ELECTRICIAN (POWER DISTRIBUTION)

NSQF LEVEL - 4

2^{nd} Year

TRADE THEORY

SECTOR: POWER

(As per revised syllabus July 2022 - 1200 Hrs)

Directorate General of Training

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

NATIONAL INSTRUCTIONAL MEDIA INSTITUTE, CHENNAI

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

Sector : Power

Duration : 2 Years

Trades : Electrician (Power Distribution) - Trade Theory - 2^{nd} Year - NSQF Level - 4 (Revised 2022)

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FOREWORD

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

The National Instructional Media Institute (NIMI), Chennai, has now come up with instructional material to suit the revised curriculum for **Electrician (Power Distribution) - Trade Theory - 2nd Year - NSQF Level - 4 (Revised 2022) - in Power Sector** in **Annual Pattern.** The NSQF Level - 4 (Revised 2022) Trade Theory will help the trainees to get an international equivalency standard where their skill proficiency and competency will be duly recognized across the globe and this will also increase the scope of recognition of prior learning. NSQF Level - 4 (Revised 2022) trainees will also get the opportunities to promote life long learning and skill development. I have no doubt that with NSQF Level - 4 (Revised 2022) the trainers and trainees of ITIs, and all stakeholders will derive maximum benefits from these Instructional Media Packages IMPs and that NIMI's effort will go a long way in improving the quality of Vocational training in the country.

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

Jai Hind

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

December 2023

New Delhi - 110 001

PREFACE

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

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

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

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

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

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

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

Chennai - 600 032 **EXECUTIVE DIRECTOR**

ACKNOWLEDGEMENT

National Instructional Media Institute (NIMI) sincerely acknowledges with thanks for the co-operation and contribution extended by the following Media Developers and their sponsoring organisation to bring out this IMP for the trade of **Electrician (Power Distribution) - 2nd Year - Trade Theory - NSQF Level - 4 (Revised 2022)** under the **Power** Sector for ITIs.

MEDIA DEVELOPMENT COMMITTEE MEMBERS

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

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

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

INTRODUCTION

TRADE PRACTICAL

The trade theory manual is intented to be used in workshop . It consists of a series of practical exercises to be completed by the trainees during the 2nd year course of the **Electrician (Power Distribution)** under **Power Sector.** Trade supplemented and supported by instructions/ informations to assist in performing the exercises. These exercises are designed to ensure that all the skills in compliance with NSQF Level - 4 (Revised 2022) syllabus are covered.

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

Module 1	-	**Control Cabinets and Equipments**
Module 2	-	**Power Generation Equipments**
Module 3	-	**Testing & Maintenance Transformer**
Module 4	-	**LT/HT Cables**
Module 5	-	**Control Elements**
Module 6	-	**Earthing**
Module 7	-	**OH Distribution Line, ABC System, HVDS**
Module 8	-	**Tower/Pole Accessories**
Module 9	-	**Energy Meter, Log Sheet Energy Accounting**
Module 10	-	**Substation Equipment Panels**
Module 11	-	**Power & Control Circuits, Drawings**
Module 12	-	**Fire Fighting Equipments**

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

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

TRADE THEORY

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

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

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

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

CONTENTS

LEARNING / ASSESSABLE OUTCOME

On completion of this book you shall be able to

S.No.	Learning Outcome	Ref. Ex.No.
1	Assemble accessories and carry out wiring of control cabinets and equipment. (Mapped NOS: PSS/N1707)	2.1.133 - 2.1.137
2	Perform on-site installation, preventive maintenance, testing, repair/ replacement of electrical power distribution equipment viz., circuit breakers, isolators, lightening arresters, reactor, capacitor bank etc. (Mapped NOS: PSS/N1708, PSS/N0106)	2.2.138 - 2.2.158
3	Carry out testing, maintenance and evaluate performance of transformers. (Mapped NOS: PSS/N2407)	2.3.159 - 2.3.178
4	Plan and prepare LT/HT cable and Underground cable joints. (Mapped NOS: PSS/N0108)	2.4.179 - 2.4.191
5	Perform testing, repair/ replacement and maintenance of control elements viz., CT, PT, etc., used for protection and measurement in power distribution. (Mapped NOS: PSS/N1707)	2.5.192 - 2.5.208
6	Plan and prepare Earthing installation, carryout testing and maintenance. (Mapped NOS: PSS/N6002)	2.6.209 - 2.6.218
7	Plan and commission overhead distribution line including ABC and HVDS. (Mapped NOS: PSS/N0108)	2.7.219 - 2.7.226
8	Carry out installation, repair/ replacement and maintenance of tower/pole and accessories in Power Distribution System. (Mapped NOS: PSS/N0108)	2.8.227 - 2.8.235
9	Monitor meter readings, generate bill, maintain & upkeep various log sheets and energy accounting. (Mapped NOS: PSS/N3001)	2.9.236 - 2.9.241
10	Examine the faults and carry out repairing of substation equipment and panels. (Mapped NOS: PSS/N2503, PSS/N2505)	2.10.242 - 2.10.249
11	Read and understand electrical Schematic drawings of power and control circuits of outdoor substation. (Mapped NOS: PSS/N2503)	2.11.250 - 2.11.252
12	Read and understand electrical Schematic drawings of power and control circuits of outdoor substation. (Mapped NOS: PSS/N2503)	2.12.253 - 2.12.254

SYLLABUS

2nd Year **Duration: Two years**

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
Professional Skill 55 Hrs; Professional Knowledge 15Hrs	Assemble accessories and carry out wiring of control cabinets and equipment. **(Mapped NOS: PSS/ N1707)**	133. Carry out wiring of control cabinet as per wiring diagram, bunching of XLPE cables, channelling, tying and checking etc. (15Hrs) 134. Mount various control elements e.g. circuit breakers, relays, contactors and timers etc. (12Hrs) 135. Identify and install required measuring instruments and sensors in control panel. (08Hrs) 136. Test the control panel for its performance. (08Hrs) 137. Design layout of control cabinet, assemble control elements and wiring accessories for: (i) Forward and reverse operation of induction motor. (06Hrs) (ii) Automatic star-delta starter with change of direction of rotation. (06Hrs)	Study and understand Layout drawing of control cabinet, power and control circuits. Various control elements: Isolators, pushbuttons, switches, indicators, MCB, fuses, relays, types of timers and limit switches etc. Wiring accessories: Race ways/ cable channel, DIN rail, terminal connectors, thimbles, lugs, ferrules, cable binding strap, buttons, cable ties, sleeves, gromats and clips etc. Testing of various control elements and circuits. (15 hrs.)
Professional Skill 58Hrs; Professional Knowledge 18Hrs .	Perform on-site installation, preventive maintenance, testing, repair/ replacement of electrical power distribution equipment viz., circuit breakers, isolators, lightening arresters, reactor, capacitor bank etc. **(Mapped NOS: PSS/ N1708, PSS/N0106)**	138. Identify outdoor and indoor switchgears. (04 Hrs) 139. Identify power and distribution transformers.(04 Hrs) 140. Visit to power and motor control centre and identify various equipment. (04 Hrs) 141. Practice Live-dead-Live test in electrical panel (HV/LV). (04 Hrs) 142. Draw layout of thermal power plant and identify function of different elements. (08 Hrs) 143. Draw layout of hydel power plant and identify functions of different elements. (08 Hrs) 144. Draw single line diagram of transmission and distribution system. (08 Hrs) 145. Identify various substation equipment viz., isolators, over current relays, earth fault relay, differential relay, REF relay, lightening arresters, Surge counter, wave trap, Reactor, Capacitor bank, Circuit breakers – ACB, SF-6 and VCB etc. (14 Hrs)	Various ways of electrical power generation by conventional and non-conventional methods. Transmission and distribution networks. General layout of substation Single line diagram, general symbols for various equipment installed at substation. Single line diagram for various 33 KV, 132 KV, 220 KV, 400 KV substations. Basic idea about distribution system Electrical Safety guidelines and regulations for HT. Direct and indirect Risks of electricity. Voltage detector and its application Basic Parameters of all equipments and their name plate. Techniques of Hotline maintenance at HVS/s. Protection of transmission line via PLCC system. (18 hrs.)

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
		146. Video demonstration of laying OPGW along with earth wire at the top of tower of HV Line. (04 Hrs)	
Professional Skill 42Hrs; Professional Knowledge 15Hrs .	Perform on-site installation, preventive maintenance, testing, repair/ replacement of electrical power distribution equipment viz., circuit breakers, isolators, lightening arresters, reactor, capacitor bank etc. **(Mapped NOS: PSS/ N1708, PSS/N0106)**	147. Practice operation of isolators. (02 Hrs) 148. Identify different components of Circuit Breakers. (02hrs) 149. Perform operation of circuit breakers in maintenance (test) mode. (03hrs) 150. Practice use of grounding rod and make visible earthing. (02 hrs) 151. Practice operation of Circuit Breakers; ACB, SF-6 and VCB etc. (06 hrs) 152. Practice filling and evacuation of gas in SF-6 Circuit breaker. (03hrs) 153. Carry out timer test on circuit breakers. (02 hrs) 154. Carry out repair and maintenance of circuit breakers. (08 hrs) 155. Identify lightening arrester in the yard and practice replacement. (04 hrs) 156. Practice reading of surge counter. (02 hrs) 157. Identify Wave Trap and LMU and practice replacement. (04 hrs) 158. Carry out maintenance on wave trap and LMU. (04 hrs)	Types of isolators like Horizontal centre break, Double break, Pantograph type. Circuit Breakers; Types of circuit breakers, their applications and functioning. Production of arc and arc quenching methods (Air blast, oil, SF-6 and vacuum) Types of male and female contacts. Types of jaws & blades of various isolators Maintenance of equipment Grounding Rod Lightening arrester, surge counter Wave Trap and LMU (Line Matching Unit); power line carrier communication (PLCC) system Corona losses in transmission lines in power system. General routine maintenance. Handling of SF6 gas (filling and evacuation procedure) Inspection of contact resistance of breakers and alignment of contacts. Opening and closing time of breakers. (15 hrs.)
Professional Skill 120Hrs; Professional Knowledge 25Hrs	Carry out testing, maintenance and evaluate performance of transformers. **(Mapped NOS: PSS/ N2407)**	159. Verify terminals, identify components and calculate transformation ratio of single-phase transformers. (07Hrs) 160. Determine voltage regulation of single-phase transformer at different loads and power factors. (07Hrs) 161. Perform series and parallel operation of two single phase transformers. (07 Hrs)	Working principle, construction and classification of transformer. Single phase and three phase transformers. Turn ratio and e.m.f. equation. Series and parallel operation of transformers. Voltage Regulation and efficiency. Auto Transformer and instrument transformers (CT & PT).

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
.		162. Verify the terminals and accessories of three phase transformer HT and LT side. (05Hrs) 163. Perform 3 phase operation (i) delta-delta (ii) delta-star (iii) star-star (iv) star-delta, by use of three single phase transformers. (07Hrs) 164. Perform BDV (Dielectric strength) and water particle content test of transformer oil. (07 Hrs) 165. Video demonstration of filtering of transformer oil. (05Hrs) 166. Carry out routine tests of transformer to check operational performance. (07Hrs) 167. Carry out IR & PI test of distribution transformer used in substations using analog& digital megger. (07Hrs) 168. Measure Transformer winding resistance. (02Hrs) 169. Carry out IR test of individual bushings of distribution transformer. (03Hrs) 170. Identify phase and neutral bushings of HV & LV side of the distribution transformer. (05Hrs) 171. Identify various components of cooler control system of the transformer. (04Hrs) 172. Carry out manual and auto operation of fan from transformer marshalling kiosk. (04 Hrs) 173. Perform transformation ratio test. (04 Hrs) 174. Carry out Short circuit test and measure impedance voltage/ short circuit impedance (principal tap) and load loss. (05 Hrs) 175. Carry out Open circuit test for measurement of no-load loss and current. (10Hrs) 176. Carry out induced Voltage Test of Transformer. (08Hrs)	Method of connecting three single phase transformers for three phase operation. Types of Cooling, protective devices, bushings and termination etc. Testing of transformer oil. Routine tests and Pre-commissioning tests of transformers. On load tap changer, driving mechanism and operation of tap. Oil test include DGA (Dissolved gas analysis) and its interpretation Metal particle analysis and FURAN test Partial discharge (PD) and tan delta test. Alarm and Trip settings for winding temperature Indicator, oil temperature Indicator and Buchholz etc. On load tap changer (OLTC), Driving mechanism and operation of tap locally as well as remotely from control room. Vector group test for parallel operation of transformers. (25 hrs.)

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
		177. Carry out tests on components / accessories viz., buchholz relay, Temperature indicators, Pressure relief devices, Oil preservation system etc. (08Hrs) 178. Carry out maintenance of transformer. (08Hrs)	
Professional Skill 80Hrs; Professional Knowledge 20Hrs	Plan and prepare LT/ HT cable and Under-ground cable joints. **(Mapped NOS: PSS/ N0108)**	179. Identify different types of HT/LT cables. (04hrs) 180. Identify different parts of various underground cables. (04hrs) 181. Practice preparation of cables for termination and joining. (08hrs) 182. Demonstrate termination kits and practice on terminations of LT/HT cables. (08hrs) 183. Make straight joint of different types of underground cable. (10hrs) 184. Carry out high voltage (high pot) test. (06 hrs) 185. Practice laying of HT/LT cables in raceways and trenches. (06 hrs) 186. Demonstrate and identify various cable glands. (05 hrs) 187. Practice passing of cables through cable entry plate for standard cables without connectors, up to IP 68 rated protection. (05 hrs) 188. Practice split cable entry for multiple pre-terminated cables, up to IP 65 rated protection. (05 hrs) 189. Practice cable entry on a switch cabinet wall. (05 hrs) 190. Demonstrate bonding and grounding of raceways, cable assembly and panels. (05 hrs) 191. Test underground cables for faults and remove the fault. (09 hrs)	Power cables: Need of HT cables, advantages and disadvantages, various types viz., PVC, XLPE, Halogen, Optical fiber, etc. Awareness of HT/LV cable Cable insulation & voltage grades. Classification of cable on the basis of construction, voltage and current. Need for cable jointing (splicing). Need of termination kits. Joints and terminations; pre-moulded, heat shrinkable, extrusion molded joints Slip on, cold shrink terminations. Types of connectors used in the cable, current path. Methods of conductor connection, contact resistance. Precautions in using various types of cables. Galvanic corrosion and use of bimetals. Connectivity for cable screen and armour, mechanical protection Kits for joints and terminations (cold and heat shrink). HV and LV cable joint procedure. Cable termination to equipment Standards and testing; type, routine, field test Stress control Basic concept of Laying procedure and necessary step during emergency restoration and isolate faulty section of power cable in HV Electrical system. Introduction to IP ratings (Ingress protection) and IP Codes format.

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
			Importance of Bonding and grounding, various types. Testing of cables, locating faults, open circuit, short circuit and leakage in cables. (20 hrs.)
Professional Skill 55 Hrs; Professional Knowledge 15Hrs	Perform testing, repair/ replacement and maintenance of control elements viz., CT, PT, etc., used for protection and measurement in power distribution. **PSS/N1707**	192. Identify Current transformers, its specifications and carry out visual inspection. (03hrs) 193. Carry out ratio test on CT. (03 hrs) 194. Carry out Polarity test on CT. (03 hrs) 195. Check insulation resistance of CT. (03 hrs) 196. Carry out winding resistance test on CT. (03 hrs) 197. Carry out Excitation (Saturation) test on CT. (04 hrs) 198. Carry out Burden test on CT. (04 hrs) 199. Carry out knee point voltage test of protection core. (03 hrs) 200. Carry out ratio change of CT by changing taps in primary and secondary side. (04 hrs) 201. Perform installation and commissioning of current transformer. (06 hrs) 202. Identify potential transformers, its specifications and carry out visual inspection. (02 hrs) 203. Perform insulation resistance tests on PT; winding to winding and each winding to ground. (03hrs) 204. Carry out Polarity test on PT. (02hrs) 205. Perform turn's ratio test on PT. (03hrs) 206. Perform installation and commissioning of potential transformer. (04hrs) 207. Identify isolation transformers and its specifications. (03hrs) 208. Carry out repair/ replacement and maintenance of CT and PT. (02 hrs)	Instrument Transformer: Necessity/ Advantages • Difference between Power Transformer & Instrument Transformer. • Location of CT and PT in the System. • Difference between Instrument Transformers used for Protection/ Measurement Testing of CT and PT Isolation transformer Basic concept of Live tank and Dead tank CT Basic concept of CVT Various types of CT categories and burden-Cl-1/0.5/0.2, Protection CT – 5P10 etc Special Protection CT – PS class Various substations; outdoor, indoor, pole mounted, Gas insulated substation (GIS), etc. Various terms like – maximum demand, average demand, load factor, diversity factor, plant utility factor etc. (15 hrs.)

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
Professional Skill 55 Hrs.; Professional Knowledge 15Hrs.	Plan and prepare Earthing installation, carryout testing and maintenance. **(Mapped NOS: PSS/ N6002)**	209. Identify various earthing components and their specifications. (05Hrs) 210. Plan and prepare pipe earthing. (09Hrs) 211. Plan and prepare plate earthing. (09Hrs) 212. Plan and prepare grid/mesh earthing. (09Hrs) 213. Practice earthing of delta connected system. (03Hrs) 214. Practice grounding of equipment and systems. (03Hrs) 215. Perform measurement of earth resistance using earth tester. (05Hrs) 216. Carry out treatment to minimize earth resistance. (04Hrs) 217. Carry out maintenance of earth system. (04Hrs) 218. Test earth leakage by ELCB and relay. (04Hrs)	Introduction Importance of Earthing Classification of Earthing: - • Depending upon use; Equipment, System, Discharge, Support and Line Earthing. • Depending upon type; Well type, Pipe, Plate, Mesh, Delta and Chemical earthing Plate earthing and pipe earthing methods and IEE regulations. Difference between grounding and earthing. Earth resistance and earth leakage circuit breaker. Balanced/ Restricted earth protection. Awareness of circuit main earth (CME) and portable earth. (12 hrs.)
Professional Skill 100Hrs; Professional Knowledge 20 Hrs	Plan and commission overhead distribution line including ABC and HVDS. **PSS/N0108**	219. Identify various conductors viz., All aluminium conductor (AAC), ACSR conductor, etc. (08Hrs) 220. Perform mechanical and electrical testing of overhead conductors. (12 Hrs) 221. Identify various sizes of copper wires and cable insulation FR/ FRLS/FRLSH. (08Hrs) 222. Practice joining of overhead line conductors. (12 Hrs) 223. Identify Aerial Bunched Cables used in distribution system. (08Hrs) 224. Plan and commission overhead distribution line using bare conductors. (20 Hrs) 225. Plan and commission distribution line using ABC. (20 Hrs) 226. Identify components and work with High Voltage Distribution System (HVDS). (12 Hrs)	Objectives of Distribution System. Classification of Conductors and Nomenclature Current rating Jointing of conductor ABC System - Prominent Considerations for Selection for ABC System; LT ABC, HT ABC Method of joining aluminum conductors. High Voltage Distribution System (HVDS) Advantages of HVDS Route survey for overhead and underground cable distribution system. Safety Procedures and Permit to Work Operation and Maintenance of Distribution System. (20 hrs.)

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
Professional Skill 75 Hrs; Professional Knowledge 23Hrs	Carry out installation, repair/ replacement and maintenance of tower/pole and accessories in Power Distribution System. **(Mapped NOS: PSS/ N0108)**	227. Identify different Supports, Transmission Towers, and various accessories.(08 Hrs) 228. Perform digging of pit, erection of supports and fitting various accessories on poles.(12 Hrs) 229. Perform stringing and sagging of line conductors.(10 Hrs) 230. Fasten jumper in pin, shackle and suspension type insulators. (10 Hrs) 231. Perform installation of overhead domestic service lines.(15 Hrs) 232. Measure current carrying capacity of conductors. (05 hrs) 233. Practice installation and sealing of energy meters.(05 Hrs) 234. Install bus bar and bus coupler on LT line. (05 Hrs) 235. Practice working with thermo vision camera. (05 Hrs)	CEA safety regulation 2010 Supports and Accessories: PCC Pole, ST Pole, Cross Arms, Clamps, Transmission Towers Different types of Line insulators Foundations - Dry, Wet, PS, FS and Well type Construction of Distribution and Transmission Network. Erection & Commissioning of Equipments. Safety precautions and IE rules pertaining to domestic service connections. Basic concept of MONO Pole, Multi circuit Tower and 90 degree crossing of two HV Transmission line in same tower. Basic concept of transposition of towers. Types of Faults in electrical system. Thermo vision supervision at substation for hot point detection. (23 hrs.)
Professional Skill 50 Hrs.; Professional Knowledge 15Hrs.	Monitor meter readings, generate bill, maintain & upkeep various log sheets and energy accounting. **(Mapped NOS: PSS/ N3001)**	236. Practice on collecting meter reading of various meters. (08hrs) 237. Practice study of MRI reports. (12 hrs) 238. Take meter reading by using USB / Optical cable. (12 hrs) 239. Observe/ Study log sheet at substation. (08 hrs) 240. Practice generation of electricity bill using SBM. (05 hrs) 241. Demonstrate shut down and work permit proforma. (05 hrs)	**Energy meters;** Types, Meter Reading, Description of MRI, General layout of Meter Test Lab. Testing of Meters, Operation of SBM (Spot billing machine) Knowledge about TOD metering **Log Sheet;** Maintenance and up keeping of daily Log Sheet at various Substation and energy accounting along with Recording of Complaints and follow-up action Shut down and work Permit. (15hrs.)
Professional Skill 75 Hrs.; Professional Knowledge 24Hrs.	Examine the faults and carry out repairing of substation equipment and panels. **(Mapped NOS:PSS/ N2503, PSS/N2505)**	242. Practice isolation procedure and switching procedure preparation. (12hrs) 243. Practice implementation of permit system and LOTO system. (12hrs)	Isolator, circuit breaker, Earth switch; Working principal and mechanism

Duration	Reference Learning Outcome	Professional Skill (Trade Practical) (With inidcative hour)	Professional Knowledge (Trade Theory)
		244. Identify various fuse sets viz., HRC, DO, 33KV fuse set, etc. (05 hrs) 245. Measure and select size of fuse wire. (06 hrs) 246. Practice reading of energy flow diagram. (06 hrs) 247. Examine faults in Control Room Wiring and practice repairing. (14 hrs)	Emergency lighting system 6 Steps of Lockout/ Tagout (LOTO), colour coding of tags and locks, different types of locks. Energy flow diagram. Necessity, Advantages / Disadvantages of fuses. Types of IT & HT fuses
		248. Identify various parts of relay and ascertain the operation. (10Hrs) 249. Practice setting of pick up current and time setting multiplier for relay operation. (10 hrs)	Drop out (DO) Fuses sets Rupturing Capacity & recommended sizes of fuse elements. Installation and maintenance. Types of relays and its operation. High power rectifier system and its application at various industries. Introduction to SCADA and GIS mapping. (24 hrs.)
Professional Skill 50 Hrs.; Professional Knowledge 15Hrs.	Read and understand electrical Schematic drawings of power and control circuits of outdoor substation. **PSS/N2503**	250. Interpret Single line/ Layout drawings with Equipment and Protection codes as per ANSI. (15 hrs) 251. Interpret Layout drawings of 400kV/220kV/132kV/66kV/33kV/ 11kV outdoor substations. (15 hrs) 252. Interpret various panel wiring drawings of substation equipment. (20 hrs)	Power and control schematic drawings with interlocks. Isolator and Earth switch wiring, PT terminal box wiring CT terminal box wiring Circuit breaker closing and tripping circuits, Marshalling box wiring, Relay and control panel wiring. RTCC panel wiring. OLTC panel wiring. Mimic panel wiring. (15 hrs.)
Professional Skill 25 Hrs.; Professional Knowledge 06Hrs.	Operate firefighting equipment and systems used in substation. **PSS/N2001**	253. Identify various fire fighting equipment used in substations. (05 hrs) 254. Practice on different fire fighting extinguishers. (20 hrs)	**Fire Fighting;** Categories of Fire-A, B, C, D & E - General description Description Fire Fighting Equipments Suitable for various categories of fire. Electrical Fire; Origin and Preventive Measures Do's and Don'ts for Electrical Safety. Fire protection system: Various type of system used in the Electrical distribution system. (06 hrs.)

Control elements, accessories - layout of control cabinet

Objectives: At the end of this lesson you shall be able to
- **explain the layout marking methods and necessity**
- **state the methods of marking, cutting, drilling, fixing of accessories and components**
- **explain the methods of mounting and wiring the accessories**
- **state the various control elements used for control panel board**
- **list the different wiring accessories used in control panel wiring.**

Introduction

Preparation of layout drawing and marking on control cabinet is very much essential, we must have a clear vision of mounting components and their location on panel board/ control cabinet.

There is no such important method in practice to make the layout on control cabinet. However a neat layout on control cabinet is very much required.

The display and indicating instruments should be selected on the top position of the cabinet. Heavy and rare operated devices such as fuse breaker etc; are to be fixed on the bottom of the cabinet.

The components and fixtures should have sufficient space in between to carryout future repair (or) replace requirements. But too much space should not be provided, that will increase the size of the cabinet unnecessarily. While finalizing the layout plan the relevant IE rulers to be followed for better result.

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.

Control panel may be often used near the process area with high temperature, humidity and dust hence the arrangement for cooling fan and dehumidifier along with filters and intake and exhaust vents should be needed.

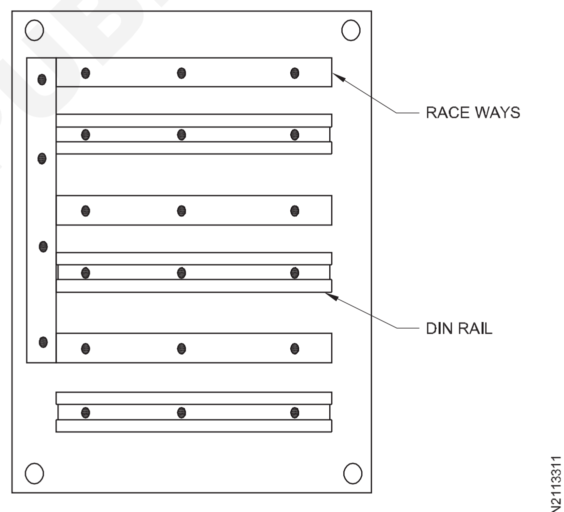
Suitable size of control panel which can accommodate all the controlling, protective, measuring, indicating and wiring accessories required for said wiring should be obtained or fabricated.

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 over load and short circuit protection may be given either ahead of the control panel by calculating the highest rating of the branch circuit or individual motors depends on space available, cost factor and sensitiveness of the operation.

The finalized layout may vary depends the individual design and mind application. However a sample layout marking for the above starter is given in the Fig 1.

Fig 1



TYPICAL LAYOUT MARKINGS

Once the panel layout is designed we must find out where and how to fit the accessories.

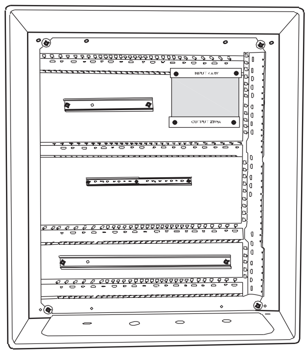
The finalized layout of accessories can be marked in the control panel using suitable marking device.

Cutting and drilling

The mounting or fixing holes along with necessary tap or die in suitable size (if any) can be prepared in the front door and inside of the control panel as in Fig 2.

Din rail is a metal rail made from cold rolled carbon steel sheet with zinc plated or chromate bright surface finish used to mount the circuit breakers and control accessories without using screws as in Fig 2. DIN rail being fixed to the chassis before fitted the contactors and other accessories as in Fig 3.

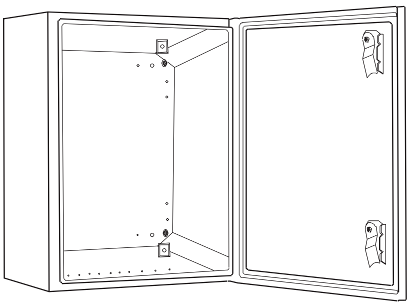
Fig 2



CONTROL PANEL WITH RACEWAYS / DIN RAILS

PD20N2113312

Fig 3

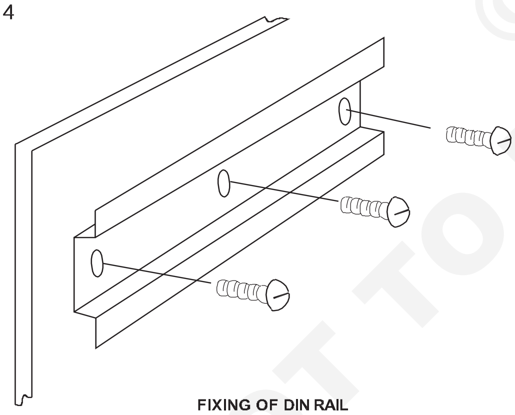


CONTROL PANEL WITH MOUNTING AND FIXING HOLES

PD20N2113313

The standard specification of widely available DIN rail is top hat rail EN 50022 which dimension is 35 mm width and a 15 mm or 7.5 mm depth. They 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 4.

Fig 4



FIXING OF DIN RAIL

PD20N2113314

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.

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.

The contactor arrangements and terminals are usually labeled which conforms to BS 5583. For example 1 and 2 for NC contacts, 3 and 4 for NO contacts, odd numbers like 1, 3 and 5 for incoming terminals and even numbers like 2, 4 and 6 for outgoing terminals of the main contacts of contactors and OLR.

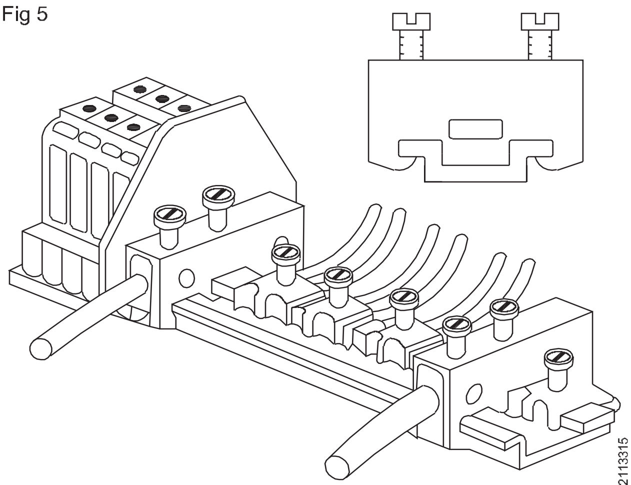
The conductor should be trimmed OFF to that the conductor does not insert more than the half way through the connectors. Single strand wire should be folded back to give additional thickness. The over tightening of screw have to be avoided otherwise this can crush the strand and give a weak connection.

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.

An insulated separator can be used to isolate the high voltage connections from others. End stops are used to clamps the connectors together and close the open terminals on one end, sometimes the earth terminal will do the same job as in Fig 5.

Fig 5



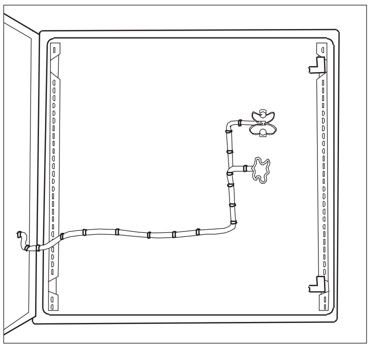
TERMINAL CONNECTORS / EARTH TERMINAL WITH SEPERATOR

PD20N2113315

The control panel should be grounded properly so that control panel should have proper earthing bolts / nuts. If more ground points are used a common earth plate should be fixed inside the cabinet as in Fig 5.

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 6.

Fig 6



U LOOP OF CABLES

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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.

The associated earth and neutral conductor should be routed close to the respective live conductors to avoid undue loop resistance.

Select the race ways to leave some slacks or looping of the cable inside it. The wires inside the race way should not more than the half fill.

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. Uses of spring cage terminals instead of standard screw terminals can reduce the termination error, the wiring and maintenance time which in turn reduce the cost and labour.

To connect the accessories, cut the individual control wires to the proper lengths, strips the insulation, mark wire identification, insert ferrules at the ends of wires, use suitable lugs or thimbles.

The wires should be neatly bundled, run in the race ways and routed with smooth radius bends.

All the terminals, wires and components should have identification marks and labels. A good labelling and identification will reduce the errors in termination, testing, maintenance and repairs. A legible and durable label in an efficient and cost effective manner may be chosen.

To the possible extent the power and control wiring should be run in separate race way or cable management which will reduce the radio interference, trouble shooting time and make the future alteration if any is easier.

By taking some extra cares like pest control, dust control, adequate terminal pressure, selection of proper wires and accessories, it can be ensured that the control panel has no failure time and with moderate maintenance it will be trouble free panel for entire life.

Where the multiple earths are used it is necessary to use a common earth terminal or connectors as in Fig 5.

Tests

Before energizing the control panel all necessary tests should be carried out like open, short, earth continuity and earth soundness etc. The supply voltage and frequency are also to be checked.

Control elements

Difference between control panel and switch board

A panel board contains a single panel or a group of panel units as single panel that includes bus-bars, protective devices and control switches, instruments and more starters etc.

In a panel board, the interior are designed to place the accessories and wires in a cabinet or cut out box or partition and accessible only from the front.

A switch board consists of a large single panel or frame or assembly of switch gears, with or without instruments, but the term switch board does not apply to a group of local switches in the final circuit. Unlike panel boards, switch boards are generally accessible from the rear as well as from the front and are not intended to be installed in cabinets. However the terms, panel board and switch board, are used normally without much discrimination.

For wiring of control panel board the following control elements / components and accessories are required.

They are

- Isolating switch
- Push button switch
- Indicating lamp
- MCB (Miniature Circuit Breaker)
- Contactors

- Electro mechanical relays
- Thermal over load relays
- Time delay relay (timers)
- Rectifiers
- Limit switches
- Control transformers etc.

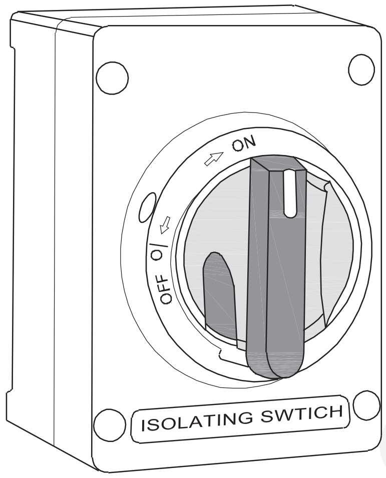
Control elements for control panel

1 Isolating switch (Fig 7)

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.

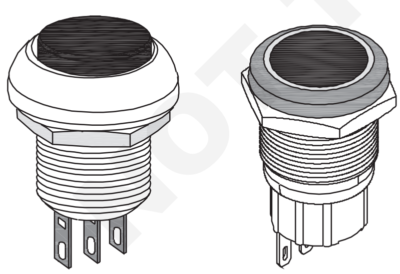
Fig 7



2 Push button switch (Fig 8)

Push button is a simple push switch mechanism for making or breaking the circuit as and when required. It is made out of hard plastic or metal. An indicating lamp is incorporated with the push button switch to indicate start or stop is also available.

Fig 8



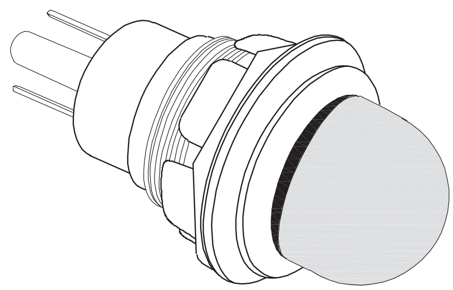
PUSH BUTTON SWITCHES

3 Indicating lamp (Fig 9)

It is a low voltage, low wattage filament or neon or LED lamps used to indicate the various indication like availability of supply or motor **ON/OFF,** mains/motors fails or trip etc.

It is available in different size, colour and wattage. It should be generally fitted in the front side of the control panel with suitable holder.

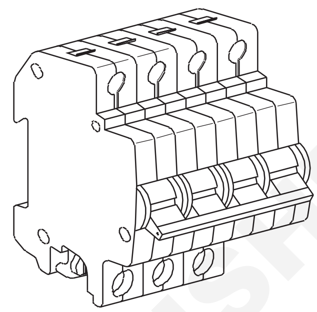
Fig 9



INDICATING LAMP WITH HOLDER

4 MCB (Fig 10)

Fig 10



MINIATURE CIRCUIT BREAKER

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.

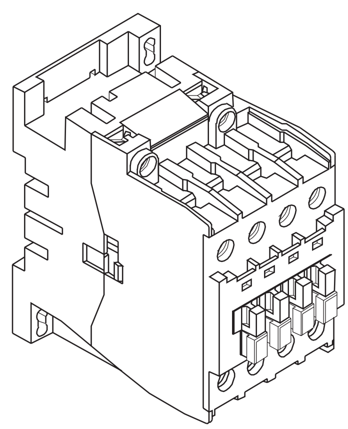
5 Fuses

It is a protective device which is connected is series with the live wire to protect the circuit from short circuit and earth fault.

6 Contactors (Fig 11)

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 11



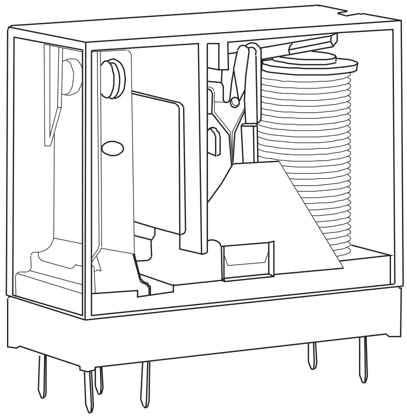
MINIATURE CIRCUIT BREAKER

7 Electro mechanical relays (Fig 12)

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.

current passes through its coil it produces a magnetic field that activates the armature to make or break a connection.

Fig 12



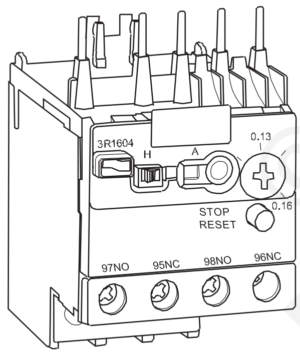
ELECTRO MECHANICAL RELAY

PD20N211331C

8 Thermal overload relays (Fig 13)

It is a thermally operated electromechanical device that protects motors from over heating and loading.

Fig 13



THERMAL OVERLOADED RELAYS

PD20N211331D

9 Time delay relay (timers) (Fig 14)

Time delay relays are simply the control relays in - built with a time delay mechanism to control the circuit based an time delay.

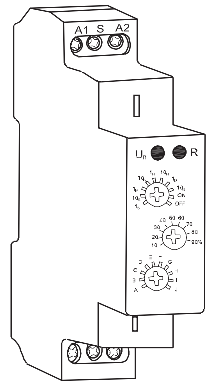
In time delay relays its contact will open or close after the pre-determined time delay either on energising or on de-energising its no volt coil. It can be classified into two types as ON delay timer and OFF delay timer.

11 Limit switches (Fig 15)

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.

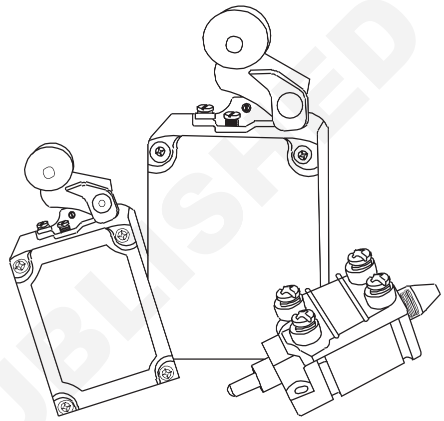
Fig 14



TIMER

PD20N211331E

Fig 15



LIMIT SWITCHES

PD20N211331F

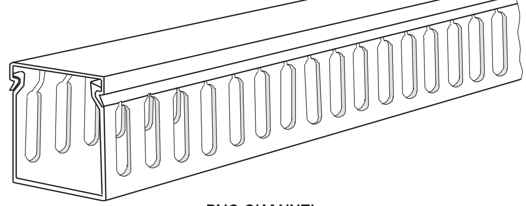
Wiring accessories for control panel wiring

1 PVC channel / Race ways (Fig 16)

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.

It protects the wires from dust, humidity, corrosion, water intrusion, heat, mechanical damage and physical threats.

Fig 16



PVC CHANNEL

PD20N211331G

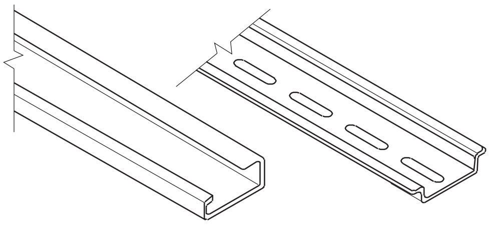
2 DIN rail (Fig 17)

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.

3 G Channel (Fig 18)

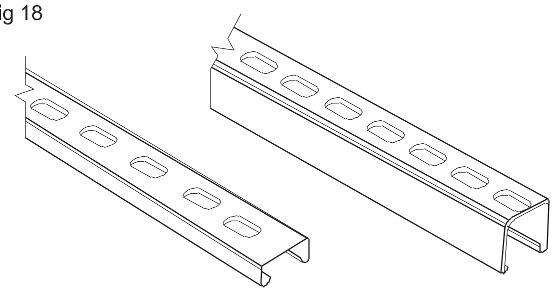
It is a zinc - coated metal channel which is especially used for mounting the feed through or spring load or double deck terminal connectors without using screw inside the control panel.

Fig 17



DIN RAILS

Fig 18

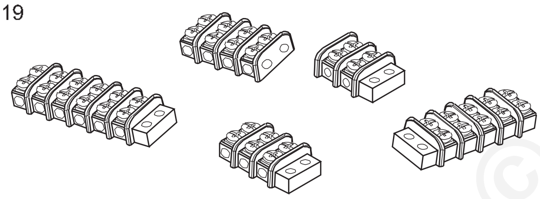


'G' CHANNEL

4 Terminal connectors (Fig 19)

It is the set of insulated screw terminals at both sides used to connect the accessories of the control panel with external control switches, limit switches, input supply and motor terminals etc.

Fig 19



TERMINAL CONNECTORS

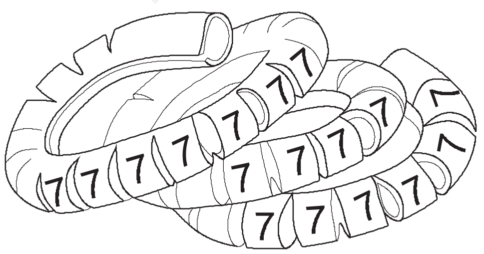
Terminal connectors with barrier strips and clamping plates provide a tight and electrically sound termination. It is available in various size, current and voltage ratings.

5 Wire ferrules (Fig 20)

It is a small circular ring made up of polymer plastics or rubber or fibre, used to easily identify the ends of wires which are to be connected into a particular terminals or accessories. It should be inserted on the both ends of a wire as collar or bracelet.

It is available is different size like 1 sq.mm, 1.5 sq.mm and 2.5 sq.mm etc generally in yellow colour printed with either numerical or alphabet letters on it.

Fig 20



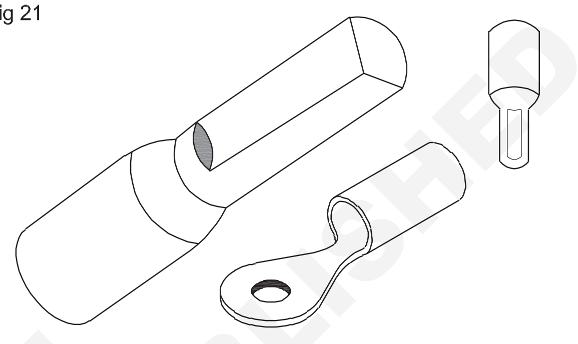
WIRE FERRULES

6 Lugs and thimbles (Fig 21)

It is a cylindrical barrel along with circular rings or cylindrical rod or U shape or flat surface made up of aluminum or copper or brass, used to ensure the sound electric connection of the cable / wire on to the terminals. It prevent flare out of stripped and stranded cable, increase the conductivity of the connection, support the cable / wire and avoid the loose connection and sparking. Suitable crimping tool has to be used to connects them with cables / wires. It is available in different size like 1 sq.mm, 4 sq.mm, 25 sq.mm, 70 sq.mm, 125 sq.mm and so on.

- Thimbles may also be referred as sockets.

Fig 21



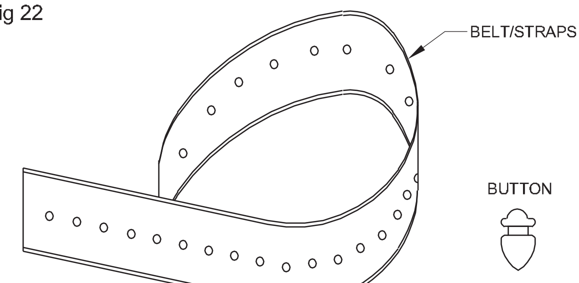
LUGS AND THIMBLES

7 Cable binding straps and button (Fig 22)

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.

It is reusable and good insulator to the heat and electricity. It is generally available 8mm, 10 mm and 12 mm width.

Fig 22



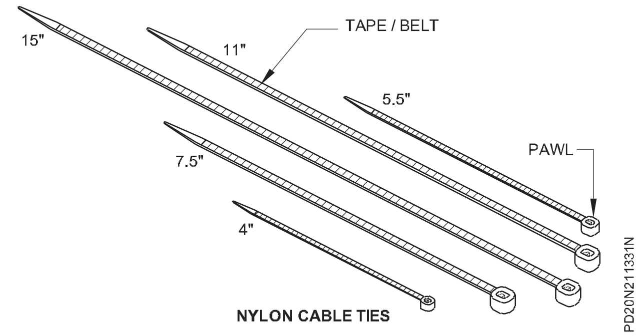
CABLE BINDING STRAPS AND BUTTON

8 Nylon cable ties (Fig 23)

- It is a type of fastener used to hold or tie or bunch the wires / cable or group of cables.
- It is made of nylon tape or belt which has teeth that will engage with head of the pawl to form a ratchet and tightens the wires.
- In general the tie can not be loosened, or removed or reused. However some reusable ties are also available.
- It is available in different colour, length and width.

- Because of its low cost and easy to use, it is widely used in general purpose application also.

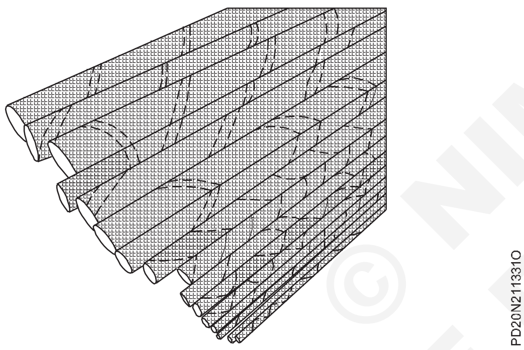
Fig 23



9 Sleeves (Fig 24)

- It is flexible tubular / cylindrical insulator into which the electric wire or cable or group of cables can be inserted.
- Apart from the electrical insulation and easy identification of wires, it also protect the wires from abrasion, heat, chemical, physical damage and radio interference.

Fig 24

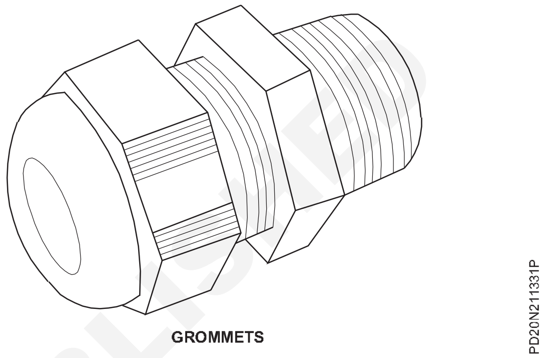


- It is available is different colour, style, materials like carbon fibre, fabrics, Teflon, fibre glass, nylon, poly ethylene (PET) wrap, braided metal and heat shrink sleeves.

10 Grommets (Fig 25)

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. It is generally made of rubber, plastic, plastic coated metal and protect the cable from twist, tug, cut, break, strain, vibration etc and prevent the entry of dirt, dust, water, insects and rats into the panel. It may also called as glands.

Fig 25



11 Wire clips

It is a type of fixing or fastening device which is used to fix and hold the cables or punch of cables in a secure manner.

Installation of instruments and sensors in control panel and its performance testing

Objectives: At the end of this lesson you shall be able to
- **state the sensor main specification, application necessity and types**
- **state the specification and types of sensors required in panel board**
- **explain the performance testing of panel control board.**

Instruments in panel board

Industrial operation for any process requires many machines, apparatus for usual supply and maintain continuous production. Some machines requires operator always to operate many control on process for example a lathe machine is required always its operator assistance to do different job, turning, shaping etc, but in some cases the machine not required continuous manual operator for single job operations.

In a workshop AC motor or DC motor is to operate for many of its intended job. Once the machine starts it will continue to work for its assigned job and requires only ON and OFF operation. This operation may need many job completion in different places located in the work shop. This operation has to be controlled and monitored in time intervals and a constant watch also may require.

The instruments are used to measure the electrical quantities, which in turn gives the feed back of load conditions and performance. A motor draws a constant current, which can monitor by a ammeter connected to them similarly the rated voltage, frequency, power factor etc, are also to be checked through the meters. If number of machines and meters are more it is difficult to watch the parameters individual places. A panel board having this meters are installed helps to collect the data at one place where different machines are working.

Selection of meters are in accordance with the machine ratings and working voltage limits. A low range meter cannot be connected in a heavy load machine for its readings it may damage the meter and its wiring.

Sensors types, classification and its application

Sensors is a device that detects/measures a physical quantity. A motor is running with its rated rpm but some cases load variations on motor affects the rpm. The quality of the product may depend on the machine accuracy, then it is very important to run the motor at its rated rpm. Automatic rpm correction is possible with relevant circuits but a sensor has to feed back the working rpm to the control circuit. In this case a Tacho generator is the device to produce the feed back of rpm of motor. Tacho generator can be fixed on the shaft of the motor and the resultant feed back quantity(V or I) can be brought to the control panel board.

Similarly, the temperature measurement also can be done by suitable sensors. Since the temperature is the big problem for all electrical applications, a constant watch on the temperature helps to increase the life of the machine and a uniform production with specified quality. In this way temperature can be controlled by installing suitable sensor preferably with a thermistor-PTC or NTC will help to control the temperature within safe limits. The sensor element will kept in the winding and the cable is brought up in the control panel, to connect the temperature indicating unit for indication.

A sensor is a special kind of transducer which is used to generate an input single to a measurement, instrumentation or control system. The signal produced by a sensor in an electrical analogy of a physical quantity, like acceleration, temperature, pressure, distance, velocity, light, level etc.

Types of sensors: There are two types of sensors

a Passive sensor

b Active sensor.

a **Active sensor:** Self generating sensor is that one can generate a signal without any external power source. Eg. photovoltaic cell, thermo couple, piezoelectric device .

b **Passive sensor:** It requires external power supply to generate the signal. E.g. Diaphragm used to convert pressure or velocity, oscillations, or sound wave's into movements of a solid sheet.

Classification of sensors: It is classified into many categories according to the output, application etc. It is mainly divided into two groups, they are; a) Digital sensor and b) Analog sensor.

Digital sensor: The resolution of this sensor is most accurate and maximum speed. Its ability to detect a change in the sensed quantity is excellent. The output is always taken as 180, high and low, or yes or no.

Analog sensor: The resolution of this sensor in less accurate corporate to digital and it records very small changes or variations resulting more error. It is usually used to record very small changes, or variations.

Further, the sensors are mainly used to measure temperature and RPM in the electrical circuits. The following sensors are used to measure temperature. They are;

a Thermo couple

b RTD (Resistance Temperature Detector)

c Thermistor

d IR sensors (Infra Red)

e Semi conductor sensors - VDR, LDR, Photo diode etc.,

The sensors used to measure RPM of motor; are in different types; they are

a Shaft encoders (rotary type) 1-5000 pulses

b Photoelectric (optical type)

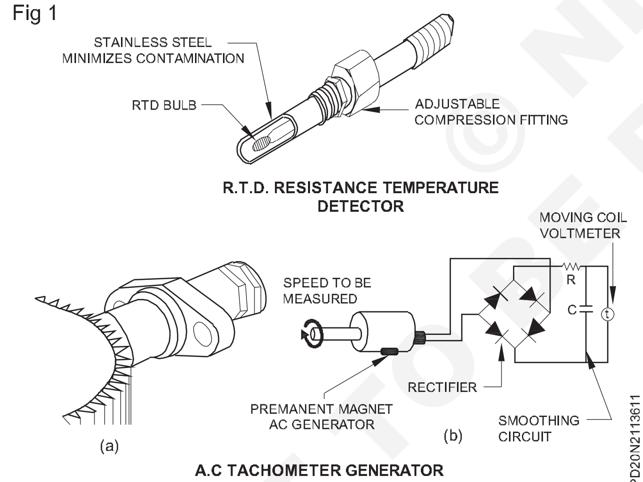
c Magnetic rotational speed (proximity type) - medium or low RPM.

d Photo sensor reflection target- Tachometer - 20-20,000 range

Sensor assembly and measurements

Temperature measurement using resistance temperature detector (RTD) and $\sqrt{1}$ assembly with position adjustment, tachometer sensor assembly and a AC tachometer generator is in Fig 1. The AC is rectified by a bridge circuit. The amplitude and frequency of the induced emf are equivalent to the speed of the shaft. Thus either amplitude or frequency is used for measuring the angular velocity.

Fig 1



R.T.D. RESISTANCE TEMPERATURE DETECTOR

A.C TACHOMETER GENERATOR

Performance testing of panel board

It is important to see that the panel board is to install carefully as it carrys a number of connection and controls. Any loose connection or wrong connection to any device will affect the performance and it may cost more.

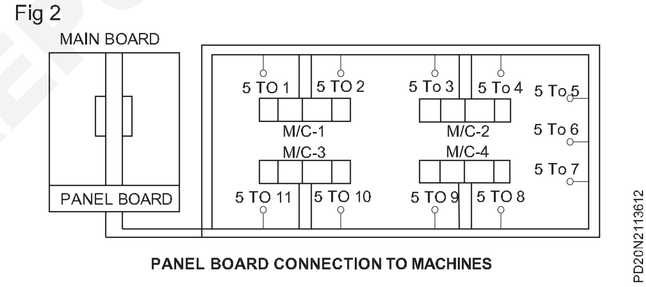
While testing the performance make sure that all connections and wiring are correct and as per IE rules. Wrong connection and substandard materials will cause heavy damage to the panel board. The continuity of cable, earth resistance values are to be kept in the safe level as per IE rule normal.

The panel board should be earthed properly and all metal parts have to be connected to earth. If the current in the panel board is heavy; a separate earthing has to be provided and maintained within the standard.

Connection to machine from panel board has to be made on short as possible. If the machine draws less current, line drop will be minimum and resultant power is low hence in cable is also low and even negligible. If the connecting cable length is much more than line loss will be too high and it will turn shorten the life of machine and cables connected. Running of cable can be made as per the situation and facilities. Keep away from direct sun light wet condition, and near fire or any other polluted areas.

A simple model panel board to the load power is given for your guidance in Fig 2.

Fig 2



PANEL BOARD CONNECTION TO MACHINES

AC/DC drives

Objectives: At the end of this lesson you shall be able to
- **state the classification and working of AC & DC drives**
- **state the applications of AC & DC drives**
- **describe the block diagram, parts of DC drive and advantages and disadvantages of DC drives.**

Electrical drives

An electric drive can be defined as an electromechanical device for converting electrical energy into mechanical energy to feed motion to different machines and mechanisms for various kinds of process control.

Motion control is required in large number of industrial and domestic applications like transportation, systems, rolling mills, paper machines, textile mills, machine tools, fans, pumps, robots, washing machines etc.

Systems employed for motion control are called Drives, and may employ any of prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors; Supplying mechanical energy for motion control Drives employing electric motors are known as Electrical drives.

Classification of electric drives

i According to mode of operation

- Continuous duty drives
- Short time duty drives
- Intermittent duty drives

ii According to means of control

  - Manual
  - Semi automatic
  - Automatic

iii According to number of machines

  - Individual drive
  - Group drive
  - Multi - motor drive

iv According to dynamics and transients

  - Uncontrolled transient period
  - Controlled transient period

V According to methods of speed control

  - Reversible and non-reversible uncontrolled constant speed
  - Reversible and non-reversible step speed control
  - Variable position control
  - Reversible and non-reversible smooth speed control

Advantage of electrical drives

1 They have flexible control characteristics.

2 Drives can be provided with automatic fault detection systems. Programmable logic controller (PLC) and computers can be employed to automatically control the drive operation in a desired sequence.

3 They are available in wide range of torque, speed and power.

4 They are suitable to almost any operating conditions such as explosive and radioactive environments.

5 It can operate in all the four quadrants of speed - torque plane.

6 They can be started instantly and can immediately be fully loaded.

7 Control gear requirement for speed control, starting and braking is usually simple and easy to operate.

Choice (or) selection of electrical drives

- Choice of an electric drive depends on the important factors are.

1 Steady state operating conditions requirements. Nature of speed torque characteristics, speed regulation, speed range, efficiency, duty cycle, quadrants of operation, speed fluctuations if any, rating etc.

2 Transient operation requirements

3 Values of acceleration and deceleration, starting, braking and reversing performance.

4 Requirements related to the source. Types of source and its capacity, magnitude of voltage, voltage fluctuations, power factor, harmonics and their effect on other loads, ability to accept regenerative power.

5 Space and weight restriction if any.

6 Environment and location.

7 Reliability

Group electric drive

This drive consists of a single motor, which drives one or more line shafts supported on bearings. The line shaft may be fitted with either pulleys and belts or gears, by means of which a group of machines or mechanisms may be operated. It is also some times called as **shaft drives.**

Advantages

A single large motor can be used instead of number of small motors.

Disadvantages

There is no flexibility. If the single motor used, develops fault, the whole process will be stopped.

Individual electric drive

In this drive each individual machine is driven by a separate motor. This motor also imparts motion to various parts of the machine.

B In this drive system, there are several drives, each of which serves to actuate one of the working parts of the drive mechanisms.

e.g Complicated metal cutting machine tools

Paper making industries.

Rolling machines etc.

A modern variable speed electrical drive system has the following components

- Electrical machines and loads
- Power modulator
- Sources
- Control unit
- Sensing unit

Electrical machine

Most commonly used electrical machines for speed control applications are the following.

DC machines

Shunt, series, compound, DC motors and switched reluctance machines.

AC machines

Induction, wound rotor, synchronous, permanent magnet synchronous and synchronous reluctance machines.

Special machines

Brush less DC motors, stepper motors, switched reluctance motors are used.

Power Modulators (Controller)

Functions

- It modulates flow or power from the source to the motor is imparted speed - torque characteristics required by the load.
- During transient operation, such as starting, braking and speed reversal, it reduces the motor current with in permissible limits.
- It converts electrical energy of the source in the from of suitable to the motor.
- It selects the mode of operation of the motor (i.e) motoring and braking.

Types of power modulators (Controllers)

- In the electric drive system, the power modulators can be any one of the following.
- Controlled rectifiers (AC to DC converter)
- Inverters (DC to AC converters)
- AC voltage controllers (AC to DC converters)
- DC choppers (DC to DC converters)
- Cyclo converters (Frequency conversion)

Electrical sources

Very low power drives are generally fed from single phase sources. Rest of the drives is powered from a 3-phase source. Low and medium power motors are fed from a 415V supply. For higher ratings, motors may be rated at 3.3KV, 6.6 KV and 11 KV. Some drives are powered from battery.

Sensing unit

- Speed sensing (from motor)
- Torque sensing
- Position sensing
- Current sensing and voltage sensing (from lines or from motor terminals from load)
- Temperature sensing

Control unit

Control unit for a power modulator are provided in the control unit. It matches the motor and power converter to meet the load requirements.

DC Drives	AC Drives
The power circuit and control circuit are simple	The power circuit and control circuit are complicated
It requires frequent maintenance	Less maintenance
The commutator makes the motor bulky, costly, and heavy	These problems are not there in these motors and are inexpensive, particularly squirrel motors
Fast response and wide speed range of control, can be achieved smoothly by conventional and solid state control	In solid state control the speed range is wide and conventional method is stepped and limited
Speed and design ratings are limited due to commutations	Speed and design ratings have upper limits

Applications

- Paper mills
- Cement mills
- Textile mills
- Sugar mills
- Steel mills
- Electric traction
- Petrochemical industries
- Electrical vehicles

Another one type of electric drive is ‘Eddy current drive’

Eddy current drives

An eddy current drive consists of a fixed speed motor and an eddy current clutch. The clutch contains a fixed speed rotor and an adjustable speed rotor separated by a small air gap. A direct current in a field coil produce a magnetic field that determines the torque transmitted from the input rotor to the output rotor. The controller provides closed loop speed regulation by varying clutch current, only allowing the clutch to transmit enough torque to operate at the desired speed. Speed feedback is typically provided via an integral AC tachometer.

Eddy current drives are slip - controlled systems the slip energy of which is necessarily all dissipated as heat. Such drives are therefore generally less efficient than AC/DC-AC conversion based drives. The motor develops the torque required by the load and operates at full speed. The power is proportional to torque multiplied by speed. The input power is proportional to motor speed and times, operating torque while the output power is output speed and times operating torque. The difference between the motor speed and the output speed is called the slip speed. Power proportional to the slip speed times operating torque is dissipated as heat in the clutch.

Working principle of DC drives

In DC motors, the speed is proportional to the armature voltage and inversely proportional to the field current. And also, the armature current is proportional to the motor torque.

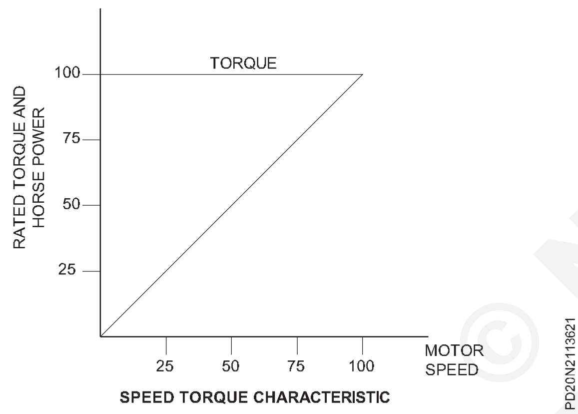
$$N \propto \frac{E_b}{I_f} \text{ and } I_a \propto T$$

Therefore, by increasing or reducing the applied voltage, the speed of the motor is varied. However, it is possible up to the rated voltage. If the speed greater than the base speed is required, the field current of the motor has to be reduced.

By reducing the field current, the flux in the motor reduces and it reduces the armature counter emf. Further, this armature current increases the motor torque and the speed will increase. These are the two basic principles employed in DC drives to control the speed of the motor.

In armature controlled DC drives, by varying the armature voltage, variable speed is obtained as in Fig 1.

Fig 1



Generally, a fixed field supply is provided in these DC drives. As the torque is constant (which describes a load type) over the speed range, the motor output horse power is proportional to the speed. The motor characteristics of this drive are in Fig 1.

Constant torque operation

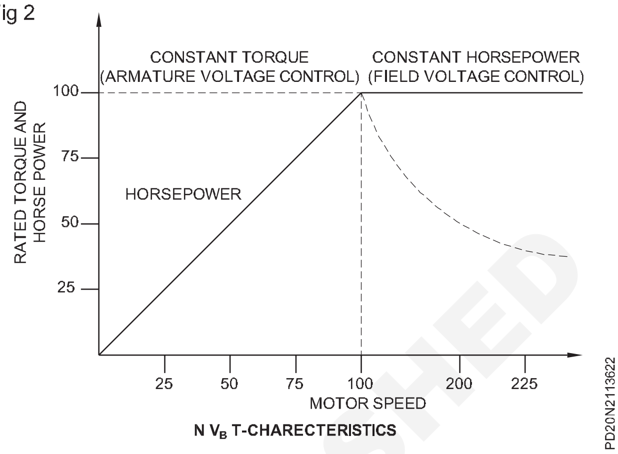
In case of armature and field controlled drives, the armature voltage to the motor is controlled for constant torque-variable HP operation up to the base speed of the motor. And for the above base speed operation, drive switches to the field control for constant HP-reduced torque operation up to maximum speed as in Fig 2 In this case, reducing the field current increases the speed of the motor up to its maximum speed as in Fig 2.

In most instances the shunt field winding is excited, with a constant - level voltage from the controller . The SCR (silicon controller rectifier), also known as thyristor, which converts the alternating current (AC) of the power source to variable DC output which is applied to the armature of a DC motor. Speed control is achieved by regulating the armature voltage to the motor.

A thyristor bridge is a technique commonly used to control the speed of a DC motor by varying the DC voltage. Important to note that the voltage applied to a DC motor can not be greater than the rated name plate voltage.

The tachometer (feedback device) converts actual speed in to an electrical signal that is summed with the desired reference signal. The output of the summing junction provides an error signal to the controller and a speed correction is made.

Fig 2



In modern DC drives, SCRs are completely replaced by MOSFET s and IGBTs in order to achieve high speed switching so that distortion to the AC incoming power and currents during switching is eliminated. Hence, the drive becomes more efficient and accurate.

Silicon controlled rectifier (SCRs) are widely used thyristors for large DC motor drives in its power conversion unit. An SCR conducts when a small voltage applied to its gate terminal. Its conduction continues till the starting of negative cycle and it turned OFF automatically once the voltage across the SCR goes through natural zero till next gated signal.

The purpose of using these SCRs in DC drives is to convert the fixed AC supply to variable DC supply that controls the motor speed. Some SCR DC drives are supplied from single phase AC supply and use four SCRs in the form of bridge for the DC rectification. In case of high power DC drives, a three phase supply with six SCRs is used for DC rectification.

In case of four quadrant operation (forward motoring, forward braking, reverse motoring and reverse braking) of the DC drive, a bridge rectifier consisting of 12 SCRs with a three phase incoming supply is used. During each quadrant operation, SCRs are triggered at a phase angle in order to provide required DC voltage to the motor.

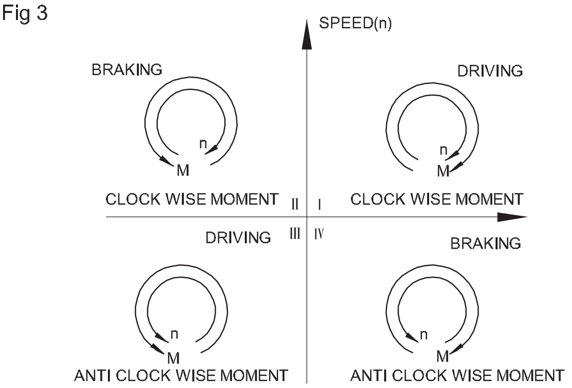
Drive operation

The drive applications can be categorized as single - quadrant, two - quadrant, three-quadrant or four- quadrant; the chart's four quadrants (Fig 3) are defined as follows.

Quadrant I: Driving or motoring forward accelerating quadrant with positive speed and torque

Quadrant II: Generating or braking, forward braking-decelerating quadrant with positive speed and negative torque.

Fig 3



ELECTRIC MOTOR SPEED-TORQUE CHART

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Quadrant III: Driving or motoring, reverse accelerating quadrant with negative speed and torque.

Quadrant IV: Generating or braking, reverse braking - decelerating quadrant with negative speed and positive torque.

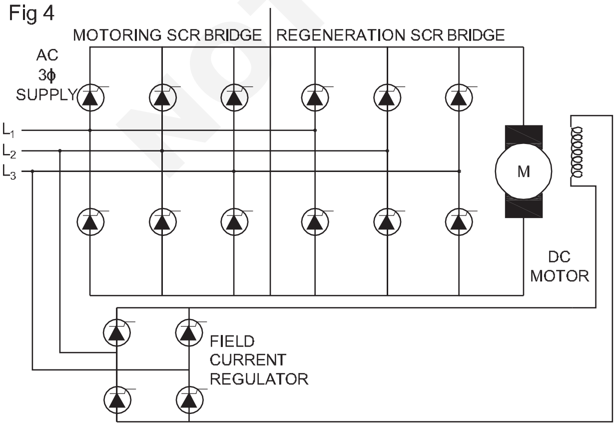
Most applications involve single quadrant loads operating in quadrant I, such as in variable - torque (e.g. centrifugal pumps or fans. etc.

Certain applications involve two - quadrant loads operating in quadrant I and II where the speed is positive but the torque changes polarity Some sources define two - quadrant drives as loads operating in quadrants I and III where the speed and torque is same (positive or negative) polarity in both directions.

Certain high - performance applications involve four - quadrant loads (Quadrants I to IV) where the speed and torque can be in any direction such as in hoists, elevators and hilly conveyors. Regeneration can occur only in the drive's DC link bus when inverter voltage is smaller in magnitude than the motor back - EMF and inverter voltage and back - EMF are the same polarity.

The connection of SCRs for four quadrant operation of the drive) from incoming three phase AC supply to the DC output is in Fig 4. In this, the motoring SCR bridge and regeneration SCR bridge achieve the drive four quadrant operation by receiving the appropriate gate signals from (analog or digital) controller.

Fig 4



3 PHASE SCR BRIDGE RECTIFIER

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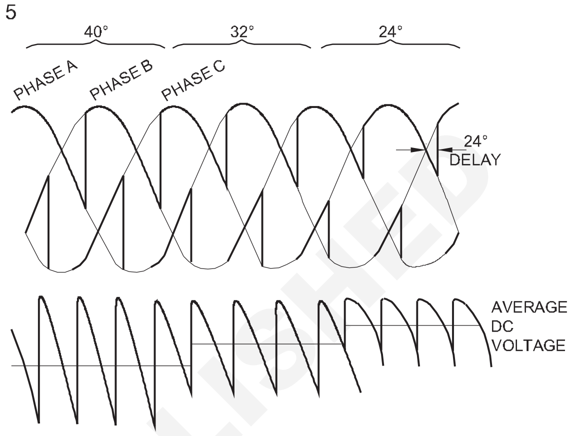
If the SCRs were gated with a phase angle of zero degrees, then the drive function as a rectifier which feeds the full rectified rated DC supply to the motor and by varying the firing angle to the SCRs, a variable DC supply is applied to the motor.

The DC output voltage waveform is related to the AC waveform for above circuit is in fig.5. This average DC output voltage is obtained for 40°, 32° and 24° firing phase angles. By this way, the average output is controlled by varying the firing phase angles to the SCRs.

Fig 5



AC INPUT & DC OUTPUT WAVE FORMS

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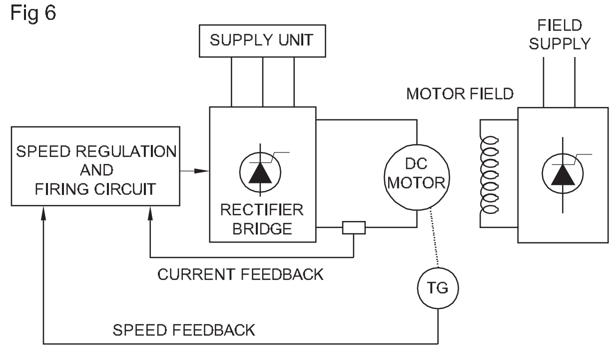
As the field winding also requires the regulated DC supply, only four SCRs are used in the field bridge converter. This is because field never requires a negative current and hence another set of SCRs is not required, which were used in armature for reversing the motor.

Block diagram of DC drive

The block diagram of a DC drive system is in Fig 6

Fig 6



COMPONENTS OF A DC DRIVE SYSTEM

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DC drive input: Some thyristor based DC drives operate on a single phase supply and use four thyristors for full wave rectification. For larger motors 3 phase power supply is needed because the waveforms are much smoother. In such cases, six thyristors are needed for full wave rectification.

Rectifier Bridge: The power component of a controlled DC drive is a full wave bridge rectifier which can be driven by three phase or single phase supply. As mentioned above the number of thyristor may vary depends on the supply voltage.

A six - thyristor bridge (in case of three phase converter) rectifies the incoming AC supply to DC supply to the motor armature. The firing angle control of these thyristors varies the voltage to the motor.

Field Supply Unit (FSU): The power is to be applied to the field winding is much lower than the armature power.

In many cases a two - phase supply is drawn from the three phase input (that supplies power to the armature) and hence the field exciter is included in the armature supply unit.

The function of the field supply unit is to provide a constant voltage to the field winding to create a constant field or flux in the motor. In some cases, this unit is supplied with thyristors to reduce the voltage applied to the field so as to control the speed of the motor above the base speed incase of permanent magnet DC motors, the field supply unit is not included in the drive.

Speed Regulation unit: It compares the operator instruction (desired speed) with feedback signals and sends appropriate signals to the firing circuit. In analog drives, this regulator unit consists of both voltage and current regulators. The voltage regulator accepts the speed error as input and produces the voltage output which is then applied to the current regulator.

The current regulator then produces required firing current to the firing circuit. If more speed is required, additional current is drawn from the voltage regulator and hence thyristors conduct for more periods. Generally, this regulation (both voltage and current) is accomplished with proportional -integral- derivative controllers.

The field current regulator is also provided where speed greater than the base speed is required.

Parts of DC drive

DC drives of various brands with different ratings are available in the market. It is generally assembled in a metallic enclosure. The front panel has the power terminals, control terminals, keypad for controlling the drive etc. It has provision for connecting to PC for programming the drive.

The main parts of DC drive are given below.(Fig 7)

1 Main drive assembly

2 Terminal cover

3 Terminal cover retaining screw

4 Blank cover

5 Keypad

6 COMMS technology box (optional)

7 Speed feedback technology card (optional)

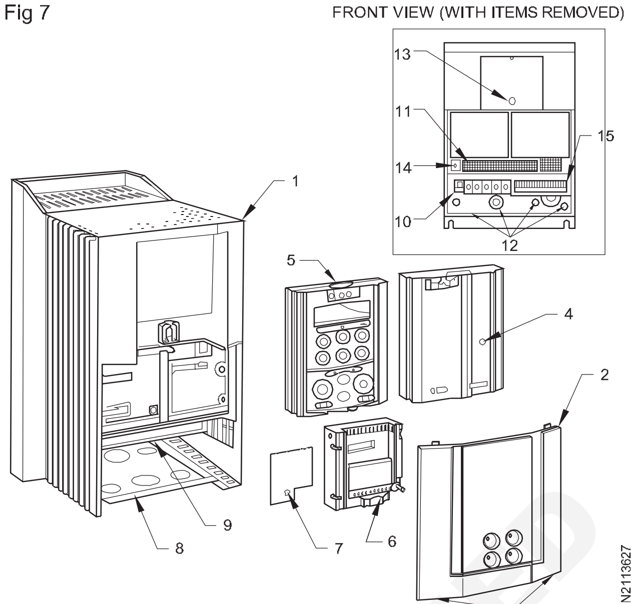
8 Gland plate

9 Power terminal shield

10 Power terminals

11 Control terminals

Fig 7



PARTS OF DC DRIVE

12 Earthing / grounding points

13 Keypad part

14 Programming part

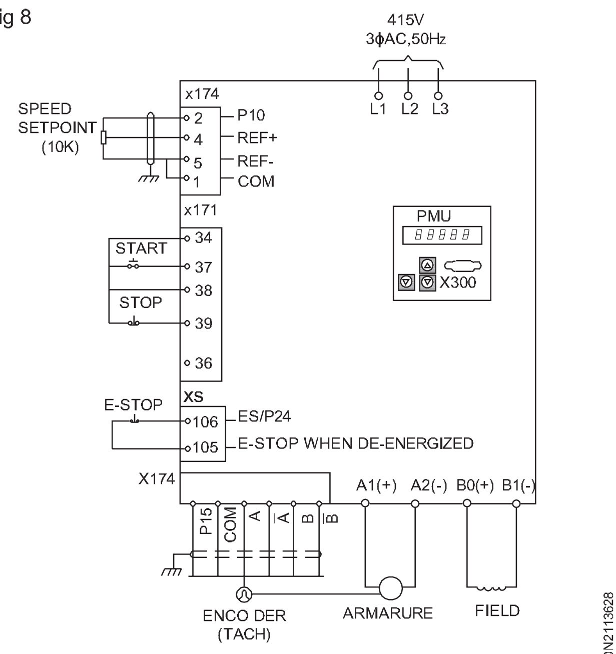
15 Auxiliary power, external contactor, blower and isolated thermistor terminals

Power and control terminals

In DC drive, the front panel has the power terminals L1, L2 and L3 where 3 phase input supply of 415V can be connected.

There are control terminals given for speed adjust potentiometer, Torque adjust potentiometer, START/RUN/ STOP switch, JOG/RUN/ switch, AUTO/MAN switch, FORWARD/REVERSE switch etc. Terminal A1 & A2 and B0 & B1 are meant for armature and field connections respectively. Names and locations are illustrated in Fig 8

Fig 8



CONTROL TERMINALS OF DC DRIVE

Advantages of DC drive

- DC drives are less complex with a single power conversion from AC to DC.
- DC drives are normally less expensive for most horsepower ratings.
- DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose.
- Cooling blowers and inlet air flanges provide cooling air for a wide speed range at constant torque.
- Accessory mounting flanges and kits for mounting feedback tachometers and encoders.
- DC regenerative drives are available for applications requiring continuous regeneration for overhauling loads. AC drives with this capability would be more complex and expensive.
- Properly applied brush and commutator maintenance is minimum.
- DC motors are capable of providing starting and accelerating torques in excess of 400% of rated value.
- Some AC drives may produce audible motor noise which is undesirable in some applications.

Disadvantages of DC drive

- More complicated because of commutators and brushes.
- Heavier than AC motors.
- High maintenance is required.
- Large and more expensive than AC drive.
- Not suitable for high speed operation.

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 - cool and nuclear based**
- **explain schematic arrangement and constituents of thermal, diesel and gas turbine 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.

i Sun : The Sun is the primary source of energy. .Solar cells are the one of the methods which uses the heat energy of the sun to generate the electrical energy in present days. this method came into large application of solar cells to produce electricity. however, than the limitations as:

a It requires a large area for the generation of even a small amount of electric power.

b It cannot be used in cloudy days or at night

c It is an uneconomical method compared to conventional method

ii Wind: This method can be used where wind flows for a considerable length of time. The wind energy is used to run the wind mill which drives a small generator. In order to obtain the electrical energy from a wind mill continuously, the generator is arranged to charge the batteries which supply the energy even the wind stops. This method has the advantages that maintenance and generation costs are negligible. However, drawbacks of the method are that it is unreliable because of uncertainly about wind pressure and power generated is quite small.

iii Water: When water is stored at a suitable place, it possesses potential energy because of the head created. This water energy can be converted into mechanical energy with the help of water turbines. The water turbine drives the alternator which converts mechanical energy into electrical energy. This method of generation of electrical energy has become very popular because it has low production and maintenance costs.

iv Fuels: The main sources of energy are fuels viz. solid fuel as coal, liquid fuel as oil and gas fuel as natural gas. The heat energy of the fuels is converted into mechanical energy by suitable prime movers such as steam engines, steam turbines, internal combustion engines etc. The prime mover drives the alternator which coverts mechanical energy into electrical energy. Although fuels continue to enjoy the place of chief source for the generation of electrical energy, yet their reserves are diminishing day by day. Therefore, the present trend is to harness water power which is more or less a permanent source of power.

v Nuclear energy: Towards the end of Second world War, it was discovered that large amount of heat energy is liberated by the fusion of uranium and other fissionable materials. It is estimated that heat produced by 1 Kg of nuclear fuel is equal to that produced by 27,50,000 kg of coal. The heat produced due to nuclear fission can be utilized to raise steam with suitable arrangements. The steam can run the steam turbine which in turn can drive the alternator to produce the electrical energy.

Comparison of energy sources

The main sources of energy used for the generation of electrical energy are water, fuels and nuclear energy. Below is given their comparison in a tabular form in Table 1.

Table 1

S.No.	Terms	Water Power	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

Solid Fuels

This can further be classified an

a Natural solid fuel

b Artificial solid fuel

The natural solid fuels are wood and different variation of coal, while the artificial solid fuels are charcoal, coke and pulverized fuel.

Liquid Fuels

This can replace coal for the production of steam. The major petroleum products, considered an liquid fuels are the following.

1 Gasoline (Petrol)

2 Kerosene

3 Gas oil

4 Diesel

Gaseous Fuels

This fuel can be divided in the following categories.

1 Natural Gas - It is obtained from soil by mean of dup wells and it is pumped out.

2 Producer Gas - This is a mixture of CO and H_2 with a little CO_2.

3 By product gases - This gas is obtained from blast furnace and coke ovens.

Advantages and disadvantages of liquid fuel

Advantages

i The design and layout of the plant where liquid fuel is used are quite simple and it occupies less space as the number and size of the auxiliaries are small.

ii Liquid fuel plant can be started quickly and can pick up the load in a short time.

iii There are no stand by losses.

iv The overall cost is much less than that of coal.

v The thermal efficiency is higher than that of a coal.

vi If requires less operating staff.

Disadvantages

i The plant where liquid fuel is used has high running cost as the fuel (i.e. diesel) used is costly.

ii The plant can generate only low power.

Advantage and disadvantage of solid fuel :-

Advantages

i The fuel (i.e coal) used in quite cheap.

ii The coal can be transported to the site of plant by rail or road.

iii Solid fuel plant requires less space as compared to the hydro-electric power station.

v The cost is lesser than that of diesel.

Disadvantages

i It pollutes the atmosphere due to the production of large amount of smoke and fumes.

ii It’s handling cost is high.

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

1 Thermal /steam power station

A generating station which converts the heat energy of coal combustion into electrical energy is known as a steam power station.

The scheme of generation can be divided into two phases (i) Formation of steam in the boiler house (ii) Generation of electrical power in the generator room.

In the boiler the fuel is burnt and the water is converted into high pressure steam which is further super heated in a super - heater. The super - heated steam is passed in to the turbine to rotate the turbine blades, thus it converts the heat energy into electrical energy.

The turbine is the generation room acts as a prime mover of the alternator which generates electric energy. The alternator is connected through the circuit breaker to the bus bars.

This type of power station is suitable where coal and water are available in abundance and a large amount of electric power is to be generated.

2 Hydro - electric power station

A generating station which converts the energy posses by the water into the electrical energy is known as hydro-electric power station.

Water is a great source of energy. There are two types of energies which the water can posses. The flowing water in stream may have only kinetic energy. The flowing steam of water may have both kinetic as well as potential energy or simply potential energy at some elevation with respect to a lower datum level. The practical examples of which are water - falls or water stored at the back of a dam. The water stored in the reservoir is allowed to fall on the blades of a water turbine placed at the foot of the dam.

The initial cost of harnessing water and converting the potential energy into electrical energy is quite high but recurring expenses etc. are quite less. So, the overall system will be very economical.

3 Nuclear Power Station

A generating station which converts the nuclear energy into the electric energy is called as nuclear power station.

The nuclear power obtained by nuclear fission is fast entering into arena of energy sources. The heat produced by nuclear fission of atomic material is utilized in special heat exchangers to produce steam to run steam turbines. The atomic materials utilized for nuclear fission are thorium and uranium. Another reason of fast development of nuclear power is that the natural resources of coal and petroleum will exhaust early if the pace of industrial development remained so fast.

4 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.

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 :** The steam power station should be located near the coal mines so that transportation costs of fuel is minimum. However, if such a plant is to be installed at a place where coal is not available, then care should be taken that adequate facilities exists for the transportation of coal.

ii **Availability of water :** As huge amount of water is required for the condenser, therefore, such a plant should be located at the bank of a river or near a canal to ensure the continuous supply of water.

iii **Transportation facilities :** A modern steam power station often requires the transportation of materials and machinery. Therefore, adequate transportation facilities must exist. i.e., the plant should be well connected to other parts of the country by rail, road etc.

iv **Cost and type of land :** The steam power station should be located at a place where land is cheap and further extension, if necessary is possible. Moreover, the bearing capacity of the ground should be adequate so that heavy equipment could be installed.

v **Nearness to load centers:** In order to reduce the transmission cost, the plant should be located near the center of the load. This is particularly important if DC supply system is adopted. However, if AC supply system, is adopted, this factor becomes relatively less important. It is because AC power can be transmitted at high voltages with consequent reduced transmission cost. Therefore, it is possible to install the plant away from the load centers, provided other conditions are favourable.

vi **Distance from populated area :** As huge amount of coal is burnt in a steam power station, therefore, smoke and fumes pollute the surrounding areas. This necessitates that the plant should be located at a considerable distance from the populated areas.

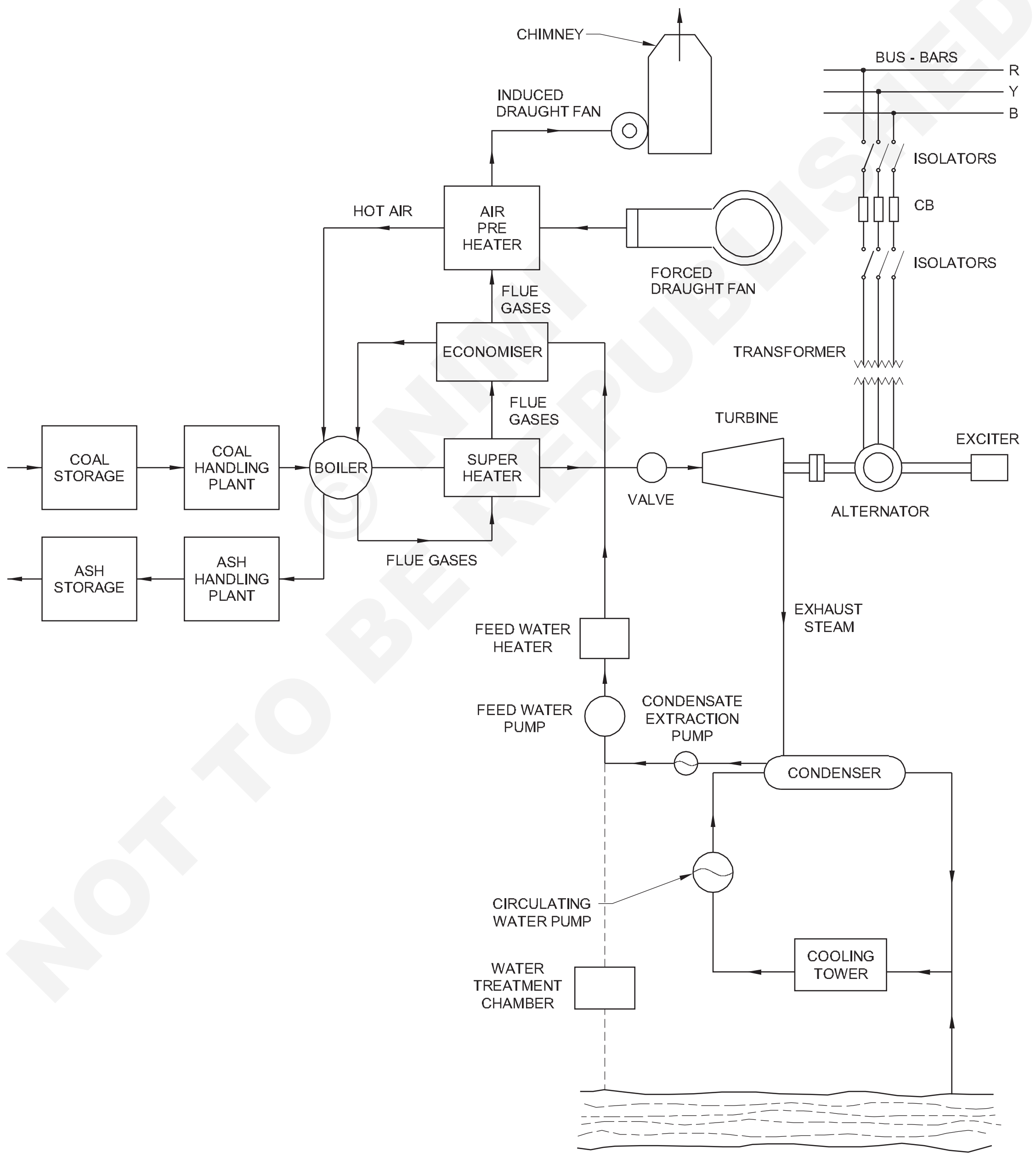
Conclusion : It is clear that all the above factors cannot be favorable at one place. However, keeping in view the fact that now- a -days the supply system in AC and more importance is being given to generation than transmission, a site away from the towns may be selected. In particular, a site by river 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.

1 Coal and ash handling arrangement
2 Steam generating plant
3 Steam turbine
4 Alternator
5 Feed water
6 Cooling arrangement

Fig 1



SCHEMATIC ARRANGEMENT OF STEAM POWER STATION

PD20N2213811

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

In a water tube boiler, water flows through the tubes and the hot gases of combustion flow over these tubes. On the other hand, in a fire tube boiler, the hot products of combustion pass through the tubes surrounded by water. Water tube boilers have a number of advantages over fire tube boilers viz. require less space, smaller size of tubes and drum, high working pressure due to small drum, less liable to explosion etc. Therefore, the use of water tube boilers has become universal in large capacity steam power stations.

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. The boiler furnace walls are made of refractory materials such as fire clay, silica, kaolin etc. These materials have the property to resist change of shape, weight or physical properties at high temperatures.

The size of furnace has to be limited due to space, cost and other considerations. This means that furnace of a large plant should develop more kilo calories per square metre of furnace which implies high furnace temperature.

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. An economizer consists of a large number of closely spaced parallel steel tubes connected by headers of drums. The feed water flows through these tubes and the flue gases flow outside. A part of heat of flue gases is transferred to feed water, thus raising the temperature of the latter.

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. A steam turbine has several advantages over a steam engine as a prime mover viz., high efficiency, simple construction, higher speed, less floor area requirement and low maintenance cost. 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

In an impulse turbine, the steam expands completely in the stationery nozzles (or fixed blades), the pressure over the moving blades remaining constant. In doing so, the steam attains a high velocity and the impulsive force on the moving blades which sets the rotor rotating.

In a reaction turbine, the steam is partially expanded in the stationery nozzles, the remaining expansion take place during its flow over the moving blades. The results is that the momentum of the steam causes a reaction force on the moving blades which sets the rotor in motion.

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

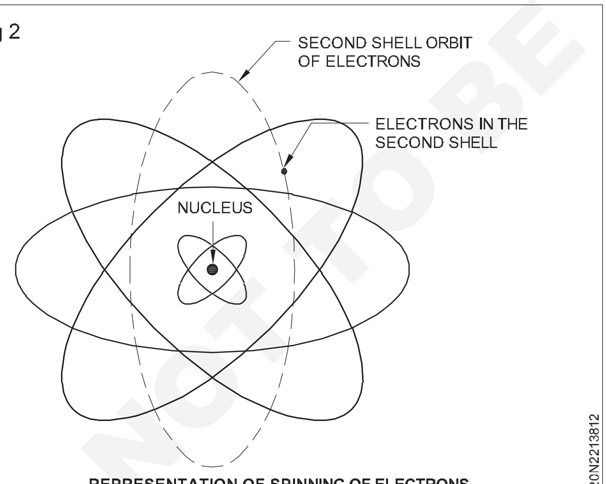
The water from the source of supply is stored in storage tanks. The suspended impurities are removed through sedimentation, coagulation and filtration. Dissolved gases etc, are removed by aeration and de-gasification. The water is then 'softened' by removing temporary and permanent hardness though different chemical processes. The pure and soft water thus available is fed to the boiler for steam generation.

Nuclear based thermal power stations

Composition of an atomic nucleus

A matter is said to be composed of small particles called atoms and the atom itself is composed protons, neutrons and electrons, arranged in a particular fashion. The centre of the atom consists of a very dense nucleus formed by protons and neutrons. Around the nucleus the electrons revolve in orbit. The system so formed is similar to that of planetary system as shown in Fig 2. The radius of the nucleus is about 10^{-12} cm. While that of electron orbit is about 10^{-5} cm.

Fig 2



REPRESENTATION OF SPINNING OF ELECTRONS

The important properties of the atomic structure are:

The mass of proton and neutrons is almost same while the mass of each electron is 1/1840 times that of a proton or neutron which shows that the mass of an atom is only due to the nucleus. From Avogadro's hypothesis, the number of atoms in a gram atom is 6.03 x 10^{23} (actually its mass is 1.008 gm)

$$= \frac{1.008}{6.03 \times 10^{23}}$$

= 1.67 x 10^{-24} gm = 1.67 x 10^{-27} kg................ (1)

The mass of 1 electron

$$= \frac{1.67 \times 10^{-27}}{1840} = 9.10 \times 10^{-31} \text{ kg} ....(2)$$

It has been practically observed that, to deposit 1 molecule gram of hydrogen 96,493.7 coulombs of electricity are required.

So, charge on each electron

$$= \frac{96.493.7}{6.03 \times 10^{23}}$$

= 1.602 x 10^{-19} coulombs .... (3)

The charge of proton is the same as that of electron

= 1.602 x 10^{-19} coulombs .... (4)

The charge and mass of an electron, proton and neutron can be summarized as.

Name of atomic ingredient	Electric charge in coulomb	Mass in kilogram	Mass in atomic mass unit (a.m.u)*
1. Electron	-1.602 x 10^{-19}	9.10x10^{-21}	0.000, 548
2. Proton	+1.602x10^{-19}	1.67x10^{-27}	1.00,758
3. Neutron	0	1.67x10^{-27}	1.00,898

*1 a.m.u = 1.6597 x 10^{-19} kg.

Atomic number and mass number: The chemical properties of an atom depend on the number of protons present in the nucleus.

The atomic number of an atom is defined as the number of protons present in the nucleus of an atom and is represented as Z.

Let, N be equal to number of neutrons in the nucleus. The mass number (A) is given as.

A= Z +N

The advantage of atomic number and mass number is that this represents an atom uniquely. Thus, for example sodium atom is represented as $_{12}Na^{23}$, where, the prefix represents the atomic number (Z) and suffix represents mass number (A), i .e 12 is atomic number and 23 is mass number.

The number of neutron (N) presents in the atom can be determined by

N = A - Z = 23-12

= 11

The atomic number, mass and number of neutrons for some elements are listed in Table 1.

Table 1

Element	Symbol	Atomic number = Z	Mass No =A	Neutrons A - Z
Hydrogen	${}_{1}H_{1}$	1	1	0
Helium	${}_{2}He_{4}$	2	4	2
Oxygen	${}_{8}O_{16}$	8	16	8
Uranium	${}_{92}U_{238}$	92	238	146

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. Although the extracting of the nuclear fuels (i.e Uranium and Thorium) is difficult and expensive, yet the total energy content are considerably higher than those of conventional fuel, viz. coal, and gas.

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 It has low running charges as a small amount of fuel is used for producing bulk electrical energy.

iv This type of plant is very economical for producing bulk electric power.

v It can be located near the load centers because it does not requires large quantities of water and need not be near coal mines. Therefore, the cost of primary distribution is reduced.

vi There are large deposits of nuclear fuels available all over the world. Therefore, such plants can ensure continued supply of electrical energy for thousands of years.

vii 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. Moreover, high salaries of specially trained personnel employed to handle the plant further raise the cost.

vi Nuclear power plants are not well suited for varying loads as the reactor does not respond to the load fluctuations efficiently.

vii 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 3. The whole arrangement can be divided into the following main stages.

i Nuclear reactor

ii Heat exchanger

iii Steam turbine

iv Alternator

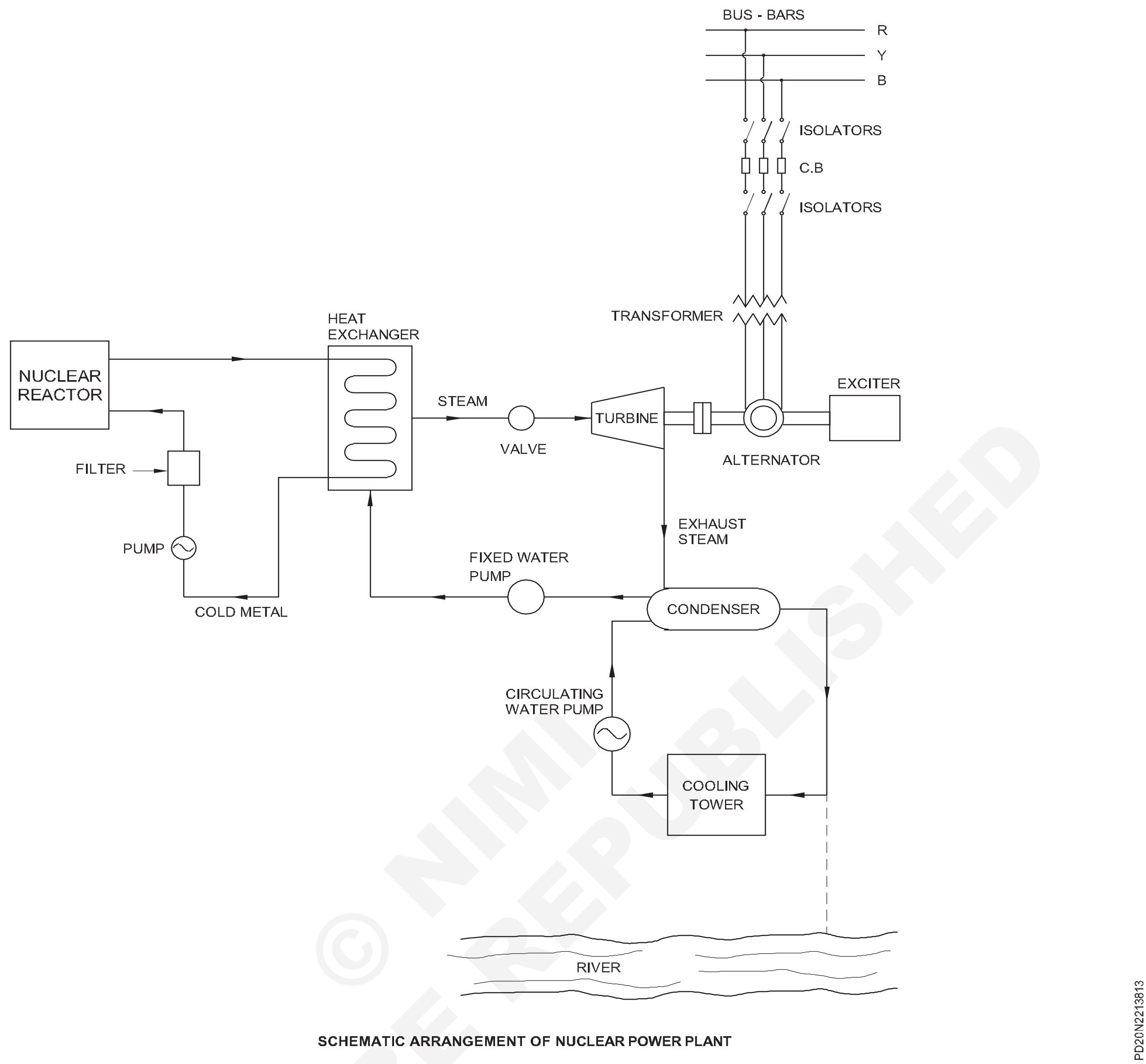
i Nuclear reactor : It is an apparatus in which nuclear fuel (U^{235}) is subjected to nuclear fission. It controls the chain reaction that starts once the fission is done. If the chain reaction is not controlled, the result will be an explosion due to the fast increase in the energy released.

A nuclear reactor is a cylindrical stout pressure vessel and houses fuel rods of Uranium, moderator and control rods (Fig 4).

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.

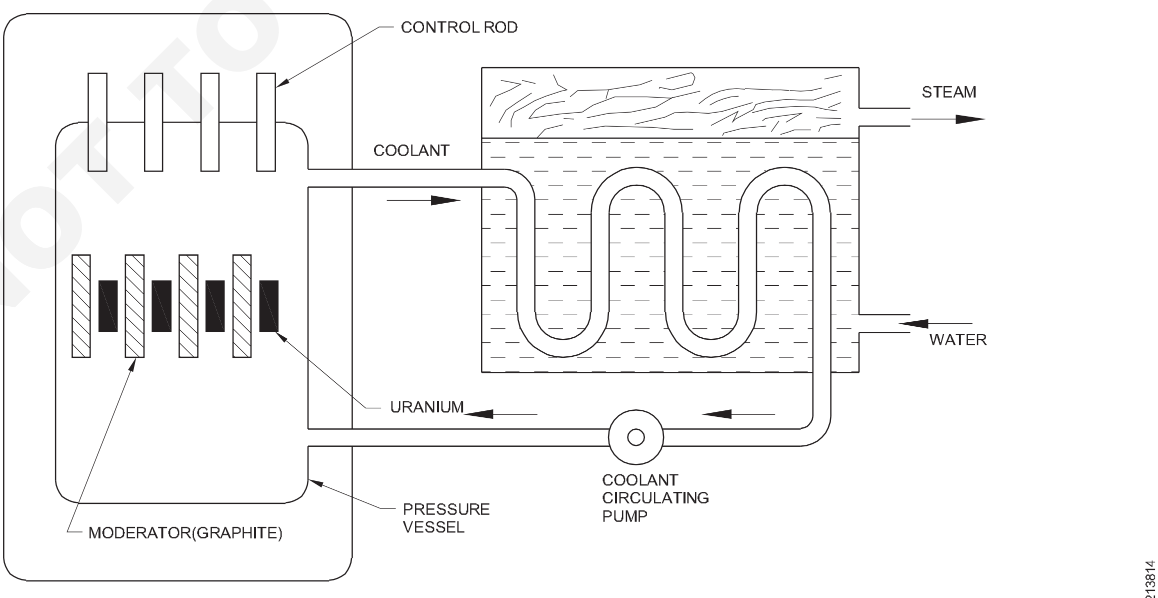
When the control rods are pushed in deep enough, they absorb most of fission neutrons and hence few are available for chain reaction which, therefore, stops. However, as they are being withdrawn, more and more of these fission neutrons cause fission and hence the intensity of chain reaction (or heat 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.

Fig 3



SCHEMATIC ARRANGEMENT OF NUCLEAR POWER PLANT

Fig 4



NUCLEAR REACTOR

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.

Selection of site for nuclear power station

The following points should be kept in view while selecting the site for a nuclear power station.

i **Availability of water :** As sufficient water is required for cooling purposes, therefore, the plant site should be located where ample quantity of water is available e.g. across a river or by sea - side.

ii **Disposal of waste :** The waste produced by fission in a nuclear power station is generally radioactive which must be disposed off properly to avoid health hazards. The waste should either be buried in a deep trench or disposed off in the sea quite away from the sea shore. Therefore, the site selected for such a plant should have adequate arrangement for the disposal of radioactive waste.

iii **Distance from populated areas :** The site selected for a nuclear power station should be quite away from the populated areas as there is a danger of presence of radio - activity in the atmosphere near the plant.

However, as the precautionary measure, a dome is used in the plant which does not allow the radioactivity to spread by wind or underground waterways.

iv **Transportation facilities :** The site selected for a nuclear power should have adequate facilities in order to transport the heavy equipment during erection and to facilitate the movement of the workers employed in the plant.

From the above mentioned factors it becomes apparent that ideal choice for a nuclear power station would be near sea or river and away from thickly populated areas.

Nuclear reactors

Nuclear reactors may be classified on the following basis.

A On the basis of neutron energy

1 Thermal reactors

2 Fast breeder reactors

B On the basis of fuel used

1 Natural uranium

2 Enriched uranium

C On the basis of moderator used

1 Graphite reactors

2 Beryllium reactors

D On the basis of coolant used

1 Water cooled reactors (ordinary or heavy)

i Boiling water reactor

ii Pressurized water reactor

iii Heavy water cooled and moderated reactor

2 Gas cooled reactors

3 Liquid metal cooled reactors

4 Organic liquid cooled reactors

E On the basis of type of core used

1 Homogenous reactors

2 Heterogeneous reactors

Boiling water reactor (BWR)

In this reactor fuel used is enriched uranium. Water is used as both the moderator and coolant. As is clear from its name it utilizes light water as a coolant. In this case the steam is generated in the reactor itself. Feed water enters the reactor tank at the bottom and takes up the heat generated due to the fission of fuel and gets converted into steam.

Steam leaves the reactor at the top and flows into the turbine. Uranium fuel elements are arranged in a particular lattice form inside the pressure vessel containing water. Feed water passes through fuel elements in the core as coolant and also as moderator. Fig 5 shows a boiling water reactor.

Advantages

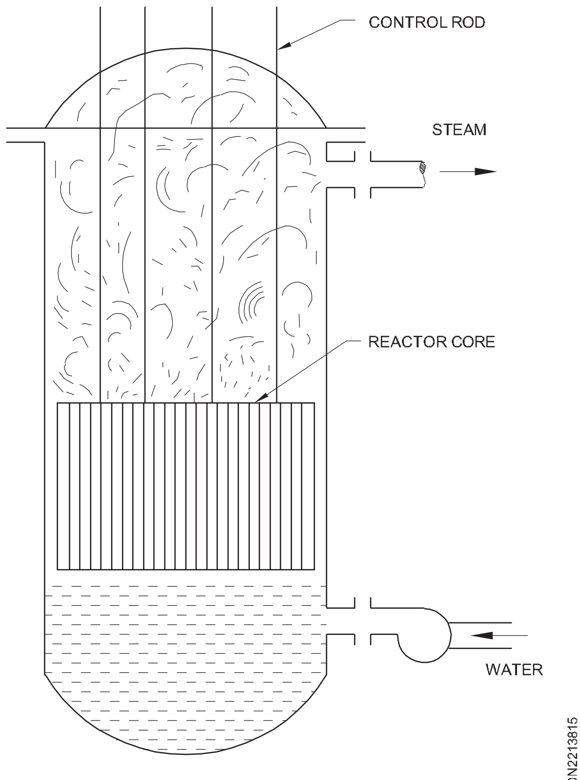
1 Heat exchanger circuit is eliminated and as a result there is reduction in cost and gain in thermal efficiency (30% to 20% for a pressure water reactor (PWR)).

2 As water is allowed to boil inside the reactor the pressure inside the reactor vessel is considerably lower than in the case of a PWR. As a result the reactor vessel can be made much lighter reducing its cost considerably.

3 The BWR cycle is more efficient than the PWR cycle since for a given containment pressure the outlet temperature of steam is appreciably higher in a BWR.

4 The metal surface temperature is lower than in the case of a PWR since boiling of water is inside the reactor.

Fig 5



BOILING WATER REACTOR (BWR)

5 A BWR is more suitable than a PWR, (In fact BWR is commonly known as a self - controlled reactor)

Disadvantages

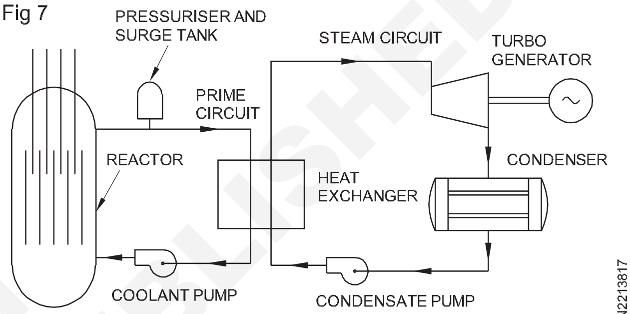
1 There is a possibility of radio - active contamination in the turbine mechanism should there occur any failure of fuel elements. Therefore more elaborate safety measures are needed. This increases the cost.

2 There is wastage of steam resulting in lowering of thermal efficiency on part load operation.

Pressurized Water Reactor (PWR)

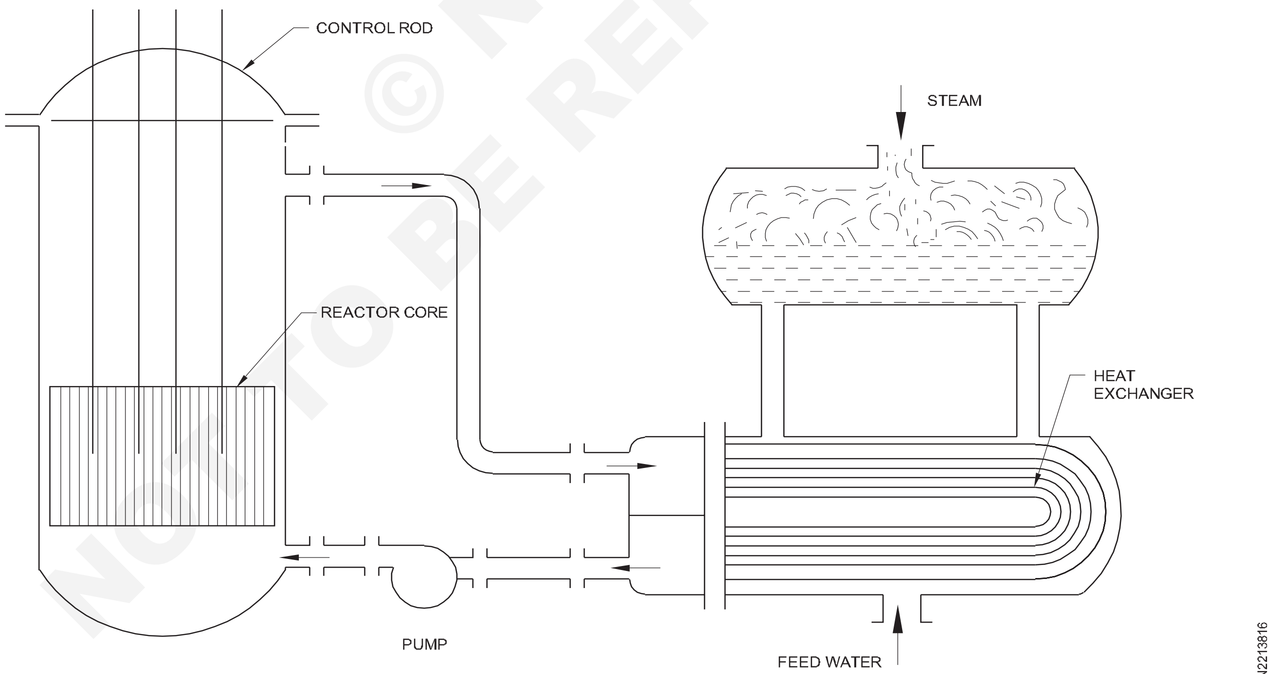
A pressurized water reactor is in Fig 6. The line arrangement of such a reactor with heat exchanger in circuit is in Fig 7.

Fig 7



LINE ARRANGEMENT OF A PRESSURISED WATER REACTOR

Fig 6



A PRESSURISED WATER REACTOR (PWR)

The fuel used is enriched uranium clad with stainless steel or zirconium alloy and water under pressure is used as both moderator and coolant. This type of reactor is designed to prevent the boiling of the water coolant in the uranium core. A pump circulates water at high pressure (as high as 140 Kg/cm^2) round the core so that water in liquid state absorbs heat from the uranium and transfer it to the secondary loop-the boiler. The boiler has a heat exchanger and a steam drum.

A pressuriser and surge tank tapped into the pipe loop maintains constant pressure in the water system throughout the load range. An electric heating coil in the pressuriser boils the water to form steam which is collected in the dome; this steam pressurizes the entire coolant circuit. Water spray is used to condense the steam when pressure is desired to be reduced.

Since water is passing through the reactor becomes radio - active the entire primary circuit including heat exchanger has to be shielded.

Advantages

1 A PWR is relatively compact in size compared with other types.

2 There is a possibility of breeding plutonium by providing a blanket of U-238.

3 The reactor has a high power density.

4 Due to use of heat exchanger containment of fission products is possible.

5 An inexpensive substance (light water) can be used as moderator - cum-coolant-cum-refractor.

6 The reactor responds to supply more power when the load increases. (The positive power demand co-efficient makes this almost automatic)

Disadvantages

1 The moderator remains under high pressure; a strong pressure vessel is required.

2 Expensive cladding material is required to prevent corrosion.

3 There is heat loss due to use of heat exchanger.

4 In comparison to other types more elaborate safety devices are required.

5 The reactor lacks flexibility; this requires the reactor to be shut down before recharging and there is difficulty in fuel element design and fabrication.

6 The thermal efficiency of a PWR is as low as 20%

Less compared with that required for PWRs and BWRs. Amongst disadvantages are : the extremely high cost of heavy water, problem of leakage and very high standard of design etc.

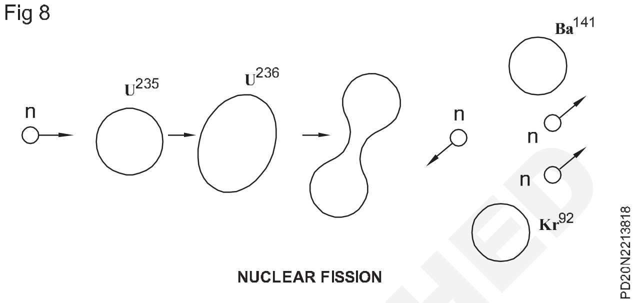
Nuclear fission and fusion

Nuclear fission : When an uranium nucleus is bombarded with a slow moving neutron, it exploded into two nearly equal fragments of Barium and Krypton.

The process of breaking up of the nucleus of a heavy atom into two fragments with the release of large amount of energy is known as fission. The fission is accompanied by the release of three neutrons and energy in the form of γ-rays.

Fig 8 shows that the compound nucleus undergoes distortion due to the excitation energy to attain the shape of a dumb-bell and finally splits up into fission products Ba^{141} and Kr^{92} with the release of three neutrons.

Fig 8



It was observed that Barium and krypton were not the only products of fission, the isotopes of different elements in the atomic number range from 34 to 58 were also obtained as the fission products.

Chain reaction

The process of nuclear fission usually results in the emission of two or three free neutrons per fission besides the other fission fragments.

When $_{92}U^{235}$ nucleus splits up, it generally release three neutrons. One of the neutrons may escape without hitting any other uranium nucleus and thus get lost. The other two may strike against other fissionable nuclei to produce further fission, accompanied by the release of still more neutrons and so on. Thus more than one neutron per fission is produced on the average.

The number of fissions taking place at each successive stage goes on increasing at a rapid rate, giving rise to what is called chain reaction. A chain reaction can be set up only if the mass of the fissionable material is greater than a critical mass.

Hydel power plants

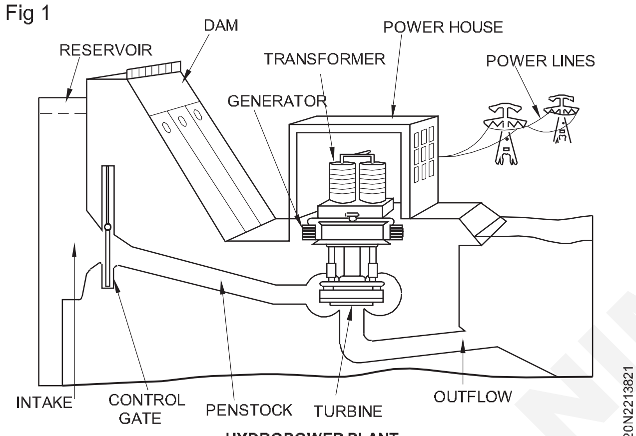
Objectives: At the end of this lesson you shall be able to
- **state the types of hydro- electric power station**
- **state the advantage & disadvantage of hydro electric power station over thermal power station**
- **list out the reason for selecting the site of a hydro electric power station**
- **explain the schematic arrangement of hydro electric power station**
- **state the turbines used in hydro electric power station with suitable reasons**
- **state the classification of hydro electric power station.**

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.E.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 requires no fuel as water is used for the generation of electrical energy

ii It is quite neat and clean as no smoke or ash is produced

iii It requires very small running charges because water is the source of energy which is available free cost.

iv It is comparatively simple in construction and requires less maintenance.

v It does not requires a long starting time like a steam power station. In fact, such plants can be put into service instantly.

vi It is robust and has a longer life.

vii Such plants serve many purposes. In addition to the generation of electrical energy, they also help in irrigation and controlling floods.

viii Although such plants require the attention of highly skilled persons at the time of construction, yet for operation, a few experienced persons may do the job well.

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.

Choice of site for hydro - electric power stations

The following points should be taken into account while selecting the site for a hydro - electric power station

i Availability of water : Since the primary requirement of a hydro - electric power stations is the availability of huge quantity of water, such plants should be built at a place (e.g. river, canal) where adequate water is available at the good head.

ii Storage of water : There are wide variations in water supply from a river or canal during the year. This makes it necessary to store water by constructing a dam in order to ensure the generation of power throughout the year.

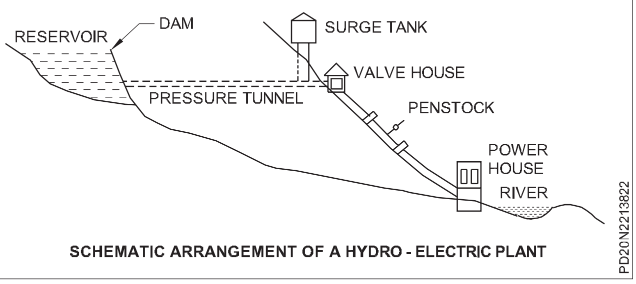
iii Cost and type of land : The land for the construction of the plant should be available at a reasonable price. Further, the bearing capacity of the ground should be adequate to withstands the weight of heavy equipment to be installed.

vi Transportation facilities : The site selected for hydro - electric plant should be accessible by rail and road so that necessary equipment and machinery could be easily transported

Schematic arrangement of hydro - electric power station : (Fig 2)

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.

Fig 2



SCHEMATIC ARRANGEMENT OF A HYDRO - ELECTRIC PLANT

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. Dams are built of concrete or stone masonry, earth or rock fill. The type and arrangement depends upon the topography of the site. The type of dam also depends upon the foundation conditions, local materials and transportation available, occurrence of earthquakes and other hazards.

ii **Spillways :** There are times when the river flow exceeds the storage capacity of the reservoir. Such a situation arises during heavy rainfall in the catchment area. In order 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. They generally include booms and racks for diverting floating debris, sluices for by - passing the debris and sediments and valves for controlling the flow of water to the turbine. The flow of water into and through head works should be as smooth as possible to avoid the head loss and cavitation. For this purpose, it is necessary to avoid sharp corners and abrupt contractions or enlargements.

iv **Surge tank :** Open conduits which leading the water to the turbine require no protection. However, when closed conduits are used, protection becomes necessary to limit the abnormal pressure in the conduit. For this reason, closed conduits are always provided with a surge tank. a 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.

A surge tank is located near the beginning of the conduit. When the turbine is running at a steady load, there are no surges in the flow of water through the conduit is just sufficient to meet the turbine requirements. However, when the load on the turbine decreases, the governor closes the gates of turbine, reducing water supply to the turbine.

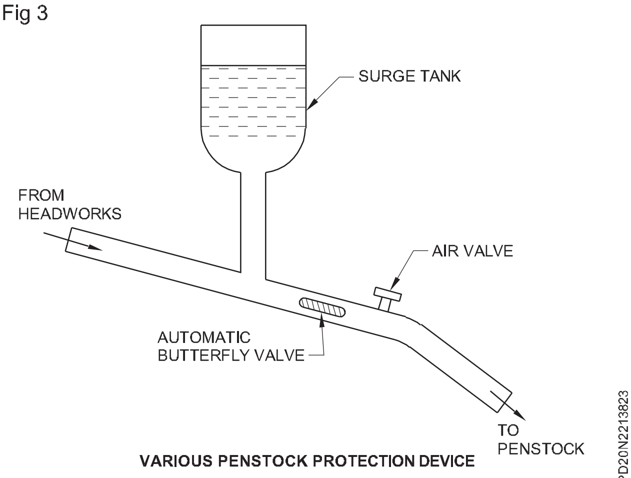
The excess water at the lower end of the conduit rushes back to the surge tank and increases its water level. Thus the conduit is prevented from bursting. On the other hand, when load on the turbine increases, additional water is drawn from the surge tank to meet the increased load requirement. Hence, a surge tank overcomes the abnormal pressure in the conduit when load on the turbine falls and acts a reservoir during increase of load on the turbine.

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

Various devices such as automatic butterfly valve, air valve and surge tank are provided for the protection of penstocks. Automatic butterfly valve shuts off water flow through the penstocks promptly of its ruptures. Air valve maintains the air pressure inside the penstock equal to outside atmospheric pressure.

When water run out of a penstock faster than it enters, a vacuum is created which may cause the penstocks to collapse. Under such situations, air valve opens and admits air in the penstock to maintain inside air pressure equal to the outside air 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. It may be the natural stream channel or a specially excavated channel entering the natural stream at some point down stream from the power house. The water surface in the tail race is known as tail race level or simply the tail race.

vii **Draft tube :** In the case of a reaction turbine there is a pressure difference existing between water in the turbine and atmosphere. Therefore this type turbine must be completely enclosed. Accordingly it is necessary to connect the turbine outlet by means of a pipe or a passage of gradually increasing cross sectional area up to tail - race level.

A draft tube has two important purposes to serve.

1 It permits a negative or suction head to be established at the runner exit thus making it possible to install the turbine above the tail race level without loss of head.

2 It converts a large proportion of the velocity energy rejected from the runner into useful pressure head i.e it acts as a recuperator of pressure energy.

2 Water turbine

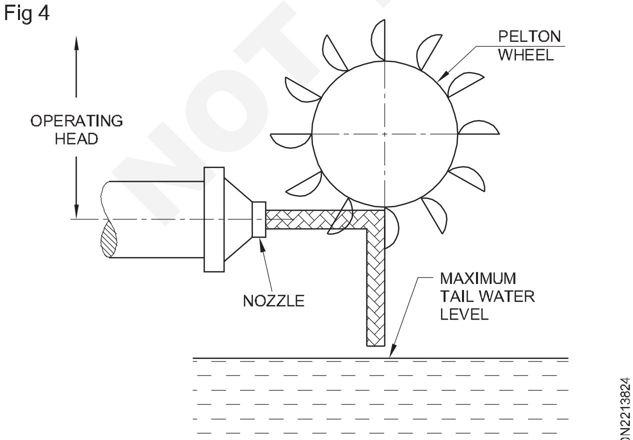
Water turbines are used to convert the energy of falling water into mechanical energy. The principal types of water turbines are :

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.

ii Reaction turbines : Reaction turbines are used for low and medium heads. In a reaction turbine water enters the runner partly with pressure energy and partly with velocity head. The important types of reaction turbine are.

a Francis turbines

b Kaplan turbines

A fancies turbine is used for low to medium heads. It consists of an outer ring of stationary guide blades for to the turbine casing and an inner ring of rotating blade forming the runner. The guide blades control the flow water to the turbine. Water flows radically inwards and changes to a downward direction while passing there the runner. As the water passes over the rotating blade of the runner, both pressures and velocity of water reduced. This causes a reaction force which drive turbine.

A Kaplan turbine is used for low heads and large quantities of water. It is similar to Francis turbine except that the runner of Kaplan turbine receives water axially. Water radially inwards through regulating gates all round sides, changing direction in the runner to axial flow causes a reaction force which drives the turbine.

3 Electrical equipment

The electrical equipment of a hydro - electric power includes alternators, transformers, circuit breaker and switching and protective devices.

Types of hydro - electric plants

There are three different methods of classifying the electric plants. The classification may be based on,

a Quantity of water available

b Available head

c Nature of load

Classification of Hydro - electric plants according to quantity of water available.

