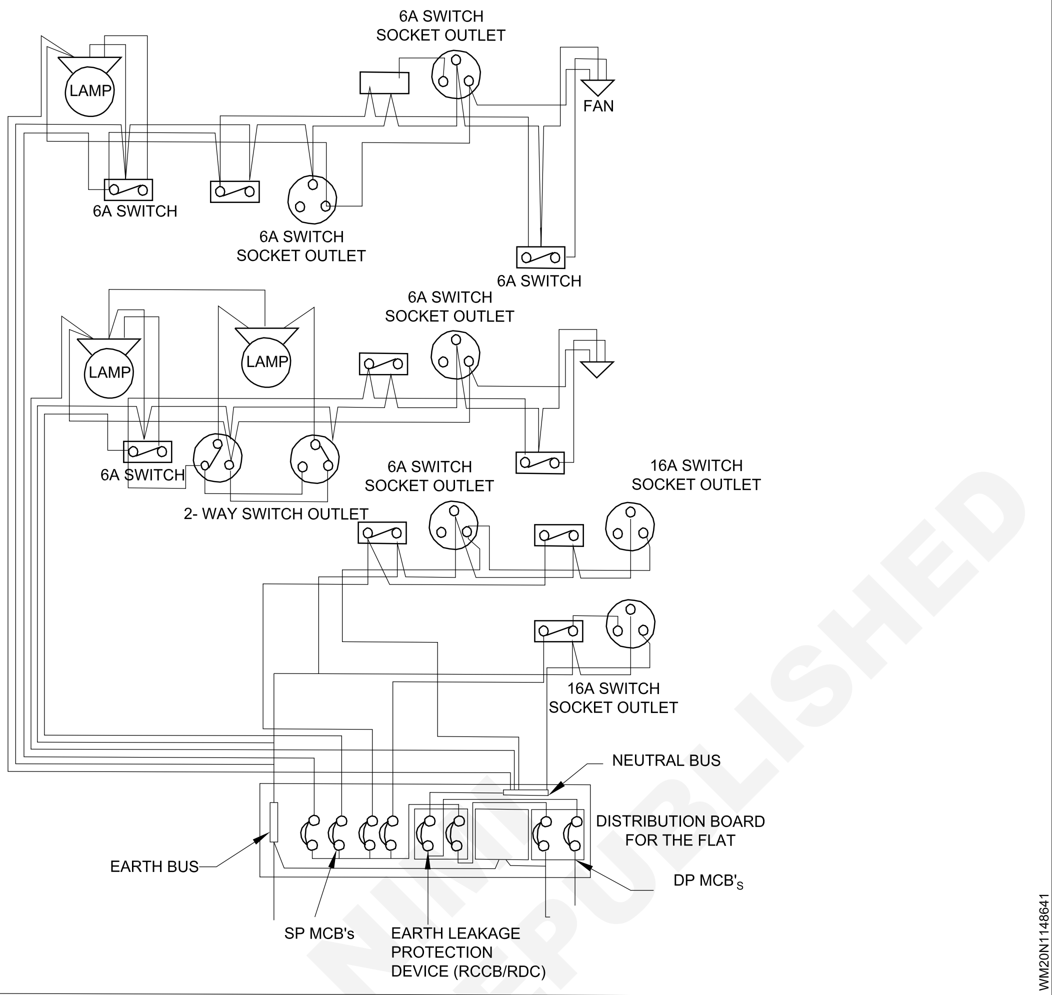
Joints and Terminals: Every connection at a cable termination shall be made by means of a terminal, soldering socket, or compression type socket and shall securely contain and anchor all the wires of the conductor, and shall not impose any appreciable mechanical strain on the terminal or socket.

Passing Through Walls and Floors: Where wires/cables are required to pass through walls, care shall be taken to see that wires/cables pass freely through protective pipe or box and that the wires pass through in a straight line without any twist or cross in wires.

The following method shall be employed for laying wires/ cables:

a Conduit wiring system . The conductor shall be carried either in a rigid steel conduit or a rigid non metallic conduit conforming to accepted standards. [(8-2 (33)] The conduits shall be colour coded as per the purpose of wire carried in the same.

Fig 1



The colour scheme may be as follows:

Conduit Type	Colour Scheme
Power conduit	Black
Security conduit	Blue
Fire alarm conduit	Red
Low voltage conduit	Brown
UPS conduit	Green

Cables shall be connected to a terminal only by soldered or welded or crimped lugs using suitable sleeve, lugs or ferrules. Cables in each circuit shall be bunched together.

If required, a pilot lamp shall be fixed and connected through an independent single pole switch and fuse to the bus-bars of the board.

PVC Clamps/PVC Channel: The clamps shall be used for temporary installations of 1-3 sheathed wires only. The clamps shall be fixed on wall at intervals of 100 mm in the case of horizontal runs and 150 mm in the case of vertical runs.

Passing Through Walls: The method to be adopted shall be according to good practice. There shall be one or more conduits of adequate size to carry the conductors. The conduits shall be neatly arranged so that the cables enter them straight without bending.

Stripping of Outer Covering: While cutting and stripping of the outer covering of the cables, care shall be taken that the sharp edge of the cutting instrument does not touch the rubber or PVC-sheathed insulation of conductors. The protective outer covering of the cables shall be stripped off near connecting terminals, and this protective covering shall be maintained up to the close proximity of connecting terminals as far as practicable.

Care shall be taken to avoid hammering on link clips with any metal instruments, after the cables are laid. Where junction boxes are provided, they shall be made moisture-proof with an approved plastic compound.

Painting: If so required, the tough rubber-sheathed wiring shall, after erection, be painted with one coat of oil-less paint or distemper of suitable colour over a coat of oil-less primer, and the PVC-sheathed wiring shall be painted with a synthetic enamel paint of quick drying type.

Conduit Wiring System: Conduit wiring system shall comply with accepted standards [8-2 (34)]. Requirements relating to conduit wiring system with rigid steel and non-metallic conduits.

Type and size: All non-metallic conduits used shall conform to accepted standards [8-2(38)] and shall be used with the corresponding accessories.

Fittings and accessories

Ceiling roses and similar attachments: A ceiling rose or any other similar attachment shall not be used on a circuit the voltage of which normally exceeds 250 V.

Socket-Outlets and Plugs: Each 16 A socket-outlet provided in buildings for the use of domestic appliances, such as, air conditioner and water cooler shall be provided with its own individual fuse, with suitable discrimination with back-up fuse or miniature circuit-breaker provided in the distribution/ sub-distribution board. The socket-outlet shall not necessarily embody the fuse as an integral part of it.

Each socket-outlet shall also be controlled by a switch which shall preferably be located immediately adjacent thereto or combined there with.

In wiring installations for residential buildings, metal clad switch, socket-outlet and plugs shall be used for power wiring. For industrial and commercial application socket outlets conforming to accepted standards [8-2(25)] with suitable circuit breakers shall be used.

A recommended schedule of socket-outlets in a residential building is given below

SI No. (1)	Location (2)	Number of 6 A Socket- Outlets (3)	Number of 16 A Socket- Outlets (4)
i	Bed room	2 to 6	2
ii	Living room	2 to 4	2
iii	Kitchen	2 to 8	2
iv	Dining room	2 to 4	2
v	Garage	1	1
vi	For refrigerator	.	1
vii	For air conditioner	.	1 for each
viii	Verandah	1 per 10 m^2	1
ix	Bathroom	1	1

Branching of circuits with respect to loads, such as lighting and power

Objectives: At the end of this lesson you shall able to

- **state the B.I.S. regulations and recommendations of the National Electrical Code of Practice with regard to the mounting levels of switches, sockets, distribution boards, cable runs etc.**
- **state the B.I.S. recommendations and the National Electrical Code pertaining to electrical 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

Refer the page no - 475-476 & Refer Theory Ex-1.13.74

Electrical 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).

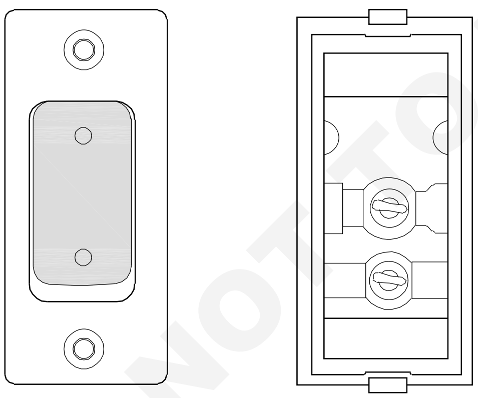
The electrical accessories used in wiring installation, are classified according to their uses.

- 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'.

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.

Fig 1

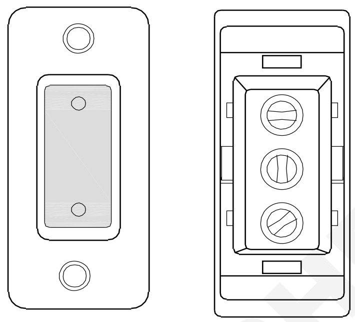


6 AMP SINGLE POLE ONE WAY FLUSH SWITCH

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.

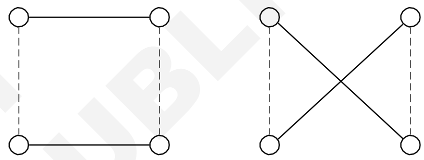
Intermediate switch: This is a four-terminal device capable of making or breaking two connections from two positions (Fig 3). This switch is used along with 2 way switches to control a lamp from three or more positions.

Fig 2



6 AMPS TWO WAY FLUSH TYPE SWITCH

Fig 3

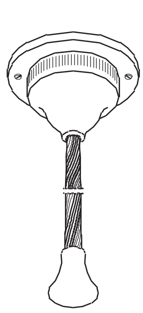


INTERMEDIATE SWITCH CONNECTIONS

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.

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

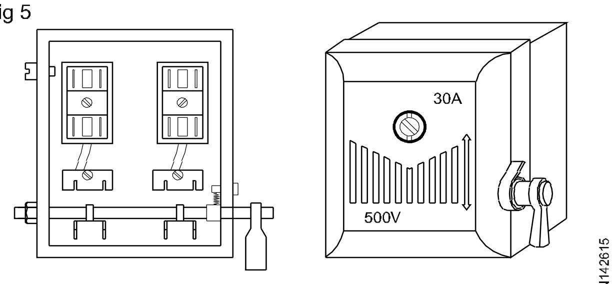


PULL SWITCH

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).

The current rating of the switch varies from 16 amps to 200 amperes.

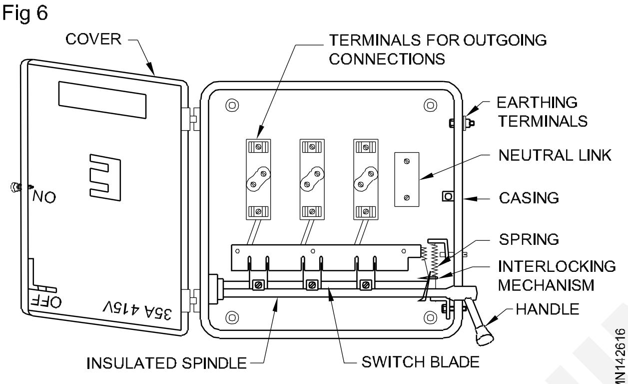
Fig 5



DPIC MAIN SWITCH

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).

Fig 6



FUSED ICTP `N' SWITCH

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.

Holding accessories

Lamp-holders : A lamp-holder is used to hold a lamp. Earlier, brass holders were most commonly used but now a days 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

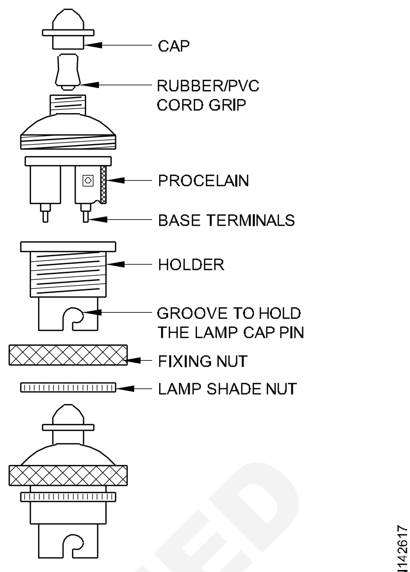
Lamp holders can be classified further as explained below.