According to this classification, the plants may be divided into.

i Run - off river plants without pondage

ii Run - off river plants with pondage

iii Reservoir plants

i Run off river plants without pondage

As the name indicates this type of plant does not store water. The plant uses water as it comes. The plant can use water only as and when available.

ii Run- off river plants with pondage

Usefulness of a run - off river plant is increased by pondage. Pondage permits storage of water during the off - peak periods and use of this water during the peak periods.

iii Reservoir plants

Water is stored behind the dam and is available to the plant with control as required. Such a plant has better capacity and can be used efficiently throughout the year.

Classification of hydro - electric plants according to available head

Hydro - electric plants may be classified into high - head, medium - head and low head plants. A plant may be classified as high - head if operating on a head above 300 meters. Low - head plants work under heads below 30 metres. Medium - head plants are those lying between the above two classes.

In the case of high - head plants water in due to rains or melting of snow is stored at high elevation. A low - head plant stores water by the construction of a dam across a river and the power plant is installed near the base of the dam of the down - stream side. The medium - head plant is similar to the low - head plant but works on a head of about 30 to 300 m.

Classification of Hydro- electric plants according to nature of load

Hydro - electric plants may be classified in to base load peak load and pumped storage plants for peak load.

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, bio-gas, micro-hydel, tidal, magnetic hydro dynamic power generation**
- **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.

Merits of non-conventional 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 Never destroyed

6 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.

7 Green house effect and global warming is avoided

8 Less environment problems.

Demerits of non-conventional over conventional sources of energy

1 Many non- conventional sources are still in their infant stages and required a lot of development efforts. The use of solar energy is a completely a very gentle / minutes operation. Cadmium is used in fabricating thin film solar cells, which is both poisonous and radio active.

  But it is very small quantity of cadmium is released from discarded PV panels, Carbon dioxide produced while forming silicon from silica increases atmospheric temperature.

2 High initial cost

3 Less reliable and efficiency

4 Can not be used for base load demand.

Bio-gas power generation

The method of generating the electrical energy by using bio-gas is termed as bio-gas power generation.

Bio-gas

Bio-gas is a good fuel. Bio mass like animal excreta, vegetable wastes and seeds undergo decomposition in the absence of oxygen in a bio-gas plant and form a mixture of gases. This mixture is the **bio-gas**. Its main constituent is methane. This is used as a fuel for cooking and lighting.

Aerobic and anaerobic bio- conversion process

There are mainly three aerobic and anaerobic bio-conversion process for the biomass energy applications. There are;

Bio-products : Converting biomass into chemicals for making products that typically are made from petroleum.

Bio-fuels : Converting biomass into liquid fuels for transportation.

Bio-power : Burning biomass directly, or converting it into a gaseous fuel or oil, to generate electricity.

Properties of biogas

Main properties of biogas are :

1 Comparatively simple and can be produced easily.

2 Burns without smoke and does not leave any ash as residues.

3 Household wastes and bio-wastes can be disposed off, usefully and in a healthy manner.

4 Reduces the use of wood and to a certain extent prevents deforestation.

5 The slurry from the bio-gas plant is excellent manure.

Bio-gas plant technology & status

The important parts of bio-gas plant are :

1 The tank where biomass undergoes decomposition (digester)

2 The tank where biomass is mixed with water (mixing tank)

3 The tank where slurry of biomass is collected (out flow tank)

4 Arrangement to store gas.

Due to the action of bacteria in the absence of oxygen, bio-gas is produced in the plant. This is collected in the tank. In the gasholder type plant, the cylinder rises up as the gas fills the tank and the storage capacity increases. The gas storage capacity of dome type will be less than that of gasholder type. Residue of biomass (slurry) can be used as good manure.

Bio-gas plants are built in several sizes, small (0.5 m^3/day) to very large (2500 m^3/day). Accordingly, the configurations are simple to complex.

Bio-gas plants are mainly classified into following two types.

- Continuous type and batch type
- Drum type and dome type

Continuous type

Continuous type bio-gas plant delivers the bio-gas continuously and is fed with the biomass regularly. Continuous type bio-gas plant is of two types.

(A) Single stage continuous type bio-gas plant

In such a plant phase - I (Acid formation) and phase -II (methanation) are carried out in the same chamber without barrier. Such plants are simple, economical, easy to operate and control. These plants are generally preferred for small and medium size bio-gas plants. Single stage plants have lesser rate of gas production than the two stage plant.

(B) Two stage continuous type bio-gas plant

In such a plant phase - I (Acid formation) and phase -II (methane formation) take place in separate chambers. The plant produces more bio-gas in the given time than the single stage plant. However, the process is complex and the plant is costlier, difficult to operate and maintain. Two stage plant is preferred for larger bio-gas plant systems.

Batch type bio-gas plant

The infeed biomass is fed in batches with large time interval between two consecutive batches. One batch of biomass infeed is given sufficient retention time in the digester (30 to 50 days). After completion of the digestion, the residue is emptied and the fresh charge is fed. The fresh biomass charge may be subjected - to aeration or nitrogenation after feeding and then the digester covers are closed for the digestion process. Thereafter, the biogas is derived from the digester after 10 to 15 days. Fermentation continues for 30 to 50 days.

Salient features

1 Batch type biogas plant delivers gas intermittently and not continuously.

2 Batch type biogas plant may have several digesters (reactors) which are fed in a sequential manner and discharged in a sequential manner to obtain the output biogas continuously.

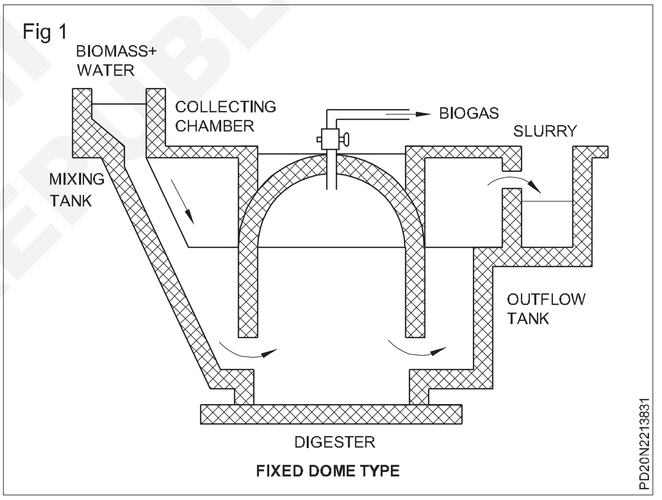
3 Batch type biogas plants have longer digestion time and are therefore more suitable for materials which are difficult for anaerobic digestion (e.g. harder, fibrous biomass).

4 Batch type biogas plant needs initial seeding to start the anaerobic fermentation.

5 Batch type biogas plant needs larger volume of the digester to accommodate larger volume of the batch. Hence initial cost is higher.

6 Operation and maintenance is relatively more complex. Batch type biomass plants need well organized and planned feeding. Such plants are preferred by European farmers. Such plants are not yet popular in India.

Fixed dome type digester (Fig 1)



In the fixed dome type digester biogas plant, the digester and gas collector (gas dome) are enclosed in the same chamber. This type of construction is suitable for batch type biogas plant. The digester is conveniently built at or below ground level in comparatively cooler zone. The construction of the digester is with locally available materials like, bricks, terracotta.

The pressure inside the digester increases as the biogas is liberated. The biogas gets collected in the upper portion of the digester in a dome shaped cavity. The outlet pipe is provided at the top of the fixed dome. Alternatively, the gas collector (gas holder) is a separately installed chamber. The digester tank and gas collector chamber are separated by a water seal tank.

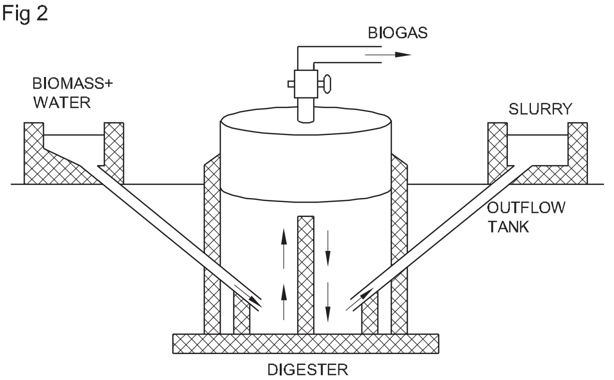
The arrangement of a separate gas collector is preferred as the tapping of gas from the gas holder does not affect the pressure and the digestion process in the main digester. The water seal tank prevents the return of the gas from the gas collector to the digester chamber.

An additional displacement chamber may be provided for providing space to the displacement slurry in the digester, due to gas pressure in the upper dome of the fixed type digester. The fixed dome type digester can be fed on daily basis with small quantities of the slurry. The excess slurry in the digester gets accommodated in the displacement chamber.

The level of the slurry in the main digester and the displacement collector can vary in accordance with the pressure and volume of the bio-gas in the fixed type of dome. The pressure in the fixed dome and the displacement gas collector are almost the same as they are connected by the outlet from the main digester.

Floating gas holder type (Fig 2)

Fig 2



FLOATING GAS HOLDER TYPE

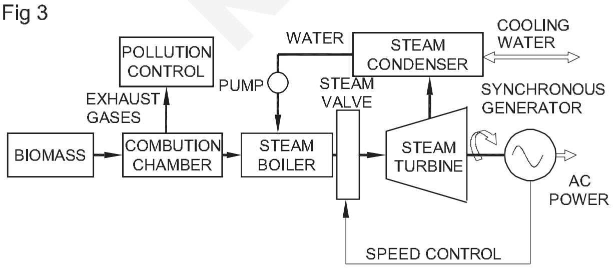
In this design a dome made floats above the slurry in the disaster. In the Fig 2 the digester tank is of cylindrical masonry construction. The floating dome is of fabricated steel construction. The dome guide shaft provides the axial guide to the floating dome.

As the gas is collected in it, the sliding bearing provides smooth sliding surface and guide to the floating dome. The gas generated in the slurry gets collected in the dome and the dome arises. The water seal tank provides separation between the gas in the dome and the outlet gas.

Electricity generating plant

Generating plant fuelled by biomass uses conventional steam turbine as used in thermal power stations with modifications to the combustion chamber and fuel handling systems to handle the bulkier fuel. The schematic arrangement is in Fig 3.

Fig 3



ELECTRICITY GENERATION POWERED BY BIOMASS

Co - generation

Because of the poor energy conversion efficiencies of biomass fuels, practical generating systems often employ a co-coal generation to achieve reasonable utilization of the generating plant.

Environmental issues

While biomass crops provide an environment friendly fuel source for generating electrical energy. The land used for disposing the slurry (waste) may be better employed for cultivation.

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

It only takes a small flow rate of water (as little as two gallons per minute) or a head as low as two feet to generate the electricity with micro hydro.

b Reliable electricity source

Hydro produces a continuous supply of electrical energy in comparison to other small - scale renewable technologies. The peak energy season is during the winter months when the large quantities of electricity are required.

c No reservoir required

Microhydro is considered to function as a ‘run- of-river’ system, meaning that the water passing through the generator is directed back into the stream with relatively little impact on the surrounding ecology.

d Cost effective energy solution

Building a small -scale hydro - power system can cost less amount depending on site electricity requirements and location. Maintenance cost are relatively small in comparison to other technologies.

e Power for developing countries

Because of the low-cost versatility micro hydro, the developing countries can adopt and implement the technology to help supply much needed electricity to small communities and villages.

f Integrate with the local power grid

If your site produces a large amount of excess energy, some power companies will buy back your electricity overflow.

g Suitable site characteristic required

In order to take full advantage of the electrical potential of small streams, a suitable site is needed. Factors to consider are; distance from the power source to the location where energy is required, stream size (including flow rate, output and head), inverter, batteries, controller, transmission line and pipelines.

Disadvantages

a Energy expansion not possible

The size and flow of small streams may restrict the future site expansion as the power demand increases.

b Low - power in the summer months

In many locations stream size will fluctuate seasonally. During the summer months there will likely be less flow and therefore less power output. Advanced planning and research will be needed to ensure adequate energy requirements are met.

c Environmental impact

The ecological impact of small - scale hydro should be minimal. Stream water will be diverted away from a portion of the stream, and proper caution must be exercised to ensure there will be no damaging impact on the local ecology or civil infrastructure.

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. Effectively getting the water into the system's pipe line is a critical issue that often does not get enough attention. Poorly designed intake often become the focus of maintenance and repair effort for hydro- electric systems.

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. The pipeline's diameter may range from 1 inch to 1 foot or more, and must be large enough to handle the design flow. Losses due to friction need to be minimized to maximize the energy available for conversion into electricity.

Turbine

The turbine converts the energy in the water into electricity. Many types of turbines are available, so it is important to match the machine to the site's conditions of head and flow.

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. Controllers generally send excess energy to a secondary (dump) load, such as an air or water heater. Unlike a solar - electric controller, a micro hydro system controller does not disconnect the turbine from the batteries. This could create voltages that are higher than some components can withstand, or cause the turbine to over speed, which could result in dangerous and damaging over voltages.

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. When demand increases beyond what is generated, the batteries can be called on to release the energy to keep your household loads operating.

Metering

System meters measure and display several different aspects of micro hydro - 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. Battery- based inverters for off -grid or grid - tied systems often include a battery charger, which is capable of charging a battery bank from either the grid or a backup generator.

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.

Tidal power generation

Objectives: At the end of this lesson you shall be able to
- **explain the features of tidal power generation**
- **state the system on which the tidal power generation works**
- **state the advantages and disadvantages of tidal power generation.**

The generation of electricity using tidal power is termed as tidal power generation. It is basically the transformation of tidal power found in tidal motion of water in seas and oceans into electrical energy.

Tidal power

Tidal power is the power inherent in tides at sea or oceans, that is power of motion of water actuated by tides. Tides are defined as the increase and decrease in water levels due to the motion of water from one place to the other. Thus there is a renewable source of energy in the tidal motion of water at seas and oceans. This source of energy could be used to generate other types of energy that could be useful in industrial applications.

This is done using a very basic idea involving the use of a barrage or small dam built at the entrance of a bay where tides are known to reach very high levels of variation. This barrage will trap tidal water behind it creating a difference in water level, which will in turn create potential energy.

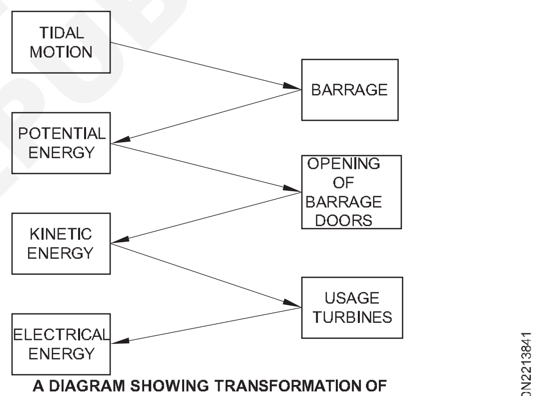
This potential energy will then be used in creating kinetic energy as doors in the barrage are opened and the water rush from the high level to the lower level. This kinetic energy will be converted into rotational kinetic energy that will rotate turbines giving electrical energy. Fig 1 shows the process in very simple terms.

Physical concepts of the tidal phenomena

Tidal movements in seas are due to the increase of water levels at certain areas in the globe and the decrease of water levels at other areas. This is basically due to two factors.

1 The gravitational forces between the Sun, Moon and Earth.

Fig 1



A DIAGRAM SHOWING TRANSFORMATION OF TIDAL ENERGY TO ELETRICAL ENERGY

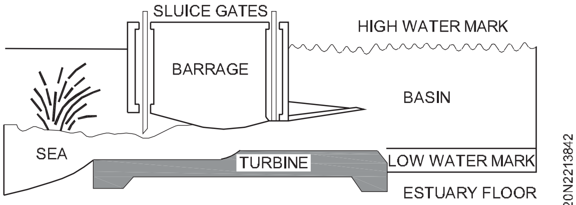
2 The rotation of the moon and earth.

As there are gravitational forces between the moon and the earth, seas or oceans water is pulled away from earth toward the moon at the area where the moon and the earth are in front of each other. At the opposite side of the earth the water is being pushed away from the earth due to centrifugal forces. Thus there are two areas where the water levels are high and other areas where the water level is low. Thus, the tidal motion of water is created. This is called the **lunar tide**.

Working of tidal power generation system

In very simple terms a barrage is built at the entrance of a gulf and the water levels vary on both sides of the small dam. Passages are made inside the dam and water flows through these passage and turbines rotate due to this flow of water under head of water. Thus, electricity is created using the turbines. A general diagram of the system is in (Fig 2)

Fig 2



GENERAL SCHEME OF THE TIDEL POWER STATION

The components of a tidal power station are :

1 **A barrage :** a barrage is a small wall built at the entrance of a gulf in order to trap water behind it. It will either trap it by keeping it from going into the gulf when water levels at the sea are high or it will keep water from going into the sea when water level at the sea is low.

2 **Turbines :** They are the components responsible for converting potential energy into kinetic energy. They are located in the passage ways that the water flows through when gates of barrage are opened.

3 **Sluices :** Sluice gates are the ones responsible for the flow of water through the barrage they could be seen Fig 2.

4 **Embankments :** They are caissons made out of concrete to prevent water from flowing at certain parts of the dam and to help maintenance work and electrical wiring to be connected or used to move equipment or cars over it.

The following is a list of different methods of obtaining power from tidal power stations.

1 Ebb method

1st - Water starts to ebb or go toward the sea

2nd - The gates are left closed keeping the water trapped in basin to increase its level.

3rd - Then water is released out toward the sea rotating turbines creating electrical energy.

2 Flood method

1st - Water is let into the basin when it is empty

2nd - As the turbines are rotated and the electrical energy is created.

3 Ebb plus pumping method

1st- The turbines are operated as pumps and pumping the water into the basin at the flood period.

2nd - The water level in the basin is increased and creating greater head.

3rd - At the ebb phase the water is let out of the basin, creating energy for longer time than usual due to be increased head.

4 Two way power generation

1st - Starting with the basin full, the gates are opened, letting water flow out and generating energy.

2nd - The turbines are reversed as the flow will be reversed

3rd - The gates are closed when the flood period or cycle starts.

4th - Water starts to build up behind the dam.

5th - When a sufficient head is achieved, the gates are opened to start the flood generation cycle as the water flows into the basin.

5 Two basin generation method

1st - Two basins are built one called a high - level basin and the other is the low - level basin .

2nd - The turbines are placed in the wall dividing the two basins.

3rd - The high level basin is filled at high tide or flood period.

4th - Then the low - level basin is filled through the turbines from the high level basin.

5th - The low level basin is emptied at low tide ebb period.

Advantages of tidal power generation

There are many advantages of generating power from the tide; some of them are listed below.

- Tidal power is a renewable and sustainable energy resource.
- It reduces dependence upon fossil fuels.
- It produces no liquid or solid pollution.
- It has little visual impact.
- Tidal power exists on a world wide scale from deep ocean waters.
- It offers short time scale between investing in the modular construction and benefiting from the revenue.
- Tidally driven coastal currents provide an energy density four times greater than air, meaning that a 15-m diameter turbine will generate as much energy as a 60m - diameter windmill.
- Tidal currents are both predictable and reliable, a feature which gives them an advantage over both wind and solar systems. Power outputs can be accurately calculated far in advance, allowing for easy integration with existing electricity grids.
- The tidal turbine offers significant environment advantages over wind and solar systems; the majority of the assembly is hidden below the water line and all cabling is along the sea bed.
- Sea water is 832 times as dense as air; therefore the kinetic energy available from a 5-knot ocean current is equivalent to a wind velocity of 270 km/h.

Disadvantages and constraint to tidal power generation

Unfortunately, there are also disadvantages and limitations to generating tidal power. Some of these are;

- At the present time both tide and wave energy are suffering from orientation problems, in the sense that neither method is strictly economical (except in few locations throughout the world) on a large scale in comparison with conventional power sources.
- Tidal power systems do not generate electricity at a steady rate and thus not necessarily at times of peak demand, so unless a way can be found of storing energy efficiently - and any storage devices currently available incur a considerable loss - they would not help in reducing the overall need for fossil power stations, but only allow them to run at a lower rating for a certain amount of the time.
- Tidal fences could present some difficulty to migrating fish.

Magneto hydro dynamic (MHD) power generation

Objectives: At the end of this lesson you shall be able to
- **explain the features of magneto hydro dynamic power generation (MHD)**
- **state and explain the system components of MHD power generation**
- **state the advantages of MHD power generation.**

Magneto hydro dynamic power generation

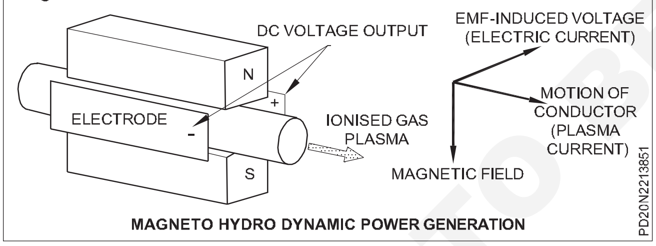
The way of generating electricity directly from a fast moving stream of ionised gases without the need for any moving mechanical parts - no rotating turbines and generators is termed as magneto hydrodynamic power generation.

MHD power generation has also been studied as a method for extracting electrical power from nuclear reactors and also from more conventional fuel combustion systems.

Working principle

Fig 1 explains the principle of operations of MHD. The MHD generator can be considered to be a fluid dynamo. This is similar to a mechanical dynamo in which the motion of a metal conductor through a magnetic field creates a current in the conductor where as in the MHD generator the metal conductor is replaced by a conducting gas plasma.

Fig 1



MAGNETO HYDRO DYNAMIC POWER GENERATION

The flow (motion) of the conducting plasma through a magnetic field causes a voltage to be generated (and an associated current to flow) across the plasma, perpendicular to both the plasma flow and the magnetic field according to Fleming's Right Hand Rule.

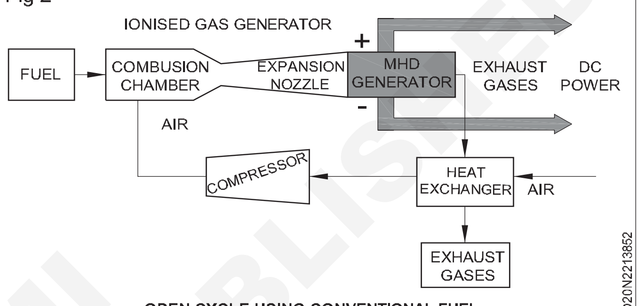
The MHD system

The MHD generator needs a high temperature gas source, which could be the coolant from a nuclear reactor or more likely high temperature combustion gases generated by burning fossil fuels, including coal, in a combustion chamber. The Fig 2 shows the components of this system.

Expansion nozzle

It reduces the gas pressure and consequently increases the plasma speed (Bernoulli's Law) through the generator duct to increase the power output. At the same time, the pressure drop causes the plasma temperature to fall (Gay-Lussac's Law) which also increases the plasma resistance, so a compromise between Bernoulli and Gay-Lussac must be found. The exhaust heat from the working fluid is used to drive a compressor to increase the fuel combustion rate but much of the heat will be wasted unless it can be used in another process.

Fig 2



OPEN CYCLE USING CONVENTIONAL FUEL

The plasma

The prime MHD system requirement is creating and managing the conducting gas plasma since the system depends on the plasma having a high electrical conductivity. The plasma can be the fourth state of matter after the solid, liquid and gaseous states, in which the atoms or molecules are stripped of their electrons leaving positively charged ions. Suitable working fluids are gases which derived from combustion, noble gases and alkali metal vapours.

The gas plasma

To achieve high conductivity, the gas must be ionised by detaching the electrons from the atoms or molecules leaving the positively charged plasma. The plasma flows through the magnetic field at high speed, in some designs, more than the speed of sound, the flow of the positively charged particles providing the moving electrical conductor necessary for inducing a current in the external electrical circuit.

Methods of Ionising the gas

Various methods for ionising the gas are available, all of which depend on imparting sufficient energy to the gas. It may be accomplished by heating or radiating the gas with X rays or Gamma rays. It has also been proposed to use the coolant gases such as helium and carbon dioxide employed is some nuclear reactors as the plasma fuel for direct MHD electricity generation rather than extracting the heat energy of the gas through heat exchangers to raise steam to drive turbine generators.

Seed materials such as Potassium carbonate or Cesium are often added in small amounts, typically about 1% of the total mass flow, to increase the ionisation and improve the conductivity, particularly of combustion gas plasmas.

Containment

Since the plasma temperature is typically over 1000°C, the duct containing the plasma must be constructed from non-conducting materials capable of withstanding these high temperatures. The electrodes must be conducting as well as heat resistant.

The faraday current

A powerful electromagnet provides the magnetic field through which the plasma flows and perpendicular to this field, two electrodes are installed on opposite sides of the plasma across which the electrical output voltage is generated. The current flowing across the plasma between these electrodes is called the Faraday's current. This provides the main electrical output of the MHD generator.

Power output

The output power is proportional to the cross sectional area and the flow rate of the ionised plasma. The conductive substance is also cooled and slowed in this process. MHD generators typically reduce the temperature of the conductive substance from plasma temperatures to just over 1000°C.

An MHD generator produces a direct current output which needs an expensive high power inverter to convert the output into alternating current for connection to the grid.

Efficiency

Typical efficiencies of MHD generators are around 10 to 20 percent mainly due to the heat lost through the high temperature exhaust.

This limits the MHD's potential applications as a stand alone device but they were originally designed to be used in combination with other energy converters in hybrid applications where the output gases (flames) are used as the energy source to raise steam in a steam turbine plant. Total plant efficiencies of 65% could be possible in such arrangements.

Experience

Demonstration plants with capacities of 50 MW or more have been built in several countries but MHD generators are expensive. Typical use could be in peak shaving applications but they are less efficient than combined - cycle gas turbines which means there are very few installations and MHD is currently not considered for mainstream commercial power generation.

Advantages of MHD generation

1 Here only working fluid is circulated, and there are no moving mechanical parts. This reduces the mechanical losses to nil and makes the operation more efficiency.

2 The temperature of working fluid is maintained the walls of MHD.

3 It has the ability to reach full power level almost directly.

4 MHD has very high efficiency

5 The price of MHD is very low.

Power generation by solar and wind energy

Objectives: At the end of this lesson you shall be able to
- **state the necessity of tapping natural resources for energy**
- **explain the basic principle and construction of the solar cell**
- **explain the characteristic and general specification of a solar cell**
- **explain the features of solar power generation system**
- **explain the features of wind power generation system**
- **calculate the required series parallel group of solar cells for a given power requirement.**

Solar cells: 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 lead 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.

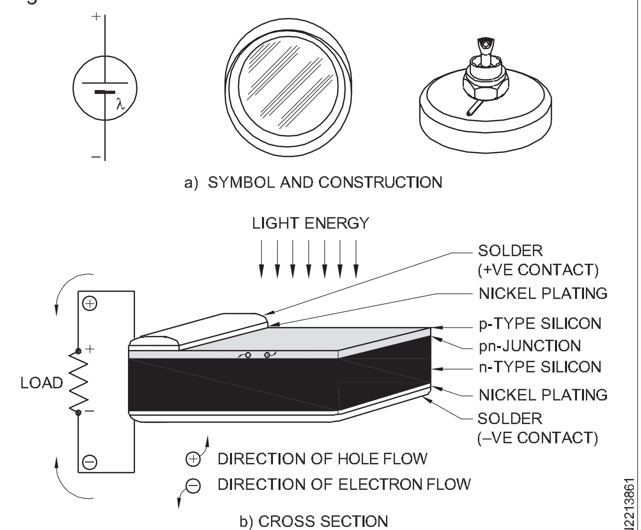
Hence the use of natural resources like heat from sun thought by several scientists and one of the solutions to the energy crisis is the invention of solar cells.

The solar cells is essentially a large photo diode designed to operate solely 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.

The construction and cross section of a typical power solar cell is in Fig 1. 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 button plating is the negative output terminal. commercially produced solar cells will be available in flat strip form for efficient coverage of available surface areas. The circuit symbol of solar cell is shown in Fig 1.

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 as shown in Fig 2. The graph (Fig 2) 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 the output voltage will be zero. On the other hand open circuited voltage of the cell will be 0.55mv but the output current is zero. Therefore again the output power is zero. For maximum output power the device must be operated at the knee of the characteristic. In solar cells the output power decreases at high temperature.

Typical output characteristics of power photocell for use as a solar energy converter. (Fig 2)

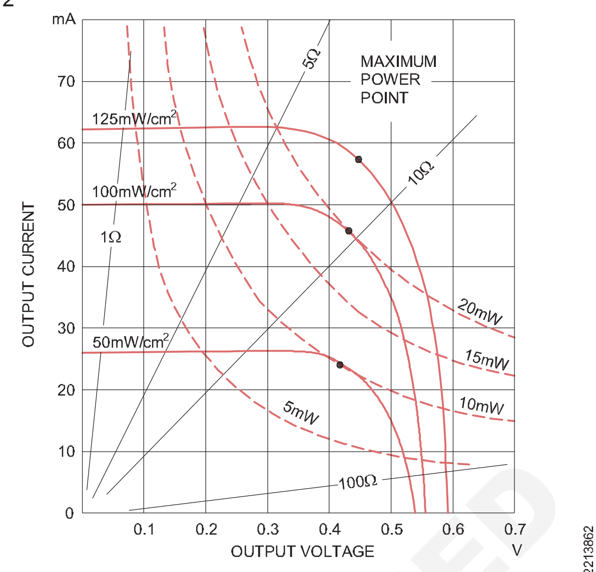
Array of solar cells connected as a battery charger. (Fig 3)

Fig 3 shows a group of series-parallel connected solar cells operating as a battery charger. Several cells must be series connected to produce the required output voltage, and number of parallel groups to be provided as per the required output current.

Example

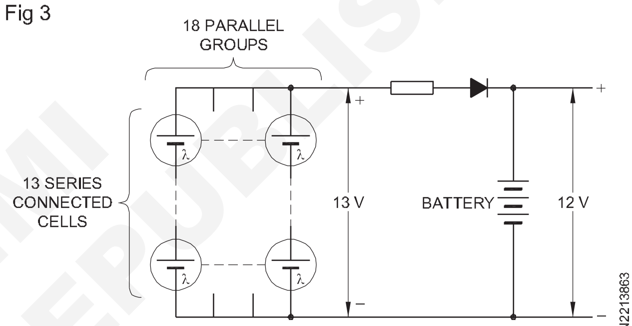
A village welfare club is having a black and white TV which operates at 24V taking a current of 3amp for four hours.

Fig 2



OUTPUT CHARACTERISTICS OF POWER PHOTOCELL FOR USE AS A SOLAR ENERGY CONVERTER

Fig 3



ARRAY OF SOLAR CELLS CONNECTED AS A BATTERY CHARGER

Normally an array of solar cells are used for charging the 24V batteries and the light source from sun available to energise the cells for about 10hours a day. Calculate the total number of solar cells of 125mw/cm^2 required and the series parallel grouping of cells.

Solution

Refer Fig 2. As per the graph the solar cells (energy converters) should be operated at approximately 0.45V and 57mA. Assuming the charging voltage should be higher than the battery voltage of 24V the solar cells should supply 26.4volt for charging the battery circuit.

Number of series connected cells

$$= \frac{\text{Output voltage}}{\text{Cell voltage}} = \frac{26.4V}{0.45V}$$

= 58.5 = say 59 cells

The charge taken by the batteries after every day of TV programme will be 3amp x 4hours = 12 ampere hours. This should be supplied by the solar cells in 10 hours. Hence the ampere (current) requirement

$$\text{Current} = \frac{\text{Ampere hours}}{\text{hours}} = \frac{12}{10}$$

= 1.2 amp

Total number of groups of cells in parallel

$$= \frac{\text{Output current}}{\text{cell current}} = \frac{1.2\text{amp}}{57\text{mA}}$$

= say 21 cells

The total number of cells required

= Number of cells in series x number of groups in parallel

= 59 x 21

= 1239 cells.

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.

In addition to its size the solar energy has two other factors in its favour. Firstly, unlike fossil fuels and nuclear power, it is an environmentally clean source of energy. Secondly, it is free and available in adequate quantities in almost all parts of the world where the people live.

However, there are many problems associated with it use. The main problem is that it is a dilute source of energy. Even in the hottest regions of earth, the solar radiation flux available rarely exceeds. 1 KW/m^2, which is a low value for technological utilization. Consequently, large collecting areas are required in many applications and these result in excessive costs.

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.

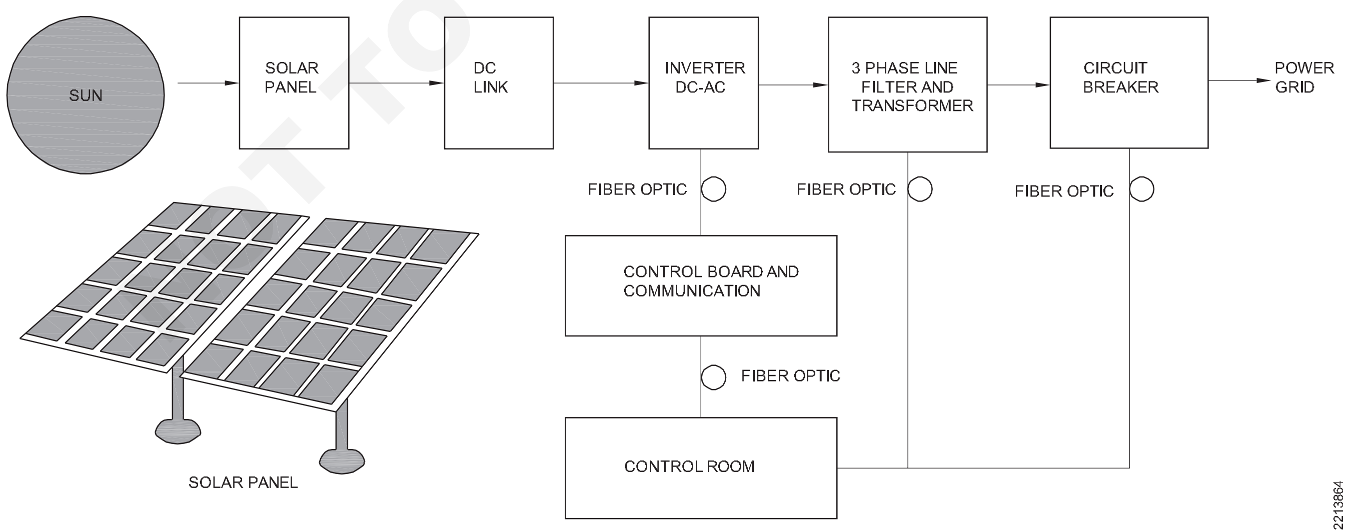
The unit of such combination of two layers of semi conductor materials, for producing electric potential difference in sunlight is called solar cell. Silicon is normally used as solar cell. For building cell, silicon material is cut into very thin wafers. Some of these wafers are doped with impurities. 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 4 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 4



SOLAR POWER PLANT

Solar panel installation norms

Solar modules must have some industry standards known as the standard test condition (STC).

It is a set of conditions to test a module, mainly includes these factors.

Irradiance (sunlight intensity)

It is the amount of sunlight falling on a plain surface. Its unit is watt per square metre. The measurement standard is unit 1000Kw/m^2.

Air mass

It is the thickness and clarity of air through which the sunlight passes to reach the modules its standard is 1.5.

Cell temperature : It is the testing temperature as 250°C.

Module efficiency : It is the ratio of output power to the input power is called module efficiency. Module uses the photons in the sunlight to produce DC electricity.

- Normally 1000W/M^2 of sunlight strikes 1 square metre area of a module. If 100W of power is produced from that square metre, then the module efficiency is 10% If it is 50W power is produced from that square metre it a has an efficiency of 5%.

For efficient cell, if must have the following key factors.

- It must have a high short circuit current.
- The open circuit voltage is also must be high for obtaining the above possible character with possible condition must be fulfilled.
- By choosing low band gap materials to get high value of short circuit current and high open circuit voltage.

Assembling and installation of solar panels

A solar panel is a able to function using the solar energy which is derived from the sun. The solar panel installed on the roof top absorb sun's light (photons) from the sun.

Silicon and the conductors in use for solar panel converts the sunlight into direct current (DC) electricity flows into the inverter. It is an renewable energy. The process of converting sunlight to electrical energy and more efficient than other process.

Solar panel contains many different silicon cells (or) solar cells. The energy derived from the sun is connected into electricity with help of solar panels.

1 The solar panels installed on the roof top absorb sun's light from the sun.

2 The silicon and the conductor in the panel convert the sunlight into DC flows into inverter.

3 The inverter then converts DC to AC which can be used at home.

4 Excess electricity that is not used, can be feedback to the grid.

5 When the solar panels produce less power than required at home.

Process of connecting solar panel to electricity

Solar panels is used a special process of connecting photons to electrons to generate a current by making use of a special type of cell known as photovoltaic cell. These cells are commonly found on the front of calculation and small gadgets are connected together, called as solar panels (photovoltaic cells) are made up of semiconductor materials such as silicon, which absorb the light from the sun. The photons in the sunlight current the electron within the sunlight.

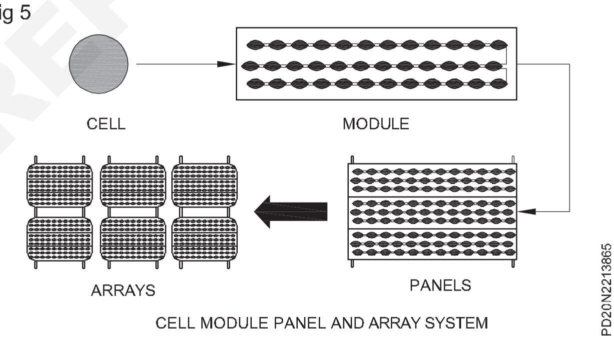
Basic idea of a solar module, array and balance of system (BOS)

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 5)

Fig 5



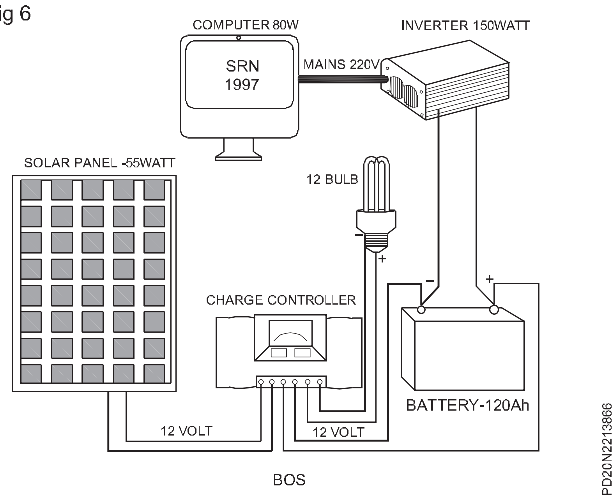
CELL MODULE PANEL AND ARRAY SYSTEM

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 6)

Fig 6



The main components is BOS assembly are:

- Storage battery
- Charge controller
- Inverter
- Support structure
- Junction boxes
- Wire, cables and fuses
- Connections and switches

The functions of the above components are explained briefly below:

Storage battery

The most small systems used for lightening needs only 12V battery for longer system like refrigerator, 24V is used. If helps to keep the wire size small and system losses to a minimum. It needs to be handled carefully. If must not be over charged or fully discharged to prevent from damage.

Charge controller

If the battery is not able to control charge on its own. This work is done by a simple automatic device known as a charge controller in the following way.

- It senses the battery charge and switches 'OFF' the charging current and avoid from damage.
- It disconnects the appliances when the battery charge goes below a set limit.
- Prevents reverse current and protects from short circuit.

Inverter

A solar system produces only DC power. But home appliances need AC power. The device (example CFL) is required for this purpose to convert DC into AC is called as inverter.

Support structure

The solar module cannot be simply placed either on ground or roof. It needs to collect the sunshine at an angle. To keep the module safe from any strong winds support structure is used for solar PV system.

Junction boxes

It is meeting point for many wires. These may be from a raw of modules are from modules to a battery bank. A junction box is made of an unbreakable material (i.e.) polycarbonate. It makes use of copper connectors for a high current flow. It protects the system from moisture.

Wires and fuses

This solar systems carry a low voltage but high current. So, the large diameter wire is needed. Fuses keep the solar equipment safe against the short circuit.

CFL (Compact Fluorescent Lamp)

It is not only energy saving lamp but also having long life (8000hrs) and less heat output common available CFL are:

- 5W - 235 Lumens
- 7W - 370 Lumens
- 9W - 600 Lumens
- 11W - 900 Lumens

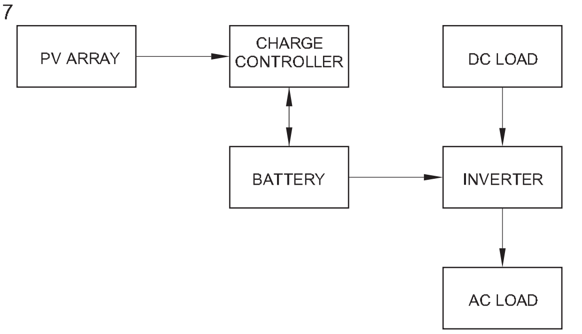
The solar panels are installed for some applications like:

- Solar power plant
- Solar lantern
- Solar lighting system
- Solar water pumping system
- Solar battery charging system
- Solar Hybrid system
- Solar grid connected power plants
- Solar home system
- Solar water heater etc.,

For example the procedure for installing of a solar home system is explained below:

Fig 7 shows the block diagram of solar panel installation.

Fig 7



BLOCK DIAGRAM OF SOLAR POWER SYSTEM

- Collect the system from the packing
- Check for the any damage from outride on the different parts of system.
- Connect the load to junction box controller
- Connect all lighting loads charge controller to load junction box with interconnecting cables.
- Place the charge controller on batter box, keep the battery inside.
- Fire module on the support structure.
- Wore the system appear box layout.

Mounting of charge controller

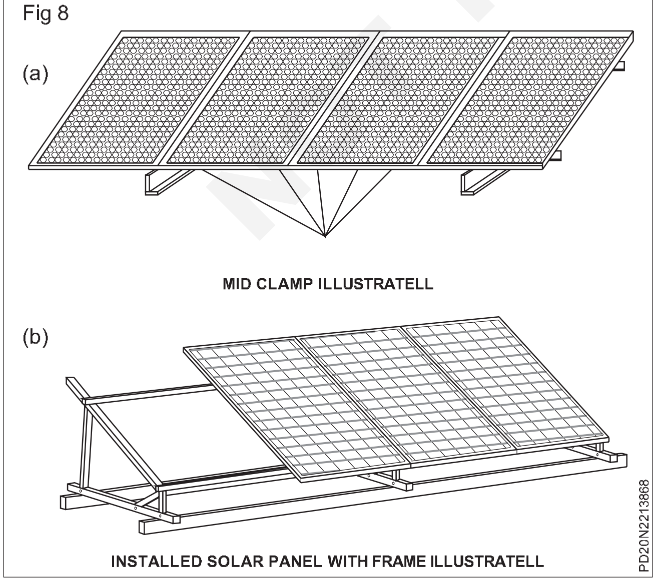
- Mount the controller to the wall into screws that fit to the wall material.
- Connect the battery cable assembly with fuse supplied along with the controller.
- Connect first controller and then battery and two modules
- Connect the wires to the load and only then to controller.

Electrical connection

- Connect the battery to the system only after getting fully charged.
- Do not switch 'ON' charged the loads for 2 - 3 days (when battery is 'ON' a full charged)
- Connect the array cable to charge controller with correct polarity.
- Keep the switch in 'OFF' position and connect the load cables and battery cables to charge controller.
- Switch 'ON' the load (i.e.) lamps for the normal operation.
- Test the solar panel installation for it's functioning.

(Fig 8a & b) shows the installed solar panel with mid clamp and with frame mounted installation are illustrated.

Fig 8



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
- Shading
- Light intensity
- Temperature
- Charge controller
- Semiconductor energy loss
- 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%.

Shading

Solar module faces the sun all day. Their shade should not be present on it. In such a place only it must be put up. But due to extended free transformer, T.V antennas etc, may cause to present shades.

A solar modules are made of a string of individual solar cells and connected in series with one another. Suppose as an example one cell from 36 cells in a module is fully shaded, the power output from the module will become zero due to high resistance. But if one cell is 50% shaded then the power output is reduced to 50% only offers high resistance.

Light intensity

More power is produced from the panel in bright sunlight. For 1000W/M^2 of sunlight, the rated output power will be full. But, if it is 500W/M^2 only the rated power output will be half. The output power is directly proportional with the increasing of solar in isolation.

Temperature

The higher the temperature the output power is reduced from a module, due to power loss. It is tested at standard temperature at 25°C. During the bright sunlight, cell may reach 70°C also. If crystalline silicon decrease from 0.4 to 0.5% per°C temperature increases above 25°C. Amorphous silicon module temperature coefficient is 0.2 to 0.25 % per°C of temperature increase.

Charge controller

If the charger controller is in continuous operation and draws a small current of about 5mA to 25mA, then the power loss is around 1%.

Semiconductor energy loss

The charge controller is having the components as MOSFET and blocking diodes, which is cause for heat energy 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.**

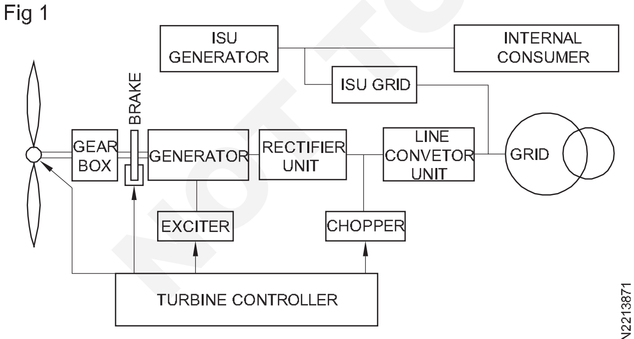
The method of generating the electrical energy by using the wind is termed as wind power generation. Since the wind has velocity and kinetic energy, it can be used to produce electricity. For that, we can use windmills. The important part of a windmill is a structure with large leaves, fixed at the top 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. If the windmill is connected to a water pump, the leaves of the windmill rotate the pump and pumping out the water.

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. Such wind mills will be highly desirable & economical to the rural areas which are far away from the existing grids.

3 There is a strong reason why wind power should be welcome by grids which have some hydroelectricity inputs in India. The water level in the hydel reservoir is at its lowest before the onset of the South West monsoon. If less water is drawn during the monsoon, a high level could be maintained for longer period. During the monsoon period wind energy can be used to feed the grid.

4 It is non polluting

5 It does not require high technology.

6 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. To avoid this, special and costly designs and controls are always required.

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 estimated cost of wind electricity generation, storage & distribution system is over 1 lakh rupees which may be considered beyond the means of most Indian villages.

Modern wind machines are still wrestling with the problem of what to do when the wind is not blowing. Large turbines are connected to the utility power network some other type of generator picks up the load when there is no wind. Small turbines are often connected to diesel/electric generators or sometimes have a battery to store the extra energy they collect when the wind is blowing hard.

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.

Visiting of electrical substation

Objectives: At the end of this lesson you shall be able to
- **state the initial preparatory work before commencing the visit**
- **explain the individual trainees main areas and its importance for preparation**
- **list out the supporting materials to carry for visit**
- **prepare a list of do's and dont's during visit.**

Introduction

A industrial visit is a very important step to tap actual working environments. During practical exercises practicing in the lab or workshop never provides actual working condition because it is a part of structure training planned to complete within a stipulated time and a assessment at later stage.

Initial preparatory work

The trainees should be in a position to interact well at the actual site. Every industry technical experts execute the work on a team and produce better results. The technician or operator concerned will be able to give a clear idea of working or procedure of a particular work and you have to extract it fully

To understand the whole process from the concerned technician or operator, you must have a sound knowledge of that particular abject or process. You should prepare well to meet the challenge whenever you go industrial visit in a factory or work place.

Preparation areas and its importance

If the process is complicated or multi level procedure involved; in that case trainees should be made small batches to interact or involve the whole process. In such cases each batch should be formed in advance and decided the section or part to be interacted. Finally all the batches together to make the end result.

Supporting materials

When the visit is at generating stations, have must collect the following:

1 Installed capacity of the plant.

2 Maximum load demand .

3 Load factor .

4 Distance of the nearest sub station.

5 Total number of alternators installed and its working conditions.

6 Details of the fuel used (Coal- Nuclear - Its availability, quality etc) and the daily expenditure for fuel.

7 Solutions to meet extra fuel in case of environmental emergency.

8 Location Map of the plant and its surroundings.

9 Gather maximum information regarding generation and distribution techniques other than guided or studied.

10 Maximum hazardous Area - PPE facility Emergency root in case of emergency.

Do's & Dont's

Do's

1 Wear uniform with name badge.

2 Ensure the protective gadgets are available otherwise carry them.

3 Follow the safety norms imposed in the particular areas, listen the instruction carefully.

4 Carry materials to record your findings and assessments to make then and their.

5 Follow strict discipline and punctuality .

6 Obey all the instructions and rules.

7 Walk in the prescribed areas only.

Dont's

1 Avoid wearing loose clothes and ornaments.

2 Not to carry any bag or attachments.

3 Do not cross-over any prohibited areas .

4 Do not operate, touch or play with any part or machine you pass over.

5 Do not sit or learn over any machine or place you come accross.

6 Do not shout or make any unusual noices when the visit is in progress or inside the factory.

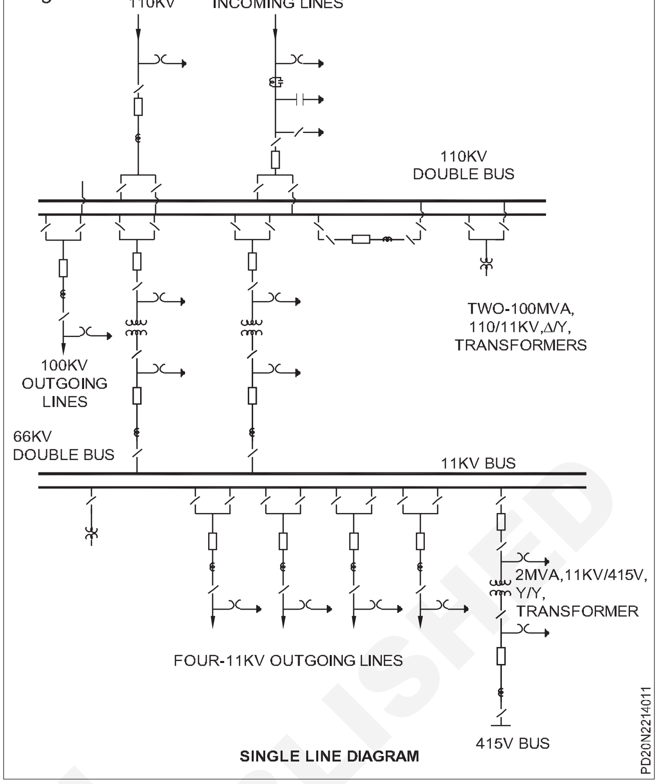
7 Do not involve any kind of horse play at the time of visiting various sections, areas.

8 Do not avoid or neglect any instruction passed on you at any time.

9 Do not indulge any horse play or encourage others to do. The person responsible for leading the visit has to arrange the programme well in advance and informs all concerned. Taking permission to visit and arrange transportation to reach in time. Arrangement may also be done to carry or provide hospitality is also the responsibility of the person concerned.

Fig 1 shows a typical single line layout diagram of a transmission and distribution substation.

Fig 1



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.

Substations are the convenient place for installing synchronous condensers for the purpose of improving power factor and it provides facilities for making measurements to monitor the operation of the various parts of the power system.

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 substations. Transformer substations are further classified into step-up substations, primary grid substations, secondary substations and distribution substations.

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 **Switching substations :** These substations are meant for switching operations of power lines without transforming the voltage. Different connections are made between the various transmission lines.

3 **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 voltage levels :** eg. AC substation : EHV, HV, MV, LV : HVDC substation.

2 **Classification based on outdoor or indoor :** Outdoor substation is in open air. Indoor substation is inside a building.

3 **Classification based on configuration**

- Conventional air insulated outdoor substation or
- SF_6 Gas insulated substation (GIS)
- Composite substations having combination of the above two.

4 **Classification based on application**

  - **Step up substation :** Associated with generating station as the generating voltage is low.
  - **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.
  - **Distribution substation:** Created where the transmission line voltage is stepped down to supply voltage.
  - **Bulk supply and industrial substation :** Similar to distribution substation but created separately for each consumer.
  - **Mining substation :** Needs special design consideration because of extra precaution for safety needed in the operation of electric supply.
  - **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 **Main office building**

- Administrative building
- Conference room etc.

3 **6.6/11/22/33/66/132 KV switch gear LV**

- Indoor switch gear

4 Switch gear and control panel building

- Low voltage AC switch gear
- Control panels, protection panels

5 Battery room and DC distribution system

- DC battery system and charging equipment
- DC distribution system

6 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.

A fault may develop in a transmission line or any other component. Some examples of this a line is hit by lightning and develops an arc, or a tower is down by a high wind. The function of the substation is to isolate the faulty portion of the system within the shorted possible time.

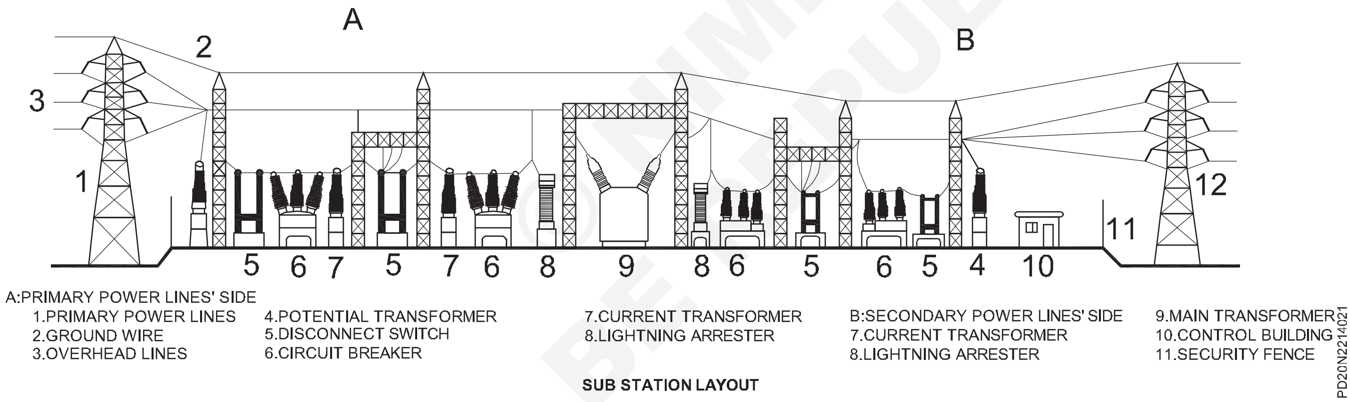
Substation layout and their components

Fig 1 shows the typical substation layout. It consists of the following components and explained below.

Power transformer : Power transformers are used for generation and transmission network for stepping-up the voltage at generating station and stepping down the voltage for distribution. Auxiliary transformers supply power to auxiliary equipment at the substations. (Fig 2).

Current transformers (CT) : The lines in substations carry currents in the order of thousands of amperes. The measuring instruments are designed for low value of currents. Current transformers are connected in lines to supply measuring instruments and protective relays. For example a 100/1A CT is connected in a line carrying 100A, and then the secondary current of CT is 1A. (Fig 3).

Fig 1



SUB STATION LAYOUT

Fig 2

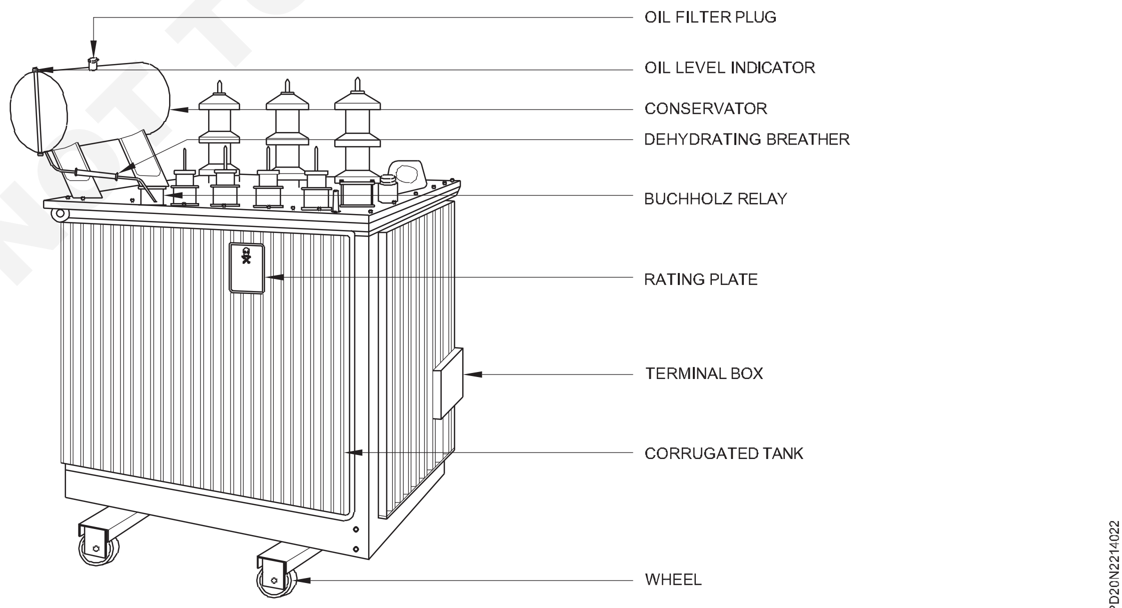
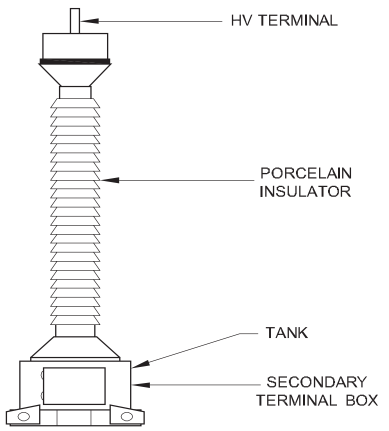


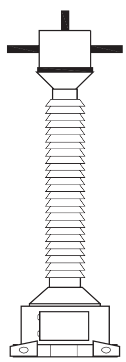
Fig 3



Potential transformers (PT): The lines in substations operate at high voltages. The measuring instruments are designed for low value of voltages. Potential transformers are connected in lines to supply measuring instruments and protective relays.

These transformers make the low voltage instruments suitable for the measurement of high voltages. For example a 11KV/110V PT is connected to a power line and the line voltage is 11KV then the secondary voltage will be 110V. (Fig 4).

Fig 4



Circuit breaker (CB): Circuit breakers are used for opening or closing a circuit under normal as well as abnormal (faulty) conditions. Different types of CBs which are generally used are oil circuit breaker, air - blast circuit breaker, vacuum circuit breaker and SF_6 circuit breaker.

Isolators for isolating switches: Isolators are employed in substations to isolate a part of the system for general maintenance. Isolator switches are operated only under load condition. They are provided on each side of every circuit breaker.

Lightning arresters (LA): Lightning arresters are the protective devices used for protection of equipment from lightning strokes. They are located at the starting of the substation and also provided near the transformer terminals.

Earth switch: It is a switch normally kept open and connected between earth and conductor. If the switch is closed it discharges the electric charge to ground, available on the uncharged line.

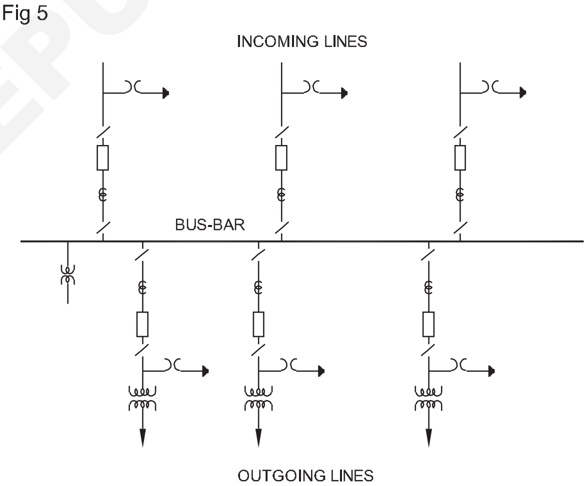
Wave trap : This equipment is installed in the substation for trapping the high frequency communication signals sent on the line from remote substation and diverting them to the telecom panel in the substation control room.

Coupling capacitor : A coupling capacitor is used in substations where communication is done by AC power line. It offers very low impedance to high frequency carrier signal and allows them to enter the line matching unit and blocks the low frequency signals.

Bus - bar : When number of lines operating at the same voltage levels needs to be connected electrically, bus - bars are used. Bus - bars are conductors made of copper or aluminium, with very low impedance and high current carrying capacity. Different types of bus - bar arrangements are single bus bar arrangements, single bus - bar with sectionalization, double bus- bar arrangements, sectionalized double bus - bar arrangement, double main and auxiliary bus - bar arrangement, breaker and a half scheme /1.5 Breaker scheme, and ring bus - bar scheme.

Single bus-bar arrangement : It consists of single bus - bar. Both incoming and outgoing lines are connected to the single bus - bar (Fig 5). The advantages of this arrangement are low maintenance, low initial cost and simple operation. The drawback of this arrangement is if any repair work is to be done on bus-bar, complete system get interrupted.

Fig 5



SINGLE BUS-BAR ARRANGEMENT

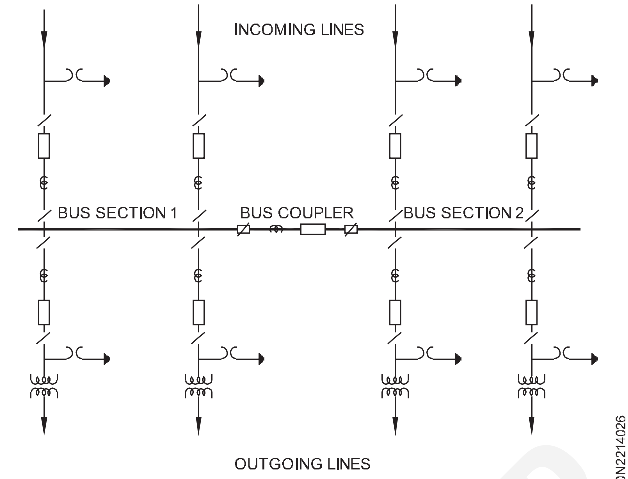
Single bus-bar with sectionalization: Single bus-bar is divided into sections. Any two sections are connected by circuit breaker and isolators. During fault or maintenance particular section can be de-energized. This eliminates complete shutdown of the system. Fig 6 shows that two incoming and two outgoing lines are connected bus section I and other two incoming and two outgoing lines are connected bus section. 2 by using bus coupler.

Double bus - bar arrangements : This arrangement is also known as duplicate bus-bar system. It consists of two bus -bars 'main' and a 'spare' of same capacity. Incoming line and outgoing lines can be connected to either bus by means of bus coupler breaker and isolators. Continuity of supply of the circuit can be maintained during maintenance of main bus-bar or fault occurring on it.

Single line diagram for substation

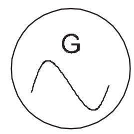
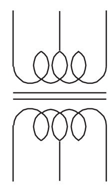
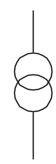
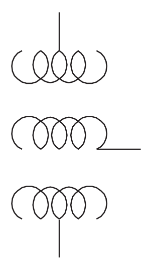
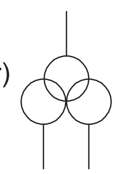
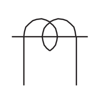
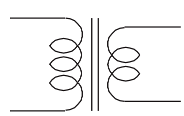
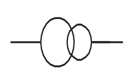
Any complex power system even though they are three phase circuits, can be represented by a single line diagram, showing various electrical components of power system and their interconnection. In single line representation of substation the electrical components such as power transformers, incoming and outgoing lines, bus- bars, switching and protecting equipments, are represented by **standard symbols** and their interconnections between them are shown by line. Single line diagrams are useful in planning a substation layout.

Fig 6



SINGLE BUS-BAR WITH BUS COUPLER SUBSTATION

Standard symbols used for single line diagram of substation

S. No.	Electrical components	Symbols
1	AC Generator	
2	Bus bar	
3	Power transformer - Two winding	 (or) 
4	Three winding transformer	 (or) 
5	Current transformer (CT)	
6	Voltage transformer or Potential transformer (PT)	 (or) 

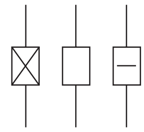
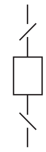
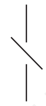
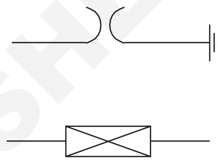
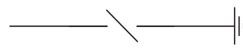
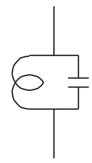
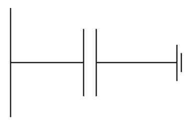
S. No.	Electrical components	Symbols
7	Circuit Breaker (CB)	
8	Circuit breaker with isolator	
9	Isolator or Group Operating Switch (GOS)	
10	Lightning Arrester (LA)	
11	Earth Switch (ES)	
12	Wave or Line trap	
13	Coupling Capacitor (CC)	

Fig 7 & 8 show the examples (1 & 2) of substation layout drawings with all equipments represented by symbols.

Example 1

Draw the single line diagram of substation having the following equipment.

i Incoming lines : Two, 110KV

ii Outgoing lines : (a) One, 110KV (b) Four, 11KV

iii Transformers : (a) Two, 100MVA, 110/11KV, ∆/Y (b) one, 2MVA, 11KV/ 415V, Y/Y

iv) Bus-bars : 110KV- Duplicate bus - bar, 11KV single bus - bar shows the positions of CTs, PTs isolators, lightning and arresters, circuit breakers.

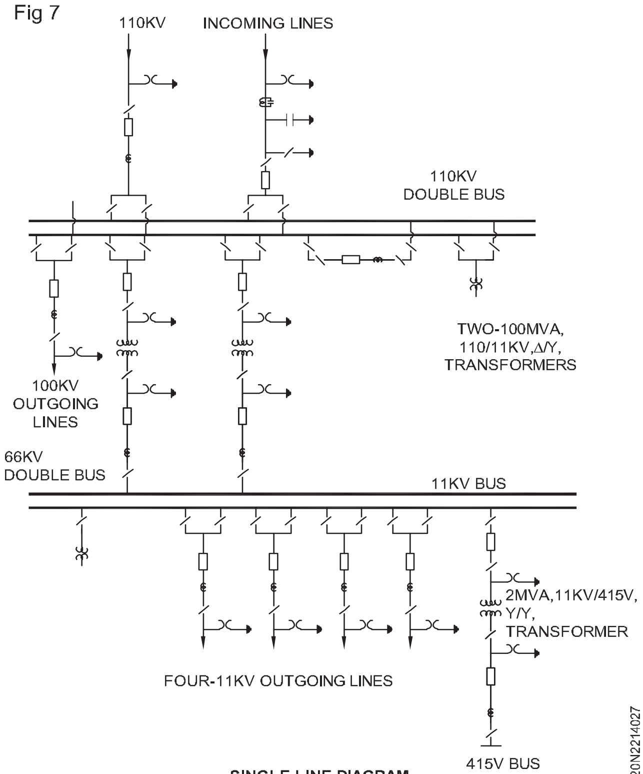
Fig 7 shows the single line diagram of the substation.

Example - 2

Draw the single line diagram of a pole mounted substation.

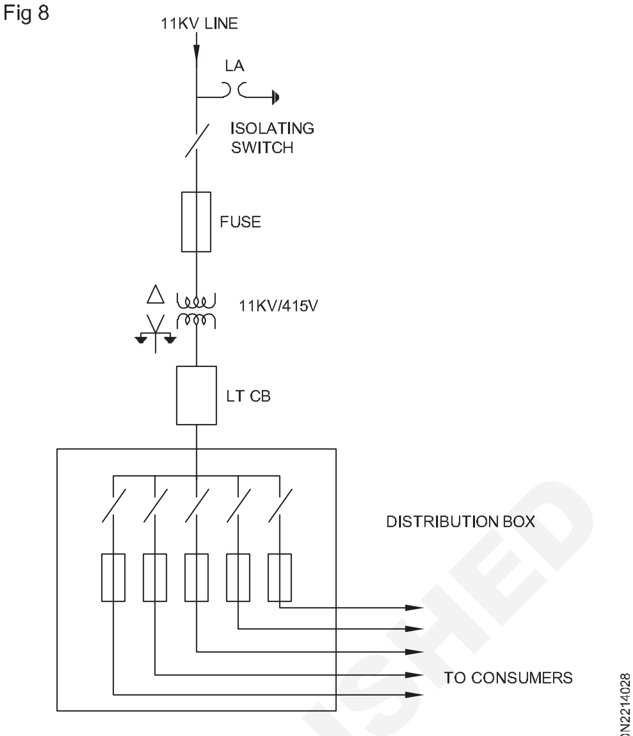
Fig 8 shows the typical single line diagram of pole mounted substation.

Fig 7



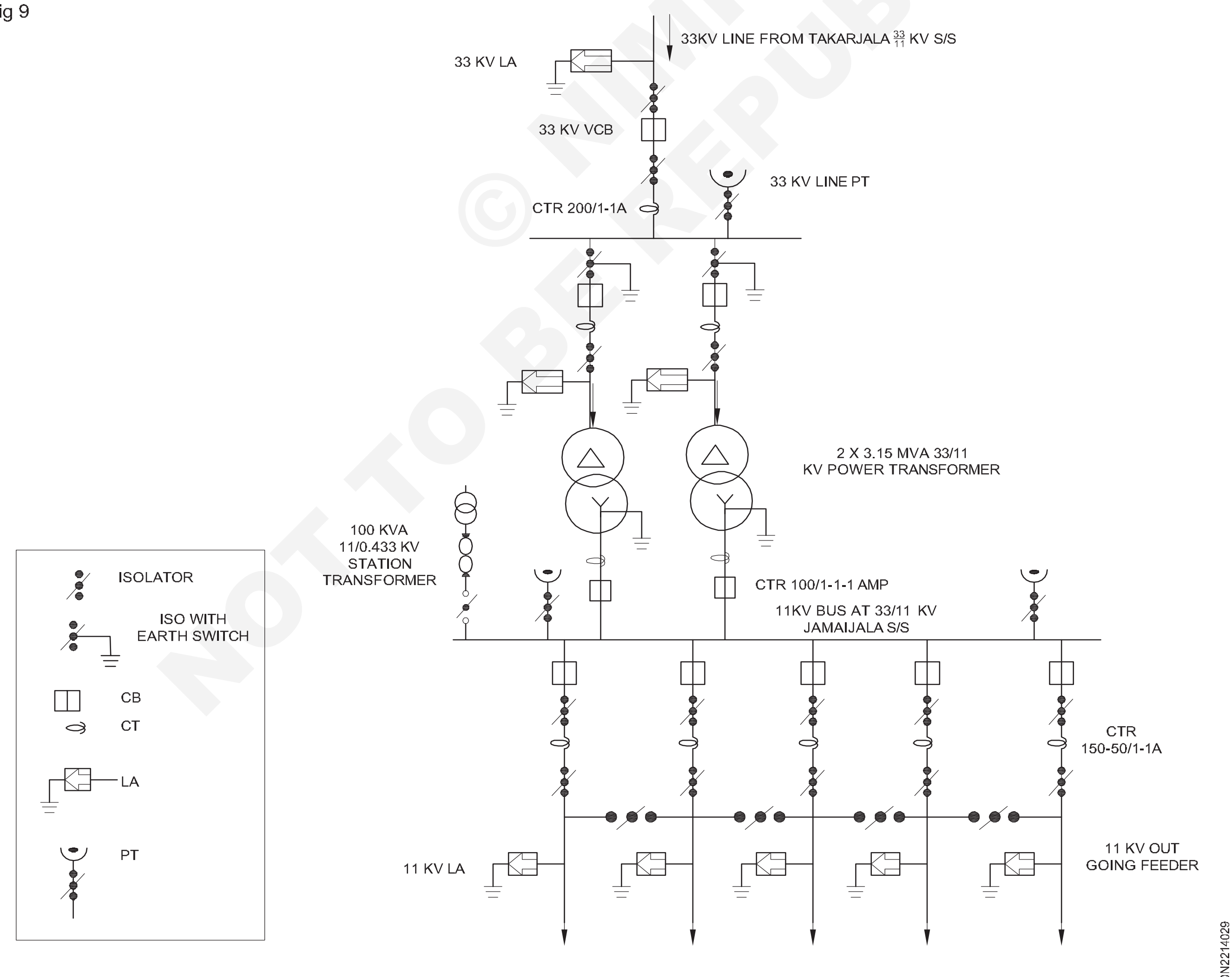
SINGLE LINE DIAGRAM

Fig 8



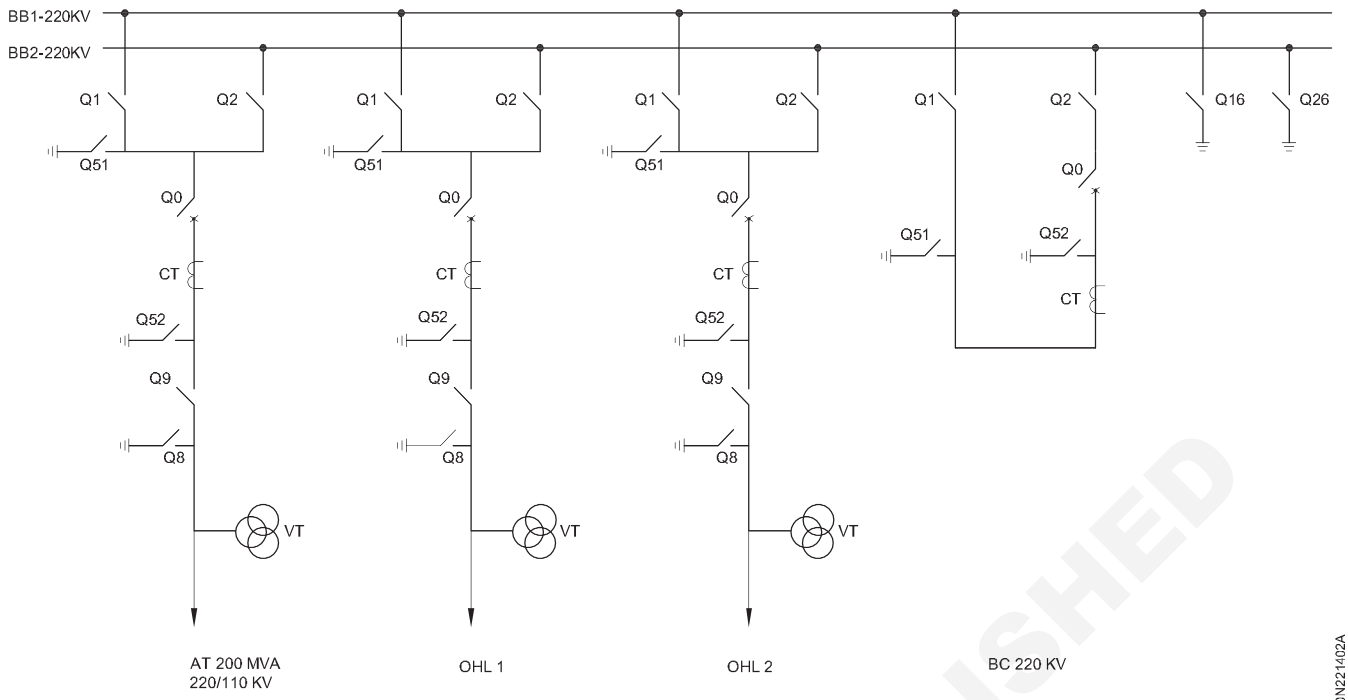
POLE MOUNTED SUBSTATION

Fig 9



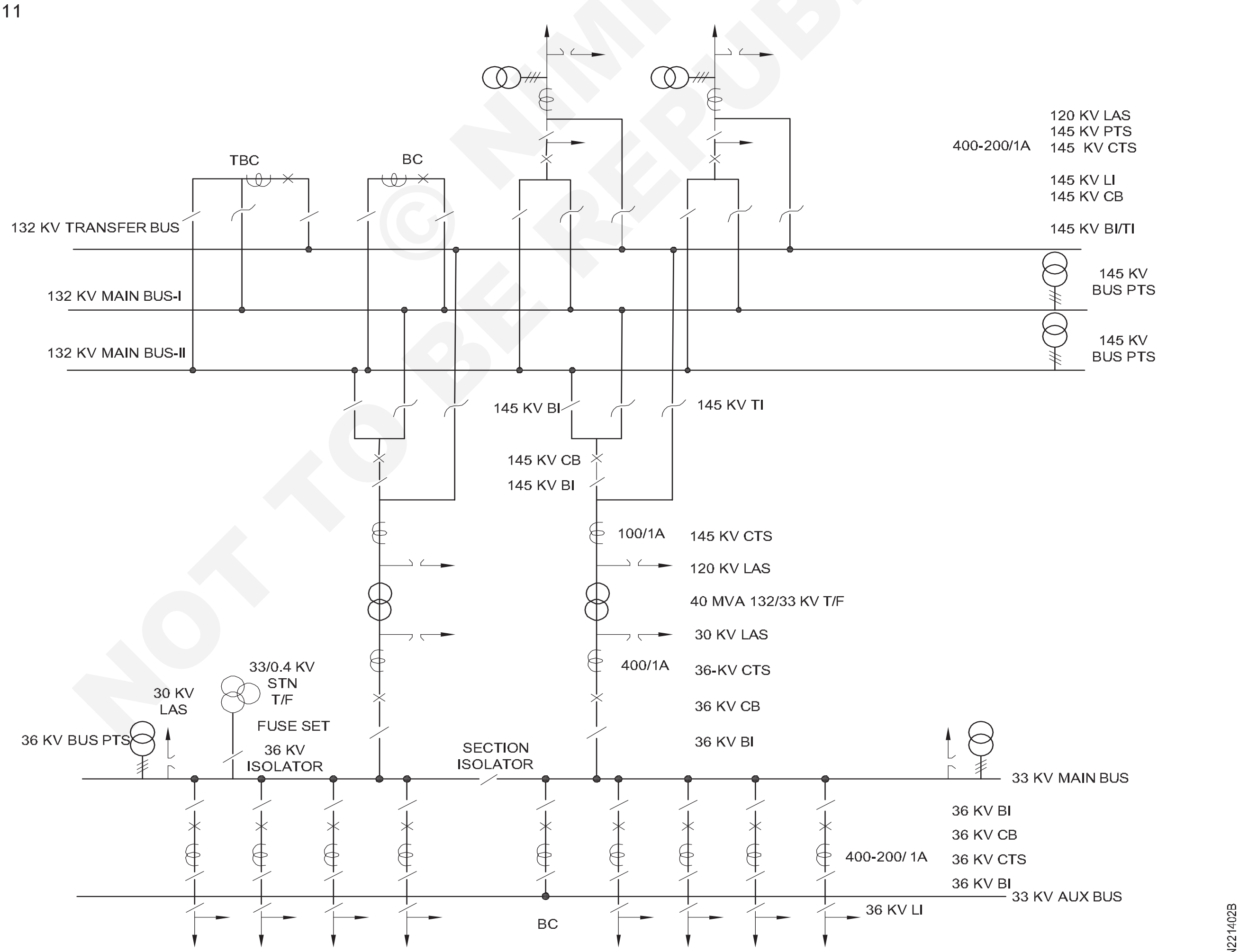
SINGLE LINE DIAGRAM 33 / 11 KV S / S

Fig 10



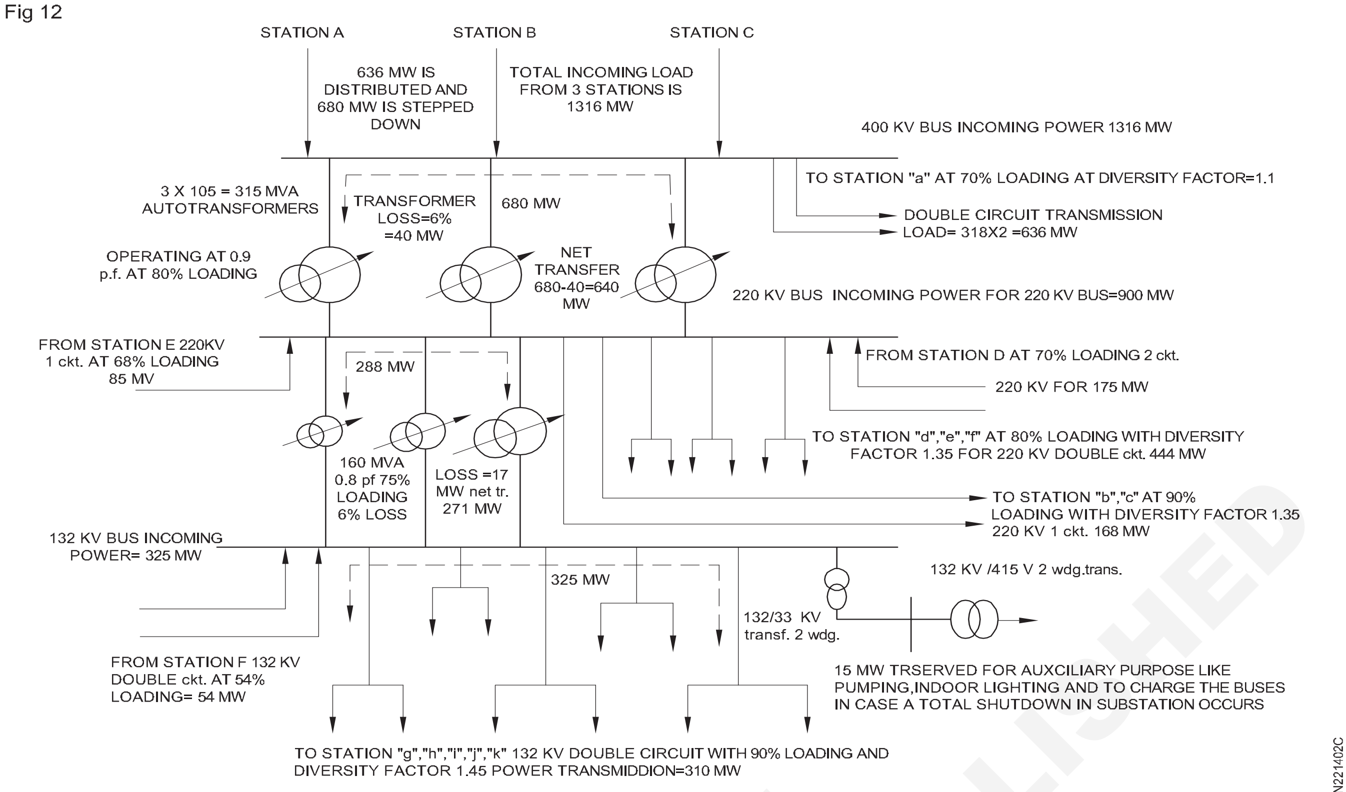
SINGLE LINE DIAGRAM FOR 220KV S/S

Fig 11



SINGLE LINE DIAGRAM OF 132 KV S/S

Fig 12



400/210/132 KV POWER SUBSTATION CONSTRUCTION AND ELECTRICAL DIAGRAM

Electrical supply system - transmission - line insulators

Objectives: At the end of this lesson you shall be able to
- **explain the electrical supply system and layout of AC power supply scheme**
- **list out the various power transmission**
- **compare AC and DC transmission**
- **state the advantages of high voltage transmission**
- **state single phase and 3 phase - 3 wire system in transmission.**

Electrical supply system

The electrical energy generated from the power plants has to be supplied to the consumers. This is large network, which can be broadly divided into two stages, (ie.) Transmission and distribution.

The conveyance of electric power from a power station to the consumers / premises is called is Electrical supply system.

The Electrical power supply system consists of 3 main components viz (i) The power station / plant (ii) The transmission lines and (iii) The distribution systems. The power is produced at power plant which is away from the consumers, It has to be transmitted over long distances to load centres by transmission and to consumers through distribution network.

This supply system can be classified into

- DC or AC system
- Over head lines (or) underground system

Now a days, 3 phase, 3 -wire AC system is universally adopted as an economical proposition. In some places 3 phase - 4 wire AC system is adopted.

The underground system is more expensive than the over-head system, therefore in our country O.H system is almost adopted.

Types of power transmission system

Universally, 3 - phase - 3 wire AC system is adopted in most of the places. However other systems can also be used for transmission under special circumstances.

Possible systems are :-

1 DC system

i DC two wire

ii DC two - wire with mid point earthed

iii DC three wire

2 AC single phase system

i Single-phase two wire

ii Single - phase two wire with mid point earthed

iii Single phase three wire

3 AC Two - phase system

i Two- phase three wire

ii Two - phase - four wire

4 AC three phase system

i Three - phase - three wire

ii Three - phase - four wire

The line network between generating station (Power station) and consumer of electric power can be divided into two parts.

- Transmission system
- Distribution system

This system can be categorized as primary transmission and secondary transmission. Similarly primary distribution and secondary distribution. This is in Fig 1.

It is not necessary that the entire steps which are shown in the diagram must be included in the other power schemes. There may be difference, there is no secondary transmission in many, schemes, in some (small) schemes there is no transmission, but only distribution.

Various stages of a typical electrical power supply system, are as follows

1 Generating station

2 Primary transmission

3 Secondary transmission

4 Primary distribution

5 Secondary distribution

Generating station

The place where electric power produced by the parallel connected three phase alternators / generators is called generating station (i.e power plant).

The ordinary power plant capacity and generating voltage may be 11KV, 11.5 KV, 12KV or 13KV. But economically. It is good to step up the produced voltage from (11KV, 11.5KV or 12KV) to 132KV, 220KV, 400KV or 500KV or greater (in some countries, up to 1500KV) by step up transformer (power transformer).

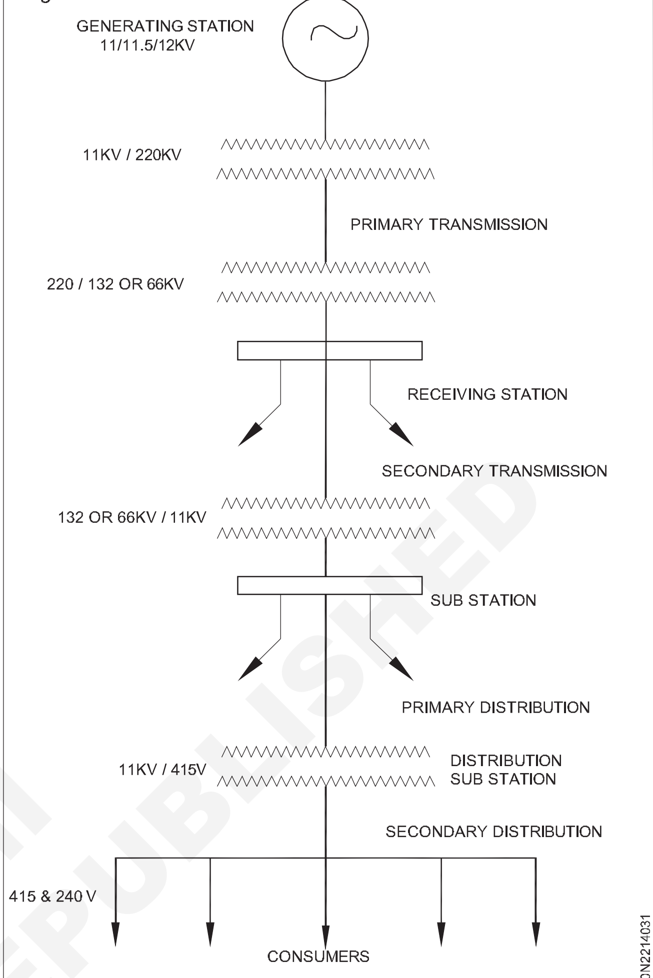
Primary transmission

The electric supply (132KV, 220 KV, 500KV or greater) is transmitted to load center by three phase three wire (3 phase - 3 wires) overhead transmission system.

Secondary transmission

Area far from city (outskirt) which have connected with receiving station by line is called secondary transmission. At receiving station, the level of voltage reduced by step-down transformers up to 132KV, 66 or 33KV and electric power is transmitted by three phase three wire (3 phase - 3 wires) overhead system to different sub stations. So this is a secondary transmission.

Fig 1



TYPICAL AC POWER SUPPLY SCHEME

Primary distribution

At a sub station, the level of secondary transmission voltage (132KV, 66 or 33KV) is reduced to 11KV by step down transformers.

Generally, electric supply is given to heavy consumer whose demands is 11KV, from these lines which carries 11KV (in three phase three wire overhead system) and they make a separate sub station to control and utilize this power.

In other cases, for heavier consumer (at large scale) their demand is about 132 KV or 33KV they take electric supply from secondary transmission or primary distribution (in 132KV, 66KV or 33KV) and then step down to the level of voltage by step -down transformers in their own sub station for utilization (i.e for electric traction etc).

Secondary distribution

Electric power is given to (from primary distribution line (i.e.) 11KV) distribution sub station. This sub station is located near by consumers area where the level of voltage reduced by step down transformers is 415V. These transformers are called distribution transformers, in 3 phase four wire system (3 phase - 4 wires), there is 415 volts (Three phase supply system) between any two phases and 240 volts (single phase supply) between neutral and any one of the phase (lives) wire.

Residential load (i.e. Fans, light, and TV etc) may be connected between any one phase and neutral wires, while three phase load may be connected directly to the three phase lines.

Elements of distribution system

Secondary distribution may be divided into three parts.

1 Feeders

2 Distributors

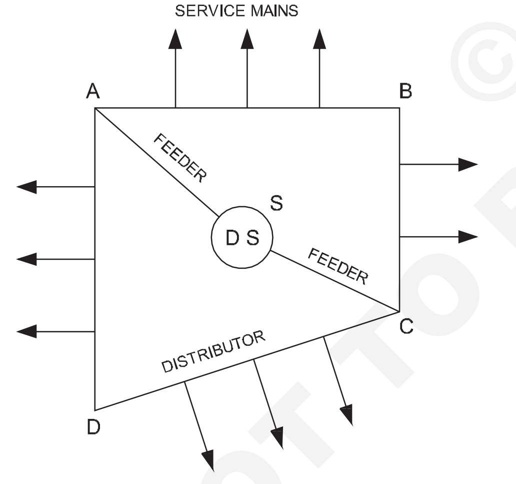
3 Service lines or service mains

Those electric lines which connect generating station (power station) or sub station to distributors are called **feeders.** Remember that current in feeders (in each point) is constant while the level of voltage may be different, the current flowing in the feeders depends on the size of conductor.

Distributors

Those tapings which extracted for supply of electric power to the consumers or those lines, from where consumers get electric supply is called **distributors** (Fig 2). Current is different in each section of the distributors while voltage may be same. The selection of distributors depends on voltage drop and may be designed according to voltage drop. It is because consumers get the rated voltage according to the rules.

Fig 2



DISTRIBUTION SYSTEM

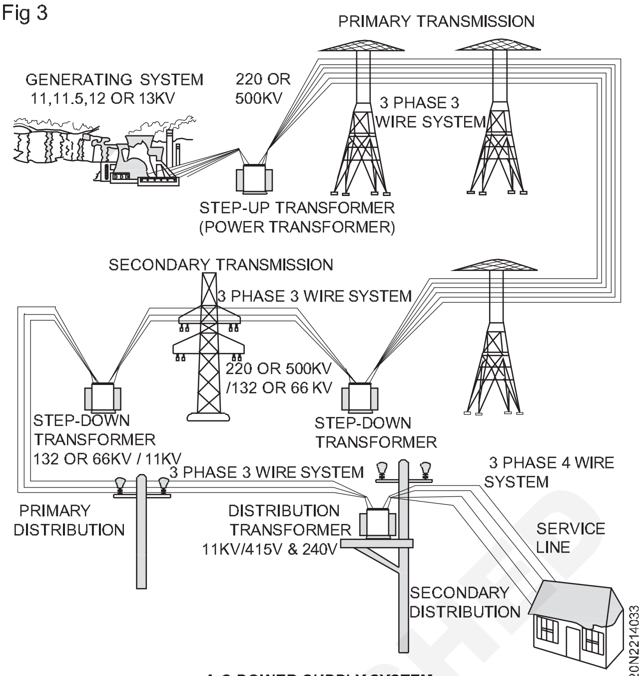
Service lines or service mains

The normal cable which is connected between distributors and consumer load terminal are called **service line or service mains.** A complete typical AC power supply system scheme is in (Fig 3)

Comparison of DC and AC transmission

The electric power can be transmitted either by means of DC (or) AC. Each system has it's own merits and demerits. Some technical advantages and disadvantages of two systems are stated below.

Fig 3



A.C.POWER SUPPLY SYSTEM

AC transmission

Some years ago, the transmission of electric power by DC has been receiving of the active consideration of engineers due to it's appreciable advantages.

Advantages of DC electric power transmission

1 It requires only two conductors

2 There is no problem of inductance, capacitance and phase displacement which is common in AC transmission.

3 For the same load and sending end voltage, the voltage drop in DC transmission lines is less than that in AC transmission.

4 As there is no skin effect on conductors, therefore entire cross - section of conductor is usefully utilized thereby affecting saving in material.

5 For the same value of voltage insulating material on DC lines experience less stress as compared to those on AC transmission lines.

6 A DC line has less corona loss and reduced interference with communication circuits.

7 There is no problem of system instability which is so common in AC transmission.

Disadvantages of DC transmission

1 Generation of power at high DC voltages is difficult due to commutation problems and cannot be usefully utilized at consumer ends.

2 Step up or step -down transformation of DC voltages is not possible in equipment like transformer.

Advantages of AC electric power transmission

1 Power can be generated at high voltages as there is no commutation problems.

2 AC voltages can be conveniently stepped up or stepped down by using transformers.

3 High voltage transmission of AC power reduces losses.

Disadvantages of AC electric power transmission

1 Problems of inductances and capacitances exist in transmission lines.

2 Due to skin effect, more copper is required.

3 Construction of AC transmission lines is more complicated as well as costly.

4 Effective resistance of AC transmission lines is increased due to skin effect.

From the above comparison, it is clear that high voltage DC transmission is superior to high voltage AC transmission. At present, transmission of electric power is carried by AC and effort is making towards DC transmission also. The convertor and inverter have made it possible to convert AC into DC and vice versa easily. Such devices can operate upto 30MW at 400KV in single units. The present day trend is towards AC for generation and distribution at high voltage DC for transmission.

The single line diagram of high voltage DC transmission is in Fig 4. The power is generated as AC and stepped up to high voltage by the transformer at sending end (T_s) . The AC power at high voltage is fed to the convertor which convert AC to DC. The transmission of electric power is carried at high DC voltage. At the receiving emf DC is converted into AC with the help of invertors. The AC supply is stepped down to low voltage by receiving end transformer (T_R) for distribution.

Advantages of high voltage transmission

Very high voltages are used for transmission systems because, as a general principle, the bigger the voltage the cheaper is the supply.

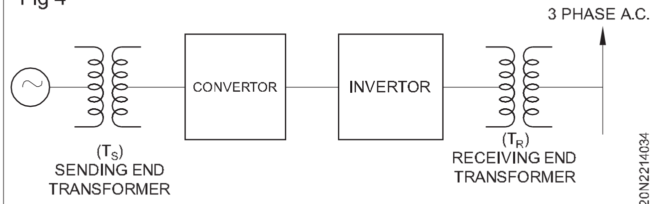
Since power in an AC system is expressed as **P=VI cos**θ**,** that means increase in voltage will reduce the current for a given amount of power. A lower current will result in reduced cable switch gear size and the line power losses, given by the equation $P = I^2R$ will also be reduced.

The 132KV grid and 400KV **supergrid transmission lines** are for the most part, steel - cored aluminium conductors suspended on steel lattice towers, since this is about 16 times cheaper than the equivalent underground cable.

The conductors are attached to porcelain insulator strings which are fixed to the cross - members of the tower is in Fig 5. Three conductors comprise a single circuit of a three phase system so that towers with six arms carry two separate circuits.

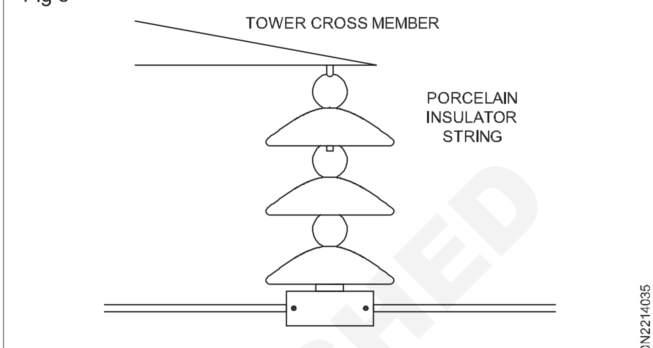
Primary distribution to consumers is from 11KV substations, which for the most part are fed from 33 KV substations, but direct transformation between 132 and 11KV is becoming common policy in city areas where over 100 MW can be economically distributed at 11KV from one site.

Fig 4



HIGH VOLTAGE D.C.TRANSMISSION

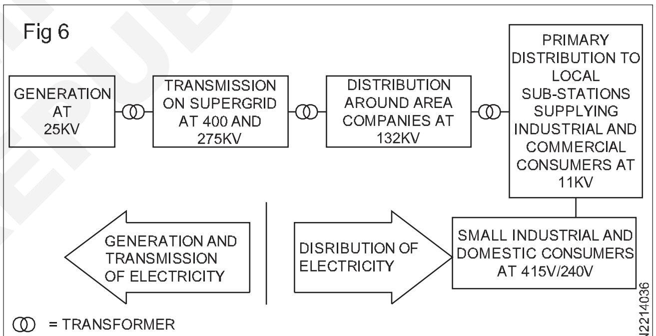
Fig 5



CROSS MEMBER OF THE TOWER

Fig 6 shows a block diagram indicating the voltage at the various stages of the transmission and distribution system.

Fig 6



VOLTAGE STAGES OF TRANSMISSION AND DISTRIBUTION SYSTEM

Distribution system at 11KV may be radial system offers continuous supply.

The maintenance of a secured supply is an important consideration for any electrical engineer or supply authority because in industrial society, a loss of supply may cause inconvenience, financial loss and danger to the consumer or the public.

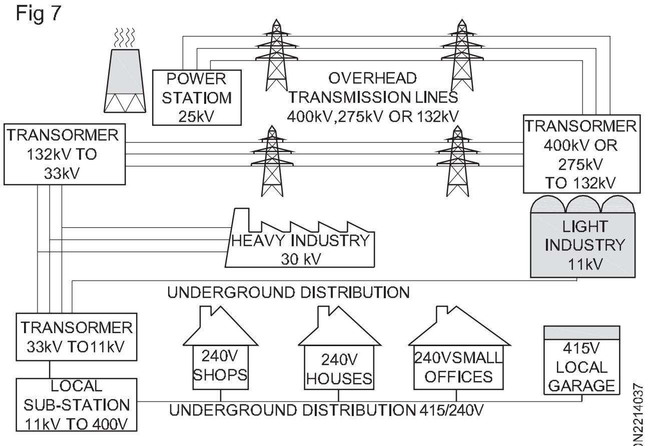
The principle employed with a ring system is that any consumer's substation is fed from two directions, and by carefully grading the overload and cable protection equipment a fault can be disconnected without loss of supply to the consumers.

Fig 7 is a simplified diagram of distribution of electricity from power station to consumer.

High voltage distribution

High voltage distribution to primary substation is used by the electricity boards to supply small industrial, commercial and domestic consumers.

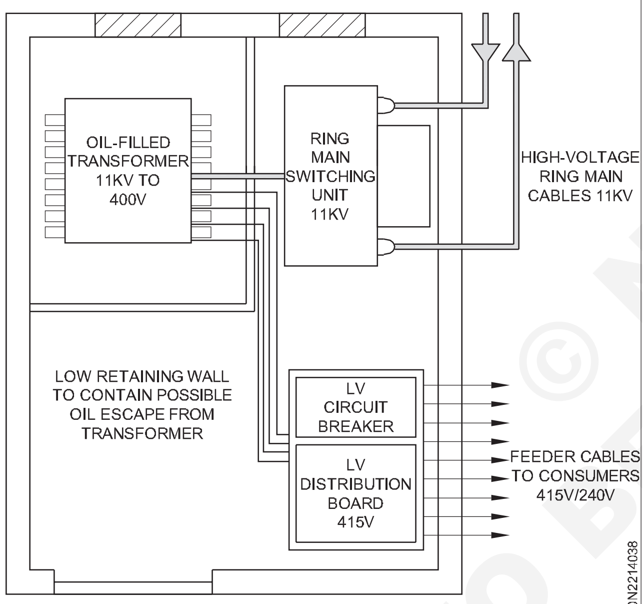
Fig 7



DISTRIBUTION OF ELECTRICITY FROM POWER STATION TO CONSUMER

This distribution method is also suitable for large industrial consumers where 11KV substations as in Fig 8 may be strategically placed at load centres around the factory site.

Fig 8



LOAD CENTRES AROUND THE FACTORY

The final connections to plant, distribution boards, commercial or domestic loads are usually by simple underground radial feeders 415V/240V.

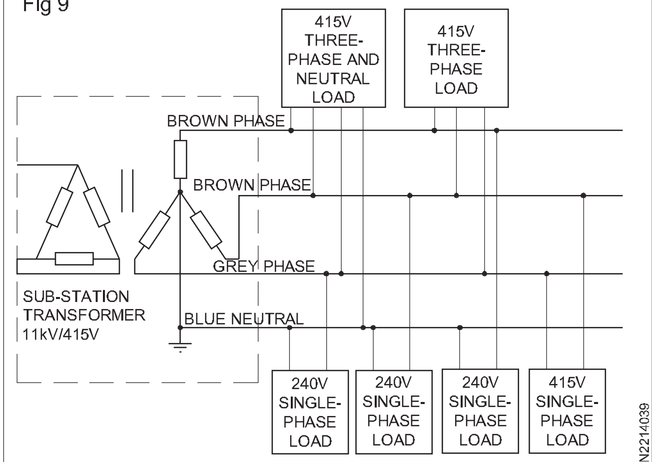
These outgoing circuits are usually protected by circuit breakers in a distribution board.

The 415 V/240V is derived from the 11KV/415V sub-station transformer by connecting the secondary winding in star is in Fig 9.

The star point is earthed to an earth electrode sunk into the ground below the substation, and from this point is taken the fourth conductor, the neutral. Loads connected between phases are fed at 415V, and those fed between one phase and neutral at 240V.

A three - phase 415V, supply is used for supplying small industrial and commercial loads such as garages, schools and blocks of flats. A single - phase 240V supply is usually provided for individual domestic consumers.

Fig 9



11kV/415V SUBSTATION WITH SECONDARY OF TRANSFORMER IN STAR

Indian Electricity Rules - Safety Requirements

The IE rules 1956 was made under sections 37 of Indian Electricity Act 1910. Now it is redefined after the enactment of the Electricity Act 2003. The Central Electricity Authority (measures relating to safety and electric supply) Regulation (CEAR) 2010 which came into effect from 20th September 2010**,** in place of Indian Electricity Rules 1956.

SAFETY RULES: Among safety rules, the following are important and indeed requires attention. Every rule in the Indian Electricity Rules 1956 is related either directly or indirectly to safety.

Special provisions in respect of high and extra high voltage installations

Rule 63: Approval of Inspector is necessary before energising any high voltage installations.

Rule 65: The installation must be subjected to the prescribed testing before energizing.

Rule 66: Conductors shall be enclosed in a metallic covering and suitable circuit breakers shall be provided to protect the equipment from overloading.

Rule 68: Incase of outdoor type of sub-station a metallic fencing of not less than 1.8 m height shall be erected around the transformer.

Provisions in terms of OH line

Rule 77: Clearance of lowest conductor above ground across street.

- Low and Medium Voltage lines - 5.8 m.
- High voltage Lines - 6.1 m.
- Clearance of lowest conductor above ground along a street. Low and Medium Voltage lines - 5.5 m.
- High voltage lines - 5.8 m.
- Clearance of lowest conductor above ground other than along or across the street. Low, Medium and High Voltage lines upto 11 KV if bare - 4.6m .
- Low, Medium and High upto and including 11KV, if insulated - 4.0m.
- High Voltage above 11 KV - 5.2 m.

Rule 80: Clearance from building of high and extra high voltage. Vertical Clearance High Voltage upto 33KV - 3.7m.

- Extra High Voltage above 33KV - 3.7 m, plus 0.3 m for every 33KV part there of.
- Clearance from building of high and extra high voltage - Pitched Roof . Vertical Clearance upto 11KV - 1.2m.
- Above 11KV upto 33KV - 2.2 m.
- Above 33KV - 2m. plus 0.3m for every 33KV part there of.

Rule 85: Maximum interval between supports. It shall not exceed 65 m except by prior approval of inspector.

Direct and indirect Risks of electricity

- The main risks to personnel working in substation are electric shock, burns or falling arising from
- The possibility of misidentifying Equipment on which it is unsafe to work, for that on which it is safe to work.
- Inadvertently infringing Safety Clearance.
- Inadequate precautions to suppress or safely discharge any inducted or impressed voltage on the Equipment
- When working or testing is to be carried out on or near to Equipment in a substation, the area demarcation is to be determined by the maintenance engineer to the satisfaction of the Shift In charge.
- Risks Notices must be placed to inform personnel that adjacent Equipment is not included in the specified work area. The notice must be attached to or fixed adjacent to adjoining Equipment in sufficient numbers to be visible from the work area at all times.

The main risks to personnel during the course of testing are electric shocks, burns and other injuries arising from

- Accidental contact with Live Equipment due to improper isolation or discharge.
- Electrical energy and mechanical pressures and forces derived from testing sources.

The main Risks when working on transmission lines are:

- The possibility of personnel mistaking identification of the circuit on which it is safe to work with the one that is still energised.
- Infringing Safety Clearance before Additional Earths are applied.
- Inadequate precautions to exclude any induced voltages present on the conductors of fittings.
- Improper use of safety equipments.
- Effect of atmosphere / surroundings which may cause imbalance of hand and footholds.
- Imbalance state of mind.

The main Risks to personnel are electric shock or burns arising from

- The Discharge of electrical energy retained by the static capacitors after they have been Isolated.
- Inadequate precautions to guard against any induced voltages in the conductors or associated fittings.

The main Risk to personnel working on a Battery Bank are electric shock or burns arising from

- The possibility of personnel inadvertently shorting battery terminals.
- Dangerous spilling of electrolyte on body.
- Asphyxiation or suffocation due to fuming of storage battery acid.

Following are the Risks while working on SF, gas filled equipments:

- Since SF, gas is heavier than air, in the storage/work area in the absence of proper ventilation there is a danger of asphyxiation (Suffocation).
- Decomposition products e.g. Sulphur-fluoride & other toxic gases pungent or unpleasant odour and / or irritation of nose, mouth and eyes.

Voltage detectors

Voltage detectors are essential electrical safety tools used to detect the presence of electric voltage in electrical systems and circuits. These devices are commonly used by electricians, utility workers and other professionals who work with electrical equipment and systems. In this article, we will discuss the importance of voltage detectors, the various types of voltage detectors and their applications.

A voltage detector is a device used to detect the presence of an electrical voltage in a circuit or piece of equipment. It is designed to alert the user to the presence of a voltage, which could be dangerous if not handled correctly.

The device typically consists of a probe or sensor that is placed in contact with the electrical conductor or circuit. When the voltage detector identifies a voltage, it signals the user with an audible or visual indicator, such as a beep or light.

Types Of Voltage Detectors

There are several types of voltage detectors available. Some of the most common types include:

- Contact Voltage Detectors: A device that requires physical contact with the electrical circuit or wire to detect voltage. It usually consists of a probe that is attached to the conductor and the user needs to touch the probe to the wire or circuit to determine if it is live. Contact voltage detectors are considered to be more accurate and provide more reliable measurements than non-contact voltage detectors as they are in direct contact with the conductor.
- Non-Contact Voltage Detectors: Detect voltage without making contact with the conductor. These voltage detectors work by using a sensor that picks

up the electromagnetic field created by voltage around the wire or circuit and alerts the user with a visual or audible signal if voltage is present. Non-contact voltage detectors are generally safer to use than contact voltage detectors since they eliminate the risk of electrical shock and require less time and effort to operate in comparison to contact voltage detectors

- Pen-style voltage detectors: Small, portable and easy to use, these handy devices can detect voltage from just a few volts up to several hundred volts. These voltage detectors and are often used by electricians, maintenance technicians and other professionals.
- Digital Multimeter: A device that can measure voltage, current and resistance in an electrical circuit.

The decision between which type of voltage detector to use depends largely on the specific application it is being used for and the level of accuracy required.

Voltage Detector Applications

Voltage detectors are commonly used in the electrical and power industries to test for the presence of live wires or electrical circuits that are still energised. They are an essential tool for those working with electrical equipment or in environments where electrical hazards are present. Voltage detectors are used in various applications, including:

- Electrical Maintenance: Electricians and other professionals use voltage detectors to test electrical systems and circuits for the presence of voltage.
- Electrical Safety: Voltage detectors are crucial for electrical safety as they can detect the presence of voltage and prevent accidental contact with live electrical conductors or circuits.
- Troubleshooting: Voltage detectors can be used for troubleshooting electrical systems and circuits. These devices can help identify faulty components or circuits that are causing problems.

Benefits Of Voltage Detectors

When used correctly, voltage detectors can provide several benefits, including:

- Electrical Safety: Voltage detectors can prevent accidental contact with live electrical conductors or circuits, protecting workers from electrical shock or electrocution.
- Time and Cost Savings: Voltage detectors can help identify faulty components or circuits, saving time and money on troubleshooting and repairs.
- Convenience: Voltage detectors are easy to use and in many cases, portable, making them a convenient tool for electrical testing and troubleshooting.
- Working with electricity can be dangerous and voltage detectors are used to prevent accidental contact with live electrical conductors or circuits. However, it is important to realise the hazards associated with voltage detectors. The misuse or failure of voltage detectors can result in serious injury or death. False readings can occur if a voltage detector is not properly calibrated or if the batteries are low. Therefore, it is important to use voltage detectors that are tested and certified to ensure they meet industry safety standards.

Hot line maintenance at HV S/S

In electrical engineering, live-line working, also known as hotline maintenance, is the maintenance of electrical equipment, often operating at high voltage, while the equipment is energized. Although this is more hazardous for personnel than working on electrical equipment with the power off, live-line maintenance techniques are used in the electric power distribution industry to avoid the disruption and high economic costs of having to turn off power to customers to perform essential periodic maintenance on transmission lines and other equipment. The first techniques for live- line working were developed in the early years of the 20th century, and both equipment and work methods were later refined to deal with increasingly higher voltages. In the 1960s, methods were developed in the laboratory to enable field workers to come into direct contact with high voltage lines. Such methods can be applied to enable safe work at the highest transmission voltages.

The maintenance of line Conductos, line insulators, structural, parts etc, without de- energizing the line and with live line is called live line maintenance. The activities in live-line maintenance include:

- Repair of conductor of overhead line or overhead bus bars, overhead earthing wire, while circuit is live.
- Inspection from close distance while circuit live.
- Inspection/repairs/replacements of Insulators, with circuit live.
- Live line washing of insulators.

These terms associated with the state of the circuits are:

Live: Connected to the voltage source.

Dead: Disconnected and earthed.

Disconnected: Disconnected, not earthed.

Condition dead is safest, but under circumstances live line maintenance is essential.

Person working in the vicinity of a live conductor is subjected to electric field stress. If the person is insulated earth, he will be charged by the alternating electric field. The charging will depend upon the position of the person in the field and the field strength. If the person is touching the grounded part, current will flow through his body to the earth.

Live-line tools were first accepted for work on lines up to 34 kV, but many linemen were hesitant to perform hotstick operations on this voltage. Because of this fear, many companies restricted live-line maintenance to 22 kV or less. As linemen began to realize that the use of live-line tools always kept them at a safe distance from energized lines, they began to lose their fear of performing this work, and restrictions were gradually relaxed, until by 1930 several companies were permitting live-line operations to be performed on 66-kV lines.

Methods Of Live Line Maintenance

In general, there are three methods of live-line working which help workers avoid the considerable hazards of live line working. In various ways, they all serve to prevent current flowing from the live equipment through the worker. There are two basic Live Line methodologies for High Voltage (HV) work, which in industry terminology are called 'Hot stick' and "Bare-hand' methods: Using hot-stick methods, direct human contact with live components is avoided. Line workers use tools fastened to insulated fibre glass poles to carry out the work, and always keep themselves at a safe distance from the live components

- Hot stick or Live Line Tool
- Insulating Gloves or Rubber Gloves.
- Bare hand or Potential.
- Unearthed or De-energised.

a Hot stick or Live Line Tool (Fig 1)

A hot stick is an insulated pole, usually made of fiberglass. used by electric utility workers when engaged on live-line working on energized high-voltage electric power lines, to protect them from electric shock. Depending on the tool attached to the end of the hot stick, it is possible to test for voltage, tighten nuts and bolts, apply tie wires (twisted lengths of ductile wire which fasten the running cable to its supporting insulators), open and close switches, replace fuses. Lay insulating sleeves on wires, and perform various other tasks while not exposing the crew to a large risk of electric shock.

Hot sticks are made in different lengths, from simple 3 foot (1 m) sticks to 30 foot (9 m) telescoping models. Because the fiberglass provides electrical insulation, the

Fig 1

hot stick allows utility workers to perform operations on power lines safely without de-energizing them or while the state of the power line is not yet known.

This is essential because certain operations (such as opening or closing combination fuse/switches) must occasionally be performed on an energized line. Additionally, after a fault occurs, the exact state of a line may not be certain; in this case, for reasons of crew safety, the utility workers. Must treat the line as though it were energized until it can be proven that it is not and safety ground cables can be applied to the line (so that the line is guaranteed to remain grounded/earthed while maintenance is performed upon it). If power tools are fitted to the end of the hot stick, they are usually powered hydraulically rather than electrically because, like the fiberglass of the hot stick, the hydraulic fluid is also a good insulator. The hydraulic power is commonly supplied from the bucket truck (cherry picker or aerial work platform) supporting the workers.

In this method the lineman will be at ground potential, working with Hot Sticks (tools) keeping safe clearance from the line.

Table 1 Standards For Safe Working

Voltage range phase to phase in KV	Meters	Feets
46.1 - 72.5	0.91	3
72.60 - 121	1.02	3.4
138 - 145	1.07	3.6
161 - 169	1.12	3.8
230 - 242	1.52	5
345 - 362	2.13	7
500 -552	3.35	11

b Insulating Glove or Rubber Glove Working

Gloves protect the worker from exposure to the live part being worked upon sometimes referred to as the 1st point of contact, the point where current would enter the body should an inadvertent contact be made. Covers of insulating material such as blankets and linehose are employed in rubber glove working to protect the worker from exposure to a part at a different potential sometimes referred to as the 2nd point of contact, the point where current would leave the body should an inadvertent contact be made. Most utilities require work to be performed from an insulating platform to provide isolation from earth/ground potential hence the term "insulate and isolate"

c Bare hand or Potential (Fig 2)

Fig 2

Live-line work performed by placing the worker at the same potential as the conductor. Here the lineman will be working at line potential keeping safe clearance from ground. For this conductive suits made of 25% microscopic stainless steel and 75% nomex will be provided. In 1937, Michel Faraday proved that electricity between two points at the same potential is same. If a Lineman can be shielded in a Faraday Cage, and the cage is bonded to an energized conductor, he may work on the conductor and associated hardware without shock or discomfort.

Safety Precautions Taken During Live Line Working

A golden rule for hot line operation is "nothing is too safe when a life is at stake". Records prove that hot line work on high voltage lines is actually safer than maintenance work on "Cold" lines which could possibly become energized while the line is being worked. Linemen working with hot sticks are always conscious of the danger involved, and being aware of this danger they work more cautiously and keep a safe distance.

- While working it should be kept in mind that the person working invariably keeps a certain distance from the earth point. In addition to this he should also keep a certain safe distance from the other phases of the lines.
- Use freely safety equipment like cross-arm guards, hand gloves, etc.
- Never use a tool which is not tested and which is not familiar, never use a damp tool.
- Do not exceed the manufacturer's ratings in the use of hot line tools. Linemen must know the approximate weight of a conductor span and the line tensions which they are dealing with. When in doubt use a longer tool or two identical tools.
- Check each tool regularly for indicating that the tool may have been overstressed.
- When not in use, tools should be kept in the tool container and not on the ground.
- All the hotline tools shall be inspected manually and electrical strength test shall be carried out as per design at site.
- All the insulators in the string must be healthy except one or two depending on voltage class.
- Altitude correction factor should be applied in the above electrical clearances.
- Distance from inadvertent movement shall be considered depending on the work procedure and expertise of the lineman.

Isolators - Parts, Types, Function

Objectives: At the end of this lesson you shall be able to
- **state about isolators**
- **describe various types of isolators**
- **define principle operation of isolators**
- **explain role and application of isolators.**

Isolators

The isolator can be defined as, it is one type of mechanical switch used to isolate a fraction of the electrical circuit when it is required. Isolator switches are used for opening an electrical circuit in the no-load condition. It is not proposed to be opened while current flows through the line. Generally, these are employed on circuit breaker both the ends thus the circuit breaker repair can be done easily without any risk.

Electrical Isolator is used to separate any type of electrical component from the system while the system is offline/ online. Isolator doesn't include any kind of system for avoiding arching throughout disconnection. As in an electrical substation, an electrical isolator switch is mainly used for disconnecting a power transformer once it is in a no-load situation otherwise a little load is there. In full load condition, isolators don't operate.

Working Principle

An electric isolator working principle is extremely easy as it operates in different ways like manually operated, semi-automatic, and fully-automatic. Sometimes, these are used like switches so-known as electrical isolator switches. This switch can be opened or closed depending on the necessity. However, several times, these are arranged in a fixed position permanently to maintain isolation like transformers, in electrical transmission lines, grid stations.

An electrical isolator switch is one kind of device used to isolate a specific circuit by maintaining as well as preventing flowing currents. These switches are used in electrical appliances like kitchen tools, power grids, etc. Isolator switches are available in different types like a single-pole, double- pole, 3-pole, 4-pole, fused, and battery isolator switches.

Operation of Electrical Isolator

When there is no arc quench method is offered in the electrical isolator, it should be worked once there is no possibility of current flow throughout the circuit. So, no live circuit must be open otherwise closed through the isolator process.

A complete live closed-circuit should not be opened through the isolator process & also a live circuit should not be closed as well as completed through the isolator process to keep away from huge arcing among isolator contacts. So, this is the reason isolators should be open once the circuit breaker is open. Similarly, the isolator must be closed once the circuit breaker is before closed.

The operation of an isolator can be done through hand locally & using mechanical mechanism from remote location. The arrangement of motorized operation is expensive as compared with hand operation; therefore choice must be taken before selecting an electrical isolator for the system which operates manually or mechanically is best for the system

The isolators which operate manually can be operated by using the system with up to 145 kV whereas, for high voltage systems using 245 kV otherwise 420 kV, motorized isolators are utilized.

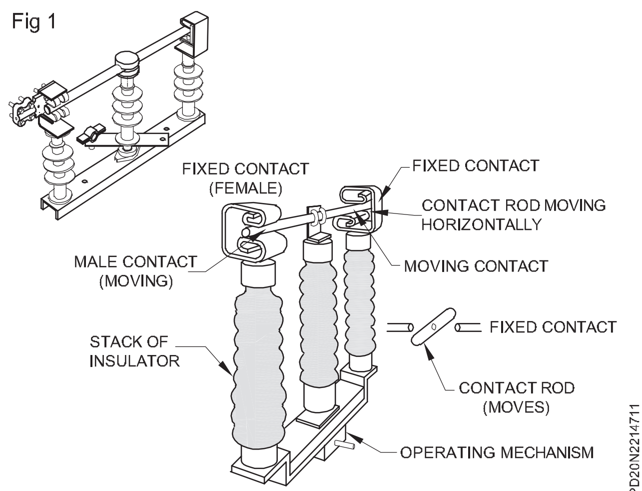
Types of Electrical Isolator

The electrical isolators are classified based on the requirement of the system which includes the following.

- Horizontal Centre Break Type Isolator
- Double Break Type Isolator
- Pantograph Type Isolator

Horizontal Center Break Type Isolator (Fig 1)

Fig 1



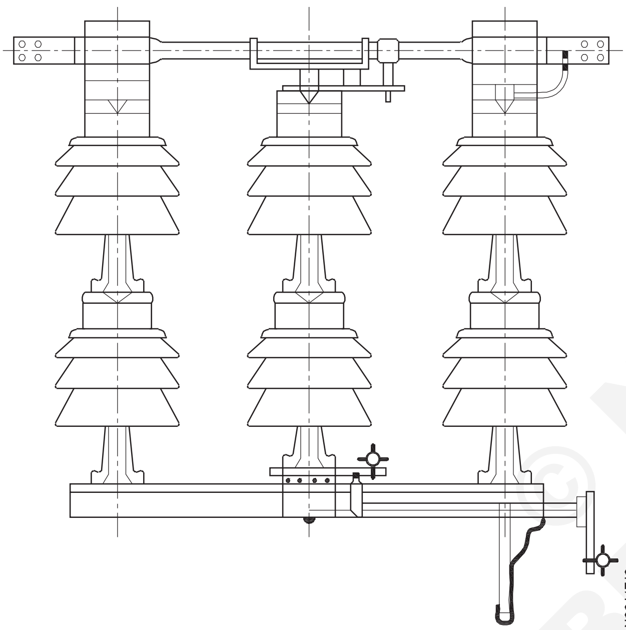
The triple pole Center/Single break type isolator is rotating type gang operated, Manual/Motor operated and designed for outdoor application. The isolator is designed to suit overhead systems used in high density urban situations or high load centers, where the load is much higher and the need of improved and steady quality power supply is much greater. Main function of this product is to isolate the Transformer, Overhead lines, System or Cables from distribution network.

It is designed to be mounted in horizontal upright position on structure. Install three phases of isolator on structure parallel to each other, couple the pole with coupling pipe, link it with operating lever, align all the elements in ON position, fix the operating pipe vertically and clamp the manual & motor operated mechanism

Double Break Type Isolator (Fig 2)

This type of isolator consists of three loads of post insulators. The middle insulator holds a flat male or tubular contact that can be turned straightly by a spin of the middle post insulator. The rotation of the middle post insulator can be done by a lever method at the bottom of the post insulator, as well as it is related to manual operation (operating handle) or motorized operation motor (using motor) of the isolator via a mechanical knot rod.

Fig 2



33 KV DOUBLE BREAK ISOLATOR (TURN & TWIST)

Pantograph Type Isolator (Fig 3)

The pantograph type isolator permits current switchgear installation, and it requires the least space. This type of insulator includes a post insulator as well as an operating insulator

What is the Role of Isolator in Transmission Line?