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.

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.

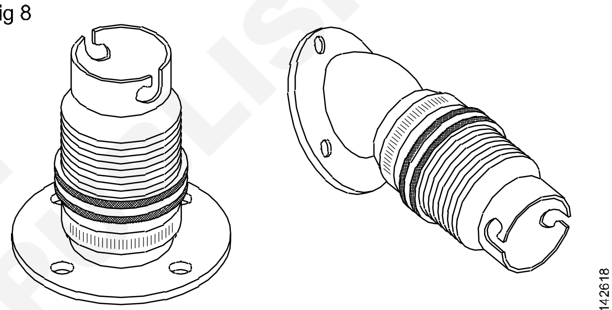
Angle holders: The angle bottom holder, (Fig 8b) is to hold the lamp in a particular angle. These are made of either brass or bakelite. These are used for advertising boards, window display, kitchens etc.

Fig 7



EXPLODED VIEW OF PENDENT HOLDER

Fig 8

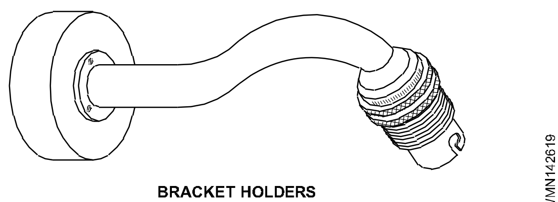


(a) BRASS BATTEN HOLDER (b) ANGLE HOLDER

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.

These are fixed on the bracket by the internal threading of the cap.

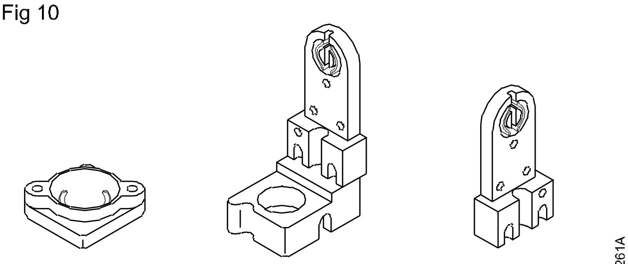
Fig 9



BRACKET HOLDERS

Tube light or fluorescent lamp-holders and starter-holders: Generally the fluorescent lamp-holders are of a bi-pin type (Fig 10).

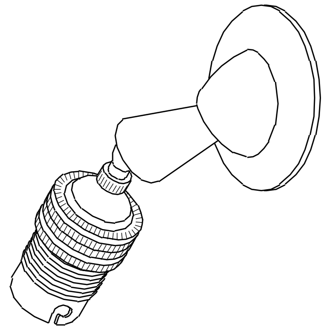
Fig 10



HOLDER FOR THE STARTER | COMBINED TUBE AND STARTER HOLDER | FLUORESCENT PIN TUBE HOLDER

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 11).

Fig 11



ANGLE SWIVEL LAMP-HOLDER

WMN14261B

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

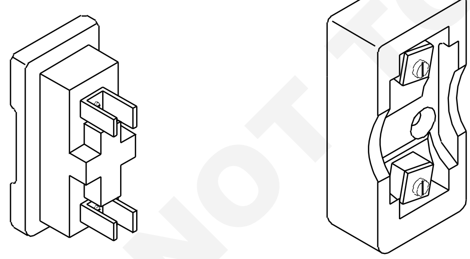
– Kit-kat type (Rewirable fuse)

– 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 12). The base is fixed but the carrier is removable.

Fig 12



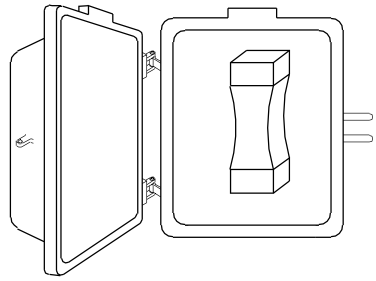
KIT-KAT FUSE

WMN14261C

Iron-clad fuse cut outs (Fig 13): 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 13



IRON CLAD CUT - OUT

WMN14261D

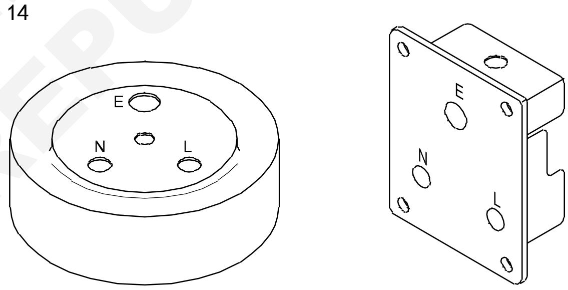
Socket outlet current rating: The standard ratings shall be 6,16 and 32 amperes and 240 volts. The following types are normally used for domestic purposes. They have to be specified according to the mounting type, number of pins, current capacity and voltage.

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 14).

Fig 14



3-PIN 16 AMP SOCKET WITH TOP COVER

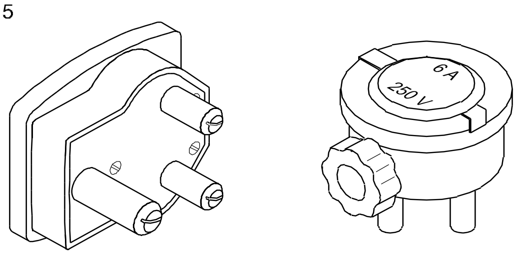
FLUSH TYPE SOCKET

WMN14261E

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 the socket. It has three pins. Two are similar in size and the third one is bigger and longer which is for earth (Fig 15). These are also rated as 6A,250V or 16A, 250V. These are made of bakelite, PVC materials.

Fig 15



THREE-PIN PLUG TOP

WMN14261F

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 multipin sockets for 3 pin of 6 amps and 16 amps are also available having 6 holes in one unit.

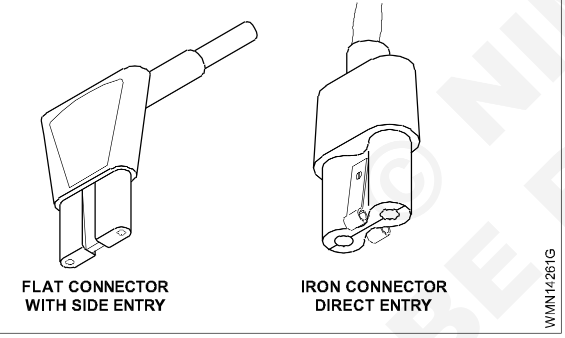
General accessories

Some accessories are used for general and special purposes such as:

- appliance connectors (or) iron connectors
- adapters
- ceiling roses
  - a) two-plate
  - b) three-plate
- connectors
- distribution board
- neutral links.

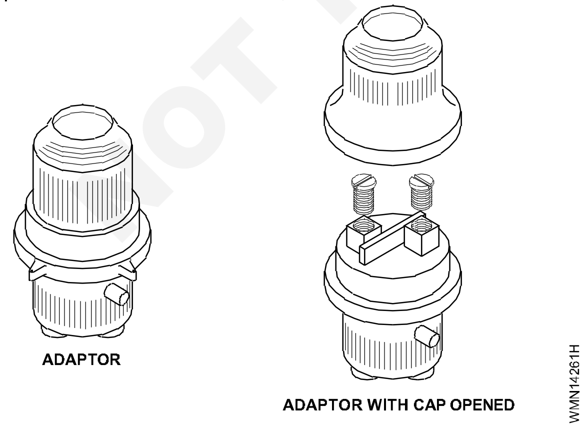
Appliance connectors or iron connectors : These are used as female connectors to supply current to electric kettles, electric iron, hotplate, heaters etc. It is made of bakelite or porcelain. These are rated as 16A, 250V (Fig 16).

Fig 16



Adaptor (Fig 17): 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 17



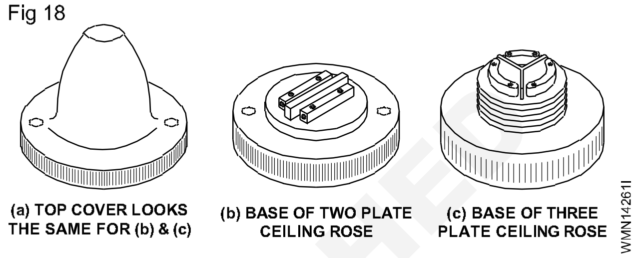
Adaptors with multiple plugs are also available for taking supply to a number of appliances from a single point.

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. Two types of ceiling roses are in use.

Two-plate ceiling rose (Fig 18a & b)**:** This is made of bakelite and it has 2 terminals (phase & neutral) which are separated from each other by a bakelite bridge. The two-plate ceiling rose is used for 6A, 250V current capacity.

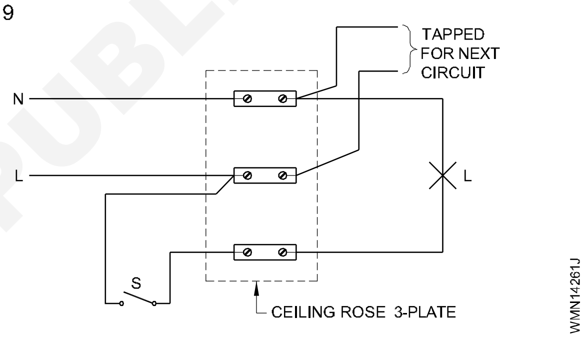
Three-plate ceiling rose: This type of ceiling rose has 3 terminals which are separated from each other by a bakelite bridge. It can be used for two purposes. (Fig 18a & c)

Fig 18



- Bunch light control
- To provide tapping for phase wire (Fig 19).

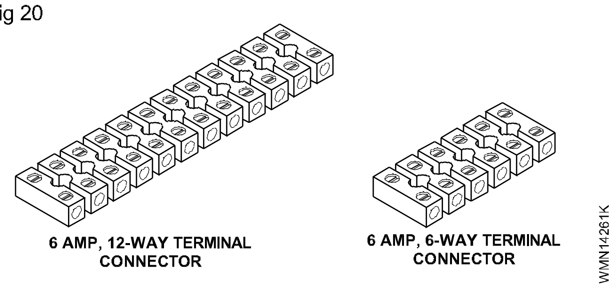
Fig 19



These ceiling roses are available in the rating of 6A, 250V.

Connectors (Fig 20): Connectors are used to extend the length of the wire without joining. They are made of porcelain, bakelite or PVC based material. 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.

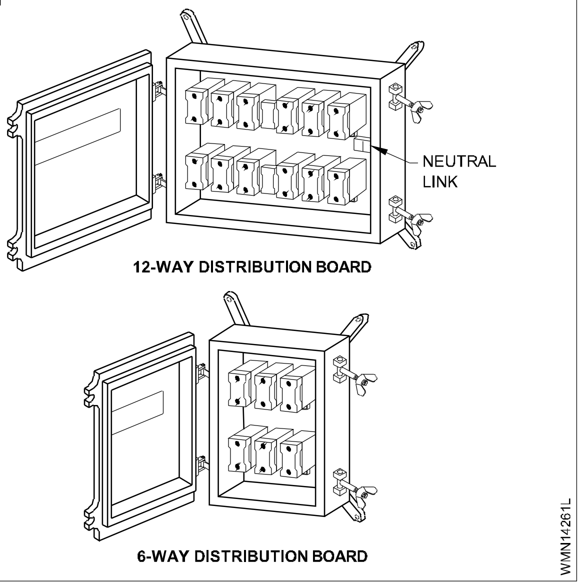
Fig 20



Distribution board (Fig 21): 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. 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.

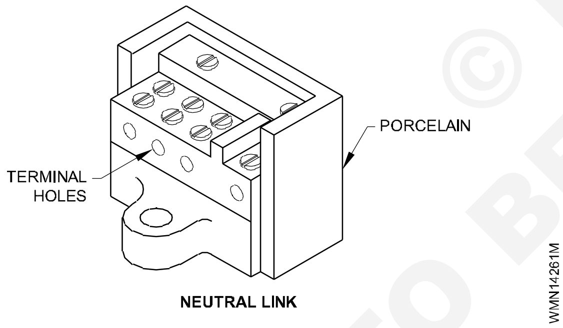
All these branch fuses are enclosed in a metal box. These boards are available as two-way, three-way, 4,6,12-way types.

Fig 21



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 22). The ratings are 16A, 32A, 63A, 100A neutral link.

Fig 22



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 23)

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.

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 24).

Fig 23

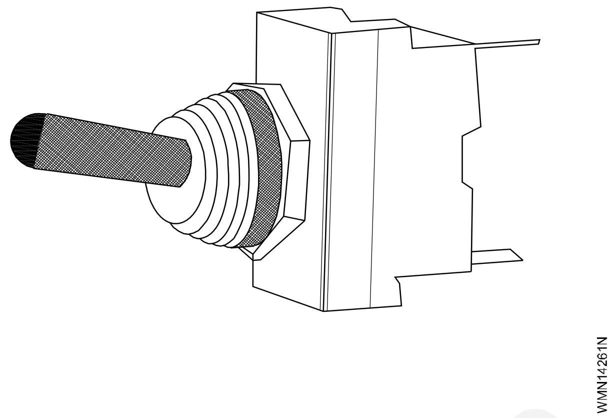
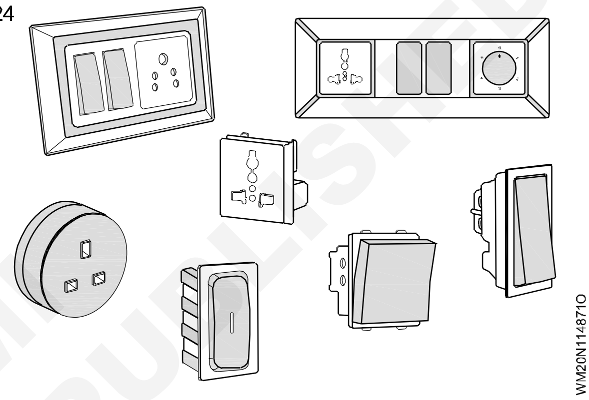


Fig 24



Main and branch distribution boards: The main and branch distribution boards shall be of any type as per the information provided earlier.

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-circuits shall not have more than a total of ten points of lights, fans and socket outlets. The load of such circuits 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 circuits. 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.
- These shall be fixed on suitable on a wall and shall be accessible for replacement of fuses.
- These shall be of either metal-clad type or all-instulated type. But, if exposed to weather or damp situations, they shall be of the weatherproof type, and, if exposed to explosive dust, vapour or gas, they shall be of flame-proof type.
- Where ther are two or more distribution fuse-boards for feeding low voltage circuits and fed from a supply at medium voltage, the distribution boards shall be fixed not less than 2 m apart.
    - Arranged so that it not possible to open the two at a time, namely, they are interlocked and the metal case is marked 'Danger 415 Volts'.
    - Installed in a room or enclosure accessible to only authorized persons.
- All distribution boards shall be marked 'Light 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 which it controls, and the current rating of the circuit and size of the fuse-element.

Wiring of distribution boards: In wiring a branch distribution board, the total load of the consuming devices shall be divided, as far as possible evenly between the branch circuits.

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.

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.

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.

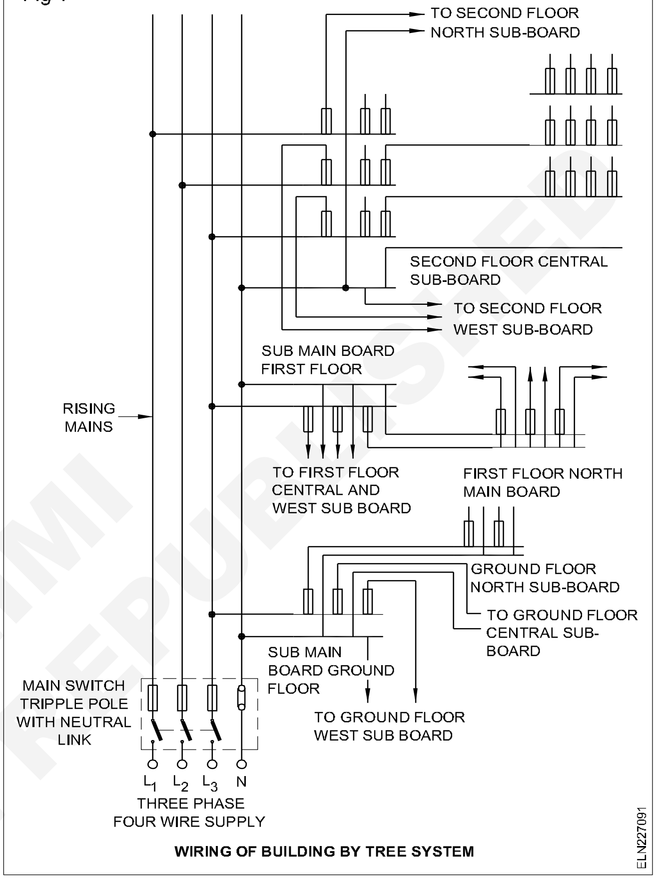
Disadvantages

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.

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&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.

Fig 1



WIRING OF BUILDING BY TREE SYSTEM

Fig 2

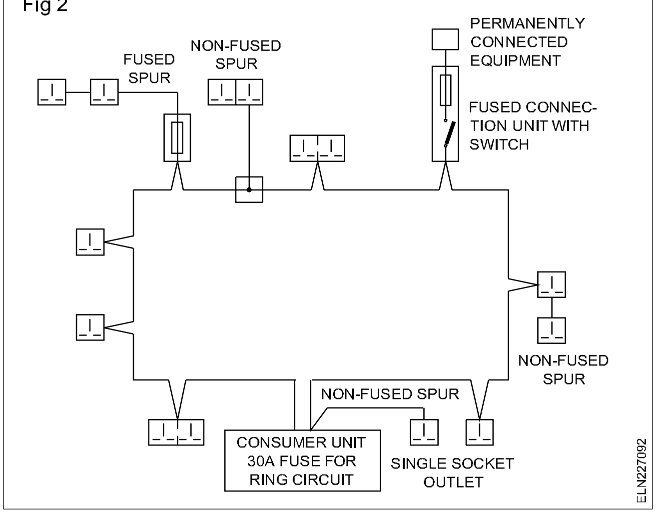
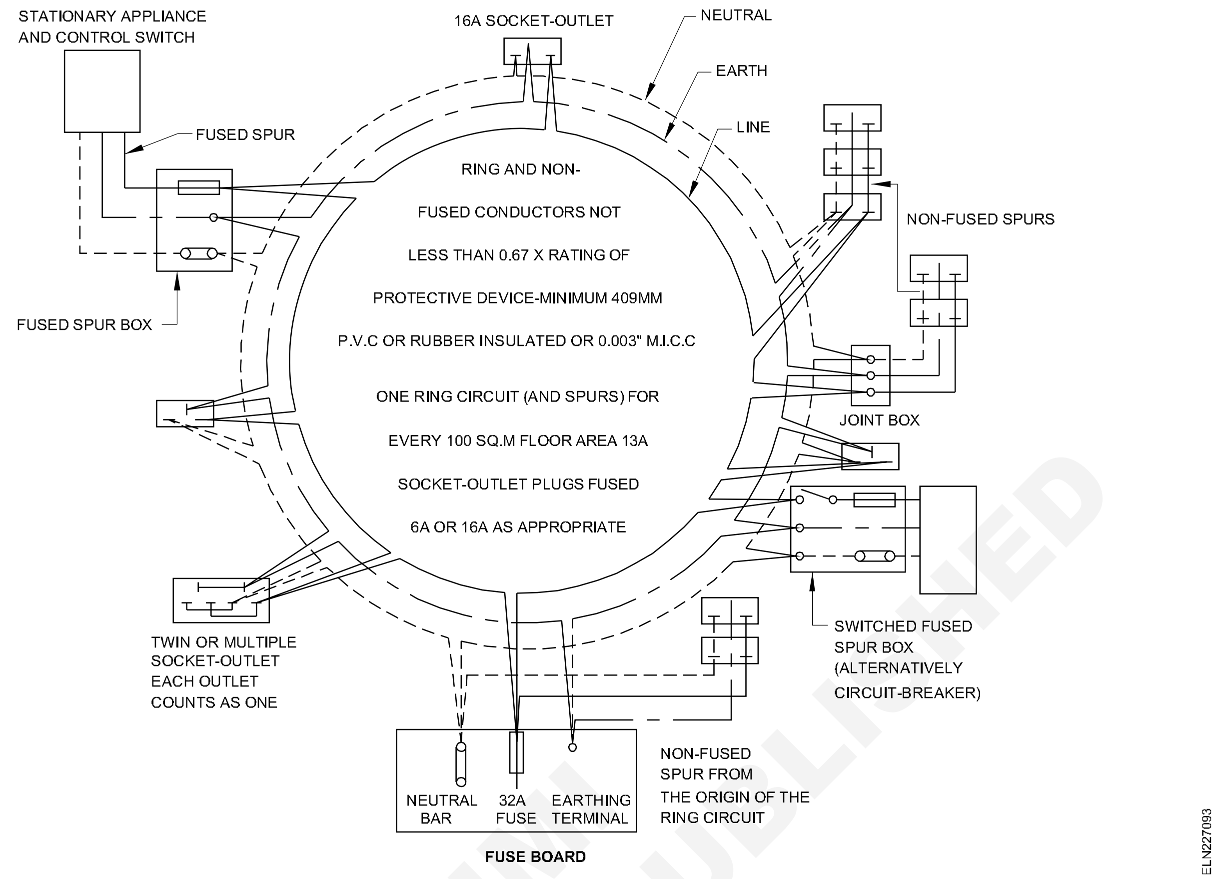


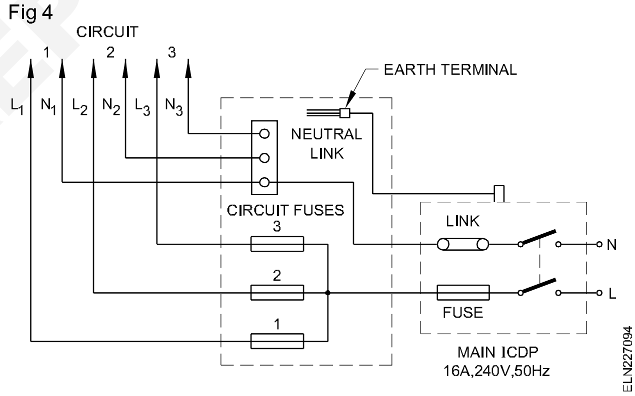
Fig 3



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 4



No joint is allowed in the cable route except in switches, ceiling roses and joint boxes.

Power wiring

Objectives: At the end of this lesson you shall be able to
- **explain 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.

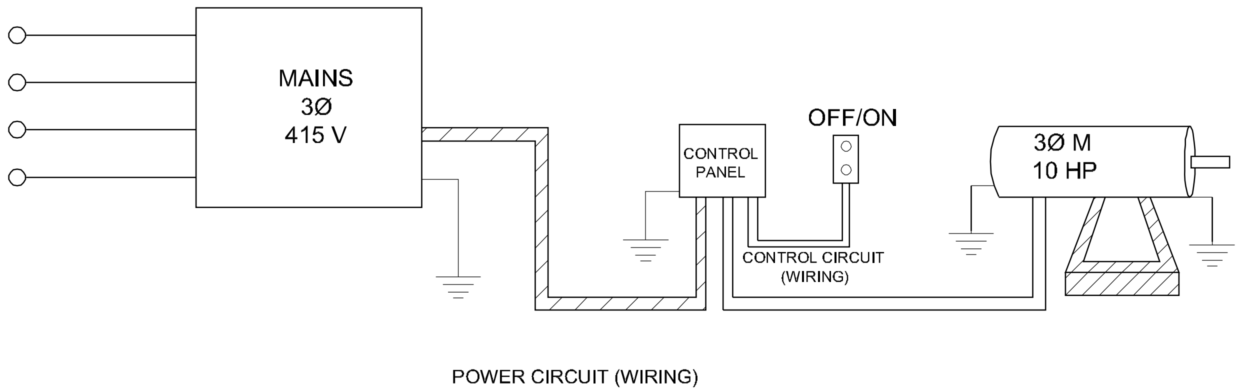
Generally all the control panel / commercial / industrial wiring invariably consists of two sections viz control wiring and power wiring.