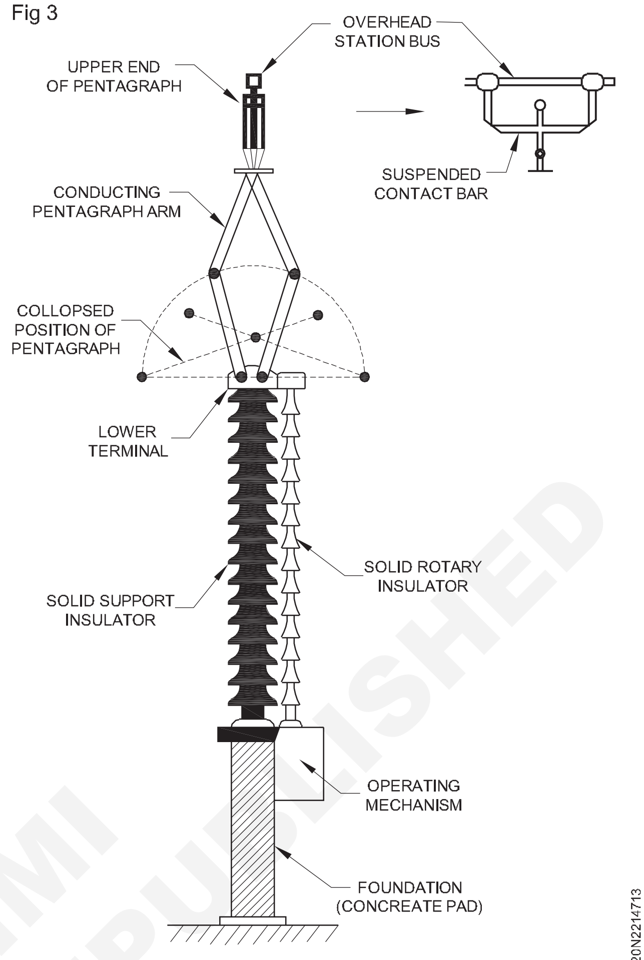
Electrical isolators play a key role within a transmission line like insulators isolate the transmission line from the conductor. Here, isolators are mainly useful to eliminate grounding loops like lowering the hazard of accidental lanes for the flow of current towards the ground.

Applications of isolator

The applications of isolators include the following.

The applications of Isolators involve high voltage devices such as transformers.

Fig 3



PANTOGRAPH TYPE ISOLATOR

These are protected with a locking system on the external or with a lock to stop accidental usage.

Isolator in Substation: When a fault occurs in a substation, then the isolator cuts out a portion of a substation.

Thus, this is all about an overview of the electrical isolator. The characteristics of this isolator include it is an offload device, operated manually, De-energize the circuit, entire isolation for secure maintenance, includes a padlock, etc.

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Fig 4

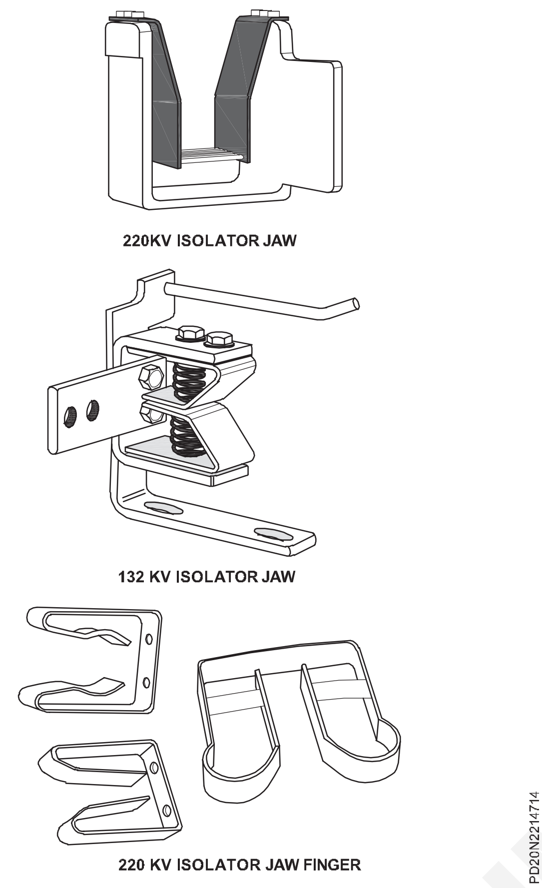
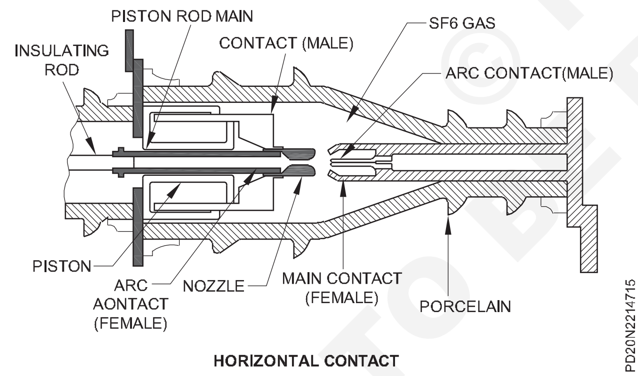


Fig 5



Types of Jaws and Blades of various is Isolator

Types of Male and Female contacts

In electrical and mechanical trades and manufacturing, each half of a pair of mating connectors or fasteners is conventionally assigned the designation male or female.

Male contact which is also known as rotating contact and female contact which is also known as isolator jaw or fixed contacts

There are two types of Male and Female contact

1 Horizontal

2 Vertical.

Fig 6

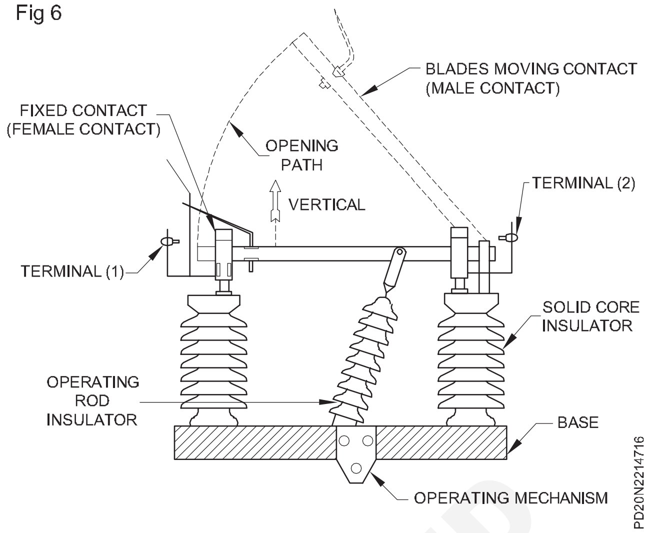


Fig 7

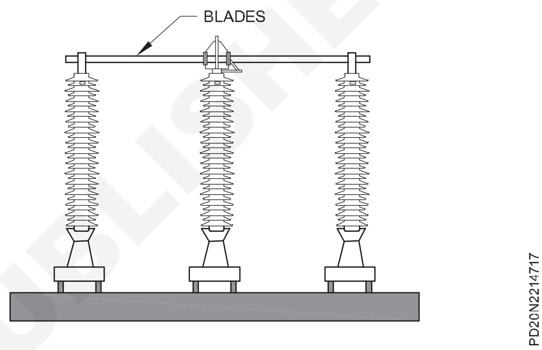


Fig 8

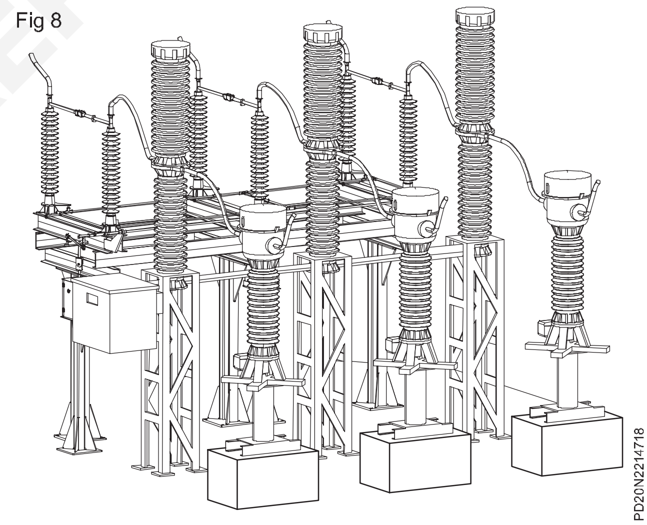


Fig 10

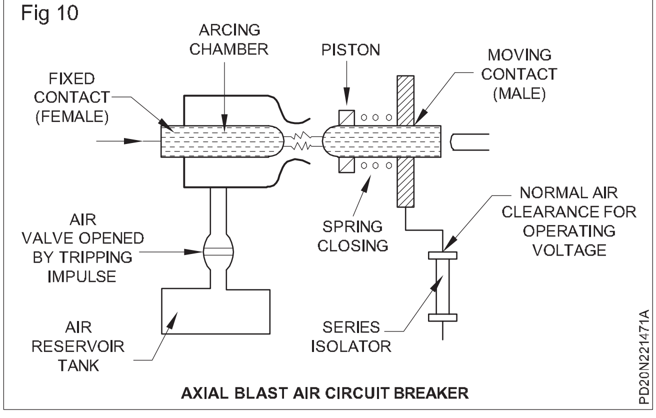
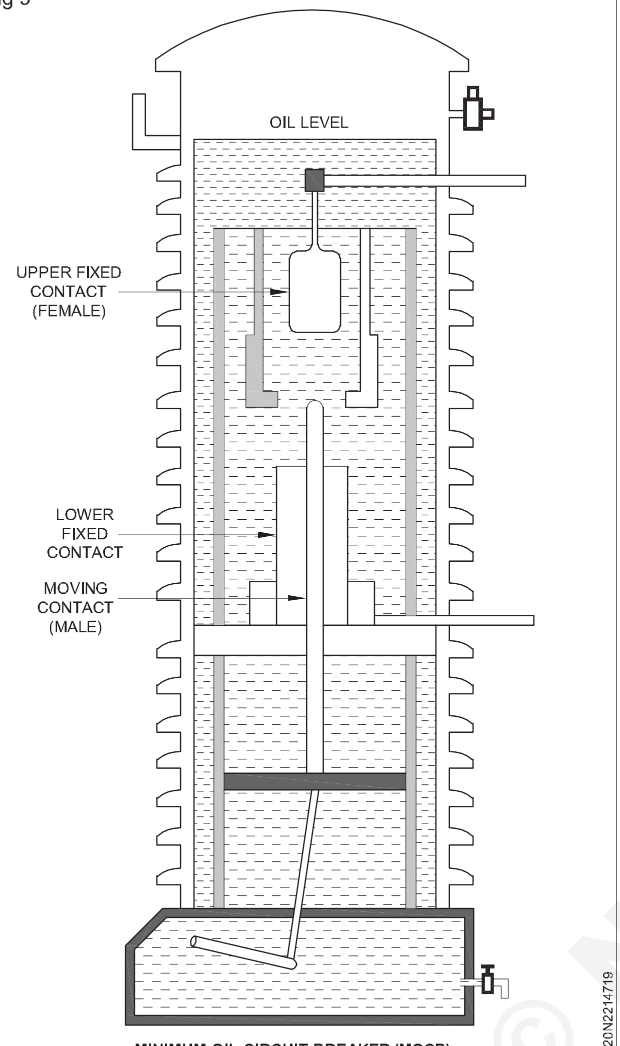


Fig 9



MINIMUM OIL CIRCUIT BREAKER (MOCB)

Fig 11

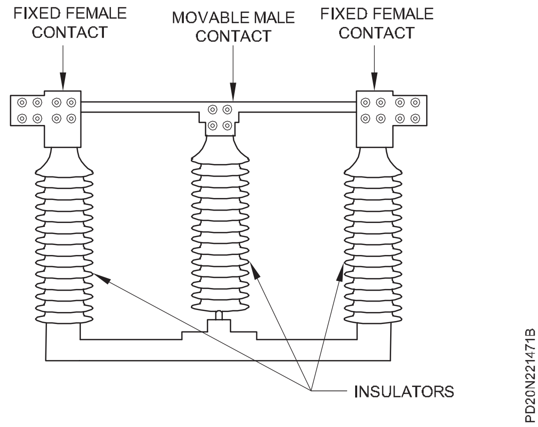
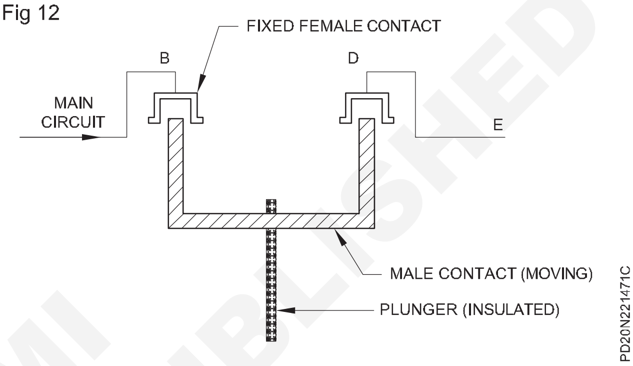


Fig 12



Circuit breakers - Parts - Functions- Tripping Mechanism

Objectives: At the end of this lesson you shall be able to
- **state about 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 this case the resultant spark at the contacts are negligible and this will not make any fire, in the circuit or contacts since the current is very low.

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. The breakers are named after the quenching medium used to control the fire such (1) air circuit breaker, (2) oil circuit breaker, (3) vaccum circuit breaker and (4) Sulphur hexafluoride (SF_6) 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.

ACB is widely used upto 15KV in place of oil circuit breaker because there is no chance of the fire due to the quenching oil as in case of OCB.

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. Other components are also associated with circuit breakers like fuses, relays, switches etc.

Construction of air - circuit breaker

External lables / parts of ACB in Fig.1

1 OFF button (O)

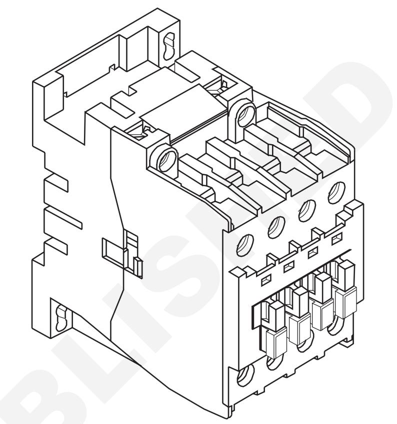
2 ON button (I)

3 Main contact position indicator

4 Energy storage mechanism status indicator

5 Reset button

Fig 1



EXTERNAL VIEW OF ACB

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

1 Sheet steel supporting structure

2 Current transformer for protection trip unit

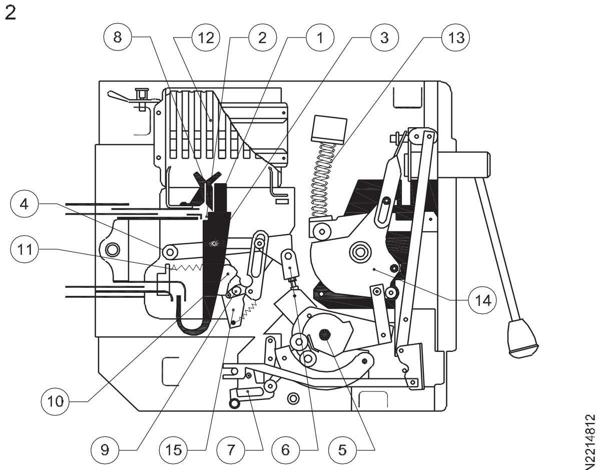
3 Pole group insulating box

4 Horizontal rare terminals

5 Plate for fixed main contacts

6 Plates for fixed arcing contacts

Fig 2



INTERNAL VIEW OF CIRCUIT BREAKER

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.

Types of air circuit breaker

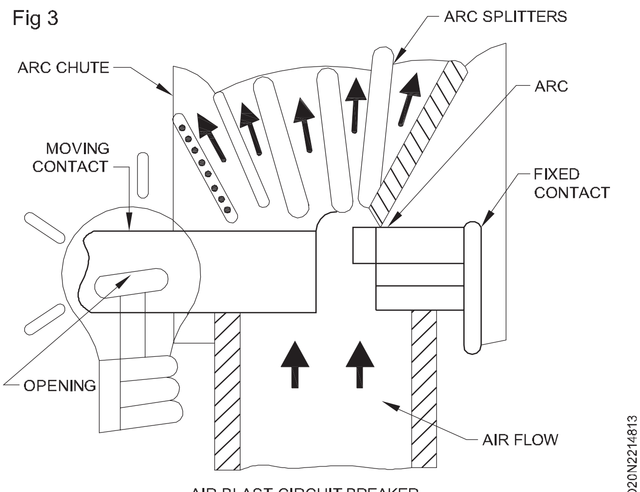
- Plain air circuit breaker
- Air blast circuit breaker

Plain air circuit breaker

In this circuit breaker a chamber is fitted surrounding the contact. The chamber is known as **"arc chute"**. The arc chute will help in achieving cooling. Arc chute is made from some refractory material.

The arc chute is divided into a number of small compartments by using metallic separation plates called **arc splitters** and behave as a mini arc chute as in Fig 3 Initial arc will split into a series of arcs and make the arc voltages higher than system voltage. They are preferable choice in low voltage application.

Fig 3



AIR BLAST CIRCUIT BREAKER

Air blast circuit breaker

ACB which uses the high pressure (blast) air as an Arc quenching medium is known as Air-Blast- Circuit-Breaker(ABCB).

This type of circuit breaker is used for high voltage application and can be further divided into three categories.

- Axial blast air circuit breaker
- Cross blast air circuit breaker
- Radial blast air circuit breaker

Advantages of air - blast circuit breaker

- Air blast circuit breaker is used where the frequent operation is required because of lesser arc energy.
- The risk of fire due to oil is eliminated in the air blast circuit breaker
- Arc quenching is much faster
- Air blast circuit breaker is small in size, because of the fast Arc quenching.
- The duration of the arc is same for all the values of current.
- Operating speed of circuit breaker is much higher.
- Stability of operation is high because of speed of operation.
- It requires less maintenance

Disadvantages of air -blast circuit breaker

- Additional air supply plant requires hence require additional maintenance.
- It require high capacity air compressor.
- There is a chance of air pressure leakage.
- There is chance of a high rate of re - striking voltage and current chopping.
- The air has relatively lower arc extinguishing properties than oil.

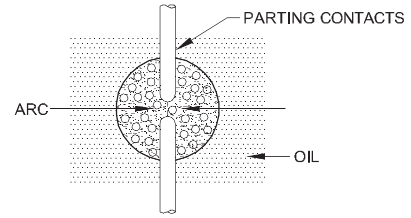
Oil circuit breakers (OCB)

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 4. The result is that arc is extinguished and circuit current is interrupted.

Fig 4



CIRCUIT BREAKER

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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.

The disadvantages of oil as an arc quenching medium.

i It is inflammable and there is a risk of a fire.

ii It may form an explosive mixture with air.

iii The arcing products (e.g. carbon) remain in the oil and it deteriorates the quality of insulating oil.

iv Periodic checking and replacement of the insulating oil is required.

Types of oil circuit breakers

a Plain break oil circuit breakers

b Arc control oil circuit breakers.

i Low oil circuit breakers

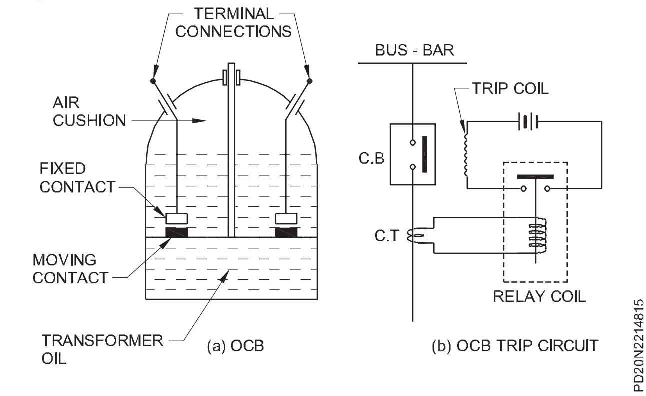
Plain break oil circuit breakers

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 5 shows a double break plain oil circuit breaker. It is called a double break because it provides two breaks in series.

Fig 5



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.

Disadvantages

i There is no special control over the arc other than the increase in gap length.

ii These breakers have long and inconsistent arcing times.

iii The speed of interruption is less.

Due to these disadvantages, plain - break oil circuit breakers are used only for low - voltage not exceeding 11 KV applications where high breaking- capacities are not important.

Arc control oil circuit breakers

In plain -break oil circuit breaker there is very little artificial control over the arc. Therefore long arc length is essential in order to quench the Arc. If some arc control is incorporated at still short contact gap than the breakers are called arc control oil circuit breakers.

They are two types

a Self - blast OCB

b Forced - blast OCB

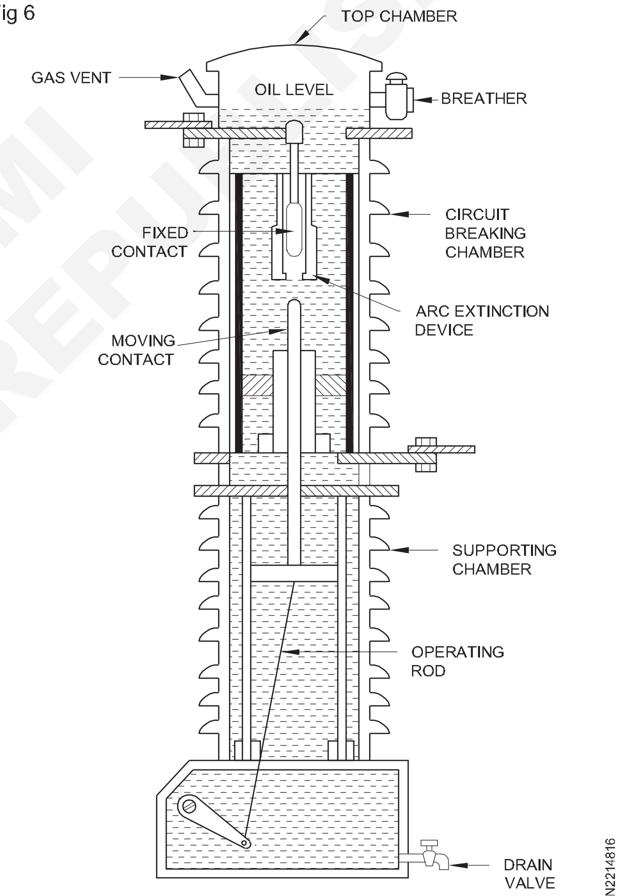
Low oil circuit breakers

In the bulk oil circuit breaker, only a small percentage of oil (about 10% of total) is actually used for arc extinction. But the huge volume of oil used in bulk oil circuit breaker increases the expenses, tank size, weight of the breaker, increases the fire risk and maintenance problems.

To over come the above disadvantages the low oil circuit breaker is developed which employs solid materials for insulation purposes and uses a small quantity of oil which is just sufficient for quenching the arc. By using suitable arc control devices, the arc extinction can be further simplified in a low oil circuit breaker.

Construction : Fig 6 shows the single phase low oil circuit breaker. There are two compartments separated from each other and filled with oil. The upper chamber is the **circuit breaking chamber** whereas the lower one is the **supporting chamber**. The two chambers are separated and the oil from one chamber is prevented from mixing with the other chamber.

Fig 6



LOW-OIL CIRCUIT BREAKER

This arrangement has three advantages.

1 The circuit breaking chamber requires a small volume of oil which is enough for arc extinction.

2 The amount of oil to be replaced is considerably reduced

3 The oil in the supporting chamber does not get contaminated by the arc.

i **Supporting chamber :** It is a porcelain chamber filled with oil which is physically separated from the oil in the circuit breaking compartment. The oil inside the supporting chamber and porcelain insulation is employed for insulation purposes only.

ii **Circuit breaking chamber :** It is a porcelain enclosure mounted on the top of the supporting chamber and filled with oil and has the following parts.

a Fixed contacts

b Moving contacts

c Turbulator

The moving contact enters top chamber through a fixed piston. The turbulator is an arc control device and has both axial and radial vents. The axial vent for low currents whereas radial vent for heavy currents rating breakers.

iii **Top chamber :** It is a metal chamber mounted on top of the circuit - breaking chamber. It provides space for the oil expansion in the circuit breaking chamber. The top chamber also has a gas vent pipe and breather through which the escaping gas and entering air may pass through to the circuit breaking chamber during the breaking of fault current.

Operation : Under normal operating conditions, the moving contact engages with the fixed contact. When a fault occurs, the moving contact is pulled down by the tripping mechanism and an arc is produced. The arc vaporizes the oil and produces gas to escape through the gas vent.

This action results the oil to pass through a central hole of the moving contact and forcing the oil through the respective vents of the turbulator. The arc are successively quenched by the effect of streams of oil passes through the vent while gas passes.

Advantages : A low oil circuit breaker has the following advantages over a bulk oil circuit breaker.

i It requires lesser quantity of oil

ii Cost of the breaker is less

iii It requires smaller space

iv The weight of the breaker in less

iv There is reduced risk of fire

vi Maintenance problems and cost are reduced

Disadvantages : A low oil circuit breaker has the following disadvantages as compared to a bulk oil circuit breaker

i There is a difficulty of removing the gases from the contact space.

ii Due to smaller quantity of oil, the effect of carbonization is increased.

iii The dielectric strength of the oil deteriorates fastly due to high degree of carbonization.

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.

The technology is only suitable for medium voltage application. For higher voltage application, the vacuum technology has been developed.

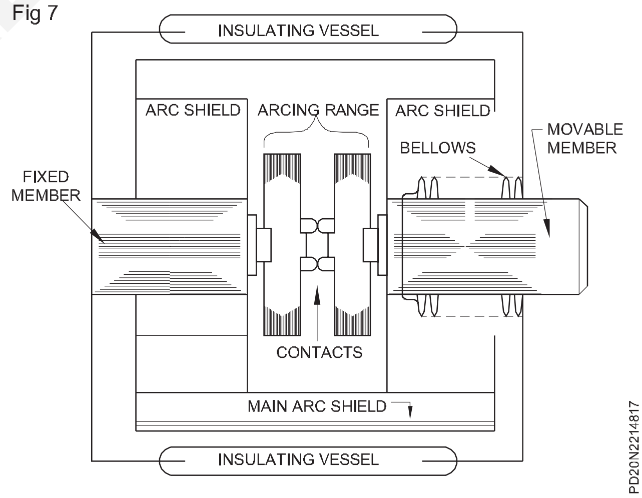
Principle of vacuum circuit breaker

- 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 7 shows the typical parts of vacuum circuit breaker

Fig 7



- 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.

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

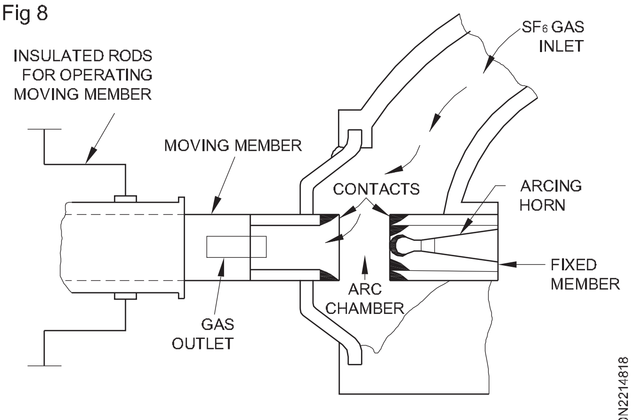
A sulphur hexafluoride (SF_6) circuit breaker consists of fixed and moving contacts enclosed in a chamber as in Fig 8. The chamber is called arc interruption chamber which contains the sulphur hexafluoride (SF_6) gas and it is connected to sulphur hexafluoride (SF_6) gas reservoir.

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.

Fig 8



TYPICAL INTERNAL VIEW OF SF_6 - CB

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.

SF_6 HANDLING PROCEDURE

a When exposed to sustained or intense electrical arcs. SF_6 gas decomposes to form sulfur-fluoride gases and meial-nuorides, which are loxic. if moisture is present, the decomposition by-produccs may also include sulfur-oxyfluoridcs, hydrofluoric acid and sulfuric acid. The Presence of these by-products can be readily detected by a white or gray powdery substance or a very pungent odor similar co rotten eggs.

b All in-service SF_6 equipment shall be assumed to contain decomposition by-products, unless the gas has been tested as Safe. When handling gas containing SF6 are by-products or solid by-products the following cautions are applicable:

i Personnel are to wear the appropriate protective clothing/ equipment.

A gas-handling unit equipped with a vacuum pump, storage tank(s),and filtration equipment necessary to recycle SF_6 gas.

The Storage tank(s) on these carts is either a large central reservoir or one or more DOT- approves cylinders.

Reservoir-equipped carts shall not be transported over public roadways if the gas pressure is above 25 psig, unless the cart is properly certified for transportation of compressed gas.

1 The amount of SF_6 gas voluntarily discharged into the atmosphere shall be minimized.

2 The Person in Charge is responsible for recording the instances of equipment being filled with SF_6

3 These instances of filling shall be recorded and entered into the appropriate substation maintenance priority system program. The number of times a piece of equipment is filled with SF_6 due to a leak will be used to help prioritize repair of the leak or replacement of the equipment.

4 To facilitate the transfer of SF_6 gas store cylinders Indoors and preheat cylinders with a blanket heater of appropriate design.

5 Prior to topping off, all filling pipe work, valves, etc, should be clean and dry. Cap off all hoses after use to maintain cleanliness and dryness.

6 Loosely connect hose to gas compartment valve.

7 Partially open the gas cylinder valve.

8 Allow SF_6 to flow through the hose and purge the air.

9 Scale all fittings as soon as the air is purged.

10 Open gas compartment valve and fill to the appropriate pressure.

Removal of Sulfur Hexafluoride Gas from In-service Equipment

1 Prior to removal of gas, check the gas compartment and associated devices for leaks using an approved halogen leak detector. Test the gas for arc by-products if there is a possibility of an internal failure.

2 Identify any components that must be repaired while SF, gas is evacuated from equipment.

3 Obtain replacement parts as necessary to repair leaks.

4 Attach the hose from the SF, Processing Cart to the gas compartment valve.

5 Draw a vacuum on the hose to remove air and moisture. Check for leaks.

6 Open the gas compartment valve.

7 Remove SF, gas from the gas compartment via the processing cart filtration system as described in the processing cart operating/maintenance instruction booklet.

8 Draw a vacuum on the gas compartment to complete the SF, gas removal process. High level of vacuums should not be drawn if equipment leaks will result contaminating the processing cart with air.

9 Break vacuum with nitrogen or dry air as applicable.

10 SF, Gas that is to be reused on the same equipment may be kept in the processing cart until maintenance is complete.

a If equipment is to be retired from use, SF, gas must be transferred to DOT approved cylinders

b Reservoir equipped gas carts must not be transported over public roadways if gas pressure exceeds 25 psig at 68° F unless the cart is properly DOT certified for transportation of compressed gas.

11 Clean interior of equipment in accordance with Section D prior to working on any internal parts.\

12 When equipment is to be returned to service, seal all portholes and fittings.

13 Fill the equipment in accordance with Section E.

Removal of Hazardous Solid By-Products:

1 After the SF, gas has been removed from the gas compartment and prior to opening the gas compartment's porthole(s), put on the following approved protective outerwear.

a Clothing, protective, rainwear - (In hot weather, a lighter weight poly-coated tyvek suit may be worn)

b Glove, safety, disposable, polyethylene, large, clear

c A supplied air respirator or a half-face or full-face reusable respirator, with two HEPA cartridges for organic vapor/acid gas.

d Goggles, chemical splash resistant, without vent, clear lens (if using half-face respirator) --

e Disposable pullover boot.

2 Open the porthole(s) to gain access to the gas compartment.

3 Before entry, ventilate gas compartment with a 50-cfm blower for at least one-half hour.

4 Test the compartment with an approved air monitor to verify a minimum of 20.9% oxygen and no presence of combustible gases including carbon monoxide.

5 Using an approved halogen leak detector, perform checks at various low points within the gas compartment to determine any presence of SF, gas.

6 Continue ventilation in low point areas until the detector indicates that SFs gas has been purged.

7 Continue ventilation while work is being performed.

8 Remove contaminated powdery deposits using an approved vacuum cleaner equipped with High-Efficiency Particle Arresting (HEPA) filters. NOTE: These deposits must be removed promptly once the gas compartment is opened, since they readily absorb

moisture, becoming corrosive and sticky, and making their removal more difficult.

9 After using the vacuum, clean up any powdery residue using approved wipes.

10 Place powdery deposits contained in the vacuum cleaner disposal bag along with any wipes and other contaminated materials in a plastic waste bag

11 Upon completion of repair and/or maintenance work, seal all portholes of the gas compartment.

12 Remove protective outerwear.

13 Place disposable coveralls, gloves, boots, and respirator cartridges, and any other contaminated materials in the plastic waste bag

14 Secure bag with filament tape.

15 Place plastic waste bag in an appropriately sized container, such as a 55 gallon drum or a 5- gallon can. SF6 by-products are corrosive and should not be placed directly in contact with a metal storage container.

16 Wash face and hands following completion of work and before eating or drinking.

17 In the states of Massachusetts and New York the waste shall be labeled as non-hazardous waste. In Rhode Island, New Hampshire and Vermont the waste shall be labeled as hazardous waste. The label shall be filled out with the date and contents. In all states the same personnel protective equipment shall be worn by employees since the waste is a corrosive solid and is regulated by OSHA in the same manner in each state.

Filling Equipment with Sulfur Hexafluoride Gas after servicing using a Gas Handling Apparatus:

1 Obtain an SF, gas reclaimer

2 Connect hose to gas compartment valve and tighten all fittings.

3 Evacuate hose using vacuum pump. Check for leaks

4 Evacuate equipment to the level and for the time specified by the manufacturer.

5 Break vacuum using SF, gas.

6 Open gas compartment valve.

7 Fill and pressurize the equipment per manufacturer's instructions.

8 Close gas compartment valve.

9 Using the vacuum pump and gas compressor reclaim the SF, from the hose back into the gas cart.

10 Disconnect hose from gas compartment valve and cap hose fitting.

H.V. Oil Circuit Breakers: Phenomenon of Arc Formation and its Quenching.

Circuit breakers are called upon to operate under short circuit conditions during which the current may be of the order of 8000 to 50000 Amps for voltages of 11 kV only. For higher voltage, the amount of short-circuit current shall be even more tremendous. When this amount of short circuit current is broken by separation of moving and fixed contacts, a heavy amount of arcing is bound to happen.

At the instant, when the contacts of a circuit breaker begin to part, there is a large current and a small voltage drop. Separation of contacts by small distance does not result in immediate cessation of current, because, as the contacts separate, the resistance between them increases and ohmic loss I^2R generates sufficient heat to ionize the air (in case of A.C.B's) or vaporize and ionize the oil vapour (in case of O.C.B's). The ionized air or oil vapour acts as a conductor, because of the large number of free electrons present and the current flows without immediate change across the are so formed. The potential drop between the contacts is just sufficient to maintain the arc and is quite small. The action of separating the contacts draws the arc out, but it is not practicable to draw are out to such a length that voltage available is insufficient to maintain the arc, as in high voltage systems a separation of many metres would be necessary for this purpose.

The conductance of the arc is proportional to number of electrons per cubic cm produced by ionisation, the square of diameter of arc and reciprocal of length. The conductance cannot be reduced by increasing the length of the are which will necessitate space in abun- dance. Therefore means should be devised to reduce the density of ionization and diameter of arc.

Repair and Maintenance of Circuit breakers Lightning arrester, Wave trap, PLCC

Objectives: At the end of this lesson you shall be able to
- **about the opening and closing time of HVCB**
- **mainteance of equipment grounding rod**
- **lighting arrester, wave trap**
- **LMU, PLCC, contant resistance.**

Opening and closing time of high voltage circuit breaker

The opening time of a high-voltage circuit breaker refers to the total time that the circuit breaker needs receiving a tip command (that is, the tripping coil is applied with voltage) to the time the circuit breaker opened until the three-phase arc is completely extinguished, called the full opening time. The full open is equal to the sum of the inherent opening time and the arcing time.

The inherent opening time refers to the period from when the circuit breaker receives a trip command to when the contacts are just separated.

The arcing time refers to the time from the moment the contact is separated to the complete extinguishment of the arc.

From the perspective of the power system's requirements for breaking short-circuit current, it is hoped that the opening is as fast as possible. Then, the inherent opening time and arcing time must be shortened as much as possible. The general opening time is 60-120ms. Circuit breakers whose opening time is less than 60ms are called fast circuit breakers.

The closing time of a high-voltage circuit breaker refers to the time required for the circuit breaker from receiving a closing command (i.e, applying voltage to the closing coil) to the time when the three-phase main contacts of the circuit breaker are in contact. The power system does not have strict requirements on the closing time, Generally, the closing time is greater than the opening time, but stability is hoped.

The different period of opening and closing time of the high-voltage circuit breaker refers to the maximum time difference between the opening and closing of each phase of the circuit breaker or the fracture of the same phase. The national standard stipulates: when there is no special requirement for the synchronization requirements of each phase, the different period of opening and closing should not be greater than 5ms, the different period of closing of 363kV and above should not be greater than 5ms, and the different period of opening should not be greater than 3ms.

Maintenance of equipment grounding rod

During fault conditions, low impedance results in high fault current flow, causing over current protective devices to operate, clearing the fault quickly and safely. The grounding system also allows transients such as lightning to be safely diverted to earth.

Use equipment grounding conductors sized equal to the phase conductors to decrease circuit impedance and improve the clearing time of over current protective devices.

Bond all metal enclosures, raceways, boxes, and equipment grounding conductors into one electrically continuous system. Consider the installation of an equipment grounding conductor of the wire type as a supplement to a conduit-only equipment grounding conductor for especially sensitive equipment.

Recommended practice is to space multiple ground rods a minimum of twice the length of the rod apart. Install deep-driven or chemically-enhanced ground rods in mountainous or rocky terrain, and where soil conditions are poor. Detailed design of grounding systems are beyond the scope of this document.

Poor grounding contributes to downtime but an excess of good grounding is also dangerous and increases the risk of equipment failure.

The purpose of earthing is to ensure human safety as well as instrument safety. Higher earth resistance can cause fault currents to flow through human body causing serious injury or death. The ideal value of earth resistance should be around 5 Ohms.

We often add water & add salts at regular intervals into the earth pits in order to maintain the value of earth resistance. This keeps the earth pit moist and damp. Over a period of time, the corrosive soils with high amount of moisture, salt content and high temperatures can degrade the earthing electrodes and their connections. The earth resistance when the earthing electrodes are installed is lower but over a longer period, the earthing rods starts eroding ultimately increasing the resistance of the ground. This may result in bad earthing adding to the risk of loss of safety.

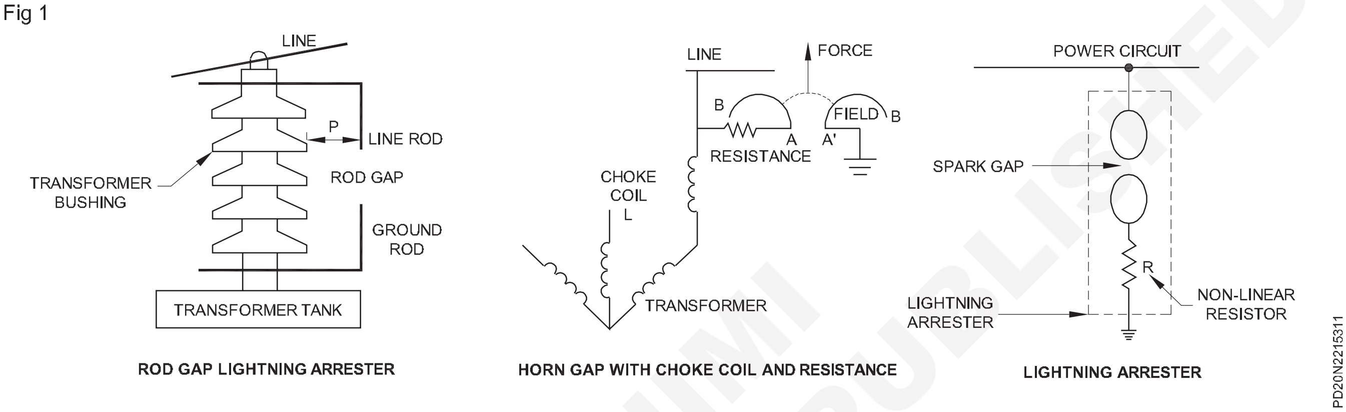
With increase in value of earth resistance, if exceeds 20 per cent, the technician should investigate the source of problem and make the correction to lower the resistance by replacing or adding ground rods to the system. Therefore, we can state that water and salts added in order to improve earth resistance over a period of time are also responsible for eroding the earth electrode ultimately increasing the earth resistance. Hence, it is necessary to check annually the condition of the electrodes so as to add or replace electrodes in order to reduce risk

Lightning arresters

A lightning arrester is a device, essentially an air gap between an electric wire and ground, used on electric power transmission and telecommunication systems to protect the insulation and conductors of the system from the damaging effects of lightning. The typical lightning arrester has a high-voltage terminal and a ground terminal. When a lightning surge (or switching surge, which is very similar) travels along the power line to the arrester, the current from the surge is diverted through the arrester, in most cases to earth.

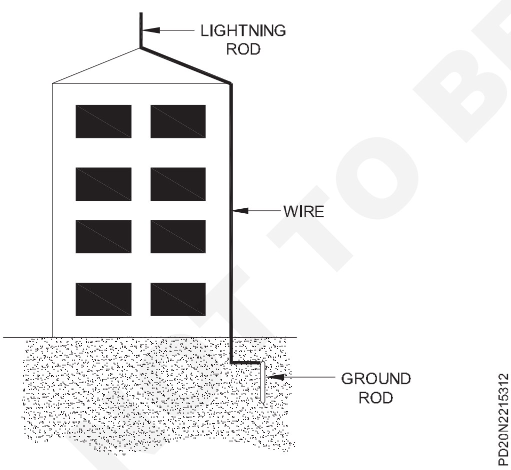
Lightning arresters are connected between each conductor in power and communications systems and the earth. These prevent the flow of the normal power or signal currents to ground, but provide a path over which high-voltage lightning current flows, bypassing the connected equipment. Their purpose is to limit the rise in voltage when a communications or power line is struck by lightning or is near to a lightning strike. (Fig 1)

Fig 1



A lightning rod or lightning conductor is a metal rod mounted on a structure and intended to protect the structure from a lightning strike (Fig 2)

Fig 2



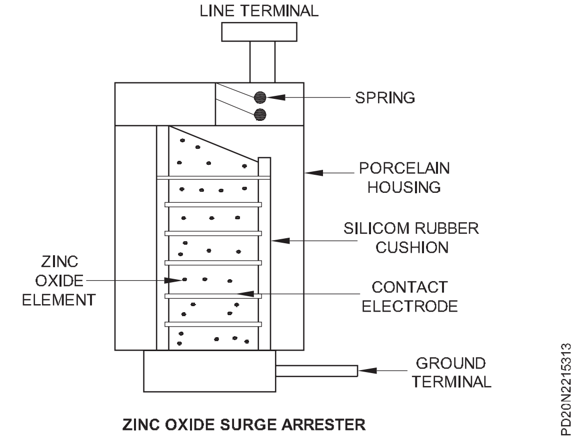
Surge Counter

Surge Counters are used to monitor the health of Surge Arresters and protect against potentially damaging events which could lead to deterioration and ultimate overload.

Impulse discharges through the arrester must also pass through the surge counter as it is insulated from, and mounted at the base of the arrester, and connected between the arrester ground terminal and the station ground. The counter will register impulse discharges through the arrester of an amplitude of 40 amperes or greater. The counter is capable of up to five registrations per second and operates without any external power source. The counter has negligible effect on the overall protection afforded by the surge arrester, since the potential across the counter is only 5000 volts during a discharge {and less than 200 volts under normal operating conditions).

Metal oxide surge arresters are commonly used in electrical networks and devices to protect them from high-voltage surges. The metal oxide semiconductor material in the arrester acts as a resistor, and it’s designed to absorb energy from any surge of voltage or current that exceeds (Fig 3)

Fig 3



Wave trap

Wave trap is a device which prevents the high-frequency carrier signals to enter the substation side. It is also known as line trap. It is connected in series with the transmission line. It is designed to carry the rated power frequency (50 Hz or 60 Hz) current, as well as to withstand the substation fault currents.

Line traps are cylinder-like structures connected in series with HV transmission lines.

The line trap acts as a barrier. or filter to prevent signal losses. The inductive reactance of the line trap presents a high reactance to high-frequency signals but a low reactance to mains frequency. This prevents carrier signals from being dissipated in the substation or in a tap line or branch of the main transmission path and grounds in the case of anything happening outside of the carrier transmission path. The line trap is also used to attenuate the shunting effects of high-voltage lines.

The trap consists of three major components: the main coil, the tuning device, and the protective device (also known as a surge arrester). The protective and tuning devices are mounted inside the main coil. A line trap may be covered with a bird barrier, in which case there are four components.

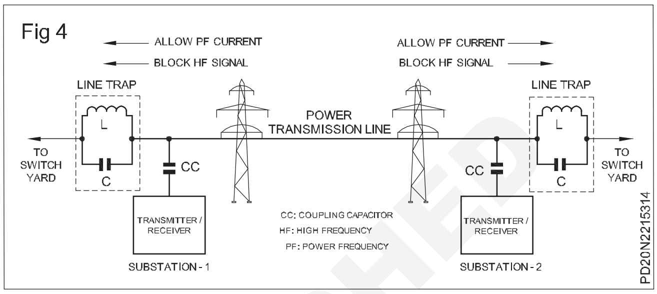
The main coil is the outer part of the line trap which is made from stranded aluminum cable. The reactor coil, depending on the device, can be made up of several aluminum wires, allowing equal distribution amongst the parallel wires. The stranded aluminum coil is wound in one layer. However, when the application of more than one layer is necessary, separation between layers is required to provide a cooling duct between them to avoid overheating. The cooling duct is created with spacer bars made out of epoxy resin and fiberglass. The coil carries rated continuous power frequency currents, therefore this is the power inductor in this system. It provides a low impedance path for the electricity flow)3I Since the power flow is rather large at times, the coil used in a line trap must be large in terms of physical size. Hence, a line trap unit is inserted between the busbar and connection of coupling capacitor to the line. It is a parallel tuned circuit containing inductance and capacitance. It has low impedance for power frequency and high impedance to carrier frequency. This unit prevents the high frequency carrier signal from entering the neighboring line.

The next major component is the tuning device. This device is securely installed inside the main coil. It adjusts blocking frequency or bandwidth, and consists of coils, capacitors, and resistors. This smaller coil is attached to both ends of the main coil. Its purpose is to create a blocking circuit which provides high impedance. There are three types of tuning devices: wide band tuning, single frequency tuning, and double frequency tuning. The tuned circuit is usually a dual-circuit broadband type. If the traps are self tuned, they do not require the use of any tuning devices. With the use of a tuning device, a line trap can be tuned to a frequency of 1000 Hz.

The last main component is the protective device, which is parallel with the main coil and the tuning device. It protects the main coil and the tuning device by lowering the over-voltage levels. The bandwidth of a line trap is the frequency range over which the line trap can provide a certain specified minimum blocking impedance or resistance.

Line traps are connected in series with power line and thus their coils are rated to carry the full line current. The impedance of a line trap is very low at the power frequency and will not cause any significant voltage drop. (Fig 4)

Fig 4



Line Matching Unit for PLC

Line matching unit for power line communication is a fundamental component of the power line infrastructure which provides galvanic insulation from the High Voltage power line, offering optimal impedance adaptation and efficient passage for high frequency communication signal.

LMU is also known as Coupling Device. Together with coupling capacitor, LMU serves the purpose of connecting Audio/Radio frequency signals to PLCC terminal and protection of the PLCC unit from the over voltages caused due to transients on power system

Power line carrier communication (PLCC)

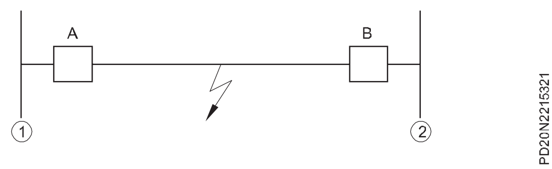
(PLCC) technology has been frequently used since 1950 by the grid stations to transmit information at high speed. Transmitting information along high-voltage lines, at high frequency, has been one of the main means of communication in electric power for over fifty years. The data collected from different sensors is transmitted on power lines thereby reducing the maintenance cost of the additional wiring. In some countries, this technology is also used to provide Internet connection. In order to communicate, high-frequency line traps are used as they allow substations to communicate with each other through the power lines at the same time as they transmit electrical power. In order to separate power from messages being sent, different frequencies are used. Electrical power has a frequency of 50 Hz or 60 Hz in most places, and the communication waves use frequencies such as 150 kHz and 200 kHz. Line traps consist of filter circuits that allow only power frequency waves to travel to that of electrical equipment. They also stop communication waves from traveling to equipment.

Power Line Carrier Communication, often called PLCC, is used for speech data transmission as well as protection of Transmission Lines. Carrier current used for Power Line carrier Communication has a frequency range of 80 to 500 kHz. PLCC is mainly for telemetry and telecontrol in modern electrical Power System.

Power Line Carrier Communication is used for the Carrier Tripping and Direct Tripping in_ case of Distance Protection. For detail of how does Distance protection relay sends and 6, receives carrier signal, read Distance Protection philosophy.

Whenever there is a fault in the line, it is very much important to isolate the fault. Merely tripping of breaker at one end of line cannot isolate the fault. Breaker at the other end of line should also open. Let us consider a simple diagram as shown below.

Fig 1



In case of fault, breaker A and B should open. Let us assume that, the fault is being sensed by relay at station 1. This relay should issue trip command to breaker A and send trip signal to the remote end. This trip signal to remote end is called Direct Trip(DT) signal. On reception of OT signal, mastedrip relay at Remote station 2 actuates which in turn actuates breaker B. This trip signal i.e. OT signal is sent via PLCC. Apart from OT signal, carrier signal is also sent via PLCC Panel. This signal is used for Auto Reclosure.

Application of PLCC:

PLCC in modern electrical power system substation is mainly used for following purpose:

1 Carrier protection relaying of transmission line so that Inter trip command can be issued by relay due to tripping of circuit breaker at any one end. To trip the line circuit breaker nearest to the fault, this is done by:

   a Distance protection relay (V/I characteristics)

   b Differential comparison method

   c Phase comparison method

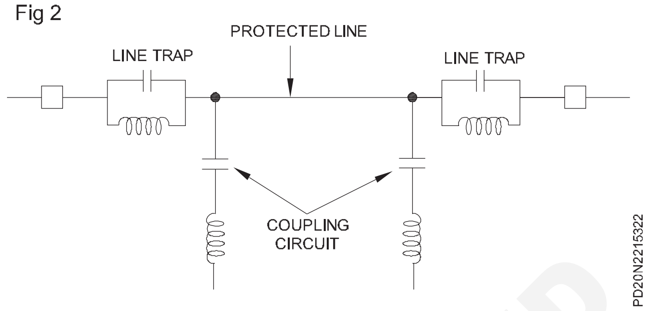
2 Station to station communication between operating personnel

   - Transmitters and Receivers
   - Hybrids and Filters
   - Line Matching Unit
   - Wave Traps
   - Power Amplifier
   - Coupling Capacitors orCapacitive Voltage Transformer

PLCC Scheme:

The output of PLCC goes to Coupling Capacitor famously known as Capacitive Voltage Transformer and then to transmission line and travels to another end where it is received through Capacitive Voltage Transformer and inputted to relay and control panel at that end.

Fig 2



As the frequency of carrier signal is high, the impedance offered by the CVT = 1/wC will be low and the carrier signal travelling on Transmission Line will be bypassed by the CVT, therefore the carrier signal is received or sent through the CVT (HF point is given on the CVT where PLCC is connected through the Fiber Optic FO Cable.)

Wave Trap is provided in the line after the CVT (If we see from Transmission line side then CVT will come first and then CVT will come.). Wave Trap is nothing but a Choke Coil which chokes out high frequency carrier signal, as the impedance offered by inductor = wl will be high which will not allow the high frequency carrier signal to enter into the substation.

Main Components of PLCC:

Following are the main components of PLCC.

Coupling Capacitor:

Thus coupling capacitor allows carrier frequency signal to enter the carrier equipment. To, decrease the impedance further and make the circuit purely resistive so that there is no reactive power in the circuit, low impedance is connected in series with coupling capacitor to form resonance at carrier frequency.

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 sur- rounding the wires if the applied voltage is low. when the applied voltage exceeds a certain value, called critical disruptive voltage, the conductors are surrounded by a faint violet glow called corona

The phenomenon of corona is accompanied by a hissing sound, production of ozone, power loss and radio interference. The higher the voltage is raised, the larger and higher the luminous envelope becomes, and greater are the sound, the power loss and the radio noise.

If the applied voltage is increased to breakdown value, a flash-over will occur between the conductors due to the breakdown of air insulation.

The phenomenon of violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as corona.

If the conductors are polished and smooth, the corona glow will be uniform throughout the length of the conductors, otherwise the rough points will appear brighter. With d.c. voltage, there is difference in the appearance of the two wires. The positive wire has uniform glow about it, while the negative conductor has spotty glow.

i Corona formation

Some ionisation is always present in air due to cosmic rays, ultraviolet radiations and radioactivity. Therefore, under normal conditions, the air around the conductors contains some ionised particles (i.e., free electrons and +ve ions) and neutral molecules. When p.d. is applied between the conductors, potential gradient is set up in the air which will have maximum value at the conductor surfaces. Under the influence of potential gradient, the existing free electrons acquire greater velocities. The greater the applied voltage, the greater the potential gradient and more is the velocity of free electrons. When the potential gradient at the conductor surface reaches about 30 kV per cm (max. value}, the velocity acquired by the free electrons is sufficient to strike a neutral molecule with enough force to dislodge one or more electrons from it. This produces another ion and one or more free electrons, which is turn are accelerated until they collide with other neutral molecules, thus producing other ions. Thus, the process of ionisation is cummulative. The result of this ionisation is that either corona is formed or spark takes place between the conductors.

Factors Affecting Corona

The phenomenon of corona is affected by the physical state of the atmosphere as well as by the conditions of the line

The following are the factors upon which corona depends:

- **i Atmosphere:**As corona is formed due to ionsiation of air surrounding the contluctors, there- fore, it is affected by the physical state of atmosphere. In the stormy weather, the number of ions is more than normal and as such corona occurs at much less voltage as compared with fair weather.
- **ii Conductor size:** The corona effect depends upon the shape and conditions of the conduc- tors. The rough and irregular surface will give rise to more corona because unevenness of the surface decreases the value of breakdown voltage. Thus a stranded conductor has ir- regular surface and hence gives rise to more corona that a solid conductor
- **iii Spacing between conductors:** If the spacing between the conductors is made very large as compared to their diameters, there may not be any corona effect. It is because larger distance between conductors reduces the electro-static stresses at the conductor surface, thus avoiding corona formation.
- **iii Spacing between conductors:** If the spacing between the conductors is made very large as compared to their diameters, there may not be any corona effect. It is because larger dis-tance between conductors reduces the electro-static stresses at the conductor surface, thus avoiding corona formation.
- **iv Line voltage:** The line voltage greatly affects corona. If it is low, there is no change in the condition of air surrounding the conductors and hence no corona is formed. However, if the line voltage has such a value that electrostatic stresses developed at the conductor surface make the air around the conductor conducting, then corona is formed.

Methods of Reducing Corona Effect

Intense corona effects are observed at a working voltage of 33 kV or above. Therefore, careful design should be made to avoid corona on the sub-stations or bus-bars rated for 33 kV and higher voltages otherwise highly ionised air may cause flash-over in the insulators or between the phases, causing considerable damage to the equipment. The corona effects can be reduced by the following methods

- **i By increasing conductor size:** By increasing conductor size, the voltage at which corona occurs is raised and hence corona effects are considerably reduced. This is one of the reasons that ACSR conductors which have a larger cross-sectional area are used in transmission lines.
- **ii By increasing conductor spacing:** By increasing the spacing between conductors, the volt- age at which corona occurs is raised and hence corona effects can be eliminated. However, spacing cannot be increased too much otherwise the cost of supporting structure (e.g., bigger cross arms and supports) may increase to a considerable extent.

What is Contact Resistance

Contact resistance is the resistance to current flow, due to surface conditions and other causes, when contacts are touching one another (in the closed condition of the device). This can occur between contacts of:

- Breakers
- Contactors
- Relays
- Switches
- Connectors
- Other switching devices

Contact resistance testing also known as Ductor testing, measures the resistance of electrical connections terminations, joints, connectors, busbar sections or cable connections and so on. These can be connections between any two conductors, for example, cable connections or busbar sections. The instrument which is used to perform the ductor test is called an Ohmmeter, and since its function is to perform the ductor test, the ohmmeter is also known as a ductor tester.

The ductor tester can be found in many variations such as Micro, Mega and Milli- Ohmmeters, static resistance tester or DLRO which stands for Digital Low Resistance Ohm Meter. Is used to measure resistance in different applications of electrical testing. This tester consists of a DC ammeter and a few other components. The test measures the resistance at the micro or milli-ohm level and is used primarily to verify that electrical connections are made properly, and can detect the following problems:

- Loose connections
- Adequate tension on bolted joints
- Eroded contact surfaces
- Contaminated or corroded contacts

The term contact resistance refers to the contribution to the total resistance of a system which can be attributed to the contacting interfaces of electrical leads and connections as opposed to the intrinsic resistance, which is an inherent property. Independent of the measurement method. This effect is often described by the term Electrical Contact Resistance or ECR and may vary with time, most often decreasing, in a process known as resistance creep. The idea of potential drop on the injection electrode was introduced by William Shockley to explain the difference between the experimental results and the model of gradual channel approximation. In addition to the term ECR, “Interface resistance”, “transitional resistance”, or just simply “correction term” are also used. The term “parasitic resistance” has been used as a more general term, where it ibusually still assumed that the contact resistance has a major contribution.

Why You Need Contact Resistance Test?

The contacts in the circuit breaker needs to checked periodically to ensure that the breaker is healthy and functional. Poorly maintained or damaged contacts can cause arcing, loosing phase, and even fire.

This test is especially important for contacts that carry large amounts of current (e.g. switchgear busbars) because higher contact resistance can lead to lower current carrying capacity and higher losses. Ductor testing is usually performed using a micro/milli-ohmmeter or low ohmmeter.

Measurement of the contact resistance helps in identification of fretting corrosion of contacts, and allows contact corrosion to be diagnosed and prevented. Increase in contact resistance can cause a high-voltage drop in the system, and that needs to be controlled.

What is Done During Contact Resistance Testing?

The two common checks conducted on the contacts of a circuit breaker are the visual inspection check and the contact resistance check.

1 The Visual inspection check involves examining the contacts of the circuit breaker for any pitting marks due to arcing and worn or deformed contacts.

2 The second check is the contact resistance measurement. This involves injecting a fixed current, usually around 100A, 200A and 300 A through the contacts and measuring the voltage drop across it. This test is done with a special contact resistance measuring instrument. Then, using Ohm’s law, the resistance value is calculated. The resistance value needs to be compared with the value given by the manufacturer. The value should also be compared with previous records.

Both these tests need to be done together. As there are cases of contacts having good contact resistance yet being in a damaged conditions. Thus, for a contact to be certified healthy, it needs to have a good contact resistance and should clear the visual inspection test.

Ductor Tester

There are two types of ductor testers in general:

the case of a dry circuit connector, the test current should be low to prevent the Joint to be melted by heat, (the current less than 100mA).

Machinery Assembly

In the case of testing the machinery assembly quality, the different test circuits should be selected according to the different structures. There are two kinds of structure, the loop structure is close, and the non-loop structure is open. Their measurement methods are different completely.

How to Measure the Contact Resistance which Includes in a Loop Circuit, but no Changing the Circuit?

A new method will solve it. This method is very useful for measuring contact resistance in complicated machinery assembles. The contact resistance is defined as the ratio the voltage across the contact to the current flown through a closed pair of contacts. It accorded with Ohm’s law. There is an interface between the metal 1 and metal 2. The current, I, which coming from the current source flows through this interface, can be read from a current meter. And then the voltage drop across the interface can be read from a voltage meter as, U. Then the contact resistance value, Rx, can be calculated by.

Rx=U/I

Because the contact resistance changes with environment and the current pass through, the condition for measurement should be close as the condition in use. The four-terminal measurement technique and eliminating thermally EMFs technique must be used in accurate measurement. This indirect measurement method can be applied in measuring contact resistance or loop resistance. It needs three test points, three steps and three formulas. This method had been approved correct, and can also be used in calibrating the loop- resistor standard.

Typical Method for Contact Resistance Test

The four-wire (Kelvin) DC voltage drop is the typical method used by micro- ohmmeters for the contact resistance test, which ensures more accurate measurements by eliminating the own contact resistance and resistance of test leads.

The contact resistance test is performed using two current connections for the injection, and two potential leads for the voltage drop measurement; the voltage cables must be connected as closer as possible to the connection to be tested, and always inside the circuit formed by the connected current leads.

1 Series Type Ohmmeter has 4 resistors, internal battery voltage E, and output terminals, A and B. When connected the A and B terminals with the R1 and R2 resistors, the battery forms a simple series circuit.

2 Shunt Type Ohmmeter, used for measuring small values of current resistance. When the A and B terminals are closed, the needle reads zero because the current flows only through the resistor RX. When these two terminals are opened, there is no current flowing through the RX resistor, thus the reading on the ductor tester is marked as infinite.

How We Conduct Contact Resistance Test?

Test Criteria

The criteria for evaluating the contact resistance of electrical connections largely depends on the type of connection (e.g. bolted, soldered, clamped, welded, etc.). the metallic contact surface area, the contact pressure, etc.. These will differ by equipment and manufacturer and there is no code or standard that mandates minimum contact resistances. As such, manufacturer recommendations need to be consulted. For example, manufacturers sometimes quote a maximum contact resistance of 10 micro-ohms for large bolted busbar joints.

Contact resistance measurement and its application domain are fairly extensive.

Electrical Connections

The electric connections of circuits have various ways and means, such as connected by welding, by pressing, by plug in and blot tightly and so on. If you want to know the quality of a connector and its conduction characteristic, you just need to measure its contact resistance. The contact resistance was often applied in quality testing of switches, relays and PCB pads.

At the aspect of the machinery assembly, the contact resistance of metals contact surface can be used in estimating the reliability and tightness of the machinery assembly. The contact resistance is associated with the conduction characteristic of contact surface. The larger area and the less impurity of the pair metals surface is, the better conductivity and the lower resistance are, and vice versa.

By the ways of measuring contact resistance we can qualitatively analyse the reliability and tightness of the machinery assembly. This technique has been already applied in quality test of the shield assembly for EMC. Measurement methods for different application are not the same. For example, in the case of measuring contact resistance of high-power switches and relays, high current should be used, a pair of contact, things just like the condition what is actually happening in working status. In

From the measurement of the voltage drop, the microprocessor controlled micro ohmmeters calculate the contact resistance, while eliminates the possible errors due to thermal EMF effects in the connections (thermal EMFs are small thermocouple voltages which are generated when two different metals are joined together) they will be added to the total voltage drop measured, and will introduce errors into the contact resistance test if they are not subtracted from the measurement through different methods (reversal of polarity and averaging, directly measuring of thermal

EMFs magnitude, etc.) If low resistance readings are obtained when testing the breaker contact resistance using a low current, then it is recommended to re-test the contacts at a higher current. Why would we benefit using a higher current? A higher current will have the ability to overcome connection issues and oxidation on terminals, where a lower current may produce false (higher) readings under these conditions.

It is very important in the contact resistance test to maintain consistent measurement conditions, to be able to compare with previous and future results for trending analysis. Therefore, when taking periodic measurements, the contact resistance test must be performed in the same position, with the same test leads (always with the calibrated cables supplied by the manufacturer), and in the same conditions, to be able to know when a joint, connection, weld or device will become unsafe.

Conclusion

Measurements of thermal conductivity are also subject to contact resistance, with particular significance in heat transport through granular media. Similarly, a drop in hydrostatic pressure (analogous to electrical voltage) occurs when fluid flow transitions from one channel to another.

Contact resistance tests provide information about how healthy the contacts are and their ability to handle their rated current.

The maximum contact resistance should be verified against manufacturers' specifications. Rated current should not be exceeded and testing at 10% of the rated current is recommended.

The minimum DC test current should be used according to manufactures specification; however, the IEC and ANSI recommended levels are: 50 A IEC 60694 100 A ANSI.

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**
- **explain Classification of transformer principle of transformer.**

Transformer

Transformer is a static electric device which transfer the electric energy from one circuit to other without changing the frequency and power.

The three-phase synchronous generator is used extensively to generate bulk power. The voltage levels at which this power is generated is typically in the range 11 kV to 22 kV. Electrical power is to be provided at a considerable distance from a generating station. It is possible to transmit the generated power directly but this results in unacceptable power losses and voltage drops.

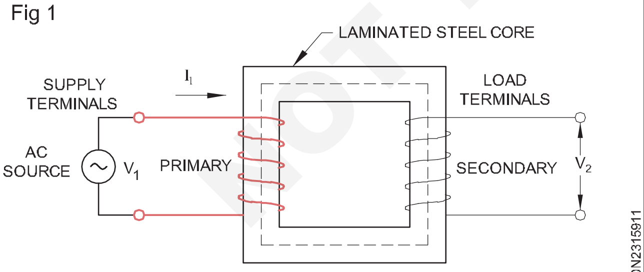
Transmission voltages vary up to the 400 kV level. This is made possible by power transformers. At the receiving end this high voltage must be reduced because ultimately it must supply three phase load at 415V or single phase load at 240V.

The transformer makes it possible for various parts of a power system to operate at different voltage levels.

> **Standard safety norms: Trainees can be instructed to refer the standard safety norms related with transformer in the International Electrotechnical commission (IEC - 60076-1) for the further details.**

Two-winding transformers: A transformer consists of two stationary windings generally called as high voltage and low voltage sides which are electrically isolated but magnetically coupled (Fig 1). The coils are said to be magnetically coupled because they link a common flux.

Fig 1



TWO-WINDING TRANSFORMER

Laminated steel core transformers are used in power applications. Fig 1, the current flowing in the coil connected to the AC source is called the primary winding or simply primary. The primary is the input to a transformer. It sets up the flux in the core, which varies periodically both in magnitude and direction. The flux links the second coil, called the secondary winding or simply the secondary.

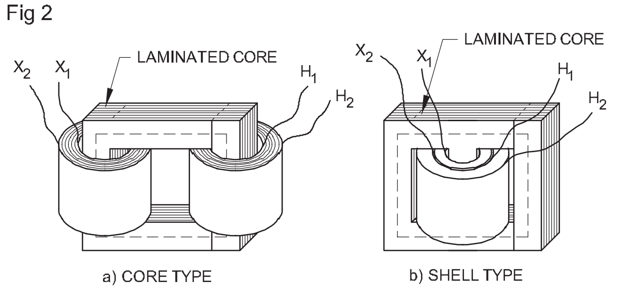
The flux is changing; therefore, it induces a voltage in the secondary by electromagnetic induction. Thus the primary receives its power from the source while the secondary supplies this power to the load. This action is known as transformer action. There is no electrical connection between these two coils.

Transformers are efficient and reliable devices used mainly to change voltage levels. Transformers are efficient because the rotational losses are absent; so little power is lost when transforming power from one voltage level to another. Typical efficiencies are in the range of 92 to 99%. The higher values apply to the large power transformers. There is no change in frequency of voltage.

Construction: There are basically two types of iron-core construction. Fig 2a shows core type already represented in Fig 1. 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 2b is employed. This is called shell type construction.

Fig 2



TRANSFORMER CONSTRUCTIONS

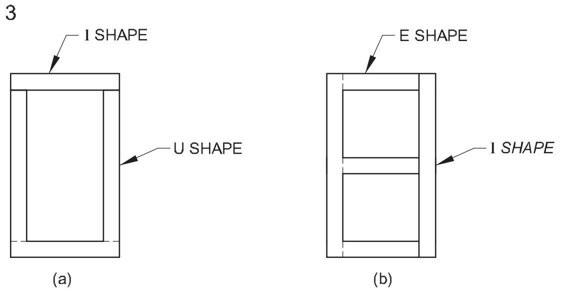
Here the two windings are wound concentrically. The higher voltage winding is wound on top of the lower voltage winding. The low-voltage winding is then located closer to the steel. This arrangement is preferable from an electrical insulating point of view. From the electrical viewpoint there is not 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. Of course, the core must then be made in atleast two sections. The laminations for the core-type transformer of Fig 2a may be made up of (└ and ┐) shaped laminations, as shown in Fig 3a. The core for the shell type transformer of Fig 2b is normally made up of E and I shaped laminations Fig 3b.

Fig 3



CORE CONSTRUCTION BUILT OF SEPARATE LAMINATIONS

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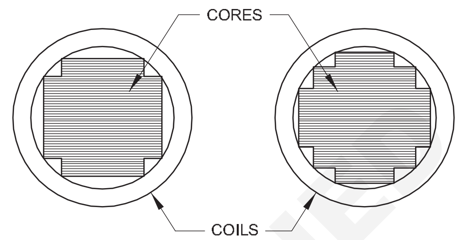
Core construction : As a rule, the number of butt joints is to be limited. The joints are tightly made and laminations interleaved so as to minimize the reluctance of the magnetic circuit. The stacking of laminations to the required core cross-section results in the core legs of square or rectangular cross-section. This permits coils to be fitted on the core legs with either square, rectangular, or circular coil spools or forms.

In larger transformers, a stepped-core arrangement is used to minimise the use of copper and reduce copper loss. (Fig 4) This construction guarantees that each length of copper conductor embraces the maximum cross-sectional area of steel.

In practice, the primary and secondary windings of a transformer have two or more coils per leg. They may be arranged in series or parallel. The laminations are pressed together by clamping in such a way as to prevent any fluttering or shifting.

Fig 4



STEPPED TRANSFORMER CORES

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The coils are impregnated. Insufficient clamping of laminations usually results in a humming sound. This generates objectionable and audible noise by the iron core of the transformer.

Transformers are usually air-cooled. Larger transformers are placed in tanks with a special transformer oil. The oil serves a dual purpose as an insulating medium as well as a cooling medium.

The heat generated in the transformer is removed by the transformer oil surrounding the source and is transmitted either to atmospheric air or water. No matter what size of transformer is dealt with, they all operate on the same principle.

Transformer principle

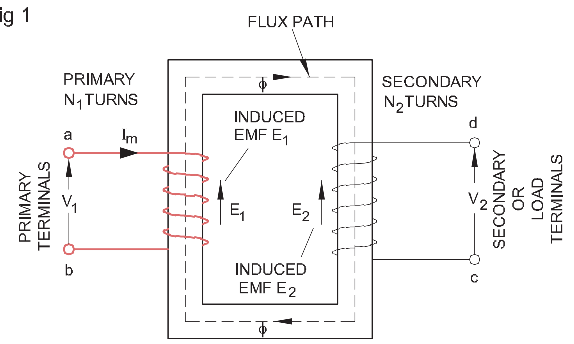
Objectives: At the end of this lesson you shall be able to
- **describe an ideal transformer and its operation on load and noload**
- **explain the principle of the operation of a transformer**
- **derive the EMF equation of a two-winding transformer**
- **derive the transformation ratio of a transformer.**

An ideal transformer: An ideal transformer is one which has no losses, i.e. its windings have no ohmic resistance and there is no magnetic leakage. An ideal transformer consists of two coils which are purely inductive and wound on a loss-free core.

However, it may be noted that it is impossible to realize such a transformer in practice; yet for convenience, we will first analyse such a transformer and then an actual transformer.

Let us consider an ideal transformer (Fig 1) whose secondary is open and whose primary is connected to a sinusoidal voltage V_1.

Fig 1



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Working principle

The transformers work on the principle of mutual induction of Faraday's law of electro - magenetic induction.

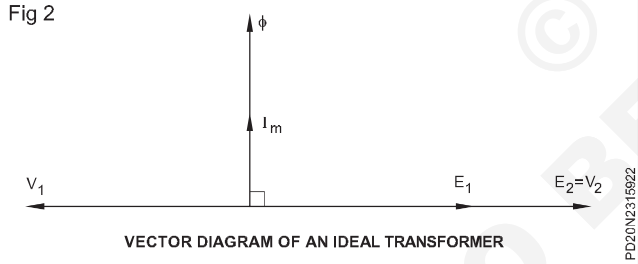
The applied voltage causes a small current to flow in the primary winding. This no-load current is meant to build up a counter-electromotive force equal and opposite to the applied voltage.

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 ϕ 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 'ϕ' by 90^0. This is shown in vector diagram Fig 2.

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 EMF will 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



Hence we can say that

$$\frac{Total\ \text{emf indued in seconday}'E_2}{Total\ \text{emf induced in primary}'E_1'}$$

$$=\frac{N_2 \times \text{emf per turn}}{N_1 \times \text{emf per turn}} \quad \text{OR}$$

$$\frac{E_2}{E_1}=\frac{N_2}{N_1}$$

$$as\ E_1 = V_1 \text{ and } E_2 = V_2$$

$$\text{We have } \frac{V_2}{V_1}=\frac{N_2}{N_1}$$

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 EMF induced 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.

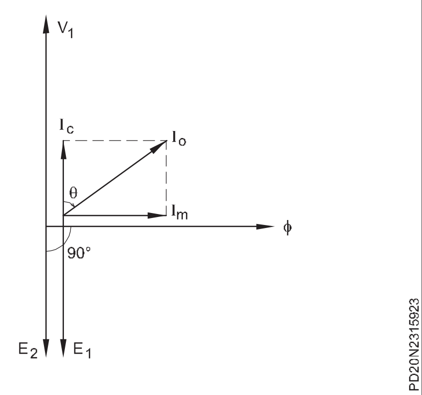
Therefore Full load primary ampere turns $\simeq$ full load secondary ampere turns

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 EMF induced in the primary, thereby enabling the primary current to vary approximately, proportional to the secondary current.

Fig 3



Theory of No-load Operation: With the secondary winding open-circuited, the no-load current I_o flows in the primary winding. This no-load current has two functions:

1) It produces the magnetic flux in the core, which varies sinusoidally between zero and ± $ø_m$ where $ø_m$ is the maximum value of the core flux; and

2) It provides a component to account for the hysteresis and eddy current losses in the core. These combined losses are normally referred to as the core losses or iron losses.

The no-load current I_o is usually a small percentage of the rated full load current of the transformer (about 2 to 5%). Since at no-load the primary winding acts as a large reactance due to the iron core, the I_o will lag the primary voltage 'V_1' by nearly 90°. Fig 3 illustrates this relationship where θ^0 is the no-load power factor angle.

Magnetising current = $I_m = I_o \sin\theta$ is 90° in phase behind the primary voltage V_1. It is this component that sets up the flux in the core; ø is therefore in phase I_m.

The second component, $I_c = I_o \cos ø_o$ is 90° is in phase with the primary voltage V_1. It is the current component that supplies the iron-loss plus a small quantity of primary Cu-loss. As I_o is very small, the no-load primary copper-loss is negligibly small.

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 (δø/δt). 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

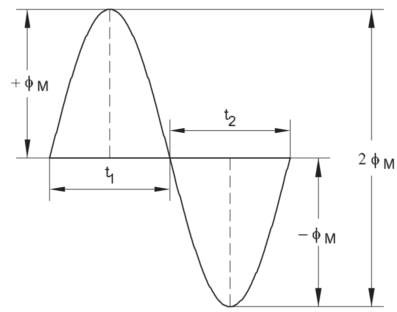
$$E_{avg} = \text{turns} \times \frac{\text{change in flux in a given time}}{\text{given time}} \quad ...(1)$$

Referring to Fig 4, it is seen that the flux change in time interval t_1 to t_2 is $2\phi_m$ where ϕ_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 of seconds, where f is the supply frequency, in hertz.

It follows that

$$E_{avg} = N \times \frac{2\phi_m}{\frac{1}{2f}} = 4fN\phi_m \quad ...(2)$$

Fig 4



SINUSOIDAL FLUX WAVE IN CORE

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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

$$E = 4.44\ f\ N\phi_m \quad ...(3)$$

Since the flux links with the primary and secondary windings, the voltage per turn in each winding is the same. Hence

$$E_1 = 4.44\ f\ N_1\phi_m \quad ...(4)$$

and

$$E_2 = 4.44\ f\ N_2\phi_m \quad ...(5)$$

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

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K \quad \text{(Constant)} \quad ...(6)$$

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.

Turns Ratio of a transformer

The ratio of the number of turns of coil in the primary (N_1) to the turnnumber of turns of coil in the secondary (N_2) is cal let the s ratio of the transformer.

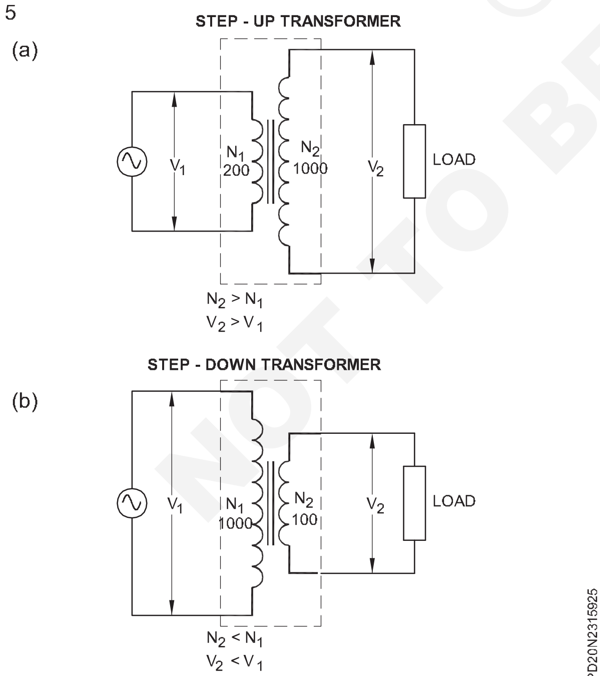
$$\text{Turns ratio} = \frac{N_1}{N_2}$$

For example, **1000 turns in the primary and 100 turns in the secondary gives a turns ratio of 1000/100, or 10:1 which is stated as ten-to-one turns ratio.**

Example: **As shown in Fig 5a, a transformer has 200 turns of N_1 and 1000 turns of N_2 its turns ratio will be,**

$$\text{Turns ratio} = \frac{N_1}{N_2} = \frac{200}{1000} = 1:5$$

Fig 5



For this transformer, if the applied AC primary voltage (V_1) is 110 V_{rms}. the secondary voltage will be stepped up in the same ratio as that of turns ratio. Hence, the secondary voltage will be twice the primary voltage, i. e, 5 x 110 = 550V_{rms}

On the other hand, when the secondary winding has lessnumber of turns than the primary winding, the primaryvoltage is said to be lowered or stepped - down. Such transformers are called Step-down transformers as shown in Fig 5b.

Example: **As shown in Fig 5b a power transformer has 1000 turns of N_1 and 100 turns of N_2 What is the turns ratio? How much is the secondary voltage V_2 when a primary voltage is 240V?**

SOLUTION:

The turns ratio is 1000/100, or 10:1. Hence, secondary voltage will be stepped down by a factor of 1/10, making V_2 equal to 240/10 or 24 Volts.

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 PF. is known of the specific load, then only the load current can be calculated otherwise the load current may be more than rated. If the transformer rating is in KVA the load current can be determined directly by knowing its voltage.

Hence the transformer are rated in VA (or) KVA, because the safety maximum load current can be calculated without knowing power factor.

The KVA of the primary must equal to the KVA of the secondary under the ideal transformer concept. We know that the terminal voltage ratio is equal to turns ratio. The primary and secondary currents are inversely related to the turns ratio.

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 x f x N_P x ϕ_m) volts

$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{E_P}{E_S} = \frac{N_P}{N_S}$$

$$V_P I_P = V_S I_S = KVA$$

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: $$\frac{V_1}{V_2} = \frac{N_1}{N_2} \text{ or } \frac{N_1}{V_1} = \frac{N_2}{V_2}$$

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

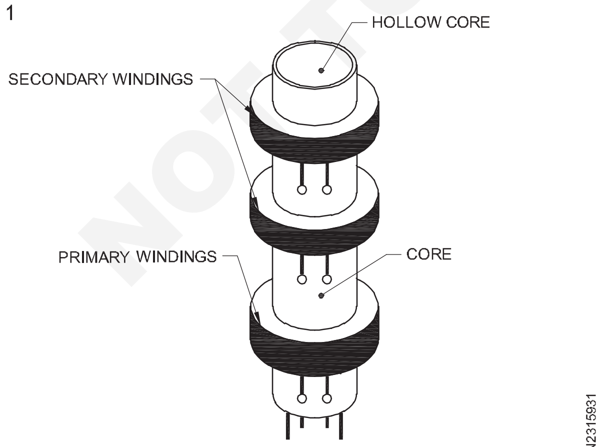
Objectives : At the end of this exercise you shall be able to
- **state the classification of transformers based on various factors**
- **state about the dry type transformers.**

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.

Fig 1

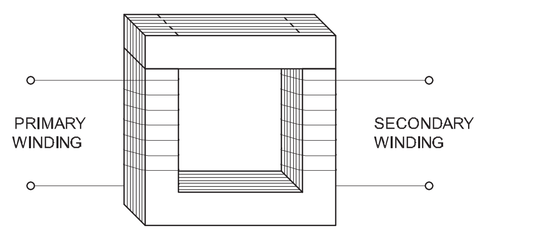


AIR CORE TRANSFORMER

Iron-loss is a type of transformer loss due to core material.

- **Iron core transformers**: Fig 2 shows a laminated iron-core transformer. This is the most common type of transformer used with mains power supply transformers,

Fig 2

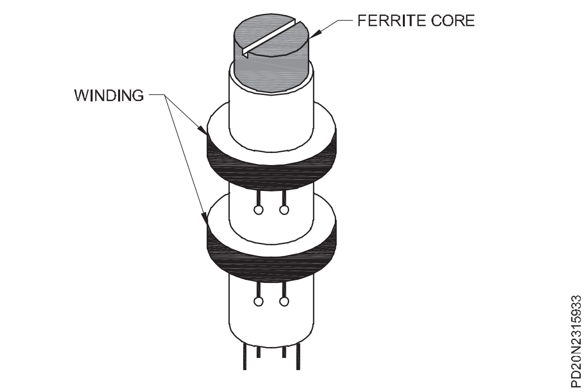


- **Ferrite core transformers**: Fig 3, these transformers have Ferrite material as its core Fig 3. In most cases, the primary and secondary windings are wound on a hollow plastic core and the ferrite material is then inserted into the hollow core. These transformers are used in high frequency to very high frequency applications as they have the advantage of introducing minimum losses.

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)

Fig 3



- **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 3). 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.

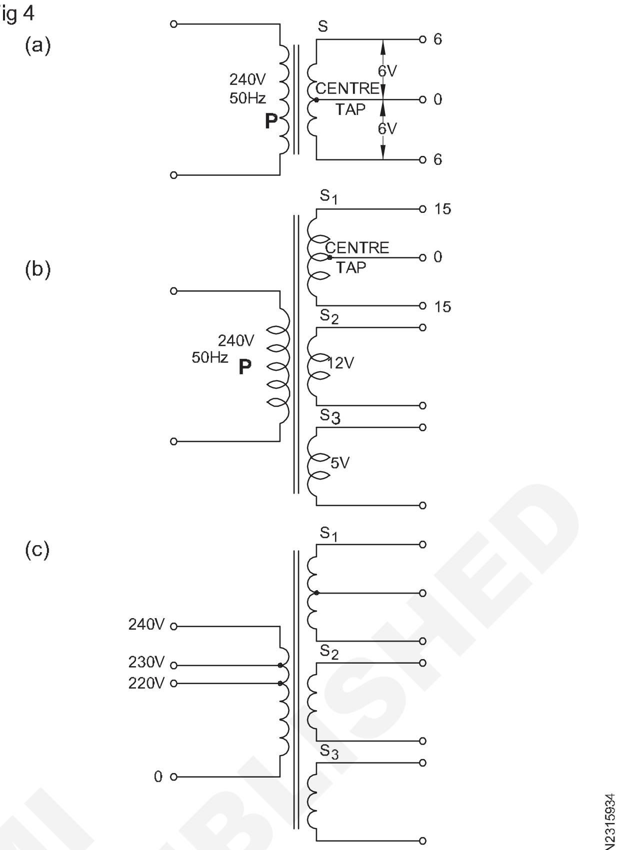
3 Classification based on the Transformation ratio

- **Step-up Transformers**: Transformers in which, the induced secondary voltage is higher than the source voltage given at primary are called step-up transformers.
- **Step-down Transformers**: Transformers in which, the induced secondary voltage is lower than the source voltage given at primary are called step-down transformers.
- **Isolation transformers**: Transformers in which, the induced secondary voltage is same as that of the source voltage given at primary are called one-to-one or isolation transformers. In these transformers the number of turns in the secondary will be equal to the number of turns in the primary making the turns ratio equal to 1.

4 Classification based on the operating frequency

- **Mains frequency transformer**: These are basically, iron-core shell type transformers. These transformers form the link between AC mains source and other devices requiring AC or DC power example, radius receivers. The secondary winding of these transformers may have a centre tap as shown in Fig 4a or may have more than one secondary windings Fig 4b. These transformers may also have more than two terminals at primary winding Fig 4c to accommodate for different AC mains levels. Tapped primary also allows changes in the secondary-primary turns ratio. All the power transformers are generally designed to work at mains supply frequency(50 Hz).

Fig 4

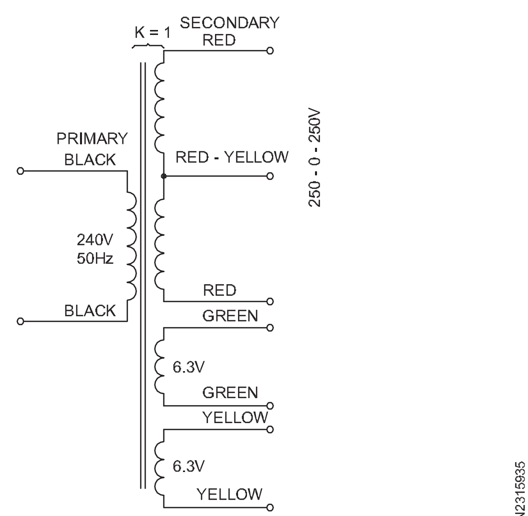


CENTRE TAPPED SECONDARY

Power transformers use colour coding scheme to identify the primary and secondary windings. (Fig 5)

- **Audio frequency (AF) transformers**: Refer Fig 5 in Chart 1. These AF transformers are very small in size. Most AF transformers are of PCB mounting type. These transformers are designed to operate over the audio frequency range of 20 Hz to 20 KHz. Audio transformers are used in,

Fig 5



A TYPICAL COLOUR CODING SCHEME FOR POWER TRANSFORMERS

- Coupling the output of one stage of audio amplifier to the input of the next stage (interstage coupling)
- The amplified audio signal from an amplifier to the speaker of a sound system.
- **High frequency transformers**: Refer Fig 6 in Chart 1. The core of high frequency transformers are made of powdered iron or ferrite or brass or air core(hollow core) Fig 1 and 3. These transformers are called Radio frequency transformers (RFTs) and Intermediate frequency transformers (IFTs).

  These transformers are used for coupling any two stages of high frequency circuits such as radio receivers. The upper frequency limit of these transformers is 30 MHz.

Another speciality of these transformers is that the position of the core can be altered, which results in varied coupling and energy transfer. These transformers also have a capacitor connected across the windings in parallel. This results in a different behaviour of the transformer at different frequencies. Hence these transformer are also called Tuned transformers.

These transformers are smaller than even audio frequency (AF) transformers. These transformers will generally be shielded/screened using a good conductor.

- **Very high frequency transformers**: These transformers also have air or ferrite or brass as core material. These transformers are constructed specially to minimize energy losses at very high frequencies. Some of these find wide application in Television receivers.

5 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 7 in Chart 1. Three phase transformers are used in electrical distribution and for industrial applications.

6 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 Transformers

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

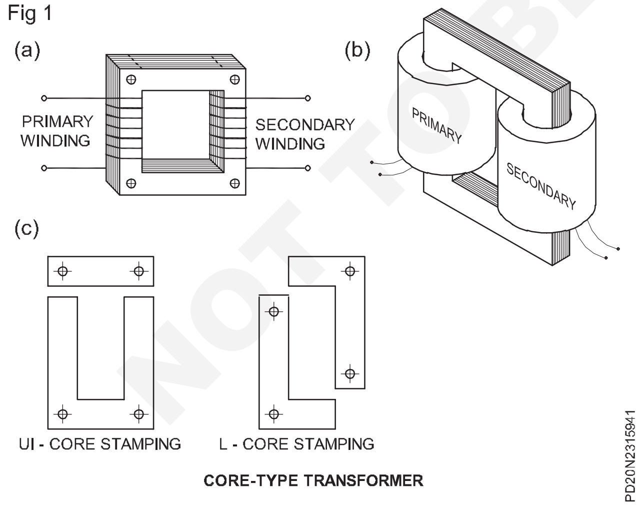


Fig 2

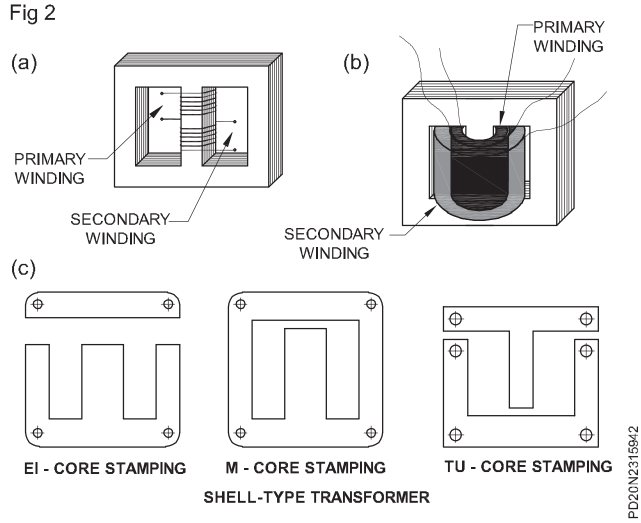
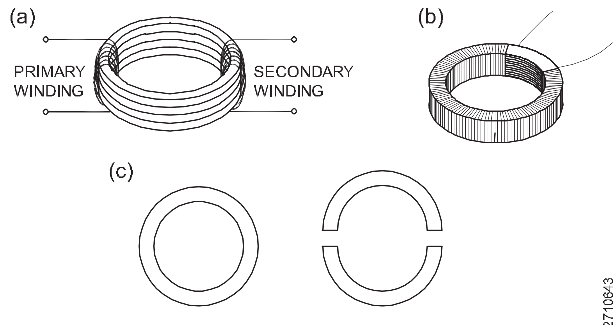
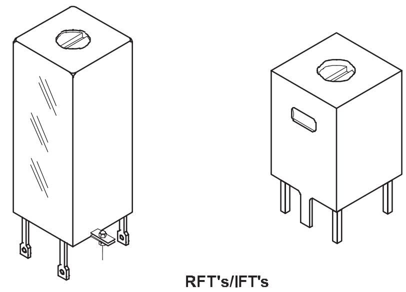


Fig 3



RING - TYPE TRANSFORMER

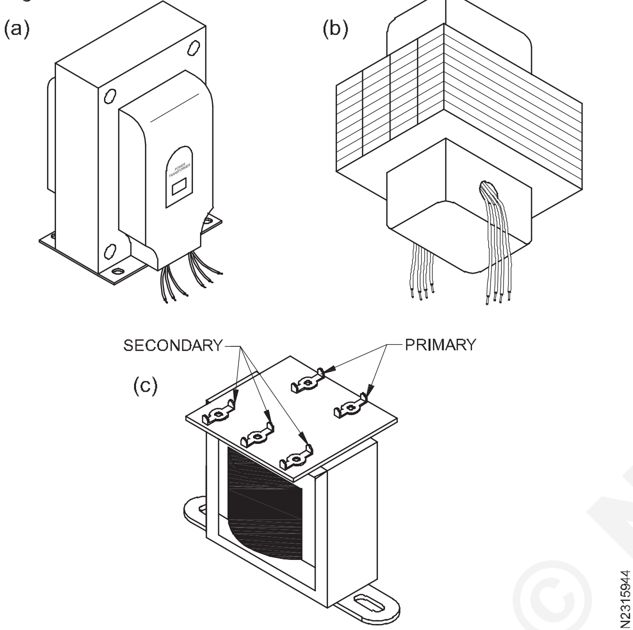
Fig 6



RFT's/IFT's

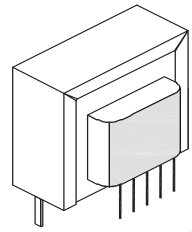
HIGH FREQUENCY TRANSFORMER

Fig 4



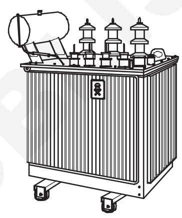
MAINS FREQUENCY TRANSFORMER

Fig 5



AUDIO FREQUENCY TRANSFORMER

Fig 7



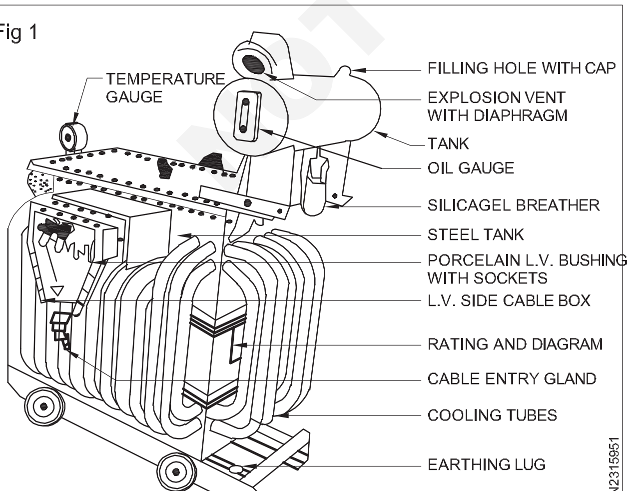
POLY - PHASE TRANSFORMER

Parts and their functions of transformer

Objectives: At the end of this lesson you shall be able to
- **list out the main parts of transformer**
- **explain the parts of a distribution transformer.**

Distribution transformer: Fig 1 shows the essential parts of a distribution transformer.

Fig 1



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

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

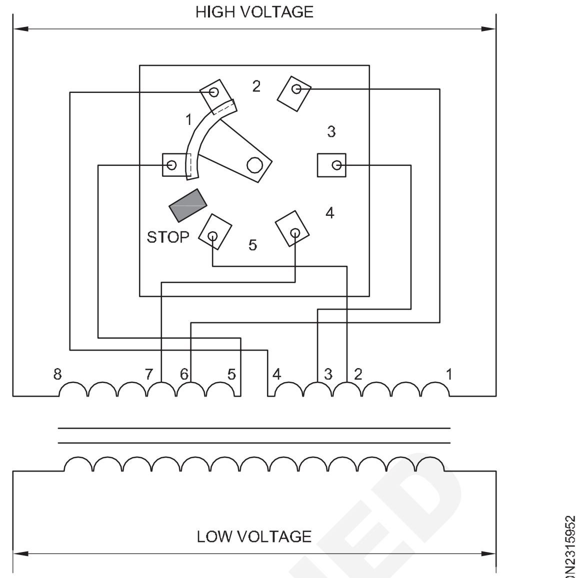
When voltages are transmitted over long distances there will be voltage drop in the conductors, resulting in lower voltage at the receiving end. To compensate this line voltage drops in the conductors, it is customary to increase the sending end voltage by tap changing transformers. These transformers may have several winding taps in their primary winding (Fig 2).

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

Fig 2



MANUALLY OPERATED TAP - CHANGING

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.

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 = $K_h B^{1.6}_m$ 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

Objectives: 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

$W_i = W_o - (I_0)^2 R$

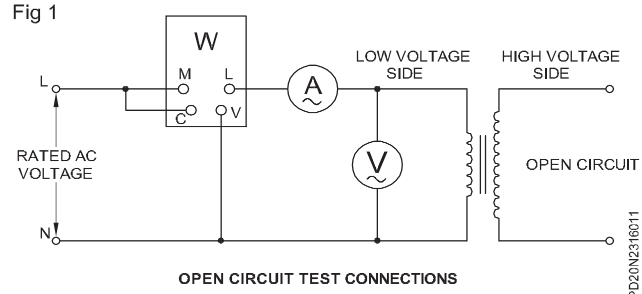
W0 = Wattmeter reading on no load

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

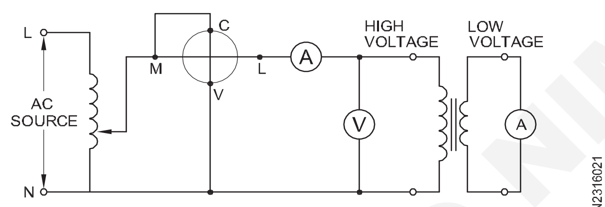
Objectives: At the end of this lesson you shall be able to

- **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.

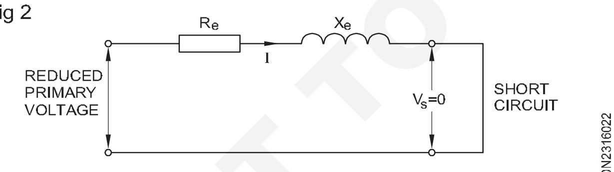
Fig 1



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 inpedenence. (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.

Example

The following data were obtained in a short circuit test on a 20 KVA 2400V/240V 50 Hz. transformer.

V_{SC}, = 72V, I_{SC} = 8.33A, P_{SC} = 268W.

Instruments were placed in the high voltage side and the secondary is short-circuited. Obtain the equivalent transformer parameters of the high voltage side.

Solution

$$R_{eH} = \frac{P_{SC}}{I^2_{SC}} = \frac{268}{(8.332)^2} = 3.86\,\Omega$$

$$Z_{eH} = \frac{V_{SC}}{I_{SC}} = \frac{72}{8.33} = 8.64\,\Omega$$

$$\text{and } X_{eH} = \sqrt{Z^2_{eH} - R^2_{eH}}$$

$$= \sqrt{8.64^2 - 3.86^2} = 7.73\,\Omega$$

Efficiency of transformer

Objectives: At the end of this lesson you shall be able to
- **calculate efficiency from the losses**
- **state the condition for maximum efficiency**
- **define all-day efficiency of a distribution transformer.**

Efficiency of transformer:

In general, the efficiency of any electrical apparatus is

$$\eta = \frac{\text{output power}}{\text{input power}} = \left|\frac{\text{output power}}{\text{output power} + \text{losses}}\right| \quad .....(1)$$

Where η is the symbol used to denote efficiency. When equation (1) is multiplied by the factor 100, the efficiency will be in percent.

The efficiency of a transformer is high and in the range 95 to 98%. This implies that the transformer losses are as low as 2 to 5% of the input power.

While calculating the efficiency, it is generally much better to determine the transformer losses rather than measured the input and output powers directly.

In transformer, the open circuit test yields the core losses and the short circuit test provides the copper losses. Thus the efficiency can be determined from these data with reasonable accuracy.

The transformer ratings are based on output KVA (MVA). Therefore, the equation for efficiency may be written as

$$\eta = \left|\frac{KVA_{out} \text{ X PF}}{\left(KVA_{out} \text{ X PF}\right) + \text{Copper loss} + \text{core loss}}\right|$$

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.

Example: A transformer with a rating of 10 KVA 2200/220V 50 Hz was tested with the following results.

Short circuit test power input = 340 W

Open circuit test power input = 168 W

Determine

i The efficiency of this transformer at full load

ii The load at which maximum efficiency occurs.

The load power factor is 0.80 lagging.

Solution

i Efficiency at full load, η_{FL}

$$n = \frac{P_{out}}{P_{in}} = \frac{(10 \times 10^3 \times 0.8)\ 100}{(10 \times 10^3 \times 0.8) + \text{Cu loss} + \text{Iron loss}}$$

$$= \frac{(10000 \times 0.8)\ 100}{(10000 \times 0.8) + 340 + 168}$$

$$= 94.0\%.$$

ii The maximum efficiency occurs at a load when the copper loss = core loss.

Thus the copper loss = core loss = 168 W.

Let the current at full load = I.

The current at maximum efficiency = I'.

Then, the copper loss at full load = $I^2 R_{eq}$ = 340 W

the copper loss at h_{max} = $(I')^2 R_{eq}$ = 168 W.

$$\text{Therefore,} \quad \frac{I^2 R_{eq}}{I'^2 R_{eq}} = \frac{340}{168}$$

$$\text{or} \quad I' = I\sqrt{\frac{168}{340}}$$

This is the factor by which the power decreases,

$$\text{Therefore, } P_{atmaxh} = \sqrt{\frac{168}{340}} \times (10000\text{x}0.8)$$

$$= 5623 \text{ W}$$

$$P_{atmaxh} = 5623 \text{ W}$$

$$= 70.26\% \text{ of } 8000 \text{ W}$$

$$= 0.7026 \text{ of full load.}$$

or

$$\text{Therefore, } h_{max} = \frac{5623}{5623 + 168 + 168} \times 100$$

$$= 94.36\%.$$

All day efficiency

Lighting transformers and most distribution transformers will not have full load for all the 24 hours in a day. To keep the operational efficiency of such distribution transformers are designed to have their maximum efficiency at a lower value than full load.

All day efficiency

$$= \frac{\text{output in 24 hours}}{\text{output in 24hours losses in 24 hours}}$$

ηallday

$$= \frac{\text{output KWh 24 hours}}{\text{output KWh (24 hours)} + \text{losses KWh (24 hours)}}$$

Here, the iron loss is considered through out the period where as copper loss depends up on the period for which transformer is loaded and percentage load.

Example: A 100 KVA distribution transformer has a full load loss of 3 KW. At full load the losses are equally divided between iron and copper loss. During a certain day the transformer connected to the lighting load operated with loads as given below.

a On full load, unity PF 3 hours.

b On half full load, unity PF 4 hours.

c Negligible and during the remaining part of the day. Calculate the all day efficiency.

Solution

As the load is primarily lighting, the PF = 1.0.

a Output energy at FL in 3 hours

= 100 KVA x 1 x 3 = 300 KWh

b Output energy at 1/2 FL in 4 hours

= 100 x 1/2 x 1 x 4 = 200 KWh.

Energy wasted in kWh during full load

= 3 KW x 3h = 9 KWh.

At full load

Iron loss = copper loss = 3.0¸2 = 1.5 KW.

Copper loss at 1/2 full load

= 1.5 x $(1/2)^2$ = 1.5/4 KW.

Total energy loss during half full load

= iron loss for 4 hours + copper loss for 4 hours

= (1.5 x 4) + (1.5/4 x 4)

= 6 + 1.5 = 7.5 KWh.

The transformer has no load for

= (24 - 7) hours = 17 hours.

Constant loss for 17 hours

= 1.5 x 17 = 25.5 KWh.

The total loss for 24 hours= (9 + 7.5 + 25.5) KWh = 42

ηallday

$$= \frac{\text{output KWh 24 hours}}{\text{output KWh (24 hours)} + \text{losses KWh (24 hours)}}$$

$$\text{KWh} = \frac{(300 + 200)}{(300 + 200) + 42} = 0.922$$

ηallday = 92.2%

Voltage regulation of transformers

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

- **define the voltage regulation of a transformer**
- **calculate the voltage regulation of a transformer.**

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.

Example:

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.

Solution:

$$\text{\% of Voltage regulation} = \frac{V_o - V_S}{V_S} \times 100$$

$$= \frac{426 - 410}{410} \times 100$$

$$\text{\% of Voltage regulation} = \frac{16}{10} \times 100$$

$$= 3.9\%$$

Series and Parallel Operation of Transformers

Objectives: At the end of this lesson you shall be able to
- **state the necessity of series operations**
- **state the conditions to be fulfilled for series operation.**

Series operation:

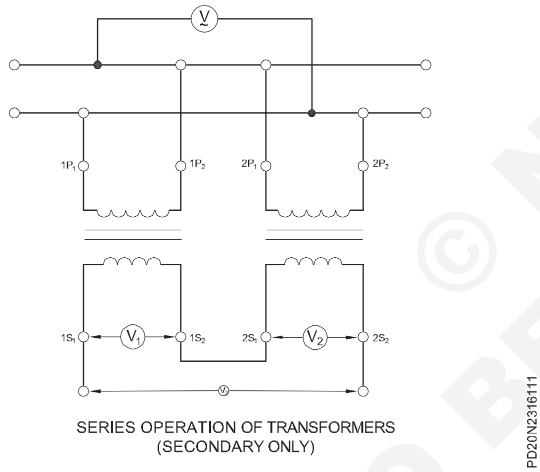
The connection diagram for series operation (secondary only) of two identical transformers is given below (Fig 1)

Necessity for series operations:

In general, the transformers are available with some standard input (primary) and output (secondary) voltages. In order to get some intermediate voltage for example , 36V, 48 V for special purpose, the series operation of transformers (secondary only) are necessary.

In series operation, individual secondary voltages of both transformers are added if they are connected with proper polarity, but the current ratings are remains same.

Fig 1



SERIES OPERATION OF TRANSFORMERS
(SECONDARY ONLY)

Condition for series operation:

Both transformers should be identical i.e,

a Voltage ratio/turns ratio must be same

b Polarities must be same

c Type of core of both transformers (core or shell type) must be same.

d Input voltages of both transformers must be same.

e KVA ratings of both transformers must be same.

f Percentage impedance or per unit impedance of both the transfers must be same.

Precautions:

- **The polarities of secondary of both transformers should be connected in proper way, same as series connection, to get the voltage added, otherwise the output voltage will be zero.**
- **As the output voltage is double that the individual secondary voltages, care to be given to ascertain the insulation level of the secondary windings.**

Parallel operation of two single phase transformers

Objectives: At the end of this lesson you shall be able to
- **state the necessity of parallel operation of transformers**
- **state the conditions to be full filled for the parallel operation of transformers**
- **explain how to determine the polarity terminals of transformer.**

Necessity of parallel operation of transformers

1 When the power demand of the load increases, two or more transformer may be operated in parallel.

2 When the power demand decreases, only required numbers of transformer may be operated with their full load capacity. Where as the remaining transformers may be switched "OFF" and taken for general maintenance/service.

3 Thus the efficiencies and life of the transformers increases and the losses are reduced.

4 It provides more reliability of power i.e., even one transformer fails or become out of service, other transformers will supply to the certain amount of load.

5 It is not economical to manufacture a single very large capacity transformer. Thus operating two or more numbers of optimal capacity transformers in parallel is more economical.

6 It is easy to plan the maintenance schedule of the transformers, hence the cost of maintenance and spares are reduced.

Conditions

1 the same voltage ratio

2 Input voltage must be same

3 the same per unit (or percentage) impedance

4 the same polarity

5 the same phase sequence and zero relative phase displacement, for 3 phase transformers.

Of these (4) and (5) are absolutely essential (1) and (2) must be satisfied to a close degree.

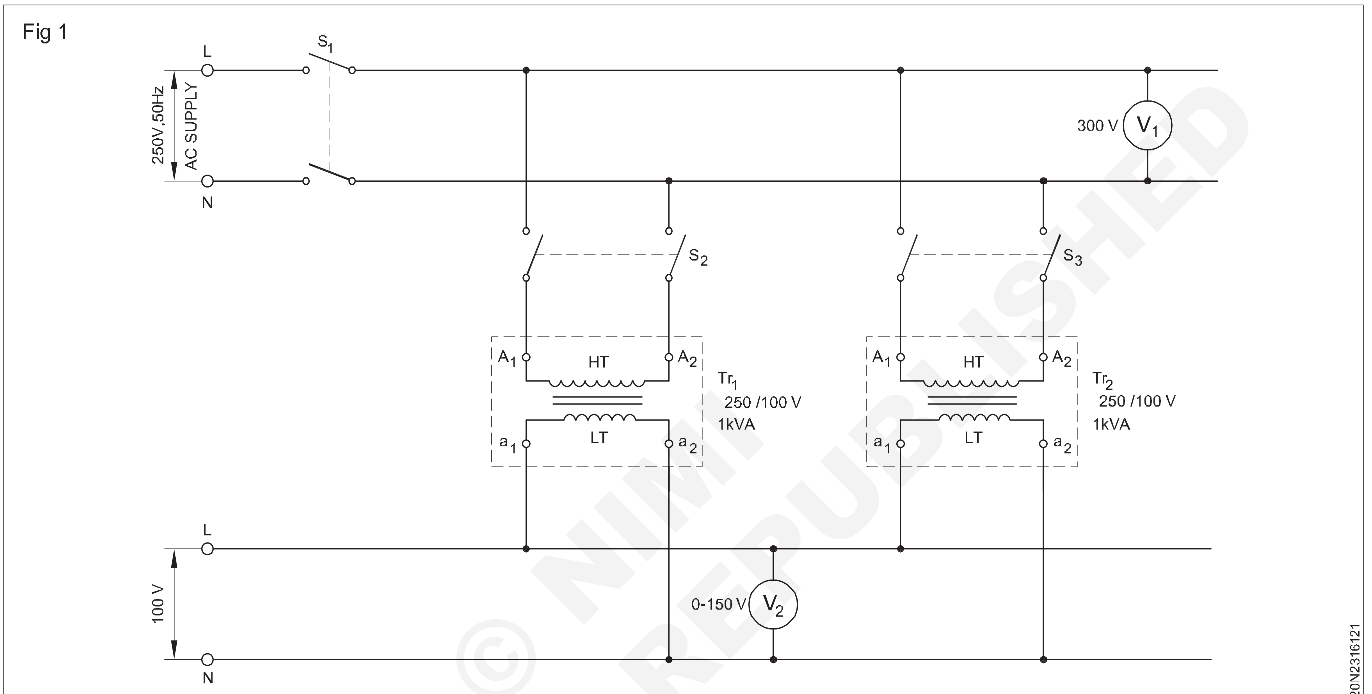
There is more allowance for a wide extent with (3), but the more nearly it is true, the better will be the load division between several transformers.

Parallel operation

Fig 1 shows two single phase transformers connected in parallel with their primary windings connected to the same supply and their secondary windings supplying a common load.

When operating two or more transformers in parallel, to have satisfactory performance the following conditions should be met

Fig 1



TWO SINGLE PHASE TRANSFORMERS CONNECTED IN PARALLEL

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 applications 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

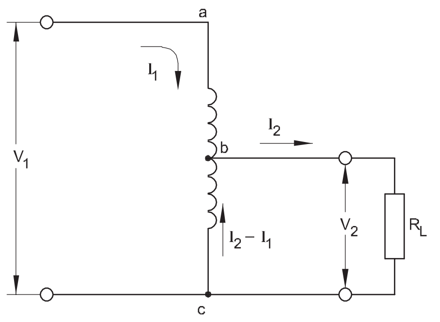
An ordinary two winding transformer may also be used as an auto-transformer by connecting the two windings in series and applying the voltage across the two, or merely to one of the windings.

It depends on whether it is desired to keep the voltage down or up, respectively.

Figs 1 and 2 show these connections.

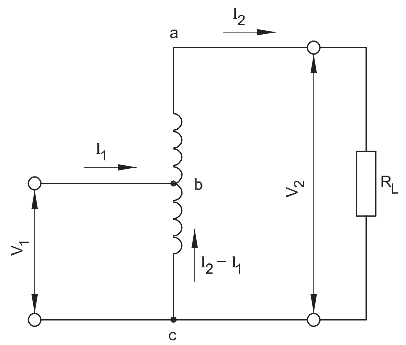
Considering Fig 1, the input voltage V_1 is connected to the complete winding a - c and the load R_L is across a portion of the winding, that is, b - c. The voltage V_2 is related to V_1 as in a conventional two winding transformer, namely,

Fig 1



AUTOTRANSFORMER STEP-DOWN

Fig 2



AUTOTRANSFORMER STEP-UP

$$V_2 = V_1 \times \frac{N_{bc}}{N_{ac}} \qquad \text{..........(1)}$$

Where N_{bc} and N_{ac} are the number of turns on the respective windings. The ratio of voltage transformation in an autotransformer is the same as that for an ordinary transformer, thus

$$a = \frac{N_{bc}}{N_{ac}} = \frac{V_2}{V_1} = \frac{I_1}{I_2} \qquad \text{..........(2)}$$

with a < 1 for step down.

Assume a resistive load for convenience and the secondary current, $I_2 = V_2 / R_L$ further, the assumption is made that the transformer is 100% efficient, the power output is

$$P_L = V_2 \, I_2 \qquad \text{..........(3)}$$

Note that I_1 flows in the portion of the winding **ab**, whereas the current $(I_2 - I_1)$ flows in the remaining portion bc. The resulting current flowing in the winding **bc** is always the arithmatical difference between I_1 and I_2, since they are always in the opposite direction. Remember that the induced voltage in the primary opposes the primary applied voltage. As a result, the current caused by the induced voltage flows opposite to the input current. In an auto-transformer, the secondary current is thus induced that is

$$I_1 + (I_2 - I_1) = I_2 \qquad \text{..........(4)}$$

Hence the ampere turns due to section bc, where the substitution $I_2 = \frac{I_1}{a}$ and $N_{bc} = N_{ac} \times a$ are made according to Fig 2 we have

Ampere turns of

$$bc = (I_2 - I_1)\, N_{bc} = \left(\frac{I_1}{a} - I_1 \right) N_{bc} = \frac{I_1 N_{bc}}{a} - I_1 N_{bc}$$

$$= I_1 N_{ac} - I_1 N_{bc} = I_1 N_{ab}$$

(ie) ampere turns due to ab.

Thus the ampere turns due to sections bc and ab balance each other, a characteristic of all transformers.

Power delivered: Equation (3) gives the power determined by the load. To see how this power is delivered, the equation is written in a slightly modified form. Substituting the equation (4) in equation (3), the following result is obtained.

$$P_L = V_2 \, (I_1 + (I_2 - I_1)$$

$$= V_2 \, I_1 + V_2 \, (I_2 - I_1) \text{ watts}$$

This indicates that the load power consists of two parts.

The first part is $P_c = V_2 \, I_1$ = conducted power to load through ab.

The second part is $P_{tr} = V_2 \, (I_2 - I_1)$ = transformed power to load through bc.

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.

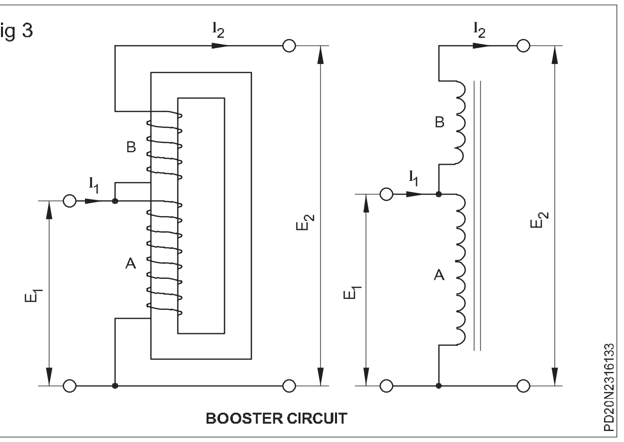
Disadvantages: Auto-transformers have two disadvantages.

- 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.

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



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.

These instrument transformers electrically isolate the instruments and relays from high current/voltage lines thereby reducing danger to the men and equipment. To obtain perfect isolation, the secondary of the instrument transformers and the core should be grounded.

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.

Instrument transformers can be further divided according to their use as a) instrument transformer used as measuring instruments and b) instrument transformers used for control relays.

The instrument transformer used for measurement purposes should have high accuracy. But for control and protective relays instrument transformers of moderate accuracy are sufficient 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.

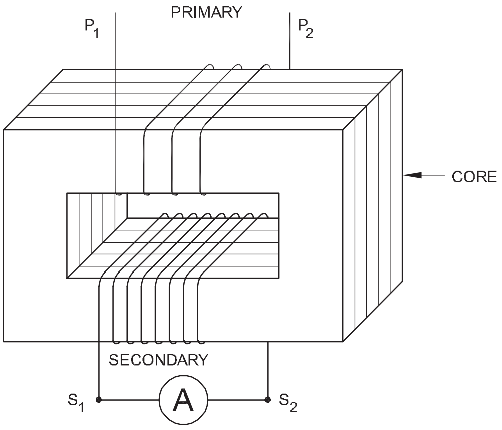
Winding: The winding should be close together to reduce the secondary leakage reactance; otherwise the ratio error will increase. In the case of a current transformer the winding must be so designed as to withstand the large short circuit current without damage.

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



WOUND TYPE CURRENT TRANSFORMER

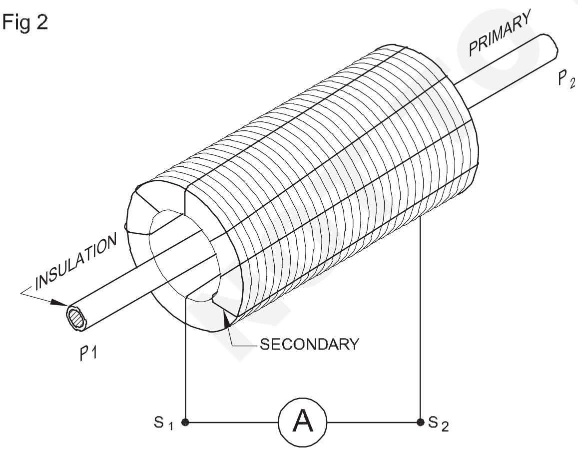
Fig 1 shows the connections of a wound type current transformer having a rectangular type of core. In general the ammeter is arranged to give full scale deflection with 5A or 1A when connected to the secondary of the current transformer.

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

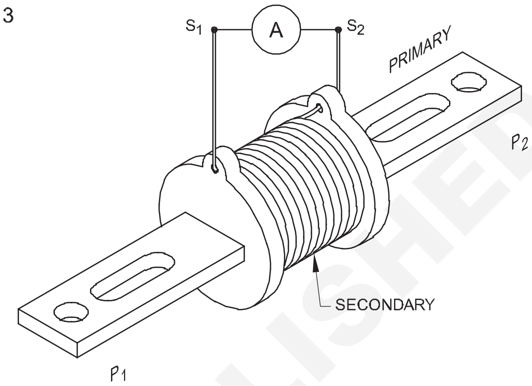
If there are 20 turns in the secondary having a current range of 5 amps, this current transformer according to the transformation ratio, could measure a primary current of 100 amps.

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).

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.

Fig 3



BAR TYPE CURRENT TRANSFORMER

Oil immersed current transformer: This is one which requires the use of an oil of suitable characteristic as insulating and cooling medium.

Recommended symbols and terminal marking as per I.S. 2012(Part XX11)-1978 (Fig 4)

Method of marking

Marking should be done following the guidelines given below. (I.S. 2705(Part I) - 1981)

The terminals shall be marked clearly and indelibly either on their surface or in their immediate vicinity.

The marking shall consist of letters, followed or preceded where necessary, by numbers. The letters shall be in block capitals.

The marking of current transformers shall be as indicated in Figs 5a to 5e.

All the terminals marked P1, S1 and C1 shall have the same polarity at any instant.

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.

Phase displacement: This is the difference in phase between primary and secondary current vectors, the direction of the vector being so chosen that the angle is zero for a perfect transformer.

Fig 4

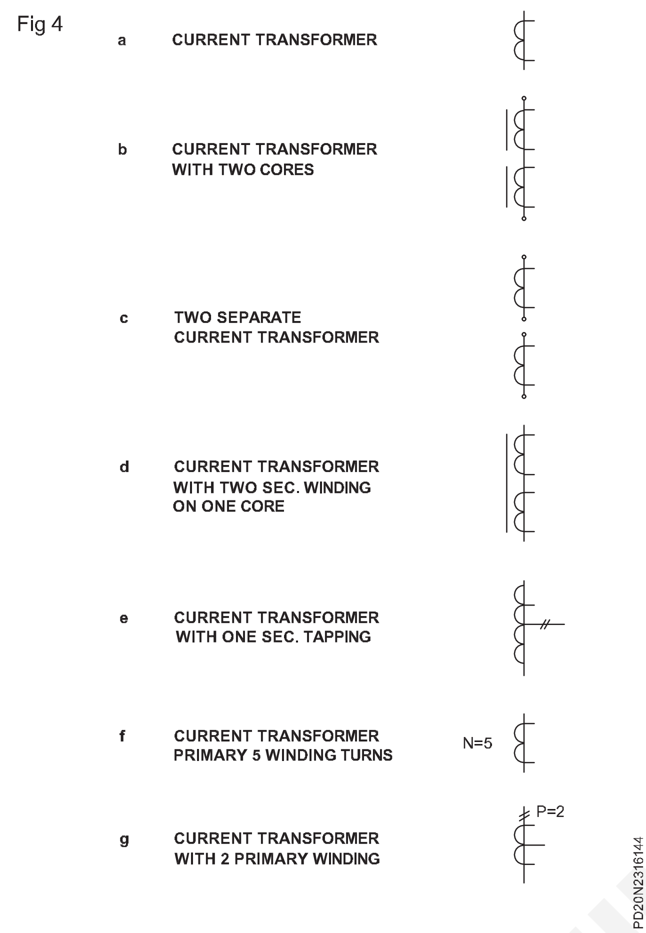
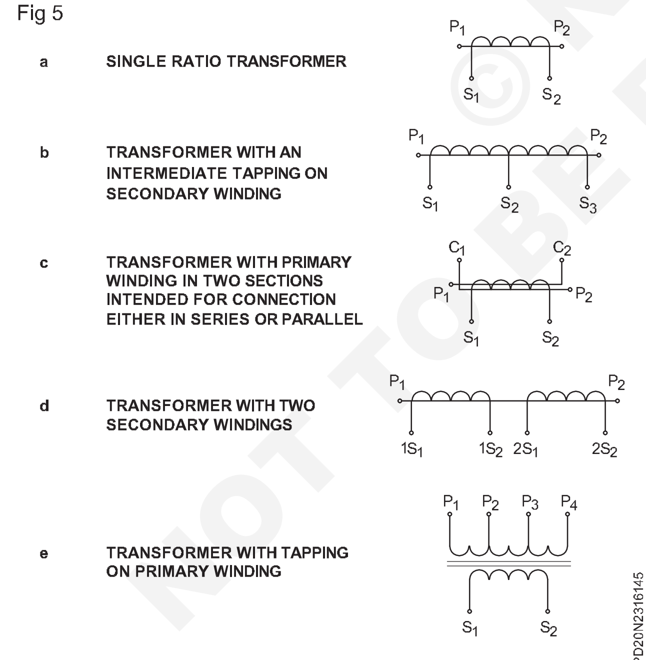


Fig 5



The phase displacement is said to be positive when the secondary current vector leads the primary current vector. It is usually expressed in minutes.

The above definition is strictly for sinusoidal currents only. The phase displacement is an important factor to be considered when connecting several current transformers together in a circuit for various measurements.

Burden: Burden is usually expressed as the apparent power in **volt amperes** absorbed at a specified power factor and at the rated secondary current. Rated burden is the value on which the accuracy requirement of this specification is based.

Rated output: This is the value of the apparent power (in volt amperes at a specified power factor) which the current transformer is intended to supply to the secondary circuit at the rated secondary current and with the rated burden connected to it. 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 the case of an ordinary transformer the supply voltage almost remains constant and the magnitude of primary current depends upon the load current.

However in a current transformer the secondary current depends upon the primary current. Further the secondary of the current transformer could be assumed to be almost short circuited as the ammeter resistance is extremely low.