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.

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.

Fig 1



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.

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.

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.

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.

Sensor

A Sensor as an input device which provides an output (signal) with respect to a specific physical quantity (input).

The term "input device" in the definition of a Sensor means that it is part of a bigger system which provides input to a main control system (like a Processor or a Microcontroller).

Different Types of Sensors

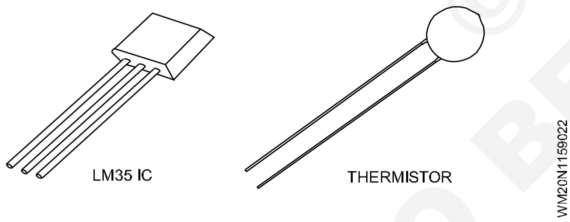
The following is a list of different types of sensors that are commonly used in various applications. All these sensors are used for measuring one of the physical properties like Temperature, Resistance, Capacitance, Conduction, Heat Transfer etc.

1 Temperature Sensor
2 IR Sensor (Infrared Sensor)
3 Pressure Sensor
4 Light Sensor
5 Ultrasonic Sensor
6 Smoke, Gas and Alcohol Sensor
7 Touch Sensor
8 Color Sensor
9 Humidity Sensor
10 Microphone (Sound Sensor)
11 Flow and Level Sensor
12 Touch Sensor
13 Proximity Sensor

Temperature Sensor

One of the most common and most popular sensors is the Temperature Sensor. A Temperature Sensor, as the name suggests, senses the temperature i.e., it measures the changes in the temperature.

Fig 2



There are different types of Temperature Sensors like Temperature Sensor ICs (like LM35, DS18B20), Thermistors, Thermocouples, RTD (Resistive Temperature Devices), etc.

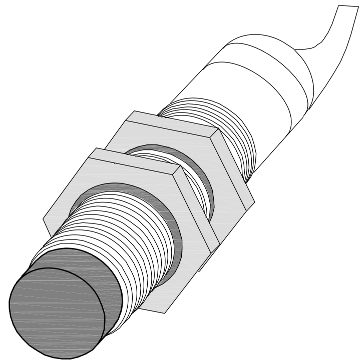
Temperature Sensors are used everywhere like computers, mobile phones, automobiles, air conditioning systems, industries etc.

Proximity Sensors (Fig 3)

A Proximity Sensor is a non-contact type sensor that detects the presence of an object. Proximity Sensors can be implemented using different techniques like Optical (like Infrared or Laser), Sound (Ultrasonic), Magnetic (Hall Effect), Capacitive, etc.

Some of the applications of Proximity Sensors are Mobile Phones, Cars (Parking Sensors), industries (object alignment), Ground Proximity in Aircrafts, etc.

Fig 3

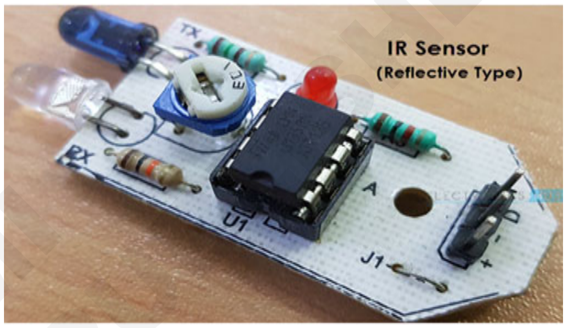


PROXIMITY SENSORS

Infrared Sensor (IR Sensor) (Fig 4)

IR Sensors or Infrared Sensor are light based sensor that are used in various applications like Proximity and Object Detection. IR Sensors are used as proximity sensors in almost all mobile phones.

Fig 4

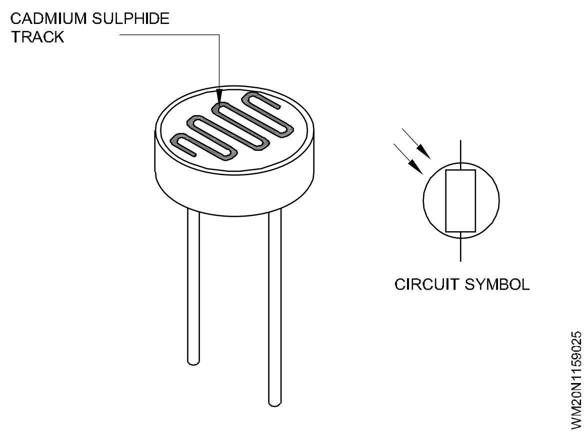


Different applications where IR Sensor is implemented are Mobile Phones, Robots, Industrial assembly, automobiles etc.

A small project, where IR Sensors are used to turn on street lights: Street Lights Using IR Sensor.

Light Sensor (Fig 5)

Fig 5

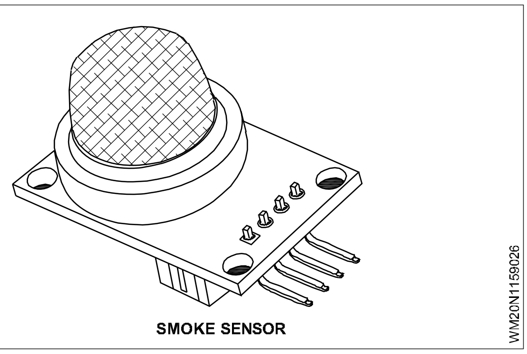


Sometimes also known as Photo Sensors, Light Sensors are one of the important sensors. A simple Light Sensor available today is the Light Dependent Resistor or LDR. The property of LDR is that its resistance is inversely proportional to the intensity of the ambient light i.e., when the intensity of light increases, its resistance decreases and vise-versa.

By using LDR is a circuit, we can calibrate the changes in its resistance to measure the intensity of Light. There are two other Light Sensors (or Photo Sensors) which are often used in complex electronic system design. They are Photo Diode and Photo Transistor. All these are Analog Sensors.

Smoke and Gas Sensors (Fig 6)

Fig 6



SMOKE SENSOR

One of the very useful sensors in safety related applications are Smoke and Gas Sensors. Almost all offices and industries are equipped with several smoke detectors, which detect any smoke (due to fire) and sound an alarm.

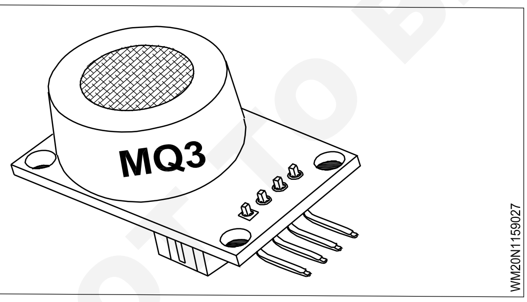
Gas Sensors are more common in laboratories, large scale kitchens and industries. They can detect different gases like LPG, Propane, Butane, Methane (CH4), etc.

Now-a-days, smoke sensors (which often can detect smoke as well gas) are also installed in most homes as a safety measure.

Alcohol Sensor (Fig 7)

As the name suggests, an Alcohol Sensor detects alcohol. Usually, alcohol sensors are used in breathalyzer devices, which determine whether a person is drunk or not. Law enforcement personnel uses breathalyzers to catch drunk-and-drive culprits.

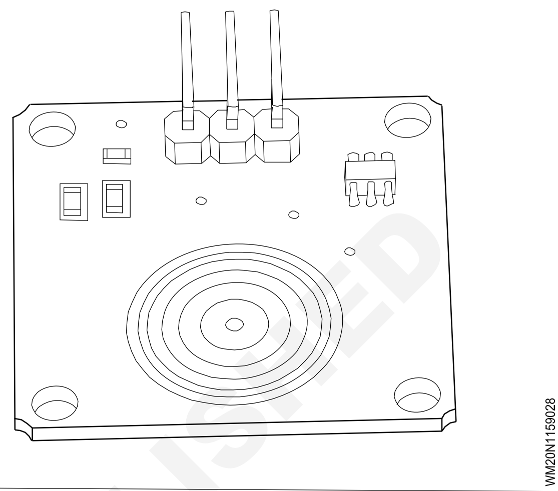
Fig 7



Touch Sensor (Fig 8)

We do not give much importance to touch sensors but they became an integral part of our life. Whether you know or not, all touch screen devices (Mobile Phones, Tablets, Laptops, etc.) have touch sensors in them. Another common application of touch sensor is trackpads in our laptops.

Fig 8

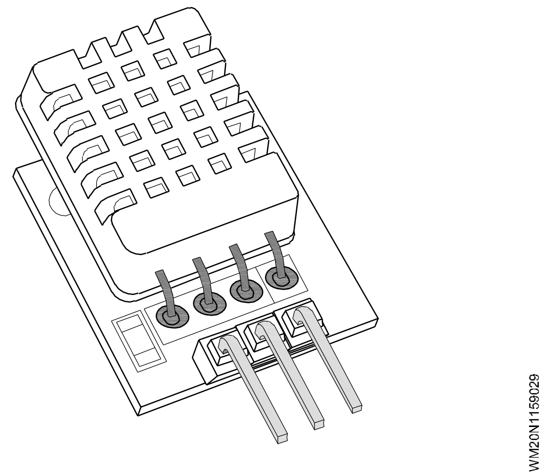


Humidity Sensor (Fig 9)

If you see Weather Monitoring Systems, they often provide temperature as well as humidity data. So, measuring humidity is an important task in many applications and Humidity Sensors help us in achieving this.

Often all humidity sensors measure relative humidity (a ratio of water content in air to maximum potential of air to hold water). Since relative humidity is dependent on temperature of air, almost all Humidity Sensors can also measure Temperature.

Fig 9



Control Panel Wiring

Objectives: At the end of this lesson you shall be able to
- **explain control panel components.**

Components of control panel

DIN Rails

Metal strip with special profile allowing components and sub assemblies to be fixed on to a chasis plate without using screws.

Type : i Top hat or symmetrical

ii Asymmetrical

They are cut to the required length and then screwed or bolted to the chassis before any wiring begin.

Plastic trunking

Cable ducting used to carry the wiring between components and it provide protection while keeping the wires and cable neat.

- The cover is removable
- The wires and cables are laid inside the trunking and leads brought out through the holes in the side.
- The holes may be closed or open at the top
- The open type for easier to push the wire into the slot.

Connector block

Terminal block provides connection path from control panel to various operations outside the panel

- There are made up using individual terminal assemblies which clip To DIN rails to make multiple strip.
- The terminals is specified in terms of the cross-sectional area it will accept.
- This varies from 1.5 mm square upward.
- The most common way of terminating wires is the screwclamp.
- Different colours may be used to aid identification of group of function.
- An Earth terminal- usually green or green yellow clamp to the rail to ensure the case and chassis are earthed
- Insulated separators can be further isolated high Voltage connection from the others.
- Endstop are used to clamp the terminal together.
- An isolating end cover plate will be needed at one end since the terminals are open on one side.
- identifying number can be clipped to them, normally matching the wire indent.

Screw terminals

Barrier Strips

These are used mainly on sub-assemblies to allow them to be connected into the system.

- Others have screw terminals at both side and can be used to join wires
- The wire should be stripped and twisted but not tinned before inserting under the screw heads
- Avoid over tightening their true because this can Crush the strand and gives weak connection.

Contactors and Relays

Relays (Fig 1)

These are mechanical switching device whose operation is controlled by an electromagnet.

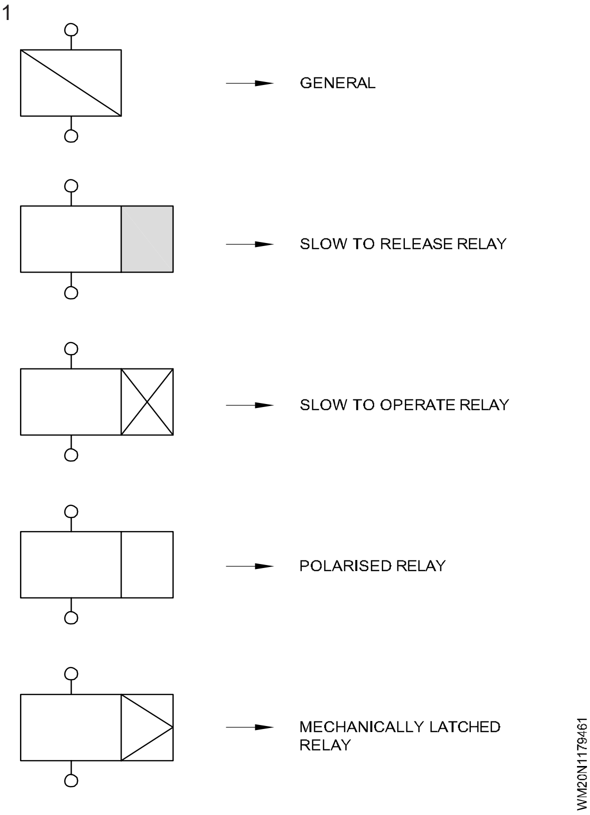
- When Electromagnet is energized the core become magnetized and attract the moving armature.The armature is mechanically coupled to a set of electrical contact. when the armature is attracted to the Electromagnet, these contact operates and complete the circuit.
- As soon as the coil is de-energized the contactor return to normal, usually under Spring and break the circuit
- Operation of contactor and relays are same but release have hinged armature.
- Contactor is used to switch higher power then a relay and need more current to operate(power circuit engineering)
- Relay contact have lower power rating had hence intended for control circuit energizing.

Power control relay

Specially designed relay to switch higher power in control panel called power controlled relay.

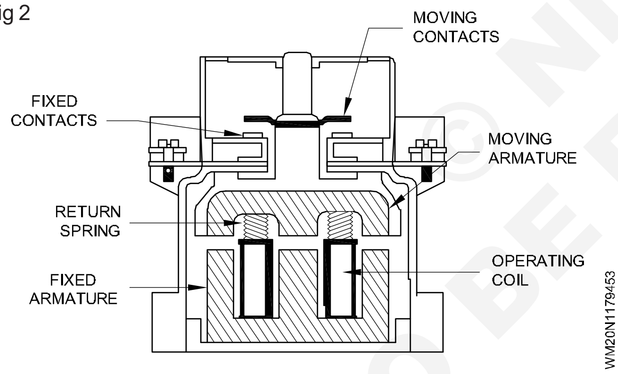
- These are a number of shapes and sizes.
- They can be either flush mounted to the chassis
- At least three set of control in the main body with the wide range of combination.
- Incorporate additional set of contact to the side and in some cases to the top of main body
- Connections are made with screw clamp terminals.
- The contact and coil terminal or at the front and shrouded to stop foreigner to town charing live contact.

Fig 1



Contractor: Contactors consists of two parts operating coil and switching contacts. (Fig 2)

Fig 2



A contactor will have number of contacts usually three power switching and a set of axillary contact for use at lower current in control circuit.

Choice of contactor depend upon the type of operation they will be used to make and break in an hour whether the load is inductive or resistive.

Fuses

- Fuses are an essential part of the safety element of the equipment.
- Fuses are electrical safety device that protect equipment and component from damage caused by overloaded circuit
- Fuse are heat sensitive component
- When current flowing in the current exceeds rated value of the fuse, the current conductor in the fuse melt and open the circuit under fault(overload or short circuit)

Fuse holder: To hold the fuse,fuse holders are designed.

Fuse holders or carrier can carry the rated current as well as a high overload current for a short time

They can withstand the highest voltage.

Chassis- Mounted fuse holder: Chassis mounted fuse holder which have plug in fuse link carrier.

- The fuse carrier is removed to fit the fuse cartridge.
- They are surface mounted either bolted Directly to the chassis or clipped to a DIN rails.
- Generally they have screw clamp wire terminals for the panel wiring
- The removable fuse carrier accept fuse cartridge

Fuse links

- Fuse links are cartridge with welded Termination brackets.A fuse link holder will only accept one style.
- Fuse links are available in a range of ampere value.

Resistors

Its a component which is designed to resist control or oppose the flow of electric current passes through it.

Carbon -to large wirewound power resistor 5 mm long in length to 200mm.

Types of Resistor

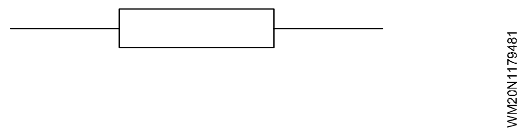
1 Fixed 2 Variable

Fixed Resistor (Fig 3)

Small wire ended resistor are solder to a printed circuit board or a lag strip to make a sub assembly.

- Most control panel wire wound resistor are present.
- This one is bolted flat to the chassis or more often a heat sink.
- To aid, the transfer of heat from resistor to heat sink, a heat sink compound is used.

Fig 3



- The wire are solenoid to the eyelet at either ends.

Variable resistor (Fig 4): These are mechanical devices where the resistance between a pair of terminals can be varied by moving a slider or wiper over a resistance track and it often called potentiometer. The are three terminals and one at the slider terminal.

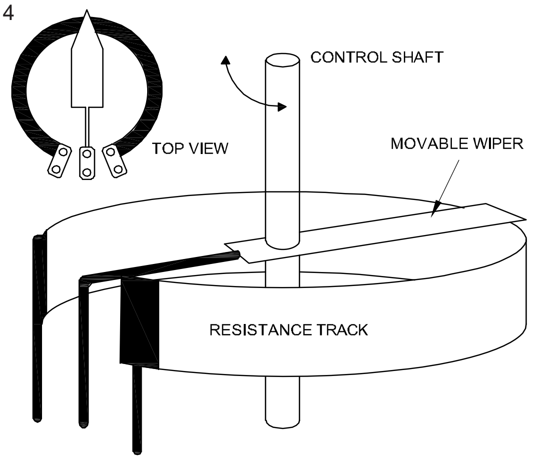
The path of resistance is circular,adjust by a control shaft or by screw driver shaft.These are called trimpot.

The Resistance track are commonly made up of

1 Carbon 2 Wirewound

3 Cermet(ceramic and metal material)

Fig 4

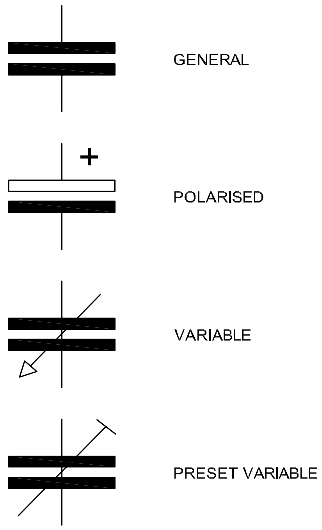


Capacitor (Fig 5): Basic symbols for a capacitor or condenser is modified to show polarisation.

1 General 2 Polarised

3 Variable 4 Present variable

Fig 5



Switches: A switch consist of a set of contact manually, operated by same form of mechanical actuator. The actuator and contact may be contained in a single moulded types unit or more likely as a molecular unit compariing a selection modular/actuator and contact sets. (Fig 6&7)

Lamps (Fig 8)

1 In control panel the purpose of the lamps is to indicate the operation. They are mounted on the front of the panel. Neon type work at high voltage more than 100V. connection are soldered.

2 Filament bulb usually operate on 12V and 24V may be screw type or bayonet cap. (Fig 9)

Labelling: Labelling provide the information about the control panel accessories, equipment, preventive measure. While carrying maintenance, time saving to analyse the fault and overcome it.

Grommets: It is used for shielding wire through in the middle of the hole. The purpose is to protect the wire being cut easily by sharp edges and they are dust proof and water proof.

Fig 6

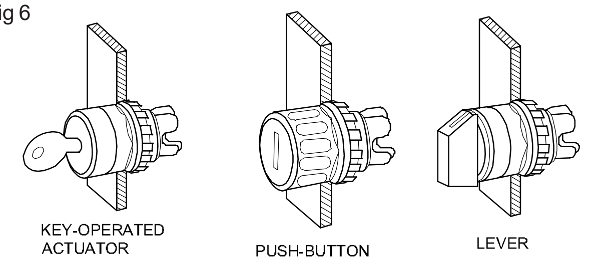


Fig 7

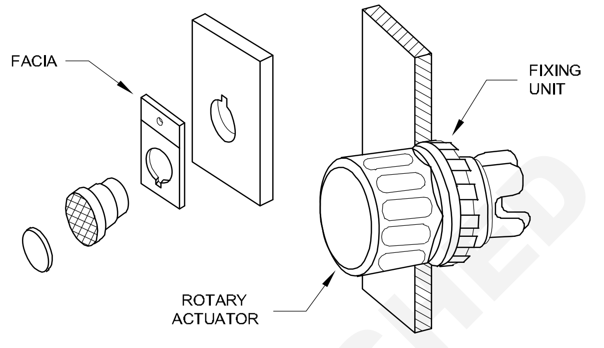


Fig 8

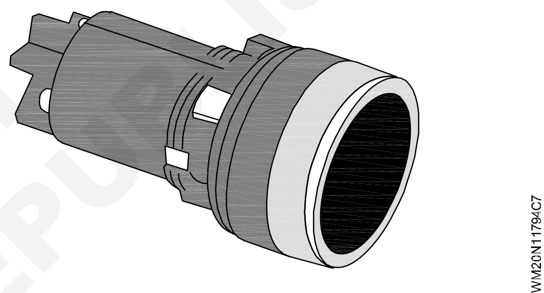
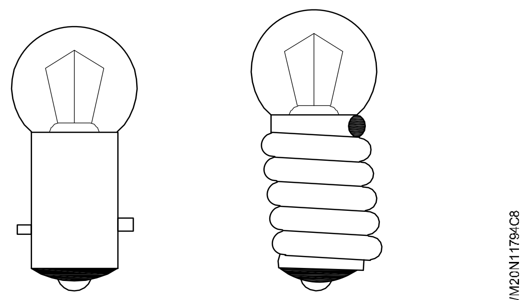


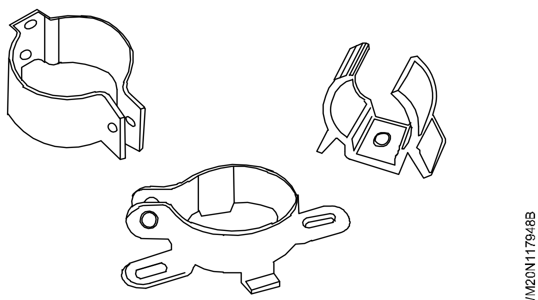
Fig 9



Clips (Fig 10): Clips may be used to fix other type to the chassis. Capacitor is placed on the clip. The clamp screw where fitted is tightened just enough to grip the capacitor firmly.

Capacitor may be fitted vertically or horizontally with clamp holding.

Fig 10



Cable form

Objectives: At the end of this lesson you shall be able to
- **prepare wiring schedule**
- **prepare cable form binding lock stitch breakouts**
- **twisted pair in cable bunch (control panel)**
- **identify the component in control panel**

Cable form: A cable form is called harness of individual wire of different size and types are bound together to form a single cable run.

Cable forms are often made up as a separate item along with other component for the equipment in which they will be installed and following information is usually provided.

- Wiring schedule
- Cable form template
- Run out sheet or table

Wiring schedule

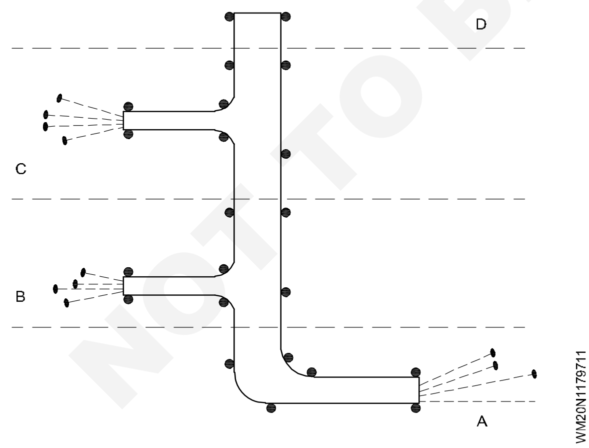
This gives details of the wire used in cable form

- Type of wire - number of strand, - size of strand - insulation - colour
- Ident marker
- Length
- Stripping or termination details

Template

Full plan view of the cable form called template. The position of forming pin as well as position of wire and will be marked. (Fig 1)

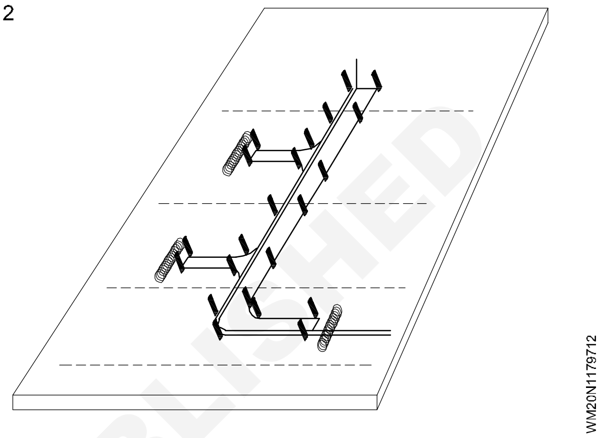
Fig 1



On larger cable form, template are divided into zones to make both ends of a wire easier to locate.