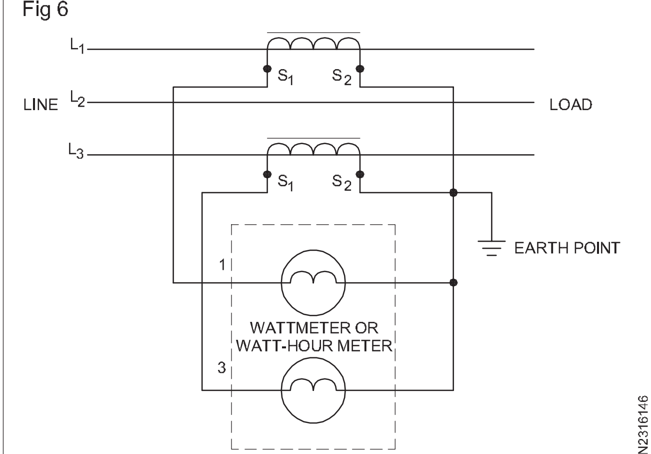
In any case, the secondary winding of the current transformer should not be open circuited. This may happen when the ammeter become open circuited or when the ammeter is removed from the secondary.

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.

While using more than one current transformer in a circuit, the grounding should be done by connecting the similar polarity ends of the current transformer and grounding the circuit at a point (Fig 6)

Fig 6



GROUP OF CURRENT TRANSFORMER WITH GROUNDING POINT

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
- Short time thermal current and its duration
- Service conditions including, for example, whether the current transformer is for use indoors or outdoors, whether for use at unusually low temperature 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, vibrations excessive dust etc.
- Accuray limit factor and any other additional requirement for current transformers for protective purposes.
- Special features, such as limiting dimensions.

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**
- **identify the I.S. symbols and markings used in the potential transformer**
- **state the general terms like accuracy, phase displacement, burden and output with respect to the potential transformer**
- **specify 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.

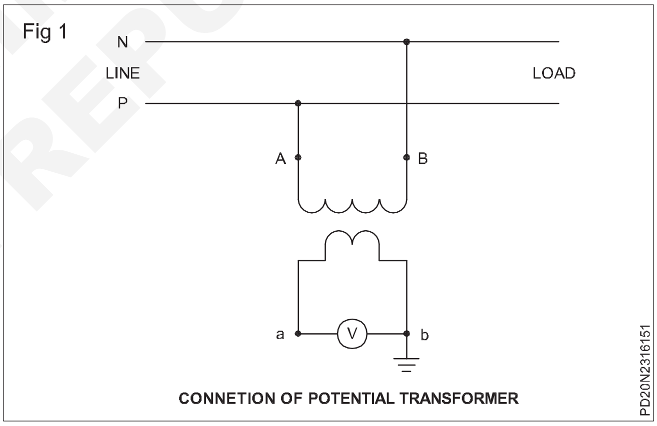
The core may be of shell or core type construction. Shell type construction is normally used for low voltage transformers.

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.

Fig 1



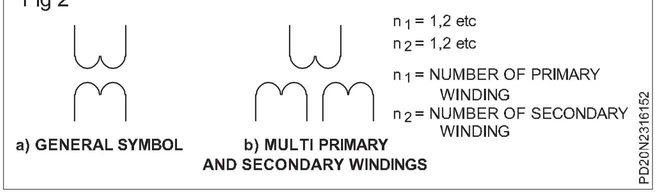
CONNETION OF POTENTIAL TRANSFORMER

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.

Recommended symbols and terminal marking as per I.S. 3156 (Part I) 1978 Fig 2

Fig 2



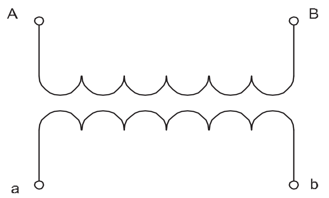
Method of marking

Marking the terminals should be done following the guidelines given below (I.S. 3156 (Part - I) - 1978.)

Figs 3 to 10 give the recommended markings used in a potential transformer as per I.S.

Marking shall be in accordance with Figs 3 to 10 as appropriate. Capital A,B,C and N denote the primary winding terminals and the lower case letters a,b,c and n the corresponding secondary winding terminals.

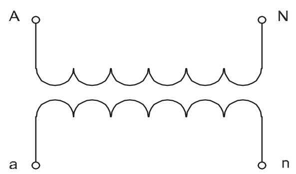
Fig 3



SINGLE PHASE TRANSFORMERS WITH FULL INSULATED TERMINALS AND A SINGLE SECONDARY

PD20N2316153

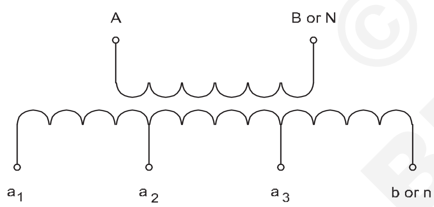
Fig 4



SINGLE PHASE TRANSFORMER WITH A NEUTRAL PRIMARY TERMINAL WITH REDUCED INSULATION AND A SINGLE SECONDARY

PD20N2316144

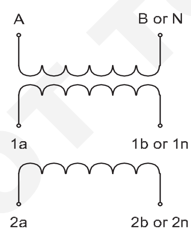
Fig 5



SINGLE PHASE TRANSFORMER WITH ONE MULTI-TAP SECONDARY

PD20N2316155

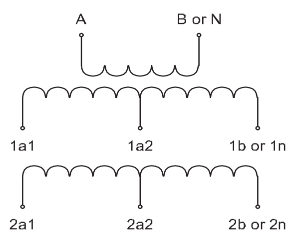
Fig 6



SINGLE PHASE TRANSFORMER WITH TWO SECONDARIES

PD20N2316156

Fig 7



SINGLE PHASE TRANSFORMER WITH TWO MULTI-TAP SECONDARIES

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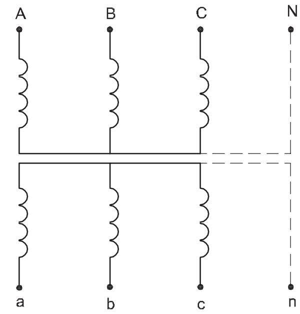
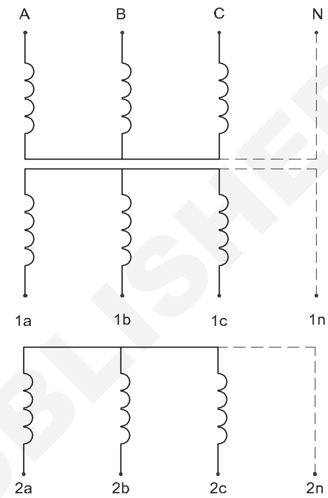
Fig 8



THREE PHASE ASSEMBLY WITH A SINGLE SECONDARY

PD20N2316158

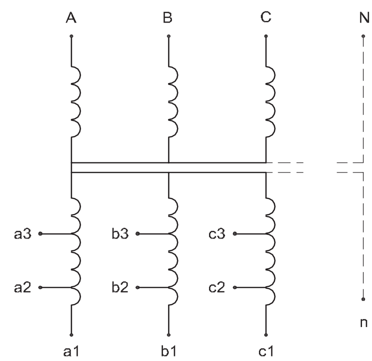
Fig 9



THREE PHASE ASSEMBLY WITH TWO SECONDARIES

PD20N2316159

Fig 10



THREE PHASE ASSEMBLY WITH TWO SECONDARIES

PD20N231615A

Three Phase transformer - Connections

Objectives: At the end of this lesson you shall be able to
- **state the transformer connections, angular divergence of the 3 phase transformers**
- **represent the phase difference between high voltage and low voltage windings for different types of connection by the hour hand of a clock**
- **state the vector group of the transformer**
- **explain the scott connection of transformer and its uses.**

Transformer Bank

Transformers, like other electrical devices, may be connected into series, parallel, two-phase or three-phase arrangements. When they are grouped together in any of these arrangements the group is called a transformer bank.

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 ($Y - \Delta$ 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
Zigzag	Z	z

Angular displacement (divergence)**:** There is a definite time phase relationship between the terminal voltages of the high voltage side and low voltage side for these connections. The time phase relationship between the voltages of high voltage side and low voltage sides will depend upon the manner in which the windings are connected.

If the high voltage side and low voltage side windings are connected in star-star (as in Fig 1a and 1b). The phase displacement will be zero. If, however, the low voltage winding connections are reversed, as shown in Figs 2(a) and (b), the time phase displacement in induced voltages between the high voltage and low voltage windings will be 180 degrees.

If the primary high voltage and secondary low voltage side windings are connected in Yd or Dy as shown in Figs 3(a) and (b), the phase displacement will be 30 degrees.

The displacement in the clockwise direction is negative. Anti clockwise is positive.

Fig 1

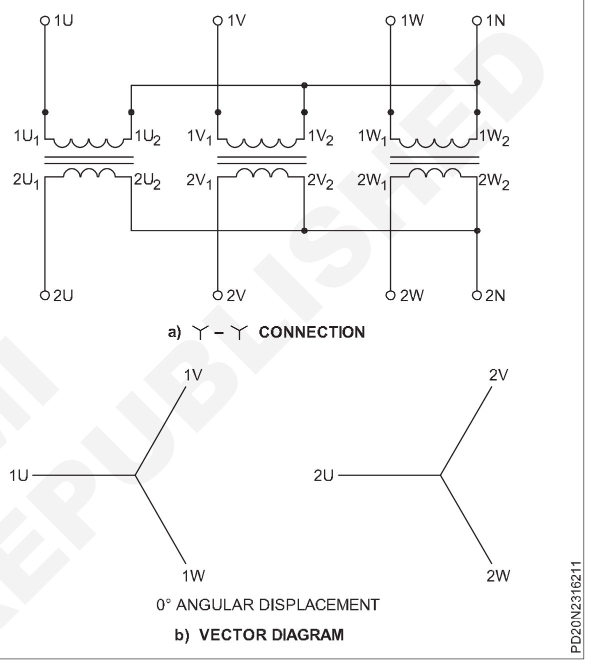
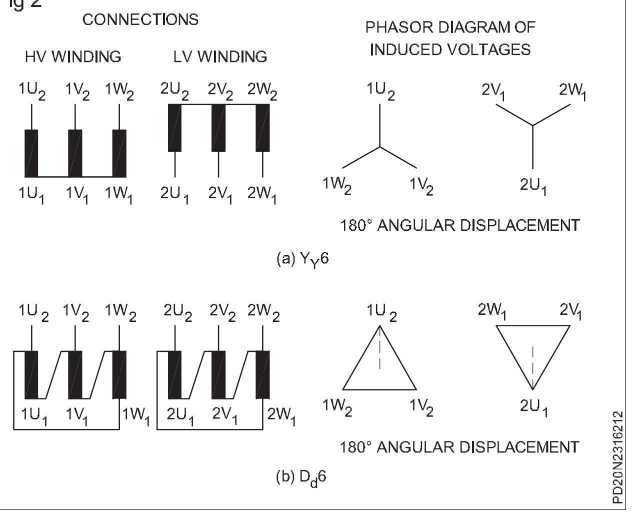


Fig 2



If the windings are connected in Yd or Dy as Figs 4 (a) & (b), the displacement of the terminal voltage will be + 30°.

Observe the change in connections made at the low voltage side in Figs 3(a) and Fig 4(a). Similarly the change in the high voltage side winding connections Figs 3(b) and Fig 4(b) causes the difference in displacement angle.

Fig 3

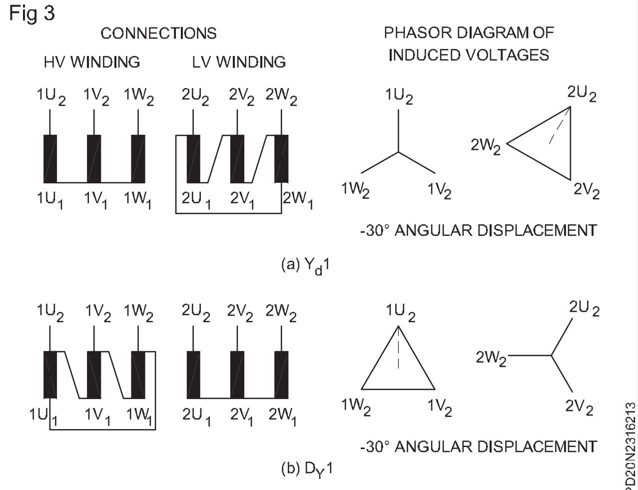
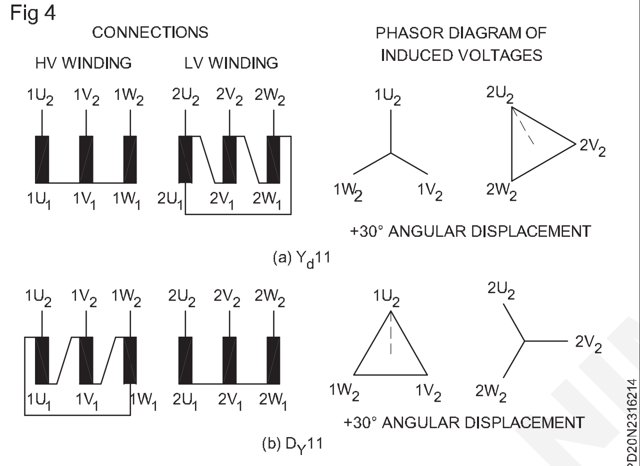


Fig 4



Representation of phase displacement by hour hand of a clock: The phase difference between the HV and LV windings for different types of connections can be represented by comparing it with the hour hand of a clock.

When the hour hand of the clock is at the 12^{O} clock position it is considered zero displacement Fig 5(a).

When the hour hand is at the 6^{O} clock position the displacement is 180^{o}

When the hour hand is at the 1^{O} clock position the displacement is -30^{o}.

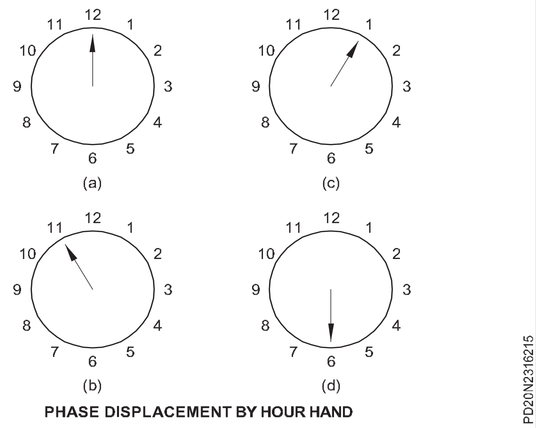
When it is at the 11^{O} clock position the displacement is +30 degrees. (Anticlockwise is positive.)

The connections of the Fig 1 to Fig 4 can respectively be represented.

Vector groups: Depending on the phase displacement of the voltages of HV and LV sides, transformers are classified into groups called 'vector groups'. Transformers with the same phase displacement between the HV and LV sides are classified into one group. Various vector group arrangements used and their connections symbols are given in Indian Standard IS:2026 (Part IV)-1977.

For satisfactory parallel operation of transformers, they should belong to the same vector group. Following are the typical of the connections for which, from the view-point of phase sequence and angular displacement, transformers can be operated in parallel.

Fig 5



Transformer 1:	Yy	Yd	Yd
Transformer 2:	Dd	Dy	Dy

Different groups	Types of connections	
0	Dd0	Yy0
1	Yd1	Dy1
5	Dy5	Yd5
6	Dd6	Yy6
11	Dy11	Yd11

Scott connection or T.T. connection: In certain special equipment the line voltage required for its 3-phase connection may not be of standard rating as available in the system. Further, the power consumption in these equipment may also be high. To meet this requirement Scott connected transformers are used. These Scott connected transformers enable transformation of 3-phase to 3-phase more economically.

This Scott connection can also be used for 3-phase to 2-phase transformation as explained subsequently.

The main transformer has centre tapped primary and secondary windings Fig 6. The primary and secondary windings are indicated by CB and cb respectively in the Fig 6. Another transformer called teaser transformer has a 0.866 tap and one end of both the primary and secondary windings of the teaser transformer (say D and d) is joined to the centre tap of both primary and secondary of the main transformer.

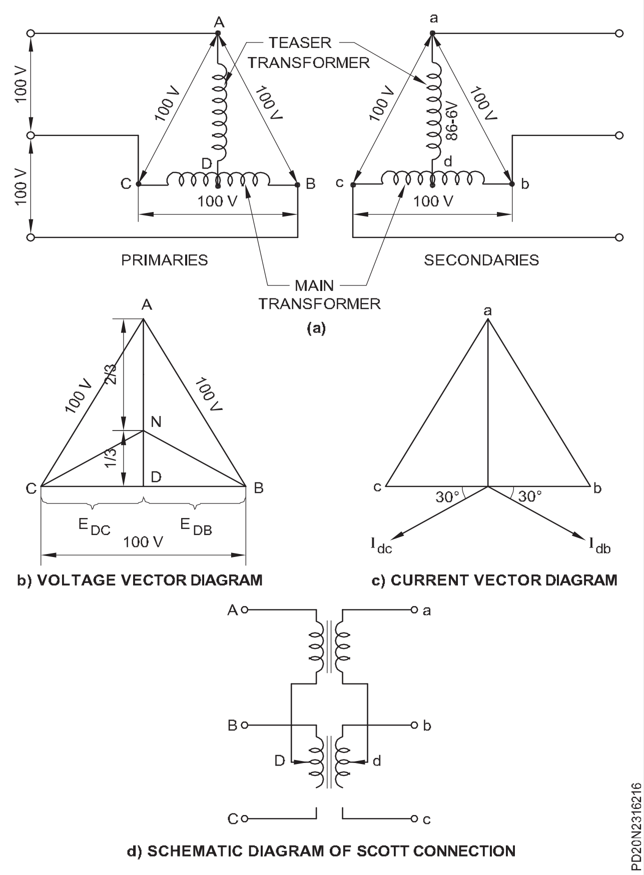
The other end A of the teaser transformer and the two ends B and C of the main transformer primary are connected the 3-phase supply.

3-phase supply is taken out from one end 'a' of the teaser transformer secondary and the two ends b and c of the secondary of the main transformer.

For convenience unity transformation ratio is choosen and the supply line voltage is assumed as 100V the (Fig 6).

By analysing the vector diagram Fig 6b, it is found that voltage E_{DC} and E_{DB} are each 50V and differ in phase by 180^{0} because both the coils DB and DC are in the same magnetic circuit and are connected in opposition. Fig 1d shows the schematic connection diagram.

Fig 6



Each side of the equilateral triangle represents 100V. The voltage E_{DA} being the altitude of the equilateral triangle is equal to $\sqrt{3}/2 \times 100 = 86.6V$ and legs behind the voltage across the main by 90^0. The same relation holds good for the secondary voltages. The transformer rating is restricted to 86.6% of its KVA rating. By suitable turn ratio the transformer rating can be improved to 92.8%.

Example: Two scott connected transformers are used to supply a 660V 33 KVA balanced load from a balanced 3-phase supply of 11000V. Calculate (a) voltage and current rating of each coil (b) KVA rating of the main and teaser transformer.

Voltage across primary 11000V

Voltage across the teaser primary = 0.866x11000

Current is same in the teaser and the main and equal to

$$\text{line current} = I_{LP} = \frac{KVA \times 1000}{\sqrt{3}EL}$$

$$= \frac{33 \times 1000}{\sqrt{3} \times 11000} = \frac{3}{\sqrt{3}} = 1.732A$$

Secondary voltage across the mains = 660V

Teaser secondary voltage = 660 x 0.866 = 572V.

$$\text{The secondary line current } I_{LS} = \frac{I_{LP}}{k} = \frac{1.732}{\frac{660}{11000}}$$

$$= \frac{1.732 \times 11000}{660}$$

$$= \frac{173.2}{6} = 28.87A$$

Main KVA rating = 11000 x 1.732 x 10^{-3}

= 19.05KVA.

Teaser KVA = 0.866 x main KVA

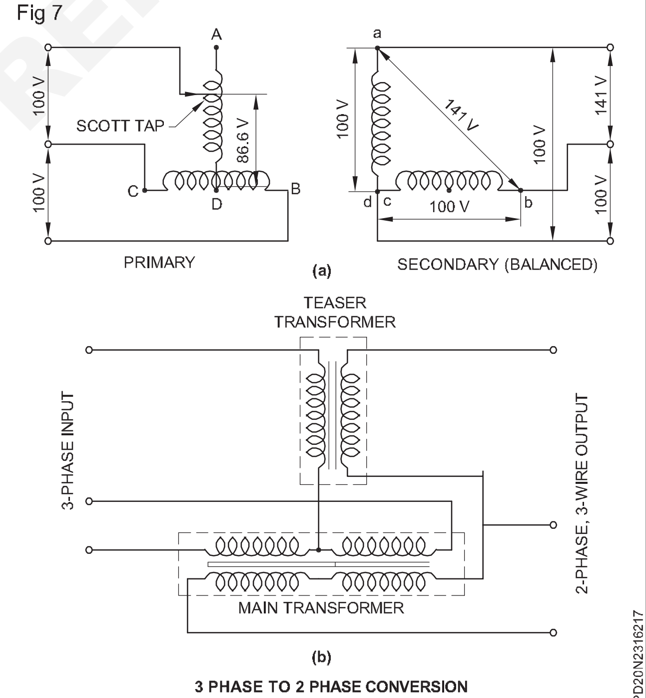
= 0.866 x 19.05 = 16.4 KVA.

3-phase to 2-phase conversion and vice versa: In industrial application of electric power supply certain equipment like electric furnaces and welding transformers require two phase supply.

At present, the available electrical supply is in variably three phase it is necessary to convert the 3 phase supply to 2 phase supply. This is accomplished by Scott connection.

For convenience 100V supply and the transformation ratio of unity are chosen Fig 7. But the transformer could be designed for required voltage and suitable transformation ratio. Fig 7(a) shows the arrangement of connection where as Fig 7(b) shows the circuit arrangement.

Fig 7



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

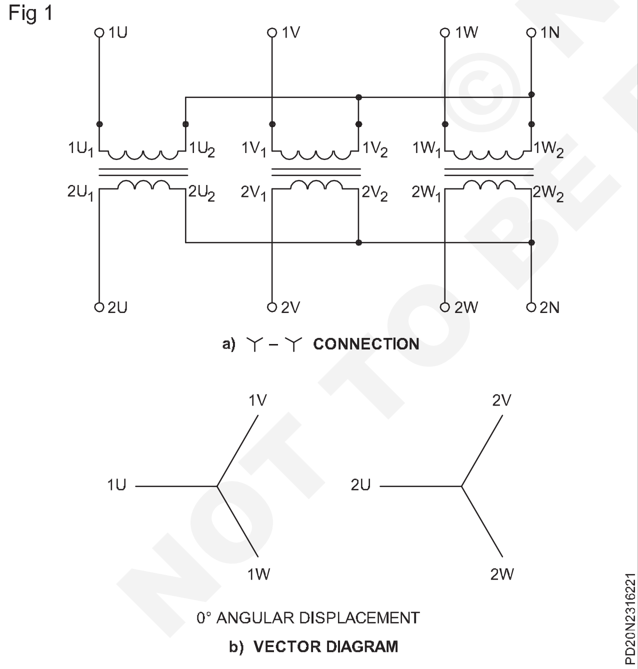
Primaries in Y, Secondaries in Δ

Primaries in Δ, Secondaries in Δ

Primaries in Δ, Secondaries in Y.

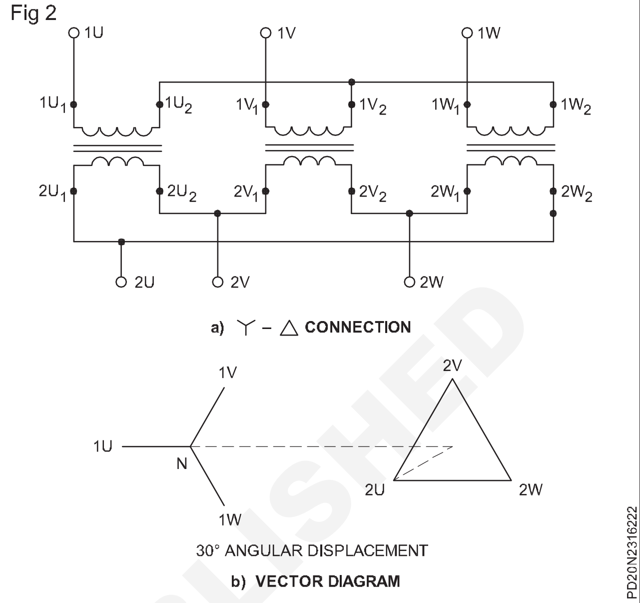
Star/Star or Y/Y connection: Fig 1 shows the connection of a bank of 3 trans-formers in a star-star. This connection is most economical for small, high voltage transformers because the number of turns per phase and the amount of insulation required is minimum. This connection works satisfactorily only 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.

Fig 1



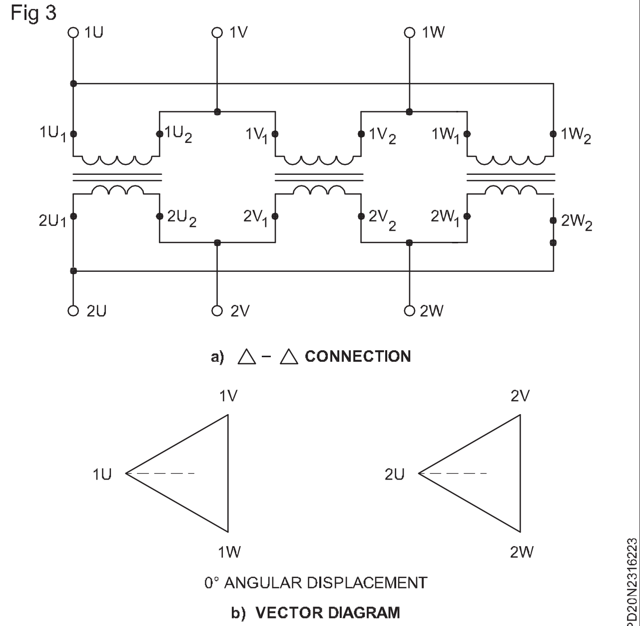
Star - Delta or Y/Δ connection: In primary side 3 transformers are connected in star and the secondary consist of their secondary connected in delta as shown in Fig 2. The ratio between the secondary and primary line voltage is $1/\sqrt{3}$ times the transformation ratio of each transformer. There is 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.

Fig 2



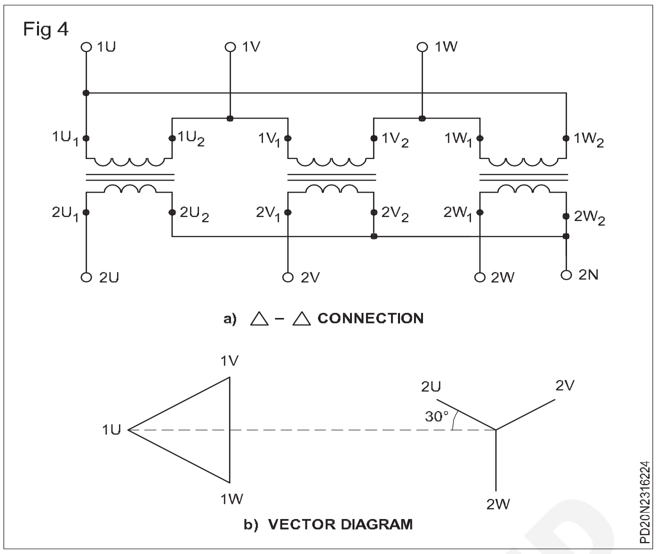
Delta - Delta or Δ/Δ connection: Fig 3 shows three transformers, connected in Δ on both primary and secondary sides. There is no angular displacement between the primary and secondary line voltages. An added advantage of this connection is that if one transformer becomes disabled, the system can continue 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.

Fig 3



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.

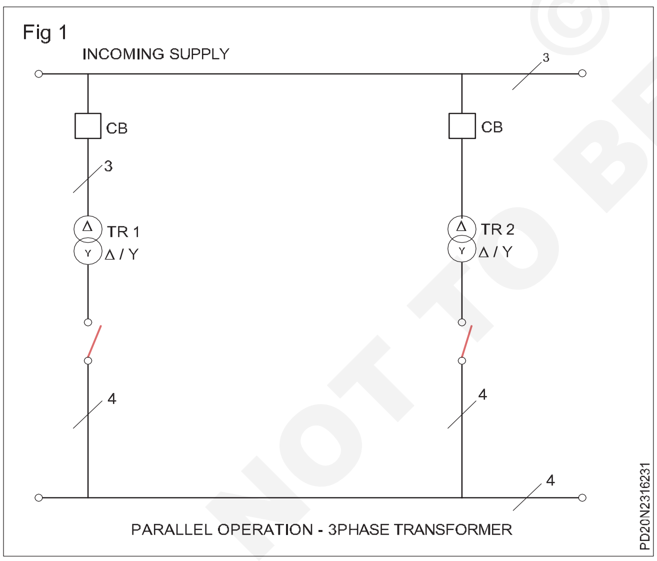


Parallel operation of 3-phase transformer

Objectives: At the end of this lesson you shall be able to
- **Define parallel operation**
- **States the conditions for parallel operation of 3 phase transformer**
- **Sates the necessity of parallel operation.**

Parallel operation

Operating two or more transformers by connecting their primaries in parallel to a common supply line and connecting their respective secondaries in parallel with a common load-busbars (Fig 1) is called as parallel operation of transformers.



Conditions for parallel operation of transformers:

When operating two or more transformer in parallel, the following conditions have to be satisfied for the best performance of the transformer.

1 The voltage ratio must be same.

2 The per unit impedance or percentage impedance should be same i.e., the ratio between the equivalent leakage reactance and the equivalent resistance(X/R) should be same.

3 The polarities must be same.

4 For three phase transformers

i The phase sequence must be same

ii The vector group must be same (i.e., The relative phase displacement between the secondary line voltages must be zero)

Parallel operation of 3-phase transformer:

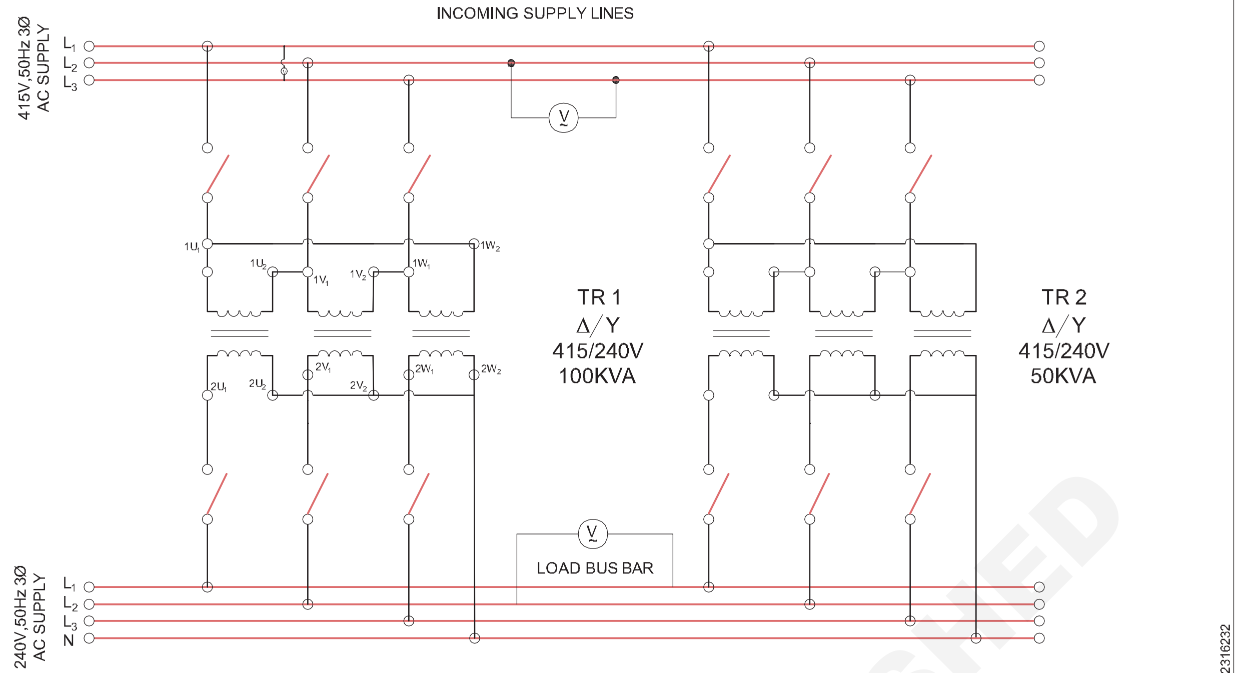
Fig 2 shows the connection diagram for parallel operation of two numbers of 3-phase transformers. In this case, the connection of both of transformer 1 and 2 are (delta - star)same.

However to operate the 2 transformers of having Y/Δ and connection, their primary and secondary line voltage Δ/Y must be same. In this case,the turns ratio may not be equal, but the voltage ratio between the terminal voltage of primary and secondary must be same.

If two transformers having different ratings, are connected in parallel the their percentage impedance must be same, where as the numerical impedance of transformer 1 will have half the impedance of transformer 2. In this case both the transformers will share the common load in proportional to their KVA ratings.(Fig 2)

For best performance of the parallel operation, the regulation of both the transformers must be same . If the percentage impedance of both the transformers are different. Than one transformer will be operating at a higher power factor and other will be operating at a lower power factor.

Fig 2



PARALLEL OPERATION - 3 PHASE TRANSFORMER - CONNECTION DIAGRAM

Cooling of transformer - Transformer Oil and Testing

Objectives: At the end of this lesson you shall be able to
- **explain the necessity of cooling**
- **state the methods of cooling.**

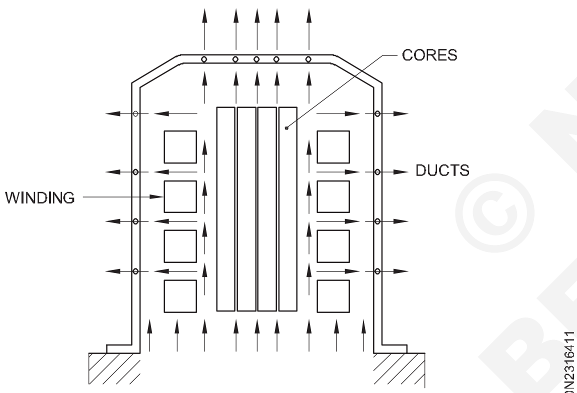
Necessity of cooling

Transformer is heated up when current flows through its, winding. This causes the liberation of heat. In large size transformer, where power rating is high, large amount of heat is liberated. This will affect the insulation of the windings as well as reduction of transformer efficiency. This heat should be transformed from transformer winding and dissipated in the atmosphere.

Methods for cooling transformers: Following are the methods of cooling employed in transformers. Any one or more methods could be adopted depending upon the size, application and location of the transformer.

- Natural air method
- Air blast method (Fig 1)

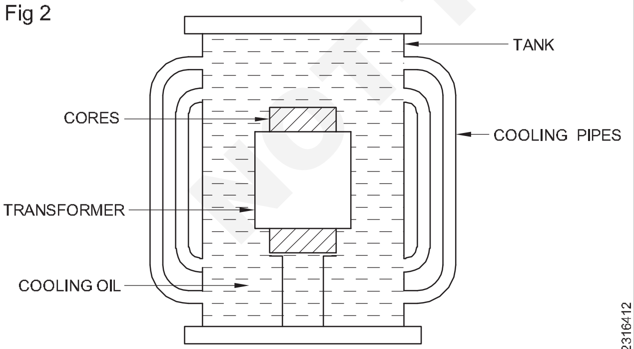
Fig 1



AIR BLOWER FAN

- Natural oil cooled method (Fig 2)

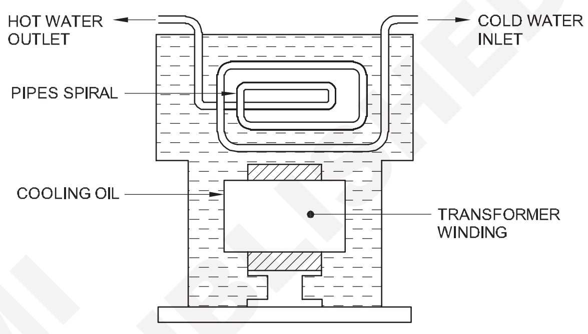
Fig 2



OIL - COOLED TRANSFORMER

- Oil blast method
- Forced circulation of oil
- Oil and water cooled (Fig 3) and
- Forced oil and water cooled

Fig 3



OIL AND WATER COOLED TRANSFORMER

Natural air cooling method is generally adopted for low capacity distribution transformer upto 100KVA. The natural circulation of the surrounding air is used to carry away the heat from the transformer winding.

In air blast method, the fans are used to blow the air on the surface of the transformer thereby the heat generated is carried away by the air blast.

Transformer of 200KVA above capacity are cooled by using an insulating oil. The winding and core are immersed in oil. The area of the tank is increased by using cooling tubes. (Radiator tubes)

In oil and water cooled system, the low pressure water tubes through the heated oil used to remove the heat from the transformer.

Transformer oil and testing

Objectives: At the end of this lesson you shall be able to
- **define the transformer oil**
- **name three insulating oils used in transformer**
- **list the important properties of a transformers oil**
- **state the necessity of transformer oil**
- **state the causes for deterioration of oil**
- **explain the methods of testings the oil for its parameter.**

Transformer oil :

It is an insulating liquid, used to cool and insulate the transformer windings and core. A cooling liquid is also considered as a part of the transformer.

Three kinds of cooling oils/liquids are used in transformers today.

- Mineral oil (inflammable)
- Silicon liquids(low flammable) and
- Hydrocarbon liquids (non-flammable)

The common transformer oil is a mineral oil obtained by refining crude petroleum. Clean and dry mineral oil is an excellent insulator. Its loss by evaporation is small. But it is an inflammable liquid and readily absorbs moisture from the air. Great care should be taken to keep the oil away from flame and moisture.

Synthetic liquids do not catch fire easily. Synthetic liquids are therefore replace mineral transformer oils of those transformers used in

- Underground mines
- Refineries and hazardous location
- Tunnels
- Workshop and plants of metal processing theatres and cinemas etc.

Transformer oil consists of organic compounds, namely paraffin, naphthalene and aromatics. All these are hydro carbons, hence insulating oil/transformer oil/ synthetic transformer oil known as ASKARELS and PYROCLORE are also in use.

Properties of transformer oil

A good transformer oil should have the following properties.

1 High specific resistance so that high insulation resistance

2 Better heat conductivity, (i.e) higher specific heat.

3 High firing point, so that not to catch fire at low temperature.

4 Do not absorb moisture easily, when exposed to air.

5 Low viscosity

Necessity of transformer oil

Large capacity distribution transformers produces more heat due to losses like core losses and copper losses, on load. It is necessary to stablize the heat within temperature class by providing suitable insulating materials.

Transformer oil acts as a good electrical insulating material. Thus it reduces electrical break down. Transformer oil will also act as cooling agent. Thus it brings thermal stability to all the internal parts of transformer.

Causes for deterioration of transformer oil

When the oil cooled transformers are in use, the oils of the transformers are subjected to normal deterioration due to the conditions of the use.

For example

1 The oil may come in contact with the air, there by presence of moisture and dust in the oil. The presence of moisture is harmful and affects the electrical characteristics of oil and will accelerate deterioration of insulating materials.

2 Sediment and precipitable sludge may be formed on the winding and core surfaces. It will reduce the cooling rate and hence it may lead to deterioration of the insulating materials.

3 The presence of certain solid iron, copper and dissolved metallic compounds will increase the acidity. In such cases, the resistivity decreases, and electrical strength also decreases, and it is also the causes for deterioration of transformer oil.

Testing of transformer oil

For reliable use and maintenance of oil cooled transformer, the transformer oil shall be tested before initial filling of the oil as well as during service of the transformers. As per the test result it may be required to filter the transformer oil or in some cases, new oil may be recommended for safe and better maintenance of oil cooled transformers.

The following tests are conducted periodically to decide the performance of the transformer oil.

1 Field test of insulation oil

2 Crackle test of insulating oil

3 Dielectric test of insulating oil

4 Acidity test.

1 Field test of insulating oil

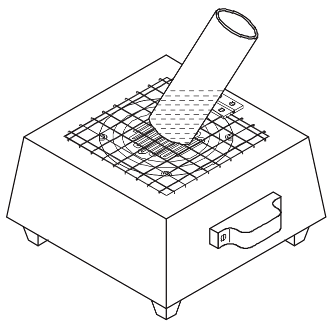
A drop of transformer oil, when placed slowly from a pipette on the still surface of a distilled water contained in heater should retain its shape when the oil is new.

In the case of used cyclooctane oils (or) paraffin oils (even though unused) the drop usually flattened. If this flattened drop occupies an area of diameter less than 15 to 18 mm, the oil may be used. Otherwise, it has to be reconditioned. Oils with the longer spreads are unsuitable.

2 Crackle test of transformer oil (Fig 1)

A rough test may be made, by closing one end of steel tube, and heating the closed end to just dull red hot. (Fig 1) When the oil sample is plunging into the tube, a sharp Crackle sound will be heard, if the oil contains much moisture. Dry oil will only sizzle.

Fig 1



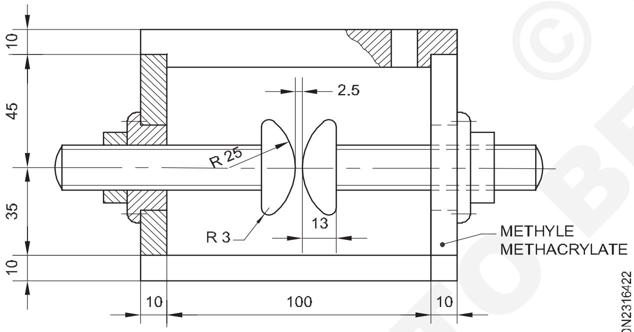
CRACKLE TEST

PD20N2316421

3 Dielectric test of transformer oil

This test is preferably conducted using standard oil test set. The oil test set consists of a container/cell made up of glass or plastic.(Fig 2)

Fig 2



OIL TEST CONTAINER/CELL

PD20N2316422

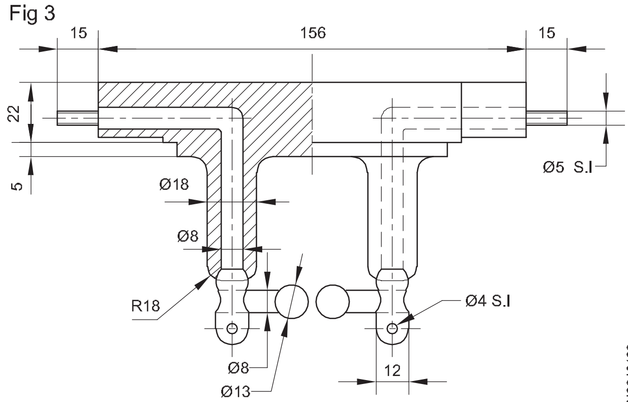
The cell shall have an effective volume between 300 to 500 ml. It should be preferably closed. Section view of container. (Fig 3)

Two numbers of the copper, brass, bronze or stainless steel in the shape of sphere of diameter 12.5 to 13 mm elliptical are mounted on a horizontal axis at 2.5 mm apart, is used as electrodes, for oil test of 11KV transformer.

The cell is mounted on a test set. HT connection to the electrodes, is made by the point contact arrangements.

The test set is also provided into step up transformer where the voltage can be varied from zero to 60KV. In some designs, the voltage is varied by electric motor, with the operation of push button switch.

Fig 3



DIELECTRIC TEST

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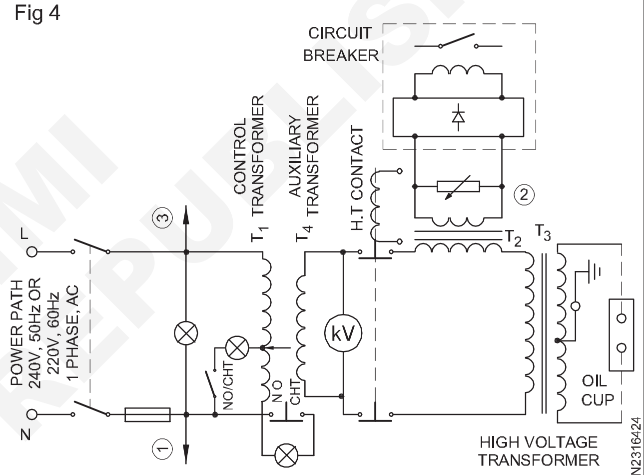
Electrical circuit diagram of dielectric test unit (Fig 4)

For conducting dielectric test on transformer oil, the oil is to be gently agitated and turned over several times so that homogeneous distribution of the impurities contained in the oil is spread all over.

Fig 4



CIRCUIT DIAGRAM OF DIELECTRIC TEST

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Immediately after this, the oil is poured down into the test cell slowly in order to avoid air bubbles. The operation is carried out in a dry place free from dust. The oil temperature at the time of test shall be same as that of ambient.

After fulfilling the above conditions the cover of the cell is placed in position. The cell is placed in the test unit and power is switched "ON".

The AC voltage across the electrode of frequency 40 to 60Hz is increased uniformly at the rate of 2KV RMS starting from 'O' up to the value of producing break down. The break down voltage is the voltage reached during the test at the time the first spark occurs between electrodes.

The circuit is opened automatically if an arc is established between electrodes. The break down voltage is recorded and the reading is interpreted according to the standard ratings. The requirements as per IS-335-1983 is: Electrical Strength (break down voltage)

1 New unfiltered transformer oil - 30KV (RMS)

2 After filtration transformer oil - 50KV (RMS)

It is recommended to filter the transformer oil if the break down voltage does not attain 30KV (RMS).

The test shall be carried out 6 times on the same cell filling. The electric strength shall be the arithmetic mean of the 6 results which have been obtained.

Acidity test

The acid products are formed by the oxidation of the oil. This oxidation will deteriorate the insulating materials like insulating paper and press boards used in transformer windings. It is therefore essential to detect and monitor the acidity formation.

To conduct this test portable test kit is available consisting of:

1 Two polythene bottles containing 100ml each of ethyl alcohol and sodium carbonate solution of 0.0085N concentration.

2 An indicator bottle containing universal indicator.

3 Four clean glass test tube.

4 Three graduated droppers, which serves as pipettes.

5 Colour chart with acidity range.

6 Instruction booklet.

PROCEDURE

The test is conducted by taking 1.1 ml of insulating oil (to be tested) in test tube, 8 ml oil 1 ml of rectified spirit is added and mixture is to be gently shakened. Further 1 ml of solution of 0.008 5 N sodium carbonate added. After shaking the test tube once again 5 drops of universal indicator is added. The resulting mixture develops a colour depending on the acidity value of the mixture.

The approximate colour range will be as follows:

Total acidity value in No.	Colour
0.00	Black
0.2	Green
0.5	Yellow
1.0	Orange

Any how the colour chart will be provided with the test kit to indicate exact value.

DGA (Dissolved Gas Analysis)

Dissolved gas analysis (DGA) is the study of dissolved gases in transformer oil.

It is also referred to as a DGA test. Whenever a transformer undergoes abnormal thermal and electrical stresses, certain gases are produced due to the decomposition of the transformer oil. When the fault is major, the production of decomposed gases are significant and they get collected in a Buchholz relay. But when abnormal thermal and electrical stresses are not significantly high the gasses due to decomposition of transformer insulating oil will get enough time to dissolve in the oil Hence by only monitoring the Buchholz relay it is not possible to predict the condition of the total internal healthiness of electrical power transformer. That is why it becomes necessary to analyze the number of different gasses dissolved in transformer oil in service. Using DGA of transformer oil, one can predict the actual condition of the internal health of a transformer.

It is preferable to conduct the DGA test of transformer oil in a routine manner to get historical information about the internal health of a transformer over its lifetime. In a DGA test, the gases in oil are extracted and analyzed to determine the quantity of gasses in a specific amount of oil. By observing the percentages of different gasses present in the oil, you can predict the internal condition of the transformer

Generally, the gasses found in the oil in service are hydrogen (H_2), methane (CH_4), Ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_3), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen (N_2) and oxygen (O_2).

Most commonly used method of determining the content of these gases in oil, is using a Vacuum Gas Extraction Apparatus and Gas Chronographs. Using this apparatus, gasses are extracted from oil by stirring it under vacuum. These extracted gasses are then introduced in gas Chronographs for measurement of each component.

Generally it is found that hydrogen and methane are produced in large quantity if the internal temperature of power transformer rises up to 150-C to 300-C due to abnormal thermal stresses. If the temperature goes above 300-C, ethylene (C_2H_4) is produced in large quantity. At the temperature is higher than 700-C a large amount of hydrogen (H_2) and ethylene (C_2H_4) are produced. Ethylene (C_2H_4) is an indication of a very high-temperature hot spot inside an electrical transformer. II during DGA test of transformer oil, CO and CO are found in large quantity it is predicted that there is decomposition of proper insulation.

Furan Analysis of Transformer Oil

Transformer core and winding have mainly paper insulation. The base of the paper is cellulose. The cellulose structure is a long chain of molecules. As the paper becomes aged, these long chains are broken into a number of shorter parts. This phenomenon we often observe in our home. The pages of very old books become brittle over time.

In a transformer, the aging effect of paper insulation is accelerated due to the oxidation that occurs in oil. When insulating paper becomes mechanically weak, it can not withstand the mechanical stresses applied during an electrical short circuit - leading to electrical breakdown. It is therefore necessary to monitor the condition of paper insulation inside a power transformer.

It is not possible to bring out a piece of paper insulation from a transformer in service for testing purpose. But we are lucky enough, that there is a testing technique developed, where we can examine the condition of paper insulation without touching it. The method is called Furan analysis Although by dissolved gas analysis one can predict the condition of the paper insulation primarily, it is not a very sensitive method. There is a guideline in IEC-599, where it is stated that if the ratio of CO and CO in DGA results is more than 11, it is predicted that the condition of paper insulation inside the transformer is poor.

Healthy cellulose insulation gives that ratio in a range of 4 to 11. But still it is not a very sensitive way of monitoring the condition of paper insulation. Because CO. and CO gases also produced during oil breakdown and sometimes the ratio may misleads the prediction When oil is soaked into paper, it is damaged by heat and some unique oil soluble compounds are realized and dissolved in the oil along with CO and CO. These compounds belong to the Furfuraldehyde group. These are sometimes called Furfural in short. Among all Furfurals compounds 2-Furfural is the most predominant. These Furfural family compound can only be released from destructive heating of cellulose or paper Furan analysis is very sensitive, as damage to a few grams of paper is noticeable in the transformer oil-even in a large transformer. It is a very significant diagnostic test, and bis generally considered the best test for assessing the life of a transformer.

The percentage rate rise of Furfurals products in transformer oil over time is used to assess the condition and remaining life of the paper insulation in a transformer.

Type Tests and Routine Tests of Transformer

Objective: At the end of this lesson you shall be able to
- **describe various types of tests conducted.**

Tests and Routine

For confirming the specifications and performances of an electrical power transformer it has to go through a number of testing procedures. Some tests are done at a transformer manufacturer premises before delivering the transformer.

Transformer manufacturers perform two main types of transformer testing – type test of transformer and routine test of transformer.

Some transformer tests are also carried out at the consumer site before commissioning and also periodically in regular and emergency basis throughout its service life.

Type of Transformer Testing

Tests done at factory

1 Type tests
2 Routine tests
3 Special tests

Tests done at site

1 Pre-commissioning tests
2 Periodic/condition monitoring tests
3 Emergency tests

Type Test of Transformer

To prove that the transformer meets customer's specifications and design expectations, the transformer has to go through different testing procedures in manufacturer premises. Some transformer tests are carried out for confirming the basic design expectation of that transformer. These tests are done mainly in a prototype unit not in all manufactured units in a lot. Type test of transformer confirms main and basic design criteria of a production lot.

Routine Tests of Transformer

Routine tests of transformer is mainly for confirming the operational performance of the individual unit in a production lot. Routine tests are carried out on every unit manufactured.

Special Tests of Transformer

Special tests of transformer is done as per customer requirement to obtain information useful to the user during operation or maintenance of the transformer.

Pre Commissioning Test of Transformer

In addition to these, the transformer also goes through some other tests, performed on it, before actual commissioning of the transformer at the site. The transformer testing performed before commissioning the transformer at the site is called the pre-commissioning test of transformer. These tests are done to assess the condition of transformer after installation and compare the test results of all the low voltage tests with the factory test reports.

Type tests of transformer include:

1 Winding resistance test of transformer
2 Transformer ratio test
3 Transformer vector group test
4 Measurement of impedance voltage/short circuit impedance (principal tap) and load loss (Short circuit test)
5 Measurement of no-load loss and current (Open circuit test)
6 Measurement of insulation resistance
7 Dielectric tests of transformer
8 Temperature rise test of transformer
9 Tests on on-load tap-changer
10 Vacuum tests on tank and radiators

Routine tests of transformer include

1 Winding resistance test of transformer
2 Transformer ratio test
3 Transformer vector group test
4 Measurement of impedance voltage/short circuit impedance (principal tap) and load loss (Short circuit test)
5 Measurement of no load loss and current (Open circuit test)
6 Measurement of insulation resistance
7 Dielectric tests of transformer.
8 Tests on on-load tap-changer.
9 Oil pressure test on transformer to check against leakages past joints and gaskets

That means Routine tests of transformer include all the type tests except temperature rise and vacuum tests. The oil pressure test on transformer to check against leakages past joints and gaskets is included.

Special Tests of transformer include

1 Dielectric tests.

2 Measurement of zero-sequence impedance of three-phase transformers

3 Short-circuit test

4 Measurement of acoustic noise level

5 Measurement of the harmonics of the no-load current.

6 Measurement of the power taken by the fans and oil pumps.

7 Tests on bought out components / accessories such as buchhloz relay, temperature indicators, pressure relief devices, oil preservation system etc.

Transformer Winding Resistance Measurement

Transformer winding resistance measurement is carried out to calculate the I2R losses and to calculate winding temperature at the end of a temperature rise test. It is carried out as a type test as well as routine test. It is also done at site to ensure healthiness of a transformer that is to check loose connections, broken strands of conductor, high contact resistance in tap changers, high voltage leads and bushings etc.

There are different methods for measuring of the transformer winding, likewise:

- Current-voltage method of measurement of winding resistance.
- Bridge method of measurement of winding resistance.
- Kelvin bridge method of Measuring Winding Resistance.
- Measuring winding resistance by Automatic Winding Resistance Measurement Kit.

Note: Transformer winding resistance measurement shall be carried out at each tap.

Transformer Ratio Test

The performance of a transformer largely depends upon perfection of specific turns or voltage ratio of transformer. So transformer ratio test is an essential type test of transformer. This test also performed as a routine test of transformer. So for ensuring proper performance of electrical power transformer, voltage and turn ratio test of transformer one of the important tests.

The procedure of the transformer ratio test is simple. We just apply three phase 415 V supply to HV winding, with keeping LV winding open. We measure the induced voltages at HV and LV terminals of the transformer to find out actual voltage ratio of the transformer. We repeat the test for all tap position separately.

Magnetic Balance Test of Transformer

Magnetic balance test of transformer is conducted only on three-phase transformers to check the imbalance in the magnetic circuit.

Procedure of Magnetic Balance Test of Transformer

1 Keep the tap changer of transformer in normal position.

2 Now disconnect the transformer neutral from ground.

3 Then apply single phase 230 V AC supply across one of the HV winding terminals and neutral terminal.

4 Measure the voltage in two other HV terminals in respect of neutral terminal.

5 Repeat the test for each of the three phases.

In case of an autotransformer, a magnetic balance test of transformer should be repeated for LV winding also.

There are three limbs placed side by side in a core of the transformer. One phase winding is wound in one limb. The voltage induced in different phases depends upon the respective position of the limb in the core. The voltage induced in different phases of a transformer in respect to neutral terminals given in the table below.

Magnetizing Current Test of Transformer

Magnetizing current test of transformer is performed to locate defects in the magnetic core structure, shifting of windings, failure in between turn insulation or problem in tap changers. These conditions change the effective reluctance of the magnetic circuit, thus affecting the current required to establish flux in the core.

1 Keep the tap changer in the lowest position and open all IV and LV terminals

2 Then apply three phase 415 V supply on the line terminals for three-phase transformers and single phase 230 V supply on single phase transformers

3 Measure the supply voltage and current in each phase

4 Now repeat the magnetizing current test of transformer test with keeping tap changer in normal position

5 Repeat the test while keeping the tap at highest position

Normally, there are two similar higher readings on two outer limb phases on transformer core and one lower reading on the center limb phase, in the case of three phase transformers.

An agreement to within 30% of the measured exciting current with the previous test is usually considered satisfactory. If the measured exciting current value is 50 times higher than the value measured during factory test, there is a likelihood of a fault in the winding which needs further analysis.

Caution: This magnetizing current test of a transformer is to be carried out before DC resistance measurement.

Vector Group Test of Transformer

In a 3 phase transformer, it is essential to carry out a vector group test of transformer. Proper vector grouping in a transformer is an essential criteria for parallel operation of transformers.

There are several internal connections of three-phase transformer are available on the market. These several connections give various magnitudes and phase of the secondary voltage; the magnitude can be adjusted for parallel operation by suitable choice of turn ratio, but the phase divergence cannot be compensated.

So we have to choose a transformer suitable for parallel operation whose phase sequence and phase divergence are same. All the transformers with the same vector ground have same phase sequence and phase divergence between primary and secondary.

Before procuring an electrical power transformer, you should ensure the vector group of the transformer, whether it will be matched with his or her existing system or not. The vector group test of transformer confirms his or her requirements.

Insulation Resistance Test or Megger Test of Transformer

Insulation resistance test of transformer is essential type test. This test is carried out to ensure the healthiness of the overall insulation system of an electrical power transformer.

Procedure of Insulation Resistance Test of Transformer

1 Disconnect all the line and neutral terminals of the transformer

2 Megger leads to be connected to LV and HV bushing studs to measure insulation resistance IR value in between the LV and HV windings

3 Megger leads to be connected to HV bushing studs and transformer tank earth point to measure insulation resistance IR value in between the HV windings and earth

4 Megger leads to be connected to LV bushing studs and transformer tank earth point to measure insulation resistance IR value in between the LV windings and earth

NB: It is unnecessary to perform insulation resistance test of transformer per phase wise in three-phase transformer. IR values are taken between the windings collectively as because all the windings on HV side are internally connected together to form either star or delta and also all the windings on LV side are internally connected together to form either star or delta.

Measurements are to be taken as follows:

- For autotransformer: HV-IV to LV, HV-IV to E, LV to E.
- For two winding transformer: HV to LV, HV to E, LV to E.
- Three winding transformers: HV to IV, HV to LV, IV to LV, HV to E, IV to E, LV to E.
- Oil temperature should be noted at the time of insulation resistance test of the transformer, since the IR value of transformer insulating oil may vary with temperature.
- IR values to be recorded at intervals of 15 seconds, 1 minute and 10 minutes.
- With the duration of application of voltage, IR value increases. The increase in IR is an indication of dryness of insulation.
- Absorption coefficient = 1 minute value/15 secs. value.
- Polarization index = 10 minutes value/1 minute value.

Dielectric Tests of Transformer

Dielectric test of a transformer is one kind of insulation test. This test is performed to ensure the expected overall insulation strength of the transformer. There are several tests performed to ensure the required quality of transformer insulation; the dielectric test is one of them. Dielectric test of the transformer is performed in two different steps.

First one is called Separate Source Voltage Withstand Test of transformer, where a single phase power frequency voltage of prescribed level, is applied on transformer winding under test for 60 seconds while the other windings and tank are connected to the earth, and it is observed that whether any failure of insulation occurs or not during the test.

The second one is the induced voltage test of Transformer where, three-phase voltage, twice of rated secondary voltage is applied to the secondary winding for 60 seconds by keeping the primary of the transformer open circuited.

The frequency of the applied voltage should be double of power frequency too. Here also if no failure of insulation, the test is successful.

In addition to dielectric tests of transformers, there are other types of test for checking insulation of transformer, such as lightning impulse test, switching impulse test and partial discharge test.

Induced Voltage Test of Transformer

The induced voltage test of the transformer is intended to check the inter-turn and line end insulation as well as main insulation to earth and between windings-

1 Keep the primary winding of transformer open circuited.

2 Apply three-phase voltage to the secondary winding. The applied voltage should be twice of the rated voltage of secondary winding in magnitude and frequency.

3 The duration of the test shall be 60 seconds.

4 The test shall start with a voltage lower than 1/3 the full test voltage, and it shall be quickly increased up to the desired value.

The test is successful if no breakdown occurs at full test voltage during the test.

Temperature Rise Test of Transformer

Temperature rise test of transformer is included in type test of transformer. In this test, we check whether the temperature-rising limit of the transformer winding and oil as per specification or not. In this type test of the transformer, we have to check oil temperature rise as well as winding temperature rise limits of an electrical transformer.

Before starting this test all the power terminal bushings should be thoroughly cleaned with a dry clean piece of cloth.

At all the tap positions, IR values of windings to earth & between windings shall be measured with designated insulation tester of suitable ratings and readings noted.

Between HV Winding and Earth (Megger) use 5000V or 2500V Insolation Tester

Between HV and LV Winding (Megger) use 5000V or 2500V Insulation Tester

Between LV Winding and Earth (Megger) use 1000V or 500V Insulation Tester

IR values obtained should be similar to those indicated in the manufacturers' test report, furnished with the handing –over documents. In humid weather, IR values obtained may be lower due to condensation on the terminal bushings

If IR values are very low and unacceptable, then it may be necessary to filter the oil / dry-out the winding till the insulation reaches satisfactory values.

Break-Down Voltage (BDV) Test:

Oil samples from tank bottom, tank top, radiator, etc, shall be carefully taken and tested for BDV value, as per clause 4.3 of this manual

BDV value of oil should be more than 50kV (rms) for 1 minute in the standard test cell

If BDV value is very low and unacceptable (30kV(rms) or less for 1 minute, then it may be necessary to dry-out & clean the oil till the insulation reaches satisfactory values.

Voltage Ratio Test

Apply 3-Phase, 433V AC supply on the HV side and the Voltage Ratio at all tap positions can be derived using suitable precision voltmeter connected to the LV side. A ratio meter, if available can be used for a more accurate measurement

The Ratio value obtained should be similar to those indicated in the manufacturers' test report, fumished with the handing over documents

Winding Resistance Measurement Test

All the auxiliary wiring from various accessories to marshaling box shall be checked with marshaling box scheme drawing furnished with the handing over documents

During testing of accessories like Buchholz relay, etc, an operation of all the alarm/trip contacts shall be checked at marshaling box terminal blocks ensuring both operation and wiring are checked correctly

Marshalling Box Scheme Check

All the auxiliary wiring from various accessories to marshaling box shall be checked with marshaling box scheme drawing furnished with the handing over documents

During testing of accessories like Buchholz relay, etc., an operation of all the alarm/trip contacts shall be checked at marshaling box terminal blocks ensuring both operation and wiring are checked correctly

Buchholz Relay Test

Relay operation for alarm and trip contact shall be checked by injecting air inside the relay through test petcock. Injected air collected inside the relay allows the alarm float/flap & trip float/flap to fall thereby operating their respective switch

Temperature Indicator Test

Indicators operation for alarm and trip contact shall be checked by manual stimulation

Off-Circuit Tap Selector (OCTS)

During shipment, the OCTS has not been separated from the transformer so it is not necessary to recheck the internal connections of tapping an internal mechanism

Means of protecting the OCTS from unauthorized operation is provided by using a padlocking arrangement at the designated tap position

Before switch on ensure that

All the Oil Shut-off Valves are OPEN and Draw-Off Valves are CLOSED

All Thermometer Pockets are near filled (85%) with oil

Oil is at the correct level in the Bushings, Conservator, etc

Desiccant color in breather is blue for silica gel or yellow/orange for envirogel

Earthing Connection of Main Tank, Neutral Bushing, Marshalling Box, Control Gear Box, Cable Box, Arcing-Horn, etc., are correctly made

Bushing arcing horn gap is set correctly

All CT Secondary Circuits are Closed

All Air Release Plugs of Main Tank: Radiator, Conservator, Buchholz Relay, Bushings, etc, are free of air pocket/bubbles

Note: After Oil-Filling or Before Commissioning, AT LEAST 12hrs should be allowed for the oil to settle-down and the air is released from all points at 2 hourly intervals

Transformer Alarms

Transformers are the most expensive piece of apparatus in a power substation and therefore must have appropriate protection equipment installed to guard against various faults. This technical article explains a few internal transformer faults that make an alarm in a substation. For substation crew it's always important to understand what is going on inside a transformer and why.

In order to react properly in faulty situations it's important for operator to understand how internal protection mechanisms of a transformer work. For example, switching operators must not energize any substation transformer that has tripped off on fault.

Together with the usual type of protection relays (i.e. Overcurrent , earth fault) used elsewhere on the system, transformers have additional protection.

These include alarms and trips that guard against:

1 Winding Temperature (over heating)

2 Oil Temperature (over heating)

3 Buchholz

1 Winding Temperature

The winding Temperature indicator is to Start auxiliary cooling fans and /or oil pumps Activate an over-temperature alarm, and Initiate a trip of the transformer continues to rise,

For example, a 20/27MVA transformer will run at 20MVA without cooling equipment, but at 27MVA with all cooling equipment running.

If a winding temperature alarm is activated it is normally due to either:

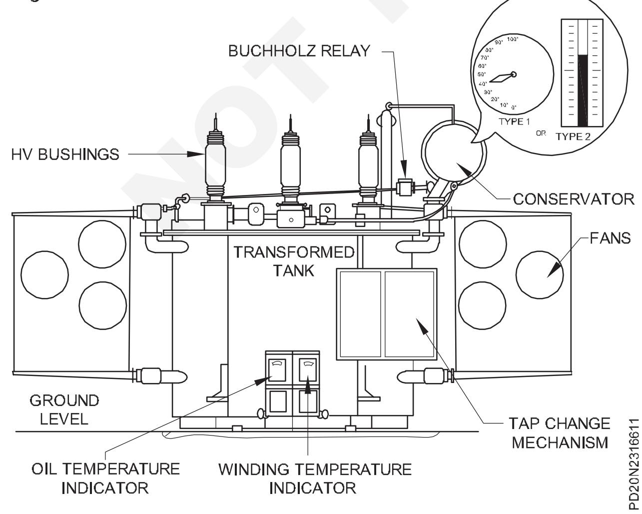
1 An overload of the transformer causing heat increase, or

2 Malfunction of cooling equipment causing a heat increase in the transformer

Inspection of the transformer and its loading will dictate what action needs to be taken. The winding temperature circuit is connected so that extra cooling facilities (fans/ pumps) are activated before the alarm/trip function.

The temperature values as shown in Figure 1 are typical values and may vary on different transformers. Care should be taken when testing cooling fans and pumps to ensure that the control circuits are restored to normal operation after testing is complete.

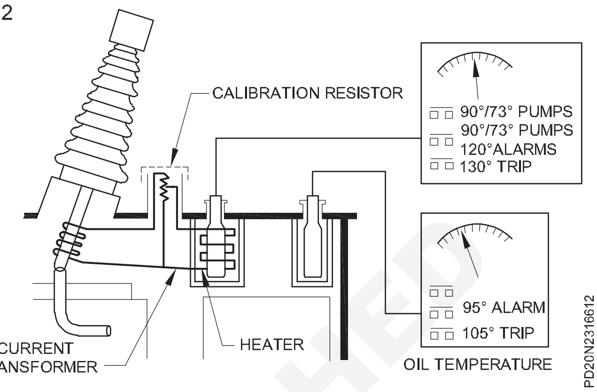
Fig 1



2 Oil Temperature

The alarm and trip settings on this protection are set lower than the winding temperature gauge. This is due to the fact that the heat generated by the windings is dissipated through the cooling medium (oil) and so the alarm setting on the oil gauge (95° C) roughly corresponds to the alarm setting on the winding gauge (120° C) (Fig 2)

Fig 2



Oil and winding protection can be used singularly or both together, they are used for the same purpose. One acts as a backup for the other, ensuring efficient protection of the transformer. Where a transformer is not fitted with pumps and fans, usually only an oil temperature alarm is fitted.

As mentioned previously, an alarm or trip on either oil or winding temperature protection, must be viewed seriously.

The response to a transformer winding or oil temperature alarm is to check the transformer load and confirm all cooling is functional. Relocating load may be considered as a solution or a decision to temporarily shut the transformer down may be made. This would allow time for the transformer to cool and for further tests if necessary.

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3 Buchholz Trip

The most important function of Buchholz is to trip the transformer, when

1 Internal fault causes a surge of gas or oil from inside the transformer, or

2 The main oil level of the transformer drops below the Buchholz relay

These points are important because the quicker these faults can be removed, the least amount of damage will result inside the transformer.

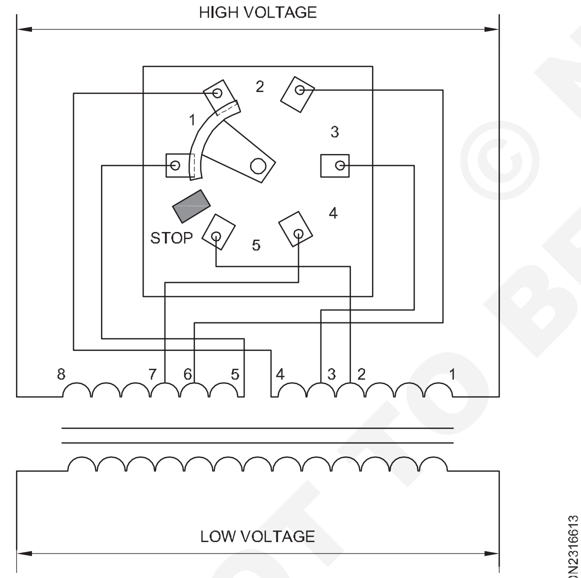
For any Buchholz trip alarm, the appropriate technical staff must be brought in to take samples of gas or oil via the Buchholz bleeder valves for chemical analysis. This analysis gives positive indication on the exact type of fault and its extent. Decisions can then be made about the transformers future.

Note: That some transformers have an additional Buchholz pressure – activated relay fitted for the tap changer tank.

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 3)

Fig 3



MANUALLY OPERATED TAP - CHANGING

There are two methods of tap changing. In one method, these taps are manually changed through a tap changing switch. (Fig 2) In this method load switch has to be opened, before the tap changing operation is to avoid heavy sparking at the contact points. This method is often referred to as "OFF-LOAD" tap changing method.

In another method the tap changing is done with the load called as ON-LOAD' tap changer. In this method the following parameters are met.

- The load current must not be interrupted during a tap change.
- The tap changing must be carried out without short circuiting a tapped section of the winding.

To meet both criteria some form of bridging or transfer impedance is required during the tap changing operation.

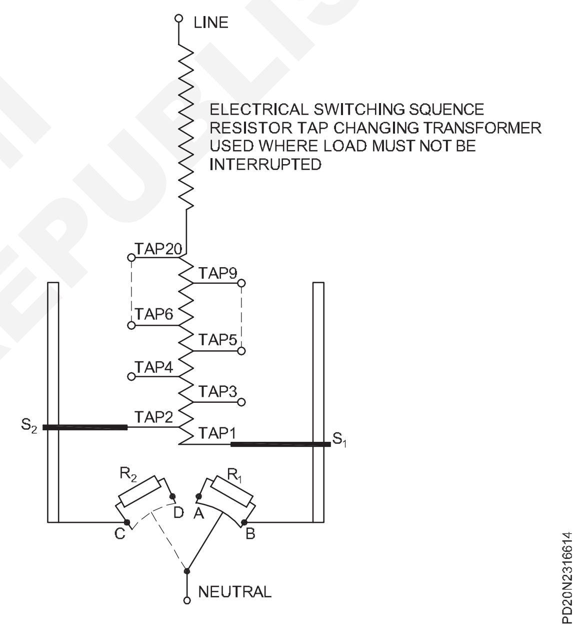
The tap changer has two main units. The tap selector switch is the unit responsible for selecting the tap on the transformer winding as shown in Fig 4, but does not make or break the load current. The diverter switch is where the actual switching of the load takes place.

The selector switch first moves to the desired tap position by the internal mechanism as selected either by automatic voltage regulator or by manual method. Then the diverter switch operates at a faster rate to the desired setting.

The operation of the ON-LOAD tap changer could be explained as below. (Only single phase operation is shown)

Referring to Fig 4, in the initial position selector switch S_1

Fig 4



is on tap 1 and S_2 on tap 2. The diverter switch connects tap 1 to the neutral point of the transformer winding. The sequence of operation in changing to tap 2 is as follows.

- The mechanism operates, the moving contact starts to travel from one side of the diverter to the other; contact 'B' is opened and the load current flows through resistor R_1 to contact 'A'.
- The moving contact 'D' then closes. Both resistors R_1 and R_2 are now in series across tap 1 and 2 and the load current flows through the mid point of these resistors.
- Further travel of the moving contact opens contact 'A' and the load current then passes from tap 2 through resistor R_2 and contact 'D'.

- Finally when moving contact reaches the other side of the diverter switch, contacts 'C' is closed and resistor R_2 is shorted out. Load current from tap 2 now flows through contact 'c' the normal running position of tap2.

The change from position 1 to 2 as described involves the movement of selector switch. If any further change in the same direction is required i.e from 2 to 3, the selector switch ST travels to tap 3 before the diverter switch moves and the diverter switch then repeats the above sequence but in the reverse order.

If a change in the reverse direction, the selector switches remain stationary and the tap change is carried out by the movement of the diverter switch only.

On-load tap changers (LTC, or, OLTC)

On-load tap changers (LTC, or, OLTC) regulate the turns ratio and thus the voltage ratio of an electrical transformer. Unlike its no-load counterpart, on-load tap changers do this without interrupting the load current. There are two main load tap changer designs, the reactance and the resistive types.

OLTC stands for On-load tap changer which is used in Transformer to regulate the output voltage. OLTC is installed inside the transformer main tank. It is operated by a Drive mechanism which is connected to OLTC through a tie rod. Generally, the Drive mechanism is mounted on the outside body of the Transformer.

Based on the requirement of output voltage, OLTC operates by the drive mechanism in a manual or automatic way through AVR (Automatic Voltage Regulating). Generally in Power Transformer, AVR relay is used in RTCC (Remote Tap Changer Control) panel. As per the command of AVR relay, the OLTC operates to change the voltage to Raise or lower direction.

Purpose of OLTC in Transformer

As we know Transformer is used in Power System to step up or step down of the voltage. If the Transformer is designed at a fixed ratio, there will be no provision for changing of output voltage. The OLTC or On-load Tap Changer is required in Power Transformer for the following reasons.

Variation of Distribution Load: The demand of load at the distribution section is not constant; it will vary at different times of the day. The output voltage of the transformer goes down due to high load during peak demand and the voltage goes up during low demand time. The changing of the output voltage is not healthy for the connected loads and stability of the Grid. In this case, the output voltage is regulated by the OLTC by changing the transformer Tap position.

Inductive or Capacitive Load: In addition to changing load demand there are different types of loads are connected to the distribution grid. Due to using of higher inductive load like Motor, Fan, Pump, Chocks, relay, contactors, etc., The output voltage dropped. For using Capacitive loads like capacitor banks, Synchronous motor, Buried cable, Radio circuits, etc., the output voltage increased.

Grid Stability: The voltage of the power system also varies due to various reasons like long length transmission lines, use of FSC, and reactors in substations. Variation of Transformer output voltage is also required for better stability of Transmission and distribution power grid.

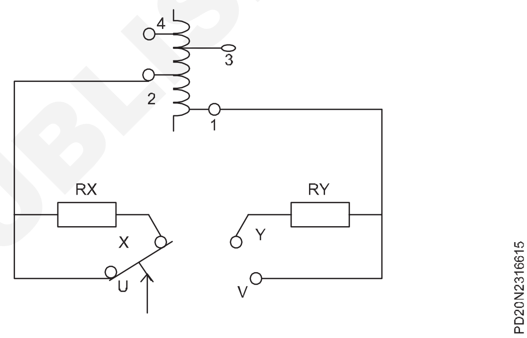
Working Principle & connection diagram of OLTC or On-Load Tap Changer

OLTC consists of two separate sections, they are Diverter switch and Tap selection. The diverter switch is a separate housing inside the transformer. The diverter switch is filled with transformer oil and a separate conservatory is used for it.

During changing of the tap from one tap position to another position, the neutral or phase connection can be discontinued for a moment. A resister unit is used in parallel with the main tap to avoid discontinuity during the changeover of the tap position.

The following connection diagram of OLTC, it is explained the working principle of OLTC in Transformer. (Fig 5)

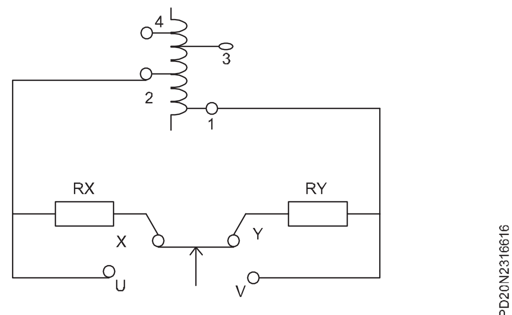
Fig 5



In the connection diagram of Fig-I, OLTC tap position is connected to the Tap-2. The load current flows through the OLTC selector contact U. Due to the high resistive path of X, the resistive path is automatically bypassed.

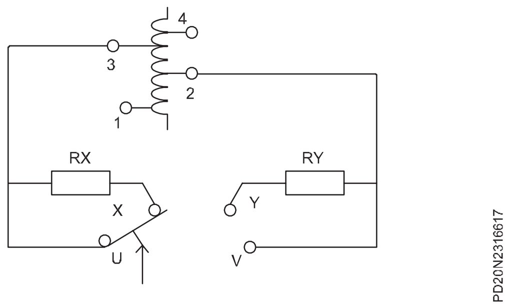
At this point, we need to change OLTC tap position from Tap-2 to Tap-3. At present, all load current flowing through the main contact U and there is no load in Main contact V. (Fig 6)

Fig 6



After receiving the tap changing command, the main contact V is shifted from Tap-1 to Tap-3 and the selector contact is connected to points X & Y and it is disconnected from main contact U. At the present moment, the load current flows through the resistance X & Y. (Fig 7)

Fig 7



After the position as mentioned in fig-2, it is moved to the position as in Fig-3. Here, the selector contact is connected to the main contact V and the resistor contact Y. In this condition, the load current flows through main contact V and the tap position 3. After shifting the selector contact to the V and X, the resistor contact will automatically be bypassed due to the high resistive path as compared to the main contact.

In this way, the OLTC changes the tap position and there is no discontinuity of current. The above change over in OLTC is done very fast to avoid the arc during changing of contacts. Generally within 50 ms, the complete sequence is done in OLTC.

Vector group testing

Vector group testing is done to ensure the parallel operation of three phase transformer connected in the power system. There are various ways of connecting three phase

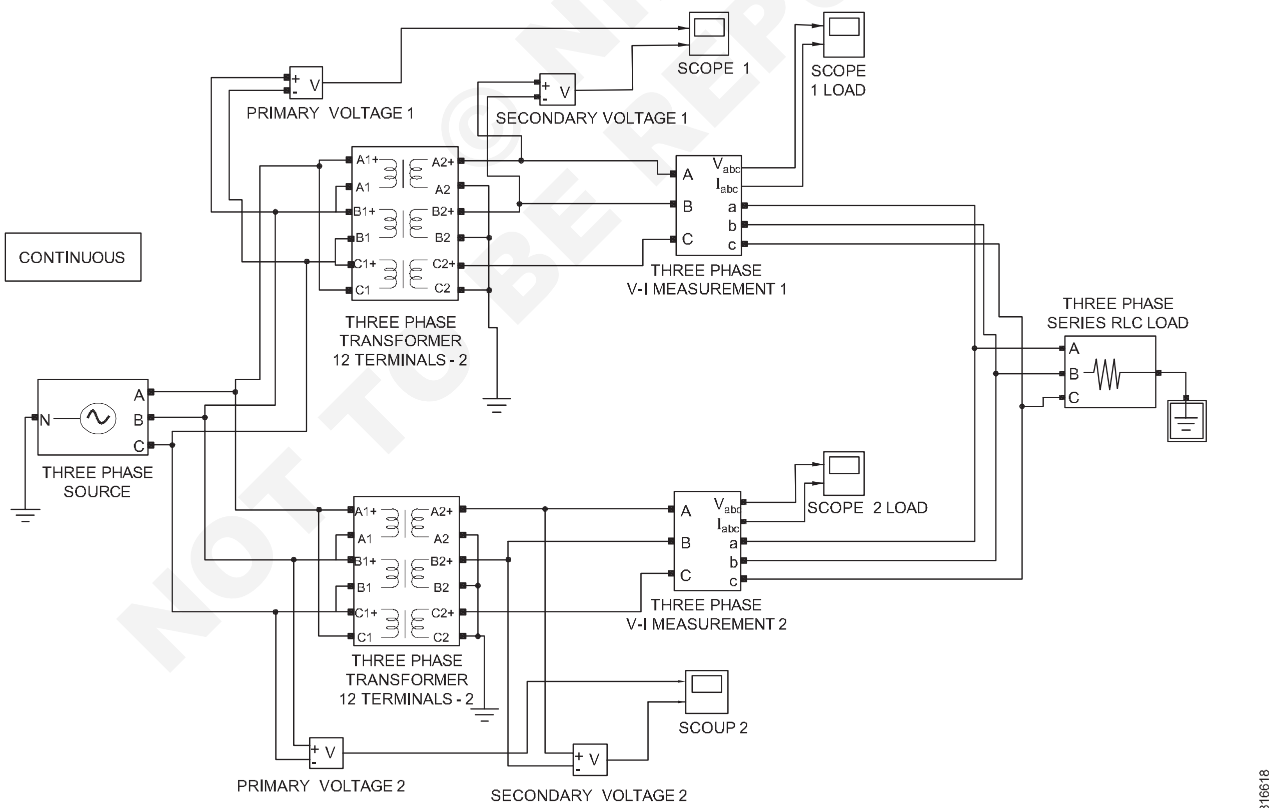
Transformers with phase shift of 00, ±300 and 1800. This phase shift is due to different ways for connecting the primary and secondary windings of the transformer. To connect the various transformer, the secondary waveform should be same for all the transformer

Otherwise a large circulating current will flow in system that may cause short circuit. To simulate the results, the Simulink from MATLAB software is used.

As the need of good quality power is increasing exponentially in vast country like India, we need to produce a huge amount of energy to meet the need of the consumers. To have the output power in synchronism with all the other system we shall connect the transformers in parallel to avoid circulating current. Circulating current causes instability in the system. When three phase transformers shares a common load, connected to more than one transformer and the phase shift between the secondary of both the transformers have zero phase shift, then it is said paralleling. In three phase transformers, phase bushing are marked as ABC, UVW or RYB

For parallel operations the transformers should have same vector group & same polarity of the winding. (Fig 8)

Fig 8



PARALLEL OPERATION OF THREE PHASE (Dnd 11)

The Dyn11 signifies various things: -

1 The H.V. side is connected in Delta.

2 The L.V. side is connected in Star with neutral.

3 11 signifies that the L.V. leads H.V. by 300

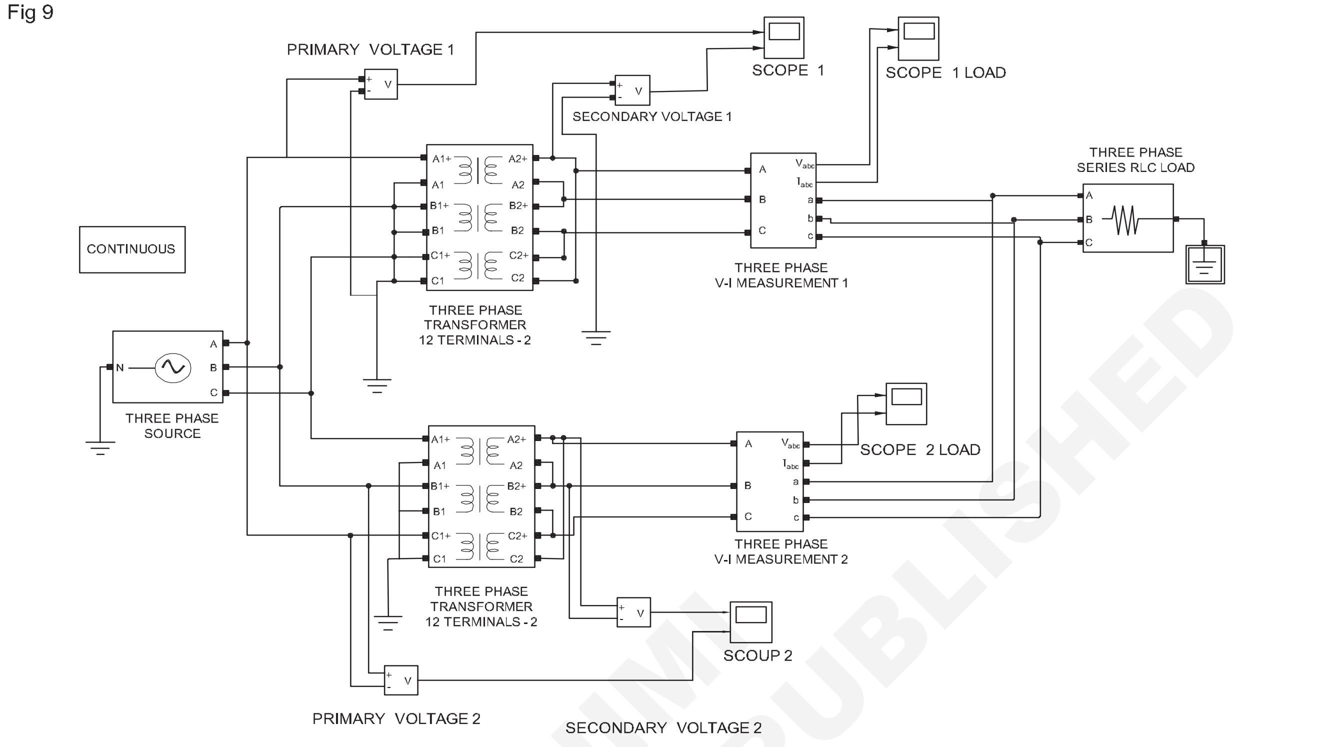
The YNd1 signifies various things: -

1 The H.V. side is connected in Star with neutral.

2 The L.V. side is connected in delta

3 1 signifies that the H.V. leads L.V. by 300

Fig 9



PARALLEL OPERATION OF THREE PHASE (Ynd1)

PD20N2316619

Bushing and Termination

Objectives: At the end of this lesson you shall be able to
- **describe various types of bushing in transformer**
- **describe various types tests and maintenance conducted on bushing**
- **describe Protective devices like breather , Buchholz relay, Explosion vent.**

High voltage Power transformers are used in transmission and distribution sector. The windings of such transformers are energised with very high voltage. Generally, when an energized conductor (may be Copper or Aluminium) is passing through a metallic section.

The metallic part is directly connected with earth, then the potential of it will be equal to the earth potential. Therefore the field of the charged conductor gets distorted with the effect of the earth potential.

The electric field of the conductor will interact with the earth potential. To prevent this, Transformer Bushings are provided with each input and output terminals. So, Transformer Bushings are used to provide a electrical isolation for the winding terminals, when any earthed material is present near to the conductors.

Generally, Transformer Bushings are designed to withstand the high electrical energy of the charged conductors passing through them. Therefore they should have sufficient dielectric strength.

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.

Capacitance graded bushing of transformer (capacitor bushings)

Basically, capacitance graded bushing is the modification of Paper Bushing. Here, very fine layers of smooth metallic foils are inserted into the paper during the winding process. The inserted foils are metallic. So they are conductive in nature.

Therefore, when these foils are interacting with charged conductors, then they develop a capacitive effect which dissipates the electrical energy more evenly throughout the Bushing.

In this way, the electric field stress is distributed throughout the Bushing and this causes lesser chance of Insulation Puncture. This type of bushing is also known as Capacitor Bushing.

There are 4 types of Capacitance graded Bushing, namely:-

- Resin Bounded Paper Bushing.
- Oil Impregnated Paper Bushing.
- Resin Impregnated Paper Bushing.
- Epoxy Resin Impregnated Paper Bushing.

Testing and maintenance of transformer bushing

There are several types of tests for transformer bushing. Some of them are done before the installation and some of them are used for routine maintenance.

1 **Measurement of tangent delta (tan δ) or capacitance:** This is a routine maintenance test. Initially, the transformer is separated from service and a strong local earthing is done for operator safety. In this test, electrical connection in between the transformer tank and bushing flange is checked for instance with a buzzer. For capacitance measurement, a capacitor test kit is required.

   The transformer capacitance has negligible value so it can be ignored during the measurement of bushing capacitance. This measurement is carried out for each phase of the transformer. The measured capacitance is further compared with the rating chart.

2 **Measurement of Partial Discharge:** This is also a routine checking process for maintenance purpose. This measurement of Partial Discharge indicates the week points of insulation. As per the new technology the partial discharges are located by using sophisticated acoustic sensors.

3 **Dissolved gas analysis:** This test is only for oil filled bushings. After opening the seal oil sample is collected from the bushing and then the necessary procedures are carried out. After the sample collection, the glaze seal of bushing should be properly placed. This test is commonly known as the DGA test of transformer bushing.

4 **Moisture analysis:** This is an important test for oil filled bushings are any type of moisture is harmful for proper operation. The oil bushings of transformer are tightly sealed.

After some period the oil sample is collected to measure the moisture content. Depending on the operating temperature, the moisture of bushings will move from paper to oil or oil to paper.

5 **Maintenance of Porcelain:** The porcelain part of bushings sometime chipped or cracked, or the glaze seal sometime eroded. So, proper maintenance of porcelain is necessary and the defected porcelain should be replaced with new one.

Beside of these, the metal parts, taps and oil levels are checked as routine maintenance.

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:

- 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

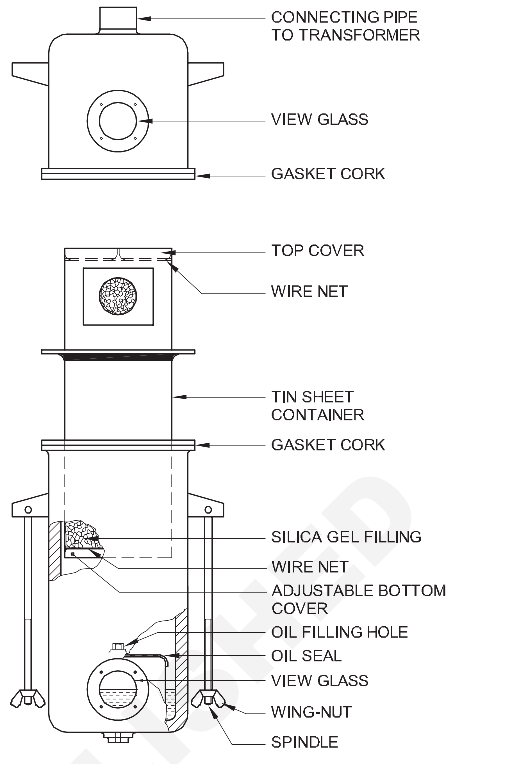
Silica gel breather is a protective device fitted to the conservator through a pipe and allows the moisture free air to and fro into the conservator when the transformer oil get heated and cools down.

As the load and heat on a transformer reduces, air is drawn in to the conservator through a cartridge packed 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.

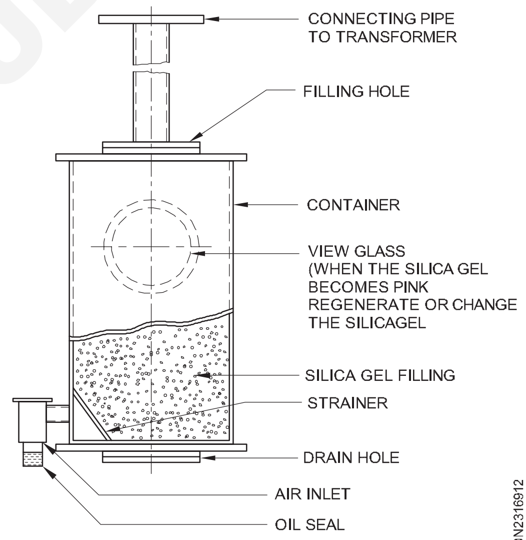
To recondition silica gel either it can be dried in sun or it could be dry roasted on a frying pan kept over a stove. Fig 1 & 2 show a cross-sectional view of such a silica gel breather.

Fig 1



SILICA GEL BREATHER

Fig 2



SILICAL GEL BREATHER

The oil seal at the bottom of the breather absorbs the dust particles that are present in the air entering the conservator.

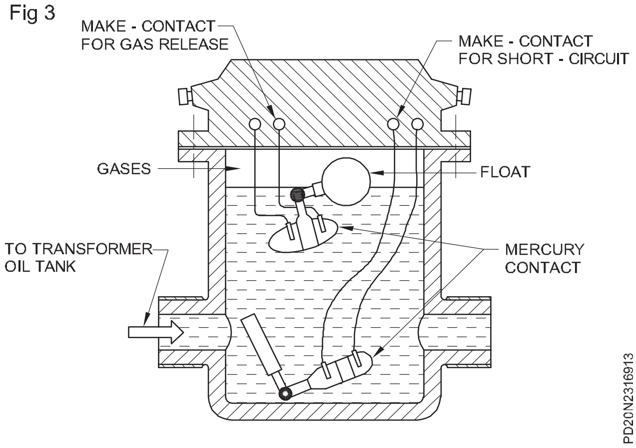
2 Buchholz relay

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.

The relay comprises of a cast iron chamber which have two floats Fig 6. Top float assembly operates during initial stages of gas/air bubble formation due to minor fault in the transformer.

Fig 3



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.

LT/HT Cable, Cable Joints, Termination, Connectors

Objectives: At the end of this lesson you shall be able to
- **define UG Cable, Differentiate HT/LT Cable,Insulating materials used in cables**
- **describe the need of cable jointing,termination kit**
- **distinguish different types of joints and terminations**
- **describe different type of connectors, method of connection.**

A high-voltage cable (HV cable) is a cable used for electric power transmission at high voltage. A cable includes a conductor and insulation. Cables are considered to be fully insulated. This means that they have a fully rated insulation system that will consist of insulation, semi-con layers, and a metallic shield. This is in contrast to an overhead line, which may include insulation but not fully rated for operating voltage (EG: tree wire). High-voltage cables of differing types have a variety of applications in instruments, ignition systems, and alternating current (AC) and direct current (DC) power transmission. In all applications, the insulation of the cable must not deteriorate due to the high-voltage stress, ozone produced by electric discharges in air, or tracking. The cable system must prevent contact of the high-voltage conductor with other objects or persons, and must contain and control leakage current. Cable joints and terminals must be designed to control the high-voltage stress to prevent the breakdown of the insulation.

The cut lengths of high-voltage cables may vary from several feet to thousands of feet, with relatively short cables used in apparatus and longer cables run within buildings or as buried cables in an industrial plant or for power distribution. The longest cut lengths of cable will often be submarine cables under the ocean for power transmission.

Like other power cables, high-voltage cables have the structural elements of one or more conductors, an insulation system, and a protective jacket. High-voltage cables differ from lower-voltage cables in that they have additional internal layers in the insulation system to control the electric field around the conductor. These additional layers are required at 2,000 volts and above between conductors. Without these semi-conducting layers, the cable will fail due to electrical stress within minutes. This technique was patented by Martin Hochstadter in 1916; the shield is sometimes called a Hochstadter shield and shielded cable used to be called H-Type Cable. Depending on the grounding scheme, the shields of a cable can be connected to the ground at one end or both ends of the cable. Splices in the middle of the cable can be also grounded depending on the length of the circuit and if a semiconducting jacket is employed on direct buried circuits. High voltage is defined as any voltage over 1000 volts. Those of 2 to 33 kV are usually called medium voltage cables, those over 50 kV high voltage cables.

Modern HV cables have a simple design consisting of a few parts: the conductor, the conductor shield, the insulation, the insulation shield, the metallic shield, and the jacket. Other layers can include water blocking tapes, ripcords, and armor wires. Copper or aluminum wires transports the current. The insulation, insulation shield, and conductor shield are generally polymer-based with a few rare exceptions. With paper insulated cables the semiconducting layers consist of carbon-bearing or metalized tapes applied over the conductor and paper insulation. The function of these layers is to prevent air-filled cavities and suppress voltage stress between the metal conductors and the dielectric so that little electric discharges cannot arise and endanger the insulation material.

The insulation shield is covered by a copper, aluminum, or lead "screen." The metallic shield or sheath serves as an earthed layer and will drain leakage currents. The shield's function is not to conduct faults but that functionality can be designed if desired. The cable jacket is often polymeric. The function of the jacket is to provide mechanical protection as well as prevent moisture & chemical intrusion. Jackets can be semiconducting or non-conducting depending on soil conditions and desired grounding configuration. Semiconducting jackets can also be employed on cables to help with a jacket integrity test. Some types of jackets are LLDPE, HDPE, polypropylene, PVC (bottom end of the market), LSZH, etc.

Aerial Bunched Cable (ABC) is a very novel concept for Over Head power distribution. When compared to the conventional bare conductor overhead distribution system, ABC provides higher safety and reliability, lower power losses and ultimate system economy by reducing installation, maintenance and operative cost. This system is ideal for rural distribution and especially attractive for installation in difficult terrains such as hilly areas, forest areas, coastal areas etc. ABC is also considered to be the best choice for power distribution congested urban areas with narrow lanes and by-lanes. In developing urban complex, ABC is the better choice because of flexibility for rerouting as demanded by changes in urban development plan.

XLPE/HDPE insulated power conductors of Aluminum (Neutral conductor and, street lighting conductors if and when necessary) are laid together (twisted) around a high tensile stranded and galvanized steel (Aluminum Alloy may be used) insulated or bare messenger wire to form the

Aerial Bunched Cable. This assembly is directly strung on to distribution pole/towers by means of standard hard wares available in the market but care shall be taken to render the messenger wire completely insulated from earthing at any point of distribution in case of HT ABC.

Mid-span jointing is not at all recommended in the case of HT lines our recommendation is for outdoor type HV terminations only. Under unavoidable circumstances, line tapping at the support points may be allowed through suitably designed clamp connectors/PG clamps.

ABC Cables are highly reliable and insulation has been developed to withstand heat, cold and intense sunlight. Disturbance and faults occur five to ten times more often in open wire lines than in ABC lines. There is no risk in touching the live cable and the insulation reduces the number of short circuits and over-voltages in overhead cables during thunder-stones.

The conductor shield is always permanently bonded to the XLPE cable insulation in the solid dielectric cable. A strippable insulation shield is purchased to reduce splicing time and skill.

Type Based on the Insulation:

Why insulation is important? Insulation is the outer part of the conductor. It should have high-temperature stability

Polyvinyl Chloride (PVC)

- They are known as PVC insulated cables are widely used in various fields.
- PVC's relatively low cost, biological and chemical resistance and workability have resulted in it being used for a wide variety of applications.
- For electric cables the PVC is mixed up with plasticizers. PVC has high tensile strength, superior conductivity, better flexibility and ease of jointing.
- PVC is a thermoplastic material, therefore, care must be taken not to overheat it; it is suitable for conductor temperatures upto 70°C. PVC insulated cables should not be laid when the temperature is less than 0°C, because it becomes brittle and is liable to crack.

Cross-linked polyethylene: (XLPE)

- They are known as PEX or XLPE Cable. It is form of polyethylene with cross links.
- XLPE creates by direct links or bonds between the carbon backbones of individual polyethylene chains forms the cross linked polyethylene structure.
- The result of this linkage is to restrict movement of the polyethylene chains relative to each other, so that when heat or other forms of energy are applied to the basic network structure cannot deform and the excellent properties that polyethylene has at room temperature are retained at higher temperatures.
- The cross linking of the molecules also has the effect of enhancing room temperature properties.
- The useful properties of XLPE are temperature resistance, pressure resistance (stress rupture resistance), environmental stress crack resistance (esc), and resistance to UV light, chemical resistance, oxidation resistance, room temperature and low temperature properties.
- XLPE cables work for the working voltage of 240 V to 500 KV.
- The jacketing material can be of PVC / Flame Retardant / Flame Retardant Low Smoke / Zero Halogen (LSOH).

Applications: Low voltage copper conductor PVC cables are extensively used for domestic home appliances wiring, house wiring and internal wiring for lighting circuits in factories, power supply for office automation, in control, instrumentation, submarine, mining, ship wiring applications etc.

XLPE is used at all voltage levels from the 600V class and up. Solid, extruded insulation cables such as XLPE account for the majority of distribution and transmission cables produced today. However, the relative unreliability of early XLPE resulted in a slow adoption at transmission voltages. Cables of 330, 400, and 500 kV are commonly constructed using XLPE today, but this has occurred only in recent decades.

Halogen-free cables

Halogen-free cables & wires are applicable in delicate areas as, for example, public buildings and institutions or railway vehicles and in areas where the general safety requirements for cables are very high.

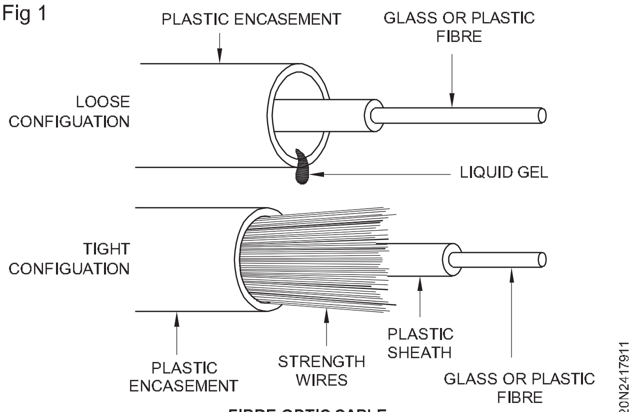
Besides being halogen free, the used cables have to be flame retardant and self-extinguishing and are not allowed to enhance flame propagation. All those characteristics are combined in our halogen-free cables & wires.

Cables can be fully recycled and in separate components newly supplied to there source cycle. Cables with outer sheath avoid flame propagation in case of local flaming and are flame retardant and self-extinguishing. They fulfil the smoke density.

Fiber optic cable

Fiber optic cable is made of light- conducting glass or plastic core surrounded by more glass and a tough outer sheath as in Fig 1 The center core provide the light path or wave guide while the glass or cladding is composed of varying layers of reflective glass. The glass or cladding is composed of varying layers of reflective glass. The glass cladding is designed to refract light back into the core. Each core and cladding strand is surrounded by a tight or loose sheath in tight configurations, the strand is completely surrounded by the outer plastic sheath. Loose configuration use a liquid gel or other material between the strand and the protective sheath.

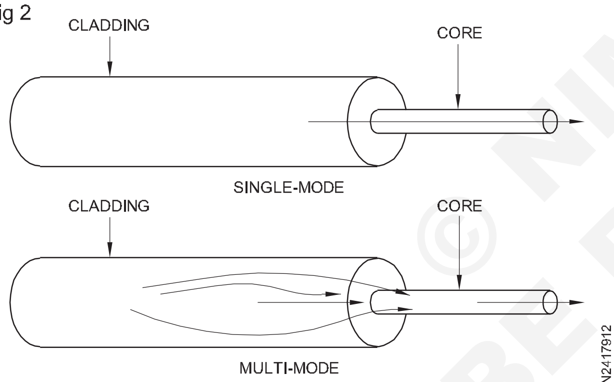
Fig 1



FIBRE OPTIC CABLE

The Optical fibers may be multimode or single mode in nature. Single mode fiber has been optimized to allow only one light path while multimode fiber allows various paths. The following figure explains single mode and multimode fibers. Fig 2

Fig 2



FIBRE OPTIC CABLE

Single mode fiber cable can be used for distance upto 10 kms. And multimode cable foe upto 2.5 km. The typical speeds are 100/1000 Mbpz. The types of optic cable are differentiated by mode, composition (glass or plastic) and core/cladding size.

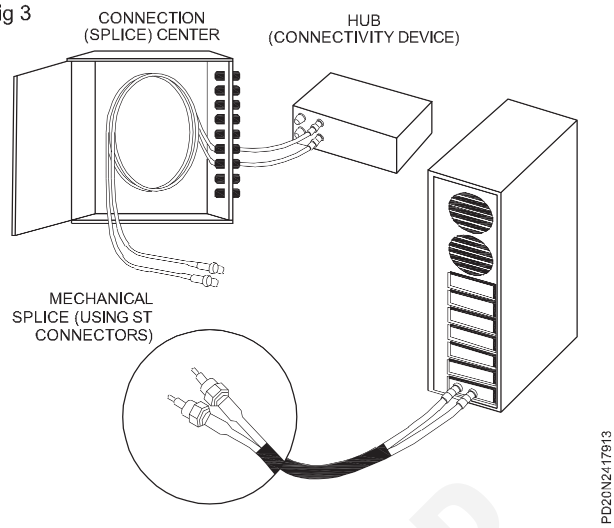
Common types of fiber optical cables:

- 8.3 micron core/125 micron cladding single mode
- 62.5 micron core/125 micron cladding multimode
- 50 micron core/125 micron cladding multimode
- 100 micron core/140 micron cladding multimode

The common fiber optic cables installation is given in the following Fig 3

The single carried by a single mode cable is generated by a laser source and that of a multimode by light emitting diode (LED). Together, these qualities allow single mode cable to operate at higher bandwidths than multimode and traverse distance upto 50 times longer. Single mode cable is cheaper than multimode and has a relatively high

Fig 3

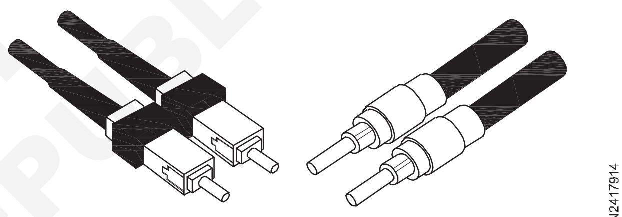


bend radius, which makes it mode difficult to work with. MMF is most commonly used.

Fiber optic connectors

The connector used fiber optic cables is called an ST (straight tip) connection shown Fig 4

Fig 4

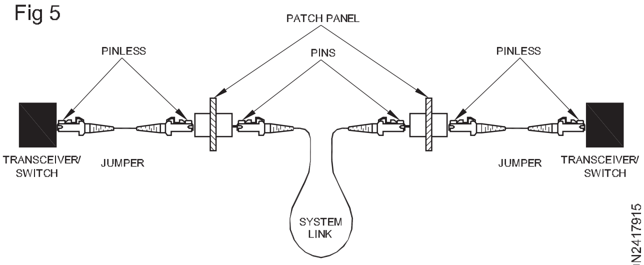


FIBRE-OPTIC SC (LEFT) AND ST (RIGHT) CONNECTORS

One more connector type is SC (subscribe connector) is coming up popularly. It has a square body and locks by simply pushing into the socket.

The MTRJ is a new fiber optic connector being used widely. It can operate at Gigbit ethernet speeds (1000 Mbps) easily. The MT-RJ has a lacthing mechanism similar to the RJ-45 UTP connector. A standard MT-RJ connection consists of 3 components: a male connector (with pins), a female MT-RJ (with guide holes) and as MTRJ adapater. It is easily to install and maintain and should be considered for any new installation. The figure 5 and 6 show the MTRJ connectors and connections in use.

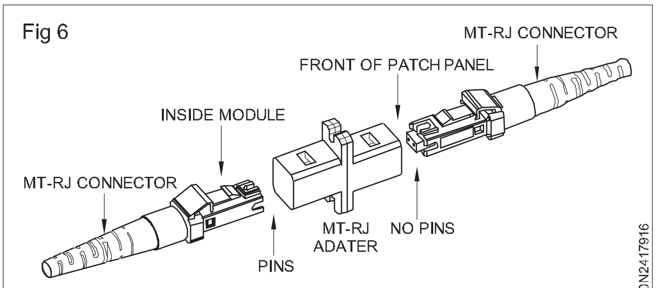
Fig 5



TYPICAL PATCH PANEL TO PATCH PANEL SYSTEM WITH MT-RJ CONNECTORS

Fiber-Optic connectors can attach to the cable in several ways, using either a crimped compression fitting or an epoxy glue.

Fig 6



MATING OF A PINNED MT-RJ CONNECTOR TO PINLESS MT-RJ CONNECTOR

Fiber cables are mainly used for backbone connectivity across the floors or when the distance cannot be covered by UTP cable limitation or when the network path to be connected is exposed to sky.

Difference between LT and HT Cable:

Cable	LT Cable	HT Cable
Rating	660 V to 1100 V	Above 3300 V
Armouring	Armoured (Flat or Round), Unarmoured	Armoured (Flat or Round)
Insulation	PVC, XLPE	XLPE
Conductor	Aluminium, Copper	Aluminium, Copper
No. of Cores	1 to 61 Cores	1 Core, 3 Core
Application	application revolving around 1.1kV range	HT cables are mainly used for power transmission and distribution of high vltage (>1.1kV)

Categorization of cables can be done as low voltage cables or high voltage cables. They are also known as high tension (HT) cables and low tension (LT) cable.

Further categorization of LT and HT Cables is done as follows:

Rating: LT cables have a rating from 660 V to 1100 V. Cables having a rating of above 3300 V (33kV) are termed as HT cables.

Armouring: Armouring refers to a protective covering for a cable. Armouring is present in both the cables either round or flat armouring, but some LT cables are unarmoured.

Insulation: Unlike other cables, LT and HT cables have a layer of insulation for protection of cable from any mechanical or external factors. LT cables have insulation of materials like polyvinyl chloride (PVC) or cross-linked polyethylene (XLPE). Most of the HT cables comprises of XLPE insulation.

Conductors: Conductors used in LT and HT cables are Aluminium or Copper. Aluminum is cheaper as compared to Copper. The market price of Copper tends to fluctuate thus the pricing of cables changes with it.

No. of Cores: LT cables include cores from 1 core, 2 core and extend up to 61 cores (LT Control cables). HT cable comprises of stranded copper or aluminum conductor cores. They are 1 core or 3 core.

Application: LT and HT cables have various areas of application. LT cables can be used in industries like power distribution, power stations, railways, etc. revolving around 1.1 kV range. While HT cables are used in power transmission and distribution that has a range greater than 1.1 kV.

Under ground (UG) cables - construction - materials - types - joints - testing

Objectives: At the end of this lesson you shall be able to
- **define UG cable**
- **explain the construction of UG cables**
- **list and state the insulating materials used in cables**
- **list out and state the types of UG cables used for 3 phase service**
- **state the types of cable joints and laying methods**
- **explain the faults and testing procedures of cables.**

Under Ground (UG) cables

“A cable so prepared that it can withstand pressure and can be installed below the ground level and normally two or more conductors are placed in an UG cable with separate insulation on each conductor”.

Electric power can be transmitted (or) distributed either by over-head lines system or by underground cable system. The underground cable system have several advantage, such

Advantages

- Less chance to damage through storms or lightning.
- Low maintenance cost.
- Less chances of fault.
- Not affected by man- made problems like sabotage, strike etc.
- Voltage regulation in UG cables system is much better, because they have less inductive losses.

- Better general appearance of area compared to O.H lines.

Disadvantages

However, their major draw back / disadvantages are

- Initial cost of UG cable system is heavy.
- The cost of joints are more.
- Introduce insulation problems at high voltages compared with O.H lines.

For these reasons UG cables are employed where it is impracticable to use O.H lines like

i Thickly populated areas, where municipal authorities prohibit O.H lines for the reason of safety.

ii Around plants

iii In Substations,

iv Where maintenance conditions do not permit the use of O.H construction.

The UG cable were used many years for distribution of electric power in congested urban areas to low and medium voltages. Then with improvement and development of design, the manufactures have made it possible to use at high voltage transmission of electric power for same moderate distances.

General construction of UG cables

An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.

Necessity requirements for cables

In general, a cable must fulfill the following necessary requirements.

i The conductor used in cables should be tinned stranded copper or aluminum of high conductivity. (Strands of cable gives flexibility and carry more current).

ii The size of the conductor should be selected, so that the cable carries the desired load current without overheating and limits the voltage drop to a permissible value.

iii The cable must have proper thickness of insulation to ensure the safety and reliability for the designed voltage.

General construction of UG cables

iv The cable must be provided with suitable mechanical protection so that it may withstand the rough use in laying it.

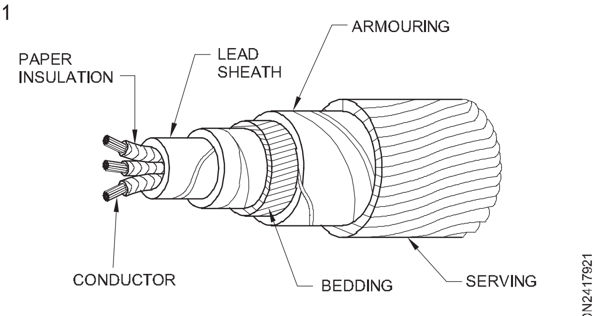
v The materials used in cables should be with complete chemical and physical stability throughout.

Construction of Cables

Fig 1 shows the general construction of a 3-core cable. The various parts are:

i Cores or conductors: A cable may have one or more than one core (conductor) depending upon the type of service for which it is intended. For instance, the 3-conductor cable shown in Fig 1 is used for 3-phase service. The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable and having high conductivity.

Fig 1



CONSTRUCTION OF CORE CABLE

ii Insulation: Each core or conductor is provided with a suitable thickness of insulation, the thickness of layer depending upon the voltage to be withstood by the cable. The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral compound. Petroleum jelly is applied to the layers of the cambric to prevent damage.

iii Metallic sheath: In order to protect the cable from moisture, gases or other damaging liquids (acids or alkalies) in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation as shown in Fig 1. The metallic sheath is usually a lead or lead alloy.

iv Paper Belt: Layer of impregnated paper tape is wound round the grouped insulated cores. The gap in the cores is filled with fibrous insulating material (jute etc.)

v Bedding: Over the metallic sheath is applied a layer of bedding which consists of a fibrous material like jute or hessian tape. The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.

vi Armouring: Over the bedding, armouring is provided which consists of one or two layers of galvanized steel wire or steel tape. Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling. Armouring may not be done in the case of some cables.

vii Serving: In order to protect armouring from atmospheric conditions, a layer of fibrous material (like jute) similar to bedding is provided over the armouring. This is known as serving.

It may not be out of place to mention here that bedding, armouring and serving are only applied to the cables for the protection of conductor insulation and to protect the metallic sheath from mechanical injury.

Insulating materials for cables

The satisfactory operation of a cable depends to a great extent upon the characteristics of insulation used. Therefore, the proper choice of insulating material for cables is of considerable importance. In general, the insulating material used in cables should have the following properties:

- i High insulation resistance to avoid leakage current.
- ii High dielectric strength to avoid electrical breakdown of the cable.
- iii High mechanical strength to withstand the mechanical handling of cables.
- iv Non-hygroscopic i.e. it should not absorb moisture from air or soil The moisture tends to decrease the insulation resistance and hastens the breakdown of the cable. In case the insulating material is hygroscopic, it must be enclosed in a waterproof covering like lead sheath.
- v Non-inflammable
- vi Low cost compared to O.H. system.
- vii Unaffected by acids and alkalies to avoid any chemical action.

The type of insulating material to be used depends upon the purpose for which the cable is required and the quality of insulation to be aimed at.

The principal insulating materials used in cables are

- i Rubber
- ii Vulcanized India rubber
- iii Impregnated paper
- iv Varnished cambric and
- v Polyvinyl chloride.

1 Rubber: Rubber may be obtained from milky sap of tropical trees or it may be produced from oil products. It has relative permittivity varying between 2 and 3, dielectric strength is about 30 KV/mm and resistivity of insulation is 10^{17} Ω cm.

It suffers from some major drawbacks viz readily

- i absorbs moisture
- ii maximum safe temperature is low (about 380 C)
- iii soft and liable to damage due to rough handling and ages when exposed to light.

Therefore, pure rubber cannot be used as an insulating material.

2 Vulcanized Indian Rubber (V.I.R.) : It is prepared by mixing pure rubber with mineral matter such as zinc oxide, red lead etc. and 3 to 5% of sulphur. The compound so formed is rolled into thin sheets and cut into strips. The rubber compound is then applied to the conductor and is heated to a temperature of about 150°C. The whole, process is called vulcanization and the product obtained is known as Vulcanized Indian Rubber.

Advantages: Vulcanized India rubber has greater mechanical strength, durability and water resistant property than pure rubber.

Disadvantages: Its main drawback is that sulphur reacts quickly with copper. So, cables using VIR insulation must have tinned copper conductor. The VIR insulation is generally used for low and moderate voltage cables.

3 Impregnated paper: It consists of chemically pulped paper made from wood chippings and impregnated with some compound such as paraffinie or naphthenic material.

Advantages:

- i Low cost
- ii Low capacitance
- iii High dielectric strength and
- iv High insulation resistance.

Disadvantages:

- i The paper is hygroscopic and even if it is impregnated with suitable compound
- ii It absorbs moisture and thus lowers the insulation resistance of the cable.

For this reason, paper insulated cables are always provided with some protective covering and are never left unsealed. If it is required to be left unused on the site during laying, its ends are temporarily covered with wax or tar.

Since the paper-insulated cables have the tendency to absorb moisture, they are used where the cable route has a few joints. For instance, they can be profitably used for distribution at low voltages in congested areas where the joints are generally provided only at the terminal apparatus. However, for smaller installations, where the lengths are small and joints are required at a number of places, VIR Cables will be cheaper and durable than paper insulated cables.

4 Varnished cambric: It is a cotton cloth impregnated and coated with varnish. This type of insulation is also known as empire type. The cambric is lapped on to the conductor in the form of tape and its surface is coated with petroleum jelly compound to allow for the sliding of one turn over another as the cable is bent. As the varnished cambric is hygroscopic, therefore, such cables are always provided with metallic sheath. Its dielectric strength is about 4 KV/mm and permittivity is 2.5 to 3.8.

5 Polyvinyl chloride (PVC): This insulating material is a synthetic compound. It is obtained from the polymerization of acetylene and is in the form of white powder. For obtaining this material as a cable insulation, it is compounded with certain materials known as plasticiser which are liquids with high boiling point.

Advantages:

- i It has high insulation resistance
- ii Good dielectric strength
- iii Mechanical toughness over a wide range of

temperature.

This type of insulation is preferred over VIR in extreme environmental conditions such as in cement factory or chemical factory.

Classification of cables

Cables for underground service may be classified in two ways according to (i) the type of insulating material used in their manufacture (ii) the voltage for which they are manufactured. However, the later method of classification is generally preferred as

i Low-tension (L.T) cables – upto 1100 V

ii High-tension (H.T) cables – upto 11,000 V

iii Super-tension (S.T cables – from 22 KV to 33 KV

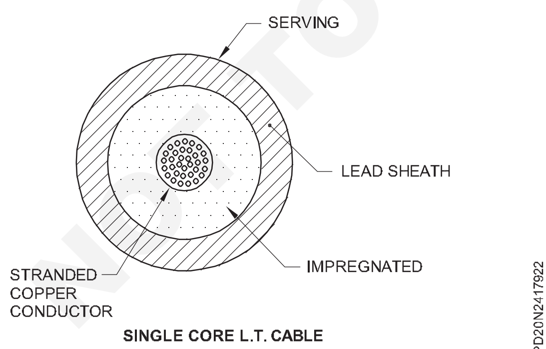
iv Extra high-tension (E.H.T) cables – from 33 to 66 KV

v Extra super voltage cables – beyond 132 KV

A cable may have one or more than one core depending upon the type of service for which it is intended. It may be (i) single-core (ii) two-core (iii) three-core (iv) four-core etc. For a 3-phase service, either 3-single core cables or three-core cable can be used depending upon the operating voltage and load demand.

Fig 2 shows the constructional details of a single-core low tension cable. The cable has ordinary construction because the stresses developed in the cable for low voltages (upto 6600 V) are generally small. It consists of one circular core of tinned stranded copper (or aluminium) insulated by layers of impregnated paper. The insulation is surrounded by a lead sheath which prevents the entry of moisture into inner parts. In order to protect the lead sheath from corrosion, an overall serving of compounded fibrous material (jute etc.) is provided. Single-core cables are not usually armoured in order to avoid excessive sheath losses. The principal advantages of single-core cables are simple construction and availability of large copper section.

Fig 2



SINGLE CORE L.T. CABLE

Cables for 3-Phase Service

In practice, underground cables are generally required to deliver 3-phase power. For the purpose, either three-core cables or three single core cables may be used. For voltages upto 66 KV, 3-core cable (i.e. multi-core construction) is preferred due to economic reasons. The following types of cables are generally used for 3-phase service.

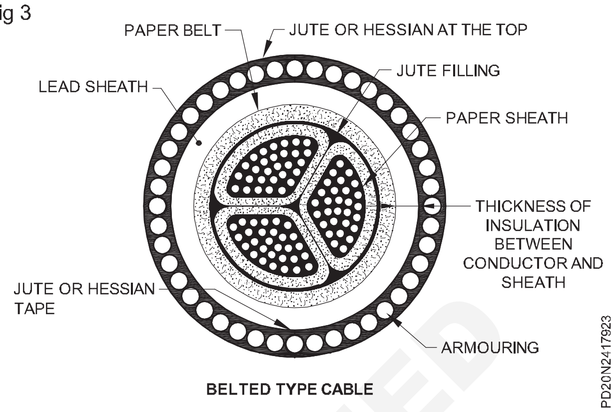
1 Belted cables – upto 11 KV

2 Screened cables – from 22 KV to 66 KV

3 Pressure cables – beyond 66 KV

1 Belted cables

Fig 3



BELTED TYPE CABLE

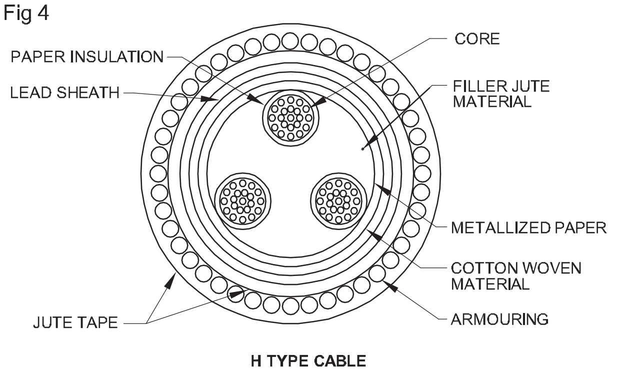
These cables are used for voltages upto 11 KV but in extraordinary cases, their use may be extended upto 22 KV. Fig 3 shows the constructional details of a 3-core belted cables. The cores are insulated from each other by layers of impregnated paper.

Another layer of impregnated paper tape called paper belt is wound round the grouped insulated cores. The gap between the insulated cores is filled with fibrous insulating material (jute etc.) The belt is covered with lead sheath to protect the cable against ingress of moisture and mechanical injury.

The belted type construction is suitable only for low and medium voltages as the electrostatic stresses developed in the cables for these voltages are more or less radial i.e. across the insulation. However, for high voltages (beyond 22 KV), the tangential stresses also become important.

2 Screened cable

Fig 4



H TYPE CABLE

These cables are meant for use upto 33 KV but in particular cases their use may be extended to operating voltages upto 66 KV. Two principal types of screened cables are H-type cable and S.L. type cables.

i H-type cables. This type of cable was first designed by H. Horchstadter and hence the name. Fig 4 shows the constructional details of a typical 3-core, H-type cable. Each core is insulated by layers of impregnated paper. The insulation on each core is covered with a metallic screen which usually consists of a perforated aluminium foil.

The cable has no insulating belt but lead sheath, bedding, armouring and serving follow as usual. As all the four screens (3 core screens and one conducting belt) and the lead sheath are at earth potential.

Advantages:

- The possibility of air pockets or volts in the dielectric is eliminated
- The metallic screen increase the heat dissipating power of the cable

ii **S.L. type cables:** Fig 5 shows the constructional details of 3-core S.L (separate lead) type cable. It is basically H-type cable but the screen round each core insulation is covered by its own lead sheath. There is no overall lead sheath but only armouring and serving are provided.

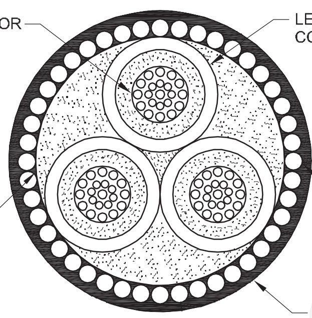
The S.L type cables have two main advantages over H-type cables.

a The separate sheaths minimize the possibility of core-to-core breakdown.

b Bending of cables become easy due to the elimination of overall lead sheath.

The disadvantage is that the three lead sheaths of S.L. cable are much thinner than the single sheath of H-cable

Fig 5



SL TYPE CABLE

Limitations of solid type cables

All the cables of above constructions are referred to as solid type cables because solid insulation is used and no gas or oil circulates in the cable sheath. The voltage limit for solid type cables is 66 KV due to the following reasons:

a As a solid cable carries the load, its conductor temperature increases and the cable compound (i.e. insulating compound over paper) expands. This action stretches the lead sheath which may be damaged.

b When the load on the cable decreases, the conductor cools and a partial vacuum is formed within the cable sheath. If the pinholes are present in the lead sheath, moist air may be drawn into the cable. The moisture reduces the dielectric strength of insulation and may eventually cause the breakdown of the cable.

c In practice, voids are always present in the insulation of a cable. Modern techniques of manufacturing have resulted in void free cables. However, under operating conditions, the voids are formed as a result of the differential expansion and contraction of the sheath and impregnated compound.

3 Pressure cables

For voltages beyond 66 KV, solid type cables are unreliable because there is a danger of breakdown of insulation due to the presence of voids. When the operating voltages are greater than 66 KV, pressure cables are used. In such cables, voids are eliminated by increasing the pressure of compound and for this reason they are called pressure cables. Two types of pressure cables viz oil filled cables and gas pressure cables are commonly used.

i Oil filled cables: In such type of cables, channels of ducts are provided in the cable for oil circulation. The oil under pressure (it is the same oil used for impregnation) is kept constantly supplied to the channel by means of external reservoirs placed at suitable distances (say 500 m) along the route of the cable.

Oil under pressure compresses the layers of paper insulation and is forced into any voids that may have formed between the layers. Due to the elimination of voids, oil-filled cables can be used for higher voltages, the range being from 66 KV upto 230 KV.

Oil-filled cables are of three types viz.

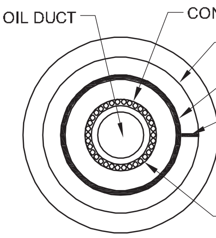
i Single-core conductor channel

ii Single-core sheath channel and

iii Three-core filler-space channels.

i Single-core Conductor channel

Fig 6



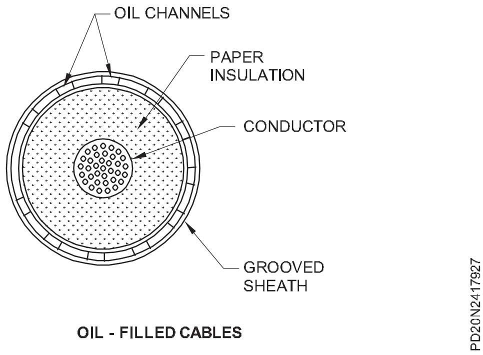
SINGLE - CORE CONDUCTOR CHANNEL OIL - FILLED CABLE

Fig 6 shows the constructional details of a single-core conductor channel, oil-filled cable. The oil channel is formed at the centre by stranding the conductor wire around a hallow cylindrical steel spiral tape. The oil under pressure is supplied to the channel by means of external reservoir. As the channel is made of spiral steel tape, it allows the oil to percolate between copper strands to the wrapped insulation.

The oil pressure compresses the layers of paper insulation and prevents the possibility of void formation. The disadvantage of this type of cable is that the channel is at the middle of the cable which is at full voltage w.r.t earth, so that a very complicated system of joints is necessary.

ii Single-core sheath channel (Fig 7)

Fig 7

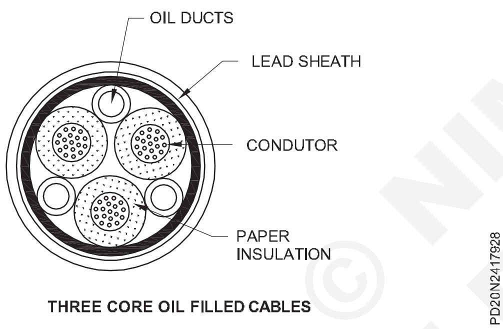


OIL - FILLED CABLES

In this type of cable, the conductor is solid similar to that of solid cable and is paper insulated. However, oil ducts are provided in the metallic sheath.

In the 3-core oil-filled cable shown in Fig 8, the oil ducts are located in the filler space. These channels are composed of perforated metal-ribbon tubing and are at earth potential.

Fig 8



THREE CORE OIL FILLED CABLES

Advantages

a Formation of voids and ionization are avoided.

b Allowable temperature range and dielectric strength are increased.

c If there is leakage, the defect in the lead sheath is at once indicated and the possibility of earth faults is decreased.

Disadvantages

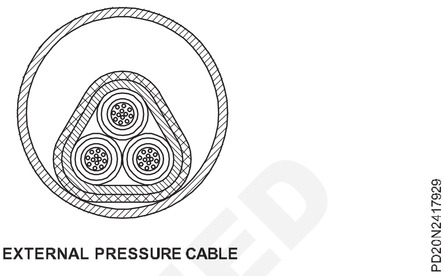
a High initial cost and complicated system of laying

i **Gas pressure cables:** The voltage required to set up ionization inside a void increases as the pressure is increased. Therefore, if ordinary cable is subjected to a sufficiently high pressure, the ionization can be altogether eliminated. At the same time, the increased pressure produces radial compression which tends to close any voids. This is the underlying principle of gas pressure cables.

Fig 9 shows the section of external pressure cable designed by Hockstadter, Vogal and Bowden. The construction of the cable is similar to that an ordinary solid type except that it is of triangular shape and thickness of lead sheath is 75% that of solid cable. The triangular section reduces the weight and gives low thermal resistance but the main reason for triangular shape is that the lead sheath acts as a pressure membrane. The sheath is protected by a thin metal tape. The cable is laid is a gas-tight steel pipe.

The pipe is filled with dry nitrogen gas at a pressure of 12 to 15 atmospheres. The gas pressure produces radial compression and closes the voids that may have formed between the layers of paper insulation.

Fig 9



EXTERNAL PRESSURE CABLE

Advantages:

a Cables can carry more load current

b Operate at higher voltages than a normal cable.

c Maintenance cost is small and the nitrogen gas helps in quenching any flame.

Disadvantages:

The overall cost is very high.

Further the cables are also classified according to their insulation system as under:

PVC insulated cables	(Poly vinyl chloride)
MI cables	(Mineral insulation)
PILC cables	(Paper insulated lead covered)
XLPE cables	(Cross linked poly ethylene)
PILCDTA cables	(Paper insulated lead covered double tape armoured)

The specification of underground cables

The cables shall carry the following information either labelled or stenciled on the reel or drum or container.

1 Reference to the Indian Standard; for example Ref. IS 694-1977.

2 Manufacturer's name, brand name or trademark.

3 Type of cable and voltage grade.

4 Number of cores.

5 Nominal cross-sectional area of conductor.

6 Cable code.

7 Colour of cores (in case of single core cables)

8 Length of cable on the reel, drum or coil

9 Number of lengths on the reel, drum or coil (if more than one).

10 Direction of rotation of drum (by means of arrow).

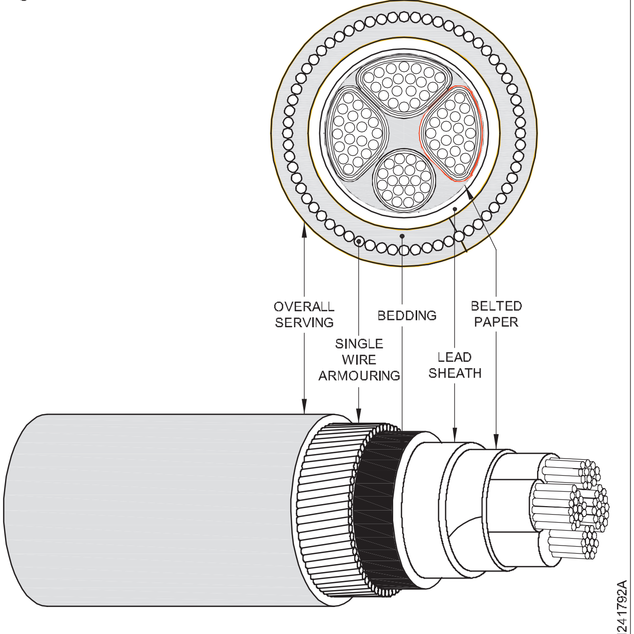
11 Approximate gross weight.

12 Country of manufacturing.

13 Year of manufacture.

Fig 10 shows the paper insulated 3 phase 3 ½ core cable.

Fig 10

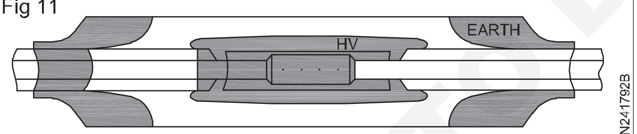


PAPER INSULATED 3 PHASE $3\frac{1}{2}$ CORE CABLE

Cable Joints

Connecting two high-voltage cables with one another poses two main problems. First, the outer conducting layers in both cables must be terminated without causing a field concentration, as with the making of a cable terminal. Secondly, a field-free space must be created where the cut-down cable insulation and the connector of the two conductors safely can be accommodated.

Fig 11



CABLE JOINT

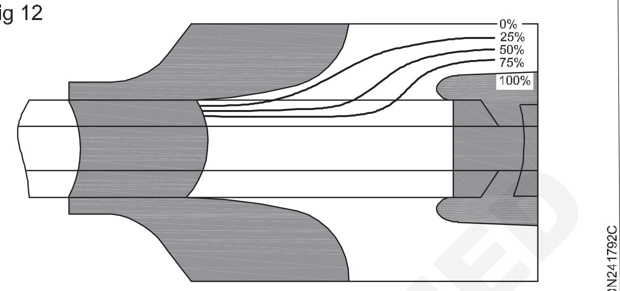
Figure shows a photograph of the cross-section of such a device. At one side of this photograph, the contours of a high-voltage cable are drawn. Here red represents the conductor of that cable and blue the insulation of the cable. The black parts in this picture are semiconducting rubber parts. The outer one is at earth potential and spreads the electric field in a similar way as in a cable terminal. The inner one is at high voltage and shields the connector of the conductors from the electric field.

The field itself is diverted as shown in figure , where the equipotential lines are smoothly directed from the inside of the cable to the outer part of the bi-manchet (and vice versa at the other side of the device).

The crux of the matter is here, like in the cable terminal, that the inner bore of this bi-manchet is chosen smaller than the diameter over the cable insulation. In this way a permanent pressure is created between the bi-manchet and the cable surface, and cavities or electrical weak points are avoided.

Installing a terminal or bi-manchet cuff is skilled work. The technical steps of removing the outer semiconducting layer at the end of the cables, placing the field-controlling bodies, connecting the conductors, etc., require skill, cleanliness, and precision.

Fig 12



Need for cable jointing (Splicing)

A splice may be considered as two or more conductors joined with a suitable connector, then reinsulated, reshielded and rejacketed with compatible materials and applied over a properly prepared surface. Whenever possible, splicing is normally avoided. However, splicing is often an economic necessity. There can be many reasons for building splices, such as:

- The supplied length of cable is not sufficient to perform the intended job,

  e.g., only so much cable can be wound on a reel (the reel ends), or only so much cable can be pulled through so much conduit, around so many bends, etc.
- Cable failures
- Cables damaged after installation
- A tap into an existing cable (tee or wye splices)

In all the above cases, the option is to either splice the cable or replace the entire length. The economy of modern splicing products, in many cases, makes splicing an optimal choice. Whatever the reason to splice, good practice dictates that splices have the same rating as the cable. In this way, the splice does not derate the cable and become the weak link in the system.

Splicing Steps

The previous definition accurately identifies the need for splicing, which leads into the five common

Steps for building a splice:

1 Prepare the surface

2 Join conductors with connector(s)

3 Reinsulate

4 Reshield

5 Rejacket

The greatest assurance against splice failure starts with the person who makes the splice. Adequate cable preparation, proper installation of all components and good workmanship require trained skills performed by people adept at them. Much has been done in the last few years to develop products and systems that make splicing easier. Yet the expertise, skills and care of the installer are still necessary to make a dependable splice.

Joints and Terminations

Hand-taped joints

Hand taped joints are the old-school method of splicing and terminating cable. The construction of these joints involves taking several types of tape and manually building up appropriate stress relief. Some of the tapes involved could be rubber tapes, semiconducting tapes, friction tapes, varnished cambric tapes, etc. This splicing method is incredibly labor and time-intensive. It requires measuring the diameter and length of the layers being built up. Often the tapes must be half-lapped and pulled tight to prevent the formation of windows or voids in the resulting splice. Waterproofing hand taped splicing is very difficult.

Pre-molded joints

Pre-molded joints are injection molded bodies created in two or more stages. Due to automation, the faraday cage will have a precise geometry and placement not achievable in taped joints. Pre-molded joints come in many different body sizes that much be matched up to the cable Semicon's outside diameter. A tight joint interface is required to ensure waterproofing. These joints are often pushed on and can cause soft tissue injuries among craftsmen.

Electrical joints and terminations provide the required electrical connection as well as the mechanical support and physical protection to the cable. It is important for the Cable jointing system to suit the service and operational requirements for all industrial cable jointing environments and applications. These devices are important for jointing the cables and wires. A good cable jointing and installation provides a better supply of power. Cable jointing has become the preferred pick over conventional systems for cable termination, cable abandonment, low voltage cable jointing and cable repair. The cable termination and jointing kits are often specialised in wire installations worldwide.

Cables play a very important role in the distribution system of power. There are different types of cables like LT cable, 11 KV cable and 33 KV cable. Cables are used in places where bare conductor cannot be used due to narrow roads. Cables are costlier than the conductor and the same cannot be replaced often.

Extrusion molded Joints

Extrusion molded joints in underground (UG) cables are typically used to provide insulation and protection to cable connections.

Prepare Your Cable Ends:

Ensure that the cable ends are properly stripped and cleaned to expose the conductors.

Depending on the type of cable, you may need to prepare it differently (e.g., high-voltage or low-voltage cables).

Design the Joint:

The design should include the joint's dimensions, materials, and any necessary features such as stress relief, sealing, and strain relief components.

Select Extrusion Material:

Choose the appropriate extrusion material, typically a specialized insulating compound or elastomer, based on the cable's requirements and environmental conditions.

Set Up Extrusion Equipment:

Ensure you have the necessary equipment for the extrusion process, including an extruder machine, molds, and any required heating elements.

Extrusion Process:

Feed the selected extrusion material into the extruder machine. Heat the material to its melting point within the extruder. Extrude the molten material onto the prepared cable ends, covering the joint area completely.

Cooling and Curing:

Allow the extruded material to cool and cure. The curing process may involve heating or chemical curing, depending on the material used.

Quality Assurance:

Inspect the extrusion molded joint for any defects or irregularities. Ensure that the insulation is uniform and free from air bubbles.

Testing:

Perform electrical and mechanical tests to ensure the joint meets the required specifications and standards.

Sealing and Protection:

If necessary, apply additional sealing and protection elements to the joint to guard against moisture, contaminants, and physical damage.

Documentation:

Maintain detailed documentation of the extrusion process, materials used, test results, and any relevant certifications or standards compliance.

Installation:

Once the extrusion molded joint is ready and validated, install it on the UG cable as per the project requirements.

Please note that the specific process and materials may vary depending on the type of cable, voltage levels, and local regulations. It's essential to follow industry standards and consult with experts in cable jointing when working with UG cables to ensure safety and reliability.

Session 1: Electrical Cable Jointing Methods

Jointing of power cables should be as simple as twisting and taping the wire. For jointing of a cable variety of in-line adapters and connectors are used. The method used for a cable joint depends on the voltage, type of cable, type of joint, type of connector, application and other factors. Proper tools and equipment are to be used for jointing the cable.

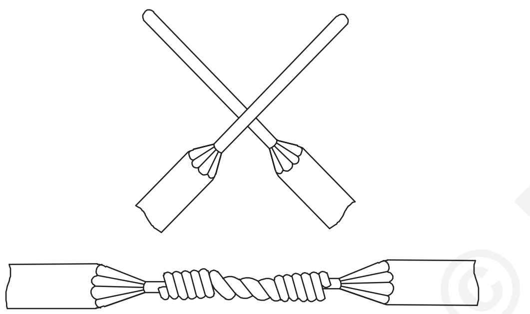
Given below are some important factors to ensure reliable connections, such as

- Proper size of connectors should be used for a particular cable,
- Proper tools and equipment are to be used,
- Cuts and stripping should be very clean,
- Proper technique is to be used for cable jointing and
- Restoring the insulation, outer-sheath and armour.

Western Union Splice Joint

The cables are manufactured for a particular length. To increase the length of a cable a straight joint is used for small solid cables (Figs 13 and 14).

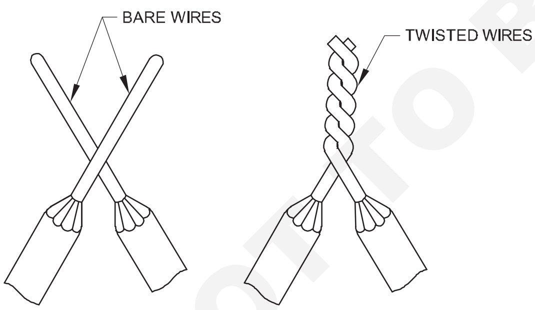
Fig 13



WESTERN UNION SPLICE JOINT AND STRAIGHT JOINTS

PD20N241792D

Fig 14



RATTAIL JOINTS

PD20N241792E

1 Remove the insulation of cable

2 Bring the two conductors to a crossed position and then make a long bend or twist in each wire.

3 Wrap the end of one of the wires around the straight portion of the other wire, and then do the same for the other wire. Repeat this for about four or five times.

4 Press ends of the wires down close to the straight portions of the wire to prevent the ends from piercing through the insulation tape.

5 Insulate the joint using the insulation tape.

Fixture Joint

This is a type of branch joint connecting a thin wire (for branch line) to the thick wire (main line),such as those used in lighting fixtures.

1 Remove the insulation of wire

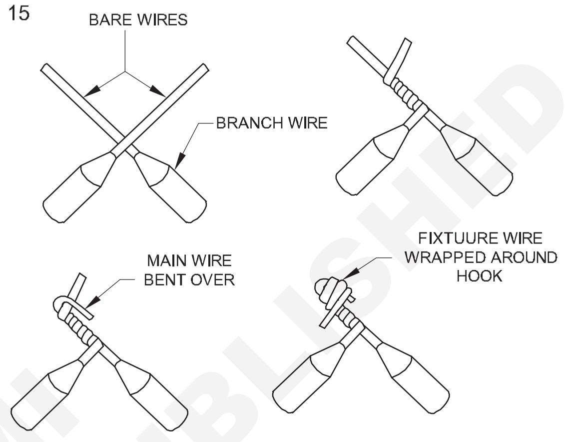
2 Wrap the fixture wire around the branch wire

3 Bend the branch wire over the completed turns

4 Wrap the remaining fixture wire over the bent branch wire

5 This can be followed by soldering and taping, or simply taping of the joint (Fig 15).

Fig 15



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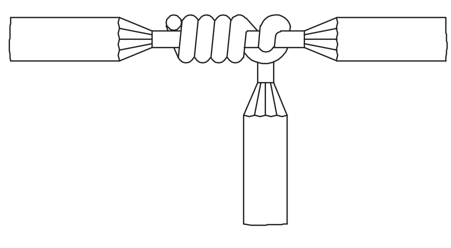
Knotted Tap Joint

The knotted tap joint is also used for branch joints to connect a branch wire (thin wire) to a continuous or main wire (thick wire) (Fig 16).

1 Remove about 1 inch of insulation from the main wire and about 3 inches from the branch wire.

2 Place the branch wire behind the main wire so that three-fourths of its bare wire extends above the main wire.

Fig 16



KNOTTED TAP JOINT

PD20N241792G

3 Bring the branch wire over the main wire, around itself, and finally over the main wire so that it forms a knot. Wrap the wire around the main conductor in short, tight turns and trim the end

Joints Using Wire Nut and Split Bolt

The rattail joint is replaced by wire nut. The nut is usually housed in a plastic insulating casing. To make a joint.

1 Strip the conductors

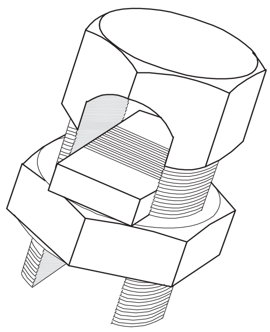
2 Place the two joints to be joined into the wire nut

3 Twist the nut

Split Bolt Connector

The split bolt is used to join big sized conductors. This replaces the knotted tap joint and can be used to join three ends or join a branch conductor to a continuous (main) conductor (Fig 17).

Fig 17



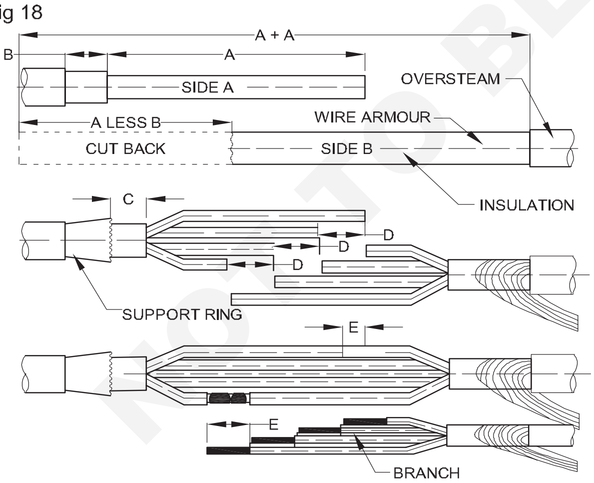
The bare wires are placed through the space between the two bolts, after which the nut is tightened to ensure Fig 15. Knotted tap joint Fig 16. Fixture joint a sound joint. The material required for making straight or branch joints for steel wired armour cables are as follows:

- Connectors
- Copper mesh tape
- Constant force springs for holding the wire armour and copper mesh tape
- Standard PVC/Vinyl tape, which provides a mechanical barrier between the over sheath layer and the armour layer.

Preparing the Cable

Preparing the cable before jointing includes the following steps (Fig 18):

Fig 18



PREPARATION OF A THREE-CORE ARMOURED CABLE

1 Remove the over sheath and the wire armour

2 Separate the wire armour and bend the wires away from the cable, place the support ring under the armour at each side of the joint

3 Cut back the cable insulation

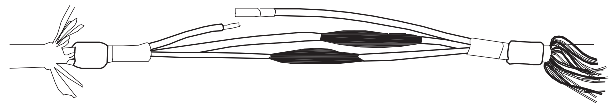
4 Remove the insulation from each of the conductors

Crimping and Insulating Each Cable

Once the cable is ready, connect each end of the three conductors to a suitable connector (copper or aluminium). Suitable-sized connectors are to be used. Tightly fix the suitable connectors and test the connection.

Tape the crimped connectors, wrap around and extend to cover at least 25mm of the cable insulation of the conductor entering the connectors (Fig 19).

Fig 19



TAPED,CRIMPED CONNECTORS ON INDIVIDUAL CABLES

Binding the Cables

Bind the wires tightly and then tape them together (Fig 20).

Fig 20

WIRES TAPED TOGETHER

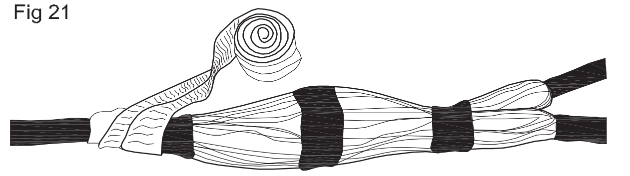
Restoring Armour and Applying Mesh Tape

1 Tightly wrap the cable from armour to armour while applying adequate tension around the insulation.

2 Join the wire armour from one end to the other end and cut excess wire to the correct length. Ensure the armour spreads evenly over the entire joint.

3 Wrap the cable with the mesh tape and then use the standard vinyl/PVC tape to wrap over the mesh to provide a insulation against stray wire ends. For the branch joint, bring both the main and branch cables together before wrapping. Next, use standard vinyl or PVC tape to wrap over the constant force springs placed over the under-armour rings. The tape provides a barrier against sharp edges (Fig 21).

Fig 21



WRAPPING THE CABLE WITH MESH TAPE

Re-establish the Over Sheath

1 Use a self fusing tape to wrap over the cable and establish the outer sheath. Start in the center and apply one layer of tape to one end, wrapping over the jacket for at least 25 mm. Apply the tape from the end towards the center so that you have two layers on each side.

2 For branch joints, wrap over the insulation for both the main and the branch cable, by at least 50mm.

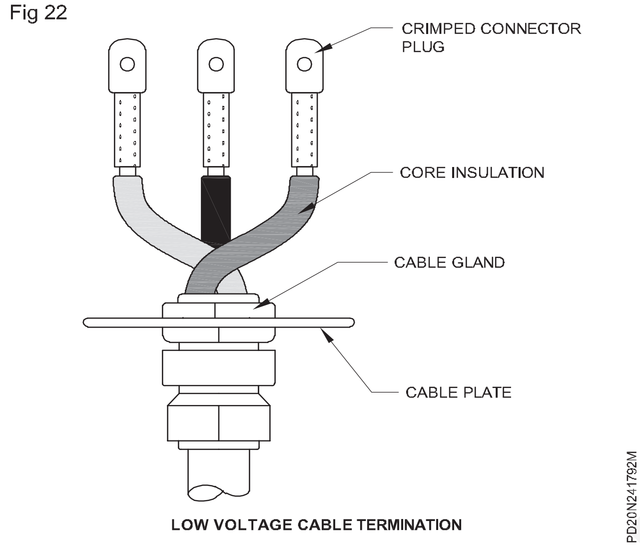
Bring the two together and fill it in with the insulating putty from both sides. Do this up to 25 mm away from the place where the branch and the main cables are joined.

3 Put the two cables together and bind the main and branch tightly over the filling. Finally, wrap the crotch while pulling the branch away from the main cable

Electrical Power Cable Terminations

The electrical cable termination is a cable end that connects to the terminal of the equipment or another cable to extend the length (Fig 22).

Fig 22



The method used for termination of the cables varies according to the type of cable, type of connector and application. Some common types of terminations are

- Crimp connection
- Soldered connection
- Compression termination
- Wire-wrapping connection
- Direct connection
- Loop or eye connection

Some of the factors which are considered for termination of cables are:

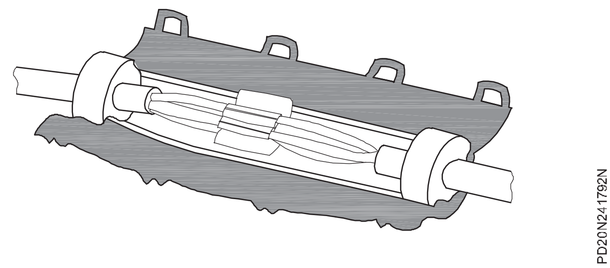
- Outdoor or indoor cable
- Voltage of the line
- Overhead or underground cable
- Type of connector on the equipment where the cable will be connected

Power Cable Joints

A power cable consists of two or more electrical conductors, held together wrapped with insulation and outer surface with an overall sheath (Fig 23).

The cables are used for transmission of electrical power. Power cables is being used for permanent wiring within buildings. The cable can be run under ground, run overhead, or exposed. Cables consist of three major components: conductors, insulation and protective jacket. The structure of individual.

Fig 23



Cables varies according to application. Power cables use stranded copper or aluminium conductors, although in some cases solid conductors is used. After the introduction of electric cables in electrical

Circuit the problem of how to join them together arises in order to achieve the degree of insulation, tensile and crushing strengths, conductivity and accessibility. To cope up the requirements a junction box is introduced. The junction box typically incorporates:

- A method of securing the cable conductors (usually by soldering, screw-clamps or compressed ferrules).
- A method of insulation, which may be air, oil, bitumen or insulation applied in the form of tapes.
- A method of enclosure and protection applicable to the environment.

As per The Electricity Regulations every joint and connection should be mechanically and electrically

Suitable for its use. In this respect the joint or connection should be of proper construction as regards conductivity, insulation, mechanical strength and protection.

Joints in Non-flexible Cables

Underground cables are joined by ferrules or lugs (crimped) and the outer protection enclosure or box is usually filled with a plastic or bituminous compound. Such joints are often used above-ground for non-flexible cables and are adequately protected and supported. Other cables which are fixed wiring installations enclosed junction boxes are used to making a joint between two cables. These junction boxes are not securing the cable against strain.

Joints in Flexible Cables

Joints in flexible cables are not usually satisfactory because:

1 Stranded conductors are not suitable for certain methods of jointing.

2 Mechanical tensile strength and resistance are difficult to maintain.

3 Fatigue damage may occur when rigid joint is being done.

Some joints and cable connectors are much more acceptable these incorporate terminals or compression fittings suitable for stranded conductors. Cable clamps are used for plugs to reduce the flexing. Heat-shrinkable or pre-stretched sleeving may be adequate in some cases but other circumstances may demand additional protection.

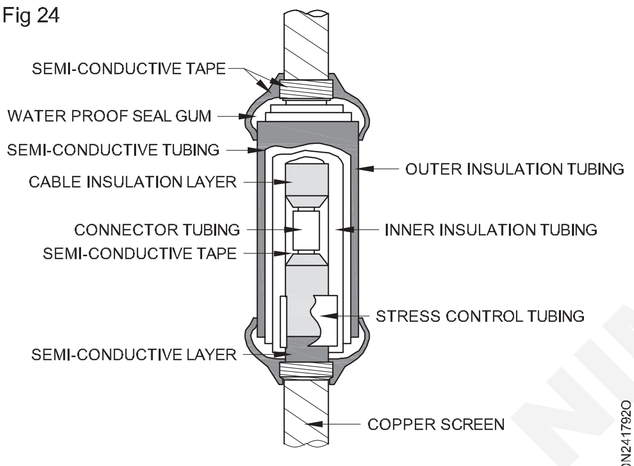
Types of Cable Joints and Equipment

A great majority of failure in cable network is associated with faulty cable jointing. It is, therefore, essential to use proper jointing technique, good quality insulating material and standard accessories for cable jointing. Cable joints are of three types:

Straight through Joint

Straight through Joints are an important part of today's power cable networks (Fig 24). These joints offer reliability and flexibility to meet the demands of cable network.

Fig 24



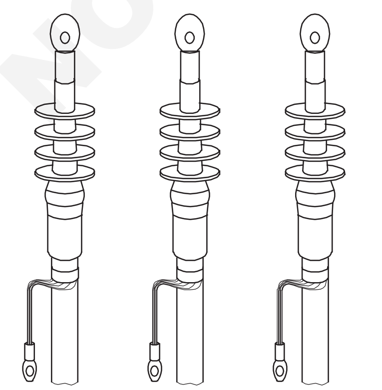
SINGLE THROUGH JOINT

Straight through Joints provide

- Quick cable preparation
- High electrical insulation
- No moisture ingress
- Good mechanical strength
- Compact dimensions and is suitable for all conductor, shape and material

Straight through Joints are made by metal joining processes, such as welding and soldering (Fig 25).

Fig 25

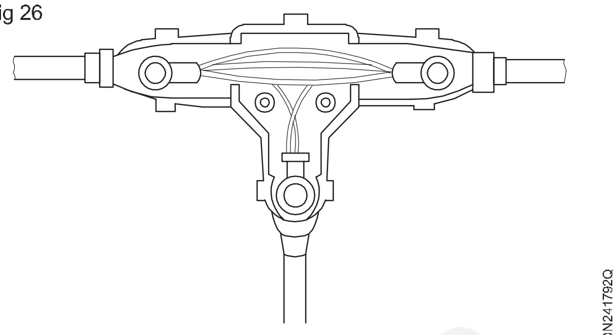


SINGLE CORE STRAIGHT THROUGH JOINT KITS

T-Joint

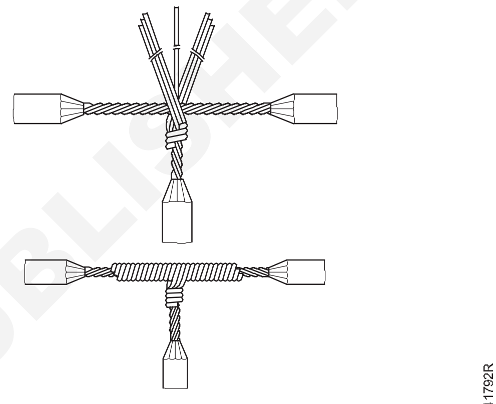
These types of joints are used for branching of a service cable from a main cable. T-joints are helpful as turning and twisting of cable damages its outer core (Fig 26 & 27).

Fig 26



T-JOINT

Fig 27

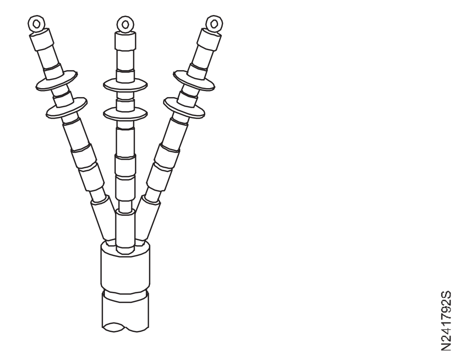


'T' JOINT

Terminal Joint

These type of joints connect cable to switch gear, transformer terminal or to an overhead line (Fig 28).

Fig 28



CABLE JOINT

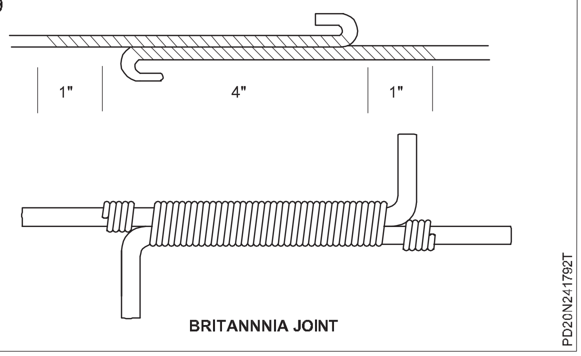
Conductor Joint

The length of distribution lines are in kilometers and one coil of conductor is unable to solve the length problem. Hence, jointing the conductor is necessary.

Britannia Joint

This type of joint is made only on solid conductors and cannot be made on stranded conductor. Two Conductors to be joined are brought in front of each other of about 6 inch (150 mm) of length. Both the conductors should be clean. If the conductor is of copper; it should make good electrical connection. Then ends of both conductors are bent through half centimetre and placed on each other. The length of contact portion should be min. 100 mm. This joint should be bound by 14 mm copper wire as shown in Fig 29.

Fig 29



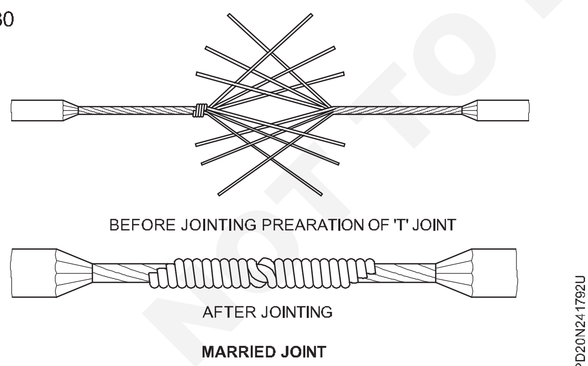
Telephone Joint (Western Union)

This joint is used only for solid conductors. It is used for conductors of size 8 SWG or higher size. First, bend is given at 100 to 125 mm from the edge and are placed over each other. Then each one is twisted with another conductor.

Married Joints

This joint is made between copper conductors having central strand of GI wire (Fig 30). It should not be made between aluminium (Al) conductors. Approximately 175 to 200 mm length conductor strands are unwound. The GI strand of both conductors should be broken up to 175 mm in length. Both conductors should be brought in front of each other and their strands should be woven in each other. The strand of one conductor is twisted on other conductor, and strand of other conductor is twisted on the first. Likewise all the strands twisted and then soldered. This is used only for small span length.

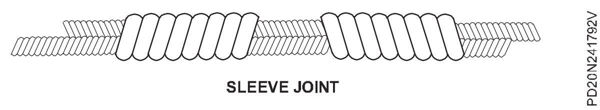
Fig 30



Sleeve Joint

It can be made with any type of aluminium conductor. Graphite Greece is applied over the conductor and as shown in Figs 30 and 31. Sleeves should be taken. These sleeves should replaced on the conductor as shown. Sleeves should be twisted by twisting wrench. This joint is made for LT,HT, ACSR, AAC conductor up to 0.06 cm^2.

Fig 31



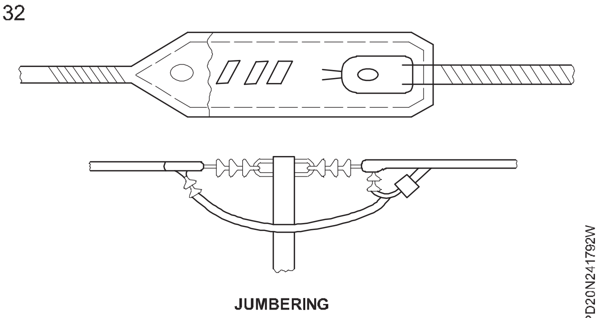
Compression Joint

This joint is used for conductors of more than 0.06 cm^2 sizes. For jointing, two different sleeves are used. Steel sleeve is used for steel conductor strands and aluminium. sleeve is used for Al. conductor strands. There are two holes in Al. sleeve. Rebating is done through these holes. Then Al. sleeve to be mounted on one side. The length of steel sleeve is then measured. Its half distance is taken. Suppose it is 'X' cm. Then the ends which are to be joined and more to 'X' cm distance is taken on the conductor is banded there. The Al. Strands are opened up to that point and cut. Steel strand should not be touched during this. They are placed in the steel sleeve. They should be kept in front of each other. Then the center of steel sleeve is compressed through compression machine. Then on the half portion of the right side sleeve be compressed and then on the left half portion. Due to compression the length of sleeve will be increased by 6mm on both sides and it will reach Al. strands. Then Al. Sleeve should be measured. It should be halved. Suppose it is 'Y' cm then 'Y' cm should be measured and marked on both sides of conductor measured from center of steel sleeve. Both parts of conductor are brought in sleeve in front of each other. The filler parts should be filled in the sleeve by Grease until it comes out of the holes.

Both the holes are then closed by rivets and hammered by hammer. There is one stencil mark on Al. sleeve. The first compression will be there; afterwards it will be compressed up to one end. Similarly the other part is compressed up to the other end.

Jumpering (Fig 32)

Fig 32



Connecting two conductors or wires is called jumpering Jumper should not be connected to the main conductor. The jumper should always be connected by PG clamps.

When the jumpers are near metallic portion, all such jumpers are covered with alkathene pipe.

Conductor joints are marked on ACSR conductor when dispatched. Mid-span joint should be made before stringing as the steel strand is not kept continuous. Hence, it is necessary to replace the company joint. Care should be taken that mid-span joint is not less than 40 ft. from pole. Every joint should be done carefully.

Where conductor strands are cut, repair sleeve is used. Conductor joint strength should be 95% that of conductor, and resistance should be that of a main conductor.

HV Cable Jointers Tools

Using the correct cable tools to prepare industrial and utility cables before cable jointing and terminating reduces catastrophic cable failures. Some of the important cable jointer tools include:

- Cable cutting tool
- Cable crimping tool (hydraulic, battery, ratchet) copper/aluminium cables
- Cable spiking tools for LV-HV cables (cartridge/hydraulic)
- Heat shrink gas torches for LV-HV jointing
- Screen scoring tools for bonded/easy peel HV cables
- Outer sheath stripping tools, LV-HV cables
- Insulation (XLPE) stripping tools, HV cables
- Insulated tools for live-working
- Cable laying rollers, socks, jacks and pulling equipment
- Conduit duct rods

Heat shrink joints

Heat Shrink and Cold Shrink Technologies are an indispensable part of the power cable industry as they contribute to the development of power infrastructure. While both heat shrink and cold shrink technologies are used for jointing power cables, they both have their pros and cons in specific situations.

Cable joints play an essential role in the electrical and electronic systems of any home or industry. They connect the power cables and ensure the flow of continuous electric current through them.

Heat shrink tubing is a kind of insulation that you use to insulate and preserve products. It offers superior insulation and resistance to abrasion, as well as moisture and dust. Heat shrink forms a protective seal and is composed of a material that shrinks in diameter when heated, resulting in secure sealing.

The brand uses specially formulated thermoplastic polymer materials that have the capability to shrink and conform with precision to different shapes. Elastic memory uses cross linking that allows them to return to their original shape after heat application. Within the advanced heat shrink product range, multi-layer tubing and unique materials science incorporate several functions into each

Salient Features:

1 Flame Retardant

2 Superior reliability

3 Resistance to thermal ageing

4 Hydrophobicity

5 Tracking and erosion resistance.

6 High thermal property

7 Resistance to surface electrical activity

8 Flame Retardant

9 Resistance to thermal ageing

10 Hydrophobicity

11 Tracking and erosion resistance.

12 High thermal property

Do you have a requirement for heat shrink or cold shrink cable accessories for your running projects? Compaq International is among the industry leaders for power cable accessories such as cable joints and cable terminations. The company manufactures products that use both heat shrink and cold shrink technologies with highly precise measurements. We not only provide top-notch products, but also unparalleled after-sales service.

Heat-shrink cable terminations

Cable terminations play a very important role in the electrical and Power industry - they make electrical connections between a cable, the terminal of an equipment or the terminal of an electrical junction. Cable terminations can be one of any technology; heat shrink type, cold shrink type or Pre-moulded Slip On type. Heat shrink cable terminations are those terminations that need heat to make connections, and this blog will highlight their benefits.

Heat shrink cable terminations can be used for LV-MV-HV power cables present indoors and outdoors. Indoors, these cable terminations connect to substation switchgear, transformers and insulated cable boxes. Outdoors, they are used in overhead and underground distribution lines.

Following are the benefits of using -

- High-quality heat shrink cable terminations have excellent strength.
- They are highly resistant to chemicals, solvents, and extreme temperatures.
- Highly quality cable terminations do not crack, melt or get displaced when applied properly.
- The flexibility of heat shrink cable terminations allow them to be used in cases where cables have to be bundled together.

While heat shrink cable terminations work well in most conditions, they are not suitable for areas which have flammable gases in their environment. For instance, heat shrink cable terminations should be avoided close to gas pipelines.

Following are the different models of heat shrink cable terminations -

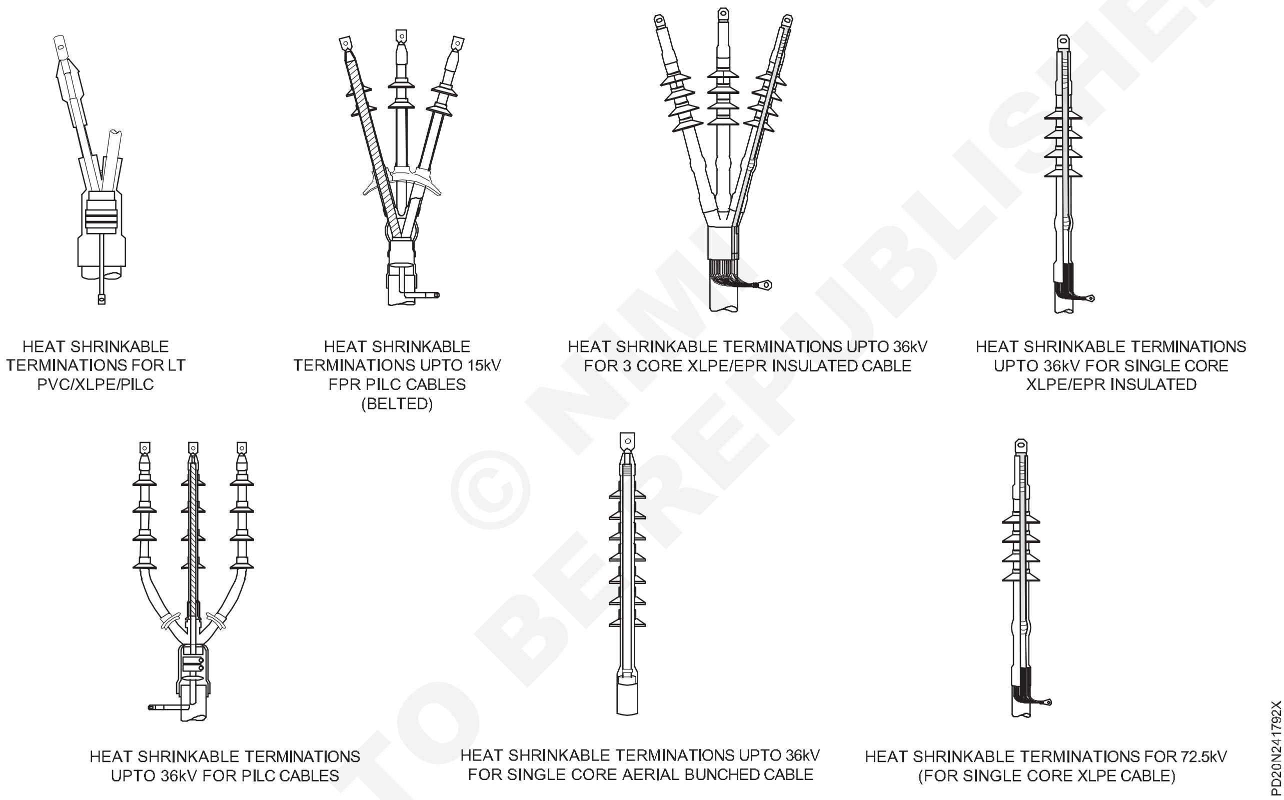
- Heat Shrink Cable Terminations for Low Voltage Polymeric Insulated Cables up to 1kV

- Heat Shrink Cable Terminations for Paper Insulated (PILC) Cables up to 1KV
- Heat Shrink Cable Terminations for Polymeric Insulated Cables up to 3.3KV
- Heat Shrink Cable Terminations suitable for 1 Core Polymeric insulated cables up to 42kV
- Heat Shrink Cable Terminations suitable for 3 Core Polymeric insulated cables up to 42kV
- Heat Shrink Cable Terminations suitable for 1 Core Aerial Bunched (ABC) cables up to 36kV
- Heat Shrink Cable Terminations suitable for 1 & 3 Core Paper Insulated (PILC) cables up to 36kV
- Heat Shrink Cable Terminations suitable for Polymeric Insulated Cables up to 72.5kV.

Heat Shrink Cable Termination Kits (Fig 33)

For connection of Cable to Switchgear Terminal, Transformer Terminal, Poles etc. termination kits are required. The Heat Shrinkable Termination kits can be Indoor or Outdoor based on actual application. It can also be single core or 3 core / 3.5 core based on cable configuration. Termination can be for XLPE & strong PILC Cable and can be used in extreme hazardous atmosphere conditions. We are also experts in manufacturing Heat Shrinkable Cable Terminations used for the requirements of low to medium voltage, the products have gained a broad and loyal clientele globally, which is an acknowledgment, for our international quality standards. Our items in this category are well-known for the stringent quality procedures.

Fig 33

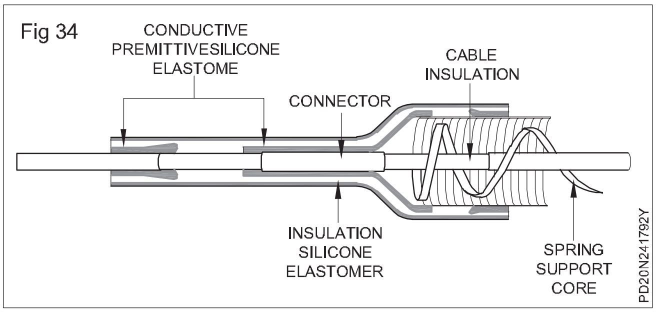


There are wide range of cable jointing systems available today, which can be classified by the way they are applied such as taped type, pre-moulded / push-on / slip-on type, cold application type and heat shrinkable type. The selection criterion for an appropriate type of jointing system by the user should be dependent on the site conditions, operating parameters, voltage applications and cable types.

Cold shrink joints (Fig 34)

Cold shrink has emerged as a convenient technique for making connections between a cable and another cable, the terminal of an equipment or the terminal of an electrical junction. Electrical installers often utilize this technology to provide a tightly fitted, protective seal around stranded and solid wire conductors as it is safe and easy to use.

Fig 34



Traditionally, cable jointing was done with heat shrink technology which involved applying heat to artificially expanded plastic tubes. Upon the application of heat, these plastic tubes shrunk to provide electrical insulation or jointing cables. However, heat shrink technology could not be utilized safely in all kinds of environments. For example, it was quite risky to use heat-producing tools in areas with flammable gasses, such as gas pipeline projects. Cold shrinking was developing as a safer alternative for terminating & jointing in areas with such issues.

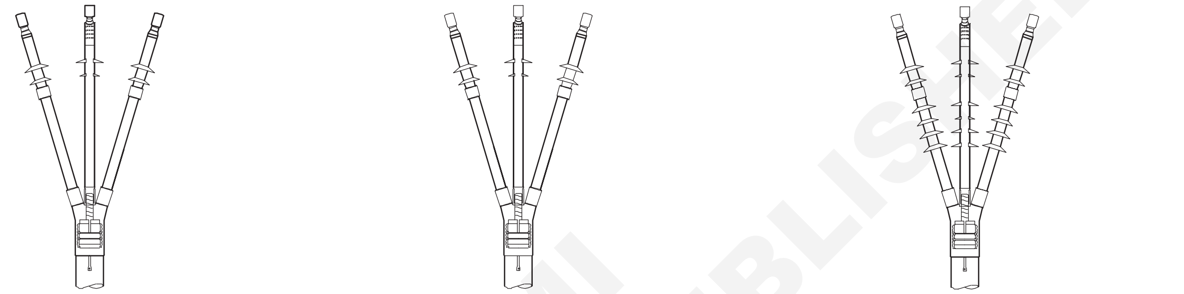
In cold shrink technology, accessories such as joint body, terminal body and tubes are made with materials such as rubbers and silicones that offer a high level of elasticity at ambient temperatures and are excellent at connecting and sealing power cables. The cold shrink tubes have a removable inner support system, which, when pulled out, causes the tube to shrink to its pre-stretched size. The tube wraps the cable perfectly and constantly exerts radial pressure for the lifetime of the joint or termination.

For correct utilization of cold shrink tubes, technician must only remove the inner core during the installation stage and not before. The cold shrink tubes must remain in their expanded state before they are actually being used for installation.

Cold shrink technology is optimized for field use and can withstand environmental conditions such as UV, pollution and chemicals, and salt fog. It can be utilized easily in onshore, offshore, indoor and outdoor environments. Furthermore, it is more suitable than heat shrink technology in places with space constraints where electrical tools and equipment cannot be used easily. Owing to these excellent practical features, cold shrink technology is experiencing widespread adoption in the electrical industry.

Cold shrink cable terminations

Fig 35



COLD SHRINK INDOOR & OUTDOOR TERMINATIONS 33kV (FOR XLPE CABLE) | COLD SHRINK INDOOR & OUTDOOR TERMINATIONS 22kV (FOR XLPE CABLE) | COLD SHRINK INDOOR & OUTDOOR TERMINATIONS 11kV (FOR XLPE CABLE)

PD20N241792Z

Cold shrink cable terminations adopt advanced cold shrink technology. No need to use open flame and special tools during installation, just gently extract the core rope. Grounding adopts a constant force spring, no welding or copper wire binding is required. The cold shrinkable cable termination is more time-saving, labor-saving, and space-saving.

- It has quick and convenient installation, and novices can also quickly get started.
- Each specification can be applied to a variety of cable diameters and cables with a variety of insulation materials.
- High-quality silicone rubber material, with strong insulation, anti-tracking, corrosion resistance and oxidation resistance.
- The unique material formula and manufacturing process make it tightly adsorb the cable and maintain the stable output of the cable.
- ZMS has a complete series of cable terminations and cable joints, and customers are welcome to cooperate.

11KV/22KV/33KV Cold Shrink Cable Termination Kits

With the advancements in today's times, people have begun to demand for things that can deliver superior performance. The 11KV/22KV/33KV cold shrink cable termination kits is exactly that. These are the kinds of equipment which is used in connecting cables to the transformer terminals, switchgear terminals, poles and much more. The reason why they are so popular is because of the fact that they are rather easy to install and are fast. Other than that, the installation process is one of the safest making the whole process completely danger-free.

Another advantage of the 11KV/22KV/33KV cold shrink cable termination kits is that they can be used indoors as well as outdoors and can be adjusted to fulfil the requirements of low to medium voltage. But, how can it be safe to use it both indoors and outdoors? Well because, they use silicone which makes it as leak proof as possible. They are also UV-stable which means that there isn't a chance of conducting a carbon path.

They are considered to be safer than the heat shrink cable terminations kits as there isn't the need of a flame to seal the application. At Yamuna Power and Infrastructure Ltd., The standard and quality of the products are maintained by using only superior quality materials. With our products, we aim towards offering superior performance and enhanced efficiency to all our users.

Important parameters for HV Terminations

1 Safety
2 Current transfer / overload, short circuit currents.
3 Environmental protection(Water /Oil seal)
4 Electric stress control(Internal Pd/ External Corona)
5 Tracking resistance, UV protection.
6 Shrink back (Over sheath or XLPE)

7 Bending force (Top bolt, Insulator, box body)

8 Earth connections

9 Conductor connection, current / heat transfer.

10 Ease of installation

11 Mechanical strength

12 Durability

Slip-on termination

Since the 1960s slip-on terminations have been in use. The installation of these premoulded accessories is very easy and simple. Due to their great elasticity they can be installed on all single or three core polymeric cables for use indoors and outdoors. The field control is done by a semi-conductive stress cone inside the (EPDM or silicone) rubber termination housing (capacitive stress control).Cold-shrinkable termination.

Type of High-voltage connectors

High-voltage connectors such as BNC, MHV, or SHV are used for connecting shielded single-core coaxial cables. Although other connectors for coaxial cables, such as SMA, SMB, and SMC, can be used, they cannot be used for very high-voltage applications.

There are three types of cable connectors: coaxial cable connectors, twisted-pair cable connectors, and fiber-optic cable connectors with the twisted pair.

The type of electrical connector that's needed depends on the intended application. Based on the component's intended function and environment, the connector can be equipped with either a shielded or unshielded cable. Shielded cables prevent electromagnetic interference and protect the cable against voltage surges; they're usually used if the cable has solid insulation. Unshielded cables, on the other hand, are typically used for network cabling.

Single-Pin High-Voltage Connectors: This type of connector is constructed with a single pin and socket pair and can be combined to include different locking systems.

Multi-Pin High-Voltage Connectors: As its name suggests, a multi-pin connector uses multiple pins and sockets in its construction. Each application will dictate the required number of pins.

High-Voltage Connectors for Extreme Environments: Extreme environments require a high-voltage connector design that accommodates temperatures between -55° C and 150° C and elevations up to 70,000 ft.

Corona Resistant or Resistant High-Voltage Connectors: When the air around an electronically charged conductor becomes ionized, it causes corona discharge, which can degrade insulators over time. Corona Resistant connectors are placed at safe distances between disparate voltages to minimize degradation. They're made with a dialectic material, have no sharp edges, and attach tightly to cables.

In-Line High-Voltage Connectors: Using male and female connectors, two high-voltage cables are joined with high-voltage connectors to function as one cable for signal continuity.

Panel Mount High-Voltage Connectors: When a connector must be fastened against or through a hole in a panel, it can be positioned on a mounting board behind the panel or with a thread and nut fastener. Technicians can use a free-hanging rectangular panel mount, circular connectors, or circular connector housings.

Methods of connection

Electrical connectors can be viewed as a type of adapter to convert between two connection methods, which are permanently connected at one end and (usually) detachable at the other end. By definition, each end of this "adapter" has a different connection method – e.g. the solder tabs on a male phone connector, and the male phone connector itself. In this example, the solder tabs connected to the cable represent the permanent connection, whilst the male connector portion interfaces with a female socket forming a detachable connection.

Plug and socket connectors

Plug and socket connectors are usually made up of a male plug (typically pin contacts) and a female socket (typically receptacle contacts). Often, but not always, sockets are permanently fixed to a device as in a chassis connector (see above), and plugs are attached to a cable.

Jacks and plugs

A jack is a connector that installs on the surface of a bulkhead or enclosure, and mates with its reciprocal, the plug.

Crimp-on connectors

Crimped connectors are a type of solderless connection, using mechanical friction and uniform deformation to secure a connector to a pre-stripped wire (usually stranded).[1] Crimping is used in splice connectors, crimped multipin plugs and sockets, and crimped coaxial connectors.

Soldered connectors

Many plug and socket connectors are attached to a wire or cable by soldering conductors to electrodes on the back of the connector. Soldered joints in connectors are robust and reliable if executed correctly, but are usually slower to make than crimped connections.

Insulation-displacement connectors

Since stripping insulation from wires is time-consuming, many connectors intended for rapid assembly use insulation-displacement connectors which cut the insulation as the wire is inserted.

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

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

Precautions for the installation of cables and bus bar trunking systems.

1 Grouping of Conductors in parallel

2 For Short Circuits

3 With respect to Magnetic effects

4 Operating current, and voltage drop.

1 Grouping of Conductors in parallel

The arrangement of conductors in a triangle (or in a trefoil) provides the best balance, but is generally limited to two or even three conductors per phase. Above this, the overlapping of layers limits cooling and installation in a bundle is preferable.

2 For Short Circuits

There are two destructive effects which can affect conductors in the event of a short circuit:

Thermal Stress and Electrodynamic Stress

When a short circuit between two active conductors occurs (the most probable), the conductors suffering the intense current of the short circuit will be repelled with a force proportional to the square of the intensity. If they are poorly secured, they will start to whip and could tear out of their ties and touch another conductor or an earth causing a new short circuit with a highly destructive arcing effect. Multi-conductor cables are designed to withstand the forces that could be exerted by these conductors.

3 Magnetic effects

Passing high currents through conductors induces magnetic effects in adjacent metallic masses, which can result in the unacceptable heating of the materials.

Few wiring precautions are therefore essential

1 To reduce the induction created, it is necessary to arrange the conductors so that the field is as weak as possible. So far as is possible, conductors should be arranged in a trefoil to reduce induced fields (see diagram for grouping conductors above).

2 To prevent significant heating in cable tray sections, it is advisable to remove the parts that create loops around a conductor.

3 Breaking the magnetic loop by removing sections is also possible. In all cases, check that the mechanical strength remains acceptable.

4 Cutting wire cable tray in order to prevent magnetic fields likely to cause heating.

Testing of high-voltage cables

There are different causes for faulty cable insulation when considering solid dielectric or paper insulation. Hence, there are various test and measurement methods to prove fully functional cables or to detect faulty ones. While paper cables are primarily tested with DC insulation resistance tests the most common test for solid dielectric cable systems is the partial discharge test. One needs to distinguish between cable testing and cable diagnosis.

While cable testing methods result in a go/no go statement cable diagnosis methods allow judgment of the cable's current condition. With some tests, it is even possible to locate the position of the defect in the insulation before failure.

In some cases, electrical treeing (water trees) can be detected by tan delta measurement. Interpretation of measurement results can in some cases yield the possibility to distinguish between new, strongly water treed cable. Unfortunately, there are many other issues that can erroneously present themselves as high tangent delta, and the vast majority of solid dielectric defects can not be detected with this method. Damage to the insulation and electrical treeing may be detected and located by partial discharge measurement. Data collected during the measurement procedure are compared to measurement values of the same cable gathered during the acceptance test. This allows a simple and quick classification of the dielectric condition of the tested cable. Just like with tangent delta, this method has many caveats, but with good adherence to factory test standards, field results can be very reliable.

Galvanic corrosion

Galvanic corrosion, also known as bimetallic corrosion, is an electrochemical process whereby one metal corrodes in preference to another metal that it is in contact with through an electrolyte. Galvanic corrosion occurs when two dissimilar metals are immersed in a conductive solution and are electrically connected.

Mechanism of Galvanic Corrosion

When two metals come in contact in the presence of an electrolyte, the more reactive metal acts as an anode whereas the less reactive metal acts as a cathode. The electrolyte offers a channel for the movement of particles, which in turn leads to the rapid eroding of the anodic metal.

Galvanic Corrosion can be used beneficially to protect a cathodic metal from corrosion. A good example of this would be the usage of zinc in batteries to promote the corrosion of zinc to create a potential difference.

Causes of Galvanic Corrosion

This type of corrosion occurs when two dissimilar metals are electrically connected and immersed in a conductive solution. The cathode metal stays safe uncorroded, whereas the anode gets corroded. The attack rate on the anode is stimulated when compared to the uncoupled metal rate. For example, if you connect aluminium and carbon steel and immerse them in seawater, the aluminium corrodes quickly and the steel will be protected.

Prevention of corrosion by bimetallic strip

This can be prevented by the use of bimetallic strips and washers when an electrical connection is needed to be made with two dissimilar metals. Bimetallic strips are made by cladding two metals such as copper and aluminium. The cladding ensures proper contact between the two metals. The aluminium side of the bimetallic strip is connected to the aluminium conductor while the copper side of the bimetallic strip is connected to the copper conductor.

Bimetallic strips are used in bus bars where sections made of different metals need to connected. They are also used when electric equipment. Which usually have windings made copper are to be connected via glands at both ends of the cable.

If the cable screen is connected via terminal lugs at both ends of a cable the effect is similar to having armour connected via glands at both ends of the cable.

In most modern medium voltage (MV) cables, especially underground, cables are shielded or screened with an earthing conductor. The screen consists of lapped copper tape or metallic foil usually less than 1mm in thickness, which is the interface between the conductor and the insulation (PVC, XLPE).

The main purpose of this conductive screen is to maintain a uniformly divergent electric field and contain the electric field within the cable core. The conductor screen is made from semi-conductive material, which is designed to hold back voltage.

This smooths out the surface irregularities of the conductor by making the voltage on the inside of the insulation the same. This semi-conductive screen material is based on carbon black, which is dispersed within a polymer matrix. The concentration of carbon black needs to be sufficient to ensure adequate and consistent conductivity.

It must also be optimized to provide a smooth interface between the conducting and insulating components of the cable, which is important as it decreases the occurrence of high stress regions on the cable. The semi-conductive screen also reduces voltage stresses where the conductive components interface with the insulating components. It accomplishes this when the expansion of the insulating layer is typically 10 times greater than that of the conductor, so that when the cable is at its maximum operating temperature of 90°C a large enough gap is formed to allow electrical discharges to occur. This then serves to even out the stresses associated with these discharges which would otherwise attack the insulation at specific points along the medium voltage cable. The screen wires are connected at each extremity of the circuit in solidly grounded systems, dispersing the circulating currents of the MV cable.

When connecting the screen wires, it is important to note whether the installation is using current transformers (CT's) for the circuit protection. Any currents on the screen wires will be phasor summed in the conductor by the CT. In the case of fault currents, this is often directly out of phase with the conductor current.

As the screen passes through the CT as part of the cable it is then necessary to bring the made-up screen wires back through the CT in the opposite direction prior to grounding. This ensures the screen current is effectively cancelled out to ensure the correct operation of circuit protection devices.

Introduction to IP Ratings and Cable testing

Objectives: At the end of this lesson you shall be able to
- **describe ingresss proctection code and explain the reference chart**
- **describe the faults occurs in cables and the testing methods**
- **explain the importance of bonding and grounding.**

Ingress Protection (IP)

The IP Code (or International Protection Rating, sometimes also interpreted as Ingress Protection Rating*) consists of the letters IP followed by two digits and an optional letter. As defined in international standard IEC 60529, it classifies the degrees of protection provided against the intrusion of solid objects (including body parts like hands and fingers), dust, accidental contact, and water in electrical enclosures. The standard aims to provide users more detailed information than vague marketing terms such as waterproof.

The digits (characteristic numerals) indicate conformity with the conditions summarized in the tables below. For example, an electrical socket rated IP22 is protected against insertion of fingers and will not be damaged or become unsafe during a specified test in which it is exposed to vertically or nearly vertically dripping water. IP22 or 2X are typical minimum requirements for the design of electrical accessories for indoor use.

*Explanation of the letters IP is given in IEC 60529 (Ed. 2.1), clause 4.1

First Digit: Solids

The first digit indicates the level of protection that the enclosure provides against access to hazardous parts (e.g., electrical conductors, moving parts) and the ingress of solid foreign objects.

Level	Object size protected against	Effective against
0	Not protected	No protection against contact and ingress of objects.
1	>50mm	Any large surface of the body, such as the back of the hand, but no protection against deliberate contact with a body part.
2	>12.5mm	Fingers or similar objects.
3	>2.5mm	Tools, thick wires, etc.
4	>1mm	Most wires, screws, etc.
5	Dust Protected	Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment; complete protection against contact.
6	Dust Tight	No ingress of dust; complete přijection against contact.

Second Digit: Liquids

Protection of the equipment inside the enclosure against harmful ingress of water.

Level	Object size protected against	Effective against
0	Not protected	-
1	Dripping water	Dripping water (vertically falling drops) shall have no harmfull effect.
2	Dripping water (vertically falling drops) shall have no harmfull effect.	Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle up to 15” from its normal position.
3	>2.5mm	Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect.
4	Spraying water	Water splashing against the enclosure from any direction shall have no harmful effect.

5	Water projected by a nozzle (6.3mm) against enclosure from any direction shall have no harmful effects	Water projected by a nozzle (6.3mm) against enclosure from any direction shall have no harmful effects.
6	Powerful water jets	Water projected in powerful jets (12.5mm nozzle) against the enclosure from any direction shall have no harmful effects.
7	Immersion up to 1m	Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion).
8	Immersion beyond 1m	The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. Normally, this will mean that the equipment is hermetically sealed. However, with certain types of equipment, it can mean that water can enter but only in such a manner that it produces no harmful effects.

IP Rating Reference Chart

Below is an easy to follow reference chart to help you decide which IP rating you need or have.

IP Number	First Digit-SOLIDS	Second Digit-LIQUIDS
IP69	Protected from total dust Ingress.	Protected from steam-jet cleaning.
IP68	Protected from total dust Ingress.	Protected from long term immersion up to a specified pressure.
IP67	Protected from total dust Ingress.	Protected from immersion between 15 centimeters and 1 meter in depth.
IP66	Protected from total dust Ingress.	Protected from high pressure water jets from any direction.
IP65	Protected from total dust Ingress.	Protected from low pressure water jets from arty direction.
IP64	Protected from total dust Ingress.	Protected from water spray from any direction.
IP63	Protected from total dust Ingress.	Protected from water spray less than 60 degrees from vertical.
IP62	Protected from total dust Ingress.	Protected from water spray less than 15 degrees from vertical.
IP61	Protected from total dust Ingress.	Protected from condensation.
IP60	Protected from total dust Ingress.	Not protected from liquids.
IP58	Protected from limited dust ingress.	Protected from long term immersion up to a specified pressure.
IP57	Protected from limited dust ingress.	Protected from immersion between 15 centimeters and 1 meter in depth.
IP56	Protected from limited dust ingress.	Protected from high pressure water jets from any direction.
IP55	Protected from limited dust ingress.	Protected from low pressure water jets from any direction.
IP54	Protected from limited dust ingress.	Protected from water spray from any direction.
IP53	Protected from limited dust ingress.	Protected from water spray less than 60 degrees from vertical.
IP52	Protected from limited dust ingress.	Protected from limited dust ingress.
IP51	Protected from limited dust ingress.	Protected from condensation.

IP50	Protected from limited dust ingress.	Not protected from liquids.
IP48	Protected from tools and small wires greater than 1 millimeter.	Protected from long term immersion up to a specified pressure.
IP47	Protected from tools and small wires greater than 1 millimeter.	Protected from immersion between 15 centimeters and 1 meter in depth.
IP46	Protected from tools and small wires greater than 1 millimeter.	Protected from high pressure water jets from any direction.
IP45	Protected from tools and small wires greater than 1 millimeter.	Protected from low pressure water jets from any direction.
IP44	Protected from tools and small wires greater than 1 millimeter.	Protected from water spray from any direction.
IP43	Protected from tools and small wires greater than 1 millimeter.	Protected from water spray less than 60 degrees from vertical.
IP42	Protected from tools and small wires greater than 1 millimeter.	Protected from water spray less than 15 degrees from vertical.
IP41	Protected from tools and small wires greater than 1 millimeter.	Protected from condensation.
IP40	Protected from tools and small wires greater than 1 millimeter.	Not protected from liquids.
IP38	Protected from tools and wires greater than 2.5 millimeters.	Protected from long term immersion up to a specified pressure.
IP37	Protected from tools and wires greater than 2.5 millimeters.	Protected from immersion between 15 centimeters and 1 meter in depth.
IP36	Protected from tools and wires greater than 2.5 millimeters.	Protected from high pressure water jets from any direction.
IP35	Protected from tools and wires greater than 2.5 millimeters.	Protected from low pressure water jets from any direction.
IP34	Protected from tools and wires greater than 2.5 millimeters.	Protected from water spray from any direction.
IP33	Protected from tools and wires greater than 2.5 millimeters.	Protected from water spray less than 60 degrees from vertical.
IP32	Protected from tools and wires greater than 2.5 millimeters.	Protected from water spray less than 15 degrees from vertical.
IP31	Protected from tools and wires greater than 2.5 millimeters.	Protected from condensation.
IP30	Protected from tools and wires greater than 2.5 millimeters.	Not protected from liquids.
IP28	Protected from touch by fingers and objects greater than 12 millimeters.	Protected from long term immersion up to a specified pressure.
IP27	Protected from touch by fingers and objects greater than 12 millimeters.	Protected from immersion between 15 centimeters and 1 meter in depth.
IP26	Protected from touch by fingers and objects greater than 12 millimeters.	Protected from high pressure water jets from any direction.
IP25	Protected from touch by fingers and objects greater than 12 millimeters.	Protected from low pressure water jets from any direction.
IP24	Protected from touch by fingers and objects greater than 12 millimeters.	Protected from water spray from any direction.
IP23	Protected from touch by fingers and objects greater than 12 millimeters.	Protected from water spray less than 60 degrees from vertical.
IP22	Protected from touch by fingers and objects greater than 12 millimeters.	Protected from water spray less than 15 degrees from vertical.
IP21	Protected from touch by fingers and objects greater than 12 millimeters.	Protected from condensation.

IP20	Protected from touch by fingers and objects greater than 12 millimeters.	Not protected from liquids.
IP18	Protected from touch by hands greater than 50 millimeters.	Protected from long term immersion up to a specified pressure.
IP17	Protected from touch by hands greater than 50 millimeters.	Protected from immersion between 15 centimeters and 1 meter in depth.
IP15	Protected from touch by hands greater than 50 millimeters.	Protected from low pressure water jets from any direction.
IP14	Protected from touch by hands greater than 50 millimeters.	Protected from water spray from any direction.
IP13	Protected from touch by hands greater than 50 millimeters.	Protected from water spray less than 60 degrees from vertical
IP12	Protected from touch by hands greater than 50 millimeters.	Protected from water spray less than 15 degrees from vertical.
IP11	Protected from touch by hands greater than 50 millimeters.	Protected from condensation.
IP10	Protected from touch by hands greater than 50 millimeters.	Not protected from liquids.
IP08	Not protected from liquids.	Protected from long term immersion up to a specified pressure.
IP07	Not protected from liquids.	Protected from immersion between 15 centimeters and 1 meter in depth.
IP06	Not protected from liquids.	Protected from high pressure water jets from any direction.
IP05	Not protected from liquids.	Protected from low pressure water jets from any direction.
IP04	Not protected from liquids.	Protected from water spray from any direction.
IP03	Not protected from liquids.	Protected from water spray less than 60 degrees from vertical.
IP02	Not protected from liquids.	Protected from water spray less than 15 degrees from vertical.
IP01	Not protected from liquids.	Protected from condensation.
IP00	Not protected from liquids.	Not protected from liquids.

Grounding And Bonding

Grounding Systems and Equipments

A **Underground Grounding Conductors:** Install bare tinned-copper conductor, No. 6 AWG minimum.

1 Bury at least 24 inches below grade.

2 Duct-Bank Grounding Conductor: Bury 12 inches above duct bank when indicated as part of duct-bank installation.

B **Grounding Bus:** Install in electrical and telephone equipment rooms, in rooms housing service equipment, and elsewhere as indicated.

1 Install bus on insulated spacers 2 inches minimum from wall, 6 inches above finished floor unless otherwise indicated.

2 Where indicated on both sides of doorways, route bus up to top of door frame, across top of doorway, and down to specified height above floor; connect to horizontal bus.

C **Conductor Terminations and Connections:**

1 Pipe and Equipment Grounding Conductor Terminations: Bolted connectors.

Equipment Grounding

A **Signal and Communication Equipment:** In addition to grounding and bonding required by NFPA 70, provide a separate grounding system complying with requirements in TIA/ATIS J- STD-607-A.

1. For telephone, alarm, voice and data, and other communication equipment, provide No. 4 AWG minimum insulated grounding conductor in raceway from grounding electrode system to each service location, terminal cabinet, wiring closet, and central equipment location.

2 Service and Central Equipment Locations Wiring Closets: Terminate grounding conductor on a 1/4-by-4-by-12-inch grounding bus.

3 Terminal Cabinets: Terminate grounding conductor on cabinet grounding terminal.

B Metal Poles Supporting Outdoor Lighting Fixtures: Install grounding electrode and a separate insulated equipment grounding conductor in addition to grounding conductor installed with branch-circuit conductors.

C Metal Structures: Install grounding electrode and insulated grounding conductor @ 60 feet, on- center for length of canopies. Provide a 2/0 grounding conductor from metal structure to ground rod.

Installation

A **Grounding Conductors:** Route along shortest and straightest paths possible unless otherwise indicated or required by Code. Avoid obstructing access or placing conductors where they may be subjected to strain, impact, or damage.

B **Ground Rods:** Drive rods until tops are 2 inches below finished floor or final grade unless otherwise indicated.

1 Interconnect ground rods with grounding electrode conductor below grade and as otherwise indicated. Make connections without exposing steel or damaging coating if any.

2 For grounding electrode system, install at least three rods spaced at least one-rod length from each other and located at least the same distance from other grounding electrodes, and connect to the service grounding electrode conductor.

C **Grounding for Steel Building Structure:** Install a driven ground rod at base of each corner column and at intermediate exterior columns at distances not more than 60 feet apart.

Field Quality Control

A **Testing Agency:** Engage a qualified testing agency to perform tests and inspections.

B **Manufacturer's Field Service:** Engage a factory-authorized service representative to inspect, test, and adjust components, assemblies, and equipment installations, including connections.

C **Tests and Inspections:**

1 After installing grounding system but before permanent electrical circuits have been energized, test for compliance with requirements.

2 Inspect physical and mechanical condition. Verify tightness of accessible, bolted, electrical connections with a calibrated torque wrench according to manufacturer's written instructions.

3 Test completed grounding system at each location where a maximum ground-resistance level is specified, at service disconnect enclosure grounding terminal. Make tests at ground rods before any conductors are connected.

a Measure ground resistance no fewer than two full days after last trace of precipitation and without soil being moistened by any means other than natural drainage or seepage and without chemical treatment or other artificial means of reducing natural ground resistance.

b Perform tests by fall-of-potential method according to IEEE 81.

4 Prepare dimensioned Shop Drawings locating each test well, ground rod and ground-rod assembly, and other grounding electrodes. Identify each by letter in alphabetical order, and key to the record of tests and observations. Include the number of rods driven and their depth at each location, and include observations of weather and other phenomena that may affect test results. Describe measures taken to improve test results.

D Grounding system will be considered defective if it does not pass tests and inspections.

E Prepare test and inspection reports.

F Report measured ground resistances that exceed the following values:

1 Power and Lighting Equipment or System with Capacity of 500 kVA and Less: 5 ohms.

G Excessive Ground Resistance: If resistance to ground exceeds specified values, notify Engineer promptly and include recommendations to reduce ground resistance.

Types of cable faults and testing procedure

The common faults which are likely to occur in cables are:

1 **Ground fault:** The insulation of the cable may breakdown causing a flow of current from the core of the cable to the lead sheath or to the earth. This is called “Ground Fault”.

2 **Short circuit fault:** If the insulation between two conductors is faulty, a current flows between them. This is called a “short circuit fault”.

Methods for locating ground and short circuit faults

The methods used localizing the ground and short circuit faults differ from those used for localizing open circuit faults.

In the case of multi core cables it is advisable, first of all, to measure the insulation resistance of each core to earth and also between cores. This enables us to sort out the core that is earthed in-case of ground fault; and to sort out the cores that are shorted in case of a short circuit fault. Loop tests are used for location of ground short circuit faults. These tests can only be used if a sound cable runs along with the faulty cable or cables.

The loop tests work on the principle of a Wheatstone bridge. The advantage of these tests is that their setup is such that the resistance of fault is connected in the battery circuit and therefore does not effect the result. However, if the fault resistance is high, the sensitivity is adversely affected. In this section only two types of tests viz., Murray and Varley loop tests are being described.

Murray Loop Test: The connection for this test are shown in Fig 8a relates to the ground fault and Fig 8b relates to the short circuit fault.

In both cases, the loop circuit formed by the cable conductors is essentially a wheat stone bridge consisting of resistances P, Q, R and X. G is a galvanometer for indication of balance,

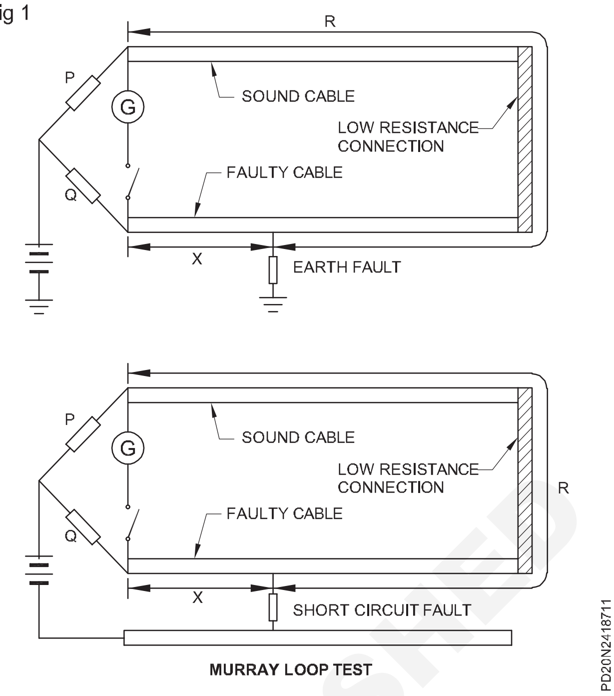
The resistors P, Q forming the ratio arms may be decade resistance boxes or slide wires.

Under balance conditions :

$$\frac{X}{R} = \frac{Q}{P} \text{ or } \frac{X}{R+X} = \frac{Q}{P+Q}$$

$$\therefore X = \frac{Q}{P+Q}(R+X)$$

Fig 1



Where (R+X) is total loop resistance formed by the sound cable and the faulty cable. When the conductors have the same cross-sectional area and the same resistivity, the resistance are proportional to lengths. If l_1 represents the length of the fault from the test end and ‘l’ is the length of each cable. Then

$$l_1 = \frac{Q}{P+Q} 2l$$

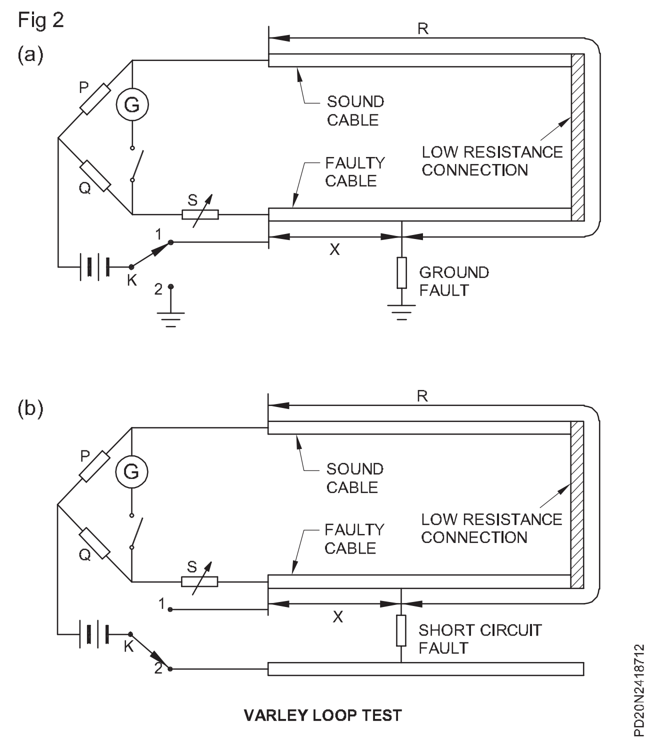
The above relation shows that the position of the fault may be located when the length of the cable is known. Also, the fault resistance does not alter the balance condition because its resistance enter the battery circuit hence effects only the sensitivity of the bridge circuit. However, if the magnitude of the fault resistance is high, difficulty may be experienced in obtaining the balance condition on account of decrease in sensitivity and hence accurate determination of the position of the fault may not be possible.

In such a case, the resistance of the fault may be reduced by applying a high direct or alternating voltage, in consistence with the insulation rating of the cable, on the line so as to carbonize the insulation at the point of the fault.

Varley loop test: In this test we can determine experimentally the total loop resistance instead of calculating it from the known lengths of the cable and its resistance per unit length. The necessary connections for the ground fault are shown in Fig 9a and for the short circuit fault in Fig 9b. The treatment of the problem, in both cases, is identical.

A single pole double throw switch A is used in this circuit. Switch K is first thrown to position ‘I’ and the resistance ‘S’ is varied and balance obtained.

Fig 2



VARLEY LOOP TEST

Measurement of resistance

Let the value of S for balance be S. The four arms of the Wheatstone bridge are P, Q, R + X, S_1 at balance:

$$\frac{R+X}{S_1} = \frac{P}{Q}$$

This determines R + X i.e. the total loop resistance as P, Q and S_1 are known.

The switch K is then thrown to position '2' and the bridge is rebalanced. Let the new value of S for balance be S_2. The four arms of the bridge now are P, Q, R, X + S_2.

At balance

$$\frac{R}{X+S_2} = \frac{P}{Q}$$

$$\frac{R+X+S_2}{X+S_2} = \frac{P+Q}{Q} \text{ or } X = \frac{(R+X)Q - S_2 P}{P+Q}$$

Hence, X is known from the known value of P, Q, S2 from this equation and R+X (the total resistance of 2 cables) as determined from Eqn. knowing the value of X, the position of the fault is determined.

Now

$$\frac{X}{R+X} = \frac{l_1}{2l} \text{ or } l_1 = \frac{X}{R+X}2l$$

Where

l_1= length of fault from the test end and

l = total length of conductor.

Equations for murray loop test and varley loop test are valid only when the cable sections are uniform throughout the loop. Corrections must be applied in case the cross-sections of faulty and sound cables are different or when the cross-section of the faulty cable is not uniform over its entire length.

Since temperature affects the value of resistance, corrections must be applied on this account if the temperatures of the two cables are different. Corrections may also have to be applied in case the cables have a large number of joints.

Instrument transformers - Current transformer and Potential transformer

Objectives: At the end of this lesson you shall be able to
- **state the necessity, types principle and advantages of the instrument transformer**
- **explain the construction and connection of the current transformer & potential transformer**
- **distinguish power transformer and instrument transformer**
- **differentiate instrument transformer used for protection and measurement.**

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.

These instrument transformers electrically isolate the instruments and relays from high current/voltage lines thereby reducing danger to the men and equipment. To obtain perfect isolation, the secondary of the instrument transformers and the core should be grounded.

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.

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.

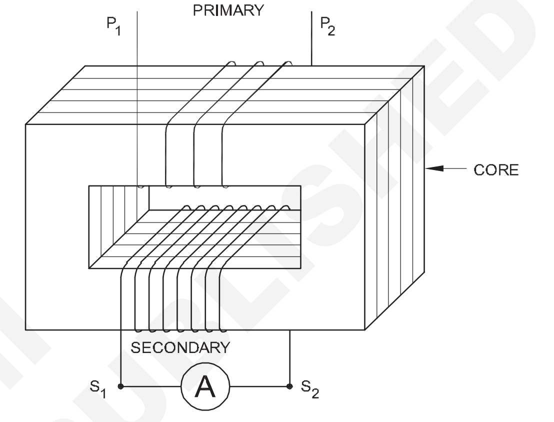
Winding: The winding should be close together to reduce the secondary leakage reactance; otherwise the ratio error will increase. In the case of a current transformer the winding must be so designed as to withstand the large short circuit current without damage.

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



WOUND TYPE CURRENT TRANSFORMER

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.

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.

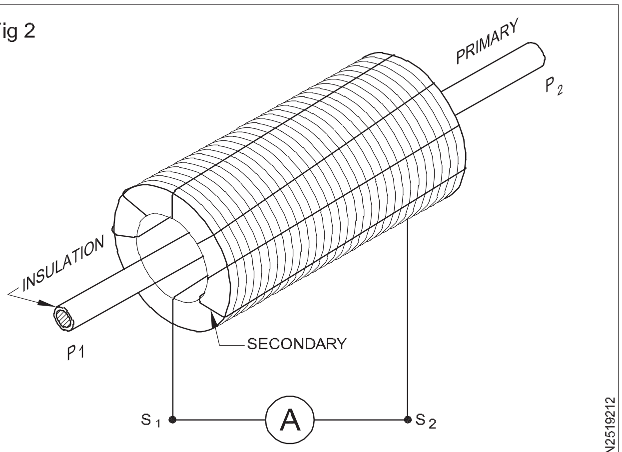
For example if the primary current is 100 amps and there are two turns in the primary, then the full load primary ampere turns is 200. Consequently, to circulate 5 amps in the secondary, the number of secondary turns must be 200/5, that is 40 turns.

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.

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.

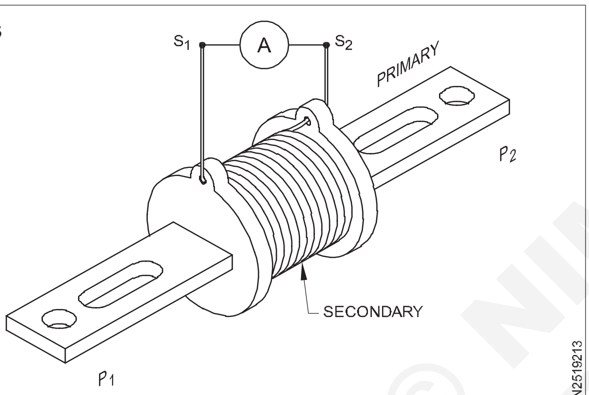
Fig 2



RING TYPE CURRENT TRANSFORMER

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.

Precautions while using the current transformer : In a current transformer the secondary current depends upon the primary current. Further 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
- Short time thermal current and its duration

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 specification of PT.**

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.

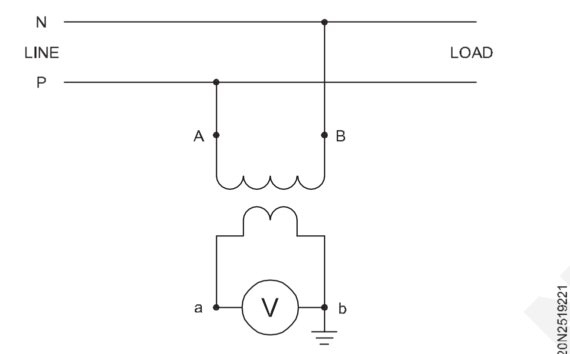
The core may be of shell or core type construction. Shell type construction is normally used for low voltage transformers.

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.

Fig 1



CONNETION OF POTENTIAL TRANSFORMER

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.

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.
- Special features, such as limiting dimensions.
- Whether the voltage transformer is required for connection between the star point of the generator and earth.
- Any additional requirement for voltage transformers for protective purposes.
- Whether the installation is electrically exposed or not.
- Any other information.
- Three phase assembly with one multi-tap secondary

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.

Advantages of Current Transformer

- Provides galvanic isolation between high-voltage and low-voltage circuits ensuring safety for operators and equipment High accuracy in current measurement, allowing precise monitoring and control of electrical
- Currents Wide dynamic range capable of measuring both high and low currents with high accuracy Low Insertion impedance, minimizing the impact on the primary circuit and maintaining system efficiency
- Ability to handle high fault currents and transient conditions without damage Provides a proportionate reduced current output that can be easily interfaced with measuring Instruments and relays.
- Enables multiple measurements to be taken from a single primary conductor, reducing the need for

additional current-carrying conductors Enhances system reliability by enabling early detection and protection against overcurrents and faults

- Can be easily integrated into existing power systems without major modifications
- Suitable for both AC and DC applications, depending on the specific design and configuration

Advantages of Potential Transformer

Some advantages of Potential Transformers are as follows:

- They provide accurate and reliable measurements of high voltages
- A potential transformer is essential for power systems safe and efficient operation.
- They isolate high-voltage power systems from lower-voltage control and measurement systems, ensuring the safety of personnel and equipment
- Typically less expensive than other high voltage measurements Used in devices such as voltage dividers or capacitive voltage transformers
- These are highly reliable and require minimal maintenance, which reduces downtime and increases operational efficiency.
- They have low power consumption, which helps to reduce energy costs and environmental impact.
- These are very easy to install and can be mounted on poles or structures, which reduces installation time and cost

Difference between Current transformer & Potential transformer

Characteristics	Current Transformer	Potential Transformer
Definition	Current transformer is used to measure current in system	Potential transformer is used to measure voltage in system
Function	Transforms high current to low	Transforms high voltage to low
Connection	Connected in series	Connected in parallel
Primary winding	It has small no.of turns	It has large no. of turns
Secondary winding	Large no.of turns	Small no. of turns
Secondary winding range	1-5A	110-120V

Difference between Current transformer & Potential transformer

A transformer is basically a passive electrical device that works on the principle of Faraday's law of Electro-Magnetic Induction by converting electrical energy from one value to another. Transformers are capable of either increasing or decreasing the voltage and current levels of power supply without modifying supply frequency or the amount of electrical power being transferred.

A transformer basically consists of 2 wound electrical coils of wire – primary and secondary. The primary is connected to the source of power and the secondary is connected to the power delivery end. These two coils are not in electrical contact with each other but are instead wrapped together around a common closed magnetic iron circuit called the core. This soft iron core is not solid but made up of individual laminations connected together to help reduce the core's losses. When AC current passes through the primary coil, a magnetic field is induced into the core which transmits a proportional voltage (or current) into the secondary coil.

Transformers can be broadly categorised as Power Transformers and Instrument Transformers based on their application. While power transformers are used in power transmission, instrument transformers find primary application in measurement of current and voltage.

Instrument Transformers are used in AC power systems for measurement of electrical quantities i.e. voltage, current, power, energy, power factor, frequency. Instrument transformers are also used with protective relays for protection of the power system. Instrument Transformers are of two types – Current Transformers and Potential (or Voltage) Transformers.

Some of the important application scenarios where CTs are installed are:

For control in high-voltage electrical sub-stations and the electrical grid

To activate the protective relay in case of a fault current and isolate a part of or the full system from the main supply

Commercial metering

Earth fault Protection/Differential Protection/Bus–bar protection system

Motor – Generator sets

Control Panel (VCB, AMF, APFC, MCC, PCC and Relay panels) and Drives

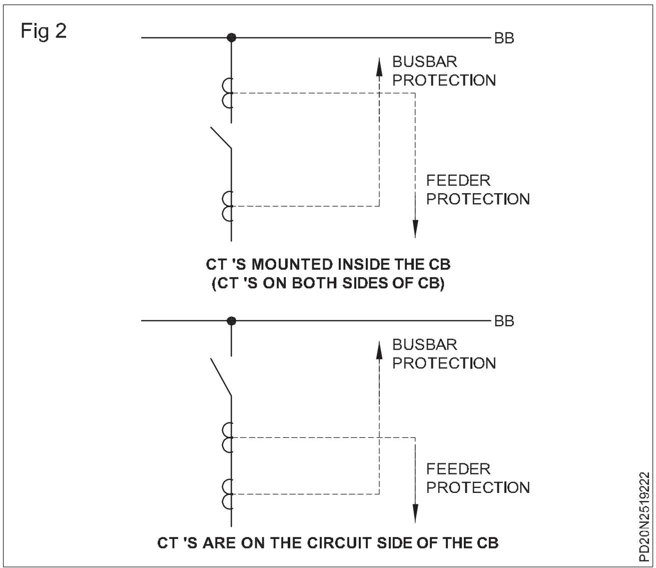
Standard CT for Laboratory purpose

Bushing type, oil-immersed CT in Power transformer

Current sensing, recording, monitoring and control

Location of CT and PT in the system

Current transformers are used for protection, instrumentation, metering and control. It is only the first function that has any bearing on the location of the current transformer.



Ideally the current transformers should be on the power source side of the circuit breaker that is tripped by the protection so that the circuit breaker is included in the protective zone.

In many circuits the power flow can be in either direction and it then becomes necessary to decide which location of fault is most important or likely and to locate the current transformers on the side of the circuit breaker remote from those faults. In the case of generator (and some transformer) circuits it is necessary to decide whether the protection is to protect against for faults in the generator or to protect the generator against system faults.

Current transformers can often be located in the generator phase connections at the neutral end and will then protect the generator from the system faults and to a large degree give protection for faults in the generator.

When current transformers can be accommodated within the circuit breaker, they can in most cases be accommodated on both sides of the circuit breaker and the allocation of the current transformers should give the desired overlapping of protective zones.

With some designs of circuit breaker the current transformer accommodation may be on one side only and it may be necessary to consider the implications of the circuit breaker position in the substation before deciding on the electrical location of the current transformers.

However the risk of a fault between the current transformers and the circuit breaker and within the circuit breaker itself is very small and so the economics of accommodating the current transformers may have an important influence on their location.

Where separate current transformer accommodation has to be provided, the cost of separately mounted current transformers and also the extra substation space required almost always results in them being located only on one side of the circuit breaker. In practice this is generally on the circuit side of the circuit breaker.

This follows metalclad switchgear practice where this is the easiest place to find accommodation, and is also the optimum position when bus zone protection is required.

Often it may be possible to accommodate current transformers on the power transformer bushings or on through wall bushings. When this is done it is usually for economic reasons to save the cost of, and space for, separately mounted current transformers.

Transformer mounted current transformers have minor disadvantages in that a longer length of conductor and, more especially, the bushing is outside the protected zone, and in the event of the transformer being removed then disconnections have to be made to the protective circuits.

Note that the arrangement of the individual current transformers within a unit should preferably be arranged that any protective zones overlap and that current transformers for other functions are included within the protected zone.

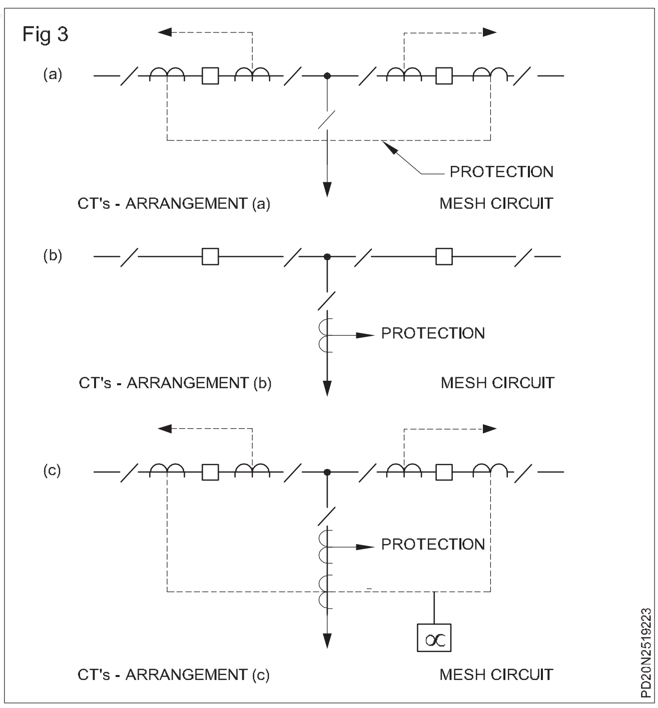
Under by-pass conditions (where this is provided) the circuit is switched by the bus coupler circuit breaker.

The location of the current transformers is determined by whether the protective relaying and current transformers are provided by the bus coupler circuit, or whether the protective relaying and current transformers of the circuit are used with the tripping signal being routed to the bus coupler circuit breaker during by-pass. If the latter method is used then the current transformers must be separately mounted on the line side of the by-pass isolator.

Possible locations of current transformers

Figures 1 (a), (b) and (c) show possible locations of current transformers in a portion of mesh substation.

Arrangement (a) (Fig 3)



Arrangement (a)

In arrangement (a) the current transformers are summed to equate to the feeder current and to operate the circuit protection.

The protection also covers a portion of the mesh and, with overlapping current transformers as shown, the whole mesh is included in discriminative protective zones. Because the feeder current may be significantly smaller than the possible mesh current, the ratio of the mesh current transformers may be too high to give the best feeder protection.

Arrangement (b)

In arrangement (b) the current transformers are in the feeder circuit and so their ratio can be chosen to give the best protection.

However there is now no discriminative protection for the mesh. Note that the current transformers can be located either inboard or outboard of the feeder isolator, the choice being dependent on the ease of shutting down the feeder circuit and the undesirability of opening the mesh if maintenance of the current transformer were required.

Arrangement (c)

The arrangement shown in (c) is a combination of (a) and (b) with, if necessary, different ratio current transformers in the feeder circuit. This arrangement however requires three sets of current transformers as opposed to two and one in arrangements (a) and (b).

Similar arrangements are possible with breaker-and-a-half substations with the slight difference that at the end of the diameter the protection becomes protection for the busbar instead of a feeder. All the diameter currents are summed for the bus zone protection.

Potential Transformers

It is not an easy way to measure the high voltage and currents associated with power transmission and distribution systems, hence instrument transformers are often used to step-down these values to a safer level to measure. This is because measuring meters or instruments and protective relays are low voltage devices, thereby cannot be connected directly to high voltage circuit for the purpose of measurement and protection of the system.

The potential transformer connected to the power circuit whose voltage should be measured is connected between the phase and the ground. That means the primary winding of a potential transformer is connected to the high voltage circuit and the secondary winding of a transformer is connected to a voltmeter.

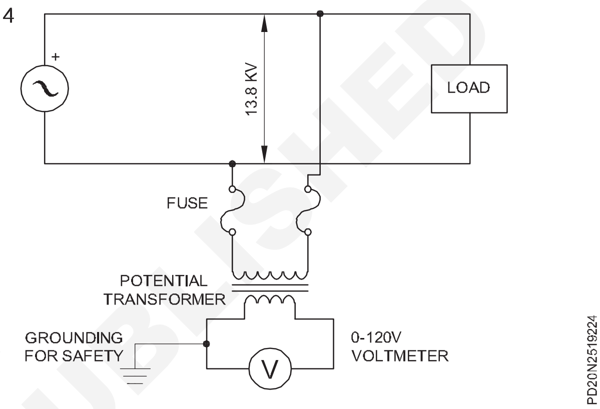
In addition to the reduction of voltage and current levels, these transformers isolate the measuring or protective circuit from the main circuit which is operating at high power levels.

The current transformers reduce the level of current to the instrument or relay operating range, whereas potential transformers transforms the high voltage to a circuit operating low voltage. In this article we are going to discuss in detail about the potential transformers.

Potential transformer is a voltage step-down transformer which reduces the voltage of a high voltage circuit to a lower level for the purpose of measurement. These are connected across or parallel to the line which is to be monitored.

The basic principle of operation and construction of this transformer is similar to the standard power transformer. In common, the potential transformers are abbreviated as PT.

Fig 4



The primary winding consists of a large number of turns which is connected across the high voltage side or the line in which measurements have to be taken or to be protected. The secondary winding has lesser number of turns which is connected to the voltmeters, or potential coils of wattmeter and energy meters, relays and other control devices. These can be single phase or three phase potential transformers. Irrespective of the primary voltage rating, these are designed to have the secondary output voltage of 110 V.

Since the voltmeters and potential coils of other meters have high impedance, a small current flows through the secondary of PT. Therefore, PT behaves as an ordinary two winding transformer operating on no load. Due to this low load (or burden) on the PT, the VA ratings of PTs are low and in the range of 50 to 200 VA. On the secondary side, one end is connected to the ground for safety reasons as shown in figure.

Similar to the normal transformer, the transformation ratio is specified as

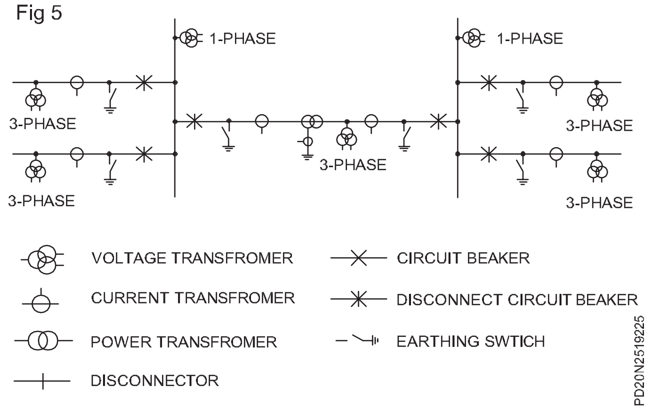
$$V_1/V_2 = N_1/N_2$$

From the above equation, if the voltmeter reading and transformation ratio are known, then high voltage side voltage can be determined.

Location in different substation arrangements

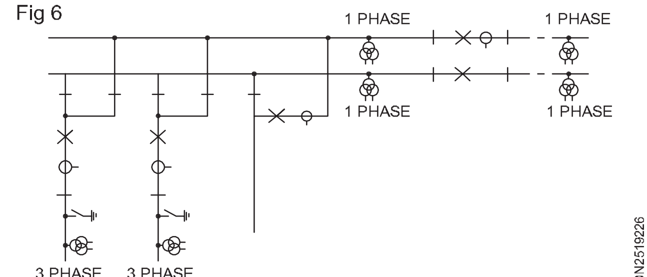
Below are some examples of suitable locations for current and voltage transformers in a few different switchgear arrangements.

Fig 5



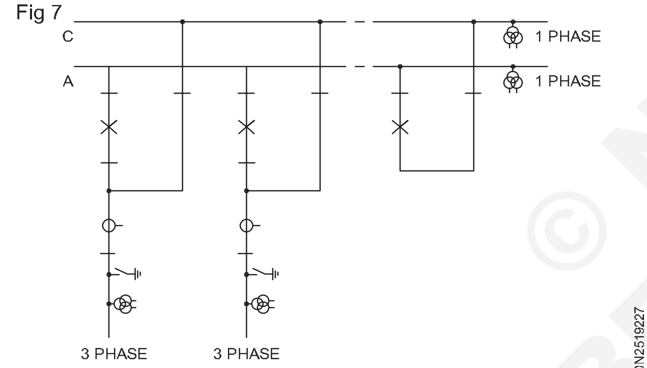
– Current and voltage transformers in a substation.

Fig 6



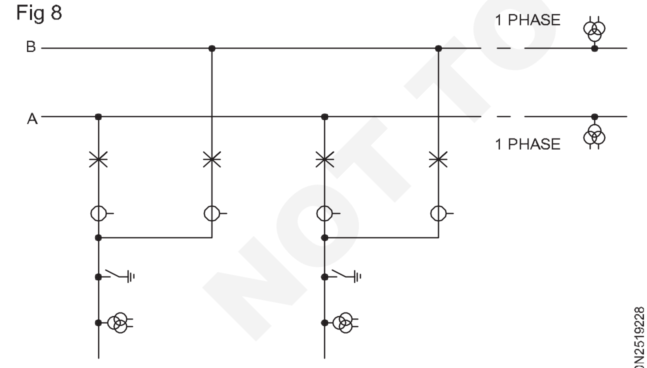
DOUBLE BUS BAR STATION

Fig 7



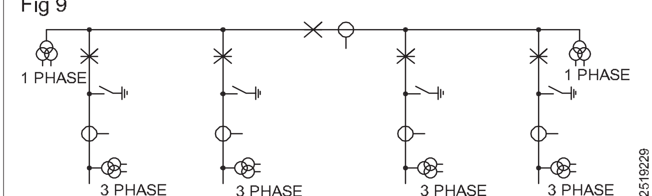
STATION WITH TRANSFER BUS BAR

Fig 8



DOUBLE BREAKER AND DOUBLE BUS BAR

Fig 9

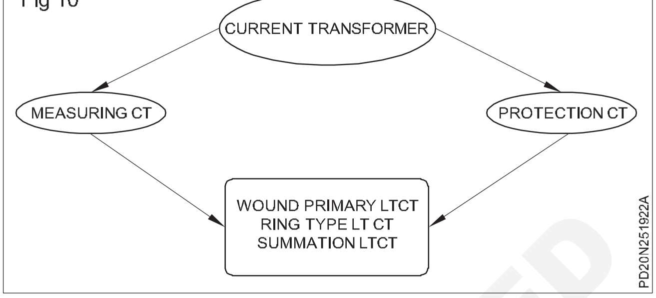


SECTIONIZED SINGLE BUS BAR STATION

Current transformer types (Fig 10)

Wound primary – In this type, the primary winding is physically connected in series with the conductor that measures the current. The primary winding has a single turn and is composed inside the transformer. Wire wound Current Transformer can be used to measure currents in the range of 1A to 100A.

Fig 10



Bus Bar – In this type, the bus bar of the main circuit itself acts as the primary winding with a single turn. So the bar type transformer has only secondary windings. The body of the CT itself provides insulation between the primary circuit and ground. By using oil insulation and porcelain bushings, such transformers can be applied at the highest transmission voltages.

Ring Type – In this type, the CT is installed over a bus bar or an insulated cable and only a low level of insulation is present on the secondary coil. To obtain non-standard ratios or for other special purposes, more than one turn of the primary cable may be passed through the ring. The core is usually laminated silicon steel and the windings are of copper.

Summation – Summation transformers are used for comparing the relaying quantities derived from the current in the three phases of the primary circuit. This is done by converting the three-phase quantities into the single phase quantity. The line Current Transformers are connected to the primary of the Auxiliary Current Transformer. These transformers are used for ensuring proper functioning of relay circuits.

The two main application areas of Current Transformers are current measurement and protection. They are also used for isolation between high voltage power circuits and measuring instruments. This not only ensures safety of the operator but also of the end device in use. It is recommended to apply current transformers for currents of 40A or higher.

CT in Measurement – A metering Current Transformer is designed to measure current on a continuous basis. They work with a high degree of accuracy but within the rated current range. Current transformers have a primary winding to which the current to be measured is fed. Measuring instruments are connected to a secondary winding. This allows them to be used in combination with measurement equipment and power **monitoring** products – from simple energy meters to power quality meters such as:

Ammeters

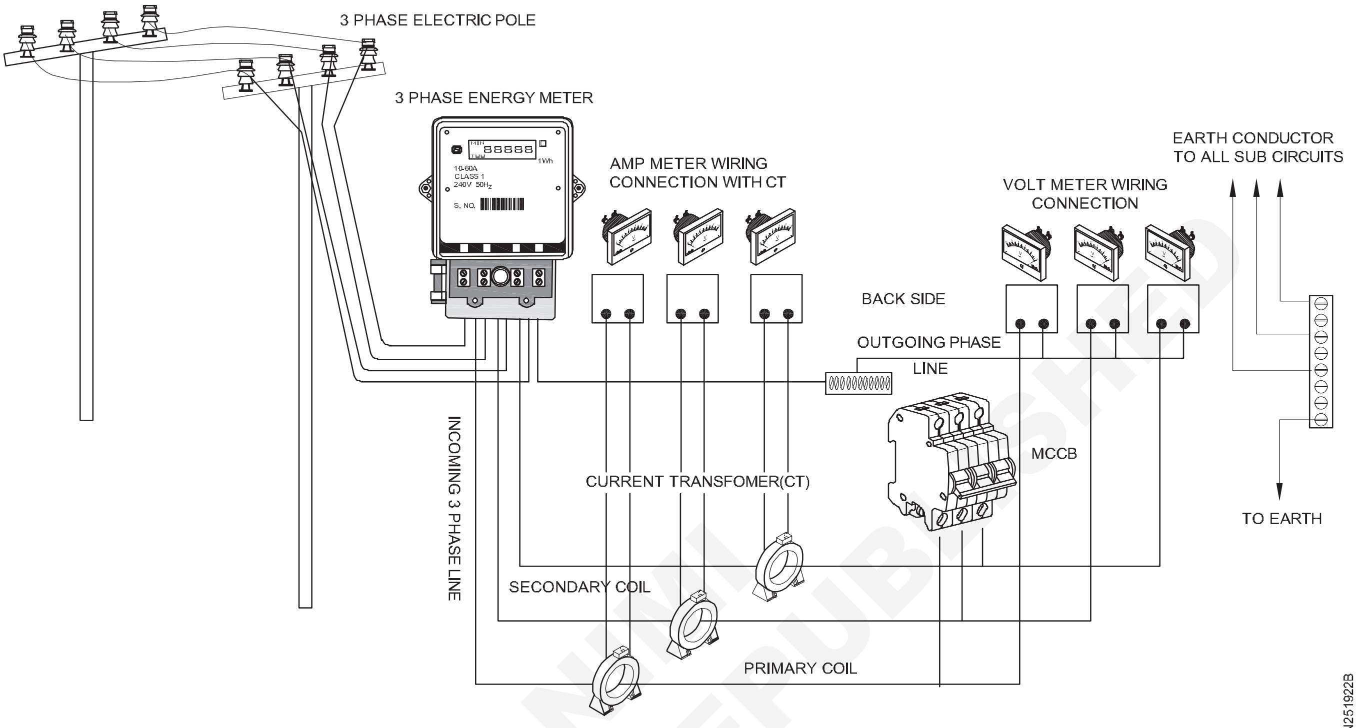
Kilowatt-hour meters

Measurement units

Control relays

Current error and phase displacement limits are determined by the accuracy class. Accuracy classes are: 0.1, 0.2, 0.5 and 1. If input current exceeds the rating, the metering CT will saturate thereby limiting the current level within the measuring instrument. Core materials for this type of CT typically have low saturation levels, such as nano-crystalline.

Fig 11

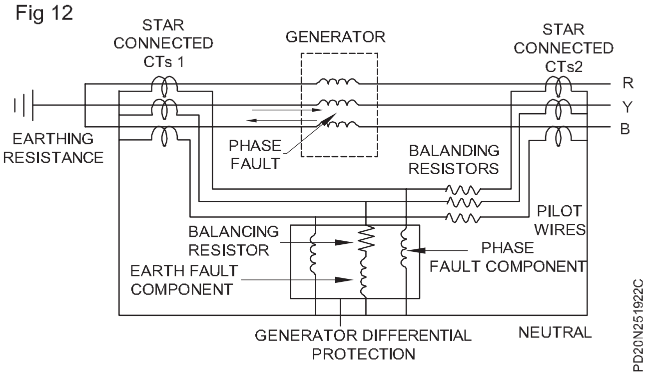


CURRENT TRANSFORMERS FOR MEASURING APPLICATIONS

Current Transformers in Power Protection System– A Protection Current Transformer is used to reduce the currents in power systems thereby protecting it from faults. These Current Transformers measure the actual current in the primary side and produce proportionate currents in their secondary windings which are completely isolated from the primary circuit. This replica current is then used as an input to a protective relay, which will automatically isolate part of the power circuit in case of a fault. Since only the faulty portion is isolated, the rest of the installation can continue to function normally protection

Current transformers for power protection applications (Fig 12)

Fig 12



Testing of Current transformers

Objectives: At the end of this lesson you shall be able to
- **conduct various tests such as ratio test, polarity test, insulation resistance test winding resistence test saturation test, burden test knee point voltage test**
- **perform installation of CT.**

Current transformers play an important role in the monitoring and protection of electrical power systems. CT's are instrument transformers used for converting primary current into a reduced secondary current for use with meters, relays, control equipment and other instruments.

The importance of instrument transformer tests is often underestimated. Current transformers for metering purposes must have a high degree of accuracy to ensure precise billing while those used for protection must react quickly and correctly in the event of a fault.

Risks such as confusing instrument transformers for metering and protection, or mixing up connections can be reduced significantly by testing before initial use. At the same time, electrical changes in a CT, caused for example by aging insulation, can be identified at an early stage.

For these reasons and more, it is essential to inspect and calibrate current transformers and their connected instruments at regular intervals. There are 6 electrical tests that should be performed on CT's to ensure accuracy and optimal service reliability:

Contents

1 Ratio Test

2 Polarity Test

3 Excitation (Saturation) Test

4 Insulation Resistance Test

5 Winding Resistance Test

6 Burden Test

1 Ratio Test

CT ratio is described as the ratio of primary current input to secondary current output at full load. For example, a CT with a ratio of 300:5 will produce 5 amps of secondary current when 300 amps flow through the primary side.

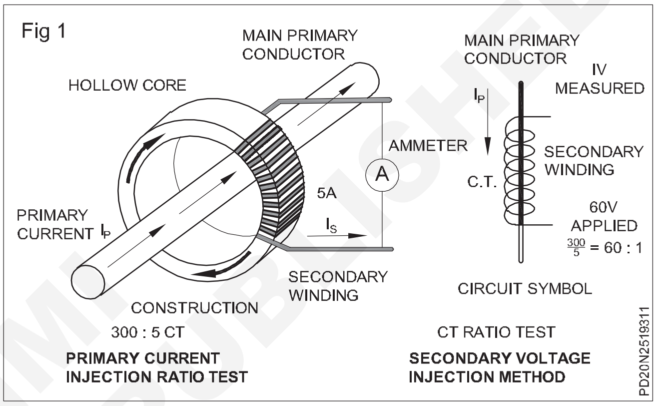
(300:5 = 60:1)

If the primary current changes, the secondary current output will change accordingly. For example, if 150 amps flow through a 300 amp rated primary the secondary current output will be 2.5 amps.

(150:300 = 2.5:5)

Unlike the voltage or power transformer , the current transformer consists of only one or very few turns as its primary winding. This primary winding can be of either a single flat turn, a coil of heavy duty wire wrapped around the core or just a conductor or bus bar placed through a central hole. (Fig 1)

Fig 1



A CT ratio test can be performed by injecting a primary current and measuring the current output, or by injecting a secondary voltage and measuring the induced primary voltage.

The ratio test is conducted to prove that the ratio of the CT is as specified, and to verify the ratio is correct at different taps of a multi tap CT. The turn's ratio is equivalent to the voltage ratio of potential transformers and can be expressed as follows:

N2/N1 = V2/V1

- N2 and N1 are number of turns of secondary and primary windings
- V2 and V1 are the secondary and primary side voltage readings

Ratio tests are performed by applying a suitable voltage (below saturation) to the secondary of the CT under test while the primary side voltage is measured to calculate the turns ratio from the expression above.

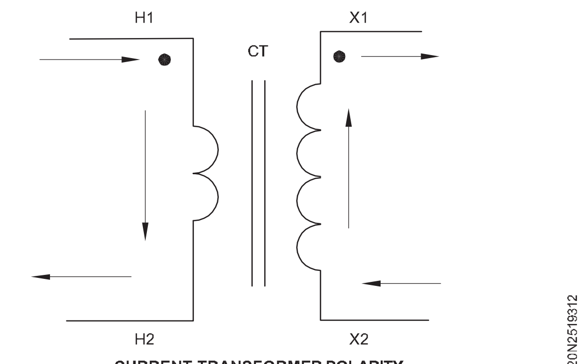
DANGER: Use caution when conducting a CT ratio test and DO NOT apply a voltage high enough that would cause the transformer to saturate. Applying a saturation voltage will result in readings that won't be accurate.

2 Polarity Test

The polarity of a CT is determined by the direction in which the coils are wound around the transformer core (clockwise or counterclockwise) and by how the leads are brought out of the CT case. All current transformers are subtractive polarity and should have the following designations to visually identify the direction of current flow: (Fig 2)

- H1 – primary current, line facing direction
- H2 – primary current, load facing direction
- X1 – secondary current

Fig 2



CURRENT TRANSFORMER POLARITY

A CT under test is assumed to have correct polarity if instantaneous current direction for primary and secondary current is opposite to each other.

The polarity marks on a CT designate the relative instantaneous directions of the currents. The polarity test proves that the predicted direction of secondary CT current (leaving) is correct for a given direction of primary current (entering).

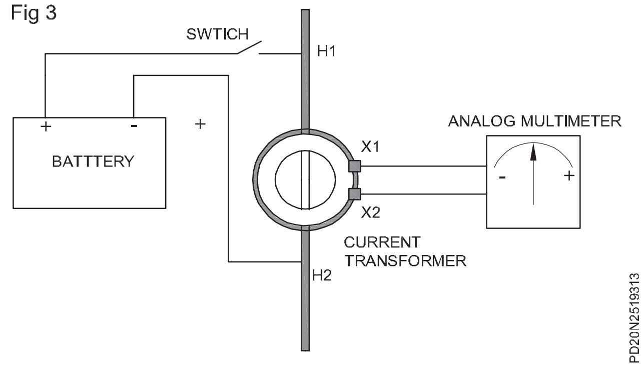
Taking care to observe proper polarity is important when installing and connecting current transformer to power metering and protective relays. At the same instant of time, that the primary current is entering the primary terminal the corresponding secondary current should be leaving the similarly marked secondary terminal.

A CT under test is assumed to have correct polarity if instantaneous current direction for primary and secondary current is opposite to each other. CT Polarity is critical when CT's are being used together in single-phase or three-phase applications.

Most modern day CT test equipment is capable of performing the ratio test automatically using a simplified test lead setup and will display polarity as correct or incorrect. CT polarity is verified manually by utilizing a 9V battery and analog voltmeter with the following test procedure: (Fig 3)

Markings on current transformers have been occasionally misapplied by the factory. You can verify the polarity of a CT in the field with a 9V battery.

Fig 3



CT Polarity Test Procedure

1 Disconnect all power prior to testing and connect the analog voltmeter to the secondary terminal of the CT to be tested. The positive terminal of the meter is connected to terminal X1 of the CT while the negative terminal is connected to X2.

2 Run a piece of wire through the high side of the CT window and shortly make contact with the positive end of the 9-volt battery to the H1 side (sometimes marked with a dot) and the negative end to the H2 side. It is important to avoid continuous contact, which will short circuit the battery.

3 If polarity is correct, the momentary contact causes a small deflection in the analog meter in the positive direction. If the deflection is negative, the polarity of the current transformer is reversed. The terminals X1 and X2 need to be reversed and the test can be carried out.

Note: Polarity is not important when connecting to ammeters and voltmeters. Polarity is important only when connecting to wattmeters, watt-hour meters, varmeters, and induction-type relays. To maintain polarity, the H1 side of the CT must be toward the source of power; then the X1 secondary terminal is the polarity connection.

3 Excitation (Saturation) Test

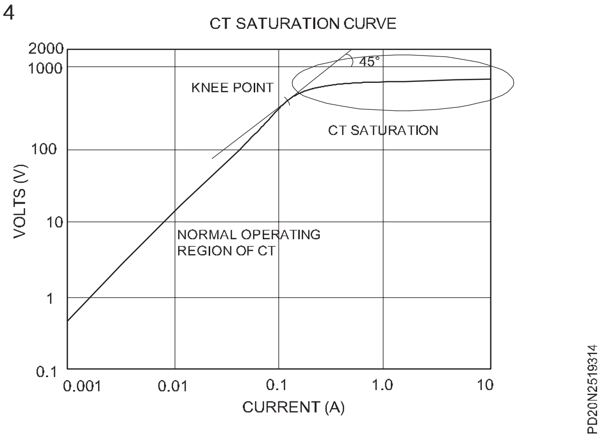
When a CT is "saturated", the magnetic path inside the CT operates like a short circuit on the transmission line. Almost all of the energy supplied by the primary winding is shunted away from the secondary winding and is used create a magnetic field inside the CT.

Saturation testing for a current transformer identifies the rated knee point against IEEE or IEC standards, the point at which the transformer is no longer able to output current in proportion to its specified ratio.

Excitation tests are performed by applying an AC voltage to the secondary winding of the CT and increasing the voltage in steps until the CT is in saturation. The "Knee" point is determined by observing a small voltage increase causing a large increase in current.

The test voltage is slowly decreased to zero to de-magnetize the CT. The test results are plotted on a logarithmic (log-log) graph and evaluated based on the transition period between normal operation and saturation. (Fig 4)

Fig 4



Current Transformer Excitation Test Explained

Excitation tests are performed by applying an AC voltage to the secondary winding of the CT and increasing the voltage in steps until the CT is in saturation.

The excitation curve around the points where current jumps up for a small increase of voltage; is very important for comparison of curves with published curves or similar CT curves. The excitation test results should be compared with published manufacturer's data or previous recordings to determine any deviations from previously obtained curves.

IEEE defines the saturation as "the point where the tangent is at 45 degrees to the secondary exciting amperes". Also known as "knee" point. This test verifies that the CT is of correct accuracy rating, has no shorted turns in the CT and no short circuits are present in the primary or secondary windings of the CT under test.

4 Insulation Resistance Test

The insulation between the current transformer windings and windings to ground should be checked for dielectric strength while performing a comprehensive CT test. Three tests are performed to determine the condition of the insulation of the CT under test:

1 **Primary to secondary:** Checks the condition of the insulation between high to low.

2 **Primary to ground:** Checks the condition of the insulation between high to ground.

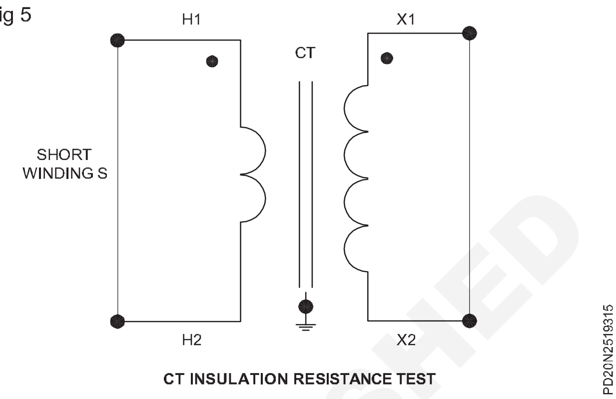
3 **Secondary to ground:** Checks the condition of the insulation between low to ground.

Insulation resistance readings should remain fairly constant over a period of time. A sharp dip in trending of insulation resistance values point towards insulation degradation and further investigation is required to diagnose the problem.

Insulation tests on current transformers rated 600V or less are usually performed at 1000VDC. Prior to testing, short the primary winding of the CT under test by connecting H1 and H2, then short the secondary winding of the CT under test by connecting X1 and X2-X5.