The template is fixed to a piece of board and used as a pattern. Forming pins or smooth nails a put in at the relevant points on the template. The cable form in made by laying the wires between the connection points and following the shape made by the forming pins which keep wire together until they are bound together into a cable form. (Fig 2)

Fig 2



Run-out-sheet

This gives the order to which the wires are laid into the cable form and the zone location of the wire ends.

Wire No	From	To	Colour
01	A	C	Black
02	A	C	Black
03	A	D	Red
04	A	B	Red

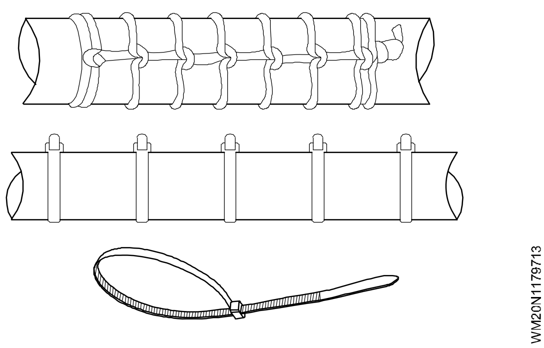
Cable form binding (Fig 3)

The cable form may be bound using on the several methods namely.

Lacing with a continuous to using PVC-covered nylon card, waxed. Nylon braid or nylon tape called stitching or lacing.

Individual tie called spot ties. There are other binding such as spiral wrap, adhesive tape and heat shring sleeving.

Fig 3



Continuous lacing (Fig 4, 5 and 6)

Starts knorts: Clove hitch is two successive half hitches around the binding of different cable together followed by over hand knot.

- Loop about 150mm of the card under the cable and pass it over the long length.
- Make another loop passing the end under the first.
- Pull light so that the cable is held form but not distorted.
- Tie an overhand knot. Apply varnish at end of finish knot.

Fig 4

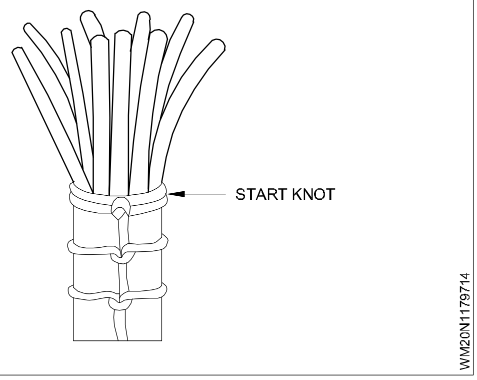


Fig 5

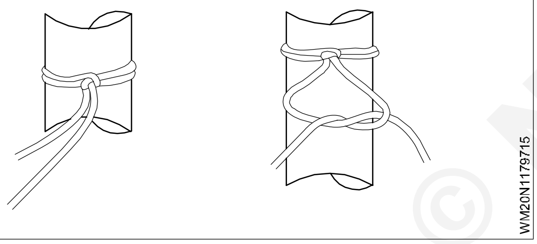
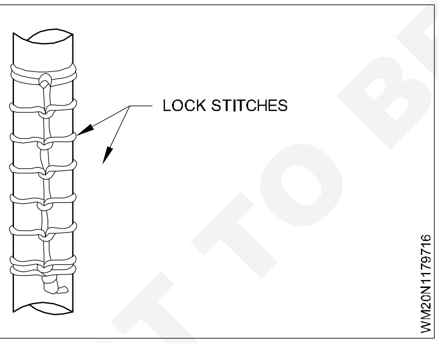


Fig 6



Lock stitch

This is the main stitching knot which tied at intervals along the hardness.

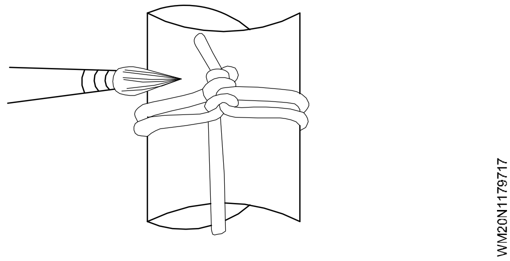
A locking knot is used that the cable form does not come apart.

- Take the cord under the cable leaving a loop.
- Hold this loop and pass the cord through.
- Pull it tight as far the start knot and at the same time the knot lane with the other.
- Space the knot at about 1.5 times cable diameter.

Finish knot (Fig 7)

- Tow lock stitches
- Followed by a reef knot.
- Pull to tighten firmly and apply approved adhesive.

Fig 7



Breakouts

Wire or group of wire leave from the main cable form called breakouts.

There are basically two types

i 'Y' Breakout (Fig 9)

ii "T" Breakout (Fig 10)

Lacing breakouts (Fig 8)

Single wire are brought out after a lock. Stitch where there are several wire called lacing breakouts.

After the breakouts make a double lock stitch before and after the breakout and continue lacing along the main cable form.

Fig 8

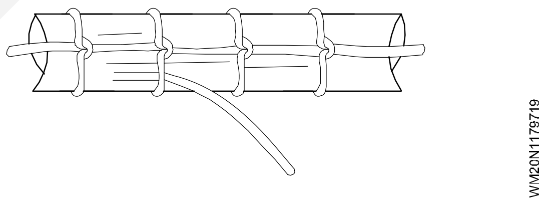


Fig 9

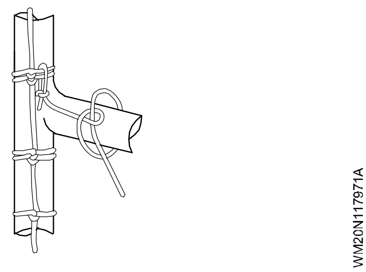
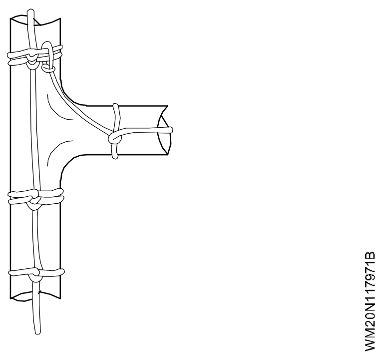


Fig 10



Lacing 'Y' breakouts

- Make a starting knots on the branch and lake on the normal manner.

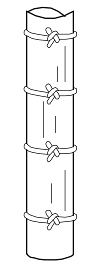
Lacing 'T' breakouts

- Less than 12 mm diameter
- Make a single lock stich on both side of the breakouts.
- If the breakout is to be laced, use starting knot and lace as normal.

Spot ties

- Lacing card (Fig 11)

Fig 11



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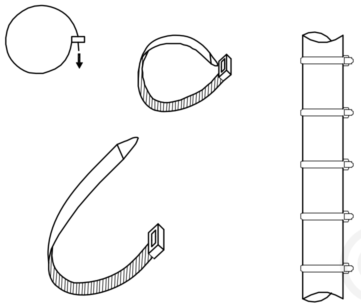
- Cable ties (Fig 12)

Fig 12



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Lacing card

Alternate of starting knot with a clove hitch and a reef knot lacing cord can be done. The knot can be sealed using adhesive or varnish.

Cable ties

Resembles like belt and buckle one side of the belt is serrated. This side goes towards the cable. The end is passed through the eye in the buckle and pull tight. Train of the waste after correct texion.

Laying the wire

Prepare the wire according to the wiring schedule and lay them on the template in the order found on the run out sheet.

- Avoid knits in the wires and lay the wire straight and parallel as possible.
- Ensure that there is no damage to the insulation.
- The wire and insulation must not be damaged in any way by the binding.

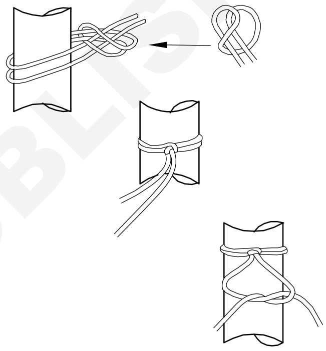
Twisted pair: Before pair to the cable form due to electrical reason wire may be twisted together are called twisted pair.

- Use one length of wire and double it remember that the finished twisted pair.
- Twist evenly and neatly
- Don't twist so tight.
- Avoid gaps and loops between wires.
- The length of twist or the number of twist it determined by the wire diameter.

Loop tie (Fig 13)

- Double the end of the lacing cord and form a small loop.
- Pass this under the cable and pass the other ends through the loop and pull tight so that the wires are held firmly but not distorted.
- Tie an overhand knot. Varnish may be applied later.

Fig 13



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Colour code

- The colours used to represent the numbers are them same as the resistor code so there is nothing new to remember!
- When the markers are the same colour as the insulation then unmarked sleeves of a contrasting colour, usually pink, are placed on either side of them to highlight their presence.
- The example illustrates this with the number 88 (grey/ grey), assigned to a wire with grey insulation.
- When the number of the last wire to be marked is more than one digit, additional zeros are added in front of the lower numbers to give them the same number of digits as the last wire.
- For instance, if the last wire is between 10 and 99, then a 'zero' or black marker is placed before all single digit numbers. This makes 1 become 01, 2 become 02 and so on.
- Similarly with a last wire number of between 100 and 999, two zeros are added so that 1 becomes 001, 11 becomes 011, and so on.

BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GREY/SLATE	8
WHITE	9

Cable Marker

- For identification of wires in cables form district number are allotted to the wires in the cable form and that number are inserted on both side of the wire.
- Often these numbers will be the same as those on the connectors to which they will be connected(as on run out sheets)

Connection and routing of cables

- Connection should be secured against accidental loosening
- If connecting plug is used to avoid loosening clamp or screw are provided to secure it
- Ensure protective binding circuit
- Two or more conductor in a single connecting terminal is allowed as per design otherwise it is not recommended to connect more than 2 conductor in single terminal connectors.
- Soldering connection should be made to the terminal if both place for crimped then no need to solder
- Terminal and terminal blocks should be clearly marked and identified to correspond to the marking in the drawing.
- Ensure that identification tags and cable markers are legible marked with a permanent ink.
- Terminal block should be mounted and wires so that internal and external wiring does not cross over the terminals.
- Flexible conduct and cables should be installed in such a way that liquid can draw away from the fitting and termination.
- Conductor and cable should run from terminal to Terminal without any intervening joints.
- Multi core cable termination should be adequate support to avoid undue strain on the conductor termination.
- The protective conductor should as far as is possible to routed close to the associated live conductor avoid under loop resistance

Consideration of EMI / EMU

- When different power rating wires and cables are in the same enclosure while switching the power writ to the different voltage the current varies.
- High current flowing conductor have higher electromagnetic field compared to the low current flow conductor
- This higher electromagnetic field can cause a voltage in other low current flow conductor, if the insulation is not proper or distance between them are not considered during designing. This make **electro magnetic interference**
- Considering the power rating of wires or cables it should be separated by a insulating barrier.
- Thus making **Electromagnet compatibility** and thus stability occur in different circuit.
- Circuit which are not switched off by the supply disconnecting device should be either separated physically from other wiring distinguished by colour so that they can easily be identified as being "live" when the disconnecting device is in the of or open position example; control panel light

Contact symbol

1 Make contact, normally open - No

2 BAEAK contact, Normally closed - NC

3 Changeover (Break before make) - c/o

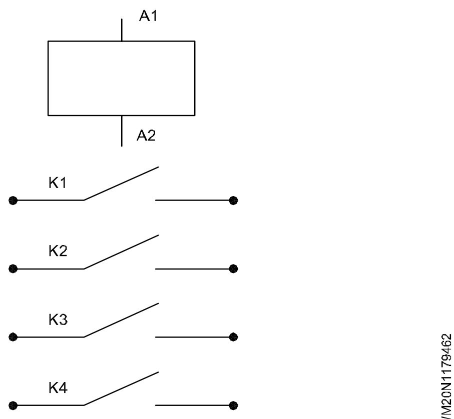
4 Changeover (make before break) - c/o

5 Make after delay

6 Break after delay.

In control panel circuit diagram operating coil may be drawn in different position from the associated contact. To identify the contact the coil designation will have the number of contact written underneath. Each contact will have then the relay indent and number (Fig 14) shows the relay has k4 has 4 contact which are designated as K1,K2, K3, K4, Mostly coil terminals are designated as A1 and A2

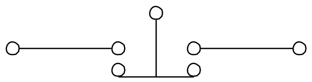
Fig 14



Normally open (Fig 15)

Symbol denote the contact are normally opened. By applying external pressure manually or through relay operation the movement of contact is activated the circuit connected to this get closes.