Remove the neutral ground and isolate the CT from any associated burden. After the windings are shorted, the CT will be a three terminal specimen. (Fig 5)

Fig 5



CT INSULATION RESISTANCE TEST

Three insulation resistance tests are performed to determine the condition of the insulation of the CT under test.

Insulation resistance test values for CT's should be compared with similar readings obtained with previous tests. Any large deviation in historical readings should call for further investigation.

ANSI/NETA MTS-2023 Table 100.5 Specifies a minimum insulation resistance of 500 Megohms at 1000VDC for dry transformer coils rated 600V or less.

The minimum insulation resistance that is generally accepted is 1 Megohm. Any reading in Megohms is considered to be a good insulation, however, it's the trending of insulation test results that gives the true condition of CT insulation.

Insulation readings are greatly affected by the specimen temperature. Should a reading be compared to previously taken readings, proper correction factors need to be applied, if taken under different temperature conditions before drawing any conclusion.

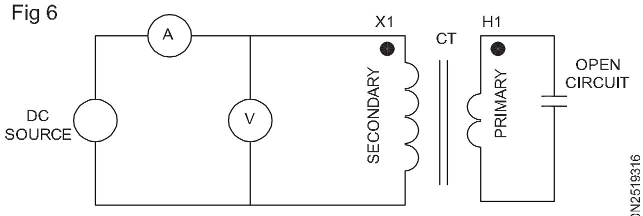
5 Winding Resistance Test

The DC winding resistance measurement is an important measurement in accessing the true condition, state and accuracy of a CT. Winding resistance in a CT will change over a period of time depending on the specimen age, use, external conditions and loading effect.

It is recommended to measure DC winding resistance periodically on a single tap or multi tap CT and trend the values. A high precision low resistance measurement circuit is required to obtain this small winding resistance.

The winding resistance of a current transformer is found by dividing the voltage drop across the winding (measured from dc millivoltmeter) with the applied dc current through the winding. The CT should be demagnetized after the completion of winding resistance test. (Fig 6)

Fig 6



CT WINDING RESISTANCE TEST

6 Burden Test

The burden of a current transformer can be defined as the total impedance in ohms on the secondary output terminals. The total burden is a combination of impedance offered by watt-hour meter coils, relay current coils, contact resistance, terminal blocks, wire resistance and test switches used in the secondary loop.

Each current transformer has a secondary burden when connected in a relay or metering circuit. CT's are expected to provide the secondary output current based upon their accuracy class .

If a current transformer is not properly sized based upon secondary loop burden, it may result in a decrease in CT secondary current. Burden testing is important to verify that CT is supplying current to a circuit that does not exceed its burden rating.

The burden test is also useful in ensuring that the CTs are:

- Not energized with shorting devices installed (if used for metering or protection).
- Not left with an open circuit when not used.
- Connected with a single ground point.
- Secure, and all connections are tight.

Measure burden by injecting the rated secondary current of the CT from its terminals towards load side by isolating the CT secondary with all connected load, and observe the voltage drop across the injection points - and at every point of the circuit to ground.

This method is time consuming, but only requires a voltage source, a resistance, and a voltmeter . Measuring the voltage drop at the source combined with ohms law will give us the burden impedance. Analyzing the voltage drop patterns throughout the circuit confirms the wiring is correct.

Current transformer burdens are typically expressed in VA. The burden test is performed to verify that the CT is capable of supplying a known current into a known burden while maintaining its stated accuracy. A burden test is typically performed at full rated secondary current value (ex. 5A or 1A).

How to calculate CT Burden

Depending on their accuracy class, current transformers are divided into two groups: Metering and Protection (Relay). A CT can have burden ratings for both groups.

Metering CT's are typically specified as 0.2 B 0.5

The last number specifies the Burden in ohms. For a CT with secondary current of 5 A the VA burden rating can be calculated as:

VA = Voltage * Current = (Current) 2 * Burden = (5)2 * 0.5 = 12.5 VA

Relaying CT's are typically specified as 10 C 400

The last number specifies the maximum secondary voltage at 20 times the rated secondary current without exceeding the 10 % ratio error. For a CT with secondary current rated at 5 A, 20 times rated current secondary current would give a burden of 4 ohms.

Burden = 400 / (20*5) = 4 ohms

Burden in VA can be specified as:

VA = Voltage * Current = (Current) 2 * Burden = (5)2 * 4 = 100 VA

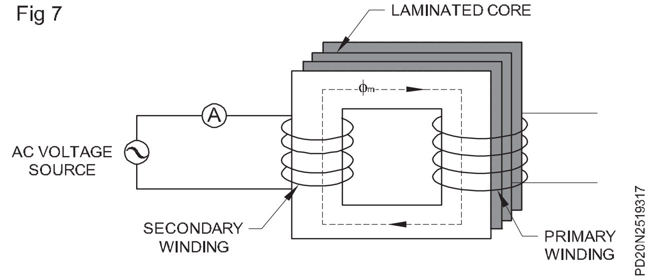
Knee point voltage

Knee point voltage is nothing but a magnitude of the saturation limit of the current transformer. Each protection class CT has to be operated in its Non saturation region. So that we have to calculate the maximum allowable voltage limit, that can be applied to the secondary winding of the current transformer. As per IEC, the Knee Point Voltage of a Current Transformer is defined as the voltage at which 10 % increase in voltage of CT secondary results in 50 % increase in secondary current.

Easy understanding of Knee Point voltage

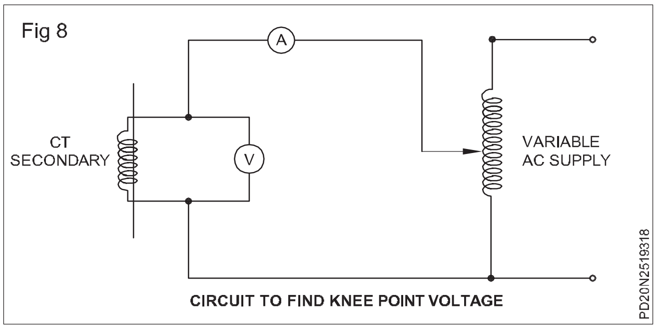
Consider transformer Voltage transformation ratio Es= 4.44 * flux * Current * Number of conductor. From this equation, the flux transfer to the core is directly proportional to the applied voltage and the current is directly proportional to the mmf (ampere turns.). Therefore, the applied voltage in the transformer increase flux in the core, but the core has the certain limit of flux transition, beyond that limit the core opposes the flux. So that, to transformer minimum voltage the transformer's winding takes more current due to that the core temperature will be increase. This is called core saturation. That limit is called knee point voltage. (Fig 7)

Fig 7



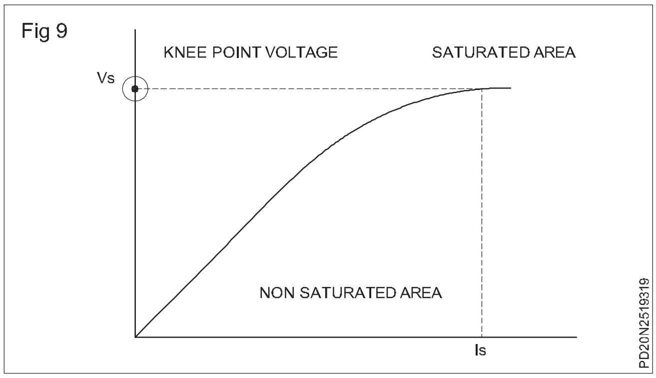
Knee point voltage testing procedure

The current transformer's secondary will be connected as shown in the figure and the primary keeps as open circuit. The input voltage to the current transformer will be increased by step by step of 10% until 120%. The secondary voltage and the current will be noted. In certain limit, applying a small voltage the transformer takes more current typically for applying 10 % of secondary voltage the transformer takes 50% of its secondary current. That voltage limits is called knee point. (Fig 8)



Graphical representation

Consider Vs as the current transformer secondary voltage and Is is the secondary current. Using above value, please draw graph. At one point, to increase a small amount voltage the current takes higher value. (Fig 9)



Significance of Knee Point Voltage

Knee point Voltage is associated with the instrument safety factor. Knee point voltage will be determined in protection class CT only. (PS class- Protection Special) to know about the CT saturation level.

Potential transformer, Isolation transformer, CVT, Various substation, Power tariffs

Objectives: At the end of this lesson you shall be able to
- **identify potential transformers, specification**
- **different types - for protection / measurement**
- **carry out tests to be done on P.T such as Insulation Resistance Test, Winding Resistance Test, Polarity Test, Ratio Test**
- **identify Isolation transformer, CVT**
- **basic concept of live tank and dead tank CT**
- **various substations, power tariffs.**

Pontential Transformer

A potential transformer (P.T.) is an instrument transformer which is used for the protection and measurement purposes in the power systems. A potential transformer is mainly used to measure high alternating voltage in a power system

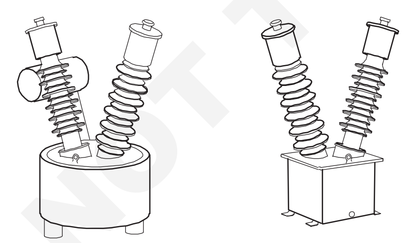
In the case of high-voltage AC transmission lines, the current and voltage are very high; therefore, they cannot be measured by using ordinary ammeters and voltmeters. To measure high currents and voltages, specially constructed accurate ratio transformers called instrument transformers are used. Potential transformers are instrument transformers used to measure high voltages. The primary function of a potential transformer in conjunction with relevant instruments, such as an ammeter and voltmeter, is metering and protection.

Types of Potential Transformers

Electromagnetic Potential Transformer

This is the most common type of potential transformer and operates on the principle of electromagnetic induction. It consists of a primary winding connected across the high-voltage circuit and a secondary winding connected to the measuring instruments. (Fig 1&2)

Fig 1

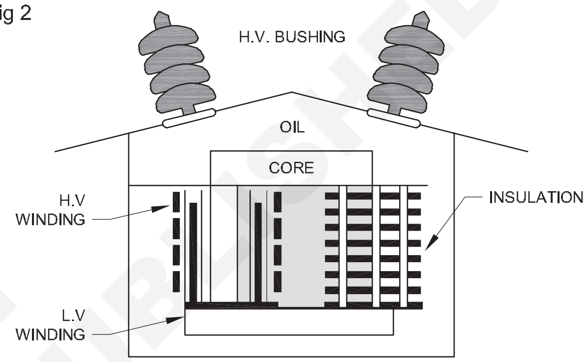


The main problem in an electromagnetic transformer is the insulation, at high voltages. Transformer designs for higher voltages than 10 kV have grown highly complicated due to insulation issues. The higher insulation standards for electromagnetic transformers result in their high cost.

Capacitive Potential Transformer

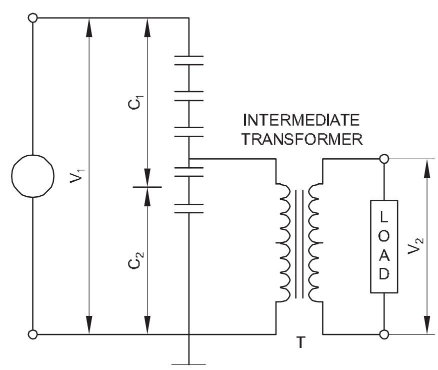
In high-voltage power systems, a Capacitive Potential Transformer (CPT) is a type of transformer used to detect voltage. This type of potential transformer operates on the principle of the capacitive voltage divider. It uses a capacitive voltage divider to reduce the voltage level of the high-voltage circuit to a level that the instruments can measure.

Fig 2



It works on the principle of capacitive voltage division, where the high voltage is divided by the capacitance ratio of the transformer. A series connection between a high-voltage and low-voltage capacitor makes up the CPT. The high-voltage capacitor is connected in parallel with the high-voltage line, and the low-voltage capacitor is connected to a measuring device. (Fig 3)

Fig 3



CAPACITIVE POTENTIAL TRANSFORMER

The capacitance of the high-voltage capacitor determines the voltage ratio of the transformer to the low-voltage capacitor. Due to the voltage division principle of capacitors, a small portion of the voltage applied to the high-voltage capacitor is transmitted to the low-voltage capacitor. The voltage across the high voltage line is then calculated using the voltage across the low voltage capacitor, which is measured subsequently.

CPTs are frequently utilized to measure the voltage of the transmission lines in high-voltage power systems as they offer precise voltage measurement with high insulation resistance and minimal signal distortion. Also, they are easier to install and maintain because they are lighter and smaller than other potential transformers.

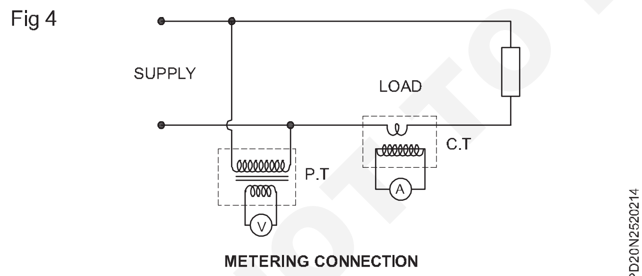
- Inductive Potential Transformer: This type of potential transformer operates on the principle of the inductive voltage divider. It uses an inductive voltage divider to reduce the voltage level of the high-voltage circuit to a level that the instruments can measure.
- Resistor-Capacitor Potential Transformer: This type of potential transformer uses a combination of resistor and capacitor to reduce the voltage level of the high-voltage circuit to a level that the instruments can measure.
- Optical Potential Transformer: This type of potential transformer uses an optical sensor to measure the voltage level of the high-voltage circuit. It is commonly used in high-voltage systems where electromagnetic interference can cause inaccuracies in measurement.

Connection of Potential Transformers

The application determines a potential transformer's connection it is used for. Voltage transformer metering and voltage transformer protection connections are the two main types of connections. (Fig 4)

Metering Connection

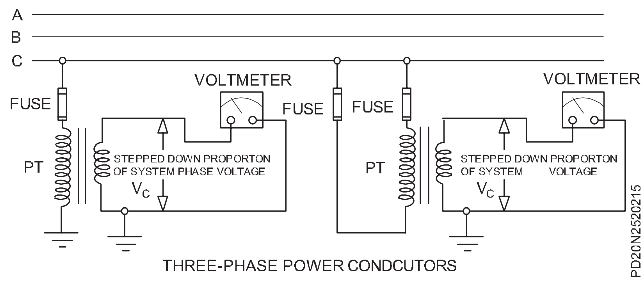
Fig 4



The voltage transformer is linked in parallel with the load via this connection, which is used to measure voltage. In this configuration, the secondary winding of the potential transformer is linked to the low-voltage circuit, which is connected to the voltmeter, and the primary winding of the potential transformer is connected in parallel with the high-voltage circuit. (Fig 5)

The actual voltage in the high-voltage circuit is determined using the voltage ratio of the potential transformer.

Fig 5

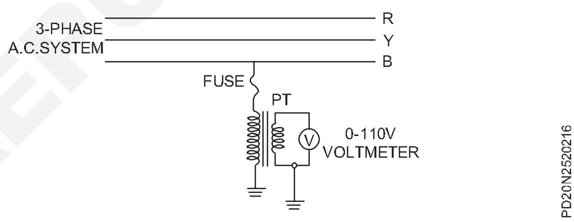


Protection Connection

The voltage transformer is linked in series with the load using the voltage transformer protection connection, which is utilized for protection. The secondary winding of the potential transformer is linked to the protection relay, while the primary winding is connected in series with the high-voltage circuit. The voltage ratio of the potential transformer is used to compute the actual voltage in the high-voltage circuit, which is compared with the set point of the protective relay. The protection relay trips the circuit breaker to isolate the fault if the voltage exceeds the set point.

In conclusion, how a potential transformer is connected relies on how it will be used. It is connected in series with the load for protection reasons and in parallel with the load for voltage measurement. (Fig 6)

Fig 6



Potential Transformer Testing Methods

The importance of transformer tests is often underestimated. Risks such as confusing instrument transformers for metering and protection, or mixing up connections can be reduced significantly by testing before initial use. At the same time, damages to the interior of an potential transformer, caused for example during shipping, can be recognized easily. Also changes in an instrument transformer, caused for example by aging insulation, can be identified at an early stage.

1 Insulation Resistance Test.

2 Winding Resistance Test.

3 Polarity Test.

4 Ratio Test.

1 Insulation Resistance Test:

Insulation resistance analysis (of windings) in transformers consists of 3 separate resistance measurements resistance between primary and secondary winding, between secondary winding and main tank and between primary winding and main tank

To know the insulation value of PT windings, we will be applying primary to Earth 5kv for 60 seconds, primary to secondary 2.5 kv for 60 seconds & secondary to Earth 1000v for 60 seconds.

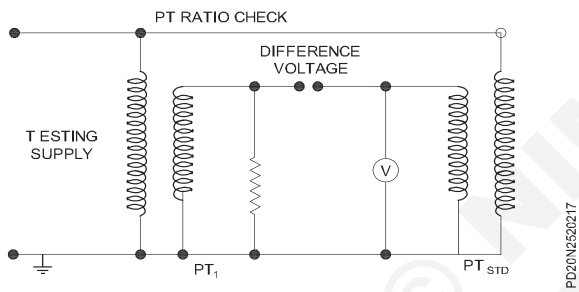
2 Winding Resistance Test:

To verify the winding resistance as specified by the manufacturer and to check for any internal winding damage in the PT this test is carried out. Winding resistance is arrived by injecting DC current through the winding and measuring the voltage drop. Compare the reading with factory test report.

3 Polarity Test :

This test is necessary to see the relative polarity of the primary and secondary terminals when terminals are not marked or to establish the correctness of the marking if already marked. This test is carried out with help of 9v (or) 12v DC battery. Apply the DC source between primary Terminals P1 (+) P2 (-) and measure the secondary side using Null deflection analog ammeter and check the correct deflection of meter & compare with polarity mark. (Fig 7)

Fig 7



4 Ratio Test:

To verify the ratio error of the PT this test is performed with help of primary injection kit. Inject the Voltage through P1- P2 (primary of VT Terminals) and measure the corresponding secondary side output voltage and calculate the ratio error from the actual and measured values.

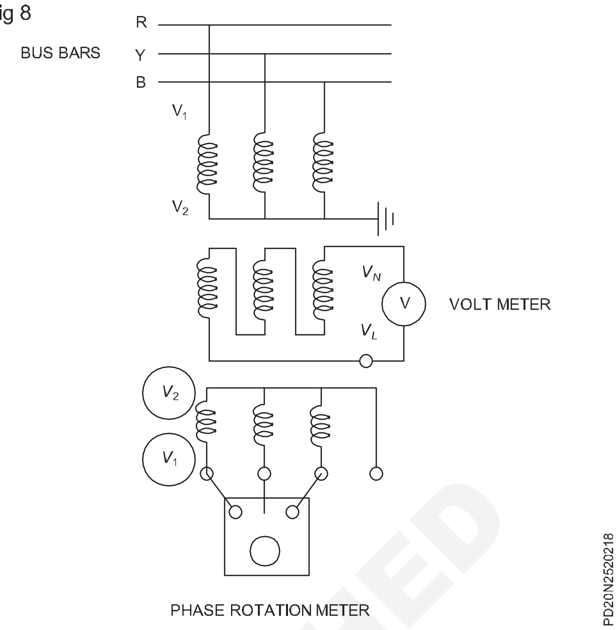
A test for ratio can be made by connecting voltmeters to the primary and secondary, one of the voltmeters sometimes being used in conjunction with a potential divider to read high primary voltages.

Another method is the comparative method. If a second PT of standard accuracy and the same ratio as the test PT is substituted for the potential divider then a fixed fraction of the primary voltage is delivered from its secondary.

Phasing check:

The incoming secondary connections for a three-phase PT or bank of three single-phase PTs must be carefully checked for phasing. With the main circuit alive the secondary voltages between phases and neutral must be measured to verify that the phase relationship is correct. The phase rotation should then be checked with a phase rotation meter connected across the three phases as shown in (Fig 8)

Fig 8



If the three-phase PT has a broken delta tertiary winding then a check should be made of the voltage across the two connections from the broken delta VN and VL as shown in Fig 8. With the rated balanced three-phase supply voltage applied to the PT primary winding; the broken delta voltage should be below 5 volts with rated burden connected.

Isolation Transformer

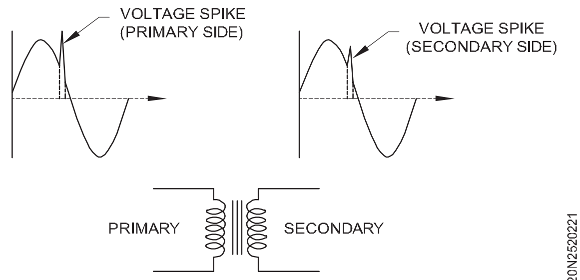
An isolation transformer is a stationary device with isolated primary and secondary windings that keeps the two circuits separated, physically and electrically. It transmits electrical energy between circuits by incorporating a magnetic induction mechanism that uses a magnetic field to generate EMF in another circuit without affecting the frequency.

Isolation transformers are used in transmission and distribution networks to step up and down voltage levels where the voltage and current capacities on both coils are equal. An essential function of an isolation transformer is to eliminate voltage spikes in supply lines that can cause service interruptions or damage equipment if they reach the load.

By connecting an isolation transformer between power supply lines, voltage spikes can be reduced before reaching the load. Another essential feature of an isolation transformer is that it prevents load equipment or the secondary side from being grounded. As a result, load ground loop interference and noise effects are attenuated. (Fig 1)

The primary coil circuit and secondary coil circuit of the isolation transformer are electrically isolated. As a result, isolation transformers refer to all transformers used in transmission and distribution networks. An isolation transformer is a device that transfers electrical power from an alternating current source to some equipment or device. This happens while isolating the powered device from the power source, primarily for safety or to reduce transients and harmonics. In general, secondary turns are bigger than primary turns in step-up transformers and vice versa in step-down transformers.

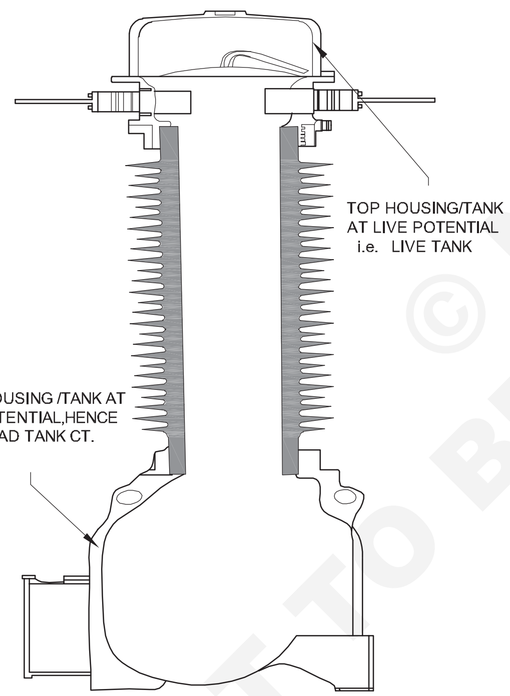
Fig 1



Difference between Dead Tank and Live Tank CT

Current Transformers are classified as Dead Tank Type and Live Tank Type CTs based on their construction. The term Dead and Live has their own meaning from the view point of potential of Secondary Windings and Core. Dead Tank itself means that the potential of the Tank of CT is at earth potential i.e. zero as shown in the figure below. (Fig 2)

Fig 2

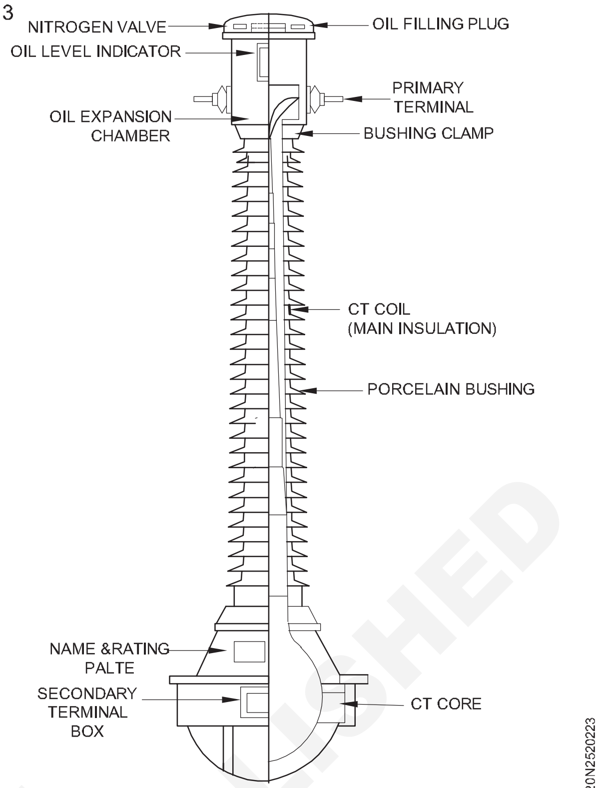


The classification of CT i.e. whether Dead Tank or Live Tank comes from whether the Core and Secondary Winding of CT is located in Dead Tank or Live Tank of CT. If the Core and Secondary Winding is located in Dead Tank, then it is Dead Tank type CT while in case the Core and Secondary Winding is located in Live Tank portion then it is Live Tank type CT. Figure below depicts the Dead Tank type and Live Tank type CT. Dead Tank type CT:

Dead Tank type CT

Observe that the Core and Secondary Winding is located in Dead Tank portion and hence it is Dead Tank type CT. (Fig 3)

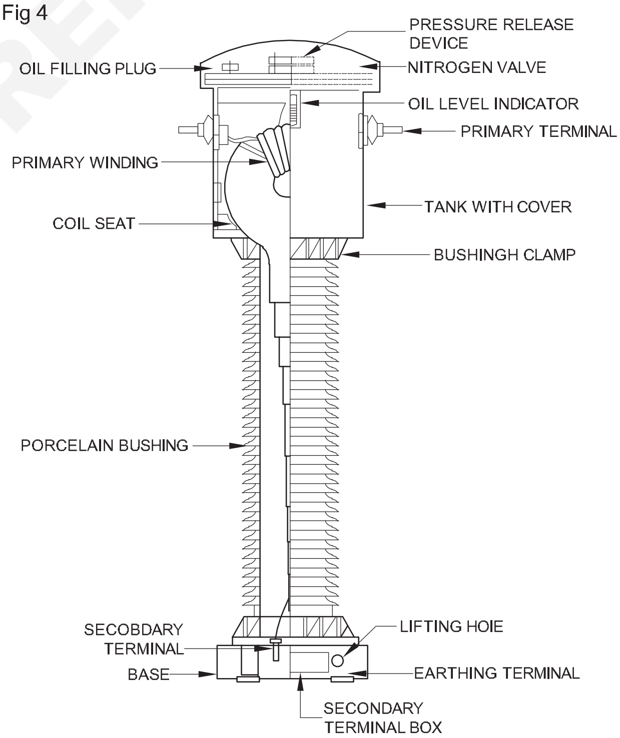
Fig 3



Live Tank type CT

Carefully observe that Core and Secondary Winding is located in the Live Tank portion.(Fig 4)

Fig 4



Basic concept of CVT (Capacitive voltage transformer)

There are three primary types of potential transformers (PT): electromagnetic, capacitor, and optical. The electromagnetic potential transformer is a wire-wound transformer. The capacitor voltage transformer (CVT) uses a capacitance potential divider and is used at higher voltages due to a lower cost than an electromagnetic PT. An optical voltage transformer exploits the Faraday effect, rotating polarized light, in optical materials

A capacitive voltage transformer (CVT), also known as capacitor-coupled voltage transformer (CCVT), is a transformer used in power systems to step down extra high voltage signals and provide a low voltage signal to the actual VT (voltage transformer) used for operating metering/protective relays.

In its most basic form, the device consists of three parts: two capacitors across which the transmission line signal is split, an inductive element to tune the device to the line frequency, and a voltage transformer to isolate and further step down the voltage for metering devices or protective relay.

The tuning of the divider to the line frequency makes the overall division ratio less sensitive to changes in the burden of the connected metering or protection devices. [4] The device has at least four terminals: a terminal for connection to the high voltage signal, a ground terminal, and two secondary terminals which connect to the instrumentation or protective relay.

Capacitor C1 is often constructed as a stack of smaller capacitors connected in series. This provides a large voltage drop across C1 and a relatively small voltage drop across C2. As the majority of the voltage drop is on C1, this reduces the required insulation level of the voltage transformer. This makes CVTs more economical than the wound voltage transformers under high voltage (over 100 kV), as the latter one requires more winding and materials.

The CVT is also useful in communication systems. CVTs in combination with wave traps are used for filtering high-frequency communication signals from power frequency. [5] This forms a carrier communication network throughout the transmission network, to communicate between substations. The CVT is installed at a point after Lightning Arrester and before Wave trap.

Varios types of CT Categories and burden

Metering CT

A metering current transformer is designed to measure current continuously and work accurately within the rated current range. Current error and phase displacement limits are determined by the accuracy class. Accuracy classes are: 0.1, 0.2, 0.5 and 1.

In watt meters, energy meters, and power factor meters, phase shift produces errors. However, the introduction of electronic power and energy meters has allowed current phase error to be calibrated out.

When current exceeds the rating, the metering CT will saturate thereby limiting the current level within the instrument. Core materials for this type of CT typically have low saturation level, such as nanocrystalline.

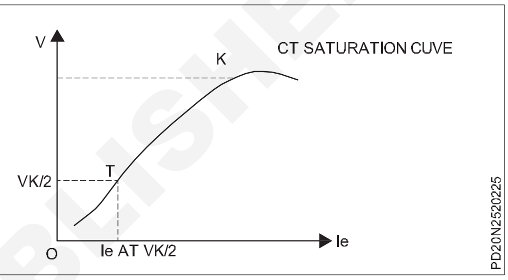
Protection CT

A protection current transformer is designed to operate well into the overcurrent range. This enables the protective relays to measure fault currents accurately, even in very high current conditions. The secondary current is used to operate a protective relay which can isolate part of the power circuit experiencing a fault condition.

Core material for this type of CT has high saturation level and is normally made from silicon steel.

The knee point voltage is important for protection class CTs, i.e. where the CT is used for protection purposes. (Fig 5)

Fig 5



Beyond point K, we need to increase current to a larger extent to have some increase in voltage. This because the curve beyond point K becomes non-linear. The voltage at point K (Vk) is called the knee point voltage.

The knee point voltage of a current transformer is defined as the voltage at which a 10% increase in voltage of the CT secondary results in a 50% increase in secondary current. This also means that an increase in current of 50% will lead to an increase in voltage of just 10%.

In current transformers (CTs), burden refers to the impedance or load connected to the secondary winding of the CT. It represents the total resistance, inductance, and capacitance that the secondary winding of the CT must overcome to deliver an accurate and proportional current output. It is generally expressed in VA(volt-ampere).

The burden of protection CTs is quite high when compared with a metering class CT, which means that voltage drop across the burden will be high. Therefore, the knee point voltage of a protection class CT must be more than the voltage drop across the burden to maintain the CT core in its linear zone.

Protection current transformers are usually defined in terms of composite error at an accuracy limit factor, i.e. how accurate the current transformer will remain when the primary current flowing is many times higher than normal under a fault situation.

Standard classes for protection CT's are 5P 10 and 10P 10, where P is the designation for protection. The number before P indicates the composite error percentage. The number after the letter indicates the factor of primary current up to which composite error will be achieved, i.e. 10x the rated primary current in 5P 10 and 10P 10.

Protection devices will normally specify the classification for the protection CT intended to operate the protection device concerned.

Table 1 - Limits of error for protective current transformers

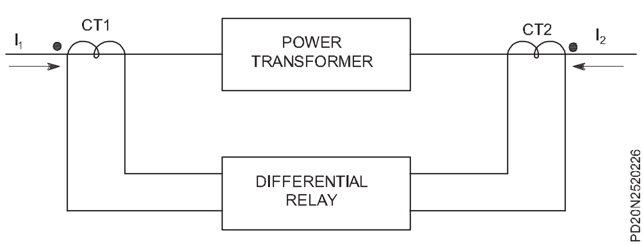
Accuracy class	Current error at rated primary current %	Phase displacement at rated primary current		Composite error at rated accuracy limit primary current %
		Minutes	Centiradians	
5P	±1	±60	±1.8	5
10P	±3	-	-	10

Special Protection CT

PS Class CT is a special class CT used for differential protection of HT motor, generator, and transformer. The PS class CT is also called PX or X type or special class current transformer.

For differential protection of transformer, (Fig 6)

Fig 6



For differential protection of transformer, Two current transformers CT1 and CT2 are mounted at the incoming and outgoing sides of the equipment to measure the current. Both the current transformers are wired in a differential protection relay. The differential protection relay measures the incoming & outgoing current and calculates the difference of the current. The relay output a trip command to breaker if found difference in the current.

For feeder protection, protection class CTs 5P10, 5P20, 10P10 are used. The protection class CT can not be used in place of the PS class current transformer

If the 5P10 protection class CTs are used for differential protection at the incoming and outgoing sides of the transformer. In case of fault, If 10 times of rated current of CT flows through it, the current transformer will not saturate because the accuracy limit factor of the current transformer is 10. The CT may function well above the 10 times current, however, it is difficult to predict at what current the CT will get saturated.

The protection class CT installed at the incoming side of the zone protection let's say saturate at 11 times current and the CT installed at the outgoing side of the zone protection saturate at 12 times current of the rated current of CT. In a faulty condition, the difference of current will be sensed once the relay senses the saturation of one of the CTs. Thus, the differential protection can not be reliably ensured with the use of protection class CTs.

The PS class CT is special protection class CT. Both the PS class CTs used for differential protection have identical saturation characteristics and their knee point voltage is the same.

The knee point voltage of the protection class CT is;

PS class Ct knee point formula

KPV = I_f (R_{ct} + R_L + R_B)

Where,

KPV = Knee point voltage, I_f = Fault current

R_{ct} + R_L + R_B = Total burden of CT

The knee point voltage is dependent on the secondary resistance of CT and its burden. To have identical knee point voltage at specified excitation current, the resistance of wires connected from CTs to protection relay should be almost identical.

When the knee point voltage of CTs used at both sides of the equipment is the same, it will not give tripping for through fault and, the differential relay will operate only when there is a fault inside the equipment. Thus, PS class CT is a must for differential protection.

The main difference between the protection current transformer and PS (special protection) current transformer is that the protection current transformer does not have fixed knee point voltage, whereas the PS class CTs have identical knee point voltage at the same excitation current.

The special protection CTs have identical Characteristics. The accuracy limit factor of PS class CT is better than the protection transformer like 5P10,5P20.

Various Sub-stations

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 voltage levels :** e.g. AC substation : EHV, HV, MV, LV : HVDC substation.

2 **Classification based on outdoor or indoor :** Outdoor substation is in open air. Indoor substation is inside a building.

3 **Classification based on configuration**

- Conventional air insulated outdoor substation or
- SF6 Gas insulated substation (GIS)
- Composite substations having combination of the above two.

4 **Classification based on application**

- **Step up substation :** Associated with generating station as the generating voltage is low.
- **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.
- **Distribution substation:** Created where the transmission line voltage is stepped down to supply voltage.
- **Bulk supply and industrial substation :** Similar to distribution substation but created separately for each consumer.
- **Mining substation :** Needs special design consideration because of extra precaution for safety needed in the operation of electric supply.
- **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 **Main office building**

- Administrative building
- Conference room etc.

3 **6.6/11/22/33/66/132 KV switch gear LV**

- Indoor switch gear

4 **Switchgear and control panel building**

- Low voltage AC switchgear
- Control panels, protection panels

5 **Battery room and DC distribution system**

- DC battery system and charging equipment
- DC distribution system

6 **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.

A fault may develop in a transmission line or any other component. Some examples of this a line is hit by lightning and develops an arc, or a tower is down by a high wind. The function of the substation is to isolate the faulty portion of the system within the shorted possible time.

Power tariff - terms and definitions

Objectives: At the end of this lesson you shall be able to
- **state the term maximum demand**
- **explain the concept of average demand**
- **explain load factor**
- **state the term of diversity factor and its application**
- **explain the importance of plant utility factor.**

Introduction

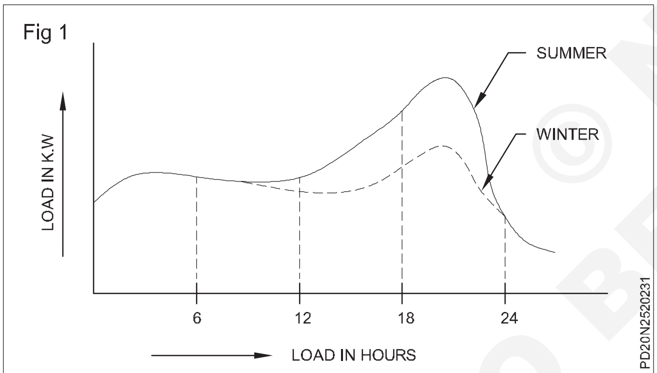
The alternators in the power station should run at their rated capacity for maximum efficiency and on the other hand, the demands of the consumers have wide variations from time to time due to uncertain demands of the consumers. This makes the design of a power station highly complex. We shall focus our attention on the problems of variable load on power stations.

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

$$\text{Demand factor} = \frac{\text{Max. Demand}}{\text{Connected load}}$$

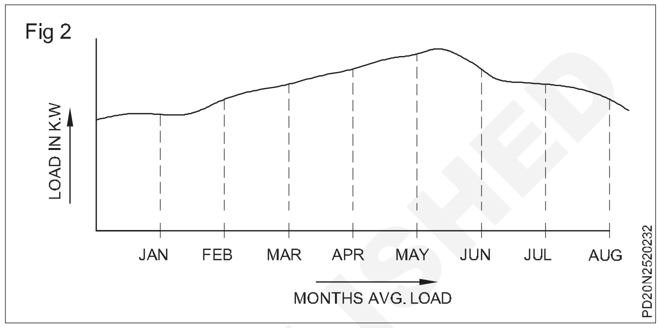
Usually it always less than one. The knowledge of demand factor is vital in determining the capacity of the plant equipment.

Average demand

It is the total demand in a month divided by number of days in that time period.

The average demand in a month taken to find the load requirement for a certain period is in Fig 2. It is evident that average load requirement is not uniform among all the months consumption as it depend on the environmental conditions; such as Winter, Summer, Monsoon seasons.

Fig 2



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.

$$f_{Load} = \frac{\text{Total load}}{\text{Maximum load in given time period}} \text{ or } \frac{\text{Total load}}{\text{Peak load.}}$$

An example, using a large commercial electrical bill:

- peak demand = 436 KW
- use = 57 200 kWh
- number of days in billing cycle = 30

Hence:

- load factor = { 57 200 kWh/ (30 d x 24 hours per day x 436 kW) } x 100% = 18.22%

It can be derived from the load profile of the specific device or system. Its value is always less than one because maximum demand is always higher than average demand, since facilities likely never operate at full capacity for the duration of an entire 24 hours day. A high load factor means power usage is relatively constant. Low load factor shows that occasionally a high demand is set. To service that peak, capacity while remaining idle for long periods, thereby imposing higher costs on the system. Electrical rates are designed so that customers with high load factor are charged less over all per kWh.

The load factor is closely related to and often confused with demand factor.

$$f_{Demand} = \frac{\text{Maximum load in given time period}}{\text{Maximum possibe load}}$$

The major difference to note is that the denominator in the demand factor is fixed depending on the system. Because of this the demand factor cannot be derived from the load profile but needs the addition of the full load of the system in question.

Diversity factor

Diversity factor (Or simultaneity factor KS) is a measure of the probability that a particular piece of equipment will turn on coincidentally to another piece of equipment. For aggregate system it is defined as the ratio of the sum of the individual non - coincident maximum loads of various sub divisions of the system to the maximum demand of the complete system.

$$\text{Diversity factor} = \frac{\text{Sum of individual max Demands}}{\text{Maximum Demand}}$$

The diversity factor is almost always larger than 1 since all components would have be on simultaneously at full load for it to be one. The aggregate load is time dependent as well being dependent upon equipment characteristics. The diversity factor recognizes that the whole loads does not equal the sum of its parts due to this time interdependence (i.e. diverseness). For example, we might have ten air conditioning units that are 20 tons each at a facility. We typically assume that the average full load equivalent operating hours for the units are 2000 hours per year. However, since the units are each thermostatically controlled, we do not known exactly when each unit turns on. If the ten units are substantially bigger than the facility's actual peak A/C load, then fewer than all ten units will likely come on at once. Thus, even though each unit run a total of 2000 hours a year, they do not all come on at the same time to affect the facility's peak load. The diversity factor gives us a correction factor to use, which results in a lower total kW load for the ten A/C units. If energy balance we do for this facility comes out within reasons, but the demand balance shows far to many kW for the peak load, then we can use the diversity factor to bring the kW into line with facility's true peak load. The diversity factor does not affect the kWh; it only affects the kW.

Plant utility factor

The utility factor or use factor is the ratio of the time that a piece of equipment is in use to total time that it could be in use. If is often averaged over time in the definition such that the ratio becomes the amount of energy used divided by the maximum possible to be used. These definitions are equivalent.

The utility factor, Ku, is the ratio of the maximum load which could be drawn to rated capacity of the system. This is closely related to the concept of load factor. The factor is the ratio of the load that piece of equipment actually draws (time averaged) when it is in operation to the load it could draw (which we call full load.

$$\text{Utility Factor} = \frac{\text{Ratio of maximum power}}{\text{Plant capacity}} \times 100$$

For example, an oversized motor - 15 kW - drives a constant 12 kW load whenever it is on. The motor load factor is then 12/15 = 80%. The motor above may only be used for eight hours a day, 50 weeks a year, The hours of operation would then be 2800 hours, and the motor use factor for a base of 8760 hours per year would be 2800/8760 = 31.96%. With a base of 2800 hours per year, the motor use factor would be 100%.

In power plant utility factor various according to the demand on the plant from the electricity market.

Earthing, Classification Methods

Objectives: At the end of this lesson you shall be able to
- **understand the importance of earthing**
- **types of earthing upon use and type**
- **pipe earthing and plate earthing**
- **IEE Regulations.**

Earthing

The process of transferring the immediate discharge of the electrical energy directly to the earth by the help of the low resistance wire is known as the electrical earthing. The electrical earthing is done by connecting the non-current carrying part of the equipment or neutral of supply system to the ground.

Mostly, the galvanised iron is used for the earthing. The earthing provides the simple path to the leakage current. The shortcircuit current of the equipment passes to the earth which has zero potential. Thus, protects the system and equipment from damage.

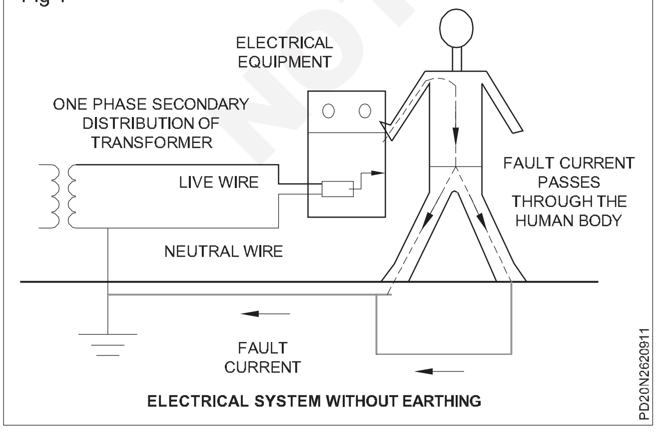
Importance of Earthing

The earthing is essential because of the following reasons

- The earthing protects the personnel from the shortcircuit current.
- The earthing provides the easiest path to the flow of shortcircuit current even after the failure of the insulation.
- The earthing protects the apparatus and personnel from the high voltage surges and lightning discharge.

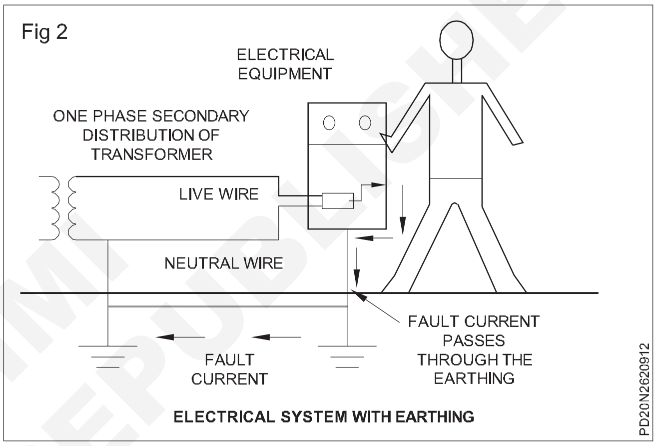
Earthing can be done by electrically connecting the respective parts in the installation to some system of electrical conductors or electrodes placed near the soil or below the ground level. The earthing mat or electrode under the ground level have flat iron riser through which all the non-current-carrying metallic parts of the equipment are connected.

Fig 1



When the fault occurs the fault current from the equipment flows through the earthing system to the earth and thereby protect the equipment from the fault current. At the time of the fault, the earth mat conductors rise to the voltage which is equal to the resistance of the earth mat multiplied by a ground fault.

Fig 2



The contacting assembly is called earthing. The metallic conductors connecting the parts of the installation with the earthing are called electrical connection. The earthing and the earthing connection together called the earthing system.

Terminology

The following terms, which are often used while referring to earthing in electrical installations, are to be understood well.

Apparatus: Electrical apparatus includes all machines. appliances and fittings in which conductors are used or of which they form a part

Bonding: Bonding is a method to connect together electrically two or more conductors or metal parts.

Damp situation: This is situation in which moisture is either permanently present, or intermittently present to such an extent as likely to impair the insulation of an installation conforming to the requirements for ordinary situations

Dead: Dead' means at or about earth potential and disconnected from any live system.

Earth: A connection to the general mass of earth by means of an earth electrode. An object is said to be earth when its electrically connected to an earth electrode, and a conductor is said to be solidly earthed when it is electrically connected to an earth electrode without intentional addition of resistance or impedance in the earth connection.

Earth-continuity conductor (ECC): The conductor, in- cluding any clamp, connecting to the earthing lead or to each other those parts of an installation which are required to be earthed. It may be in whole or in part of the metal conduit or the metal sheath or armour of the cables, or a special continuity conductor, cable or flexible cord incorporating such a conductor.

Earth current: A current flowing to earth.

Earth electrode: A metal plate, pipe or other conductor or an array of conductors electrically connected to the general mass of the earth.

Earth fault: Live portion of a system getting accidentally connected to earth.

Earth (earthing) terminal: A terminal provided on a piece of apparatus for the purpose of making a connection to earth.

Earth wire: A conductor connected to earth and usually situated in proximity to the associated line conductors.

Earthed circuit: A circuit having one or more points which are intentionally connected to earth.

Earthed pole: The pole or line of an earthed circuit which is connected to earth.

Earthed system: A system in which the neutral or any one conductor is deliberately connected to earth directly or through an impedance.

Earthing lead: The conductor by which the connection to the earth electrode is made.

Earthing ring (or earth bus): A ring or bus formed by connecting earth electrodes.

Earthing resistor (earthing resistance): Aresistor through which a system is earthed which serves to limit the current flowing in the event of an earth fault.

Fault: Any defect in the plant, apparatus or conductor, which impairs normal operation or safety.

Fault current: A current flowing from one conductor to earth, or to another conductor, owing to a fault in the insulation.

Double insulation: Denotes insulation comprising both functional insulation and supplementary insulation.

Functional insulation: Denotes the insulation necessary for the proper functioning of equipment and for basic protection against electric shock

Reinforced insulation: Denotes an improved functional insulation with such mechanical and electrical qualities that it provides the same degree of protection against electric shocks as double insulation

Supplementary insulation (Protective insulation): De notes an independent insulation provided in addition to the functional insulation in order to ensure protection against electric shock in case of failure of the functional insulation

Leakage: The passage of electricity in a path, other than that desired, due to imperfect insulation,

Leakage current: A fault current of relatively small value, as distinguished from that due to a short-circuit.

Live: An object is said to be 'live' when a difference of potential exists between it and earth.

Multiple-earthed neutral system: A system of earthing in which the parts of an installation specified to be earthed are connected to the general mass of earth, and in addition, are connected within the installation to the neutral conductor of the supply system.

Potential(at a point): The potential difference between that point and earth.

Resistance area (of an earth electrode only): The area of earth (around an earth electrode) within which practically the whole of the potential difference between the electrode and the general mass of earth occurs when it is carrying an earth fault or test current.

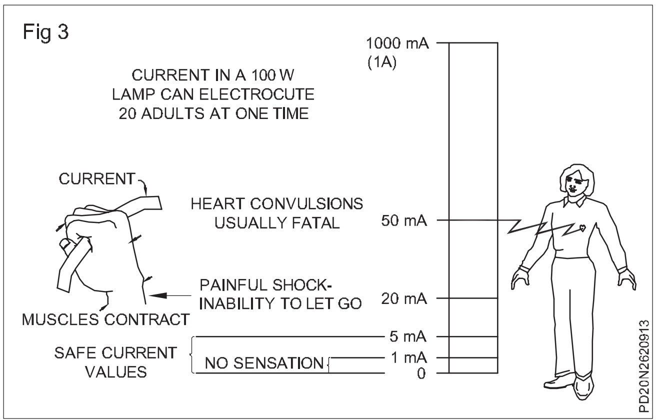
Service line: Any electric line through which energy may be supplied by the supply authorities to a consumer either from a distributor or directly from their premises.

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 pace or 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 on an object likely to carry a fault current such that the points can be touched by person.

Importance of Earthing: The 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 3 shows the magnitude of current and its effect.



However, the degree of danger is dependent not only on the current flow through the body but also on the time during which it flows. The applied voltage is in itself only important in producing this minimum current throught 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 connect to an apparatus having a load resistance of 50 hr that the defective insulation of cable make body live and the metal body is not earthed.

As shown in Fig 4, 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.

The value of current through the body = $\frac{V}{R_{Body}}$

$= \frac{240}{1000}$ =0.24 amps or 240 milliamps.

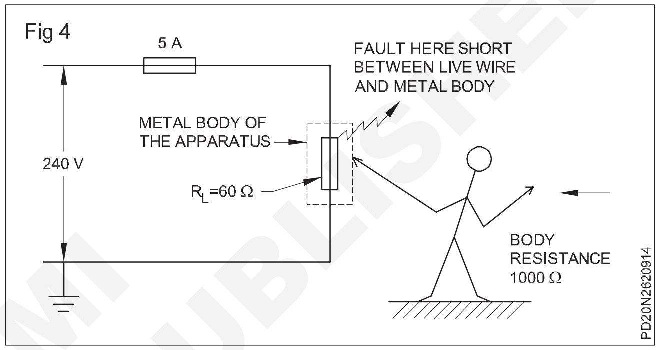
This current, as can be judged from Table 1, is highly dangerous, and might prove to be fatal. On the other hand, the 5 amps fuse in the circuit will not blow for this additional leakage current of 240 milliamperes. As such the metal body will have 240V supply and may electrocute any person touching it.

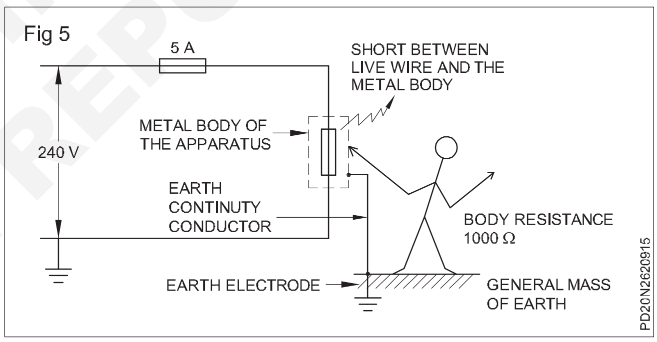
CASE 2 Metal body of apparatus when earthed In case the metal body of the apparatus is earthed a Shown in Fig 5 the moment the metal body comes in contact with the live wire, a higher amount of leakage current will flow through the metal body to earth.

Assuming that the sum of the resistance of the main cable, metal body, earth continuity conductor and the general mass of earth is to the tune of 10 ohms

the leakage currect = $= \frac{V}{R_{Total}} = 240/10 = 24$amps

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.





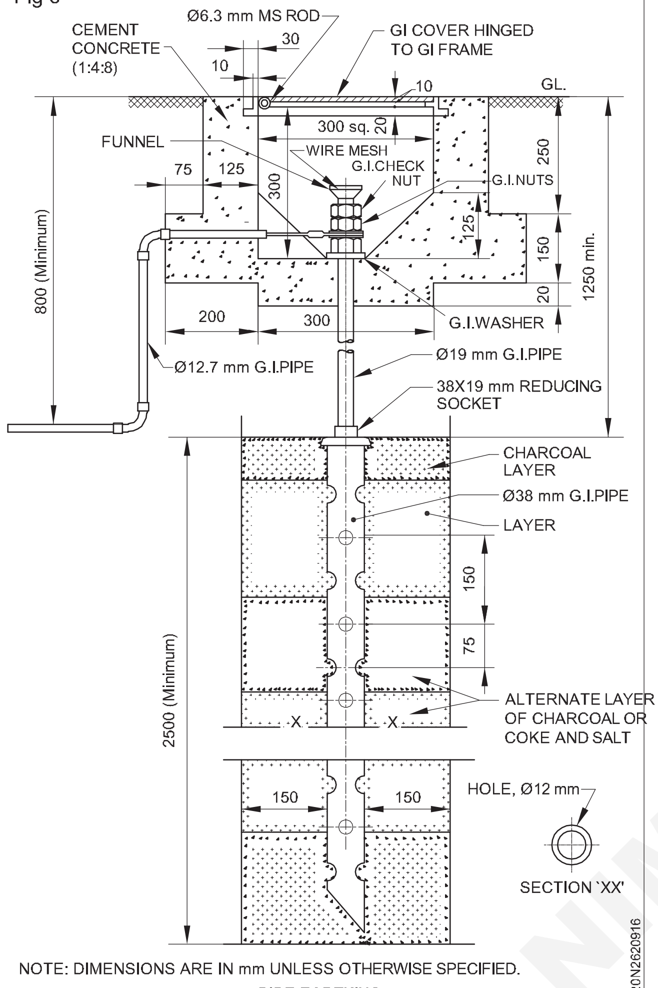
By studying the above two cases, it is clear that a properly earthed metal body eliminates the shock hazards to persons and also avoids fire hazards in the system by blowing the fuse quickly in case of ground faults.

General: In general all parts of an apparatus, other than the live parts, shall be at earth potential. For this earthing purpose, earth electrodes are used. These earth electrodes shall be provided at generating stations, substations and consumer premises. A number of earth electrodes in parallel is necessary to bring down the earth resistance to an acceptable low value such that the system's protective devices like earth fault relays and fuses operate properly in case of faults. As far as possible, these earth electrodes shall be visible.

Classification pipe earthing Rod and pipe electrodes (Fig 6)

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 6



PIPE EARTHING

Rod electrodes of steel or galvanised iron shall be at least 16 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 25 m. Where rock is encountered at a depth of less than 2.5 m. the electrodes may be burned inclined to the vertical In this case too, the length of the electrodes shall be atleast 25 m. and the Inclination not more than 30 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 connect, together.

Plate earthing (Fig 7)

Fig 7

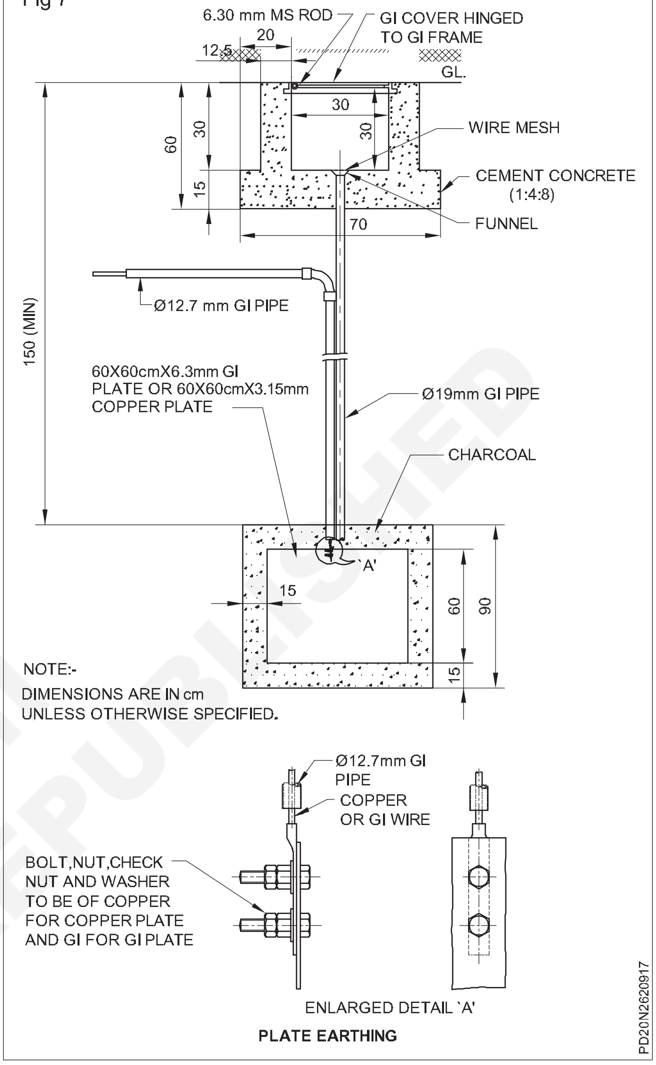


PLATE EARTHING

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.

Plate electrodes shall be burned 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 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 reducing the resistance of an earth electrode to an acceptable value

The main purpose of equipment earthing is to safeguard human beings from shock hazards This purpose will be totally defeated if the supply under the faulty circuit is not opened by protective devices like fuses or circuit breakers. To achieve efficient operation of the protective devices, 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 lower the earth electrode resistance.

5 Avoiding rust in the earth electrode connections lowers the earth electrode resistance.

6 Mesh earthing

7 Delta earthing

8 Chemical earthing

I.E.E. Regulations pertaining to earthing

Objectives: At the end of this lesson you shall be able to
- **state the I.E. rules pertaining to earthing**
- **list the Indian Standards required for reference for earthing.**

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

I.E. Rules pertaining to earthing

Extracts from Indian Electricity Rules, 1956

Rule no. 32: **Identification of earthed and earthed neutral conductors and position of switches and cut-outs therein**

Where the conductors include an earthed conductor of a two-wire system or an earthed neutral conductor of a multi-wire system or a conductor which is to be connected thereto, the following conditions shall be compiled with.

1 An indication of a permanent nature shall be provided by the owner of the earthed or earthed neutral conductor, or the conductor which is to be connected thereto, enable such a conductor to be distinguished from live conductor. Such indication shall be provided.

a Where the earthed or earthed neutral conductor is the property of the supplier, at or near the point of commencement of supply

b Where a conductor forming part of a consumer's system is to be connected to the supplier's earthed or earthed neutral conductor at the point where such connection is to be made.

2 No cut-out, link or switch other than a linked-switch arranged to operate simultaneously on the earthed or earthed neutral conductor and live conductors shall be inserted or remain inserted in any earthed or earthed neutral conductor of a two-wire system or in any earthed or earthed neutral conductor of a multi-wire system or in any conductor connected thereto with the following exceptions:

a A link for testing purposes or

b A switch for use in controlling a generator or trans former.

Rule No.51: **Provisions applicable to medium, high or extra high voltage installations**

All metal work enclosing, supporting or associated with the installation, other than that designed to serve as taconductor, shall, if considered necessary by the inspector, be connected with earth.

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.

a The neutral conductor of a three-phase four-wire system, and the middle conductor of a two-phase three-wire system shall be earthed by not less than two separate and distinct connections with earth both at the generating station and at the substation. It may also be earthed at one or more points along the distribution system or service line in addition to any connection with earth which may be at the consumer's premises.

b In the case of a system comprising electric supply lines having concentric cables, the external conductor of such cables shall be earthed by two separate and distinct connections with earth.

c The connection with earth may include a link by means of which the connection may be temporarily interrupted for the purpose of testing or for locating a fault.

d In the case of an alternating current system, there shall not be inserted in the connection with earth any impedance (other than that required solely for the operation of switchgear or instruments), cut-out or circuit-breaker, and the result of a test made to ascertain whether the current (if any) passing through the connection with earth is normal, shall be duly recorded by the supplier.

e No person shall make connection with earth by the aid of, nor shall be keep it in contact with, any water main not belonging to him except with the consent of the owner thereof and of the inspector.

f Alternating current systems which are connected with earth as aforesa may be electrically interconnected. Provided that ach connection with earth is bonded to the metal sheathing and metallic armouring (if any) of the electric supply lines concerned.

2 The frame of every generator, stationary motor, and so far as is practicable, portable motor, and the metallic parts (not intended as conductors) of all transformers and any other apparatus used for regulation or control- ling energy and all medium voltage energy consuming apparatus shall be earthed by the owner by two separate and distinct connections with earth.

3 All metal casings or metallic coverings contained or protecting any electric supply-line or apparatus shall be connected with earth and shall be so joined and connected across all junction-boxes and other openings as to make good mechanical and electrical connection throughout their whole length:

Provided that where the supply is at low voltage, this sub-rule shall not apply to isolated wall tubes or to brackets, electroilers, switches, ceiling fans or other fittings (other than portable hand lamps and portable and transportable apparatus) unless provided with earth terminal.

Provided further that where the supply is at low voltage and where the installations are either new or renovated, all plug sockets shall be of the three-pin type and the third pin shall be permanently and efficiently earthed.

4 All earthing systems shall, before electric supply lines or apparatus are energised, be tested for electrical resistance to ensure efficient earthing.

5 All earthing systems belonging to the supplier shall, in addition, be tested for resistance on a dry day during the dry season not less than once every two years.

6 A record of every earth test made and the result thereof shall be kept by the supplier for a period of not less than two years after the day of testing and shall be available to the Inspector when required.

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

a The neutral point shall be earthed by not less than two separate and distinct connections with earth, each having its own electrode at the generating station and at the sub-station and may be earthed at any other point, provided that no interference of any description is caused by such earthing;

b In the event of an appreciable harmonic current flowing in the neutral connections so as to cause interference with communication circuits, the generator or transformer neutral shall be earthed through a suitable impedance.

2 In the case of a system comprising electric supply lines having concentric cables, the external conductor shall be the one to be connected with earth.

3 Where the earthing lead and earth connection are used only in connection with earthing guards erected under high or extra-high voltage overhead lines where they cross a telecommunication line or a railway line, and where such lines are equipped with earth leakage relays of a type and setting approved by the Inspector, the resistance shall not exceed 25 ohms.

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 sup- port 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.

APPENDIX B

List of Indian Standards required for reference for earning

IS:732-1963 (revised)	Code of practice for electrical wiring installations. (System voltage not exceeding 650V)
IS:900-1965	Code of practice for installation and maintenance of induction motors (Revised)
IS:1866-1961	Code of practice for maintenance of insulating oil.
IS;1885(Part XXX)- 1971	Electrotechnical vocabulary: Part XXX overhead, transmission and distribution of electrical energy.
IS:1886-1967	Code of practice for installation and maintenance of transformers. (First revision)
IS:2026 (Part I)	Power transformers. Part I: General.
IS:2026 (Part XI)-1969	Graphical symbols used in electrotechnology. Part XI: Electrical installations in buildings
IS:2274-1963	Code of practice for electrical wiring installations (systems voltage exceeding 650 volts).
IS:2309-1969	Code of practice for the protection of buildings and allied structures against lighting (first revision).
IS:2516(Part I &II/Sec-l) 1963	Alternating current circuit breakers; Part-I & II Requirements and tests, Section 1. Voltages not exceeding 1,000 v ac or 1200 Vdc.
IS:2516(Part I/Sec 2) - 1963	Alternating current circuit-breakers; Part-I Requirements, Section 2 Voltage range 1,000 to 11,000 volts.
IS:2516(Part I/Sec 3) -1972	Alternating current circuit-breakers; Part-I Requirements, Section 3 Voltages above 11 kV.
IS:2551-1963	Danger notice plates.
IS:3043-1966	Code of practice for earthing.
IS:3072(Part-1)-1965	Code of practice for installation and maintenance of switchgear, Part I Switchgear (system voltages not exceeding 1,000 volts).

Classification of Earthing:

Depending upon use, the earthing is classified into

1 System Earthing

2 Equipment Earthing

3 Discharge Earthing

4 Support earthing

5 Line Earthing

1 System Earthing

In System earthing, the current carrying parts are directly connected to the ground. The earthing provides the return path for the leakage current and hence protects the power system equipment from damage.

When a fault occurs in the equipment, the current in all three phases of the equipment becomes unbalanced. The earthing discharges the fault current to the ground and hence makes the system balance.

Important Points:

For, earthing black color wire is used.

The System earthing balanced the unbalanced load.

The earthing wire is placed between the neutral of the equipment and the earth.

In earthing the equipment is not physically connected to the ground, and the current is not zero on the ground.

The earthing gives the path to an unwanted current and hence protects the electrical equipment from damage.

- The earthing is classified into three types. They are the solid earthing, resistance earthing and reactance earthing.

2 Equipment Earthing

The 'earthing' means the connection of the non-current carrying part of the equipment to the earth. When the fault occurs in the system, then the potential of the non-current part of the equipment raises, and when any human or stray animal touches the body of the equipment, then they may get shocked.

The earthing discharges the leakage current to the earth and hence avoids the personnel from the electric shock. It also protects the equipment from lightning strokes and provides the discharge path for the surge arrester, gap, and other devices.

Important Points:

- For earthing, green color wire is used.
- The earthing protects the equipment and human from an electrical shock.
- In earthing the earth electrode is placed between the equipment body and the earth pit which is placed under the ground.
- In earthing the system is physically connected to the ground and it is at zero potential.
- The earthing decreases the high potential of electrical equipment which is caused by a fault and thus protects the human body from the electrical shock.
- Earthing can be done in five ways. The different methods of earthing are pipe earthing, plate earthing, rod earthing, earthing through tap, and strip earthing.

3 Discharge Earthing

The release and transmission of electricity in an applied electric field through gas as a medium is known as an electric discharge.

Electric discharge takes place during the rapid transfer of electrons from one object to another. It produces visible sparks. The most common and observed phenomenon of electric discharge is lightning. Sometimes, these electric discharges can lead to big accidents and cause a lot of accidents.

In HV transmission lines, lightning may cause a towering rise of voltage before reaching the ground wire. It may cause flashovers. To minimize this and control the degree of flash-overs proper grounding and Earthing of the poles are implemented by deep Earthing rods or counterpoise wires.

4 Support earthing

Earthing of Transmission Structures

Wood Pole

Three-phase grounding application on structures using grounding cluster bars is preferable. These bars are:

Placed just below the lowest elevation of the lineman's feet at the work zone (approximately at the same elevation as the phase conductors.)

They are bonded to the pole structure ground leads (if provided.) The bar provides a convenient point of attachment for protective grounds and a bond to the pole structure ground wire.

5 Line Earthing

For distribution lines, wire earthing is used by low resistance wire known as the earth wire. This earth wire is connected to Earth Electrodes, buried in the ground. For this, horizontal trenches are dug, and strip electrodes get buried inside these trenches. The electrodes are of copper, galvanized iron, or steel. Sometimes, round conductors are also used on the ground.

Earth wires offer a shield to the line. Earth wires intercept lightning strikes before they can hit the conductors or power lines, protecting them from damage and power surges. These earth wires are bare conductors placed and attached at the top of the transmission towers.

Generally made of steel, ground wires do not carry any current and are firmly connected to the ground at each tower in the transmission and distribution system.

Properly implemented earthing systems help protect a structure in several ways:

1 Personnel working with the electrical lines are protected from being hit or injured due to short-circuits current. The faulty current gets neutralised as it flows easily through the earth wire even if there is fault insulation or leakage.

2 Ensures undisrupted power supply despite short-circuits or lightning strikes and protects personnel who perform routine tasks.

3 Electrical lines, poles, apparatus, and personnel are protected from high voltage surges during a lightning discharge.

Depending upon type; the earthing is classified into

1 Well Type earthing

2 Pipe earthing

3 Plate earthing

4 Mesh earthing

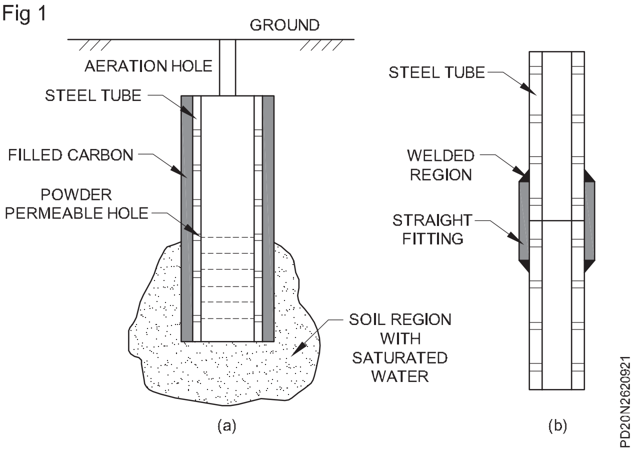
5 Delta earthing

6 Chemical earthing

1 Well earthing

Earth Wells & Accessories (Fig 1)

Fig 1



Earth wells for a specific building or installation are actually the location, where the pure zero potential is provided and practically act as drain pits for any rush current which accidentally appears in the earthing system grid in the event of an earth fault (connection of electrical live parts to the earthing system),

Depending on the soil conductivity of the location in which the earth wells are installed and also depending on the required technical specifications of the earthing system, different types of components can be used to set up an earth well

Followings are the prime components and accessories of an earth well

- Earth rod
- Earth plate
- Earthing clamp
- Earthing rod coupling
- Earthing rod tip
- Earthing rod driving head
- Carbon bedding mixed with salt
- Concrete earth pit
- Concrete slab cover

4 Mesh Earthing

The mesh method is one of the three routes for lightning protection system design defined by IEC 62305, the international standard for lightning protection design. After the first step of determining the class of lightning protection decided by the Risk Assessment, the lightning protection system design can be done using the Rolling Sphere, Protection Angle method, or the Mesh method. The system design will provide information such as the location of the lightning arresters, down conductors, earth electrodes, other equipment, and the complete Bill of Material

The mesh method is a flexible design tool because it is not dependent on the height of the structure. However, it requires flat surfaces, it cannot be used on curved surfaces. However, the surface does not necessarily have to be horizontal – it can also be used on vertical surfaces to protect against flashes. In the mesh method, a mesh of conductors should be placed on the structure and the separation distance of the conductors is based upon the class of protection determined during the risk assessment. The maximum mesh size should be in accordance with the table below.

Mesh Size

Class of LPS	Mesh Size
I	5 X 5 m
II	10 X 10 m
III	15 X 15 m
IV	20 X 20 m

The mesh method also requires that:

1 Air termination is placed on:

   1 Roof edges

   2 Roof overhangs, and

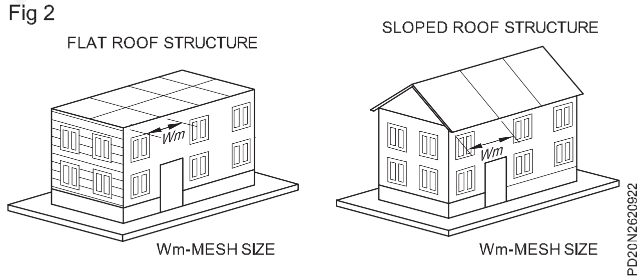
   3 Roof ridge lines when the pitch is in excess of 1/10 (5.7°)

2 No metal structure can protrude outside the volume protected by this method.

3 The network is constructed such that at least two separate paths exist to the earth electrodes and that these conductors follow the most direct path to the ground.

Research has indicated that the corners and edges of roofs are most susceptible to damage due to lightning. Therefore, designers and installers should place the conductors as close to the edge of the roof as possible. (Fig 2)

Fig 2



IEC 62305 allows for the use of conductors under the roof of a structure. Thus, the natural components of a structure can be used as part of the mesh grid, or even the whole grid. These components may be the rebar structure underneath the roof or dedicated lightning protection conductors, but they must be connected to the air termination rods that are mounted above the roof.

For structures, with a protruding metallic structure, the Protective Angle Method is generally used as a supplement to the Mesh Method.

3 Chemical Earthing

Chemical earthing is also called Maintenance Free Earthing. Chemical Earthing consists of 1)Earthing Electrode/Rod, 2) Backfill Chemical Compound& 3) Earth pit cover.

- Earthing Electrode – Earthing electrodes are available in GI or Copper material. The function of electrode is to direct the fault current into the ground. Cu electrode is most preferred choice for almost all types of earthing. Its available in different diameters & lengths like 40mm(D) X2000mm (L),40mm(D) X3000mm (L), 50mm(D) X2000mm (L), 50mm(D) X3000mm (L), 76mm(D) X2000mm (L), 76mm(D) X3000mm (L) etc.
- Backfill Compound – The function of backfill compound is to reduce the soil resistance & creates a low resistance zone around the electrode. It is available in powder form & it is mixed with water before pouring it into the pit. This compound is compacted on adding water & has capability of absorbing moisture up to 13 times its dry value.

Advantage of back filled compound over salt & charcoal

1 Environment friendly, it has no negative impact on environment,

2 No need of water filling,

3 It has no negative effect on electrodes,

- Pit Covers – Earth pit covers are used to protect earthing terminations from damage. These covers may be brick/concrete/ readymade heavy duty Polypropolyne/FRP. These Pit covers should be of heavy duty in nature.

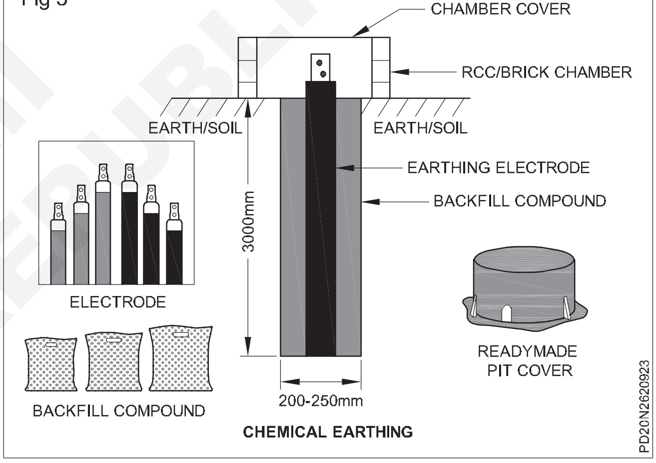
Detail of chemical earthing is given in the below diagram (Fig 3)

4 Delta Earthing

In cases where the neutral points of a three-phase system are not accessible or where the transformers or correct with original generator connected star earthing transformer, generally called neutral earthing compensate the help of an in Fig 4 (a). Earthing transformer is three-limbed type transformer having two equally proportioned windings on each limb. One set of windings is connected in star to provide the neutral point. The other ends of this set of windings are connected to the second of windings as shown so that the directions of the currents in the two windings on each limb are opposite to each other. With this arrangement of windings the transformer offers a low impedance path to the flow of zero phase sequence currents under system fault conditions since the only magnetic flux which results from the zero sequence currents is the leakage flux about each winding section. Under normal operation only small exciting currents circulates in the windings of the earthing transformer.

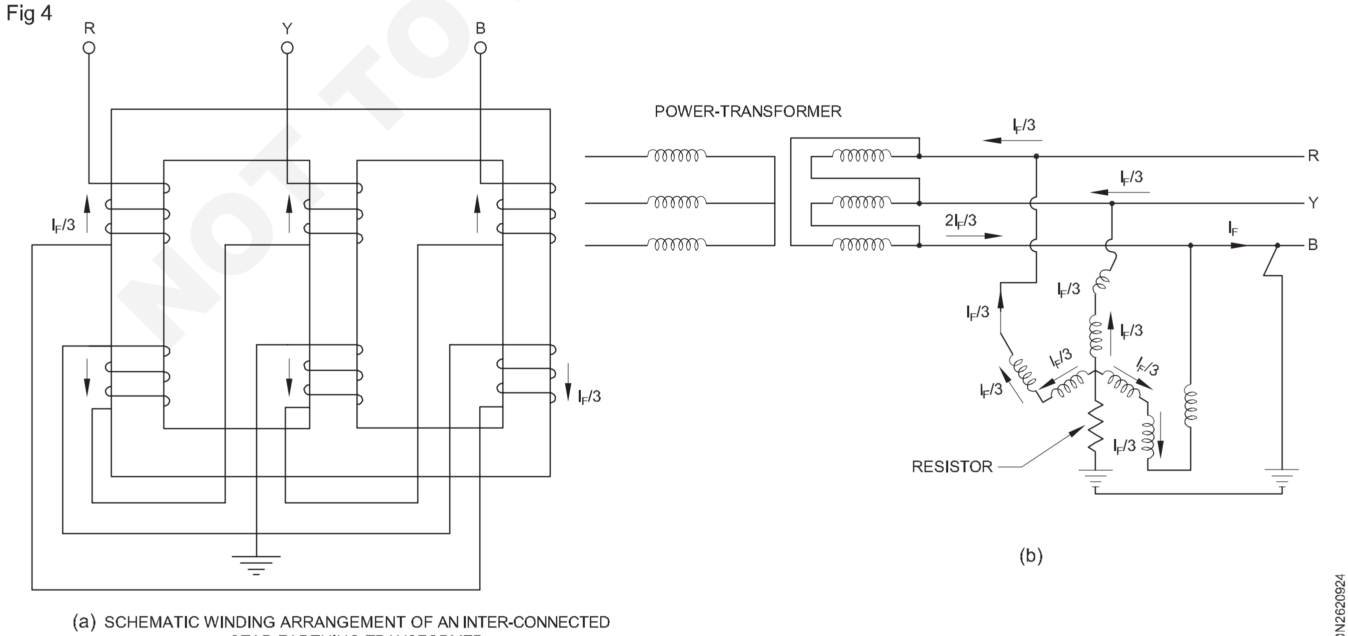
Owing to the very low impedance of the earthing transformer windings under fault conditions it is necessary sometimes to limit the value of the fault current by the addition of a resistor in series with the neutral earthing connection as shown in Fig 4 (b). This is necessary in systems operating at voltage between 22 kV and 33KV where the total power source capacity exceed 5,000 KVA

Fig 3



CHEMICAL EARTHING

Fig 4



(a) SCHEMATIC WINDING ARRANGEMENT OF AN INTER-CONNECTED STAR FARTHING TRANSFORMER

Earthing & Grounding

Objective: At the end of this lesson you shall be able to
- **to study the difference between grounding and earthing.**

Earthing & Grounding

One of the most misunderstood and confused concept is difference between Bonding, Grounding and Earthing. Bonding is more clear word compare to Grounding and Earthing, but there is a micro difference between Grounding and Earthing. Earthing and Grounding are actually different terms for expressing the same concept.

We need to understand that there are really two separate things we are doing for same purpose that we call Grounding or Earthing.

The Earthing is to reference our electrical source to earth (usually via connection to some kind of rod driven into the earth or some other metal that has direct contact with the earth).

The grounded circuits of machines need to have an effective return path from the machines to the power source in order to function properly (Here by Neutral Circuit).

In addition, non-current-carrying metallic components in a System, such as equipment cabinets, enclosures, and structural steel, need to be electrically interconnected and earthed properly so voltage potential cannot exist between them. However, troubles can arise when terms like “bonding”, “grounding”, and “earthing” are interchanged or confused in certain situations.

Earthing

Earthing means connecting the dead part (it means the part which does not carries current under normal condition) to the earth for example electrical equipment’s frames, enclosures, supports etc.

The purpose of earthing is to minimize the risk of receiving an electric shock if touching metal parts when a fault is present. Generally green wire is used for this as a nomenclature.

Under fault conditions the non-current carrying metal parts of an electrical installation such as frames, enclosures, supports, fencing etc. may attain high potential with respect to ground so that any person or stray animal touching these or approaching these will be subjected to potential difference which may result in the flow of a current through the body of the person or the animal of such a value as may prove fatal.

To avoid this non-current carrying metal parts of the electrical system are connected to the general mass of earth by means of an earthing system comprising of earth conductors to conduct the fault currents safely to the ground.

Earthing has been accomplished through bonding of a metallic system to earth. It is normally achieved by inserting ground rods or other electrodes deep inside earth.

Earthing is to ensure safety or Protection of electrical equipment and Human by discharging the electrical energy to the earth.

Grounding

Grounding means connecting the live part (it means the part which carries current under normal condition) to the earth for example neutral of power transformer. It is done for the protections of power system equipment and to provide an effective return path from the machine to the power source.

For example grounding of neutral point of a star connected transformer.

Grounding refers the current carrying part of the system such as neutral (of the transformer or generator).

Because of lightening, line surges or unintentional contact with other high voltage lines, dangerously high voltages can develop in the electrical distribution system wires. Grounding provides a safe, alternate path around the electrical system of your house thus minimizing damage from such occurrences.

Generally Black wire is used for this as a nomenclature.

All electrical/electronic circuits (AC & DC) need a reference potential (zero volts) which is called ground in order to make possible the current flow from generator to load. Ground is May or May not be earthed. In Electrical Power distribution it is either earthed at distribution Point or at Consumer end but it is not earthed in Automobile(for instance all vehicles’ electrical circuits have ground connected to the chassis and metallic body that are insulated from earth through tires).

There may exist a neutral to ground voltage due to voltage drop in the wiring, thus neutral does not necessarily have to be at ground potential.

In a properly balanced system, the phase currents balance each other, so that the total neutral current is also zero. For individual systems, this is not completely possible, but we strive to come close in aggregate.

This balancing allows maximum efficiency of the distribution transformer’s secondary winding.

Earth Resistance and Earth Leakage Circuit Breaker(ELCB)

Objectives: At the end of this lesson you shall be able to
- **define earth resistance, its value,**
- **how to measure the earth resistance and the method to reduce it**
- **explain the working principle, different types and construction of an ELCB**
- **explain the technical specifications of ELCB's.**

Earth Resistance

Definition: The resistance offered by the earth electrode to the flow of current into the ground is known as the earth resistance or resistance to earth. The earth resistance mainly implies the resistance between the electrode and the point of zero potential. Numerically, it is equal to the ratio of the potential of the earth electrode to the current dissipated by it. The resistance between the earthing plate and the ground is measured by the potential fall method.

The resistance of the earthing electrode is not concentrated at one point, but it is distributed over the soil around the electrode. Mathematically, the earth resistance is given as the ratio of the voltage and the current shown below.

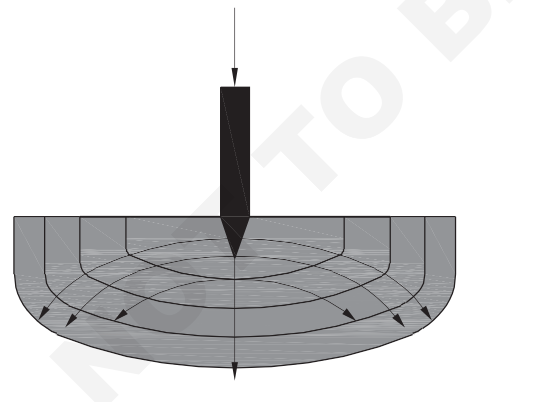
$$\text{Earth Resistance} = \frac{\text{Potential to earth electrode}}{\text{Currect}}$$

$$\text{EarthResistance} = \frac{V}{I}$$

Where V is a measured voltage between the voltage spike and I is the injected current during the earth resistance measurement through the electrode.

The value of the earth resistance for different power stations is shown below (Fig 1)

Fig 1



Large Power Station - 0.5 ohms

Major Power Station - 1.0 ohms

Small Substation - 2.0 ohms

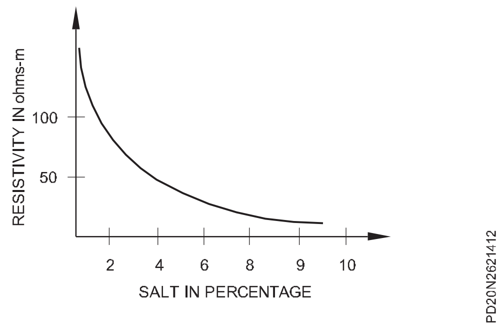
In all other cases - 8.0 ohms

The region around the earth in which the electrode is driven is known as the resistance area or potential area of the ground. The fault current which is injected from the earth electrode is passing away from the electrode in all directions shown below in the figure. The flow of current into the grounds depends on the resistivity of the soil in which the earth electrode is placed. The resistivity of the soil may vary from 1 to 1000 ohm-m depends on the nature of the soil.

The resistivity of the earth depends on its temperature. When the temperature is greater than 0°C, then its effect on ground resistivity is negligible, But at 0°C the water in the soil starts freezing which increase their resistivity. The resistivity of the earth is also affected by the composition of some soluble salts as shown in the figure below. (Fig 2)

The resistance of the earth varies from layer to layer. The lower layer of soil has more moisture and lower resistivity. If the lower layer contains hard and rocky soil, then their resistivity increases with depth.

Fig 2



ELCB - types - working principle - specification

Objectives : At the end of this exercise you shall be able to
- **explain the working principle, different types and construction of an earth leakage circuit breaker (ELCB)**
- **explain the technical specifications of ELCB's.**

Introduction

The sensation of electric shock is caused by the flow of electric current through the human body to earth. When a person comes in contact with electrically live objects like water heaters, washing machines electric iron etc., the extent of damages caused by this current depends on its magnitude and duration.

This kind of current is called the leakage current which comes in milli-amps. These leakage current being very small in magnitude, hence undetected by the fuses/MCBs are the major cause for the fires due to electricity.

The leakage current to earth also results in the wastage of energy and excessive billing for electricity not actually used.

Residual current operated circuit breakers are internationally accepted means of providing maximum protection from electric shocks and fires caused due to earth leakage current and also prevents the waste of electrical energy. These residual current circuit breakers (RCCB) are popularly called as Earth leakage circuit breakers (ELCB). The effect of electric current on human body in various levels represented in graph (Fig 1).

Basically ELCBs are of two types namely voltage operated ELCBs and the current operated ELCBs.

Voltage operated ELCB

This device is used for making and breaking a circuit. It automatically trips or breaks the circuit when the potential difference between the protected metal work of the installation and the general mass of earth exceeds 24V. This voltage signal will cause the relay to operate (Fig 2).

Voltage operated ELCBs are meant to be used where it is not practicable to meet the requirements of IEE wiring regulation by direct earthing or where additional protection is desirable.

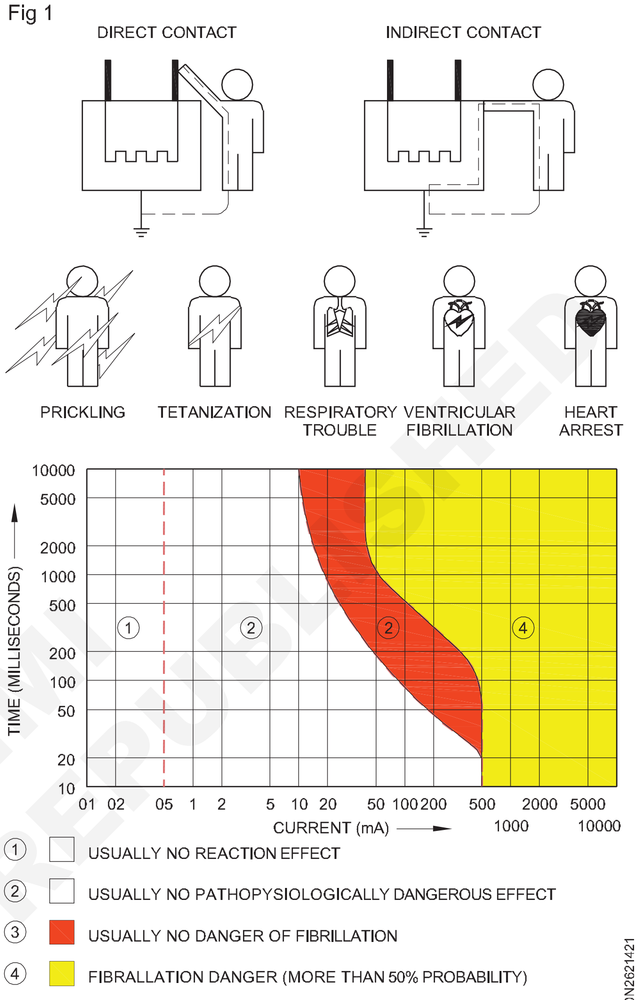
Current operated ELCB

This device is used for making and breaking a circuit and for breaking a circuit automatically when the vector sum of current in all conductors differs from zero by a predetermined amount. Current operated ELCBs are much more reliable in operation, easier to install and maintain.

Construction of current operated ELCB

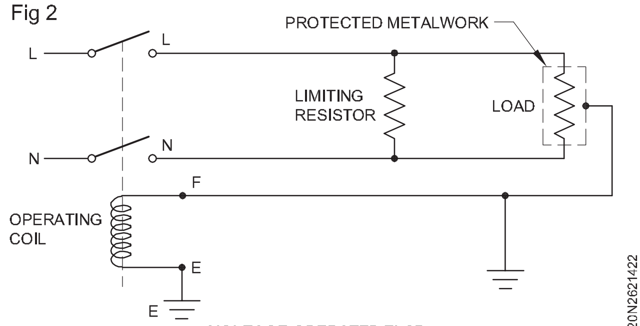
It consists of a Torroid ring made of high permeability magnetic material. It has two primary windings each carrying the current flowing through phase and neutral of the installation. The secondary winding is connected to a highly sensitive electro - magnetic trip relay which operates the trip mechanism.

Fig 1



EFFECT OF ELECTRIC CURRENT ON HUMAN BODY

Fig 2



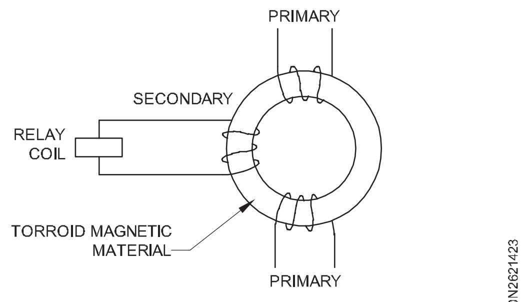
VOLTAGE OPERATED ELCB

Working principle

The residual current device (RCD) is a circuit breaker which continuously compares the current in the phase with that in the neutral. The difference between the two is called as the residual current which is flowing to earth.

The purpose of the residual current device is to monitor the residual current and to switch off the circuit if it rises from a preset level (Fig 3).

Fig 3



RESIDUAL CURRENT DEVICE

The main contacts are closed against the pressure of a spring which, provides the energy to open them when the device trips. Phase and neutral current pass through identical coils wound in opposing direction on a magnetic circuit, so that each coil will provide equal but opposing numbers of ampere turns when there is no residual current. The opposing ampere turns will cancel and no magnetic flux will be set up in the magnetic circuit.

In a healthy circuit the sum of the current in phases is equal to the current in the neutral and vector sum of all the current is equal to zero. If there is any insulation fault in the circuit then leakage current flows to earth. This residual current passes to the circuit through the phase coil but returns through the earth path and avoids the neutral coil, which will therefore carry less current.

So the phase ampere turns exceeds neutral ampere turns and an alternating magnetic flux results in the core. The flux links with the secondary coil wound on the same magnetic circuit inducing an emf into it. The value of this emf depends on the residual current, so it drives a current to the tripping system which depends on the difference between them and neutral current.

When tripping current reaches a predetermined level the circuit breaker trips and open the main contacts and thus interrupts the circuit. A 3 - phase 4 wire electric system can also be protected by providing a 4 pole RCCB (Fig 4).

Test Switch

A test switch is a requirement as per BS842 (Fig 5). It is used to test the functioning of ELCB. When the test button is pressed it circulates additional current through neutral coil which is determined by the value of current limiting resistor R. As a result there exists a difference in current flowing through phase and neutral coils and hence the ELCB trips OFF.

Technical specification

The current ratings of ELCB are 25A, 40A and 63A.

No. of poles - 2 and 4

Nominal voltage - 240/415V 50Hz.

Sensitivities: ELCBs are designed to trip at leakage currents of 30mA, 100mA, and 300mA.

Electrical life: More then 10,000 operations.

Fig 4

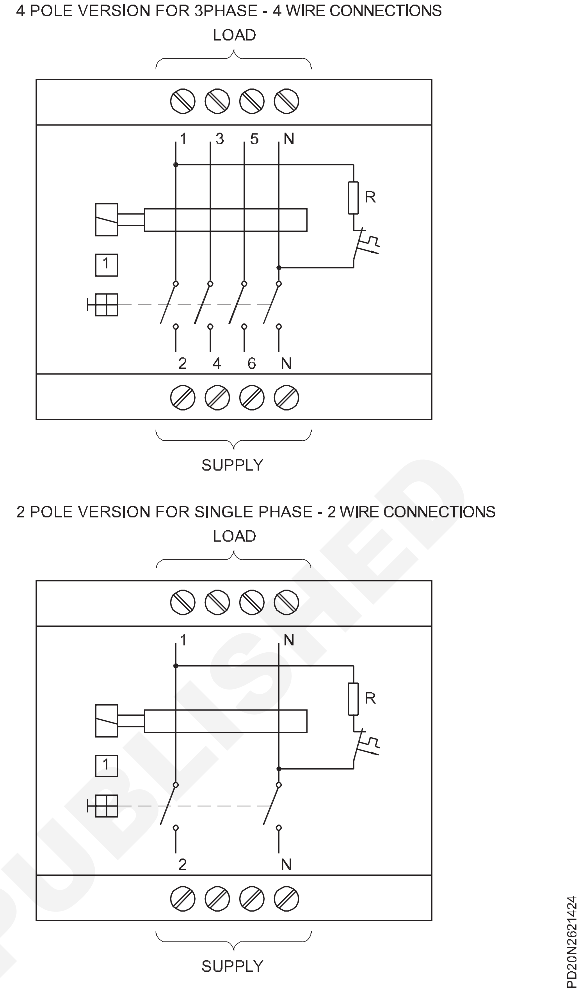
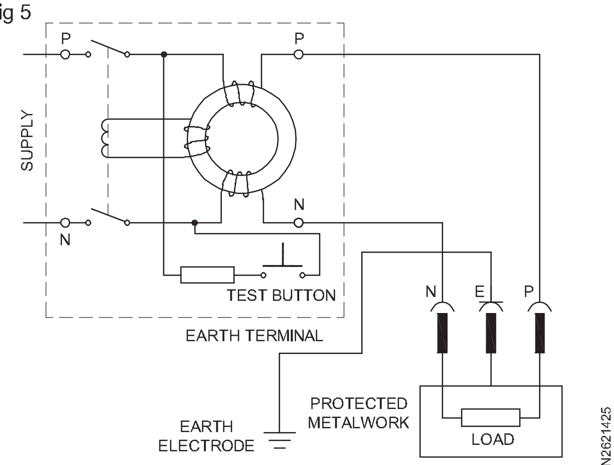


Fig 5



TEST SWITCH

Mechanical life:

20000 to 100000 operations.

Tripping time - < 30ms.

Time delayed RCCB

There are cases, where more than one RCCB is used in an installation, for example a complete installation may be protected by an RCCB rated at 100mA, while a socket intended for equipment may be protected by 30mA device.

Discrimination of the two devices then becomes important. For example an earth fault occurs in the equipment giving an earth fault current of 250mA. Since the fault current is higher, than the operating current of both devices, both will trip.

It does not follow, that the device with smaller operating current will trip first. This is a lack of discrimination between the two devices. To ensure proper discrimination, the device with a larger operating current, has a deliberate time delay built into its operation. It is called time-delayed RCCB.

Earth fault loop impedance

Earth wire from an equipment to the earth electrode is called earth loop. Earth fault loop impedance (Z_E) is the impedance of the fault current path. It must be low enough to ensure that the productive devices like ELCB will operate within the specified time.

In any case, the multiplication value of earth fault loop impedance in Ohms and the rated tripping current (I_t)in ampere of ELCB should not exceed 50V .

$Z_E \times I_t < 50V$.

Resistance to be measured. The unknown resistance is connected between the terminals L and E.

When the armature of the magnet is rotated, an emf is produced. This causes the current to flow through the current coil and the resistance being measured. The amount of current is determined by the value of the resistance and the output voltage of the generator.

The torque exerted on the meter movement is proportional to the value of current flowing through the current coil.

The current through the current coil, which is under the influence of the permanent magnet, develops a clockwise torque. The flux produced by the voltage coils reacts with the main field flux, and the voltage coils develop a counter-clockwise torque.

For a given armature speed, the current through the voltage coils is constant, and the strength of the current coil varies inversely with the value of resistance being measured. As the voltage coils rotate counter-clockwise, they move away from the iron core and produce less torque.

A point is reached for each value of resistance at which the torques of the current and voltage coils balance, providing an accurate measurement of the resistance. Since the instrument does not have a controlling torque to bring the pointer to zero, when the meter is not in use, the position of the pointer may be anywhere on the scale.

The speed at which the armature rotates does not affect the accuracy of the meter, because the current through both the circuits changes to the same extent for a given change in voltage. However, it is recommended to rotate the handle at the slip speed to obtain steady voltage.

Because megohmmeters are designed to measure very high values of resistance, they are frequently used for insulation tests.

Connection for measurement

When conducting insulation resistance test between line and earth, the terminal 'E' of the insulation tester should be connected to the earth conductor.

Precautions

- A megohmmeter should not be used on a live system.
- The handle of the megohmmeter should be rotated only in a clockwise direction or as specified.
- Do not touch the terminals of a megohmmeter while conducting a test.
- Support the instrument firmly while operating.
- Rotate the handle at slip speed.

Uses of a megohmmeter

- Checking the insulation resistance
- Checking the continuity.

Specification of Megger :

Nowadays electronically operated, Meggers are available, called as push button type for general application and for industrial application motorised megger are also available. Hence a megger is basically specified based on the voltage generated by it .

Example: 250V, 500V, 1KV, 2.5KV, 5KV.

Earth resistance tester

Objectives: At the end of this lesson you shall be able to
- **state the necessity of earthing**
- **state the precautions to be followed while selecting a site for the earth electrode**
- **define earth resistance tester**
- **explain the principle construction and working of an earth resistance tester**
- **explain the method of measuring the earth resistance**
- **state the IE rules pertaining to earthing.**

Necessity of earthing

Earthing the metal frames/casing of the electrical equipment is done to ensure that the surface of the equipment under faulty conditions does not hold dangerous potential which may lead to shock hazards. However, earthing the electrical equipment needs further consideration as to ensure that the earth electrode resistance is reasonably low to activate the safety devices like earth circuit leakage breaker, fuses and circuit breakers to open the faulty circuit and thereby protect men and material.

Precautions to be followed while selecting the site for earth electrode: However, even the earth electrode, either rod or plate type, implanted properly in the earth according to the specified recommendations is found to have high resistance resulting in failure of safety. This defect is mainly due to the soil and moisture condition. The explanation given below is to guide an electrician to select a proper site for providing an earth electrode so that the earth electrode resistance could be kept at a reasonable level.

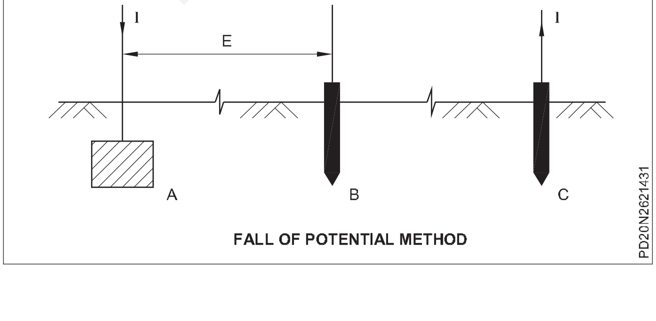
Necessity of measuring of earth electrode resistance: Physically an earth electrode may look alright, but its resistance may be high enough to damage the safety requirement. The only way to ensure the acceptable value of earth electrode resistance is to measure the resistance with the use of an earth resistance tester.

Earth resistance tester: It is an electrical measuring instrument used to measure the resistance between any two points of the earth. It is also called as earth tester. Even varieties of earth testers are available in market, the hand operated earth tester is explained below.

Principle: The earth tester works on the principle of the fall of potential method.

In this method the two auxiliary electrodes B and C are placed at a straight line (Fig 1).

Fig 1



FALL OF POTENTIAL METHOD

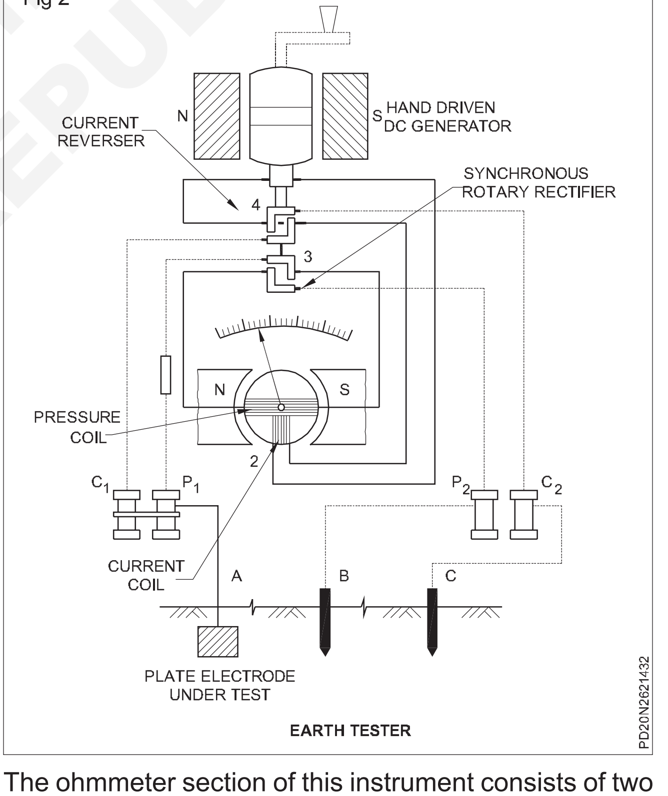
An alternating current of Iamps magnitude is passed through the electrode A to the electrode C via the earth and the potential across electrodes A and B is measured.

The resistance of electrodes B and C does not influence the measurement result.

This is achieved by placing the electrode C at a sufficient distance from A so that the resistance areas of A and C are quite independent. A distance of above 15 metres between electrode A and C is regarded as sufficient distance.

Construction and working of earth tester : The earth tester essentially consists of a hand drive generator which supplies the testing current and a direct reading ohmmeter (Fig 2).

Fig 2



EARTH TESTER

The ohmmeter section of this instrument consists of two coils (potential and current coils) kept at 90° to each other and mounted on the same spindle. The pointer is attached to the spindle. The current coil carries a current proportional to the current in the test circuit whereas the potential coil carries a current proportional to the potential across the resistance under test.

Thus the current coil of the instrument acts as an ammeter in the fall of potential method and the pressure coil acts as the voltmeter. Since the deflection of the ohmmeter needle is proportional to the ratio of the current in the two coils, the meter gives resistance readings directly.

When DC is used in electrode resistance measurement the effect of electrolytic emf interferes with the measurement and the reading may go wrong. To avoid this, the supply to the electrodes should be AC.

To facilitate this the DC produced by the hand generator is changed to AC through a current reverser. After the alternating current passes through the electrodes, the measurement should be done by an ohmmeter which requires DC supply.

To change the alternating voltage drop outside the instrument to direct voltage drop inside, a synchronous rotary rectifier is used (Fig 2)

Sometimes the meter needle vibrates during measurement due to the fact that strong alternating currents of the same frequency as the generated frequency enters the measuring circuit.

In such cases the handle rotating speed of the instrument may be either increased or decreased. In general these instruments are designed such that the readings are not affected by strong currents or by electrolytic emfs.

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 1)

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.

Methods of 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.

Balanced/Restricted earth protection

Objectives : At the end of this exercise you shall be able to
- **to explain balanced /restricted earth protection**
- **awareness of circuit main earth and portable earth**

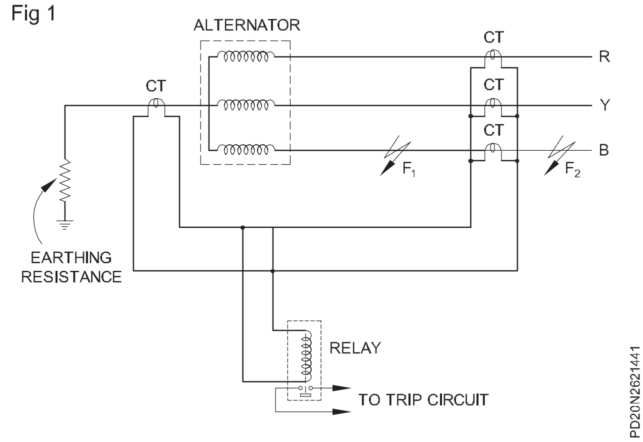
It provides protection against the stator winding of the earth fault in the stator and does not operate in case of an external earth fault. This scheme is also called restricted earth fault protection scheme. Such type of protection is provided in the large generator as an additional protection scheme.

Balanced Earth Fault Protection:

In small-size alternators, the neutral ends of the three-phase windings are often connected internally to a single terminal. Therefore, it is not possible to use Merz-Price circulating current principle described above because there are no facilities for accommodating the necessary current transformers in the neutral connection of each phase winding. Under these circumstances, it is considered sufficient to provide protection against earth-faults only by the use of Balanced Earth Fault Protection scheme. This scheme provides no protection against phase-to-phase faults, unless and until they develop into earth-faults, as most of them will. (Fig 1)

Schematic arrangement: Fig. 22.6 shows the schematic arrangement of a Balanced Earth Fault Protection for a 3-phase alternator. It consists of three line current transformers, one mounted in each phase, having their secondaries connected in parallel with that of a single current transformer in the conductor joining the star point of the alternator to earth. A relay is connected across the transformers secondaries. The protection against earth faults is limited to the region between the neutral and the line current transformers.

Fig 1



Operation: Under normal operating conditions of Balanced Earth Fault Protection, the currents flowing in the alternator leads and hence the currents flowing in secondaries of the line current transformers add to zero and no current flows through the relay. Also under these conditions.

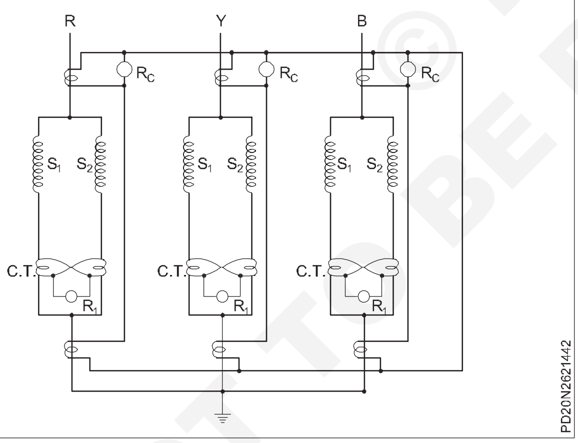
The current in the neutral wire is zero and the secondary of neutral current transformer supplies no current to the relay.

If an earth-fault develops at F, external to the protected zone, the sum of the currents at the terminals of the alternator is exactly equal to the current in the neutral connection and hence no current flows through the relay. When an earth-fault occurs at F, or within the protected zone,these currents are no longer equal and the differential current flows through the operating coil of the relay. The relay then closes its contacts to disconnect the alternator from the system

Stator Inter Turn Protection:

Merz-price circulating-current system protects against phase-to-ground and phase-to-phase faults It does not protect against turn-to-turn fault on the same phase winding of the stator. It is because the current that this type of fault produces flows in a local circuit between the turns involved and does not create a difference between the currents entering and leaving the winding at its two ends where current transformers are applied. However, it is usually considered unnecessary to provide protection for inter-turn faults because they invariably develop into earth-faults (Fig 2)

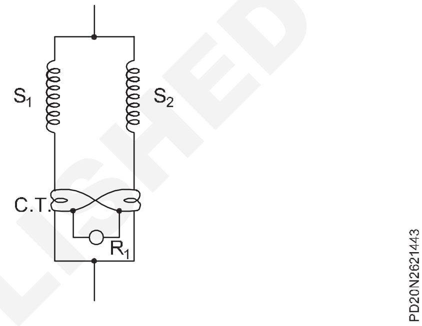
Fig 2



In single turn generator (e.g. Large steam-turbine generators), there is no necessity of protection against inter-turn faults. However, inter-turn protection is provided for multi-turn generators such as hydro-electric generators. These generators have double-winding armatures (i.e, each phase winding is divided into two halves) owing to the very heavy currents which they have to carry Advantage may be taken of this necessity to protect inter-turn faults on the same winding Fig.22.7 shows the schematic arrangement of circulating-current and inter-turn protection of a 3-phase double wound generator. The relays R. Provide protection against phase-to-ground and phase-to-phase faults whereas relays R. provide protection against inter-turn faults.

Fig 3 shows the duplicate stator windings S and S, of one phase only with a provision against inter-turn faults. Two current transformers are connected on the circulating-current principle. Under normal conditions, the currents in the stator windings S. and S, are equal and so will be the currents in the secondaries of the two CTs. The secondary current round the loop then is the same at all points and no current flows through the relay R.. If a short-circuit develops between adjacent turns, say on S,, the currents in the stator windings S, and S, will no longer be equal. Therefore, unequal currents will be induced in the secondaries of CTs and the difference of these two currents flows through the relay R. The relay then closes its contacts to clear the generator from the system. (Fig 3)

Fig 3



Circuit Main Earth (CME) - Circuit main earth: An earth connection applied for the purpose of making apparatus safe to work on before a permit to work or sanction for test is issued, and which is nominated on the document. OR

An approved earth connection which is applied as per the instruction or with the consent of the system control Engineer before the issue of a Permit-to-Work or Sanction for-Test or any other safety document and quoted in the respective safety document as CME.

Circuit Main Earths (CME):

a Application of Circuit Main Earth (CME)

No earthing switch shall be operated or Circuit Main Earth (CME) connection attached or moved except on the instruction of, or with the consent of, the System Control Engineer, by a Senior Authorized Person or Competent Person acting under his immediate and direct supervision. Each operation shall be reported to the System Control Engineer as soon as possible after completion, where the location of each connection to earth must be recorded on the relevant Safety Document (Permit-to-Work, Sanction-for-Test, etc).

b Recording of Earthing (CME)

The System Control Engineer shall record in his Log the time of application and the location of all Circuit Main Earth (CME) connections and the time of their removal

Portable Earthing Devices

Portable Earthing Devices (portable earths) are personal, protective devices which are used to protect electrical, workers if the high voltage equipment they are working on is re-energised. In the event that a conductor is energised.

Electrical supply system

Objectives: At the end of this lesson you shall be able to
- **explain the electrical supply system and layout of AC power supply scheme**
- **list out the various power transmission**
- **compare AC and DC transmission**
- **state the advantages of high voltage transmission**
- **state single phase and 3 phase - 3 wire system in transmission.**

Electrical supply system

The electrical energy generated from the power plants has to be supplied to the consumers. This is large network, which can be broadly divided into two stages, (i.e..) Transmission and distribution.

The conveyance of electric power from a power station to the consumers / premises is called is Electrical supply system.

The Electrical power supply system consists of 3 main components viz (i) The power station / plant (ii) The transmission lines and (iii) The distribution systems. The power is produced at power plant which is away from the consumers, It has to be transmitted over long distances to load centres by transmission and to consumers through distribution network.

This supply system can be classified into

- DC or AC system
- Over head lines (or) underground system

Now a days, 3 phase, 3 -wire AC system is universally adopted as an economical proposition. In some places 3 phase - 4 wire AC system is adopted.

The underground system is more expensive than the over-head system, therefore in our country O.H system is almost adopted.

Types of power transmission system

Universally, 3 - phase - 3 wire AC system is adopted in most of the places. However other systems can also be used for transmission under special circumstances.

Possible systems are :-

1 **DC system**
   - i DC two wire
   - ii DC two - wire with mid point earthed
   - iii DC three wire

2 **AC single phase system**
   - i Single-phase two wire
   - ii Single - phase two wire with mid point earthed
   - iii Single phase three wire

3 **AC Two - phase system**
   - i Two- phase three wire
   - ii Two - phase - four wire

4 **AC three phase system**
   - i Three - phase - three wire
   - ii Three - phase - four wire

The line network between generating station (Power station) and consumer of electric power can be divided into two parts.

- Transmission system
- Distribution system

This system can be categorized as primary transmission and secondary transmission. Similarly primary distribution and secondary distribution. This is in Fig 1.

It is not necessary that the entire steps which are shown in the diagram must be included in the other power schemes. There may be difference, there is no secondary transmission in many, schemes, in some (small) schemes there is no transmission, but only distribution.

Various stages of a typical electrical power supply system, are as follows

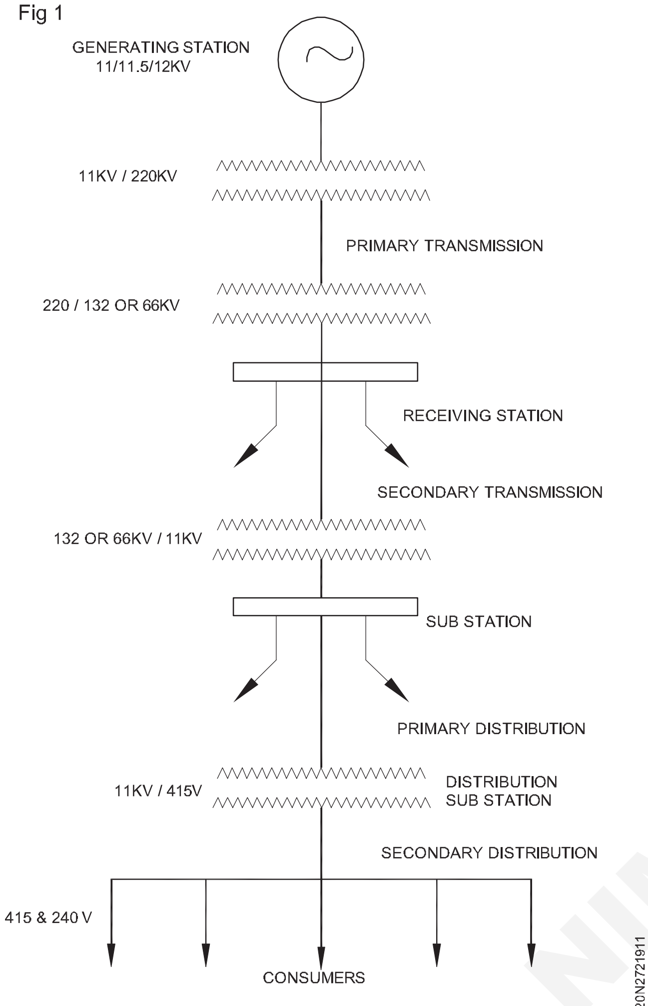
1 Generating station
2 Primary transmission
3 Secondary transmission
4 Primary distribution
5 Secondary distribution

Generating station

The place where electric power produced by the parallel connected three phase alternators / generators is called generating station (i.e power plant).

The ordinary power plant capacity and generating voltage may be 11KV, 11.5 KV, 12KV or 13KV. But economically. It is good to step up the produced voltage from (11KV, 11.5KV or 12KV) to 132KV, 220KV, 400KV or 500KV or greater (in some countries, up to 1500KV) by step up transformer (power transformer).

Fig 1



TYPICAL AC POWER SUPPLY SCHEME

Primary transmission

The electric supply (132KV, 220 KV, 500KV or greater) is transmitted to load center by three phase three wire (3 phase - 3 wires) overhead transmission system.

Secondary transmission

Area far from city (outskirt) which have connected with receiving station by line is called secondary transmission. At receiving station, the level of voltage reduced by step-down transformers up to 132KV, 66 or 33KV and electric power is transmitted by three phase three wire (3 phase - 3 wires) overhead system to different sub stations. So this is a secondary transmission. `

Electric Power Distribution System Basics

Electrical power is dominant as it is relatively much easier to transmit and distribute than other forms of energy such as mechanical. Imagine transmitting mechanical energy to just 20 feet of distance. Isn't it much easier to use wires instead of belts, chains or shafts?

We have seen how electrical energy is generated in generating stations and how it is transmitted over long distances through transmission networks. Now, let's see how electrical power is distributed to the consumers.

Power Distribution System

A distribution substation is located near or inside city/ town/village/industrial area. It receives power from a transmission network. The high voltage from the transmission line is then stepped down by a step-down transformer to the primary distribution level voltage. Primary distribution voltage is usually 11 kV, but can range between 2.4 kV to 33 kV depending upon region or consumer.

A typical power distribution system consists of -

- Distribution substation
- Feeders
- Distribution Transformers
- Distributor conductors
- Service mains conductors

Along with these, a distribution system also consists of switches, protection equipment, measurement equipment etc.

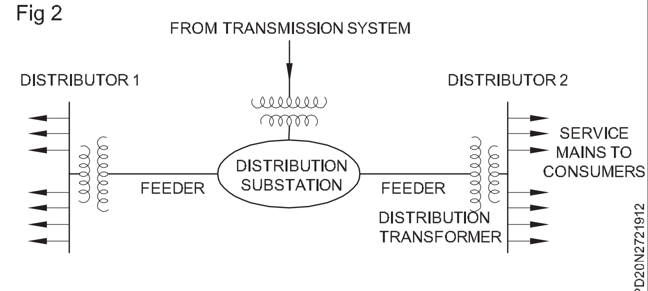
Distribution feeders: The stepped-down voltage from the substation is carried to distribution transformers via feeder conductors. Generally, no tappings are taken from the feeders so that the current remains same throughout. The main consideration in designing of a feeder conductor is its current carrying capacity.

Distribution transformer: A distribution transformer, also called as service transformer, provides final transformation in the electric power distribution system. It is basically a step-down 3-phase transformer. Distribution transformer steps down the voltage to 400Y/230 volts. Here it means, voltage between any one phase and the neutral is 230 volts and phase to phase voltage is 400 volts. However, in USA and some other countries, 120/240 volts split-phase system is used; where voltage between a phase and neutral is 120 volts.

Distributors: Output from a distribution transformer is carried by distributor conductor. Tappings are taken from a distributor conductor for power supply to the end consumers. The current through a distributor is not constant as tappings are taken at various places throughout its length. So, voltage drop along the length is the main consideration while designing a distributor conductor.

Service mains: It is a small cable which connects the distributor conductor at the nearest pole to the consumer's end

Fig 2



The above figure shows a simple radial AC power distribution system. The figure does not show other equipment like circuit breakers, measuring instruments etc. for simplicity purpose.

Primary Distribution

It is that part of an AC distribution system which operates at somewhat higher voltages than general residential consumer utilization. Commonly used primary distribution voltages in most countries are 11 kV, 6.6 kV and 3.3 kV. Primary distribution handles large consumers such as factories and industries. It also feeds small substation from where secondary distribution is carried out. Primary distribution is carried out by 3-phase, 3-wire system.

Secondary Distribution

This part directly supplies to the residential end consumers. Domestic consumers are fed with single phase supply at 230 volts (120 volts in USA and some other countries). Three phase supply may also be provided at 400 volts for big properties, commercial buildings, small factories etc. Secondary transmission in most countries is carried out by 3-phase, 4-wire system.

Classification Of Power Distribution Systems

- According to nature of current:
  - DC distribution system
  - AC distribution system
- According to type of construction:
  - Overhead distribution system
  - Underground distribution system
- On the basis of scheme of connection:
  - Radial distribution system
  - Ring main distribution system
  - Inter-connected distribution system

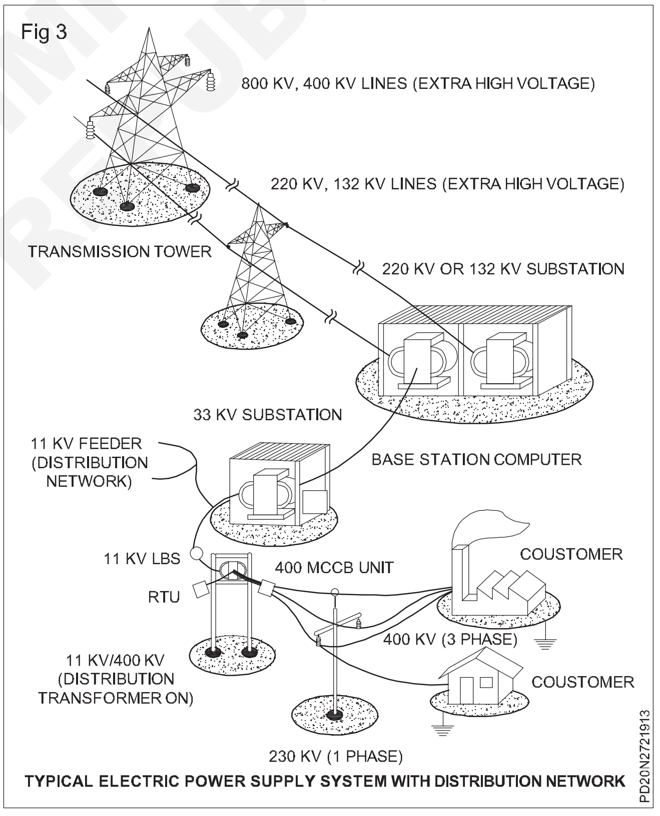
Description of the power distribution system

You are familiar with the power supply system. You know that electricity is often generated at 11 kV by electrical generators, which utilise the energy from thermal, hydro, nuclear, or renewable energy resources. To transmit electricity over long distances, the supply voltage is stepped up to 132/220/ 400/800 kV, as required. Electricity is carried through a transmission network of high voltage lines. Usually, these lines run for hundreds of kilometres. The common pool of all the interconnected lines is called the grid. Thus, many generating stations deliver power into the grid, which, in turn, is connected to load centres (cities) through a sub-transmission network of usually 33 kV (or sometimes 66 kV) lines. These lines terminate into a 33 kV (or 66 kV) substation, where the voltage is stepped-down to 11 kV for power distribution to load points through a distribution network of lines at 11 kV and lower voltages.

The power network of concern to the end-user is the distribution network of 11 kV lines, or feeders downstream of the 33 kV substations. Each 11 kV feeder, which emanates from a 33 kV substation, branches further into several subsidiary 11 kV feeders to carry power close to the load points (localities, industrial areas, villages, etc.).

At these load points, a transformer further reduces the voltage from 11 kV to 400 V to provide the last-mile connection through 400 V feeders (also called Low Tension (LT) feeders) to individual customers, either at 230 V (as single-phase supply) or at 400 V (as three-phase supply). The utility voltage of 400 V, 3-phase is used for running the motors for industry and agricultural pump sets and 230 V, single-phase is used for lighting in houses, schools, hospitals and for running industries, commercial establishments, etc.

A feeder could be either an overhead line or an underground cable. In urban areas, owing to the density of customers, the length of an 11 kV feeder is generally up to 3 km. On the other hand, in rural areas, the feeder length is generally larger up to 20 km. A 400 V feeder should normally be restricted to the power about 0.5-1.0 km. unduly long feeders lead to low voltage at the consumer distribution end. The power supply system, including the distribution network, is depicted in Figure 3.



TYPICAL ELECTRIC POWER SUPPLY SYSTEM WITH DISTRIBUTION NETWORK

The distribution system contains:

- Sub-transmission system in voltage ranges from 33 kV to 220 kV. The energy goes from power substations to distribution substations through primary system and then from distribution substations to secondary distribution system for local voltage distribution.

- Primary circuits of feeders, usually operating in the range of 11 kV to 33 kV, supply the load in well defined geographical areas.
- The distribution transformers, usually installed on poles or near the consumer sites, transform the primary voltage to the secondary voltage, which is usually 230/400 V.
- Secondary circuits at service voltage, which carry energy from the distribution transformers along the streets, etc.

Elements of Distribution System

The main components of the power distribution system and their brief descriptions are given below in Table 1.1.

Power System Network

Components	Description
Grid Substation (GSS)	Power from transmission network is delivered to sub-transmission network after stepping down the voltage to 66 kV or 33 kV through 220/132/66/33 kV grid substations
Sub-transmission Network	Power is carried at 66 or 33 kV by overhead lines or underground cables
Power Sub-transmission (PSS)	Power is stepped down by 66-33/11 kV to 11 kV for distribution
Primary Distribution Feeders	Power is delivered from PSS through primary feeders at 1 to 6.6 kV to various distribution transformers
Distribution Substation (DSS)	Power is further stepped down by 11/0.4 kV transformers to utilisation voltage of 400 V
Secondary Distribution Network	It carries power from DSS at 400 V (230 V single phase) to various consumers through service lines and cables

We also describe various components of power distribution system as substations, transformers, feeders, lines and metering arrangements.

In the Power Distribution System

Power System Segments	Voltages
Generation voltages	415 V, 6.6 kV, 10.5 kV, 11 kV, 13.8 kV, 15.75 kV, 21 kV and 33 kV
Transmission voltages	33 kV, 66 kV, 132 kV, 220 kV and 400 kV
High voltage primary transmission	3.3 kV, 6.6 kV, 11 kV, 22 kV, 33 kV and 66 kV
Low voltage distribution phase	400 V (3 phase) and 230 V (1 phase)

Higher voltages are used for 3-phase, 3-wire supply to large consumers. Low voltage distribution of generally 400 V, 3-phase 4-wire system and 230 V single phase, two wire, phase to neutral system is used for small and medium consumers. The size and, hence, voltage of supply to a consumer is decided by the load of the consumer.

Load Categories

Loads are categorised according to the use which are as follows :

Commercial

It is applicable to Market, Shopping Centre, Multiplexes, Malls, Healthcare centre, Government offices, etc.

Industrial

It is applicable to Factories of all types and manufacturing facility, etc.

Agricultural

Agricultural/farming.

Residential

Independent Houses, Housing Societies, Multi-storied building.

Institutional

Research facilities, School, Colleges, Universities, etc.

Survey and Marking of LT and HT Line Routes

- Survey is carried out for installation of lines.
- Right of the way is assessed for LT and HT lines.
- Clearance from forest department, railways and municipal body.
- Route marking for installation of HT and LT lines.

Objectives of distribution system

Characteristics of any utility can be judged by the performance of its distribution system.

Some main objectives of power distribution organisation are:

a Planning, modernisation and automation of Distribution System.

b To provide service connections to various urban, rural and industrial consumers in the allocated area.

c Maximise the security of supply.

d Safety of consumers, utility personals.

e Collection of Energy Payments.

f To provide electricity of accepted quality in terms of

- Balanced 3 Phase AC supply.
- Appreciable power factor.
- Steady voltage within permissible limits of variation.

g Minimum interruptions in power supply with minimum duration of interruptions.

- Minimum voltage dips (very frequent/frequent/less frequent) within permissible limits.
- No voltage flickering.
- Reducing faults and strengthening the power supply.

h Be a Self Sustaining Business Organization.

Conductors - insulators - wires - types

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

Conductors and insulators

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

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

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

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

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

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

Conductors

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

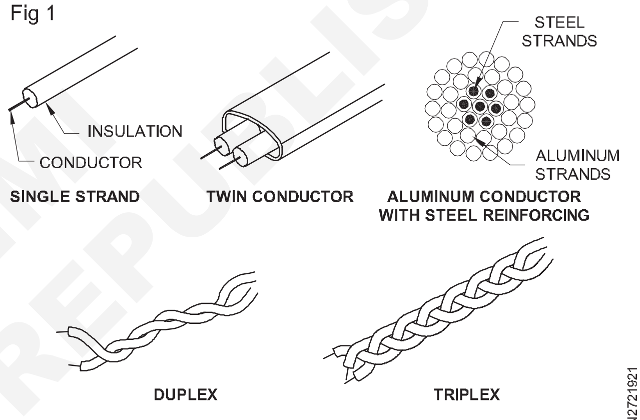
The I E regulations and I S cover all electrical conductors listing the minimum safety precautions needed to safeguard people, buildings and materials from the hazards of using electricity.

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

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

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

Fig 1



VARIOUS FORMS OF CONDUCTOR

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

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

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

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

Size of conductors

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

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

Classification of conductors

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

Bare conductors

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

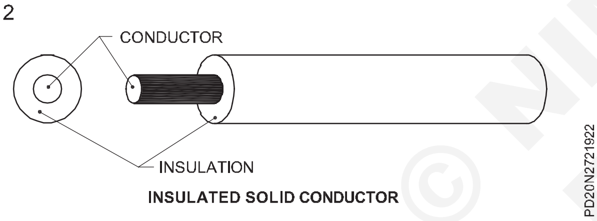
Insulated conductors

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

Solid and stranded conductors

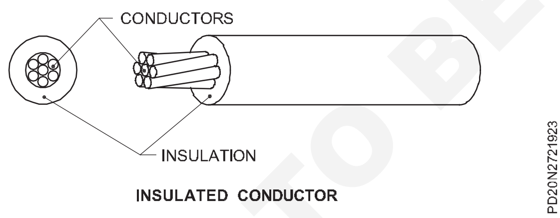
A solid conductor is one in which there will be only one conductor in the core as shown in Fig 2. A stranded conductor is one in which there will be a number of smaller sized conductors twisted to form the core as shown in Fig 3.

Fig 2



INSULATED SOLID CONDUCTOR

Fig 3



INSULATED CONDUCTOR

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

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

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

Cable

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

Cable (Armoured)

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

Cable (Flexible)

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

Core

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

Wire

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

Copper and aluminium

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

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

Characteristics of copper

1 It has the best conductivity next to silver.

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

3 It can be drawn into thin wires and sheets.

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

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

6 It is durable and has a high scrap value.

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

Characteristics of aluminium

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

2 It is lighter in weight.

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

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

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

6 It is cheaper than copper.

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

Table 1

Characteristics of conductor materials

S. No.	Properties	Copper (Cu)	Aluminium (Al)
1	Colour	Reddish	White brown
2	Electrical conductivity in MHO/metre	56	35
3	Resistivity at 20°C in ohm/ metre (Cross-sectional area in 1 mm2)	0.01786	0.0287
4	Melting point	1083°C	660°C
5	Density in kg/cm3	8.93	2.7
6	Temperature coefficient of resistance at 20°C per °C	0.00393	0.00403
7	Coefficient of linear expansion at 20°C per °C	17 x 10-6	23 x 10-6
8	Tensile strength in Nw/mm2	220	70

Types Of Conductors Used In Overhead Power Lines

A conductor is one of the most important components of overhead lines. Selecting a proper type of conductor for overhead lines is as important as selecting economic conductor size and economic transmission voltage. A good conductor should have the following properties:

- High electrical conductivity.
- High tensile strength in order to withstand mechanical stresses.
- Relatively lower cost without compromising much of other properties.
- Lower weight per unit volume.

Conductor Materials

Copper was the preferred material for overhead conductors in earlier days, but, aluminium has replaced copper because of the much lower cost and lighter weight of the aluminium conductor compared with a copper conductor of the same resistance. Following are some materials that are considered to be good conductors.

- **Copper:** Copper has a high conductivity and greater tensile strength. So, copper in hard drawn stranded form is a great option for overhead lines. Copper has a high current density which means more current carrying capacity per unit cross-sectional area. Therefore, copper conductors have relatively smaller cross-sectional area. Also, copper is durable and has high scrap value. However, due to its higher cost and non-availability, copper is rarely used for overhead power lines.
- **Aluminium:** Aluminium has about 60% of the conductivity of copper; that means, for the same resistance, the diameter of an aluminium conductor is about 1.26 times than that of a copper conductor. However, an aluminium conductor has almost half the weight of an equivalent copper conductor. Also, tensile strength of aluminium is less than that of copper. Considering combined factors of cost, conductivity, tensile strength, weight etc., aluminium has an edge over copper. Therefore, aluminium is being widely used for overhead conductors.

  AAC, AAAC, ACSR form part of the family of Overhead Conductors, Transmission Conductors and Power Distribution Conductors. These cables are formally known as All Aluminium Conductor (AAC), All Aluminium Alloy Conductor (AAAC) and Aluminium Conductor Steel Reinforced (ACSR). These overhead aluminium conductors are used as power transmission and distribution lines. All aluminium conductors are made up of one or more strands of aluminium wire depending on the specific application.

Aluminium Overhead Line Specification

AAC–ASTM-B All Aluminium Conductor

AAC are a refined Aluminium stranded conductor with a minimum metal purity of 99.7%. It is principally used in urban areas where spacing is short and the supports are close. It can be used in coastal regions owing to its high degree of corrosion resistance and is also used extensively within the Railway and Metro industries.

AAAC-ASTM-B All Aluminium Alloy Conductor

AAAC are used as a bare conductor cable on aerial circuits that require a larger mechanical resistance than the AAC and a better corrosion resistance than the ACSR. The sag characteristics and the strength-to-weight ratio of the AAAC conductor cable is better than both AAC and ACSR.

ACSR-ASTM-B Aluminium Conductor Steel Reinforced

ACSR are available in a range of steel contents ranging from 6% to 40% for additional strength. The higher strength ACSR conductors are commonly used for river crossings, overhead earth wires, and installations involving extra-long spans. The ACSR conductor can, against any given resistance, be manufactured to different tensile strengths, so a high tensile strength combined with its lightweight properties means it can cover longer distances with fewer supports. Due to the greater diameter of the ACSR conductor, a much higher corona limit can be obtained which is advantageous on high and extra high voltage overhead lines.

Current rating of conductors

Objective: At the end of this lesson you shall be able to
- **current rating of conductors.**

Distributors designed from the point of view of a)its current carrying capacity b)operating voltage c)voltage drop in it. d)operating frequency. Distributors designed from the point of view ofa)its current carrying Distributors are an essential component of electrical power systems. They are used to distribute the electrical power from the main source of power to various loads. Distributors are designed to ensure that the voltage drop in the system is minimized. The following are the reasons why distributors are designed from the point of view of voltage drop: Voltage Drop The voltage drop is the difference in voltage between the source and the load. It is caused by the resistance of the conductor that carries the current. The voltage drop is an important consideration when designing distributors because it affects the efficiency of the system. If the voltage drop is too high, the load will not receive the required voltage, and the system will be inefficient. Current Carrying Capacity The current carrying capacity of the distributor is the maximum amount of current that it can carry without overheating or damaging the conductor. The current carrying capacity is determined by the size of the conductor, the material used, and the cooling mechanism. While the current carrying capacity is an important consideration, it is not the primary concern when designing distributors.

Technical data for 1100 Volts pvc Insulated cables as per IS:694

Finecab 1100 volts single core FR/FRLSH PVC insulated multistrand copper conductor cables conforming to IS:694

Nominal area of conductor	Nominal thickness of insulation	Nominal overall diameter	Max. conductor resistance at 20°c	Current carrying 2 cables, Single phase AC	
				Enclosed in conduit / Trunking	Unenclosed clipped to a surface or on cablee tray
Sq.mm	mm	mm	Ohms / Km	Amps	Amps
1.0	0.70	2.8	18.10	11	12
1.5	0.70	3.1	12.10	13	16
2.5	0.80	3.8	7.41	18	22
4.0	0.80	4.6	4.95	24	29
6.0	0.80	5.3	3.30	31	37

Note: Sizes 1.0 to 2.5 sq.mm. are with conductor class 2 and 4.0 to 6.0 sq. mm are with conductor class 5

Finecab 1100 volts single core pvc insulated multistrand copper conductor industrial wiring cables.

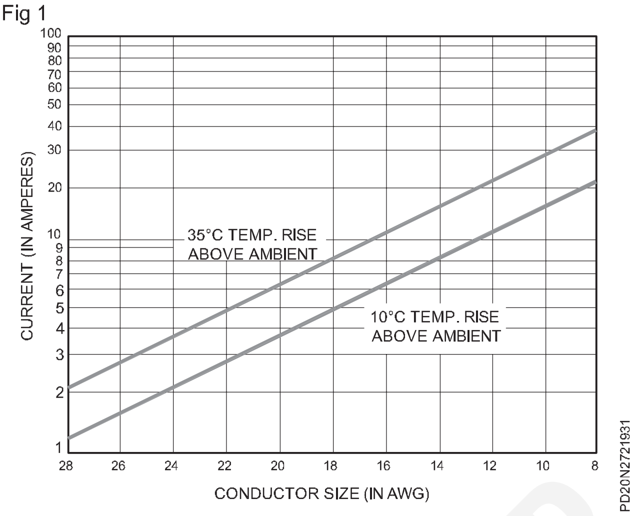
Nominal area of conductor	Nominal thickness of insulation	Approx overall diameter	Max. conductor resistance at 20°c	Current carrying capacity bunched & enclosed in conduit or trunking		Current carrying capacity clipped direct to a surface or on cable tray bunched & unenclosed	
				2 Cables single phase AC or DC	3 pr 4 Cables single 3 phase AC	2 Cables single phase AC or DC	3 or 4 Cables single 3 phase AC
Sq.mm	mm	mm	Ohms / Km	Amps	Amps	Amps	Amps
10	1.0	6.5	1.91	42	35	51	45
16	1.0	7.5	1.21	57	48	68	61
25	1.2	9.5	0.780	71	60	86	78
35	1.2	10.5	0.554	91	77	110	99
50	1.4	12.0	0.386	120	100	145	135

Current Ratings

In electronic cables, the maximum continuous current rating is limited by the size of the conductor, the total number of conductors within the cable, and conditions within the surrounding environment including ambient temperature and airflow.

To use the current capacity chart, determine the conductor size of the desired wire to be used, as well as the temperature rating and the number of conductors. Then find the current value on the chart for the proper temperature rating and conductor size. In order to calculate the maximum current rating per conductor, you have to multiply the chart value by the appropriate conductor factor found in the table below. This chart assumes that the cable is surrounded by still air at an ambient temperature of 25°C. These currency values are in RMS Amperes and are only valid for copper conductors.

Fig 1



Wire joints - Types - Soldering methods

Objectives: At the end of this lesson you shall be able to
- **state the different types of wire jointsand their use**
- **state the necessity of soldering and types of soldering**
- **state the purpose and types of flusxes**
- **explain the different method of soldering and techniques of soldering**
- **explain the type of solder and flux used for soldering aluminium conductor.**

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

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

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

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

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

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

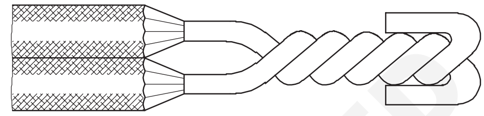
Some of the commonly used joints are listed below.

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

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

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

Fig 1



RAT TAIL JOINT

PD20N2722211

Fig 2

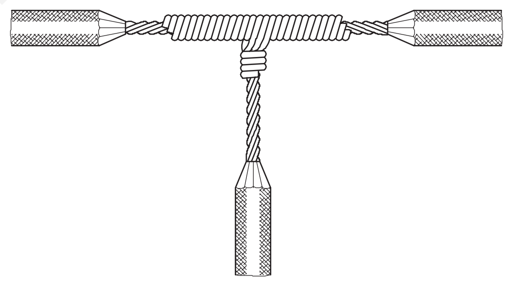
MARRIED JOINT

PD20N2722212

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

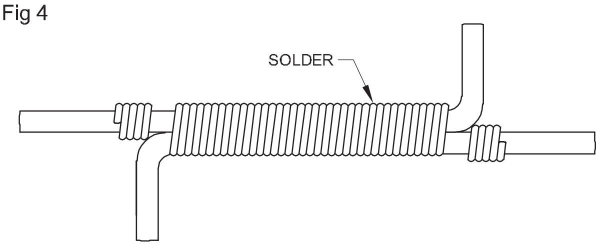


TEE JOINT

PD20N2722213

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

Fig 4



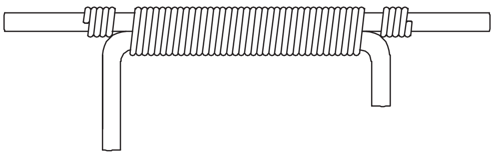
BRITANNIA JOINT

PD20N2722214

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

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

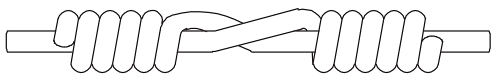
Fig 5



BRITANNIA TEE JOINT

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.

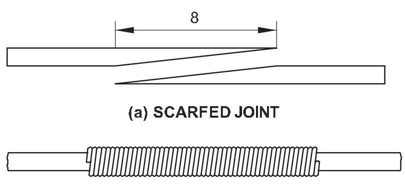
Fig 6



WESTERN UNION JOINT

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



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

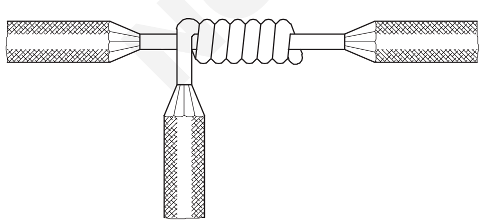
By definition, a tap is the connection of the end of one wire to some point along the run of another wire.

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.

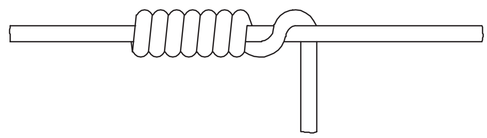
Fig 8



PLAIN TAP JOINT

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

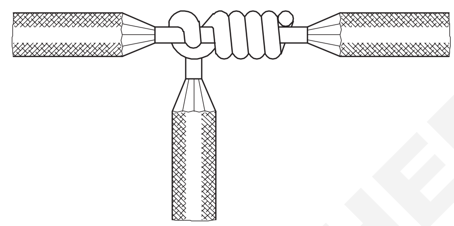
Fig 9



AERIAL TAP JOINT

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

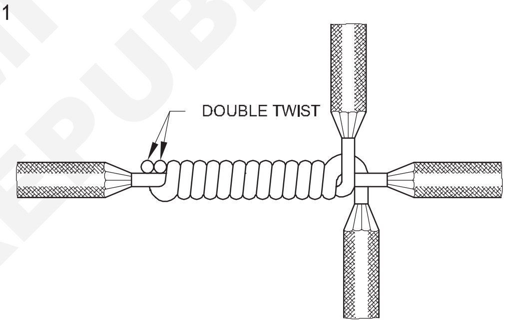
Fig 10



KNOTTED TAP JOINT

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.

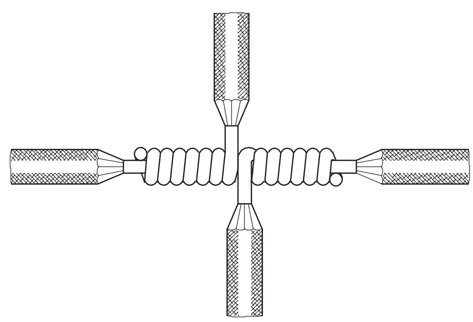
Fig 11



DUPLEX-CROSS TAP JOINT

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

Fig 12



DOUBLE-CROSS TAP JOINT

ABC System

Aerial Bunch Cables is an excellent idea derived to provide electricity or power through a procedure of overhead power distribution. These cables are used in cities where aerial power supply is prefered. These cables are better than bare conductor overhead distribution system which isn't safe and reliable. Aerial Bunch Cables or simply ABC provides a safer way to distribute an overhead supply of electricity/ Power.

ABC or Aerial Bunch Cables are placed mostly in the densely populated cities. The reason behind this is simple, underground cables are difficult to set up in densely populated cities because of the complex structure and layout of the cities: narrow roads and drainage system. These two structure complexities actually hinder the process of laying out underground cables. The most effective, efficient, and feasible way to set up the power distribution system is to use ABC for overhead power distribution.

Aerial Bunch Cables are highly effective as they supply power while lowering power loss. These cables are cost efficient too.

It is a system of Overhead Insulated Conductors bundled and laid up as

Overhead cables on the distribution poles. It is of two types :

LT ABC and HT ABC

Prominent Considerations for Selection of ABC System

a Elimination of cable trenching work in grounds, especially important at places having high water table, making trenching difficult, and along narrow streets, which may cause serious public inconvenience.

b Utilization of existing assets such as poles and structures for supporting the cable, which leads to reduced cost of installation.

c Elimination of cable faults due to digging and damages caused by other agencies.

d Speedy service connections in LT distribution.

LT ABC

In LT ABC'S the following two types are commonly used.

- An un-insulated (base) steel or AAAC centenary supporting the phase and neutral conductors and one or two lighting conductors.
- An insulated AAAC combined neutral and centenary supporting the phase conductors and one or two lighting conductors.

HT ABC

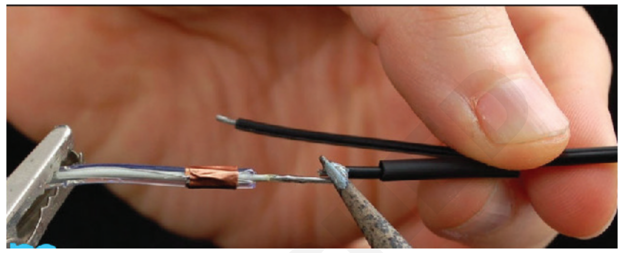
HT ABC are meant for high power LT ADC for low power distribution. They have induced conductors which in normal cells are applied externally. This save money and human resources.

An uninsulated steel or AAAC catenary wire supporting the three phase conductors insulated with HT insulation.

This is also called as fully insulated HT ABC.

Here copper screen wires provide a higher cross-sectional area for the flow of earth fault current.

Fig 13



Whether wiring a motor or repairing a broken appliance, joining aluminum wires correctly and safety is essential.

Methods of Joining Aluminum Wires

The most common way to join aluminium wires is by using crimp terminals. Crimp terminals are small metal sleeves that fit over stripped wire ends and then get compressed with crimping pliers. Crimp terminals come in different sizes and styles depending on the application. Once crimped, they provide an electrical connection between two aluminum wires that can withstand vibration and temperature changes. However, ensuring the crimped connection is secure before relying on it for any electrical circuit is important.

Conclusion:

Joining aluminium wires correctly is essential if you want your electrical circuit to work properly and stay safe from harm! When connecting two aluminum wires, there are three main methods you can choose from – crimp terminals, solderless splices, or soldering with flux – each of which has its advantages and disadvantages, depending on the application. Whichever method you choose, always ensure your connections are secure before relying on them for any power supply!

Joining of aluminium conductor

Objective: At the end of this lesson you shall be able to
- **method of joining aluminium conductor.**

Joining accessories in O.H lines: Normally connectors are used for joining the O.H. aluminium conductors. Connectors maybe of several types of which few are described below.

1 Sleeved joints

2 Straight through connectors / taps

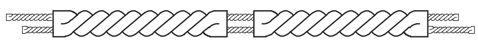
3 Vice - clamp connectors /taps with parallel grooves

4 Nut and bolt connector

Sleeved joints

Twisted joints: Oval shaped aluminium sleeves are inserted over the conductors to be joined and then twisted as in Fig 1.

Fig 1

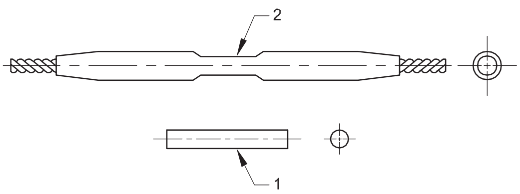


TWISTED JOINTS

Only one sleeve is sufficient for all aluminium conductors whereas two concentric sleeves are used for ACSR conductors. One each for the aluminium and steel portions. Twisting joints are recommended for conductors up to 15 mm diameter. Only special wrenches should be used for twisting the sleeves.

Compression joints: ACSR conductors are joined by compression joints having two sleeves as in Fig 2. The larger sleeve is of aluminium , fitting over the entire conductor, and the smaller one is of steel fitted on the steel portion of the wire eccentrically. Conductors to be joined are inserted into the sleeves one after the other and compressed either by hand or by hydraulic compressors. Compression joints for all aluminium conductors consist of aluminium sleeve only .

Fig 2

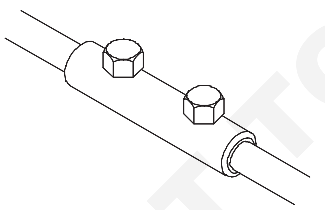


COMPRESSION JOINT FOR ASCR

Straight through connectors / taps: Two types of connectors are used to join two straight through run of wires in such locations where mass concrete foundations are to be adopted to avoid collapse of foundation in the black cotton soil.

Straight sleeve and nut connector: This is in Fig 3. It has a sleeve (round or oval in section) made of cadmium plated brass or aluminium. The conductors are inserted into the sleeve and tightened by the nuts.

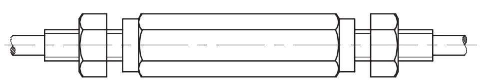
Fig 3



STRAIGHT SLEEVE AND NUT

Compression connector: In this, the conductors are wrapped at both ends and then compressed with nuts as in Fig 4.

Fig 4



COMPRESSION CONNECTOR

Vice-clamp connectors/taps with parallel grooves (PG): There are several types as explained below.

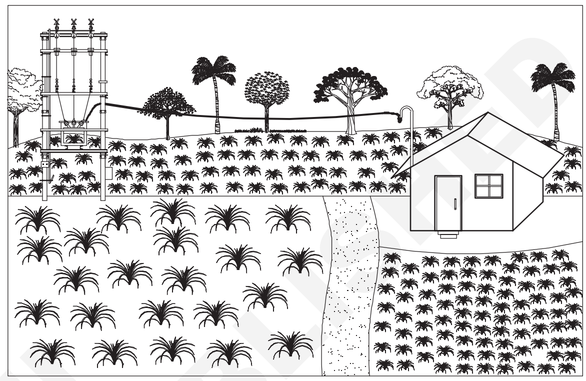
Standard P.G. clamps: This clamp as in Fig 5 consists of two aluminium halves, having two semi-circular parallel grooves in each half. After inserting the conductors to be joined, the galvanized steel nuts.

High voltage distribution system (HVDS)

As you would know, significantly high losses take place in the secondary distribution system. This is due to the higher current densities and the ease of pilferage at low voltages. One of the latest innovations in efforts to reduce technical and commercial losses is the use of High Voltage Distribution System (HVDS) or LT-less (almost!) system.

Typing high voltage distribution system

Fig 5



Adavantages of HVDS

We now describe the advantages of HV or HT distribution compared to conventional LV or LT distribution system. Low Losses and Improved Voltage Profile The comparison of current losses and voltage drop for the distribution of the same power through HT and LT systems is presented in Table 2.1. We have considered 100 as the base value for LT system. From the table, you can see that for the distribution of the same power, technical losses and voltage drop are much less in HT distribution system when compared to LT distribution systems.

Comparison of Current, Voltage Drop and Power Losses for Power Distribution through HT and LT Distribution Systems

	Single phase 6.35 kV HT distribution system	3 phase 415 V LT Distribution system
Current (Amps)	11.0	100.0
Losses (kW)	8.5	100.0
Voltage drop(V)	12.7	100.0

LT distribution systems are easily accessible and prone to pilferage and the use of HVDS reduces the chances of theft of electricity to a very low level. Now-a-days, utilities are installing meters at the HT transformer itself to ascertain commercial losses on that particular transformer. To sum up, the HT distribution system has the following advantages :

- Use of small size ACSR or aluminium alloy conductor or high
- Conductivity steel wire;
- Better voltage profile;
- Reduced Line Losses; And
- Reduced Commercial Losses.

Improved Reliability and Security of Supply

The use of HT distribution leads to improved reliability and security of supply for the following reasons:

The Faults on HT Lines are Far Less Compared to those of LT Lines.

In order to avoid theft in LT lines from transformer to consumer premises, usually Aerial Bunched Cables (AB Cables) are used to supply power at LT to consumer from the distribution transformer. With AB Cables, the faults on LT lines are almost eliminated. This, in turn, reduces the failure rate at the distribution transformers and enhances reliability of supply.

Since the number of the small capacity distribution transformers is higher in the HVDS, the failure of one transformer affects only a limited number of consumers, and does not affect supply to the other consumers connected to other transformers. In the event of failure of distribution transformers, only a small number of consumers (2 to 3 power consumers or 10 to 15 domestic consumers) would be affected. On the other hand, a large distribution transformer supplies power through LV distribution lines to even remotely located consumers in LVDS. Hence, the failure of an existing large size distribution transformer would affect a group of 40 to 50 power consumers and/or 100 to 200 domestic consumers.

Route survey for overhead distribution system

Objective: At the end of this lesson you shall be able to
- **describe the route survey, safery procedures, its operation and maintenance.**

The first step before any construction of the distribution lines in the electrical system is an initial Survey of the proposed line route, it is really essential to create a proper detailed survey of the area where the power line is passed and the survey map should consist the road crossings streams, rivers, railway line, brides, houses, commercial building and all necessary construction which affected the area of the power line. These survey maps are really helpful in the design process where the optimal changes can add into where it is necessary

While on the initial survey and the initial planning of the respective electrical power line there are special things to make consider to have a better initial design.

Normally the shortest route is the best route. Because when creating a power line the cost also getting higher proportion to the distance So it really needs to keep in mind that the line distance should be shortest as practicable

Normally after the construction of power line, the routine maintenance and breakdown need to take care

It is really good to have better access to those lines and towers with short time. So when there are access roads are close to power lines it is really great to perform maintenance in snort period. So while designing and construction of the power line the accessibility also needs to take care

While construction of the distribution line it is also better to consider the places where the demand gets high in future. When the demand is getting high it is much easier to connect those demand into existing line rather then creating a new line to the demand growing area.

One of the main construction parts of any distribution power line is an electrical tower. When the towers in lines go the straight way it mentions as suspension towers

When the towers go in a zig zag like shapes those towers are known as angle towers. Normally the construction costs of the angle towers are higher than the normal tower So it is really essential to minimize the number of angle towers while construction and design of the electrical power line

Before doing a detailed survey it is better to do a preliminary walkover survey to find out the and have a general idea on what are this line route looks like

While on preliminary walkover survey find out the path where the minimum tree growth and if there are any alternative paths can use for the line route, it is also better the have check on these routes also to find out the optimum economical route path.

Normally details survey performed by the professional surveyor by using theodolite Normally angle towers are marked with survey stones while performing the detailed surveying.

All important parameters need to show in detail on survey maps such as, other extra high tension line crossings, river crossings, crossings of railway and roads, etc.

Ones the surveyed line is fixed it needs to get approval from other government authorities to avoid conflicts.

Route survey for underground distribution system

Objective: At the end of this lesson you shall be able to
- **describe the route survey for UG distribution system, safety procedures, its operation and maintenance.**

Selection of the cable route

Prior to start excavation of cable trench, conduct a preliminary survey of the cable route and prepare a plan drawing and obtain approval from all concerned authorities if necessary. Following points may be considered while selecting cable route.

1 Select the shortest but the easiest route to reduce the overall cast.

2 Due consideration shall be given for access/ transportation of cable drums. Check the road conditions, turns and width.

3 As far as possible avoid paved roads and follow the footpaths.

4 The route should be as far as possible, away from parallel running gas, water pipes and telephone/ telecommunication cables.

5 Suitable locations for cable joints and terminations should be selected as required.

6 Take due consideration of future expansion or upgrading the system.

Electrical safety procedure

Introduction

Electricity has become an essential part of our everyday life. It is used to power research equipment,office equipment, heating and cooling equipment, etc. Electricity can be dangerous, causing shocks, fires, explosions, or burns. Accidents involving electricity may cause minor injury or may result in serious disabling injuries or death. Electricity must be recognized and respected as a serious workplace hazard.

Most injuries involving electricity could have been prevented if unsafe equipment had been taken out of service or if unsafe work areas and work practices did not exist. To minimize the risk of injury from electrical sources, it is necessary to assure that electrical "sources" are properly insulated and grounded, that circuit-protecting devices are utilized, and that safe work practices are followed.

Procedures:

The required training and work procedures include but are not limited to:

1 De-energized parts

2 Verification of de-energization

3 Re-energization

4 Distinguish live parts from other parts

5 Work on or near overhead power lines

6 Portable ladders

7 Conductive apparel

8 Housekeeping duties

9 Electrical safety interlocks

10 Lockout/tagout

11 Cord and plug connected equipment

12 Eye and face protection

13 Safe clearance distances for voltages, and

14 Insulated tools.

Responsibility :

Each department is responsible for complying with this section.

Electrical safety-related work practices apply to:

Qualified persons - those familiar with the construction and operation of electrical equipment, and the hazards involved and who have training in avoiding the electrical hazards of working on or near energized parts;

Unqualified persons - those with little or no such training working on, near or with the following installations:

- Premises Wiring: Installations of electric conductors and equipment within or on buildings or other structures, and on other premises such as yards, parking lots, other lots, and industrial substations.
- Wiring for connection to supply: Installations of conductors that connect to the supply of electricity.
- Other Wiring: Installations of other outside conductors on the premises.
- Optical Fiber Cable: Installation of optical fiber cable where such are made along with electric conductors.

Other work covered by unqualified persons includes work on, near or with:

- Generation, transmission, and distribution installations
- Communications installations
- Installations in vehicles
- Railway installations

Excluded work by qualified person includes work on or directly associated with the following installations:

- Generation, transmission and distribution installations for the generation, control, transformation, transmission, and distribution of electric energy (including communication and metering) located in buildings used for such purposes, or located outdoors.

Note 1: Included in this practice is work on or directly with installation of utilization equipment that is not an integral part of a generating installation

Note 2: Work on or directly with generation, transmission, or distribution installations includes:

a Repairing overhead or underground distribution lines or repairing a feed-water pump for the boiler, in a generating plant.

b Line-clearance, tree trimming and replacing utility poles.

c Work on electric utilization circuits in a generating plant provided that:

- Such circuits are co-mingled with installations of power generating equipment or circuits; and

- The generation equipment or circuits present greater electrical hazards than those posed by the utilization equipment or circuits (such as exposure to higher voltages or lack of over current protection).

- Installations in vehicles include: ships, watercraft, railway rolling stock, aircraft, or automotive vehicles other than mobile home and recreational vehicles.
- Railway installations for generation, transformation, transmission, or distribution of power used exclusively for operation of rolling stock or installations of railways used exclusively for signaling and communication purposes.

Safe working practices:

1 Electrical cords must be inspected for frays, cracks, exposed wires, and to ensure that the insulating jacket is intact. Check the plug and cord for defects, and

replace or repair prior to further use.

2 Electrical cords must not come in contact with heat sources such as pipes or radiators, hazardous substances, or sharp objects and must not be run through water.

3 Equipment must not be placed where the electrical connection could be hit, tripped over, or walked on.

4 Extension cords shall not be used as a permanent source of wiring.

5 Electrical utility rooms containing circuit breakers shall not be blocked with equipment, clutter, etc. Equipment/articles should not be placed within three feet of a circuit breaker.

6 Employees should know the location of circuit breakers in their work area.

7 Circuit breaker switches must be identified as to the equipment controlled.

8 Multi-plug adaptors (inclusive of extension cords, cube adaptors, and strip plugs) must meet the following requirements:

- Nationally recognized testing laboratory approval.
- Insertion into a properly grounded outlet and not used in tandem or in conjunction with other adaptors.
- Current breaker overload safety device and not exceed a maximum rating of 15 amps.
- Protection from physical damage, not affixed to structures or extended through walls, ceilings, floors, under doors or floor coverings or be subject to any damage/impact.
- No alterations in any manner.

9 De-energize electrical equipment before inspecting or making repairs. Prior to inspecting or repairing equipment, turn off the current at the switch box and lockout/tagout the system. Accidental or unexpected sudden starting of electrical equipment can cause severe injury or death.

10 Check the receptacle for missing or damaged parts. Do not plug equipment into defective receptacles.

11 When plugging in or unplugging power equipment, the power switch must always be in the OFF position.

12 Plugs must not be removed from outlets by yanking the cord.

13 Care must be taken when electrical equipment is used in areas where oxygen, flammable gases, or anesthetics are present. Sparks from electrical equipment can cause a fire or explosion.

14 Insulated tools are recommended when working near energized equipment.

15 When working with equipment that may pose an electrical hazard, wear the proper personal protective equipment, e.g., rubber, insulating gloves; hoods; sleeves; helmets; shoes; etc.

16 Prior to beginning a task that may involve an electrical hazard, be sure you are familiar with all safety procedures.

17 Supervisors are responsible for assuring that equipment such as radios, coffee pots, etc., meet the guidelines for proper grounding and other electrical safety standards.

18 In the event that a fellow employee receives an electric shock, turn off the current. Do not touch the victim until he or she can be separated from the current source. Use a nonconductive item such as a wooden broomstick

Permit to work

Procedure for Permit to Work (Line Clear)

A line clear or a permit to work (PTW) on any electrical equipment or line is issued by a duly authorised person to another duly authorised maintenance person. If there are more than one gangs working under the same supervisor, each gang takes sub-line clears from the supervisor who has taken the line clear. In case, the line clear has to be issued for the supervisor, s/he takes self line clear. In this case also, all the precautions that are to be followed in issue and return of line clear are followed.

Line clear books are very important records. Pages in these books are serially numbered and no paper from this book is used for any other purpose. If any page is to be destroyed, the custodian specifically mentions the reasons for doing so. It is attested by his/her dated signature. The line clear books are reviewed periodically by the Competent Authority.

Line clear can be issued/received over telephone. It is desirable that the issuer/receiver recognize each other's voice. Else, there must be a clear identification of the person. The requisition for line clear and the line clear issue messages are repeated by both the parties to ensure that line clears are issued/received on the equipment on which it is intended. A secret code number is followed in such cases.

Operation and maintenance of distribution system

Operation and Maintenance

The O and M issues properly documented manuals for each and every substation equipment and distribution lines, so that the maintenance personnel know the standards prescribed for the equipment. Adhering to these standards would ensure the smooth operation of the equipment. The distribution system constitutes the interface of a utility with its consumers, who judge the performance of the utility by the performance of its distribution system. Therefore, proper operation and maintenance of the power distribution system is essential.

Any failure on this account may deprive the user of electric supply and lead to chaotic conditions. There are two types of maintenance:

Preventive Maintenance and Breakdown Maintenance.

There is also Condition Based Maintenance, but it shall not be considered here.

Preventive Maintenance is maintenance done on a routine basis and as suggested by the O & M. In practical terms, it is the maintenance activity mainly undertaken prior to the onset of Monsoon and after the end of Monsoon.

Breakdown Maintenance is done on the failure of any equipment, i.e. on breakdown in the installation.

Let us now discuss the general O & M objectives and activities for the power distribution system.

Objectives of Operation and Maintenance

The prime goal of a power utility, like any other business is to achieve consumer satisfaction with optimum effort and costs while maintaining reasonable profit levels. The operation and maintenance (O & M) practices of a utility contribute significantly in attaining this goal. These activities should help in improving the reliability and the useful life of the plant and equipment, maximising the capacity utilisation, increasing the operating efficiency, and reducing the operation and maintenance cost.

The objectives of O & M for distribution systems may thus be spelt out as follows.

For Distribution System :

- Ensuring quality and reliability of supply to consumers.
- Reducing equipment operating and maintenance costs through effective utilisation of capacity and resources.
- Increasing the availability and reliability of plant and equipment with effective maintenance planning.
- Improving spares planning and reducing spares inventories.
- Standardising work procedures.
- Ensuring the safety of maintenance personnel.
- Providing a mechanism for making estimates and controlling maintenance expenses.
- Generating MIS reports for better decision-making and control.
- Bringing down technical and commercial losses to an optimum minimum level.
- Avoiding any bottleneck in capacity by matching expansion with the growing demand.

Activities Involved in Operation and Maintenance

The following activities are involved in the operation and maintenance of the Distribution System :

- Continuity of service;
- Technical Operation and Maintenance;
- Training and retraining of operational staff;
- Renewal of maintenance contract;
- Upkeep of spare parts inventory;
- Record keeping of faults in the network/ equipment problems,solutions, modifications and enhancements;
- Close monitoring of budgeted expenditure;
- Preparation, continuous updating and proper maintenance of operational and network data;
- Record of protective and isolating devices installed and their relay settings;
- Record of schedule of maintenance and preventive and routine maintenance of network elements;
- Development of spare parts;

Supports and Accessories in Over Head System

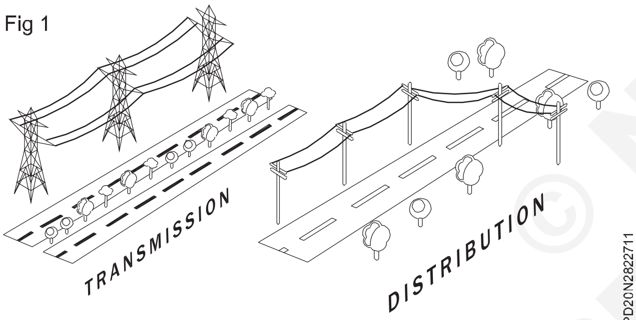
Objectives: At the end of this exercise you shall be able to
- **identify different types of poles, towers and accessories**
- **identify different type of Line Insulators**
- **understand different foundations.**

Transmission & Distribution

Transmission and distribution refers to the different stages of carrying electricity over poles and wires from generators to a home or a business. The primary distinction between the two is the voltage level at which electricity moves in each stage.

After electricity has been generated, a system of electrical wires carries the electricity from the source of generation to our homes and businesses. These lines can be found overhead or sometimes in the ground, and, combined, transmission and distribution lines make up what is commonly called "the grid." Transmission and distribution are two separate stages or systems on the grid.

Fig 1



Transmission is the "interstate highway" of electricity delivery. It refers to the part of electricity delivery that moves bulk electricity from the generation sites over long distances to substations closer to areas of demand for electricity. Consumers may recognize transmission lines as the larger, taller poles/towers carrying many wires over longer distances. Transmission lines move large amounts of power at a high voltage level – a level that is too much to be delivered directly to a home or business. Transmission lines, transformers, substations and other equipment have voltages of 100 kV (100,000 volts) and above.

Transmission Line Supports

The supporting structures used for overhead transmission line conductors, such as poles and towers, are called the transmission line supports.

Generally, the transmission line supports supposed to possess the following properties −

- The line supports should have high mechanical strength so that it can withstand the weight of conductors and wind loads, etc.
- It should be light in weight without the loss of its mechanical strength.
- It should have longer life.
- It should be cheap in cost and economical to maintain.
- Accessibility of line conductors for maintenance is to be easy.

There are various types of line supports available. The choice of supporting structure for a particular case depends upon the line span, area of cross-section, transmission line voltage, cost and local conditions, etc.

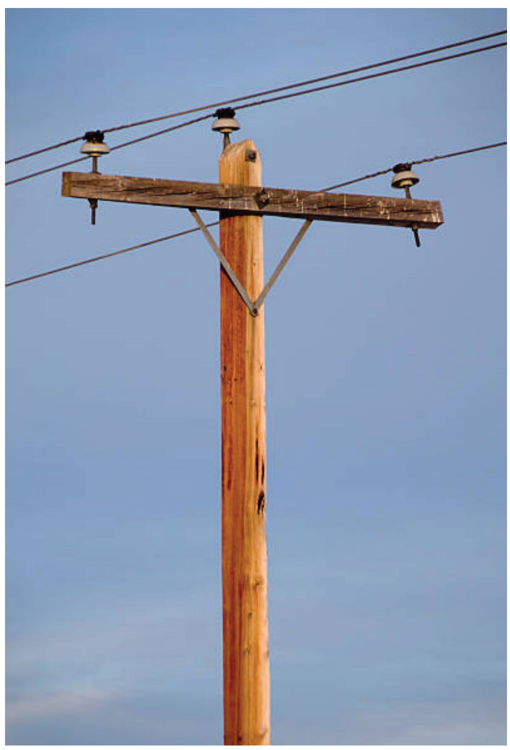
Types of Line Supports

The line supports used for transmission and distribution of electrical power are classified into following types-

- Wooden Poles
- Steel Poles
- R.C.C. Poles
- Lattice Steel Towers

Wooden Poles

Fig 2



The wooden pole supports are made up of seasoned wood such as sal or chir and are suitable for the transmission lines of moderate cross-sectional area and of relatively shorter spans up to 50 meters. The advantage of wooden supports are as follows –

- Cheap
- Easily available
- Provides insulating properties, etc.

Therefore, the wooden poles are widely used for distribution purposes in rural areas as an economical proposition. However, the wooden poles tend to rot below the ground level and hence, causing the foundation failure. Therefore, to prevent this, the portion of the pole below the ground level is impregnated with preservative compounds like creosote oil.

Also, the double pole structures of the 'A' or 'H' type are often used to obtain a higher transverse strength. The primary objections to the wooden pole supports are as follows-

- Tendency to rot below the ground level.
- Smaller life (about 20 to 25 years).
- Cannot be used for high voltages (> 20 kV).
- Have less mechanical strength.
- Require periodic inspection and maintenance.

Steel Poles

Fig 3

The steel poles are generally used for distribution purposes in the cities. These line supports possess greater mechanical strength, longer life and longer span as compared to the wooden poles. However, the steel poles need to be galvanised or painted for preventing from the corrosion.

The steel poles are of following types–

- Rail Poles
- Tubular Poles
- Rolled Steel Joints

R.C.C. Poles

The RCC (Reinforced Cement Concrete) poles are also used for the distribution purposes and have become very popular as line supports in recent years. The RRC poles have the following properties–

- Greater mechanical strength
- Longer life
- Longer line span than steel poles
- Good insulating properties
- Require little maintenance, etc.

The main problem associated with the use of RCC poles is the high transportation cost owing to their heavy weight. Thus, these poles are often manufactured at the site so that the heavy transportation cost can be avoided.

Fig 4

Lattice Steel Towers

Fig 5

The steel towers are employed for the transmission of electrical power to long distances at high voltage (> 11 kV). The main properties of the steel towers are as –

- Greater mechanical strength
- Longer life
- Can withstand most severe climatic conditions
- Can be used for longer line spans. This reduces the risk of interrupted service due to broken or punctured insulation considerably.

In practice, the tower footings are grounded by driving rods into the earth. This minimises the lightning troubles since each tower acts as a lightning arrestor.

The tower supports can be either single circuit or double circuit. The double circuit tower support has the advantage that it ensures continuity of supply, i.e. if there is breakdown of one circuit, the continuity of supply can be maintained by the other circuit.

A transmission tower supports an overhead power line. The other names of transmission towers are power transmission towers, power towers, and electricity pylons. The transmission towers carry high-voltage transmission line to transport power from the generating station to electrical substations. The electrical substations transport power to the end users through distribution lines. The distribution line uses utility poles to carry the low-voltage conductor.

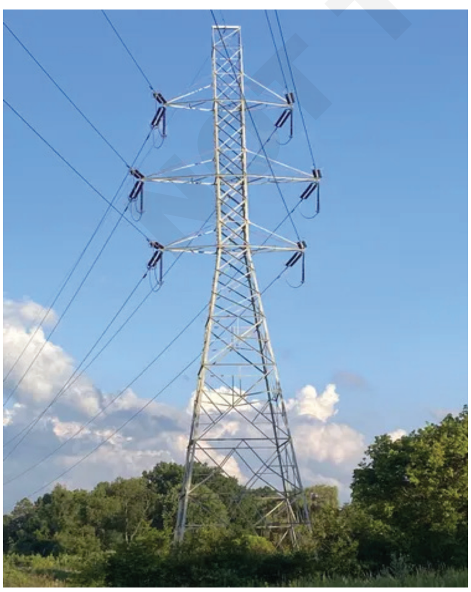
Transmission towers have to carry the heavy transmission conductors at a sufficient safe height from the ground. In addition to that, all towers have to sustain all kinds of natural calamities. Therefore, the transmission tower design is an important engineering job where civil, mechanical, and electrical engineering concepts are equally applicable.

In order to decrease the transmission losses, after the generation of power, we step-up the voltage in order to transmit it over a long distance. At receiving end, we again step down the voltage value and use it for electrical loads. There are various transmission lines at various voltage levels throughout the power system network in order to transmit the bulk power.

A transmission tower (usually a steel lattice tower) supports the overhead power line. Transmission towers have to carry the heavy transmission conductors at a sufficient safe height from the ground depending on the voltage (132kV/220kV/400kV/765kV). Thus, the transmission towers maintain the minimum ground clearance according to the system voltage.

Parts of Transmission Tower

Fig 6



An EHT transmission tower consists of the following parts:

1 The peak of the tower(the portion above the top cross arm)

2 The cross arm (Cross arms of the transmission tower hold the transmission conductor)

3 Cage of transmission tower(portion between tower body and the peak is known as a cage of transmission tower)

4 Transmission Tower Body(The portion from the bottom cross arms up to the ground level)

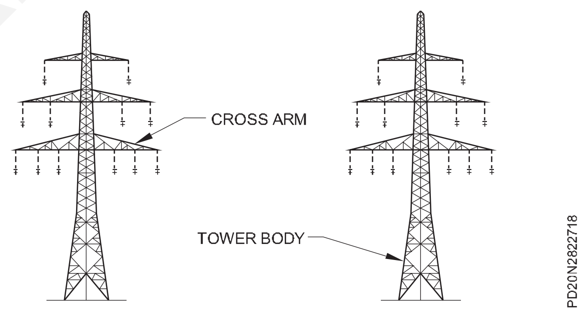
5 Leg of transmission tower

6 Stub/Anchor Bolt and Base plate assembly of the transmission tower.

Electrical Cross Arms:

Fig 7

Fig 8



Power pole cross arms

The electrical cross arm, also known as the power pole cross arm and utility pole cross arm, has different configurations in the electronic application setups. An insulator pin connects the pole cross arms while power delivery is made possible with the connection of the wire to the insulator.

To get the right electrical cross arm that is suitable for a specific application, you'd better know about all the types and installation processes involved, so you have a better idea about which one to install.

An electrical cross arm is composite equipment utilized in the pole line technology for holding electric equipment such as power lines. Only an efficient electrical cross arm will last long in tangent as well as dead end applications. For rightly fulfilling transmission and distribution needs, a well-engineered cross arm would ensure optimum performance.

Cross arm in transmission line

Electrical cross arms have different functions that adjust according to the type of application. The cross arm finds its use no only electrical utility companies and telephone companies but also refineries, cable companies, and railroads.

Electrical cross arms optimize the efficiency and resilience of the process in different conditions, such as weather change. It assists street light power lines when used in light poles, and supports conductors when used in distribution and transmission lines.

It also functions as a link for the insulator and the cable to the tower and provides a certain height to the conductor above the ground, which is another important requirement. The even spaces among the electrical cross arms are for the smooth and safe transmission of electricity.

Classification of Electrical Cross Arm

There are different types of electrical cross arms available in the market, with each having a specific function and installation process associated with it. These are categorized in terms of the nature of the job they do.

1 Power pole cross arms

The cross arms coming in the category of power pole cross arms connect the insulators to the conductors and ensure that there is a successful transmission of electricity.

2 Line-cross arms

This particular type of cross arms is utilized for short as well as long transmissions. The pole usually separates the cross arm, which distributes the weight in equal proportions. A straight line is usually used for the connection having a firm base of the electrical cross arm.

3 Side arms

Also known as the braced horizontal arm, the side arms connect to the pole on single circuits.

4 Telephone pole cross arms

These are the cross arms with the most extension as they enable multiple connections at a time on each side. Depending on the connection, the telephone pole cross arms present on a pole vary in number.

5 Light pole cross arms

These cross arms support different types of light poles such as traffic lights and street lights and have a varied length that depends on the total bulbs that will be supported on it.

Purpose of Electrical Cross Arms

Electrical cross arms are utilized for performing various tasks that are based on the application mode and are a crucial part of the infrastructure that is utilized on the telephone companies, railroads, electrical utility services, refineries, and cable companies. These applications need to have electrical cross arms that significantly improves the efficacy and the resilience of the whole system that withstands the different weather conditions.

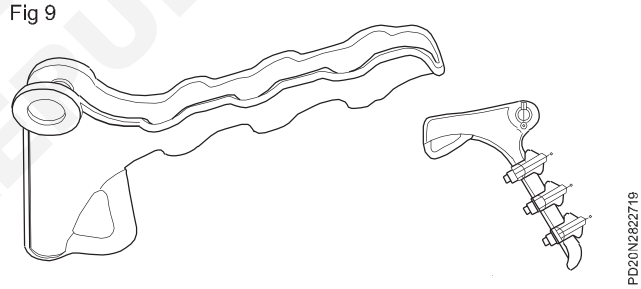
The purpose of the electrical cross arms in different light poles is to provide assistance for the power lines of street lights. The electrical cross arms are used for providing support to the conductors that are used in the distribution and the transmission lines. It is utilized in holding the insulator as well as the cable close to the main body which is commonly the tower. Moreover, it is highly essential for keeping the conductor above the ground level to ensure the safe and efficient flow of electricity. In addition, these cross arms are used .

Clamps & Connectors

1 Envelop type susp. Clamp

Generally used in normal suspension assemblies up to 220KV & in pilot assemblies for 400KV & above, hence also known as pilot clamps. Installation of Envelop type Susp. Clamps is comparatively easy. These clamps offer less power loss & heating due to hysteresis effects at higher currents.

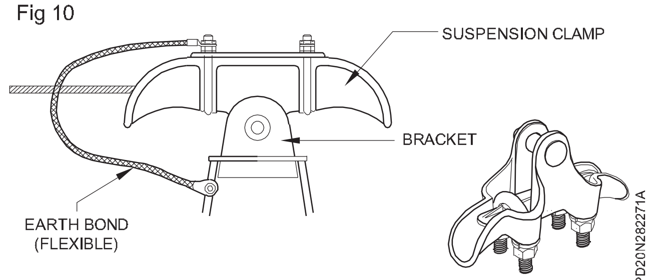
Fig 9



2 Bolted Type Tension clamps

These Clamps are made up of permanent mould aluminium alloy to reduce hysterisis and eddy current losses. These type of clamps are widely used in distribution lines, transmission lines up to 110KV & substations. The main feature of bolted tension clamp is ease in installation. Properly designed clamps can offer slip/mechanical strength up to 95% of conductor UTS.

Fig 10



3 Free Center Susp Clamps

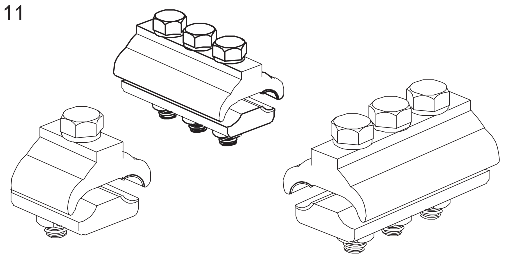
These clamps are widely used for line conductors up to 400KV voltage systems, with or without P A rods. The main features of this clamp are

1 Comparatively low power loss

2 High mechanical efficiency as centrally supported

3 Maximum swing mobility hence minimum moment of inertia resulting in minimum stresses on conductor during oscillation due to wind.

Fig 11



4 PG Clamps

Parallel groove clamps serve mainly for transmitting current between the interconnected conductors. They have grooves conforming to conductor sizes which ensures sufficient surface contact and low electrical resistance. The clamp body is made up of aluminium alloy cast out of permanent mould or made out of extruded alumimium.

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.

Properties of insulators

i High mechanical strength in order to withstand conductor load, wind load etc.

ii High electrical resistance of insulator material in order to avoid leakage currents to earth.

iii High relative permittivity of insulator material in order that dielectric strength is high.

iv The insulator material should be non - porous, free from impurities and cracks otherwise the permittivity will be lowered.

v High ratio of puncture strength to flash over.

The most commonly used material for insulators of overhead line is porcelain but glass, steatite and special composition materials are also used to a limited extent.

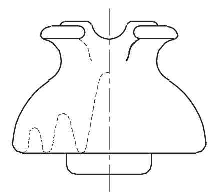
The following are the common types of insulators in use.

- 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

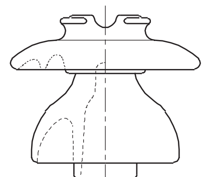
(Fig 2) and triple shed (Fig 3) The single -shed pin insulators are used for low and medium voltage lines. The double and triple shed pin insulators are used for over 3000V. These sheds are used to drip off the rain water.

Fig 1



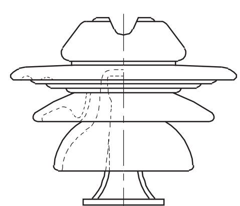
SINGLE SHED TYPE OF PIN INSULATOR

Fig 2



DOUBLE SHED TYPE OF PIN INSULATOR

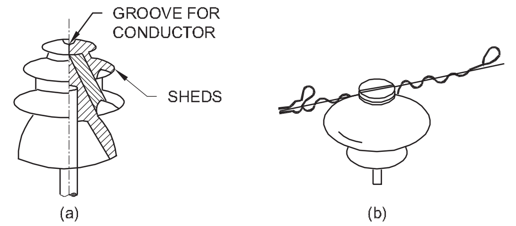
Fig 3



TRIPLE SHED TYPE OF PIN INSULATOR

The part section of a pin type insulator is in Fig 4a & 4b As the name suggest, the pin type insulator is secured to the cross - arm on the pole. There is a groove on the top of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor.

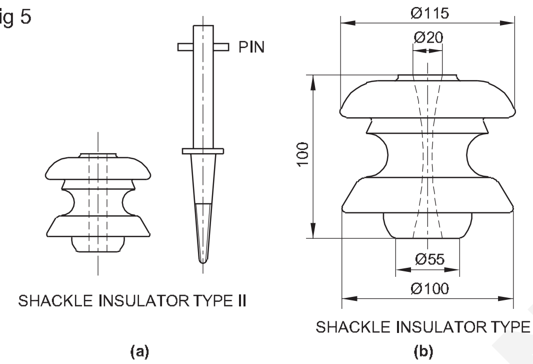
Fig 4



SECTION VIEW OF A PIN INSULATOR

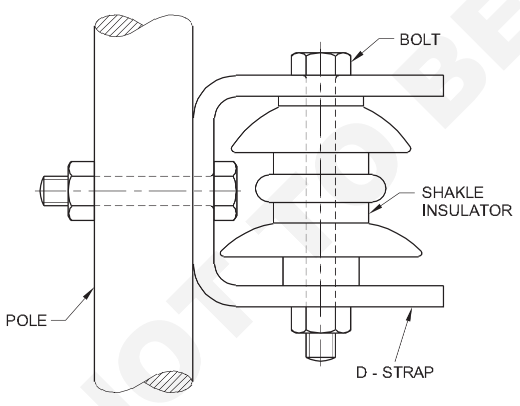
Shackle insulators: Shackle insulators are generally used for terminating on corner poles. These insulators are used for medium voltage line only. (Fig 5a & 5b)

Fig 5



But now a days, they are frequency used for low voltage distribution lines. Such insulators can be used either in horizontal position or in a vertical position. They can be directly fix to the pole with a bolt or to the cross arm.

Fig 6



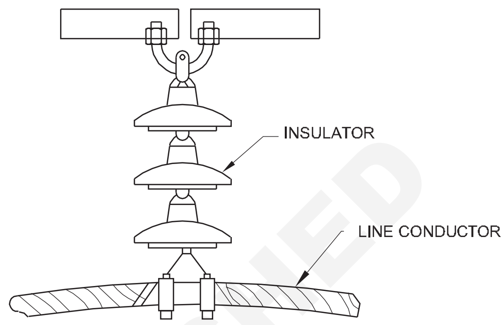
SHACKLE TYPE INSULATOR

Fig 6 shows a shackle insulator fixed to the pole. The conductor in the groove is fixed with a soft binding wire.

Suspension type insulators

The cost of pin type insulator increases rapidly as the working voltage is increased. Therefore, this type of insulator is not economical beyond 33 KV. For high voltage (>33KV), it is a usual practice to use suspension type insulators as in Fig 7. 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 7



SUSPENSION INSULATOR

Advantages

1 Suspension type insulators are cheaper than pin type insulators for voltage beyond 33 KV.

2 Each unit or disc of suspension type insulator is designed for low voltage, usually 11KV. Depending upon the working voltage, the desired number of discs can be connected in series.

3 If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

4 The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

5 In case of increased demand on the transmission line it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.

6 The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross arm of the tower, therefore, this arrangement provides partial protection from lighting.

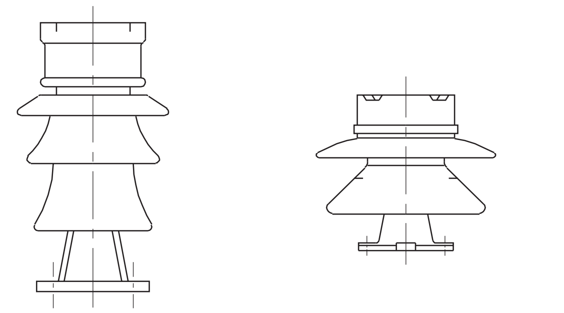
Strain insulators

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. For low voltage lines (<11KV) shackle insulators are used as strain insulators. However for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators. The discs of strain insulators are used in the vertical plane. When the tension in the lines is excessively high, as at long river spans, two or more strings are used in parallel.

Post insulators

Cap and pin type (Fig 8a & 8b) : 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 8

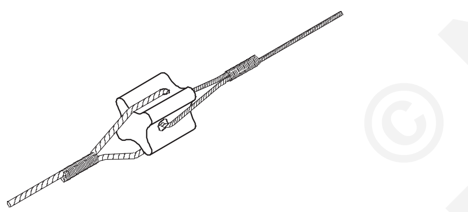


a) CAP AND PIN INSULATOR FOR GOAB SWITCH

b) ANOTHER DESIGN OF CAP AND PIN INSULATOR FOR GOAB SWITCH

Stay insulators (Fig 9): 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.

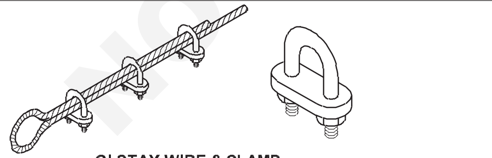
Fig 9



STAY INSULATOR

The supporting wire which is used in the opposite direction of tension on the pole due to overhead conductors is known as 'stay wire'. It prevents the bending of the pole due to tension of the conductor. These stay wires consist of 4 to 7 strands of GI wire is in Fig 10. The correct size to be used depends upon the tension on the pole.

Fig 10

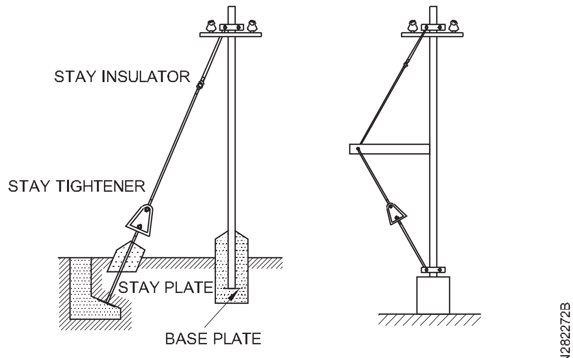


GI STAY WIRE & CLAMP

Stays and struts: Stays and struts are the different types of supporting wires for the pole. Stays are generally used for angle and terminating poles to prevent the bending of the pole whereas struts are used where space for stay is very limited. Fig 11 shows both the stay and the strut.

One end of the stay is fixed at the top of the pole and its other end is grouted in the concrete foundation.

Fig 11



STAY TYPE SUPPORT

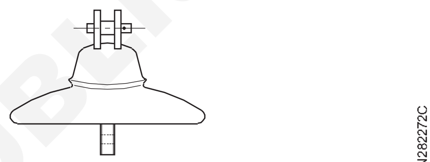
STRUT TYPE SUPPORT

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. (Figs 12, 13 and 14)

These are available in four designs:

Tongue and clevis type (Fig 12): A round pin with a cotter pin is used to hold the tongue of one unit in the clevis of the other.

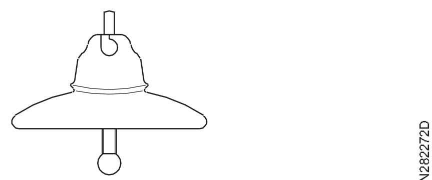
Fig 12



DISC INSULATOR TONGUE AND CLEVIS TYPE

Ball and socket type (Fig 13): In this case insulators are assembled by sliding the ball of one insulator from the side. A cotter pin is slipped in from the back of the socket so that the ball cannot slide out. These are used at dead ends.

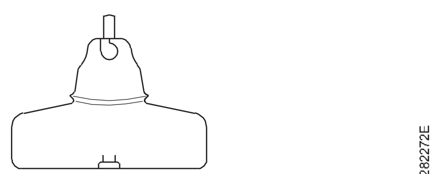
Fig 13



DISC INSULATOR BALL AND SOCKET TYPE

Insulators for cold climate (Fig 14): For cold climate the depth of the lower cap is increased to get creepage distance which becomes necessary in cold climates. Two designs known as fog type and anti-fog types are available.

Fig 14



DISC INSULATOR COLD AND CLIMATE TYPE

Foundation of a transmission tower

Foundation of a transmission tower is the basic structure to support the tower in its position. It plays an important role in safety and satisfactory performance of the structure as it transmits mechanical loads of the electrical transmission system to earth.

Cement concrete footings shall be used for all types of towers, in conformity with the present day practice followed in the country, and the specifications laid herein. RCC foundation may be used for locations where cement concrete footings are not possible to be laid. All the four footings of the towers shall be similar.

Foundation Depth

The depth of the foundation may vary from 1.5 to 3.5 meters.

Classification of Foundation

- Depending on the type of soil, the sub-soil water table and the presence of surface water, four types of foundation will be used for each type of tower location. Classified in the following manner:

a Normal dry type: To be used for location in normal day cohesive or non-cohesive soils.

To used for locations.

Where sub-soil water is met at 1.5 m or more below the ground line.

b Wet type: or

Which are in surface water for long periods with water penetration not exceeding one metre below the ground line.

and

iii) In black cotton soils

c Partially sub-merged type:

To be used at locations where sub soil water table is met between 0.75 metre below the ground line.

d Fully sub-merged type:

To be used at locations where sub-soil water table is met at less than 0.75 metre below the ground line.

In addition to the above, depending on the site conditions, other types of foundations may be introduced suitable for

i Intermediate conditions under the above classification to effect more economy, or

ii For locations in hilly and rocky areas.

iii For locations where special foundations (well type or piles) are necessitated. The proposal for this shall be submitted by the contractor based on the Board.

Testing of Soil

It is desirable to undertake testing of soil for all the tower locations and report should be obtained about the sub-soil water table, as prevalent in the month of September and October type of soil encountered, bearing capacity of soil, possibility of submergence and other soil properties required for the correct casting of casing of foundations. Testing should be carried out about soil resistively in dry season and its record should be kept properly along with route alignment map. After soil investigation along the line alignment, the final quantities of foundation types should be worked out based on the soil investigation carried out and such foundations should be casted and installed only after proper checking and approval.

Excavation

• Except as specifically otherwise provided, all excavation for footings shall be made to the lines and grades of the foundation. The excavation walls shall be vertical and the pit dimensions shall be such as to allow a clearance of not more so as to maintain a clean sub-grade, until the footing is placed, using timbering, shoring or casing, if necessary. Any sand, mud, silt or other undesirable materials which may have accumulated in the excavation pit shall be removed before placing concrete.

- The soil to be excavated for tower foundation shall be classified as under
- **Normal soil:** Soil removable by means of ordinary pick axes, shovels & spades such as types of soil found in gigantic plains, black cotton soil etc.
- **Wet Soil:** Soil where the sub soil water table is encountered within the range of foundation depth, the soil below the water table and that at locations where pumping or bailing out of water is required due to presence of surface water, will be treated as wet soil.
- **Rocky Soil:**
- Soft rocks-This will mean decomposed rock, hard gravel, kankar, lime stone, laterite or any other soil of similar nature which can be easily excavated with pick axe or spade.
- Hard rocks-Hard rock will be that which requires chiselling or drilling and blasting.
- Where rock is encountered, the holes for tower footings, shall preferably be drilled, but where blasting is to be resorted to as an economy measure, it shall be done with the utmost care to minimise the use of concrete for filling up the blasted area. All necessary precautions for handling and use of blasting materials shall be taken. In case where drilling is done, the stubs may be shorten suitably with the approval of the Engineer.
- Shoring of pits with shuttering will be done when the soil condition is so bad that there is likelihood of accident due to the falling of surrounding earth. However, the necessity of shoring of pits with shuttering shall be decided by the Supervising Engineer, depending upon the site conditions.

- Depending on the condition of water available in the pits, following methods of dewatering will be adopted
- **Manual:** Where dewatering is done by men with the help of buckets etc.
- **Mechanical:** Where dewatering is done by hand pump.
- **Power driven:** When engines or electrical power driven pumps with power input not less than half H.P. are used for dewatering.

Setting up of Stubs

- The stub shall be set correctly in accordance with approved method at the exact location and alignments and alignment and in precisely correct levels. The stub setting templates shall be used for proper setting of stubs. Stubs shall be set in the presence of well conversant Junior Engineer/ Assistant Engineer.
- The foundations are to be made as per designs and drawings approved by the Engineer. Extent of the work as defined by such drawings shall not be exceeded except in very exceptional cases where the prior approval of Supervising Engineer is to be obtained.
- Setting of stub at each location shall be approved by the Assistant Engineer/Executive Engineer.
- Details of Foundations
- The thickness have been designed such as to satisfy that conditions specified herein.
- The thickness o concrete in the chimney portion of the tower footing would be such that it provides minimum cover of not less than 100 mm from any part of the stub angle to the nearest outer surface of the concrete in respect. of all dry locations limiting the minimum section of chimney to 300 mm square. In respected of all wet locations chimney should have an all round clearance of 150 mm from any part of the tub angle limiting to 450mm square minimum.
- The chimney top or muffing must be at least 225 mm above ground level and also the coping shall be extended upto the lower most joint level between the bottom lattices and the main corner leg of the tower.
- The spread of concrete pyramid or slabs will be limited to 45 deg. with respect to the vertical.
- At least 50 mm thick pad of size equal to the bases of pyramid with its side vertical will be provided below the pyramid to account for the unevenness of soils and impurities likely to be mixed in concrete due to direct contact of wet concrete with earth and for allowing stone aggregate reaching upto corner edges. This pad will also be provided in cases where pyramids are provided over concrete slabs.
- In case of fully submerged type foundation one base slab, not less the 200 mm thick has been provided.
- The minimum distance between the lowest edge of the stubs angle and the bottom surface of concrete footings shall not be less than 100 mm or more than 150 mm in case of dry locations and not less than 150 mm or more than 200 mm in case of wet locations.
- The portion of the stub in the pyramid has been provided with the cleats.
- Back - Filling and Removal of Stub Template
- Following opening of Form-Box and removal of shoring and shuttering, if any back filling shall be started after repairs, if any, to the foundation concrete. Back filling shall normally be done with the excavated soil, unless it consists of large boulders which shall be broken to a maximum size of 80 mm.
- The back fill materials should be clean and free from organic or other foreign materials. The earth shall be deposited in maximum 200 mm layers, levelled, and wetted and damped properly before another layer is deposited. Care shall be taken that the backfilling is started from the foundation end of the pits, towards the outer ends. After the pits have been backfilled to full depth the stub template may be removed.
- The backfilling and grading shall be carried to an elevation of about 75 mm above the finished ground level to drain out water. After backfilling, 150 mm high earthen embankment (bandh) will be made along the sides of excavation pits and sufficient water will be poured in the backfilled earth for at least 24 hours.
- The stub setting template shall be opened only after the completion of backfilling. level of backfilled earth does not go below the surrounding ground level. However, level with the surrounding ground.

Curing

The concrete after it is 24/72 hours (as the case may be) old shall be cured by keeping the concrete wet continuously for a period of 10 days after laying. The pit may be backfilled with selected earth sprinkled with necessary amount of water and will consolidated in layers not exceeding 200 mm of consolidated thickness after a minimum period of 24/72 (as the case may be) hours and thereafter both the back filled earth and exposed chimney top shall be kept wet for the remainder of the prescribed time of 10 days. The uncovered concrete chimney above the backfilled earth shall be kept wept wet by providing empty cement bags dipped in water fully wrapped around the concrete chimney for curing and ensuring that the bags are kept wet by frequent pouring of water on them.

Construction of Distribution and Transmission Network

Objective: At the end of this lesson you shall be able to
- **describe the methods followed for the pre-construction,facilities set up, construction, commissioning of distribution and transmission network.**

Transmission Lines

Figure 2 provides a schematic for the entire power transmission and distribution process from generation end to the consumer end.

Design Criteria

Transmission line is linear project (See Glossary 64) and one of the key factors that govern the design of transmission projects is the possible infringement of populated/forest/cultivated area and scarce land. For selection of optimum route, the following design criteria are usually taken into consideration by project proponents:

i Normally, the route of the transmission lines does not involve any human habitation. As a principle, alignments are generally cited at-least 500 m away from major towns, whenever possible, to account for future urban expansion and electromagnetic field for at-least 50 m away from any houses or structures.

ii Any monument of cultural or historical importance is not affected by the route of the transmission line.

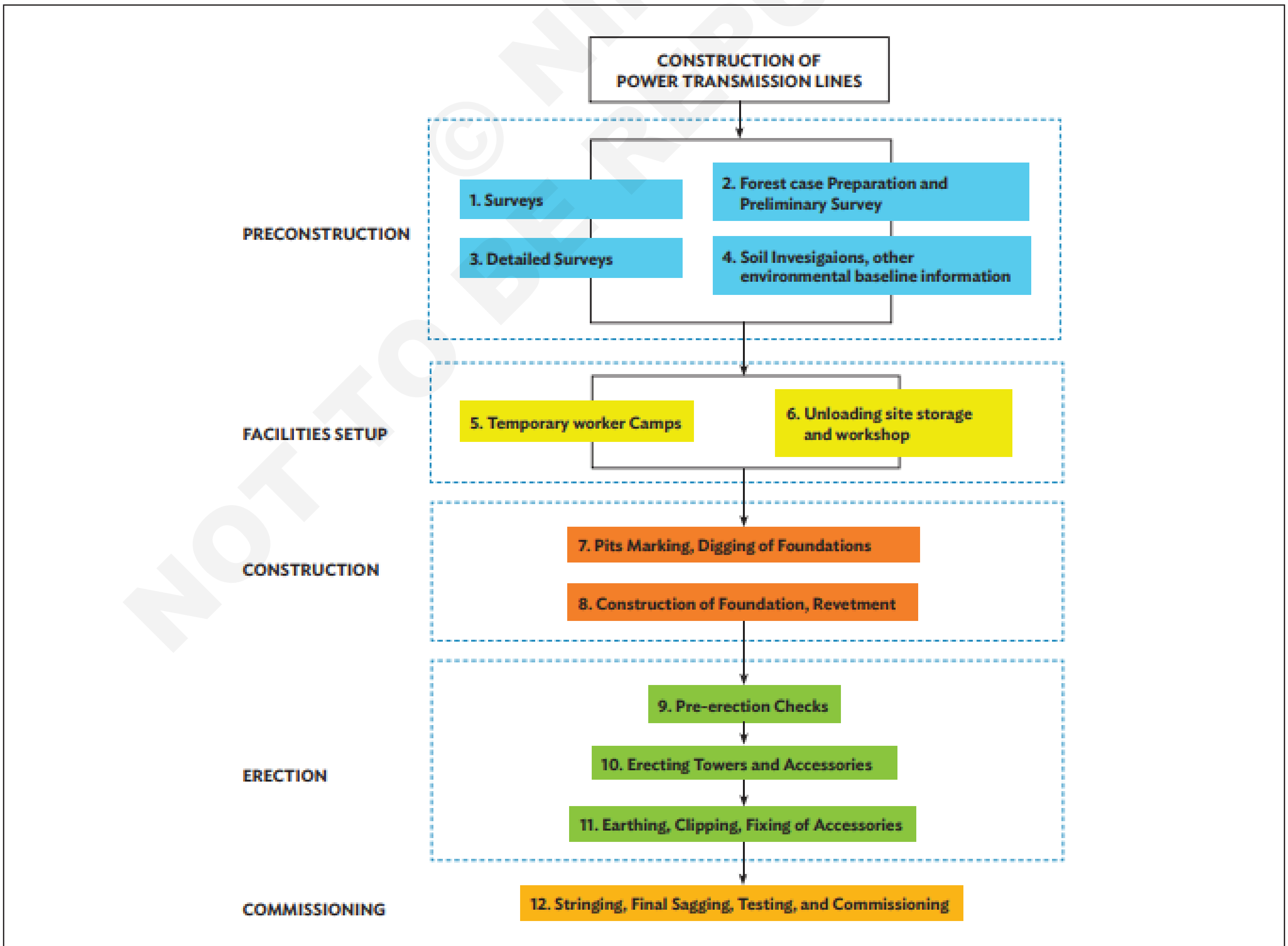
iii The proposed route of transmission line does not create any threat to the survival of any community or indigenous peoples.

iv The proposed route of transmission line does not affect any public utility services, playgrounds, schools, community places, temples and other establishments etc.

v The line route does not pass through any sanctuaries, protected park etc. Similarly, plantations/ forests are avoided to the maximum extent possible. Whenever it is not possible, a route is selected in consultation with the forest department that causes minimum damage to existing plantation/forest resources.

vi The line route does not infringe with area of natural resources. Alignments selected to avoid wetlands and unstable areas for both financial and environmental reasons.

Construction Practice, their Environmental Impacts, Mitigation and Work Process



Preconstruction	
1 Surveys: Several surveys are carried out prior to design of transmission system to ensure technical, financial, environmental viability.	
1 Initial Survey is conducted along shortest distance between the two points- sending (generating end) and the receiving end (substation) of the transmission line (known as a Bee line) (See Glossary 12). 2 Reconnaissance Survey Information on field data required for transmission line design. Major power line crossing details (66 kV and above), railway crossing details, major river crossing details, distance from community resources-worship place, village common grounds, community centers, schools, hospitals etc. Picture a depicts a typical ongoing survey. Picture b. shows a potential tower location. 3 Alternative analysis survey. All alternative routes proposed and collection of details about features observed and facilities marked on topographical map (150,000). See Picture c	
Activity causing Impact and Location	**Impact of activity and its type**
Enumeration of trees for cutting identification of locations for digging of soil for tower base, development of quarrying sites, stacking area for construction material etc. (Location Tower Base)	Potential impact on physical resources-Topography, possible loss of biodiversity, interference with public utilities. (Type Planning stage)
Impact Mitigation	**Work process**
Better choice of route alignment and tower bases to avoid adverse impact to common property resources, biodiversity, public utilities, etc	Transact walk along alternative tower alignments through the land, fields, forest area, adjoining village areas, crossings roads, utility. rivers, canals, railways, etc. Local public resistance to give free tower land may cause delays in preparing alternate analysis case.

Preconstruction	
2 Forest Case Preparation and Preliminary Survey	
1 Forest case preparation (See Glossary 45) Enumeration of trees to be cut, lopped/trimmed in the Right of Way (ROW) (See Glossary 95) clearance according to girth, height, type of tree. (See Pictures a and b) 2 Preliminary survey. A schedule of angle points (See Glossary 4) (a point where the line makes a deviation from a straight line) along with the brief description of terrain and physical features that lie between each angle point section is done. The alignment is plotted an Government survey maps. Details of places of worship/electricity/ forest/ telecommunications/mads/railways tracks, bank, police station, hospital, schools, restricted plantations etc. to be recorded. (See Pictures c-f).	
Activity causing Impact and Location	**Impact of activity and its type**
Marking of trees/vegetation for cutting at the tower base and for Potential impact on physical resources, topography during trimming inside the right of way, access roads etc. (Location Tower)	Potential impact on physical resources, topography during construction and loss of tree cover which would lead to erosion, Landslips and landslides in hilly areas causing topographical impacts creating gullies, ridges etc.) (Type: Planning stage)
Impact Mitigation	**Work process**
Proper clearance from appropriate agencies such as railways, roads, airports etc. Planning for compensation afforestation details in consultation with Forest Department in consonance with watershed development plans of the area.	Requires about 3-4 months of trees survey along the ROW-enumeration, age, guth, etc. along selected alternative. Forest department prepares and processes details for trees, wild life corridors, or plantations (if any) etc for compensatory afforestation (See Glossary 22). Also, record coordinates for railway tracks, places of worship and the like.

3 Detailed Surveys

All details along the line up to 200 m on either side to be recorded and depicted on the plan and details-villages, temples, physical cultur resources, etc.

Leveling Plan and Profile, Tower spotting and plotting sag of wire

Normally, a final alignment and pegging (location marking of towers) to be carried out (See Picture a). After spotting of towers, the ground clearance curves for conductor drawn, a list of tower positions, type of tower, angle of tower (known as tower schedule (See Glossary (24) is prepared using a workstation (See Picture b), GPS coordinates (See Glossary 49) are also recorded. (See pictures c)

The profile sheet that is drawn for the complete line using contours of the area details the type of towers, standard extensions and leg extension, normal wind and weight span, conductor sagging and maximum single spans for complete line as shown in Pictured d.

Activity causing Impact and Location	Impact of activity and its type
Towers located in agricultural fields, forest areas, portions of houses/ buildings falling in tower foundations (Location: Tower Bases)	Potential impact on physical resources, topography Possible loss biodiversity, soil erosion, land slips/ landslides in the area. (Type: Planning stage)
Impact Mitigation	**Work process**
Potential tower locations deviated by at least 5-10 m sideways to avoid transmission line directly over the houses, or any existing asset which would negatively impact the land owner.	Manual checking of location of center peg plotting of position of various landmarks on to the profile sheet. Derive specifications for tower alignment, tower type, angle of conductor, sag and direction and controlling elevations, sag of we area topography and plot them on the profile sheet.

4 Soil Investigation, other environmental baseline information

Air, water, soil and noise samples are also collected for testing to develop an environmental baseline for the area. Besides, the soil investigation (soil/rock formation, clay, gravel, rock etc.) is important to determine the transmission tower placement in any area-hilly plain level area, or marshy areas. General characteristics of the soil mentioned above, wind, weather, rainfall etc that occur in the area has a direct influence on the design of type of foundations and towers.

Picture & shows pit level manual soil collection and Picture b. Shows dust samplers in operation.

Activity causing Impact and Location	Impact of activity and its type
Collection of soil samples by digging manually/using machines as well as collection of water from wells/water sources nearby ROW Location Tower Base)	Minor impact of collection of soil samples on topography or pollution of water source during sample collection. (Type Planning Stage)
Impact Mitigation	**Work process**
Avoid marshy areas, low-lying areas, riverbeds, earth slip zones that would involve risk to stability of the foundations. Baseline development will help in monitoring environmental parameters on a regular basis during construction period. Reduces potential impact on environmental resources in the area-air quality, noise quality, ground water quality and surface water quality during construction.	Soil samples taken manually by digging holes or using an augur tool (See Glossary 7) or digging machine.

Facilities Set-up	
5 Temporary Worker Camps	
Temporary worker camps are set up en-route the transmission line.	
Activity causing Impact and Location	**Impact of activity and its type**
Scatter of kitchen waste, toilet waste, scrap, unusable/ nonrecyclable waste in the area. Solid waste disposal, liquid waste disposal in camps spillage into river, streams. Poaching of animal life, fishing, harvesting of wood by workers. (Location: Worker Camp)	Oils, untreated wastewater, sewage etc. flowing into water body, river, drainage areas from the camps causing impact to surface water, ground water, any aquatic life downstream. The downstream water in river can be polluted making it unfit for bathing or potable water. The camps can also adversely impact on ecological resources through poaching of wildlife and using wood from trees as firewood causing ecological damage in the area. (Type: Temporary)
Impact Mitigation	**Work process**
Contract provisions specifying minimum setback requirements for construction camps from water bodies, reserved areas etc. Engineering Procurement and Construction (EPC) contractor can provide liquefied petroleum gas cylinders for cooking etc. to workers. Provision of adequate washing and toilet facilities by the contractor to the workers should be made obligatory.	The worker camps mainly migratory in nature and away from local populations. Given the strength of man-power to be between 10 - 20 and the duration of work in one place might be for 2 - 3 weeks before moving on to next place; the impact will not be permanent.

6 Unloading of material at site, storage and workshop	
The tower erection sites are normally very remote where mechanized equipment is not readily available or are not accessible (e.g. in hilly regions). Storage and workshop areas are established in an area accessible easily by trucks, motorized equipment, has power availability and storage area. Mostly a small mechanized boom crane (see Picture a.) is available, otherwise it is manually unloaded using chain and pulleys blocks (see Picture b.)	
Activity causing Impact and Location	**Impact of activity and its type**
Levelling of soil for creation of storage place. Transportation of equipment to sites using heavy cranes to unload/ load equipment (See Picture c.) (Storage areas, Tower Bases) Toilet waste, scrap, unusable/nonrecyclable waste, oils, sewage, slurry from machines, dripping oils from trucks etc. Welding, cutting and fabrication of raw material etc. (See Picture d.) (Location: Workshops, stores, machine shops)	Levelling of soil, vehicular emissions impacts air quality/ noise levels in the area. Cutting of trees, soil erosion will impact terrestrial ecology of the area. (Type: Temporary) Workshop wastes impacts ecological resources due to unplanned solid waste, unsafe wastewater, other liquid waste disposal flowing into water bodies, drainage etc. affecting the ground water, aquatic ecology of water bodies in the area. (Type: Temporary)
Impact Mitigation	**Work process**
Select locations for material storage yards and Workshops established away from any environmental sensitive areas. The vehicles used at the site must be compliant with pollution standards of the country. Protective equipment (PPE) (See Glossary 86) for handling of material and in the workshop is required.	Cutting of trees and levelling ground to create a storage facility, arrange transportation and unloading of equipment and raw material using cranes.

<table>
<tr><th colspan="2">Construction</th></tr>
<tr><td colspan="2">7 Pit Marking, digging of foundation</td></tr>
<tr><td colspan="2">After the location marking (see step 3) has been done, the marking of the pits for excavation for the foundation is done. Each and foundation is specific to the type of tower to be erected at that location. Angle of deviation (See Glossary 5) for each tower must be compared with the profile sheet. Pits must be free from excess soil after excavation. Clearing of any trees etc. near the foundations is required.</td></tr>
<tr><th>Activity causing Impact and Location</th><th>Impact of activity and its type</th></tr>
<tr><td>Clearing of land for tower in agricultural fields or hilly areas (See Pictures a. & c.) Improper soil type encountered making the tower footing very huge and contour specific.
Pie foundation (See Glossary 75) in case of marshy lands, hilly and river basins may be required (see Pictures b. & c.)
Stacking of dug up soil, usage of digging machines for foundations. (Location Tower Foundation)</td><td>Impact on physical resources, topography during constrain -loss of trees would lead to erosion, landslips and landslides hilly areas creating gullies, ridges etc.)
Ground and surface water quality, aquatic ecology may be affected due to surface soil run-off, dripping of oils from engines of digging machines Impact on environmental resources ar quality/noise levels due to use of machinery for digging or stacking of loose soil. (Type: Temporary)
Loss of agricultural land would impact on human environment (Type: Permanent)</td></tr>
<tr><th>Impact Mitigation</th><th>Work process</th></tr>
<tr><td>Ensure proper drainage, proper soil type to ensure minimum tower base footing due to contour, tower alignment, distance from trees, sensitive areas.
Ensure minimum/noise pollution at digging points.</td><td>Manual labor or a backhoe loader (See Pictured) used to dig the foundations and for removing excess mud from tower foundation sites.</td></tr>
</table>

<table>
<tr><td colspan="2">8 Construction of Foundation, Revetment</td></tr>
<tr><td colspan="2">Bending steel rods, tying with steel wires and mixing concrete for the foundation is done manually. This is followed by pouring in concrete prepared using a manual mixing machine (See Picture a). This steel-concrete structure is known as Reinforced Cement Concrete (RCC).
The concrete is casted manually into the foundations and footing prepared manually using ply-boards and/or wood casts made as pe design (See Picture b)</td></tr>
<tr><th>Activity causing Impact and Location</th><th>Impact of activity and its type</th></tr>
<tr><td>Surface run-off of prestacked soil, oil leakages from engine and vehicles.
Steep contour, improper soil type encountered. (Location: Tower base)</td><td>Ground and surface water quality, aquatic ecology may be affected due to surface soil run-off, dripping of oils from engines of digging machines.
Steep contour, improper soil type encountered making the tower footing very huge and contour specific requiring revetment. (Type: Temporary)</td></tr>
<tr><th>Impact Mitigation</th><th>Work process</th></tr>
<tr><td>Restore the loose soil from foundations through ramming (See Picture c.). Excess soll is laid out in areas that do not interfere with local drainage pattern.
For any revettent structure, the weep holes are placed (Picture e.) to ensure water/moisture shall pass through easily without damaging the structure.</td><td>Erection takes from 2-3 weeks for construction of RCC structure.
The construction work for all foundations including concreting is done manually at all remote tower locations where no access roads exist (such as those shown in Picture d.).</td></tr>
</table>

<table>
<tr><th colspan="2">Erection</th></tr>
<tr><td colspan="2">9 Pre-Erection Checks</td></tr>
<tr><td colspan="2">Checking of all tower locations with respect to design type, the wind load, the conductor weight, the type of accessories, the angle of wire and determine the tower erection methodology for sag and tensioning (see Picture a.). Cutting of trees and vegetation for the night of way (See Picture b.).</td></tr>
<tr><th>Activity causing Impact and Location</th><th>Impact of activity and its type</th></tr>
<tr><td>Shifting of distribution lines, water supplies, cutting trees etc under the planned right of way. (Location Tower base and Right of Way)</td><td>Disturbances to local population due to temporary outages of power as distribution lines are disconnected.

Utilities such as water supply etc. may be disturbed because of the above. (Type: Temporary)</td></tr>
<tr><th>Impact Mitigation</th><th>Work process</th></tr>
<tr><td>Re-routing of public utilities affected by the transmission line- distribution lines, power lines, telecom lines etc.</td><td>Engineering design team reviews potential tower loads, method of erection and stringing to wire to balance loading at each location of the tower (either situated on steep hill or any plain area).</td></tr>
</table>

<table>
<tr><td colspan="2">10 Erecting towers, arms, Erection, Tightening and Punching</td></tr>
<tr><td colspan="2">The Lattice structure (See Glossary 67) tower parts are moved/loaded manually up to the erection point and then lifted manually using chain pulleys to the top. There is no high boom crane available in remote areas to help lift the towers parts to the top.</td></tr>
<tr><th>Activity causing Impact and Location</th><th>Impact of activity and its type</th></tr>
<tr><td>Personal Protective Equipment (PPE) not used by workers and not available to nearby residents. Adequate distances not maintained from neighboring properties and structures.

Loose soil left unattended after completion of erection of tower. (Location: Tower)</td><td>Unsafe erection of tower can result in injuries to the workers and residents in the area. Untrained workers can lead to more accidents and fatalities. Weather conditions in hilly areas could result in tower failure or topple partially or fully during erection and stringing due to uneven stringing loads, severe wind conditions.

Soil erosion as discussed in "Activity 2 and 3" earlier. (Type: Temporary)</td></tr>
<tr><th>Impact Mitigation</th><th>Work process</th></tr>
<tr><td>Use of proper PPE (See Glossary 72) for workers, safety protocols during erection process must be observed. Proper on-site training to staff and residents must be provided by EPC contractor. The EPC contractor will ensure proper design of tower structure to avoid accidents due to toppling (partially or fully) takes place during erection and stringing due to uneven stringing loads, severe wind conditions.

Soil erosion to be contained as mentioned in activities 2 &3.</td><td>Single tower erection takes at least a team of 5-8 workers for a week.

Manual hauling of the tower parts using chain pulleys to the top of the structure and erecting each of them individually. See Picture a.

After completion of erection EPC contractor must compact and remove extra soil from tower base (See Picture b.).</td></tr>
</table>

11 Earthing, clipping and fixing of accessories (See Glossary 20), installation of OPGW (Optical Ground Wire) (See Glossary 68)

Double earthing of each tower is done using manual labor to ensure proper protection of the entire system from faults and accidents. All accessories are erected manually using small pulley and tensioner (See Picture a) followed by erection of disk insulators. (Sew Glossary 34)

Earth wire or OPGW is usually strung first on the top arms of the tower followed by accessories on the lower arms. (See Picture b.). followed by stringing of power conductor.

Activity causing Impact and Location	Impact of activity and its type
Installation of Earth wire and Accessories. Earthing the tower and the conductor. (Location: Tower)	Accident at tower site due to falling of accessory, snapping of earth- wire of incorrect tensioning etc. Impact on safety of workers due to lack of PPEs. Improper refilling of soil at earthing location may cause soil run-off. (Type: Temporary)
Impact Mitigation	**Work process**
EPC contractor must ensure proper PPEs are worn by work staff and safety protocols for earthing, accessories and installation of OPGW are followed. Ensure proper earthing and maintaining specified distances from the under erection earth wire in case the tower line is passing over another live transmission or distribution line.	A tower earthing needs digging for 3.6 m depth using a manual auger tool. The installation of tower earthing takes about 2-3 days. Manual hauling of the accessories using chain pulleys to the top of the structure and erecting each of them individually. The OPGW erection process is undertaken one segment at time depending on the location and altitude of power line.

Commissioning

12 Stringing and final sagging and tensioning of earth-wire and power conductor, Testing and Commissioning

The paying out/stringing (See Glossary 110) of power conductor (See Glossary 82) is done manually using aerial rollers (See Glossary 112)/ pullers (See Glossary 88), tensioners (See Glossary 123) winches etc. to provide the correct sag (See Glossary 101) prescribed for the wire.

Activity causing Impact and Location	Impact of activity and its type
Stringing of cable onto the erected towers, accessories manually or using equipment. (See Pictures a.-c.). Addition lopping of trees required within the ROW. (Location: Tower line)	Snapping of stringing blocks (See Glossary 111), unbalance load during stringing on tower leading to collapse, falling cables injuring workers, others etc. Stringing the wire loosely may result in cable touching the ground and other obstructions that could cause damage. Extensive lopping of branches etc. in hilly terrain may be required to maintain ROW as compared to lines running over level ground. (Type: Temporary)
Impact Mitigation	**Work process**
Proper tension maintained between the tensioner and the puller keeps the conductor clear of the ground and other obstructions that could cause damage (See Pictures d-f). Scaffolding shall be used where roads, rivers, channels, telecom lines, overhead power lines, railway lines, fences or walls have to be crossed during stringing operations. No. of trees to be lopped needs to be ascertained.	Towers are provided with stays/ anchors to balance one sided load on them when stringhag is done initially on one side only. One end of pulling line (See Glossary 87) (Picture c.) attached to the conductor end, is strung through each stringing block between the puller and tensioner. The conductor is then pulled through the stringing rollers until the end reaches the puller. Length of conductor segments is equal to length of cable in the drum (See Glossary 39).

Distribution Lines

Power lines having voltage carrying capacities above 33 kV are termed as transmission lines; those carrying 33 kV are termed subtransmission (See Glossary 116) lines whereas 33 and 22, kV and 11 kV lines as medium voltage (MV) (See Glossary 128) and 0.4 kV low voltage (LV) distribution lines. The distribution line projects being funded usually consists of erection of subtransmission, MV and LV lines.

Overhead distribution lines would involve the following:

i Distribution network is constructed on using either of the three types of poles – concrete, steel poles and steel rail. Besides, some select subtransmission 33 kV lines for long distance also use lattice towers.

ii The distribution lines emanating from power substations connect to step down voltage distribution transformers (DTRs) of various sizes ranging from 3 kVA to 100 kVA depending on power required at the load centers – industrial, commercial, residential urban areas, rural as well as agricultural feeders. Following is all illustrative sizing of DTRs as per their tentative applications at consumer end:

Rural feeders, residential (rural/urban)	- 0 - 3 kVA
Residential, small commercial	- 3 - 10 kVA
Residential, Commercial	- 10 - 25 kVA
Commercial, Group Housing	- 25 - 50 kVA
Large Housing, Commercial, Industrial	- 50 -100 kVA
Industrial	- 100-200 kVA

The above transformers are rated for voltages upto 33 kV and is illustrative in nature.

Design Criteria

For selection of optimum route, the following design criteria are usually taken into consideration by project proponents

iii The route of the proposed 33/11/0.4 kV lines does not involve any uprooting of habitation. As a principle, distribution alignments generally pass through all towns and villages, but the minimum right of way (RoW) distance shall be kept safe distance away from any houses or structures.

iv Ensure that Polychlorinated Biphenyls (PCBs) are not used in the transformers installed in the project-funded facilities.

v Any monument of cultural or historical importance is not affected by the route of the distribution line.

vi The proposed route of distribution line does not create any threat to the survival of any community with special reference to tribal community.

vii The proposed route of distribution line does not affect any public utility services, playgrounds, schools, other establishments etc.

viii The line route does not pass through any sanctuaries, protected park etc. Similarly, plantations/forests are avoided to the maximum extent possible. When it is not possible, a route is selected that causes minimum damage to existing plantation/forest resources.

ix The line route does not infringe with area of natural resources. Alignments are selected to avoid wetlands and unstable areas for both financial and environmental reasons.

Construction Practice, their environmental impacts, mitigation and Work process

The Flow Chart in Figure 4 displays activities as they progress while constructing a distribution line. On the left are the “Steps” involved in the process of project implementation such as “Pre Construction, Facilities Setup, Construction, Erection, and Commissioning”. The “Tasks” performed are numbered in a sequential manner i.e. 1-10 (as shown by arrows). Some “Tasks” are grouped together in a particular “Step” in the order of their occurrence in a project cycle. Their placement (i.e. 1&3, 2&4) has no particular significance. For example, The construction related environmental impacts usually occur during implementation of “Tasks” 5-10. These “Steps” are usually performed by the Engineering Procurement and Construction (EPC) contractor.

Table 3 provides information about each of the step involved in transmission line design, construction, testing and commissioning, the environment impacts and the proposed mitigation, and work process involved. The “Steps” involved in the erection of distribution lines are nearly common up to point 6 in Table 2 (for transmission lines). 31. In Table 3, layout of the each box is represented as follows:

The colored box on top left of the Table represents the “Steps” matching the color of boxes in the Figure 4. y

“Tasks” lists work undertaken to accomplish the “Steps” shown in Figure 4. This followed by explanation of the task conducted.

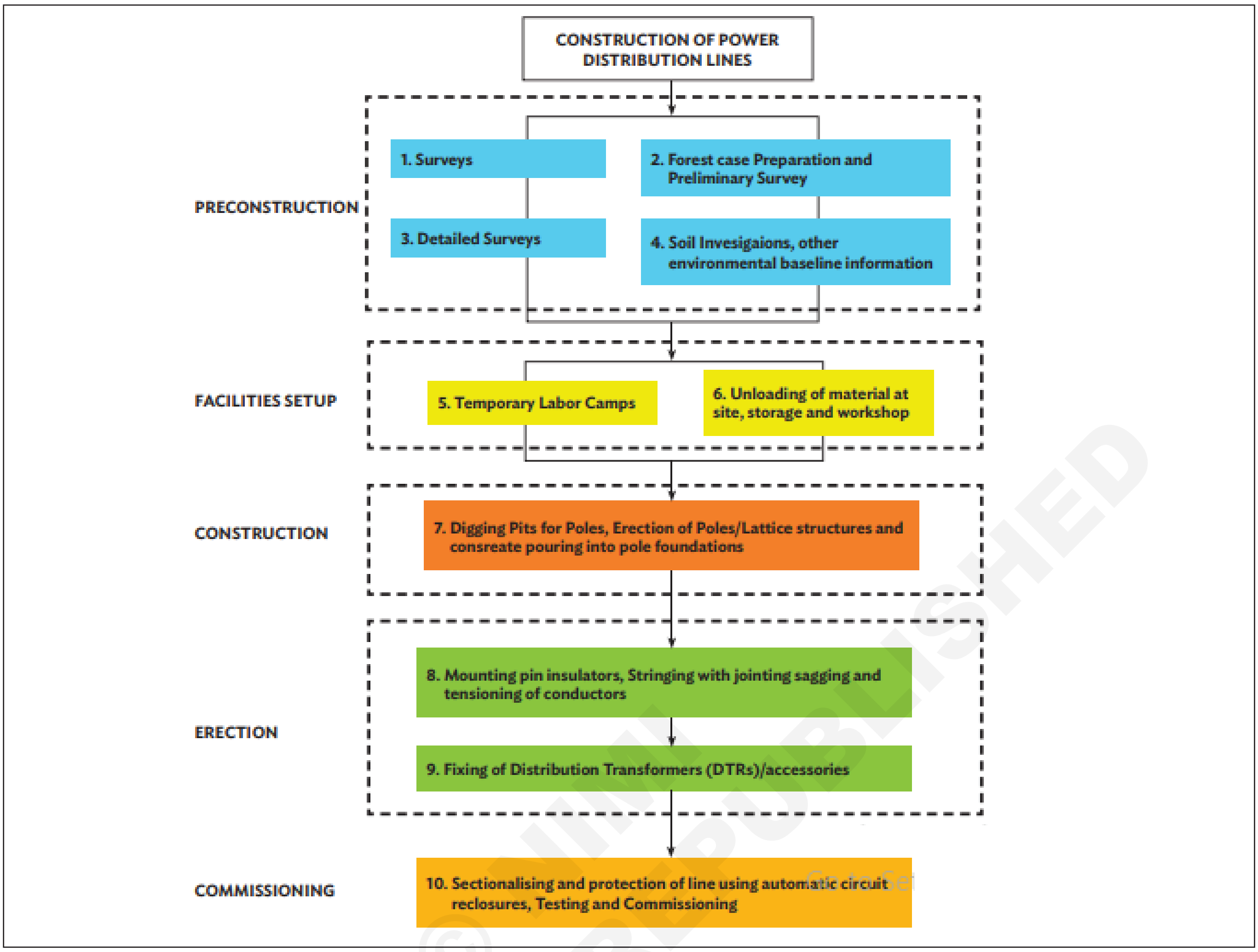
“Activity causing Impact and Location” lists the activity undertaken to accomplish each “Task” that impacts the environment and also gives the location of the environmental impact in brackets.

“Impact of activity and its type” describes the impact on environment of each activity and lists it type – temporary, permanent, planning etc. in brackets.

“Mitigation Measure for the Impact” lists environmental mitigation measures taken to mitigate the impact.

“Work process” provides a write up on the work done by EPC contractor for each “Task” and the human aspect involved during task completion.

The right side of the Table 3 contains pictures from actual working sites that are mapped



Distribution Lines - Stepwise Project Activities, Construction Impacts, Mitigation and Work Process Involved

<table>
<tr><th colspan="2">Construction</th></tr>
<tr><td colspan="2">Digging Pits of poles, Erection of Poles/lattice structures and concrete pouring in pole foundations</td></tr>
<tr><td colspan="2">Distribution networks - both urban and rural areas normally use poles/lattice structures (see Pictures a-c.) at erection sites are normally located away from the road (both in level or hilly regions).
Foundation pits for these poles are very small and they are dug manually in both level and the hilly areas Concrete mixture for the foundation prepared using a manual mixing machine and casted manually using ply-boards and or wood casts
The poles are unloaded manually at the erection point using chain and pulleys blocks. Mostly a small mechanized truck such as the one in Picture d. is available at the loading/unloading point</td></tr>
<tr><th>Activity causing Impact and Location</th><th>Impact of activity and its type</th></tr>
<tr><td>Digging of pale foundations using manual auguring tool along the mads and agricultural/barren land.
Using concrete to erect the pole (Location: Pole base locations)</td><td>Surface soil run-off of soil not compacted at the pole base.
Agricultural/barren land (small area of max 1 sq. m.) affected. Excess concreting raw material left strewn in the area after work complete. (Type: Permanent)</td></tr>
<tr><th>Impact Mitigation</th><th>Work process</th></tr>
<tr><td>Restore the excess soil through ramming and ensuring the loose soil is removed and construction material from pale base so that it does at site. not interfere with drainage of the area.
Ensure lines do not cross the agricultural fields in manner that adversely affects the famers</td><td>The poles are prefabricated whereas the lattice structure is erected at site.
The concrete mixture is prepared and poured manually at most pole line locations</td></tr>
</table>

a Urban distribution 33/11/0.4 kV

Fig 1

b Under construction lattice type 33 kV line

Fig 2

Erection	
Mounting pin insulators (See Glossary 76), Stringing with jointing, sagging and tensioning of conductors	
The stringing of wires is done manually using pulleys, ropes to provide the correct sag prescribed for the wire. (Pole line)	
Activity causing Impact and Location	**Impact of activity and its type**
Stringing of cable onto the erected poles, accessories manually or using equipment (Location: Pole line)	Improper distance from houses, trees, and other building effected due to distribution line. Stringing the wire loosely may result in cable touching the buildings, trees and other obstructions that could cause damage and accidents during operations. (Type: Temporary)
Impact Mitigation	**Work process**
Distances from public receptors maintained as per the mandatory requirements of the country. Proper sag and tension maintained between conductors installed to keep it clear of the buildings, trees and other obstructions that could cause accidents/short circuits during operation. (See Pictures a-b).	Poles are provided with permanent stays/ anchors to balance them during stringing as well as operational stages. The conductor is laid on the ground between each pole and is pulled up through a chain pulley and attached to the accessories on the pole Checking of final sagging is done manually.

Fixing of Distribution Transformers (DTRs)/accessories	
DTR transformers have rating ranging from 3 KVA-100 KVA, which depends upon the power requirements at the consumer end are installed on single pole, double pole or four pole structures based on their sizes. (See Pictures a-c)	
Activity causing Impact and Location	**Impact of activity and its type**
DTRs on poles and ground are installed close to consumer end Ie close to industrial, commercial, residential buildings as well as agricultural fields The poles will be erected along the roads or along agricultural and/or barren lands (Location: Poles and Right of way)	Pole structures for mounting DTRs are normally not secured by protective fencing and can become a hazard if someone climbs over Physical cultural resources (PCR) (See Glossary 74) can be affected Dripping of transformer all may cause soil pollution Loss of agricultural land, and interference with other utilities and traffic may happen during erection process (Type: Temporary)

Impact Mitigation	Work process
Ensure DTR is installed at safe distance from human reach, does not spill oil, and has secure connections to the 33/22/11 kV line Line through agricultural lands must be carefully routed to ensure no loss of land, or disruption of water utilities occur during construction Care to ensure Physical Cultural Resources are not affected by the DTR placement	Installation of each DTR is done manually using chain pulley method to lift and place it on to the pole by a 3-4 persons

COMMISSIONING	
Sectionalizing & protection of line using automatic circuit reclosers (See Glossary 8), Testing and Commissioning	
Installation of fault-break devices to detect and isolate sections to ensure supply to consumers using automatic circuit recloser and other associated equipment.	
Activity causing Impact and Location	**Impact of activity and its type**
Connecting DTR's and newly strung distribution lines using reclosers, switches/other accessories. (Location: Pole line)	Improper sag and distance from nearby structures causing breakage of lines and falling on people etc. (Type: Temporary)

Impact Mitigation	Work process
Use of shielded Ariel bunched conductor (ABC) to avoid short circuits and shocks to nearby residents.	Installation of reclosers/switches group the network into sections thereby reducing the number of customers disconnected due to permanent faults.

Fig 3

a Distribution transformer on pole

b DTR on two pole structure

Fig 4

a Tapping of 0.4 kV line

b Connection of lines

c 11 kV lines emanating from 33/11 kV substation

Basic concept of MONO pole, Multi Circuit Tower, 90° crossing of two HV transmission line in same tower, Transposition of towers

Objectives: At the end of this lesson you shall be able to
- **distiguish the concept of Mono pole, multi circuit tower, and its advantages**
- **understand the advantage of 90° crossing**
- **understand the concept of transposition of towers**

Monopoles

Once widely used only in US and European countries, monopoles are now becoming popular in India too. This is because monopoles have distinct advantages over the lattice towers w.r.t space, speed of erection, short delivery time and more. The benefit of smaller base installation space, even while rising higher than 40 to 50 m, makes monopoles an eco-friendly alternative as well. Bajaj was the first to design, manufacture and erect steel monopoles in India, and now it continues to bring in an expertise of over 10 years to the table.

The Bajaj EPC Power Transmission segment was the first and the only one in India to design, type test, manufacture and install monopoles of 400 kV double-circuit line with a height of 42 m for Power Grid Corporation of India Limited for their project line from Dadri to Ballabhgarh. Apart from PGCIL, another notable project where BEL displayed its expertise is UPPTCL-132 kV 90-degree deviation monopole line at Agra. The steel monopole structures are designed as per ASCE/ASTM manual 72. Right now, Bajaj is executing 400 kV monopole project for UPPTCL at Noida, which is India's largest ever.

Certified by TUV NORD for ISO 9001: 2008, ISO 14001:2004 and BS OHSAS 18001: 2007, the BEL plant meets all the stringent quality standards. Moreover, all the 400 kV, 220 kV and 132 kV monopoles are type tested at a third party independent reputed lab for additional quality checks. Bajaj Electricals is equipped with a very strong in-house design and engineering team that offers complete solution from concept to commissioning.

Domestic service line - IE rules

Objectives: At the end of this exercise you shall be able to
- **explain the domestic service connection with bare and insulated conductors**
- **state the method of laying the service cable from the pole to the consumer premises**
- **state the safety precautions to be followed in domestic service connections**
- **list out the IE rules pertaining to domestic service connections**
- **explain the methods of taping service connections.**

Service connections

The distribution networks ends at consumer premises either single phase or three phase connections. The category of connections either single phase or three phase depends as the maximum load demand by the consumer and the wiring of the house or the premises. The decision of power allocation by the electricity officials after surveying the wiring and load demand by the consumer.

Once the power requirement finalised and arrived the connection to the consumer the point from where the service line to be connected. It is also decided the drawing of line from the pole cross arm structure to the consumer mains panel either in over head or through UG cable. If the distance from over head pole terminal to consumer panel board is more than 50 Mtrs separate pole should be erected and OH line to be drawn from the distribution pole cross arm structure.

Service connection with bare conductor: Any of the following methods shall be adopted as specified.

The bare conductors shall be strung with shackle insulators fixed to the cross arms on both ends. The feeding end cross-arms shall be fixed to the support and the one at the receiving end shall be mounted on a G.I. pipe of a maximum diameter of 5 cm. The bare conductors shall be kept at a height of atleast 2.5 m from the top of the structure in accordance with Rule 79 of I.E. rules.

The G.I. pipe shall be provided with double bends at the top. The pipe shall be secured by alteast 2 clamps made of 50 mm X 6 mm. with M.S. flats fixed firmly to the wall in the vertical position. It shall in addition be provided with a G.I. stay wire of 7/3.15 mm size anchored to the building with one eye bolt. Service connection shall be given with weather proof/PVC insulated cable through this G.I. pipe. Wooden/PVC pushings shall be provided at both ends of this G.I. pipe.

The bare conductors shall be strung with shackle insulators as above except at the receiving end where the insulators shall be fixed to a bracket made of an angle iron, of a size not less than 50 mm x 50 mm x 6 mm. The ends of the bracket shall be cut and split and embedded in the wall with cement mortar. The bare conductor shall be kept atleast 1.2 m away from the edge of the structure, in accordance with Rule 79 of I.E. Rules.

The service connection shall be given with weather proof/PVC insulated cable through GI pipe of a minimum diameter of 4 cm. Fixed to the wall. The GI pipe shall be bent downwards near the service entry. Wall fitting wooden/PVC bushes shall be provided at both ends of the G.I. pipe.

Service connection with insulated conductors: Service connection may be given by weather-proof/PVC insulated cable on a GI bearer wire. The cables shall be supported by the bearer wire by means of suitable link clips spaced 30 cm apart or by wooden/porcelain cleats 50 cm. apart. The GI bearer wire shall be of a minimum 10 SWG size.

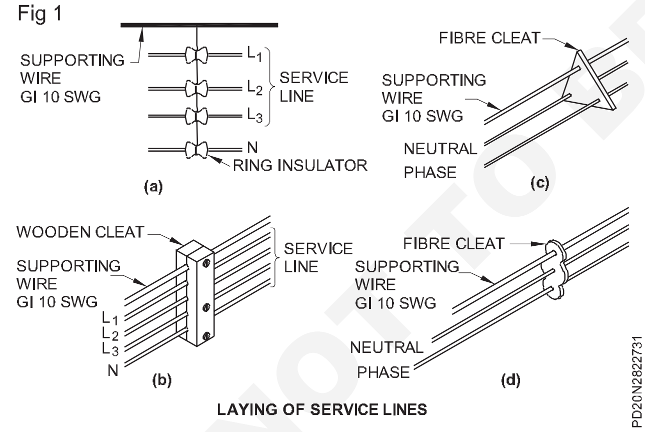
One end of the GI bearer wire shall be attached to a clamp which is fastened to the nearest pole carrying distribution lines from where the service connection is intended to be given. The other end of the GI bearer wire shall be fastened to a 5 cm. dia. GI pipe for a span up to 4.5m which is fixed to the wall with guy etc.

The GI pipe shall be fixed to an angle iron of size 40 mm x 40 mm x 6 mm with a suitable guy for high supports and for a span exceeding 4.5 m. Alternatively when the height of the structure permits minimum ground clearance, the other end of this GI bearer wire may be fixed to a hook, eye bolt or bracket embedded with cement mortar in the wall.

The weather proof/PVC insulated cable shall pass through a GI pipe of minimum diameter 5 cm, which is bent downwards. Wall fittings wooden/PVC bushes shall be provided at both ends of the GI pipe.

Method of laying the service cable from the pole to the consumer main: In practice either a glass or porcelain ring insulator or wooden fibre cleats are used to lay the overhead service line from the pole to the consumer mains as in Fig 1.

Fig 1



LAYING OF SERVICE LINES

Safety Precautions to follow while connecting pole to consumer premises

1 The cable conductor size must be as per the IE rule standard either single phase or three phase.

2 If the service line crosses public road the clearance must be as per IE rule.

3 The conductor slag should not exceed as per the IE rules.

4 If UG cables are providing the depth of cable in ground should be as per IE rules.

5 Do not keep much more cable unused and buried in soil in the coil form in case of UG cable laying.

6 The excess cable should not be kept by making coil and kept on the pole cross arm. Use only required cable for connection.

7 If the cable passing through excess heat producing areas in near to chimney, kitchen etc; adequate protection from heat to be provided.

8 Service cable run along with stay wire tightly tied with stay wire to avoid tension on service cable.

9 No rain water flows along with service cable and reach to consumer main panel. Necessary looping of cable to be provided either side.

10 The connection to main line is to be made so tight and clean surface, so that loose contact, sparking and formation of oxide coating can be avoided.

I.E. Rules pertaining to domestic service connection

Rule 10. Construction, installation, protection, operation and maintenance of electric supply lines and apparatus

All electric supply lines and apparatus shall be sufficient in power and size and of sufficient mechanical strength for the work they may be required to do, and so far as practicable, shall be constructed, installed, protected, worked and maintained in accordance with standards of the Indian Standards Institution so as to prevent danger.

Rule 30. Service lines and apparatus on consumer's premises.

1 The supplier shall ensure that all electric supply lines, wires, fittings and apparatus belonging to him or under his control which are on a consumer's premises are in a safe condition and in all respects fit for supplying energy, and the supplier shall take due precautions to avoid danger arising in the premises from such supply lines, wires, fittings and apparatus.

2 The consumer shall also ensure that the installation under his control is maintained in a safe condition.

Rule 31. Cut-out on consumer's premises.

The supplier shall provide a suitable cut-out in each conductor of every line other than an earthed or earthed neutral conductor, or the earthed external conductor of concentric cables within a consumer's premises, in an accessible position. Such cut-out shall be contained within adequately enclosed fire-proof receptacle.

Where more than one consumer is supplied through a common service line, each such consumer shall be provided with an independent cut-out at the point of junction to the common service.

Rule 33. Earthed terminal on consumer's premises.

The supplier shall provide and maintain on the consumer's premises, for the consumer's use, a suitable earthed terminal in an accessible position at or near the point of commencement of supply as defined under Rule 58.

Provided that in the case of medium, high or extra high voltage installation the consumer shall, in addition to the afore-mentioned arrangement provide his own earthing system with an independent electrode.

Rule 48. Precautions against leakage before connecting.

1 The supplier shall not connect with his works the installation or apparatus on the premises of any applicant for supply unless he is reasonably satisfied that the connection will not at the time cause a leakage from the installation or the apparatus exceeding five thousandth part of the maximum current supplied to the premises.

2 If the supplier declines to make connection under the provisions of sub-rule(1) he shall serve upon the applicant a notice in writing stating his reason for so declining.

Rule 54. Declared voltage of supply to consumer.

Except with the written consent of the consumer or the previous sanction of the State Government, a supplier shall not permit the voltage at the point of commencement of supply as defined under Rule 58, to vary from the declared voltage by more than 5 percent in the case of low or medium voltage or by more than 12½ percent in the case of high or extra high voltage.

Rule 77. Clearances above ground of the lowest conductor.

1 No conductor of an overhead line, including service lines erected across a street shall at any part thereof be at a height less than :-

  a for low and medium voltage lines 5.791 m

  b for high voltage lines 6.096 m.

2 No conductor of an overhead line including service lines erected along any street shall at any part thereof be at a height less than:

  a for low and medium voltage lines 5.486 m

  b for high voltage lines 5.791 m.

3 No conductor of an overhead line including service lines, erected elsewhere than along or across any street shall be at a height less than:

  a for low, medium and high voltage lines upto and including 11,000 V if bare 4.572 m

  b for low, medium and high voltage lines upto and including 11,000 V if insulated 3.963 m.

Rule 79. Clearances from building of low and medium voltage lines and service lines.

1 Where a low or medium voltage overhead line passes above or adjacent to or terminates on any building, the following minimum clearances from any accessible point, on the basis of maximum sag, shall be observed.

  a For any flat roof, open balcony, verandah, roof and lean-to-roof.

    i When the line passes above the building, a vertical clearance of 2.439 m from the highest point.

    ii When the line passes adjacent to the building, a horizontal clearance of 1.219 m from the nearest point.

  b For pitched roof

    i When the line passes above the building, a vertical clearance of 1.219 m immediately under these lines.

    ii When the line passes adjacent to the building, a horizontal clearance of 1.219 m.

2 Any conductor so situated as to have a clearance less than that specified in sub-rule (i) shall be adequately insulated and shall be attached by means of metal clips at suitable intervals to a bare earthed bearer wire having a breaking strength of not less than 517.51 kg.

3 The horizontal clearance shall be measured when the line is at maximum deflection from the vertical due to wind pressure.

Tapping service connections: No service connection line should be tapped from an OH line from any point mid span, except at the point of support. When a service connection is taken overhead with a bare conductor, it should be provided with guard wires.

Basic Concept of Monopole:

I found an example of both is one picture. It is pretty self explanatory, but I'll explain it anyways. The pole is in the forefront of the picture, steel monopole double-circuit construction, in the back is the self supporting lattice tower, also double-circuit construction.

Multi-circuit Tower

To reduce the allocation of land for the construction of electric power facilities, it is possible to leverage multi-circuit overhead transmission lines (MCTLs), in which the conductors of several circuits of different voltage classes are placed on the same tower. The unique features of the arrangement of conductors on MCTL towers cause unequal inductances and capacitances of different phases. In addition, there are significant mutual electromagnetic influences on the line circuits. To account for these factors, it is advisable to model the power flow of electric power systems equipped with MCTLs using the phase frame of reference. On the basis of such models, it is possible to determine the power flows while taking into account lateral and transverse asymmetries and to analyze electromagnetic safety conditions along the routes of multi-circuit transmission lines. We proposed a technique for modeling power flows and electromagnetic fields of multi-circuit power transmission lines, in which conductors of several circuits of different voltage classes are placed on the same tower. The methodology is based on the application of phase coordinates, which are the most natural description of three-phase power systems. The method is versatile enough to be applied to solving the specified problems for MCTLs of different designs. The article presents the results of research aimed at developing a method for modeling MCTL power flows. The results of modeling power flows of an electrical network including a three-circuit power transmission line are presented. The practical use of the models developed by the authors will make it possible to make well-grounded choices regarding the options for the use of multi-circuit power lines.

Fig 2

1 Introduction

0The issue of reducing the allocation of land for the construction of power transmission lines (transmission lines) has become particularly urgent in recent years. One of the most effective ways of addressing this issue can be put into practice on the basis of applying power transmission lines of multi-circuit design [1,2]; in this case, the conductors of several lines of different voltage classes are placed on the same transmission tower Fig 3.

Fig 3

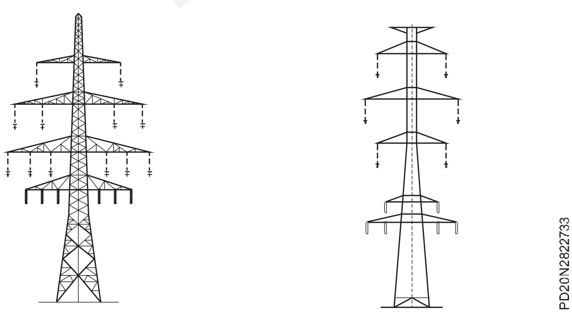


Fig 3 - Design of transmission towers of (a) a six-circuit 2 × 380 kV + 2 × 220 kV + 2 × 110 kV MCTL and (b) a four-circuit 2 × 400 kV + 2 × 110 kV MCTL.

Multi-circuit overhead transmission lines (MCTLs) have been in use since the seventies of the last century. For example, Germany uses a six-circuit MCTL with four cross arms: the top two are used to secure 380 kV line conductors. The conductors of two 220 kV lines are placed on the middle cross arm, and the same number of 110 kV line conductors are placed on the bottom cross arm (Fig 1). The total number of conductors placed on the transmission tower is eighteen. A four-circuit 66–230 kV transmission line was built in Egypt, and a similar line with 400 and 110 kV circuits operates in Slovakia (Fig 1).

The following MCTLs are currently installed in Russia:

- Four-circuit 110 kV line in the Tyumenenergo grid;
- A 220–110 kV MCTL located in the Moscow region;

- Three-circuit sections of the 500 kV line providing power transmission from the Sayano–Shushenskaya HPP.

The classification of transmission lines according to the number of circuits is illustrated by the diagram and photos of the transmission towers shown in Fig 4.