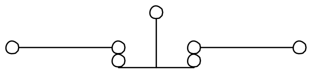
Fig 15



Normally closed (Fig 16)

Symbol denote the contact are closed. By applying the external pressure manually or through relay operation the movement of the contact is activated, the circuit connected to this get's open.

Fig 16



Change over (make/break after delay)

Change over relay depend upon the relay energised (or) de energised. It has two state "ON" and "OFF".

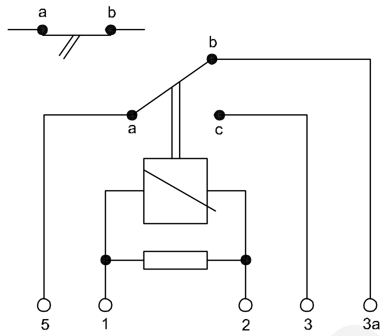
State "ON" - Relay get a activated a contact point get engaged with 'b' contact circuit connected to be get closed.

State "OFF" - Relay deactivated "a" contact point got engaged with "C" contact circuit connected to a get closed.

Testing of various control elements and circuits

Primary and secondary inject test are conducted to check the operation of breakers and their protective relay/devices. (Fig 17)

Fig 17



Primary injection test

Primary injection testing involves injecting the actual current required to operate a protective device through the circuit breaker. Primary injection testing normally require specialists injection sets/test rigs and measurement equipment.

The primary injection testing performed by injecting a current at low voltage (say 5-10V) from a purpose built transformer with high current capable secondary winding. The current is passed through the breaker or busbar section.

The terms equipment consist of a loading transformer. Controlled by a variable to angular to get a required current on the primary side of CT under test.

Primary injection is carries out to test to determine the integrity of the whole secondary. Circuit including CTS, CT leads and control cubical wiring. It proves the CB trip in response the an over current.

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 principle and construction of primary cells**
- **state the principle and construction of lead acid.**

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

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.

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.'

Mass $\propto$ E.C.E

$M \propto Z$

Where Z = electro-chemical equivalent

According to Faraday's laws of electrolysis

$m = Z \cdot I \cdot t$

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

$$\text{Equivalent weight} = \frac{\text{Atomic weight}}{\text{Valency}}$$

$$\text{E.C.E. of nickel} = \frac{\text{Equivalent wt. of nickel}}{\text{Equivalent wt. of silver}} \times \text{E.C.E. of silver}$$

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 Extraction of metals.

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.

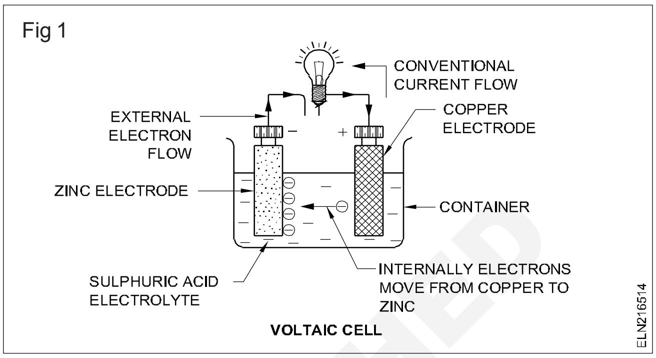
A dry cell is one that has a paste or gel electrolyte. With newer designs and manufacturing techniques, it is possible.

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.

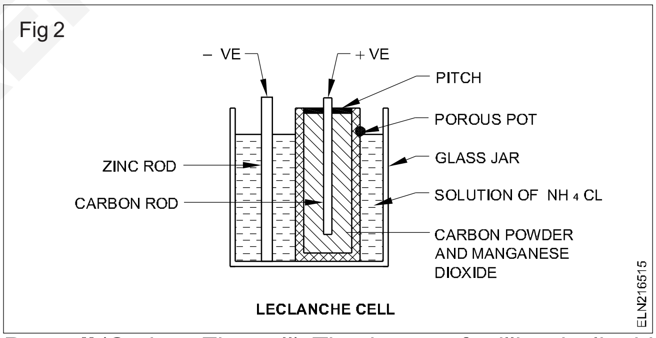
Types of primary cells:

- 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 1).



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 2).



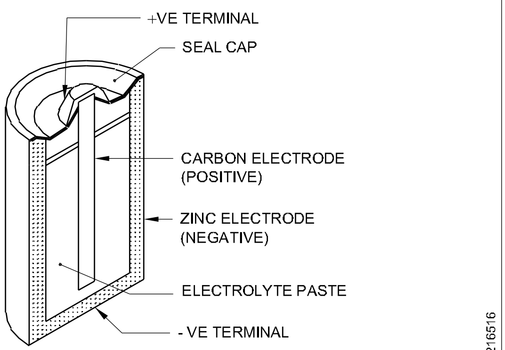
Dry cell (Carbon-Zinc cell): The danger of spilling the liquid electrolyte from a Leclanche type of cell led to the invention of another class of cells called dry cells.

The most common and least expensive type of a dry cell is the carbon-zinc type (Fig 3). 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.

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).

Fig 3

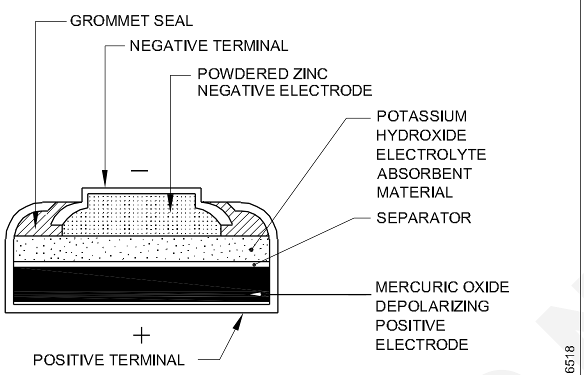


CARBON-ZINC DRY CELL

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 4).

The electrolyte used in this cell is alkaline and the electrodes are of mercuric oxide (cathode) and zinc (anode).

Fig 4



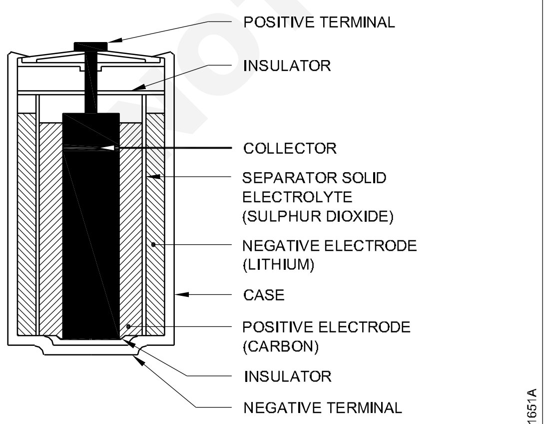
MERCURY CELL

Lithium cells: The lithium cell is another type of primary cell (Fig 5). 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.

Fig 5



LITHIUM CELL

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.

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.

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.

The local action is prevented by amalgamating the zinc plate with mercury.

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.

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

Parts of Lead acid cell (Fig 6)

1 Container

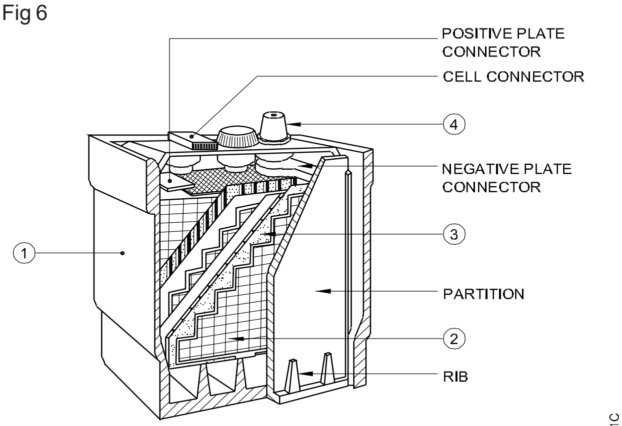
2 Plates

3 Separators

4 Post terminals

Container (Fig 6): 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 6



PARTS OF LEAD ACID CELL

ELN21651C

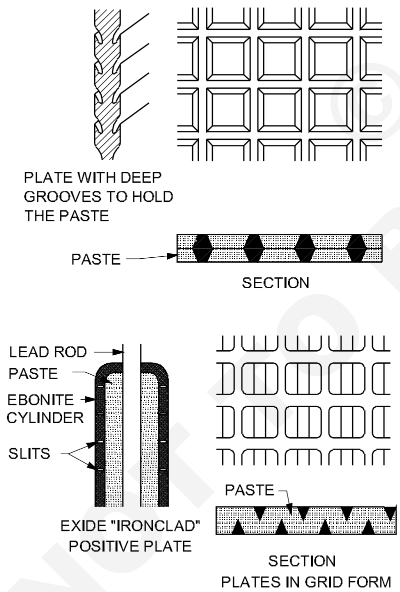
Plates: Positive plates are of two types.

- 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 7).

Fig 7



CONSTRUCTION OF PASTED-TYPE ACCUMULATOR PLATES

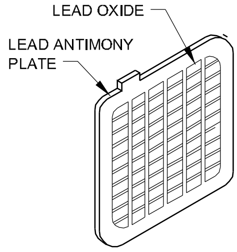
ELN21651D

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 8).

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 9).

Post terminal: A small pole extended upward from each group of welded plates from the plate connecter (Fig 10) forms the post terminal.

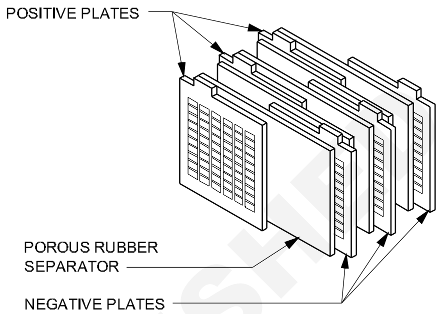
Fig 8



SINGLE LEAD PLATE

ELN21651E

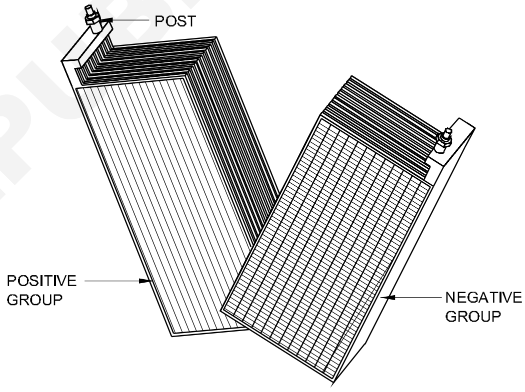
Fig 9



ARRANGEMENT OF PLATES AND SEPARATORS

ELN21651F

Fig 10



ELN21651G

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).

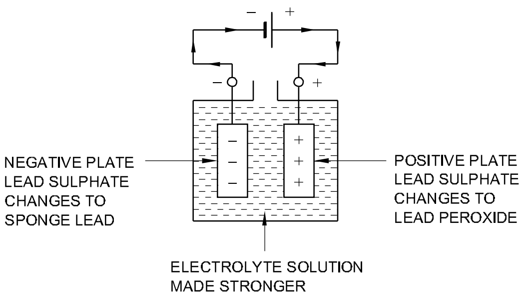
At the same time the electrolyte solution is strengthened and becomes strong sulphuric acid (H_2SO_4) (Fig 11).

The general recommended specification of a storage cell(battery) is given below.

- Voltage/cell
- Ampere hour capacity

- Specific gravity of electrolyte
- No. of cells grouped

Fig 11



DURING CHARGING PROCESS

ELN21651H

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

Temperature and specific gravity: The temperature of the electrolyte must be kept at 27°C and the specific gravity at 1.250 ± 0.010.

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

$$= \frac{\text{AH efficiency} \times \text{Average volts on discharge}}{\text{Average volts on charge}}$$

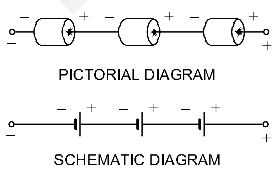
Grouping of cells

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.**

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

ELN216611

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.

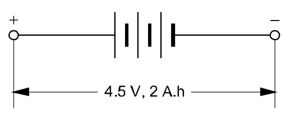
Example: Suppose three `D' flashlight cells are connected in series (Fig 2). Each cell has a rating of 1.5 V and 2 AH The voltage and ampere hour rating of this battery would be:

V Battery = V per cell x No.of cells

= (1.5V) (3)

= 4.5 V

Fig 2



CIRCUIT SCHEMATIC

ELN216612

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:

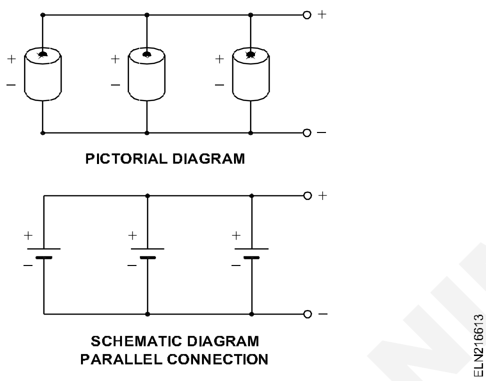
V Battery = (1.5V)+(1.5V) – (1.5V)

= (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).

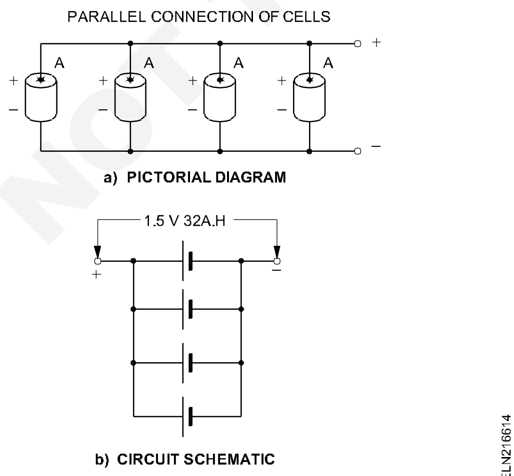
Fig 3



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



V Battery = V rating of 1 cell

= 1.5 V

AH Battery rating = AH rating per cell x no. of cells

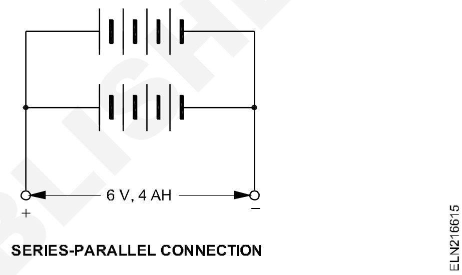
= (8 AH) (4)

= 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



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.

Battery charging method - Battery charger

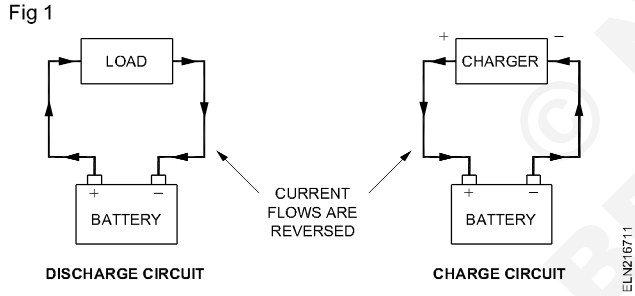
Objectives: At the end of this lesson you shall be able to
- **state the necessity of charging a battery**
- **describe the use of a hydrometer and high rate discharge tester**
- **state the precautions to be followed while charging and discharging a battery**
- **describe the different types of charging methods of secondary cells**
- **explain a 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.

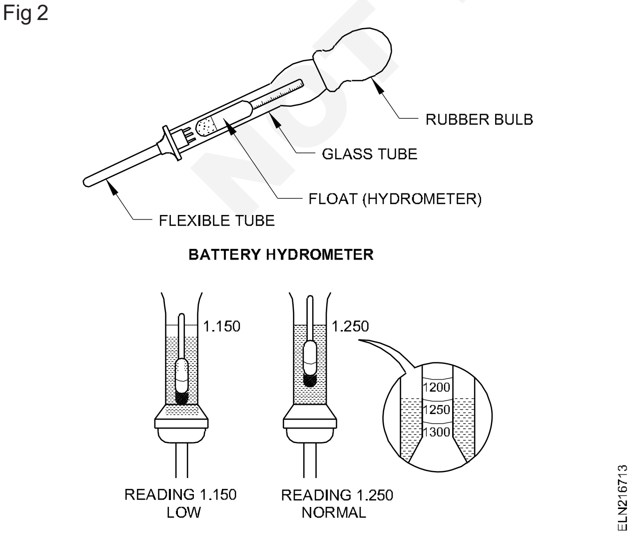
Fig 1



Instrument for testing the condition of cells

Hydrometer : The specific gravity of an electrolyte is measured with a hydrometer (Fig 2).

Fig 2

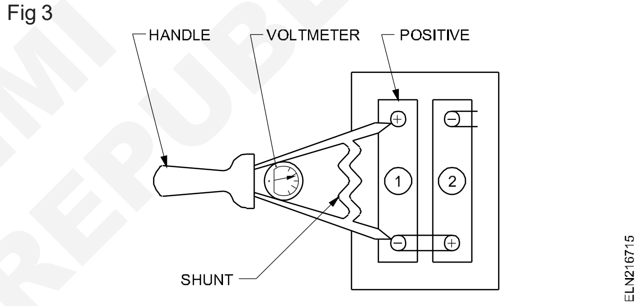


The charged condition of battery can be tested by means of a battery hydrometer. This instrument measures the relative density of the battery electrolyte.

Cell condition	Hydrometer reading
Full charge	1.26
50% charge	1.20
Discharged	1.15

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 3). 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.

Fig 3



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.

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.

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.

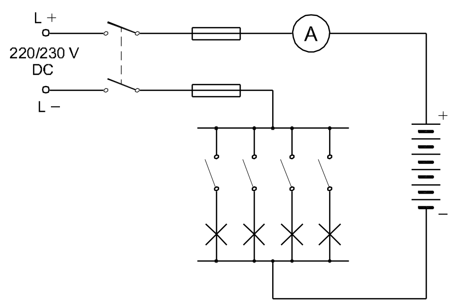
Improper electrolytes must not be used for compensating the electrolyte after it is fully charged.

The methods of charging the secondary cells are:

- constant current method
- constant potential method
- rectifier method.

Constant current method: This method is used where the supply is high voltage DC 220 V, 110 V, etc. but the battery is of low voltage 6 V, 12 V, etc. The emf of the battery is small in comparison to the supply voltage so a lamp-load or a variable resistor is connected in series with the battery (Fig 4). This causes a loss of energy, so, the method is inefficient.

Fig 4



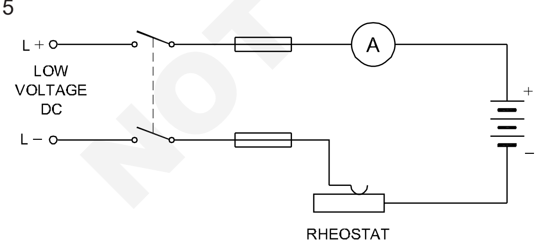
CONSTANT CURRENT METHOD

ELN216716

Use: For charging more number of cells at constant current rating.

Constant potential method: In this method, the voltage is maintained at a fixed value about 2.3 V per cell; the current decreases as the charging proceeds. A variable resistor is connected in series, so a voltage source of 2.5 to 2.6 V per cell is required. For a 12 V motor car battery, the charging dynamo is of about 15 V. In comparison to the constant current method less power is wasted for charging and less time is taken. Fig 5 shows the connections for a constant potential method of charging batteries.

Fig 5



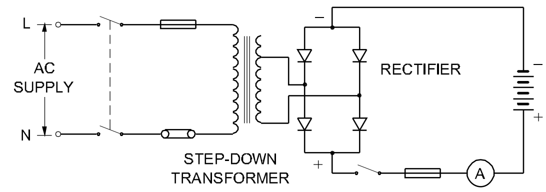
CONSTANT VOLTAGE METHOD

ELN216717

Use: For charging batteries of constant voltage rating.

Rectifier method: A rectifier for battery charging is generally made of diodes connected in the form of a bridge (Fig 6). A transformer is used to step down the AC voltage to that suitable for diodes. Ammeter, voltmeter, switches and fuses are also used in the rectifier set.

Fig 6



RECTIFIER METHOD

ELN216718

Trickle charge: When the battery is charged at a very low rate, that is 2 to 3% of the normal rate for a long period, it is said to be a trickle charge.

Use: For central or sub-station batteries and for emergency lighting systems.

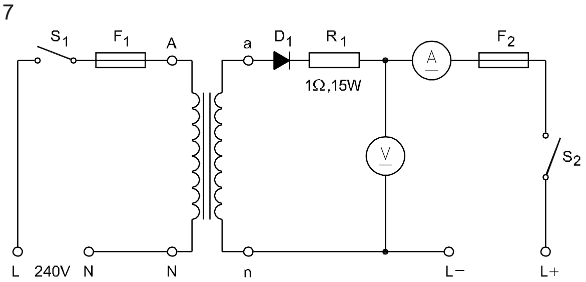
Boost charge: If a battery is in danger of becoming over-discharged during a working shift, you can give it a supplementary charge during a rest period. This boost charge is not a conventional method of charging the storage battery. It is not recommended as a standard procedure. It is generally a high rate charge of short duration, used only to ensure that the battery will last until the end of the shift.

Working: A number of circuits are available for battery chargers commonly used circuits is explained here.

The AC main supply to the primary of the step-down transformer is protected by a fuse and controlled by a toggle switch (Fig 7). Step-down secondary voltage is fed to the metal rectifier or diode and the output is passed 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.

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.

Fig 7



ELN21671B

Installation, care and maintenance of batteries

Objectives: At the end of this lesson you shall be able to
- **state the guidelines for care and maintenance of batteries**
- **state the precaution to be followed while charging and discharging of battery.**

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.

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.**

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:

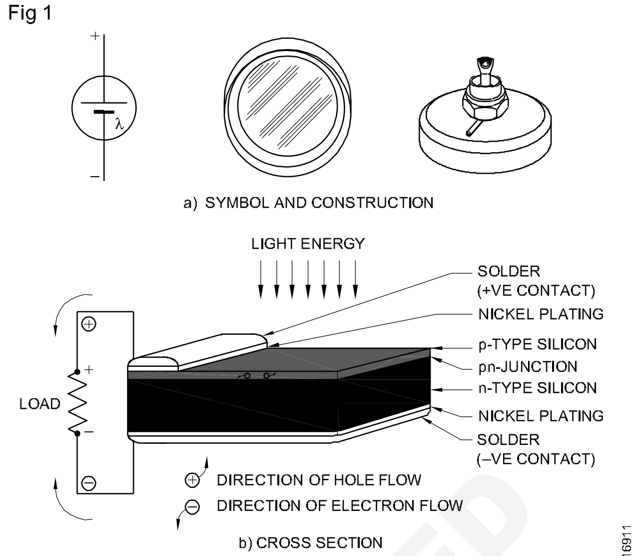
- The absorption of light, generating electron-hole pairs extraction.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

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.

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.