Fig 4

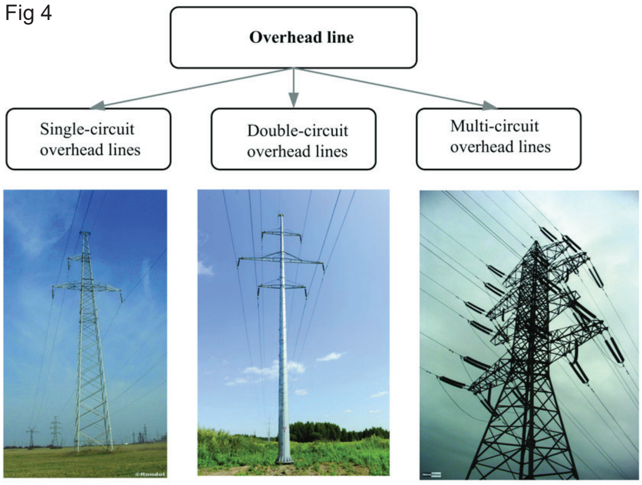
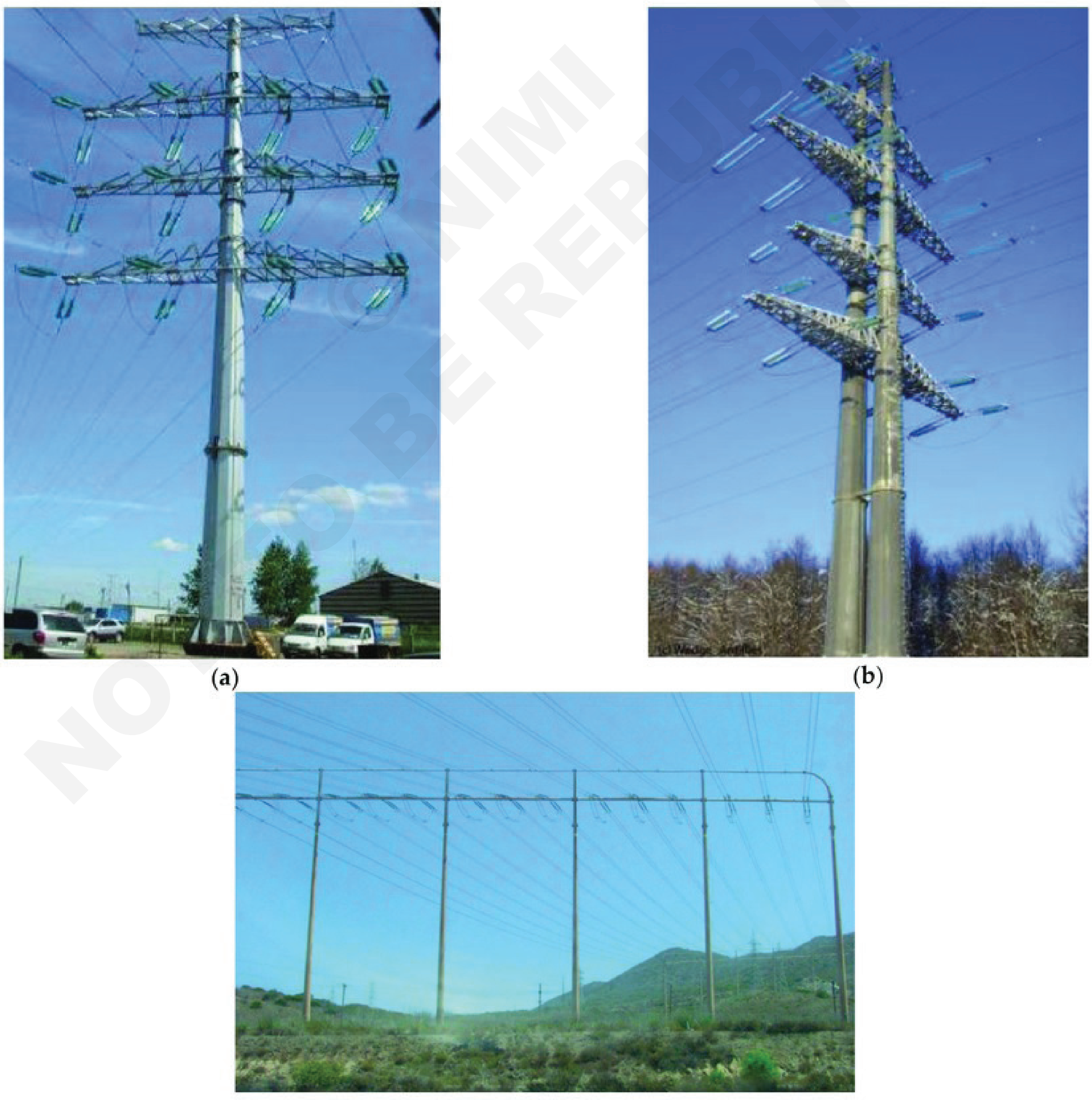


Fig 4. **Classification of overhead power lines by number of circuits.**

For MCTL construction, tower designs are used that differ in material, version of the structure, and the way current-conducting parts are secured. On conventional single-circuit and double-circuit lines, standard designs of wooden, metal, and reinforced concrete transmission towers are used. For MCTLs, towers of unique design are developed, some of which are shown in Figure 3. The most promising for the construction of MCTLs are multifaceted towers (see Figure 3a,b). Low-voltage MCTLs can be constructed on the basis of using insulated conductors (see Figure 4).

As the overhead transmission line corridor is less and less, multi-circuit transmission line tower application would become more common. Introduction In recent years, the overhead transmission line corridor selection and planning is more and more difficult, the construction cost is higher and higher, especially in economically developed areas and densely populated urban areas, overhead transmission line corridor is increasingly limited

Fig 5



and valuable, some areas have even without the new overhead transmission line corridor may, the situation in some areas has seriously restricted the power grid planning and construction. In overhead transmission line, using multi-circuit tower can effectively improve the unit line corridor transportation capacity, which can both to meet the requirements of power grid construction and adapt to the needs of the local development planning, thus facilitating the coordination of social economy and power grid construction, and sustainable development.

Main problems of multi-circuit tower type design Meteorological conditions . The current regulation is based on the different line level with different return period to determine the design meteorological conditions, 110kV ~330kV transmission line and large crossing line return period should be 30years .

For multi-circuit tower type design, first must according to the highest voltage grade to determine the return period, followed must be based on the status of multi-circuit transmission line in the system to determine an appropriate increase in the value, if its importance in the system has reached or exceeded a voltage level, should improve the meteorological condition value standard.

Safe factor of conductor, earth wire and fittings . The conductor and earth wire safety factor not only affects the safe operation of the line, but also related to the strain tower load. As a result of multi-circuit transmission lines is more and more used in city corridor complex region, strain tower, large angle tower used in large proportion, safety factor is often a great influence on the line tower material consumption.

Compared with the single-circuit tower, multi-circuit tower of the external load and tower pressure will increase several times, tower weight, the foundation force will increase substantially too. On the use of large-section conductor multi-circuit tower, in order to reduce material shape coefficient and the tower wind pressure, can consider to use steel tube structure.

Multi-circuit transmission line tower is higher, conductor number is more, tower load is larger, than single and double-circuit tower ,so the design standards should be appropriately raise after combined with the operation experience. The line corridor, tower force, lightning protection, live working are the main factors that affect the multi-circuit transmission line tower plan, so the design must be considered.

Fig 6

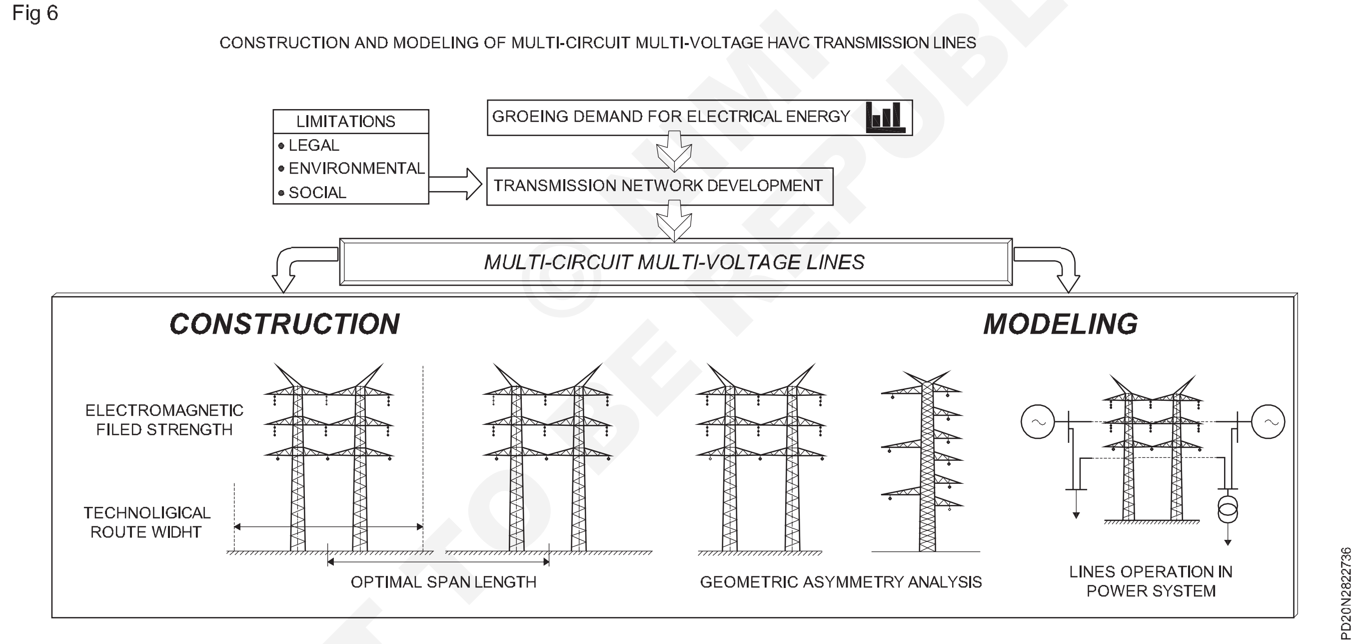
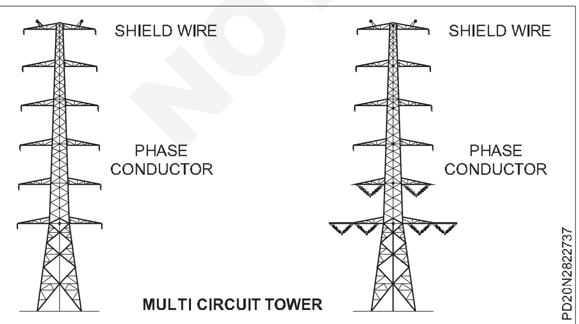


Fig 7



Electric field distribution at the top of the tower at different angles

When the UHV transmission lines span over the top of 220 kV transmission line towers, the total electric field at the top of the towers vary from angle to angle, which will affect the electric field distribution at the top of the towers. When the crossing distance is 10 m and the offset distance is 0, the overall electric field and the potential distribution of the model with 30° crossing angle are calculated and It can be seen that the electric field strength near the pole of the upper cross-arm and the top of the tower is much larger. The main reason is that they are close to the lower phase conductors of the

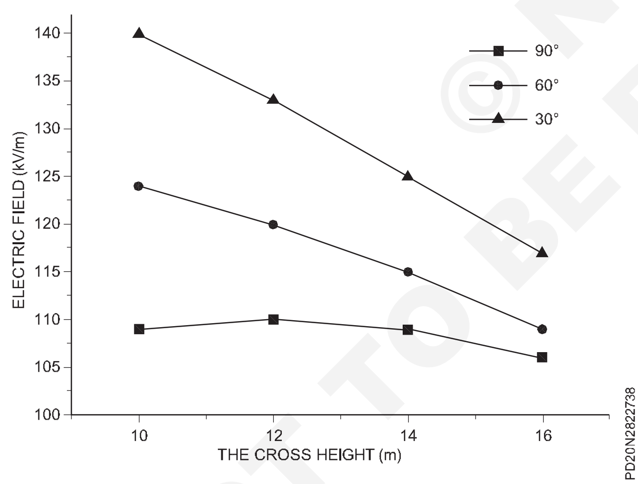
UHV transmission line, which has the largest potential. The calculation results of the tower surface electric field is shown in Table 1 and the maximum values are 109 kV/m, 124 kV/m, 140 kV/m, located at the tip of the upper cross-arm; when angle decreases from 90 degrees to 30 degrees, the maximum value of electric field is increased by 28.7%.

Electric field distribution at the top of the tower at different angles Fig. 7 shows the maximum electric field at the top of the tower when the UHV transmission lines cross the 220 kV line towers with different cross distances at 90°, 60°, and 30°. It can be seen that the influence of the crossing distance on the electric field distribution at the top of the tower is different from the different angles. At 90°, the maximum field strength at the top of the tower decreases with the increase of crossing distance.

Table 1

Maximum electric field strength of the tower top area (kV/m)			
Offset distance	Cross Angle		
	90°	60°	30°
0 m	109	124	140
0.5 m	106	120	138
1 m	103	117	136

Fig 8



When the distance increase from 10 m to 16 m, the maximum value of electric field at the top of the tower are 109 kV/m, 106 kV/m, 103 kV/m, 103 kV/m, and the difference is within 1.3%, the increase of span height has little influence on the field strength distribution at the top of the tower.

At 60°, the maximum value of electric field decreases from 124 kV/m to 109 kV/m with the cross height increasing from 10 m to 16 m, reduced by 11.6%; At 30°, the maximum value decline from 140 kV/m to 117 kV/m, which was reduced by 22.6%.

With the decrease of the span angle, the influence of the crossing height on the electric field. It can also be seen from Fig. 7 that the maximum electric field strength on the tower increase by 13.6% when cross-angle decrease from 90° to 60° with the cross height of 16 m, which is much smaller than the increase at the cross height of 10 m. Thus, the effect of cross-angle on the electric field distribution becomes smaller with the cross height increasing.

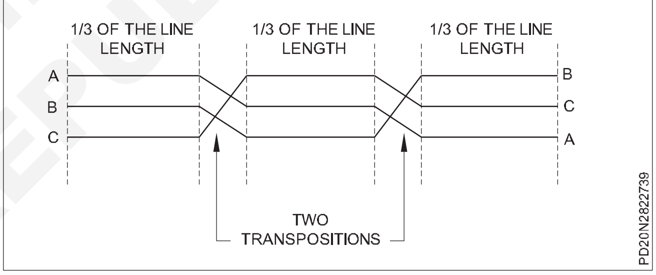
Electric field distribution at the top of the tower at different angles When the UHV line crossing the 220 kV line tower, the offset distance increases from 0 to 1.5 m at 90°, 60°and 30°, the maximum electric field strength on the tower top area is shown in Table 1.

The maximum electric field strength of the tower top area decreases 5.4%, 7.2%, 4.3%, respectively, at different cross angles. At different crossing angles, the offset distance has different influence on the electric field distribution in the overhaul area, which has the least influence at 30°, and the greatest influence at 60°.

At the distance of 1.5 m, the maximum electric field on the tower increase 30.1% as the cross-angle decreasing from 90° to 30°, and this is close to that of the increase with the offset distance of 0, which is 28.6%. Therefore, the offset distance within 1.5 m has a slight influence on the electric field distribution at the top of the tower.

Transposition Towers

Fig 9



Current flowing through transmission lines induces a magnetic field that surrounds the lines of each phase and affects the inductance of the surrounding conductors of other phases. The conductors' mutual inductance is partially dependent on the physical orientation of the lines with respect to each other. Three-phase lines are conventionally strung with phases separated vertically. The mutual inductance seen by a conductor of the phase in the middle of the other two phases is different from the inductance seen on the top/bottom.

Unbalanced inductance among the three conductors is problematic because it may force the middle line to carry a disproportionate amount of the total power transmitted. Similarly, an unbalanced load may occur if one line is consistently closest to the ground and operates at a lower impedance. Because of this phenomenon, conductors must be periodically transposed along the line so that each phase sees equal time in each relative position to balance out the mutual inductance seen by all three phases. To accomplish this, line position is swapped at specially designed transposition towers at regular intervals along the line using various transposition schemes.

In AC transmission system, Transposition towers are used to change the physical configuration of the transmission line conductors in polyphase system to reduce the voltage imbalance in transmission line conductors.

The transposition of transmission line conductors equalize the mutual inductance and capacitance of the transmission line and reduce the voltage imbalance in phases of the transmission line.

Electrical Faults in Transmission Systems

Objectives: At the end of this lesson you shall be able to
- **detect the faults occure in the systems**
- **understand the method to rectify the faults**

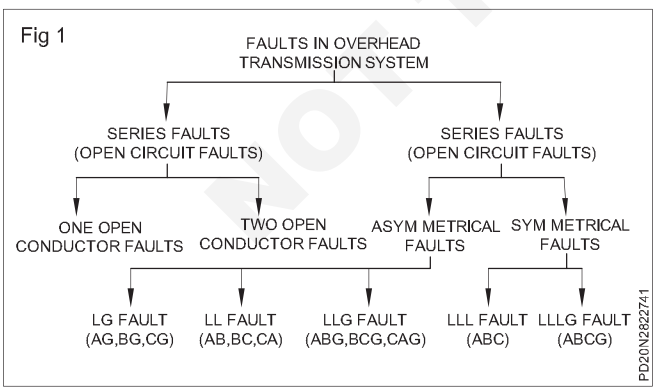
An electrical fault is a malfunction or breakdown in an electrical system that can cause a loss of power or damage to the system. Defects can occur in any electrical system, including transmission, distribution, and power plants

The electrical power system is very large, complex and spread over a large geographical area. The electrical power system consists of a generator, transformer, transmission lines and load. A fault in a circuit is the disturbance or failure, which interfere the normal system operation.

Fault (shown in Fig.1) usually occurs in a power system due to insulation failure, flashover, physical damage such as wire blowing together in the wind, an animal coming in contact with the wire. Fault usually causes the flow of excessive current, abnormal voltages, induce overvoltage on neighboring equipment and cause hazards to human, animals, etc. Fault analysis is generally needed to select the size of circuit breaker fuse and characteristics, setting of the relay. Fuse, circuit breaker, relays, lighting power protection device are some of the fault limiting devices.

In this paper, we present a review of power system faults and their prevention methods. The organization of the paper is as follows. The next section presents the types of faults. The effects of faults are discussed in the third section. Methods for prevention of faults are discussed in the fourth section and finally in the last section the conclusions are presented..

Fault in a transmission line



Various types of faults that can occur within three-phase power transmission systems.

Types Of Faults

Faults are classified into two types, i.e. short circuit fault due to the sudden overvoltage condition also said as shunt fault and open circuit fault due to cessation of current flow and also called as a series fault. Series fault is categorized by the increase of voltage and frequency and fall in current in the faulted phase such as when system hold one or two broken lines. Further, short circuit fault is classified into two types, namely: symmetrical fault and unsymmetrical fault.

Symmetrical fault- A fault due to short circuit in all three phases is categorized as a symmetrical fault. It is the most severe fault. Generally symmetrical fault is found rarely. Roughly 5 % of all faults involve all three phases. It affects each of three phases equally.

Asymmetrical fault- It is unbalanced in nature. This fault happens due to a short circuit of phase with ground. It occurs as single line to ground fault, line to line fault, and double line to ground fault. Fig 2.b, 2.c, 2. d shows Line to ground fault, Line to line fault and double line to ground fault respectively

Types of faults:

1 Single line-to-ground fault: This type of fault occurs when one of the conductors in the transmission line comes into contact with the ground, causing a short circuit.

2 Line-to-line fault: This type of fault occurs when two conductors in the transmission line come into contact with each other, causing a short circuit.

3 Double line-to-ground fault: This type of fault occurs when two conductors in the transmission line come into contact with the ground, causing a short circuit.

4 Open circuit fault: This type of fault occurs when a transmission line breaks, causing an interruption in the power supply.

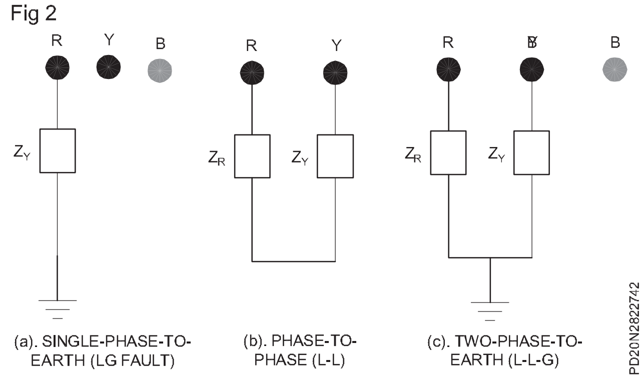
5 Transient fault: A transient fault, also known as a temporary fault, is a type of electrical fault that occurs briefly and then disappears on its own. These types of faults are typically caused by external factors, such as lightning strikes or tree branches falling on a power line.

It is important to have protection schemes in place to detect and mitigate the impact of faults in an electrical transmission system. This helps to ensure the reliability and stability of the power supply and minimize the risk of damage to the transmission system.

1 Single line-to-ground fault

A single line-to-ground fault is a type of electrical fault that occurs when one of the conductors in an electrical transmission system comes into contact with the ground, causing a short circuit. This type of fault can be caused by a variety of factors, such as damaged insulation on the conductor, a broken conductor, or a conductor coming into contact with a tree branch or other external object.

Fig 2



A single line-to-ground fault can cause a significant amount of damage to the transmission system and can result in a loss of power to customers. To protect against this type of fault, transmission systems typically have protective relays and other fault detection systems in place to quickly identify and isolate the fault.

Several types of protective schemes can be used to mitigate the impact of a single line-to-ground fault on the transmission system, including ground fault protection, over current protection, and ground fault detectors. These schemes help to ensure the stability and reliability of the power supply and minimize the risk of damage to the transmission system.

2 A line-to-line fault

A line-to-line fault is a type of electrical fault that occurs when two conductors in an electrical transmission system come into contact with each other, causing a short circuit. This type of fault can be caused by various factors, such as damaged insulation on the conductors, broken conductors, or conductors coming into contact with each other due to external forces.

3 Double line-to-ground fault

A double line-to-ground fault is a type of electrical fault that occurs when two conductors in an electrical transmission system come into contact with the ground, causing a short circuit. This type of fault can be caused by various factors, such as damaged insulation on the conductors, broken conductors, or conductors coming into contact with external objects.

A double line-to-ground fault can cause significant damage to the trans

A double line-to-ground fault can cause significant damage to the transmission system and can result in a loss of power to customers. To protect against this type of fault, transmission systems typically have protective relays and other fault detection systems to quickly identify and isolate the fault.

4 Open Circuit Fault

An open circuit fault is a type of electrical fault that occurs when there is a break in the electrical transmission system, causing an interruption in the power supply. This type of fault can be caused by a variety of factors, such as damaged conductors, broken insulators, or tree branches falling on the transmission line.

5 Transient faults

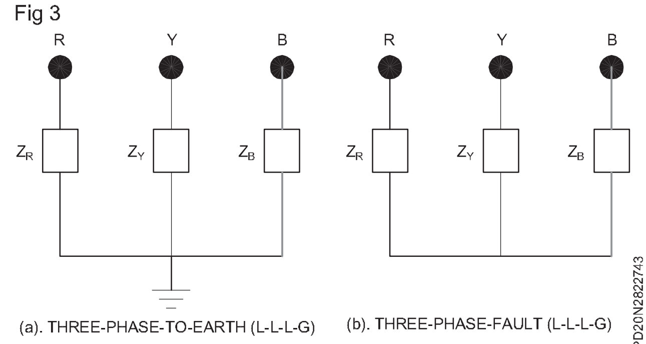
A transient fault, also known as a temporary fault, is a type of electrical fault that occurs briefly and then disappears on its own. Transient faults are typically caused by external factors, such as lightning strikes or tree branches falling on a power line. These types of faults can cause a temporary interruption in the power supply, but they do not cause permanent damage to the electrical system.

Transient faults can be difficult to detect and protect against, as they often occur for a very short period and are not always visible to protective relays or other fault detection systems. However, several protection schemes can be used to mitigate the impact of transient faults on the electrical system, such as surge arresters, ground fault protection, and overcurrent protection.

It is important to note that transient faults should not be confused with permanent faults, which are caused by damage to the electrical system and require repair to restore power. Permanent faults can cause significant damage to the electrical system and may require extensive repairs to fix.

Effects of Faults

Fig 3



The damaging effect of faults depends upon the type of fault ,as we know short circuit is the most dangerous fault as the current is maximum approximately 10 times the nominal current of instrumentation, given below is the effect:

Due to heating by fault, electrical equipment like bus bar, generator, transformer are going to be broken & excessive heating of lines, cables may result in fire or explosion.

Negative sequence current rises from unsymmetrical fault will result in heating.

Stability of the power system may be adversely affected and can lead to a complete shutdown of the power system.

Sometimes the short circuit takes the form of arc on an overhead transmission line if not quickly cleared will burn the conductor causing it to break resulting in long time interruption in supply.

A reduction in the voltage in power system due to a fault sometimes be so large so that relays having pressure coil tends to fail.

In an industry where we see interconnected system, when a fault develops it is followed by a fall in voltage and frequency, this may result in loads such as motor which normally takes the power from supply will start to feed or deliver the power to fault location. During the fault, induction motor and synchronous motor feed the fault.

Methods to overcome faults

To overcome fault in the system we isolate the faulted parts from the rest of the electrical network. Many devices are introduced such as relay, Instrument transformer, circuit breaker, fuses, etc. to provide this isolation of fault. These devices are used for safety purpose, are also accurate and economical.

Relay- It senses the fault and sends the command to circuit breaker for tripping unhealthy parts from healthy parts. It prevents from damages to alternator or to transform. It can handle the high power required to directly control electric motors and other load.

Instrument transformer-It includes current transformer or voltage transformer. It is used to isolate or transform voltage or current level. The most common use of this is to operate instrument or metering device from high voltage or high current circuit.

Circuit breaker-It is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. It is used to detect fault condition and interrupt current flow.

Substation hot-spot monitoring system automatic online thermography

Objective: At the end of this lesson you shall be able to
- **understand about the softwares and cameras used for monitoring the hot spots in substaions.**

High Resolution Thermal Imaging based automatic hot spot temperature monitoring and reporting system for predictive maintenance

Objective Of Substation Monitoring

A Typical substation consists of several electrical equipment such as CT (Current Transformer), PT (Power Transformer), CB (Circuit Breakers), Surge or Lightning Arrester, Busbars, Earth Connectors, Potential Transformer etc. These components are connected together that form “joints”. Normally, over the period of time, these joints develop hot-spots due to the high voltages and currents passing through them which require timely and daily monitoring. These hot spots may cause breakdown of the sub station which may result in shutdown of plants which is dependent on power from the substation. It may also cause accidents. So, it is important to monitor “hot spots” in a substation regularly to prevent such breakdown or accidents.

Sparkview helps preventive maintenance of your switch-yard/substation

Key Components of SparkView

One unit of SparkView Consists of the following equipment

1 **ThermCAM-384:** Its a high resolution (384x288 Pixels) thermal camera which is the core of the SparkView Substation Monitoring System. It uses a lens which is selected as per desired area to measure hot-spots in the switch-yard or substation.

2 **2MP Visual Camera with 20x optical zoom:** Visual Camera is used for better identification of the joints manually during the hot-spot location during installation from control room or during any manual inspection remotely from control room.

3 **PT-Drive with Enclosure:** This is a PAN and TILT System which helps the SparkView cover more areas per unit. Its a weather proof industrial grade system designed to perform in harsh weather conditions.

4 **SparkView™ Software:** This is a Windows Based Thermal Image Acquisition and processing software which detects hot-spot , and visual camera helps in detecting the exact location of the generated hot-spot. The Camera systems comes with PTZ unit (Pan-Tilt & Zoom) through which it can rotate 360° and tilt in the range of -85° to +40°, the visual camera is provided with 20x optical zoom.And generates reports automatically once or twice a day. The period can be configured. SparkView™ Software has many features which are useful for switchyard monitoring system.

Apart from above main components, a panel box that houses all power supplies, (network equipment if any) are kept at the location near to the installation of the SparkView. Also, it is normally mounted on a rugged pole at approx 45 degree angle to cover large area of the switch-yard or substation.

Normally, at least 1GBPS data link is required from the SparkView installation site to the control room where a Server Grade PC is located with SparkView™ Software. If continuous monitor is not needed, than multiple (upto 8) units of SparkView can be connected to the same data link as well as the same PC.

Fig 1

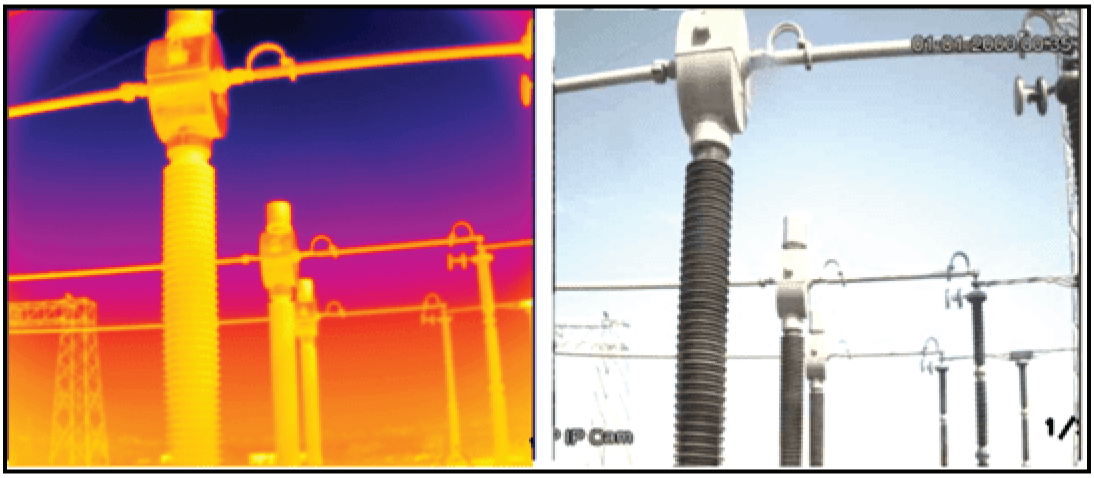
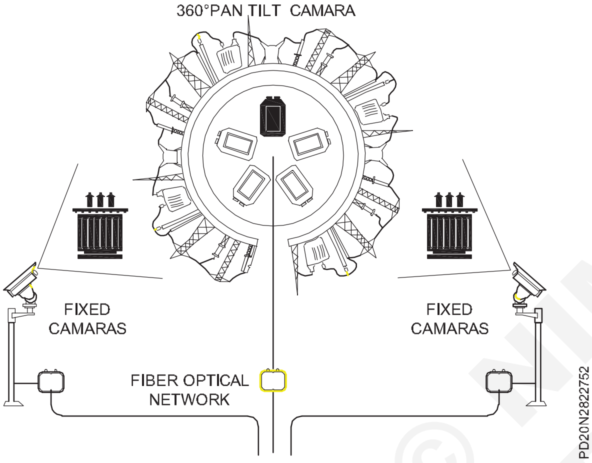


Fig 2



Operation concept

Infraview Software is configured to take temperature of all probable hot-spot locations (normally joints between components in switch-yard/substation) at a predefined time. Every hot-spot location is checked if the measured temperature exceeds the threshold set for that joint. If it exceeds the thresh-hold, then it is considered hot spot and report/alarm is generated.

Normally, **Infraview Software** is installed at the Control Room of the Substation, and monitored. If any hot spot is detected, its manually checked and rectified and its status is updated.

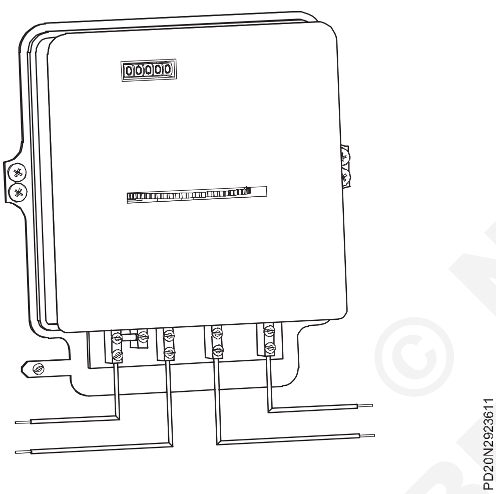
A weekly (or monthly) report can be generated with all hot-spots checked, temperature recorded. One can plot a graph of any hot-spot location against time/dates to see rising pattern which helps analysis and preventive maintenance.

Energy meter, MRI meter test lab, TOD

Objectives: At the end of this exercise you shall be able to
- **distinguish different types of energy meters**
- **describe the measurement of energy**
- **describe MRI**
- **describe meter test lab, spot billing machine**
- **describe TOD metering.**

Energy Meter or Watt-Hour Meter is an electrical instrument that measures the amount of electrical energy used by the consumers. Utilities are one of the electrical departments, which install these instruments at every place like homes, industries, organizations, commercial buildings to charge for the electricity consumption by loads such as lights, fans, refrigerator, and other home appliances.

Fig 1



The basic unit of power is watts and it is measured by using a watt meter. One thousand watts make one kilowatt. If one uses one kilowatt in one-hour duration, one unit of energy gets consumed. So energy meters measure the rapid voltage and currents, calculate their product and give instantaneous power. This power is integrated over a time interval, which gives the energy utilized over that time period.

Types of Energy Meters

The energy meters are classified into two basic categories, such as:

- Electromechanical Type Induction Meter
- Electronic Energy Meter

Energy meters are classified into two types by taking the following factors into considerations:

- Types of displays analog or digital electric meter.
- Types of metering points: secondary transmission, grid, local and primary distribution.
- End applications like commercial, industrial and domestic purpose
- Technical aspects like single phases, three phases, High Tension (HT), Low Tension (LT) and accuracy class materials.

The electricity supply connection may be either single phase or three phase depending on the supply utilized by the domestic or commercial installations. Particularly in this article, we are going to study about the working principles of single-phase electromechanical induction type energy meter and also about three-phase electronic energy meter from the explanation of two basic energy meters as described below.

Single Phase Electromechanical Induction Energy Meter

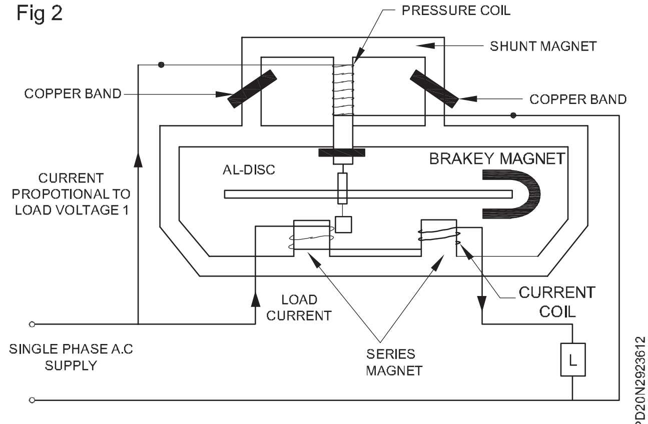
It is a well-known and most common type of age-old energy meter. It comprises a rotating aluminum disc placed on a spindle between two electromagnets. The rotation speed of the disc is proportional to the power, and this power is integrated by the use of gear trains and counter mechanism. It is made of two silicon steel laminated electromagnets: shunt and series magnets.

Series magnet carries a coil which is of a few turns of thickness wire connected in series with the line; whereas the shunt magnet carries a coil with numerous turns of thin wire connected across the supply.

Braking magnet is a kind of permanent magnet that applies the force opposite to the normal disc rotation to move that disc a balanced position and to stop the disc while power gets off.

Single Phase Electromechanical Induction Energy meter

Fig 2



Series magnet produces a flux which is proportional to the flowing current, and shunt magnet produces a flux proportional to the voltage. These two fluxes lag at 90 degrees due to inductive nature. The interface of these two fields produces eddy current in the disk, utilizing a force, which is proportional to the product of instantaneous voltage, current and the phase angle between them. A braking magnet is placed over one side of the disc, which produces a braking torque on the disc by a constant field provided by using a permanent magnet. Whenever the braking and driving torques become equal, the speed of the disc becomes steady.

A Shaft or vertical spindle of the aluminum disc is associated with the gear arrangement that records a number proportional to the revolutions of the disc. This gear arrangement sets the number in a series of dials and indicates energy consumed over time.

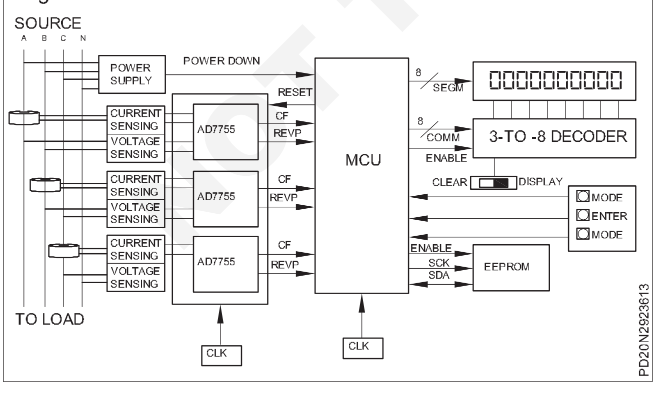
This type of energy meter is simple in construction and the accuracy is somewhat less due to creeping and other external fields. A foremost problem with these types of energy meters is their proneness to tampering, which necessitates an electrical-energy-monitoring system. These series and shunt type meters are widely used in domestic and industrial applications.

Electronic energy meter are accurate, precise and reliable type of measuring instruments when compared to electromechanical induction type meters. When connected to loads, they consume less power and start measuring instantaneous. So, electronic type of three-phase energy meter is expected below with its working principle.

3-Phase Electronic Energy Meter

This meter is able to perform current, voltage and power measurements in three phase supply systems. By using these three phase meters, it is also possible to measure high voltages and currents by using appropriate transducers. One of the types of three-phase energy meters is shown below (given as an example) that ensures reliable and accurate energy measurement compared to the electromechanical meters.

Fig 3



It uses AD7755, a single-phase energy measurement IC to acquire and process the input voltage and current parameters. The voltage and currents of the power line are rated down to signal level using transducers like voltage and current transformers and given to that IC as shown in the figure. These signals are sampled and converted into digital, multiplied by one another to get the instantaneous power. Later these digital outputs are converted to the frequency to drive an electromechanical counter. The frequency rate of the output pulse is proportional to the instantaneous power, and (in a given interval) it gives energy transfers to the load for a particular number of pulses.

The microcontroller accepts the inputs from all the three energy measurement ICs for three-phase energy measurement and serves as the brain of the system by performing all the necessary operations like storing and retrieving data from EEPROM, operating the meter using buttons to view energy consumption, calibrating phases and clearing readings; and, it also drives the display using decoder IC.

Till now we have read about the energy meters and their working principles. For a deeper understanding of this concept, the following description about the energy meter gives complete circuit details and its connections using a microcontroller.

Energy Meter Circuit Using Microcontroller:

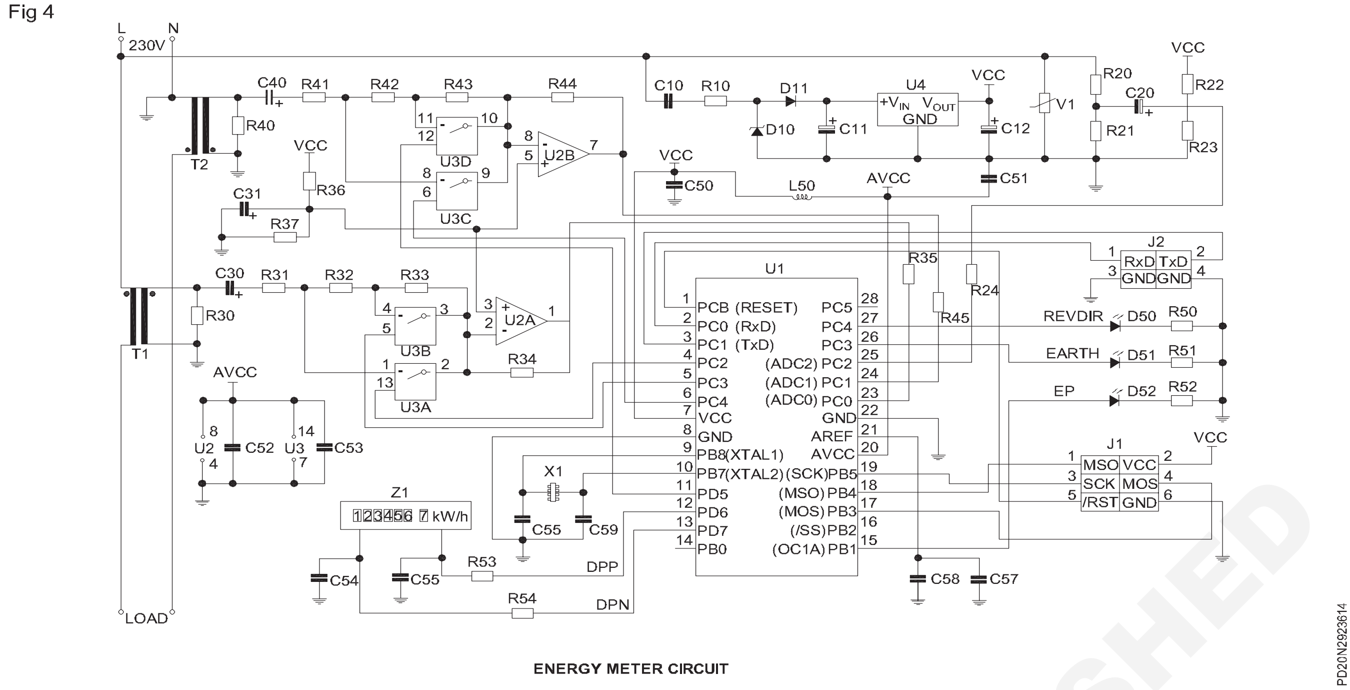
The below figure shows the watt-hour meter circuit implemented by using Atmel AVR microcontroller. This circuit continuously monitors and acquires voltage and current parameters of the mains single phase supply. Microcontroller gets these parameter values from a signal conditioning circuit, which is driven by OP-AMP ICs .

Energy Meter Circuit Using Microcontroller

This circuit has two current transformers connected in series with each supply line: phase and neutral. The current values from these transformers are sent to the respective ADC of the microcontroller, and then the ADC converts these values to digital values, and thus the microcontroller does necessarily calculations to find the energy consumption. The Microcontroller is programmed in such a way that the voltage and current values from the ADC are multiplied and integrated over a specified time period, and then correspondingly drive the counter mechanism that displays the number of units consumed (KWs) over a time period.

In addition to the energy measurement, this system also provides earth fault indication in case of any fault or overcurrent that may occur in neutral or earth line and appropriately turns the Light Emitting Diodes indication for earth fault detection as well as for every unit consumption.

Fig 4



ENERGY METER CIRCUIT

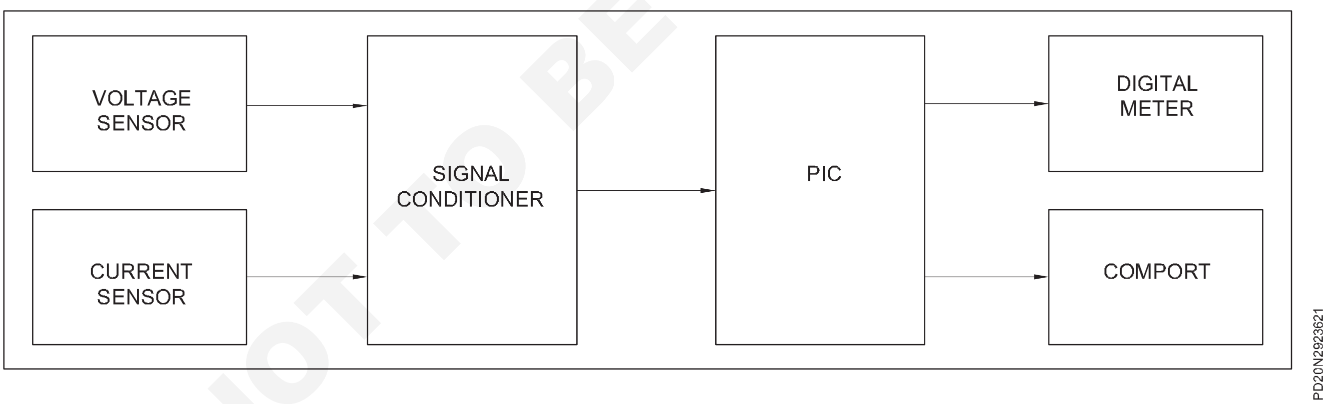
Digital Energy meters

Objective: 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)

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. Integration over time gives energy used, measured in kilo-Watt hour. The block diagram for a digital meter is shown in Fig 1. The two sensors, voltage and current sensors are employed.

Fig 1



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 .

It's inbuilt around a current transformer and other active devices (voltage comparator), which converts the sensed current to voltage for processing. The output from both sensors is then fed into a signal (voltage) conditioner which ensures matched voltage (or) signal level to the control circuit containing multiplexer. It enables sequential switching of both signal to the analogue input of the Peripheral Interface Controller (PIC).

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.

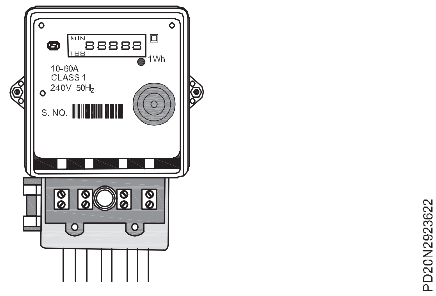
The PIC is programmed in 'C' language. It stimulates to use the received data to calculate power consumption per hour, as well as the expected charges. These are displayed on the liquid crystal display (LCD) attached to the circuit.

Fig 2 shows the image of a digital energy meter.

Advantages

DIGITAL electronic meters are much more accurate than electromechanical meters. There are no moving parts and, hence, mechanical defects like friction are absent

Fig 2



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. The function of a 3-phase energy meter is similar to that of a single phase energy meter.

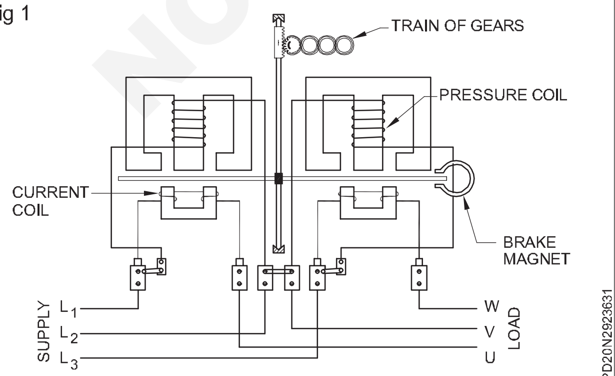
Types of 3-phase energy meters

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)

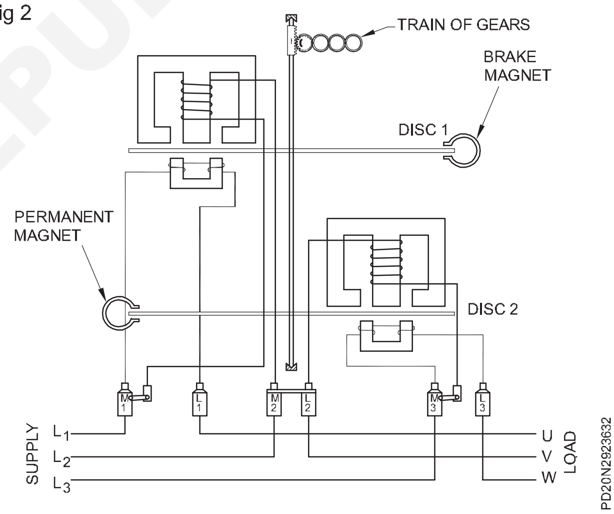
Two element 3-phase energy meters: This energy meter works on the principle of measurement of power by the two wattmeter method. Two elements of a current coil and two elements of a potential coil are used in this energy meter. These assemblies can be arranged on the different sectors in a horizontal 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.

Fig 2

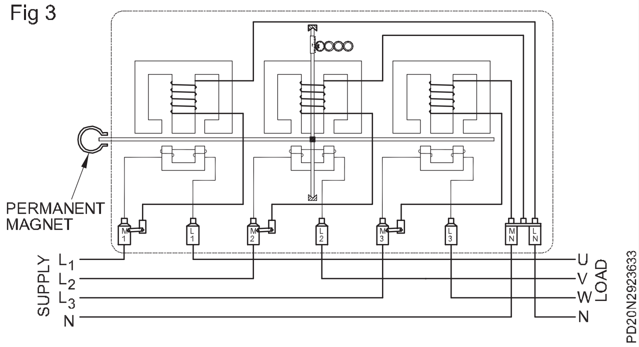


In both the cases the driving torque produced by individual elements are summed up. The recording mechanism which is attached to the train of gears i.e., cyclometer or counter type dial shows the sum of the energies that has passed through the elements. The two element energy meter is only suitable for 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.

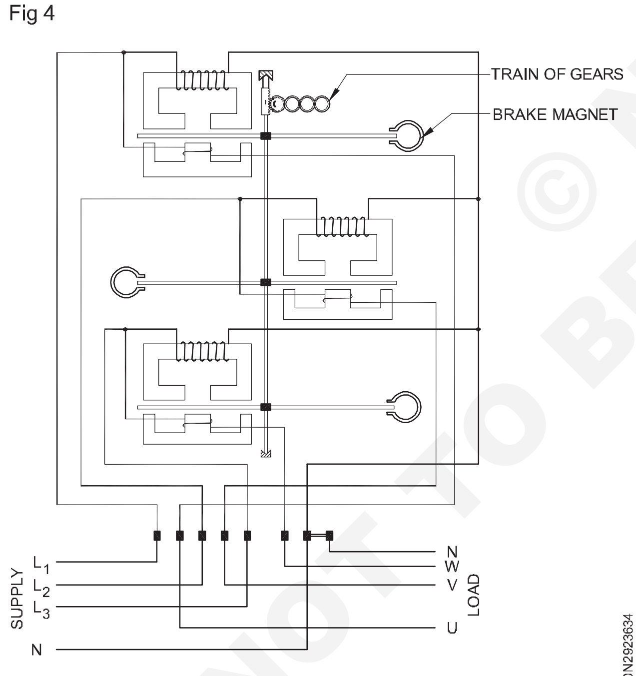
The current coils are connected in series to the individual lines. As is the case with the two element energy meter, these three elements can be arranged in the different sectors of a common single aluminium disc which serves as a rotating part connected to driving dial (Fig 3).

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

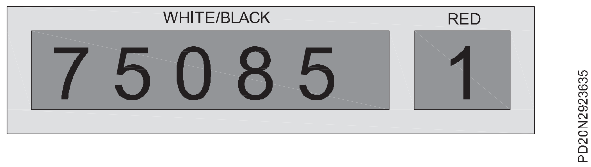
Application of 3-phase energy meter: A two element 3-phase energy meter is used with three phase loads in which a neutral is not used such as for an industry or irrigation pumpset motors etc. having three phase loads only or with an 11kV 3-phase 3-wire supply to an industry.

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.

Example

This meter reading is 75085. The red number should be ignored.

Fig 5



A digital meter has an electronic or digital display. It will show 5 numbers in black or white, and might be followed by 1 or more red numbers.

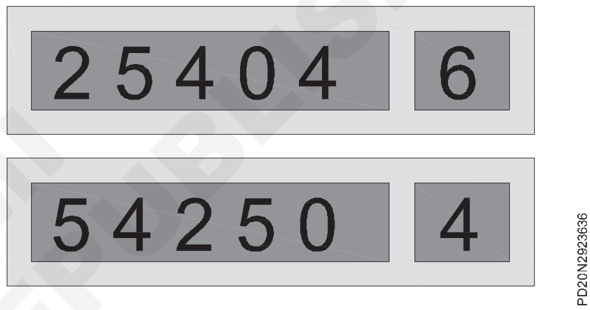
To read the meter:

1 Write down the first 5 numbers shown from left to right.

2 Ignore any other numbers.

Two rate digital meter

Fig 6



Example

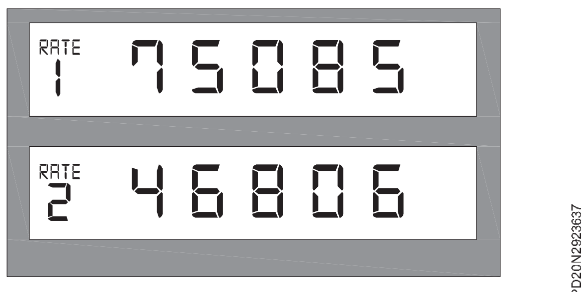
This meter has 2 readings - 25404 and 54250. You'll need to give both readings to your supplier.

If you get cheaper electricity at certain times, you might have a two rate (or 'dual-rate') meter. This means it will have 2 rows of numbers.

The top row (labelled 'low' or 'night') shows how many units of cheaper electricity you've used.

The bottom row (labelled 'normal' or 'day') shows how many units of standard-price electricity you've used.

Fig 7



To read the meter:

1 Read both the top and bottom rows.

2 Write down the numbers shown left to right.

3 Ignore any numbers shown in red.

Two rate single display meter

Example

This meter has 2 readings - 75085 and 46806. You'll need to give both readings to your supplier.

Some two rate (or 'dual rate') meters only have 1 digital display. They will either flash up the different rate readings in a cycle or have a button that you need to press to make the display cycle through the readings for the different rates.

Most meters will have a label that tells you which rate is 'low' or 'night' and which is 'high' or 'normal'. If there's an 'N' on the label this will stand for 'normal' - it doesn't stand for 'night'.

If you're not sure which rate is which, make a note of the numbers in the morning and check again later that day. The number that's changed must be your 'high' or 'normal' rate.

To read the meter write down the numbers shown left to right, for each reading.

To read this meter:

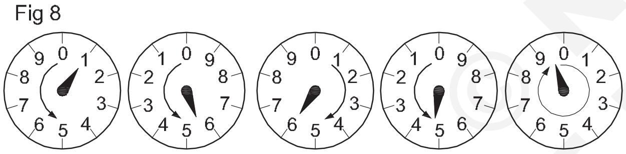
1 Write down the numbers shown left to right.

2 Make sure you get both readings.

There might be more numbers after the high and low rates. You don't need any of these extra numbers for your reading.

Dial meter

Fig 8



PD20N2923638

Example

The dials show 1 5 6 5 9. After following the meter reading instructions, the meter reading you would give to your supplier is 1 5 6 4 9.

An electricity dial meter has 5 or more dials. They each turn to point to a number between 0 and 9.

Each dial on your meter will turn in the opposite direction to the ones next to it. Some dial meters start with a clockwise dial and some start with an anticlockwise dial - check the direction of your dials before you read them.

To read the meter:

1 Read the first 5 dials from left to right - ignore any red dials or dials marked 1/10.

2 If the pointer is between two numbers, write down the lower number - if it's between 9 and 0, write down 9.

3 If the pointer is directly over a number, write down that number and underline it.

If you've underlined a number, check the next dial to the right. If the pointer on that dial is between 9 and 0, reduce the number you've underlined by 1. For example, if you originally wrote down 5, change it to 4.

Gas meters

Digital metric meter

Fig 9

PD20N2923639

Example

This meter reading is 00544.

A digital metric meter will have an electronic or digital display, showing 5 numbers then a decimal point, followed by some more numbers.

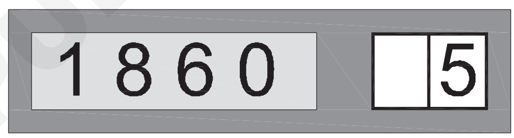
To read the meter:

1 Write down the first 5 numbers shown from left to right.

2 Ignore the numbers after the decimal point, sometimes shown in red.

Digital imperial meter

Fig 10



PD20N292363A

Example

This meter reading is 1860.

A digital imperial meter has an electronic or digital display, showing 4 black or white numbers, followed by 2 numbers shown in red.

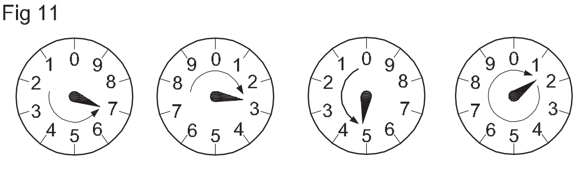
To read the meter:

1 Write down the first 4 numbers from left to right.

2 Ignore the rest of the numbers, shown in red.

Dial meter

Fig 11



PD20N292363B

Example

This meter reading is 7241.

A gas dial meter has 4 or more dials. Each one turns to point to a number between 0 and 9.

Each dial on your meter will turn in the opposite direction to the ones next to it. Some dial meters start with a clockwise dial and some start with an anticlockwise dial - check the direction of your dials before you read them.

To read the meter:

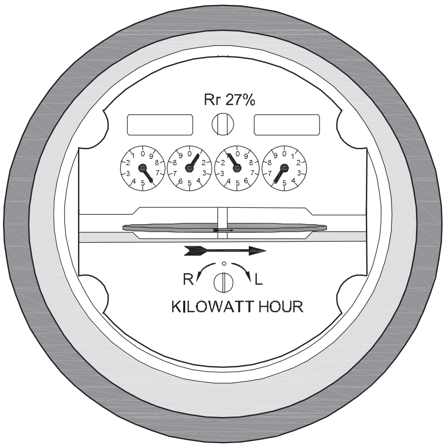
1 Read the first 4 dials from left to right - ignore the large dials or red dials.

2 If the pointer is between two numbers, write down the lower number - if it’s between 9 and 0, write down 9.

3 If the pointer is directly over a number, write down that number.

Analog Dial Meters

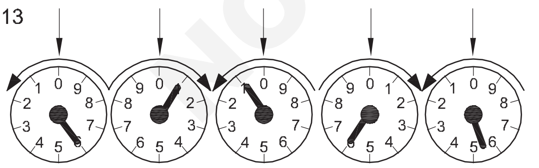
Fig 12



1 Read the numbers from the left to the right. Locate the 4 or 5 small dials on the1 face of your electrical meter. The dials are arranged with the biggest digit on the lift and the smallest digit on the right,just like you're reading a line in a book.

- A lot of sources and energy companies will tell you to read the meters right to left, but frankly, that's just complicating things unnecessarily.
- You can either write down the numbers, or draw each dial on paper and analyze them indoors if it's cold out.
- Some meters have 4 dials, while others may have 5 dials. The number of dials doesn't change this process at all.
- Note, this process only applies to the dial meters-not the analog rotary meterswith spinning numbers. The rotary meters are read like digital meters.

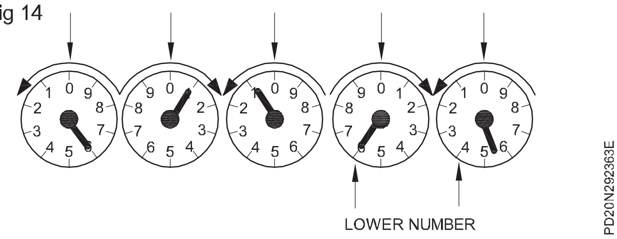
Fig 13



2 Note which direction the pointer on each dial is supposed to go. Each dial on your meter will normally alternate between clockwise and counterclockwise. Look on top of each dial to see if the numbers are front to back,or back to front.

- Some meters will even have little arrows on top of each dial displaying which a direction they go.
- You may even be able to see the little dials moving in the direction they're meant to travel if you're currently using a lot of juice.

Fig 14



3 Round down when the dial is between two numbers. The pointer on the dial is 3 rarely going to be sitting exactly on a number. When it's between two digits, always round down to the lower number. So, if the pointer sits between 5 and 6, read it as a 5.

  - Remember! We're rounding down by number, not direction here-for then counterclockwise dials, the lower number will be to the left, not the right.
  - The one exception is if the dial is between a 9 and 0 on a clockwise-oriented dial. Here, the 0 actually represents "10," so rounding down is the 9.

Fig 15

4 Round down if the dial is on a number but the dial to the right reads 0. If a number sits directly on a number and the dial to the right doesn't read as "0," record the number the pointer is sitting on top of. If the dial on the right is a 0 though, round down to the next lowest number.

  - For example, if the pointer on a dial rests perfectly on a 4 but the dial to the right ofit sits clearly at 0, then treat the digit as a 3.

M.R.I. (Meter Reading Instrument)

MRI is Meter Reading Instrument, reading solutions that involve meter networking, collecting meter data and transporting such data to a central station for display, analysis and report generation using suitable cost-effective media.

- Hand Held Unit (HHU) for Meter Reading.
- Small, compact DOS or Windows Computer
- Capable to Communicate with :
- Static Energy Meters /Computer

Uses of MRI

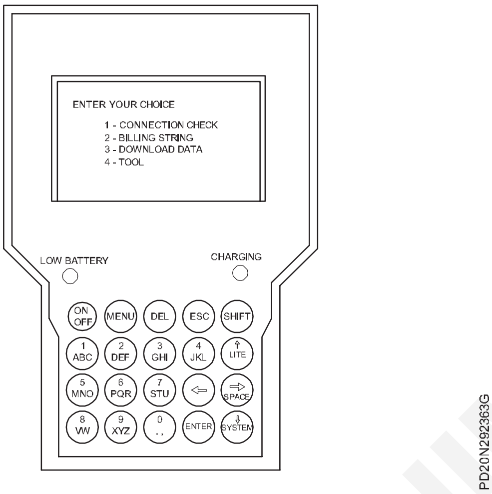
- Data Collection from Meter

- Can read different make meters with Common MRI (CMRI)
- Instantaneous Parameters checked by

Features Of MRI

- Battery Operated Instrument.
- Comprises of:
  - A Keypad.
  - LCD Display.
  - Communication Ports.
  - Charger Connector.

Fig 16



Menu Visible on MRI Screen

1 Sems

2 Sems- Chk

3 L & T

4 Phasor

5 Duke

   a Press 1 to read Secure Meters

   b Press 3 to read L&T Meters

   c Press 4 to read phasor of meter

   d Press 5 to read Duke meter

Pressing Option-1 for Secure Meter

1 Quit

2 Read Meter Data

3 Dump Data

4 Read Energy

5 Calibration

6 Terminal

7 Space

8 Identification No

9 Load survey Days

For L & T Meter press 3

- Collect Data
- Current Billing
- Previous Billing
- Tamper Data
- Instantaneous Data
- Collect Setting
- Load Survey
- Md Reset
- Tamper Reset
- Programming Mode
- Pc Communication
- Hht Download
- Accuracy Test
- Memory Status
- Exit

Electronic Meter Reading Methods

- Direct Reading through MRI.
- Reading by Low Power Radio.
- Reading by GSM/GPRS/PSTN.

Meter Data Downloading

After Reading the Meter its Data can be downloaded in respective BCS (Base Computer Software).

This data contains all the data like Instantaneous, Billing, Load Survey, Event & Transaction data.

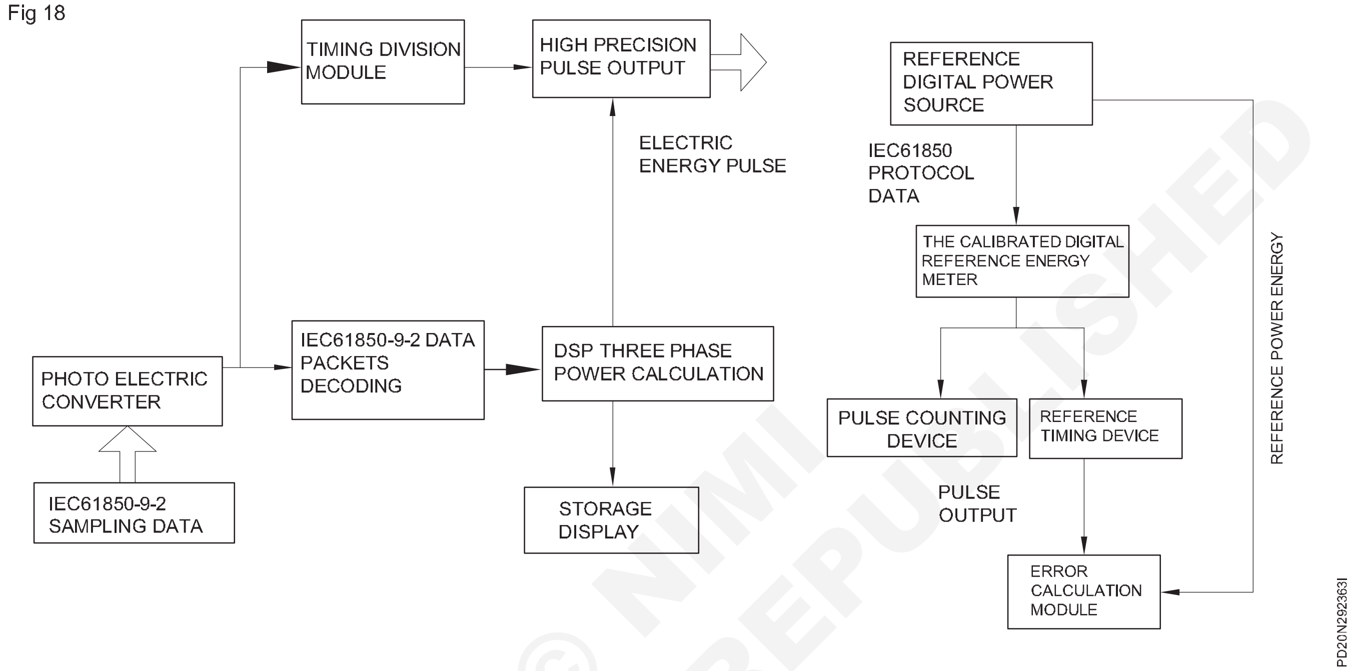
File name extension of data is .mrd in case of Secure meters and VIN in case of L & T meters.

Fig 17

Testing Of Meters

We cannot think of life without electricity and when there is electricity consumption there is a need to measure its consumption. Here energy meter comes into picture. In every residence, malls, industry, everywhere energy meters are used to measure the electrical energy consumed. Those consumers which consume large energy y 1 needs better technology to manage their energy consumption and need more data to improve their services. Improvement in energy meter technology has increased the value-added features such as remote sensing, LCD display, recording of tempering events, and many more quality monitoring features in it,along with compactness of size. But it has raised the problem of electromagnetic interference which affects the performance of the equipment. So for better reliability, energy meters have to pass through various electromagnetic compatibility (EMC) tests where meters are compared under various normal and abnormal conditions with a laboratory to ensure its accuracy in the field.

Fig 18



Standard Tests for Energy Meters

The performance tests of an energy meter as per IEC standards are divided mainly in three segments which include its mechanical aspects, electrical circuiting, and climatic conditions.

1 Mechanical component tests.

An electromagnetic compatible test is the most important test which finally ensures the accuracy of the energy meter. This test is fragmented in two parts- one is Emission tests, and the other is Immunity test. The electromagnetic interference problem is very common today. Those circuits in use today, can emit electromagnetic energy which can affect the performance and reliability of both its inner circuitry and the nearby equipment. EMI can travel through conduction or by radiation. When EMI goes through the wire or through cables, it is called conduction. When it travels through free space, it is called radiation.

Emission Test

In an electronic system, there are many components like switching elements, chokes, circuit layout, rectifying diodes and much more which produce EMI. This test ensures that the energy meter does not affect the performance of the nearby instruments or we can say that it ensures that it does not conduct or radiate EMI beyond a definite limit. There are two types of are checked to measure the EMI escape, and it covers emission test based on the EMI escapes from the system.

Conducted emission test

In this test, power lead and cables small meter of the frequency range from 150 kHz to 30 MHz.

Radiated emission test

This test measures the EMI escape through free space, and it covers large meters of the frequency range from 31 MHz to 1000MHz.

Immunity Test

The emission test ensures that meter does not work as the source for EMI for other nearby equipment; similarly immunity test ensures that meter does not work as a receptor and properly function in the presence of EMI. Again, immunity tests are of two types based on radiation and conduction.

Conducted immunity test

These tests ensure that meter's functioning do not get disturbed if it is in the blanket of EMI. The electromagnetic interference source either in contact through data, interface lines, power lines, or by contact.

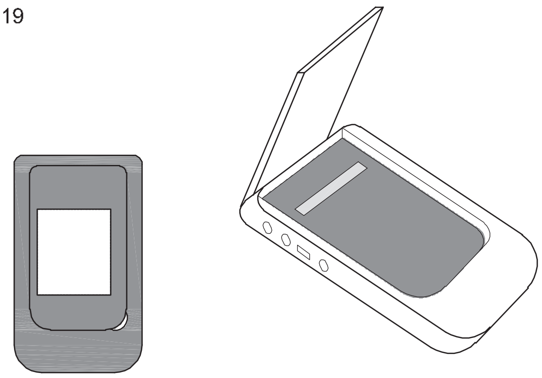
Radiated immunity test

During this test, meter functioning is monitored and if it gets affected by EMI present in the surrounding area, that fault is recognized and corrected their only. It also is known as the electromagnetic high-frequency field test. Radiations generated by sources like small handheld radio transceivers, transmitters, switches, welders, fluorescent lights, switches, operating inductive loads etc.

Spot Billing Machine

The Spot Billing system is a system, in which the meter reader visits the consumer's premises, records the meter reading and issues the bill on the spot using a hand-held computer/Simputer (Fig 1)

Fig 19



SHORT FOR SIMPLE COMPUTER SIMUTER

Spot billing is a revolutionary solution devised with the intention of enabling the power distribution utilities to streamline and implement an effective metering and billing system, improve cash flows and to make the processes customer integrating various activities being centred. The spot billing process helps handled by several people at multiple locations into a single window operation. Has many advantages (Box).

Box: Advantages of Spot Billing

- On the spot billing with accurate meter reading to the satisfaction of the customer.
- Spot billing leads to much greater revenue-collection, increased efficiency and better decision systems.
- It brings intangibles like transparency and better customer service to the system.
- Reduction in consumer complaints
- Instant access to MIS after billing information is fed into the server the same day

Characteristic Features of a Simputer/Spot Billing Machine

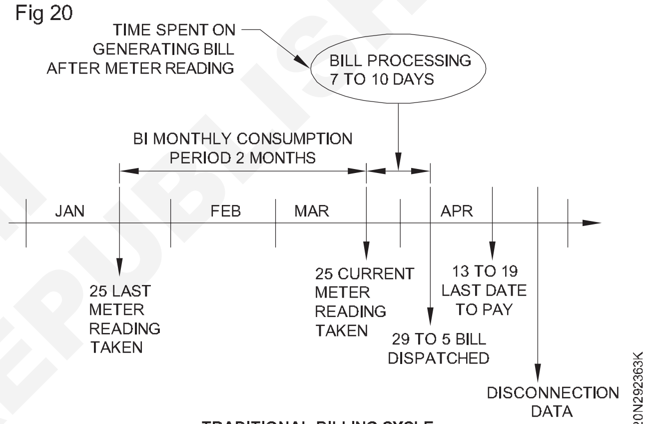
We describe below the characteristic features of a Simputer/spot billing machine.

- It is a full-featured handheld computer and its hardware and software can easily be customized as per the utility's requirements.
- With up to 64 MB of RAM and a 206 MHz processor, it is one of the most powerful handheld computers in the world. This power ensures that there are no compromises in terms of performance.
- The Simputer has 32 MB of permanent storage space which can hold lakhs of customer records. Moreover, storage space can be extended to 1 GB by using a thumb-sized USB flash stick.

Advantages of Revised Billing Cycle (Spot Billing) Over

Traditional Billing Cycle and Revised Billing Cycle In the traditional billing cycle, thebi-monthly basis (Fig 2) After themeter reading used to be carried out oncompletion of the meter reading activity, approximately 7-10 days of time wasspent in the correction of exceptional reading cases, bill processing, bill extraction.bill printing and bill distnbution. Consumers were given 8 to 14 days of time forpayment of the bill. This process involved extra time of approxmately 20 to 20days after completion of the meter reading activity.

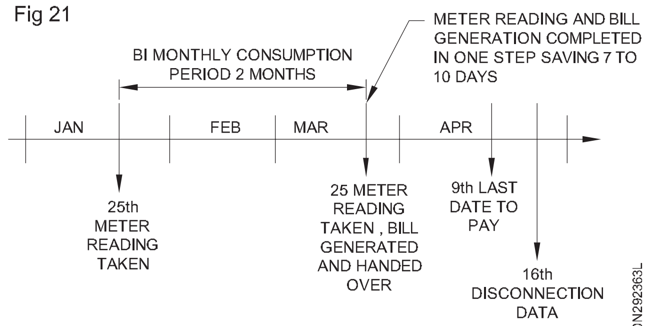
Fig 20



TRADITIONAL BILLING CYCLE

In the Revised Billing cycle all the activities pertaining to the recording of meterreading, correction of exceptional reading cases, bill processing, bill extraction,printing and hand over of bill to consumers is completed in one step and it savesthe 7-10 days of extra time.

Fig 21

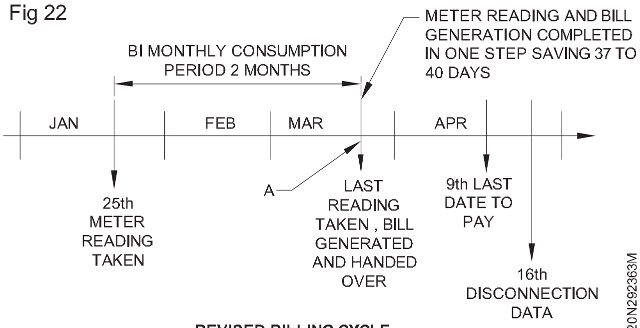


REVISED BILLING CYCLE

In the Revised Billing Cycle (Spot Billing), the reading of the meter is conducted at the site and the bill is generated on the spot through spot billing machine (Fig) This reduces the time of 37-40 days spent in competing the activities of meter reading and bill processing.

In some utilities spot billing is used in an altogether different manner. Here consumers are expected to bring their meter readings every billing cycle at specified locations At these locations, utility officials punch the reading brought by the consumer in their computer which to connected to the central computer through a dedicated communication link. The reading is processed and the bill is generated in the central computer but it is printed at the key in location. The bill is delivered to the consumer and if she wants. She can also make payment of the bill at the specified counter in the same building.

Fig 22



REVISED BILLING CYCLE

Usage Scenario: How a Field Executive would Work with a Simputer/Spot Billing Machine.

We now describe the process of using the Simputer/ Spot billing machine.

- When a field executive leaves office, s/he collects addresses and details of all the households s/ he should visit in the day. This is actually the data transferred from a PC to a Simputer by an officer.
- She inserts her/his Smartcard into the Simputer to authenticate herself/himself: this provides a high degree of security, as unauthorized persons cannot have access to the data.
- On the field, the field executive can easily get answers to queries like "Show me names and addresses of people who have defaulted payments for the last three months."
- Once s/he reaches the user premises and takes a reading, s/he can quickly enter it on to the Simputer using a soft key-board.
- S/he then prints out a receipt/bill for the home owner, and collects the money due as per the bill.
- Finally, when s/he is back in office, s/he puts cable, in a simple 2-minute process. The data is used for archives, MIS reports, etc. The money collected is deposited at the specified branch of the bank in the specified format.

Advantages of Revised Billing Cycle (Spot Billing) Over

Traditional Billing Cycle and Revised Billing Cycle In the traditional billing cycle, the meter reading.

- Its interfaces can be in any Indian language (or English), and can be used by even people who have no experience with technological devices.
- The Simputer works well with mobile handheld printers, so that receipts/bills can be given to customers on the spot.
- It has built-in Smartcard reader/writer which makes a Simputer both secure, and shareable between many field personnel.
- It has many modes of exchanging data with PCs and meters: USB, Serial, Infrared (Wireless). Bluetooth (Wireless). Thus, the Simputer is future proof.
- It can also be used to send and receive data over the Internet, with the help of a regular phone line and a thumb-sized modem. This eliminates the need for field executives to make repeated trips to the office.

Types of Spot Billing Technology

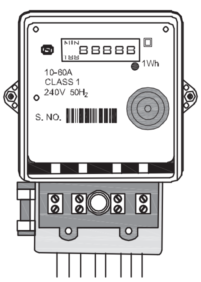
Technology-wise, spot billing is of the following two types:

Technology 1: The Simulator has a small billing engine. When reading is fed into it, the Simulator processes it, and generates and prints the bill at consumer premises.

Technology 2: The billing engine is at a central location. Meter reader enters reading into the Simulator. The Simulator sends the reading to the computer where the billing engine is residing. The computer processes the reading and generates the bill. The generated bill information is send back to the Simulator. The Simulator prints the bill at the consumer premises.

TOD Meter

Fig 23



What is TOD Meter or Time of Day Meter?

Time Of Day (TOD) meter is an energy meter that records the demand, time, and energy usage of electricity.

TOD metering normally splits rates into an arrangement of multiple segments including on peak, off-peak, and critical peak.

TOD metering benefits customers by providing reduced usage rates during off-peak times,which gives customers a chance to reduce their utility bills.

What is Time of Day (ToD) and Why It'sRequired?

Time of Day metering (ToD), also known as Time of Usage (ToU), metering involvesdividing the day into tariff slots with higher rates at peak load periods and low tariff rates at off-peak load periods.

While this can be used to automatically control usage on the part of the customer resulting in automatic load control), it is often simply the customer's responsibility to control his own usage, or pay accordingly (voluntary load control).

This also allows the utilities to plan their transmission infrastructure appropriately.

TOD metering normally splits rates into an arrangement of multiple segments including on peak, off-peak, mid-peak and critical peak.

A typical arrangement is a peak occurring during the day, such as from 5 pm to 11 pm.

More complex arrangements include the use of critical peaks that occur during high demand periods. The times of peak demand/cost will vary in different markets around the world.

Large commercial users can purchase power by the hour using either forecast pricing or real-time pricing.

TOD Meter with Automated Meter Data Acquisition System

By Implementing the Automated Meter Data Acquisition System coupled with GIS the utility will not only be able to find out the accurate Technical Losses occurring from Feeder to DT to HT but also find out the reason of such losses.

Their can be losses due to sub standard asset quality, pilferage or any other reason but the same can be pin pointed with the MDAS application Accountability and Transparency in the system will increase as exact ownership of the Loss can be identified.

In case of dealing with any fault we would be able to pinpoint the exact location where there is a fault and contact the relevant teams who would repair the same

By using the Network Analysis tool the Utility would be able to find out which feeders or transformers are being over used and which are under utilized.

This would be useful to them for Capacity Planning and Enhancement purposes as they would know where exactly there is excess capacity which can be diverted and wherever there is a need for Capacity Enhancement.

There would be minimal human interference in the entire metering process thereby reducing chances of mischief.

All this would definitely lead to Increased Customer Satisfaction.

Log sheed/ Book, Shut down and Work permit

Objectives: At the end of this exercise you shall be able to
- **Describe maintenance and up keeping of daily log sheet at various substation**
- **Describe shut down and work permit.**

1 Log book in substation

Log book is a record book which is used for manual storing perameters data of equipment, events and machines. The perameters data is taken in a frequency according requirement as 9 hourly 4 hourly or per day.

Different types of log books are used in a different format are used according equipments. Here log book formats for technical equipments like transformer and panel room equipment and capacitor are given. Energy acconting and troubleshoot log book model format is also attached.

Annual energy audit (accounting) is performing by verification of existing pattern of energy distribution across periphery of distribution substation and accounted energy flow at all applicable voltage levels of network.

We can observe the transformer condition on daily basis, monthly basis, quarterly basis and annually basis. If any parameters is not functioning according default value then we can check and find out the problem. If any fault is occurred suddenly then we can check log book data related fault.

2 LT panel logbook format:

LT Panel Logbook															
Date:															
S. No.	Time	Voltage			Load (A)			Out Going Feeder Loda (A)						Freq.	Power Factor
		R	Y	B	R	Y	B	Chiller Palnt	Server UPS	WTP	ETP	Tower A	Tower B		
1	00:00														
2	02:00														
3	04:00														
4	06:00														
5	08:00														
6	10:00														
7	12:00														
8	14:00														
9	16:00														
10	18:00														
11	20:00														
12	22:00														

3 Types of logbook parameters. :

Different types parameters are noted down in logbooks in technical system as per requirement. which below mentioned.

- Date and time.
- All phase incomer voltage.
- All phase current.
- Frequency.
- Power factor.
- All feeders current.

1 Date and Time:

Date and time is the most important in log book. If we want to know about exact parameters from last week then we can easily find out.

2 All phase incomer voltage

HT energy consumption is taken from HT meter in the format of KVAh. Many reading are available in HT meters but billing is processed in KVAh formate.

3 All phase current

Ones time recorded highest load limit is called a maximum demand. It should be low in against of section load. Section load is the highest load of premises which has to be approved from electricity board authority.

4 Frequency

HT voltage is received from electricity board according HT connection like as 11KV or 33KV. If the voltage is receiving as low or high against 11KV or 33KV then we will have to increase or decrees from substation.

5 Power factor.

Premises total load is checked in HT panel through amp meter. R, Y and B phase amp are taken for checking load and unbalance load.

6 All feeders current

Line power factor should be .98 of .99 . If the power factor value is low as .85 then energy consumptions will be 100 present but actual energy will be used only.85 %. It means 15 % energy losses so power factor value is important for system.

Table

Line Patrol Log Sheet

S. No.	Points to be checked during inspection and defects noticed	Location Nos.			Action taken for Rectification	Inspection Officer's Remarks
	General					
1	Adequate clearance to conductorsand poles are available from trees, shrubs, bushes etc.		Yes	No		
2	Vertical and horizontal clearance from the neighbouring structuresunder construction etc., are adequate		Yes	No		
3	Anynew road, channels, earth embankment are constructed near orbelow the lines reducing clearance		Yes	No		
	Poles					
4	The pole is leaning and if sowhether stay is required to make it plumb		Yes	No		
5	Earth around the pole has sunkeroded		Yes	No		
6	The metal is corroded at ground level		Yes	No		
7	Any cracks have been developed in PCC/RCC poles		Yes	No		
8	The pole is intact and free from mechanical injury due to vehiclesdashing against them		Yes	No		
	Cross Arms					
9	Any bird nest, or creeper observed on cross arms		Yes	No		
10	The cross arm is tilted		Yes	No		
11	The cross arm is rusted		Yes	No		
	Binding/Clamps/Jumpers					
12	The bindings/jumpers are cut,		Yes	No		
	Loose, Charred or Burnt					
13	Visible indications for heating of the PG clamps are observed		Yes	No		
14	Visible dangers like cut strands, andburn marks, corrosion etc. observed		Yes	No		
15	The conductors are loose, increasingthe sag		Yes	No		
16	Kites or green creepers are observed on the conductors		Yes	No		
17	The conductor/ground wire has sufficient clearance over roads,rivers, channels, railways and telecommunication circuits, haystacks etc.		Yes	No		

18	The guarding and earth, provided forconductors are intact		Yes	No		
	Guys					
19	Corosion of guy rod and stay wire isobserved		Yes	No		
20	The guy wire is tight		Yes	No		
21	The guy insulators provided are intact		Yes	No		
22	Any green creepers on the stay wire		Yes	No		
23	Guy pits have been washed away/sunk		Yes	No		
24	The sleeve concreting is in order		Yes	No		
	AB Switches and Fuse					
25	There is any visual indication for the defective closing of the switch		Yes	No		
26	The lock is missing		Yes	No		
27	The earth wire is cut or damaged		Yes	No		
28	There is too much of dustaccumulatedon the insulators		Yes	No		
29	The blades/contacts/arcing hornsare burnt out or charred		Yes	No		
	Lightning Arresters					
30	The porcelain is damaged		Yes	No		
31	The line and earth connections are intact		Yes	No		
32	There is any external indicationshow the lightning arresters havebeen punctured		Yes	No		
	11 kV Cable and Cahle Bazes					
33	The cable and cable baxes areproperly supported		Yes	No		
34	The insulators are damaged andcompound leaking from the box		Yes	No		
35	The terminal connection with theoverhead line is intact		Yes	No		
36	The earthing lead from the cable box intact		Yes	No		
	Earthing System					
37	The earthing connections ofthe metal supports and fittingsare intact		Yes	No		
	Schednie of Periodical RoutineInspection of Lines Lightning Arresters					
38	The porcelain is damaged		Yes	No		
39	The line and earth connections are intact		Yes	No		
40	There is any external indication to show the lightning arresters have been punctured		Yes	No		
	11 KV Cable and Cable Boxes					
41	The cable and cable boxes are property suported		Yes	No		
42	The insulators are damaged and composind leaking from the box		Yes	No		
43	The terminal connection with the overhead line is intact		Yes	No		
44	The earthing lead from the cable box is intact		Yes	No		

Schedule of Periodical Routine Inspection of Lines

The lineman should adhere to the time limits as per the performance standard prescribed by the State Electricity Regulatory Commission.

The following table indicates the time standards as prescribed by the Delhi Electricity Regulatory Commission (DERC);

Schedule for Inspection of Lines

Nature of Cause of Power Supply Failure	Maximum Time Limit for Power Restoration
Fuse blown out or MCB tripped	• Within three hours for urban areas. • Within eight hours for rural areas
Service line broken, snapped from the pole	• Within six hours for urban areas. • Within 12 hours for rural areas.
Fault in distribution mains	• Temporary supply to be restored within four hours from alternate source, wherever feasible. • Rectification of fault and thereafter restoration of normal power supply within 12 hours.
Distribution transformer failed/burnt	• Temporary restoration of supply through mobile transformer or another backup source within eight hours, wherever feasible. • Replacement of failed transformer within 48 hours.
HT mains failed	• Temporary restoration of power supply within four hours wherever feasible • Rectification of fault within 12 hours.
Problem in grid 33 kV substation	• Restoration of supply from alternate source, wherever feasible within six hours. • Roster load shedding may be carried out to avoid overloadingof alternate source. • Repair and restoration of supply within 48 hours.
Failure of power transformer	• Restoration of supply from alternate source, wherever feasible within six hours. • Roster load shedding may be carried out to avoid overloading of alternate source. • Replacement action to be intimated to the Commission within 72 hours and replacement of power transformer within 20 days.
Burnt meter	• Restoration of supply by bypassing the burat meter within six hours. • Replacement of burnt meter within three days.
Street light complaint	• Restoration within 72 hours.

Maintenance

The schedule maintenance of equipment installed in sub-station is essential to ensure trouble free service and avoiding un-necessary interruptions.

Following safety precautions should be observed during maintenance of transformers:

- Ensure all arrangements are safe.
- Isolate the transformer from supply and earth the terminals properly.
- Check & record the oil level in the tank before unseal the tank and unscrew the nuts and bolts.
- Ensure the work place is fire proof; care should be taken to prevent fire.
- Put a caution board "NO SMOKING".
- The staff should not have anything in his breast pocket and should not wear watch or ring.

Item wise activities involved in various schedules of sub-station equipped with a transformers up to 1000 kVA are as follows:

Daily Schedule (If manned)

Items	Schedule Inspection	Action required
Switch yard		
All jumpers & other connections	Check visually for flash/spark marks	Tighten the respective bimetallic clamp/connection
Transformer		
Temperature	Check oil temperature during peak load hours. Check ambient temperature.	Either switch off some load orshare with other transformer.
Tank	Check for oil leakage	Arrest the leakage
Dehydrating breather	Check visually colour ofsilica gel.	Ensure blue colour of silica gel.
Control Panel Room		
Relays	Check visually target position	Take corrective action
MCCB/Fuse		
Load (amp.)	Check against rated figure	Reduce load if higher
Voltage	Check against rated figure	Take corrective action
PF meter	Monitor the PF reading	Take corrective action. It should be nearly unity
General	Ensure general cleanliness of room and panels	
Capacitor Bank		
All connections	Check visually for flash/spark marks	Tighten the clamp/ connection

Maintenance Proforma

Daily Maintenance Proforma

STATION: LOCATION: DATE:

Items	Work to be done	Work done/ Remark if any	
Switch yard			
All jumpers &other connections	Check visually for flash/ sparkmarks		
Transformer		**TR-1**	**TR-2**
Temperature	Check oil temperature duringpeak load hours. Check ambient temperature		
Tank	Check for oil leakage		
Dehydratingbreather	Check visually colour of silica gel		
Control Panel Room			
Relays	Check visually target position		
MCCB/Fuse	Check for overheating		
Load (amp.)	Check against rated figure		
Voltage	Check against rated figure		
PF meter	Monitor the PF reading		

Capacitor Bank				
	All connections	Check visually for flash/ spark marks		

Signature of supervisor

Signature of operator/ technician

Signature of in-charge

Trouble Shooting

Failure of equipment in Substation is not a sudden phenomenon, for that matter each and every failure will take place only after alerting through some pre-signs. If they went failure of equipment in Substation is not a sudden phenomenon. For that matter each unnoticed or unattended will results into a failure. Therefore it wise on the part of the maintenance personnel to act upon the pre failure signs noticed well in advance to keep the equipment failure free and serviceable at all times.

If new equipment is installed for which there is no past experience, it will be difficult to forecast the defects and probable failures. Further if a failure occurred even though all the known precautions were observed, then it is necessary to investigate and more advantageous into the failure in such a manner to pull a out the actual reasons of failure so that action shall be initiated to avoid recurrence.

An Approach To Equipment Failure Investigation

1 **On Failure Aspects**

1 Occurrence

2 Date of occurrence

3 Past similar occurrences if any

4 Analysis of failure i.e. why did it happen?

5 Whether the rate of failure is worse than other installations?

2 **On Maintenance Aspects**

1 Whether schedule maintenance & required testing have been carried out on the failed equipment as per norms stipulated?

2 Does the frequency of maintenance require change?

3 Was the work properly supervised?

4 Was any RDSO modification required to be done?

5 Is any modification possible to avoid failure?

3 **About Staff**

1 Is the quality of work done satisfactorily?

2 Is the skilled staff properly trained to carry out the work?

3 Is the SMI available with them?

4 Are proper tools available with the staff?

4 **About Material**

1 Is the material received from approved source?

2 Whether the material is as per approved specification?

3 Can a better material be used?

5 **About Testing**

1 Is the testing equipment available?

2 Could testing procedure be improved to weed out the failures?

3 Whether testing equipment are calibrated?

6 **General Points**

Whether following points were checked/performed properly?

1 Proper contact

2 Clearances

3 Capacity

4 Proper contact pressure

5 Crack detections

6 Cleaning

7 Proper connections/alignment

8 Cross checks/super checks

7 **Any other Findings not covered in the above**

Causes Of Failures And Their Remedies

Common Failures of Transformer

Some of the common failures/ defects occurred in transformer are as under

- Oil leakage
- Low BDV
- Bushing failure
- Winding failures
- Excessive overheating of oil
- Low IR value
- Humming sound

- **Oil leakage**

Location	Possible causes	Remedial action
From screw joints	• Foreign material in threads • Poor threads • Improper assembly	• Remove the foreign material. • Check the threads & replace if required. • Ensure proper assembly.
From gasket joints uniformly	• Insufficient or unevencompression. • Improper preparation of gasketsand gasket surfaces. • Old gaskets	• Tight gasket joints uniformly. • Provide proper gaskets. • Provide new gaskets.
From weldjoints	• Shipping strains, imperfect weld.	• Repair welds following properprocedure.

Location	Possible causes	Remedial action
From couplings &their joints	• Cracks in couplings. • Defective coupling joints.	• Replace couplings and securethe pipe lines near couplings properly. • Make proper coupling jointsand tight the screws.
From drain plugs	• Defective thread portion. • Defective oil seal.	• Check the threaded portion. • Replace the oil seal and tightthe drain plug.

Low BDV

Type of failure	Possible causes	Remedial action
Low BDV	Moisture contamination in transformer oil due toinactive silica gel (pink colour).	Reactivate silica gel crystals orreplace them. Purify the transformeraoil to restore dielectric strength.
	Leaks around coveraccessories, breathing air from leaks.	Attend leaks, replace gasketnecessary. Purify the transformer oilto restore dielectric strength.
	Humid atmosphere in rainy season.	Purify the transformer oil to restoredielectric strength and check theBDV & water content.

Bushing Failure

Type of failure	Possible causes	Remedial action
H V Bushing flash over	• Lightening dischargeor over voltage. • Dirty bushing.	• It may be a break in the turns or end lead, flash marks on the endcoil and earthed parts close to it. • Ensure cleaning of porcelainbushing during each inspection.
HV Bushing porcelain insulator petticoat broken / cracked	• External hitting.	• Ensure proper cleaning andvisual checking of porcelainbushing during each inspection.

Winding Failures

Type of failure	Possible causes	Remedial action
Primary winding lead open circuited / earthed.	Due to overload or brazingf ailure.	Check the winding in one or alle phaseswould show signs of overheating and charring.
Bulging and interturn short, inter layer short orinter coils short.	Coils shrink andin betweeninsulation failure.	Investigate for over loading and take corrective action accordingly.

Shorting between LV and HV coils.	Insulation failure.	During manufacturing rewinding of thetransformer, the coils should be presseddown, heated and cooled repeatedly until the acoil height stabilizes.
Flash mark on the Deadcore and support.	- Dead short-circuit due tolateralor displacement ofthe coil. - Winding loose on the core.	- Nomex paper insulation sheet should beprovided between H.V. & L.V. coils soas to strengthen the insulation level,Ensure that this insulation sheet does notacause any obstruction in the passage of oil flow. - Replace the transformer and core to belifted for thoroughly checking and takecorrective action accordingly. - Repair the winding if possible.

Excessive overheating of transformer

Type of failure	Possible causes	Remedial action
Temperature rise of transformer oil	• Any internal fault such as shortcircuited core, core bolts/ clampsinsulation failure etc. • Low oil level in conservator. • Slugged oil. • Overloading	• Replace the transformer and core tobe lifted for thoroughly checking.Take corrective action according toobservations and oil test report. • Check the oil level in conservatorand top up if required.. • Carry out purification of oil toremove sludge. • Adjust the load

Low IR value

Type of failure	Possible causes	Remedial action
Low IR value	• Moisture in oil.	• Purify the oil with high vacuum type oilpurification plant and test the oil foraclectrical strength and water content.
	• Insulation failure between windingand core. • Internal connectionleads insulationdamage. • Weak brazing	• Replace the transformer. Lift the active part and check the winding thoroughly forinsulation damage and take correctiveaction accordingly. • Check the internal connection leads bylifing the active part and re-tapeinsulation paper of damaged portion. • Clean the joint and braze properly.

Humming sound

Type of failure	Possible causes	Remedial action
Humming sound	• Loose core. • Winding loosedue to shrinkageof coils.	• Lift the active part and tight all thepressure bolts and clamping bolts. • During manufacturing/ rewinding of thetransformer, the coils should be presseddown, heated and cooled repeatedly untilthe coil height stabilizes. and core. • The winding pressure boltsclamping bolts should be edduring thefirst POH after commissioning to take care of shrinkage.

Investigation Into Causes Of Failures Of Transformer

In most cases the causes of the fault can be surmised by careful observation of the condition of windings, e.g. displacement of the turns or coils, coil insulation (brittle or healthy), evidence of overheating, carbon deposit or flash marks on the core, supports, the inner surface of the tank or cover. The following notes may be helpful in identifying the causes.

Failure due to Lightening Discharge or Over Voltages

This is characterized by break down of the end turns close to the line terminal. There may be a break in the turns or end lead, and also flash marks on the end coil and earthed parts close to it, but the rest of the coils will be found to be healthy.

Sustain Overloads

The windings in one or all phases would show signs of overheating and charring; the insulation would be very brittle and would have lost all its elasticity.

Inter-turn short, Inter-layer short, or Inter coils short

The same signs as for indicated for sustained over load would be noticed, but only on affected coils, the rest of the coils being intact. This is likely if the differential relay or the Buchholz relay has operated.

Dead Short-circuit

This can be identified by the unmistakable, lateral or axial displacement of the coils. The coils may be loose on the core, some turns on the outermost layer may have burst outwards and broken asunder tension. If, in addition to these signs, the windings are are completely charred, it is conclusive evidence that the short circuit has continued for an appreciable period, not having been cleared quickly by the protective relays.

Buchholz Relay Tripping

If the upper chamber of the Buchholz relay alone has tripped, check the insulation of cored bolts, by applying a voltage of 230V to 1000V between the core and each bolt. If it fails, renew the insulating bush. Observe also all the joints, and tap-changer contacts, for overheating and arcing.

Internal Flashover

If the oil shows a low BDV, it does not necessarily mean it has caused the breakdown. At high voltage ratings, excessive moisture content in the oil may result an internal flashover between the live parts and earth, which all leave corresponding tell tale marks.

DO's & DON'Ts

Do's

1 Ensure all safety arrangement while working on electrical installation.

2 Ensure that all tools & tackles are in good & working condition.

3 Check and thoroughly investigate the transformer whenever any alarm or protection is operated.

4 Check the protection system periodically.

5 Ensure every employee is familiar with the instructions for restoration of persons suffering from electric shock.

6 Trained the staff in operating the fire-fighting equipment.

7 Always avoid un-balance loading on phase.

8 Do earthing of all points before starting maintenance.

9 Keep all spares away from dirt.

10 Work with full confidence.

11 Ensure thorough and full cleaning of insulators, since partial cleaning is worse than no cleaning.

12 Ensure perfect isolation of supply before commencement of maintenance work.

13 Put a caution board when on work.

Energy accounting

You must be familiar with financial accounting. You may perhaps be maintaining your household accounts! Energy accounting is just like financial accounting, except that instead of money, we account for energy. You know that financial accounting has the function of balancing and controlling the flow of money. The practices in financial accounting enable proper accounting of funds to detect the leakages, misappropriation, fraudulent transactions, etc. and contribute in improving the financial performance of the organization. In the same way, energy accounting helps in balancing the flow of energy and related costs, and determining the magnitude of energy losses. The underlying idea is to treat One Energy Unit (kWh) as a unit of electrical money and develop a system for accounting each unit, which is the same as the procedure followed in financial accounting and auditing.

Why is Energy accounting

Energy accounting is a system to record, analyze and report energy consumption and cost on a regular basis. In the power sector, energy accounting involves preparation of a “balance sheet” of energy, i.e., the preparation of accounts of • the energy flow to various segments, • energy consumption by various categories of consumers, • energy losses including both technical and commercial losses at various stages, and • energy required for meeting the technical requirements of the system out of the total quantum of energy available over a specified time period. This helps in an accurate accounting of the energy generated, energy consumed, energy lost, revenue realised and revenue losses at each level of power generation, transmission and distribution

For example, an energy accounting system (Fig. 2.5) at the distribution level should account for the energy made available at substation/11kV feeder/Distribution transformer, compare it with the quantum of units consumed by end-users, determine the difference between the two which gives the energy losses, and check whether these are reasonable and within permissible limits. This exercise will help the utility in estimating the revenue realised and the revenue losses. This comparison will enable it to ensure that all energy is billed and the revenue realized in an effective manner

Purpose of Energy accounting

Energy accounting helps in establishing the energy input and quantum consumed by/billed to various categories of consumers, identifying high loss areas, and evolving strategies and action plans for reduction of losses.

Energy accounting is as fundamental to energy management as cost accounting is to financial management. It can be one of the most cost-effective tools that an organization can use to cut energy costs and conserve energy. You should understand that energy accounting by itself does not reduce energy demand or costs. However, it is the basis to identify weaknesses and to select and prioritize appropriate measures for the improvement of the energy system. For example, energy accounting can raise the awareness about reducing energy demand and help in energy conservation efforts. In fact, there are many more reasons why your utility should go in for energy accounting. Let us explain them in the context of the power sector.

Need for Energy Accounting

You know that power is a critical infrastructure for the growth of our economy. The power sector has to be financially and commercially viable and be able to attract fresh investments in order to spur our country's economic growth. However, you have studied in Unit 1 of the course BEE-001 (and Unit 3 of the course BEE-003) that the financial health of most of the power utilities is a matter of grave concern and their AT&C losses have reached an alarming level. For a country like India, which generates over one lakh MW of power, even a small percentage of loss translates into a very large amount of power in absolute terms. Preventing this loss would effectively serve as capacity addition, thereby reducing the demand-supply gap and improving supply. Even 1% reduction in AT&C losses would provide substantial financial benefits to the utilities.

Technical losses can be reduced through system improvement, e.g., by reducing overloading of lines and transformers, improvement of voltage profile, etc. But these measures require large capital investments. However, commercial losses can be reduced at a comparatively lesser cost and in a shorter time frame through administrative and legislative action with greater financial gains. We need to find out the quantum of such losses and take action to reduce them. There are many other reasons why power utilities should undertake energy accounting. We list some of these here. A comprehensive energy accounting system would enable the utility to quantify losses in different segments of the system and pinpoint the areas that lead to high commercial losses. Energy auditing, about which you will study in the next unit, would provide the means to identify the areas of leakage, wastage or inefficient use. This would help in identifying measures suitable for reduction of T&D losses. Thus the first and foremost reason for energy accounting in a power utility is to record the available energy and attribute energy consumption and losses in the power generation, transmission and distribution system. Energy costs depend on the amount of energy consumed and its price. Energy accounting will make it possible to compare energy use and cost among the various components of the power supply system and to monitor how energy use changes over time. This information will help those responsible for managing energy costs − maintenance staff, site managers, and others − to get feedback on how well their utility is performing. Energy problems and billing errors could be identified and tackled. By consistently tracking energy use, you can identify problems in the system. A sudden unexplained increase in energy consumption, for instance, would require investigation of the cause. Billing errors can also be caught. Energy accounting would provide a basis for prioritizing energy capital investments and preparing a more accurate budget. You could identify operations or segments in which the utility incurs the highest energy costs and consider targeting them for energy management and cost reduction efforts. With the help of energy accounting, power utilities could evaluate the success of their energy conservation and management efforts. Did they save as much energy as they thought they would from their energy conservation efforts? Such questions can be answered only through energy accounting

Utilities could create incentives for energy management. Energy management is still not a priority for a majority of the utilities. There is apparently little incentive to take on this task. But if the power distribution utilities realise the benefits of increasing energy savings and reducing energy costs, they can appreciate the need for energy management. Energy accounting makes it possible to set quantifiable energy cost reduction goals, which could be used to augment the budget.

Objectives and Functions of Energy Accounting

For power distribution utilities, the specific objectives of energy accounting could be to:

Prepare an energy account on each feeder to record the quantum of energy received and the quantum of energy supplied to various customers;

Segregate losses into technical/non-technical losses;

Identify areas of mismatch between billing and revenue collection;

Improve metering, billing and collection;

Identify high loss areas and remedial steps for reduction of both technical and commercial losses; prepare benchmarks of actual system losses with the standards;

Continuously review the progress made in the remedial action initiated earlier.

Energy Accounting Functions

- Generating Station Efficiencies, and T&D Efficiencies;
- Monitoring conformity with metering requirements;
- Preparing energy flow diagrams;
- Energy balancing;
- Performance degradation analysis;
- Benchmarking;
- Fuel procurement and handling efficiency;
- Estimation of non-metered consumption;
- Trend Analysis and Forecasting;
- Auxiliary and captive consumption; and
- Generating Management Information System Reports.

Utilities can also provide energy accounting as a service to its consumers and play an important role in energy conservation. So far we have introduced the concept of energy accounting and discussed the need for it as well as its objectives and functions as applicable to power distribution utilities. You have learnt that one of the objectives of energy accounting is to segregate losses into technical and non-technical losses. For this, you should also know about the losses in the power system, which occur as electrical power flows from the power generating station to the end-user. You will learn about the causes of these losses and how to manage them in detail in Block 4 of the course BEE-001. At the moment, we are concerned with a basic understanding of what these are for incorporating them into the energy accounting procedure. You will learn about their segregation in Sec. 2.4, when you study the energy accounting procedure.

AT&C Losses in the Power Distribution Network

The term AT&C loss covers technical losses and commercial losses that together contribute to revenue losses and hence need attention from the energy accounting point of view. As electric current flows from the power plant through the transmission lines to the distribution segment, every element in the power system (e.g., a line or a transformer, etc.) offers resistance to it and the electrical energy is converted to heat energy, which is lost to the system. The cumulative energy lost by all the elements in a power system is classified as Technical Loss. You will learn about the reasons for these technical losses in detail in Block 4 of the course BEE-001. Here we state them briefly.

Technical losses in the network occur on account of: Accounting

- Losses in conductors due to the conversion of electrical energy to heat energy (technically termed the copper losses or I 2R losses);
- Transformer losses;
- Overloading of existing lines and substation equipment;
- Poor maintenance and repair of equipment;
- Inadequate reactive compensation;
- Lack of modernisation of old lines and equipment;
- Low HT: lt ratio, etc. Low capital investment is also a major reason for increase in technical losses in the power distribution sector. Commercial losses in the network occur due to:
- Non performing, under performing and defective meters;
- Erroneous multiplying factors;
- Defects in circuitry;
- Non-reading of meters;
- Pilferage by manipulating or by-passing of meters;
- Tampering of meter reading by mechanical jerks, placement of powerful magnets or disturbing the disc rotation by foreign materials; and
- by direct tapping.

These are all due to non-metering of actual consumption. Besides these factors, low accountability of employees, absence of energy accounting and auditing mechanisms also contribute to these losses. The sum total of "Technical" and "Commercial" losses is termed as T&D loss. It is the difference between the units input and units for which bills are raised. T&D loss does not capture revenue losses on account of factors such as non realization of payment for the billed units due to reasons such as non-billing, defective billing and poor collection. The aggregate of T&D loss and revenue loss is termed as the "AT&C loss" (Aggregate Technical and Commercial loss). It is the difference between the units input into the system and units for which the payment is collected (payment realised). AT&C losses to the utility are the sum total of technical losses, commercial losses and losses due to non-realisation of total billed demand.

In energy accounting, we measure the flow of energy at various points and maintain a record. Thus, for proper understanding of the energy accounting mechanism you must also grasp the fundamentals of the metering, billing and collection system in the power distribution sector.

Metering, Billing and Collection: The Key to Understanding Energy Accounting You have studied that metering is required for energy measurement. Bills should correctly reflect the cost of actual energy used by the consumer. Energy accounting can tell you how accurate the billing is and whether the collections match the cost of energy supplied at the input. The difference gives us an estimate of the losses. We discuss each of these aspects briefly.

Metering: Meters should be placed at appropriate points in the electricity distribution network for proper measurement of the energy input and output at those points (You may like to see Fig. 2.7 to understand meter placements). The absence of meters at any point in the distribution network signifies loss of revenue to the utility since energy flow at that point is not accounted for.

Billing: For accounting to serve any purpose, the measured energy must be billed to the consumer of that energy. You have studied about the billing problems encountered by utilities in Unit 1 of the Course BEE-001 and Unit 3 Example 1: Estimating AT&C losses 1. Units input 100 MU 4. Suppose revenue collection with reference to billed demand is 90% 2. Units billed 70 MU 5. This means that out of 70 MU billed, payment is realised for 90% of 70 MU, i.e., for 63 MU 3. T & D Losses 30 MU 6. AT&C losses = 100 MU − 63 MU = 37 MU 51 Energy Accounting of the Course BEE-003. Correct billing and timely serving of the bill will go a long way in improving the collections. Computerised spot billing can solve these problems and increase collection. You will study more on this aspect in Block 4 of this course

Collection: Utilities should take stringent action against defaulters and provide increased facilities for bill

Type of Loss	Description of Loss
Technical loss	The aggregate of T & D loss and revenue loss.
T & D loss	The cumulative energy lost by all the elements in a power system because of the resistance offered by them to the electric current flowing through them.
AT & C losses	The sum total of technical losses are losses in the network on account of non-metering of actual consumption.

payments to improve collections. These aspects have been dealt with in detail in Units 2 and 3 of the course BEE-003 and Block 4 of BEE-001.

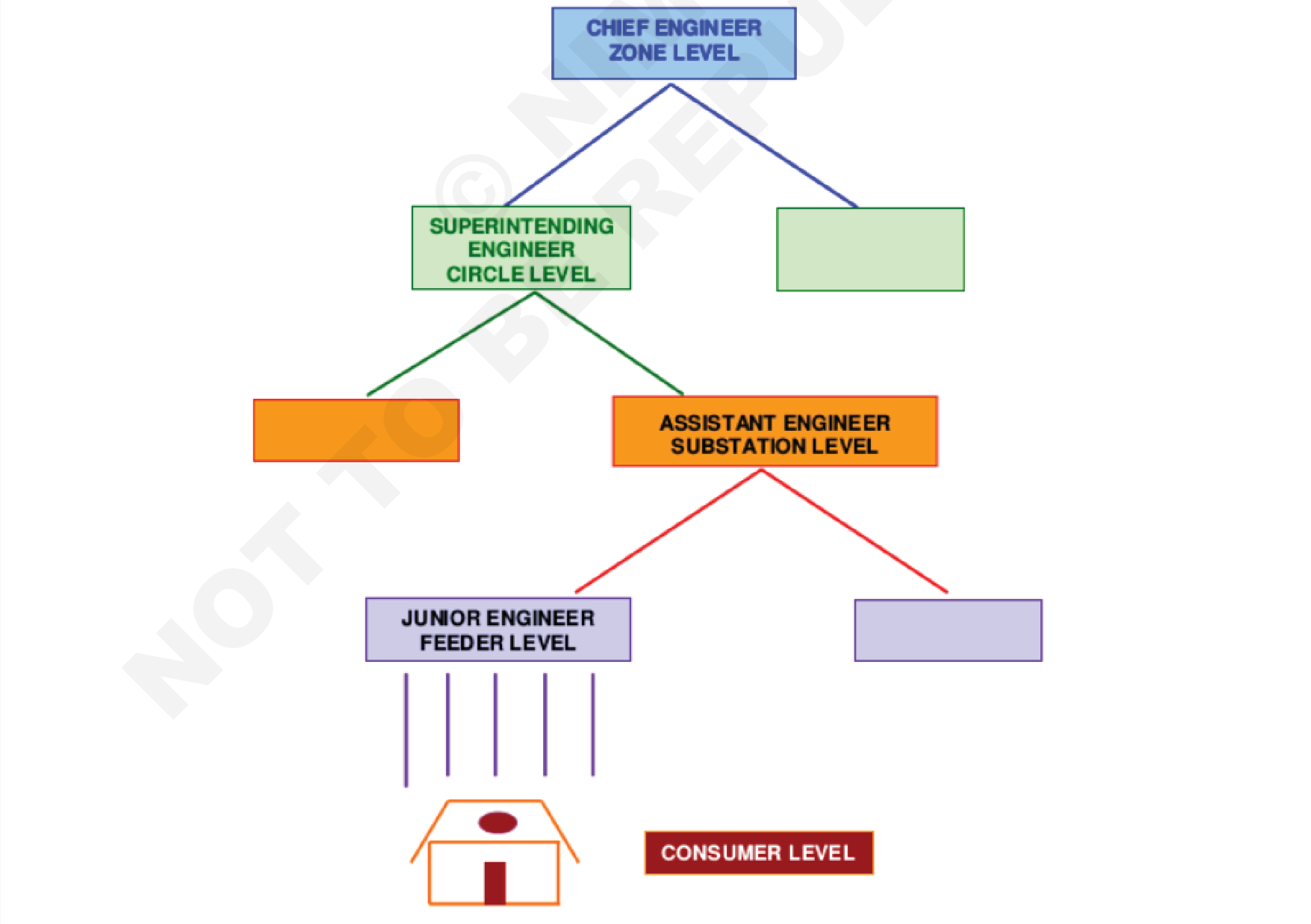
Understanding Energy Accounting

Energy Accounting Procedure

The various steps in the energy accounting procedure are:

- Measurement of the available energy (the energy input);
- Measurement of the energy consumed; and

estimating the energy lost, the revenue realised and the commercial losses.



The Town Level Grid to Consumer Supply and the Administrative Setup from the JE to CE Level

The deficit in the cost of energy available at the meter and the billing collections give an estimate of the AT&C losses.

Table shows how a typical town area could be divided for the purposes of energy accounting.

Organisational Structure and Areas of Responsibility for Energy Accounting

LEVEL	AREA OF RESPONSIBILITY
CE LEVEL	Town divide into circles, p circles in each town.
SE LEVEL	Circle divided into a set of substations, say, q substations in each circle.
EE LEVEL	Each substation divided into a set of feeders, say, r feeders.
JE LEVEL	Each feeder cater to, say, s customers through the secondary of the distribution transformer connected to it.

We shall discuss in a while how the technical and commercial losses can be segregated.

For distribution utilities, the focus of energy accounting should be on grid substations where sub-transmission systems (66/33/11kV) take off generally as a radial system to supply power to consumers at different voltage levels. Note that feeders emanate from each substation towards the customers. The feeders at 11kV are taken to the load centre and terminated into a distribution transformer (DTR). The customers are connected at 220 V from the secondary of the distribution transformer.

In order to implement the energy accounting procedure successfully, utilities should adopt a bottom-up rather than a top-down approach to energy accounting. The reason is very simple. The first view of the loss can be obtained by monitoring the energy input to a particular feeder and the amount of energy bill collected. Thus feeder becomes the focal point and must, therefore, be the first point of check and measure. Each Junior Engineer should be entrusted with the responsibility of covering one or more 11 kV feeder(s), which could be feeding a number of consumers. S/he should be responsible to account for the energy received by the feeder and billing of consumers connected to it.

The following steps could be taken at the feeder level for energy accounting:

Measure the energy received at the feeder;

List the customers billed;

Record the revenue from bills;

Compute the difference in billing and collections from customers; and

Obtain the difference in input energy cost at the feeder level and the total revenue realised from collections.

In the next step, energy accounting could be done for the set of feeders at the substation level and then for the group of substations at circle level and finally for the town area. The hierarchy in this distribution could be matched with the administrative hierarchy for the purpose of accounting as shown in Fig.

Responsibility could be fixed for the higher levels like EE Level, SE Level and CE Level. The exercise would involve establishment of an energy measurement system and preparation of energy balance related to the different responsibility areas. It would also require the segregation of technical and commercial losses. Let us now look at these aspects.

Energy Measurement

Preparation of an effective energy account will be possible only if: Meters are installed on both sides of each element of the network as indicated in Fig. Accurate energy meters are installed in all the consumer installations. The accuracy class of the 11 kV feeders must be Class 1 / Class 0.5 while the accuracy class of the meters at consumer installations must be Class 2.Energy meter readings are taken at the sending end and at all the consumer installations simultaneously. Similar accuracy class meters are installed both for measuring energy input to the system and energy sales. Electronic trivector meters with data logging facilities are provided on the 11 kV feeders/secondary side of distribution transformers to record load curve which facilitates assessment of load factors and loss load factors. The data to be registered at the 11 kV meter level includes:

- 3 phase energy;
- kW of all the phases at peak kva interval;
- kVAr of all the three phases at peak kVA of interval;
- Phase voltages of each phase with respect to neutral; and
- Power down time in minutes during the interval.

The time interval may be 15 or 30 minutes.

You may not be familiar with the terms kVA and kVAr.

- kVA is the product of kilovolts and amperes. It is also called the apparent power.
- kVAr is the reactive power, i.e., the portion of apparent power that does no work. This power must be supplied to all reactive loads, for example,transformers, motors, magnetic equipment, etc. Energy measurement at various points informs you about the losses between those points.

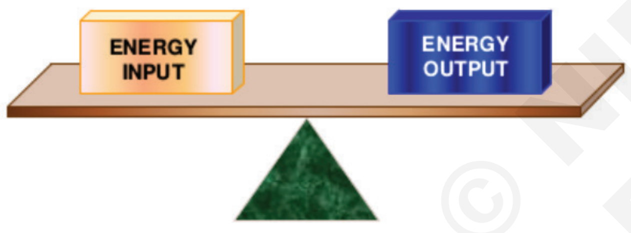
All meters should be regularly tested and calibrated as the efficacy of the data for energy accounting would largely depend on the quality of meters employed in the system. Network metering and consumer metering system should be reviewed regularly. Working, non-working, defective, un-metered supply, etc. Should be documented for taking corrective measures.

S. No.	System Elements	Losses (MU)	Losses as 5 of Energy Available in the System
1	220 kV Line	M 7 - M 9	
2	220 kV/132 kV transformation	M 9 - M 10	
3	132 kV Line	M 11 - M 12	
4	132/33 kV Transformation	M 12 - M 15	
5	33 kV Line	M 16 - M 17	
6	33/11 kV Transformation	M 17 - M 21 - M 22	
7	11 kV Line and Distribution Transformers	M 21 - M 23 - M 24	
8	IV Lines $	M 25 - Σ M 31	

A sample format for computation of losses is given in Table

Preparation of Energy Balance

An energy balance is a set of relationships accounting for all the energy that is produced and consumed. It matches inputs and outputs in a system over a given time period (Fig.).



Energy Balance Matches Energy Input with Energy Output in a System

The system could be the entire country or a limited area or even a process in a factory. An energy balance is usually made with reference to a year, though it can also be made for consecutive years to show variations over time.Energy balances are used to quantify the energy used or produced by a system. These are usually constructed from two sides:

1 From end-uses back to total primary energy consumption, and

2 From resource extraction to primary energy supply.

The basic equation of an energy balance is:

Source + Import = Export + Variation of stock + Use + Loss + Statistical differences

In this equation,

Sources are local primary energy sources;

Imports are energy sources which come from outside the area under consideration (e.g., the country, region, village, etc.);

Exports go to other areas (countries, regions, etc.);

Variation of stock is reduction of stock (wood, oil) and storage;

Use can be specified sector-wise or by energy form or by end-use. This includes use of fuels for non-energy purposes;

Losses can be technical and administrative;

Statistical difference is included to balance for inaccuracies in supply and demand, for example, due to evaluation of losses. These statistical differences can sometimes be as high as 10%.

We need to quantify all these quantities while preparing the energy balance for energy accounting. An important part of preparing an energy balance is the construction of an energy chain to trace the flows of energy within an economy or system, starting from the primary source(s) of supply through the processes of conversion, transformation and transportation, to final/delivered energy and finishing with end-use.

All too frequently, energy balances are constructed in terms of primary energy without taking into account conversions or transformations. This can lead to incorrect conclusions. The most common example is electricity,which is a secondary form of energy. Electricity is usually included in a primary energy balance on the basis of the amount of fossil fuel needed to produce it. Or, when electricity is generated from hydro, renewable energy resources or nuclear energy, an energy equivalent or heat content is used. However, it is not simply a matter of taking a conversion of one single fuel to another, since the conversion efficiency varies with the primary energy source.

For example, for hydro it is around 90%, whereas for coal it is around 40%.The amount of energy required to produce electricity should reflect these differences. For example, it would take at least twice the amount of energy to produce one unit of electricity if coal were used instead of hydro. An energy balance should include the accounting of commercial energy, non-commercial energy, non-energy products, and energy imports and exports.

We now briefly explain what is involved in this Commercial Energy: It should be clearly specified which energy forms are included in commercial and non-commercial energy categories.Non-commercial Energy: Non-commercial energy usually includes biomass (woody and agricultural residues) and animate energy . Despite their important contribution to the energy supply, particularly in rural areas, these sources do not usually appear in national energy balances. They are difficult to quantify physically since they are traded and used in non-standard units. Their flows are not monitored since they fall outside the purview of the monetised economy. A few countries now include agricultural processing residues, such as bagasse and rice husk, in their energy balances.

Non-energy Products: These include products from primary energy carriers such as petrochemicals from crude oil, coal and natural gas and should be listed separately Energy Imports and Exports: These include imports, exports, storage,stock changes, transformation (conversion of one fuel to another, for example, coal to coke), distribution and conversion losses as well as self consumption by the energy industry (if relevant). These must be included while constructing an energy balance for the Energy Accounting System.

Energy balances provide overviews, and constitute basic energy planning tools for analysing the current and projected energy situation. The overviews aid sustainable resource management, indicating options for energy saving, or for policies of energy pricing and redistribution, etc. Having explained the concept of energy balance, we would like to discuss the measurement and separation of technical and commercial losses.

How to Measure and Separate the Technical and Commercial Losses

The separation of commercial loss from the total technical and commercial loss involves comparison of the losses as measured by ‘Energy Accounting’ with the losses as estimated by network simulation studies. For an 11 kV feeder, the procedure can be outlined as follows:

Undertake energy accounting for the particular 11 kV feeder. The difference of energy input measured at feeder end and the recorded.

Consumption is the total loss:

Total loss = (Energy input measured at feeder end) − (Recorded consumption)

Using modern distribution system analysis software, carry out a simulation study for the load flow for different loading conditions during the Energy Accounting period.

The difference of total loss and the loss obtained from simulation studies (technical loss) is an indication of the non-technical loss in each distribution feeder:

Non-technical loss = Total loss − Loss obtained from simulation studies (technical loss)

This accounting and analysis would enable segregation of technical and non- technical losses in the system and help in drawing up strategies for achieving results on both the fronts. It is also essential to identify network elements with high technical losses.

Identification of Elements with High Technical Losses

The technical losses computed for each element of the network from load flow studies are to be compared with reasonable level of losses for that element. The reasonable level of losses in various segments of the system have been set out by the Committee of experts/ Central Electricity Authority in the“Guidelines for Development of Sub-transmission and Distribution System” for conditions prevailing in the country. These are given in Table.

ZONE	SYSTEM ELEMENTS	POWER LOSS (%)
A	Step-up transformer and EHV transmission system	0.50 % to 1.00 %
B	Transformation to intermediate voltage level, transmission system and step-down to sub-transmission voltage level.	1.50 % to 3.00 %
C	Sub-transmission system and step-down to distribution voltage level	2.25 % to 4.50 %
D	Distribution lines and service connections	4.00 % to 7.00 %
	Total losses	8.25 % to 15.50 %

Level of Power Losses in Various Segments of the System

Estimation of losses in LT network may be done initially for a sample network emanating from representative distribution transformers covering different categories of consumers and load density. With full computerisation of the database, it would be feasible to cover the whole LT system as per needs. After going through this section, it must have become amply clear to you that proper ‘Energy Accounting’ is a must for identifying the technical and commercial losses, separating them and also identifying the ‘culprit’ feeder.

We now discuss special cases and the precautions required in taking energy measurements.

Special Cases and Cautions in Measurements

Here, we discuss special cases that may arise in the Sub-transmission and Distribution systems.

Case of Feeders Crossing Boundaries

In the Sub-Transmission and Distribution systems in a responsibility area,some feeders may cross the boundaries and feed the loads (either in part or in full) of other areas also. Such inter-area exchanges should be avoided at 11 kV level by network reconfiguration and administrative/jurisdictional adjustments.

In cases where such network restructuring is not feasible or economical,additional energy meters could be placed at appropriate locations. Or else, relevant data on energy transfers/billed consumption could be exchanged between the units to avoid complication of accounting. The network within the unit at Division/ Sub-Division/feeder level may also be reconfigured so as to minimise the Inter-Division/Sub-Division/feeder exchange of energy so that there is no dilution of responsibility in actual practice.

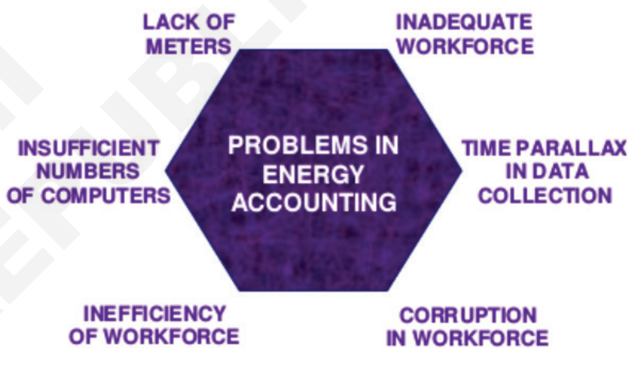
Measurements and Corrections

The following practices would enhance the reliability and correctness of energy accounting:well defined procedures for reading of the energy meters (on 11 kV feeders) not having data logging facilities, and consumer meters simple procedures to correct for non-simultaneous reading of consumer meters and billing cycles;accounting for un-metered consumption, till such time as 100% consumer metering is in place. For this purpose, data derived from sample metering at selected distribution transformers and sample surveys of consumption of various categories of consumers on a system wide basis would be required.

Scientific sampling techniques should be adopted for getting optimum results. The size of the sample and the actual location of the meters to be installed should be based on a detailed analysis of the consumers' profile, identification of regional factors and other parameters having an impact on consumption.

For example, in the case of agricultural consumers, the parameters would be cropping pattern, ground water profile, irrigation practices, agro-climatic factors, etc. For domestic and commercial consumers, the parameters could be based on income levels, sanctioned/connected load, etc. In the case of street lighting, the season-wise sample survey, hours of supply and number of working light points, etc., should be considered. With the analysis of data from such surveys, the energy consumption of un-metered consumers could be worked out on a reasonable basis. Accordingly, a reasonably reliable figure of energy losses for each feeder could be derived.

Even after achieving 100% metering of consumers, it would be necessary to have metering of some selected distribution transformers, serving different categories of load to provide a reference point for checking the energy balance. The data from consumer level metering and sample survey data should be utilized to firm up consumption of each class of consumer and derive validated data. The sample metering data would enable the utility to establish norms of consumption. The utility would also be able to investigate any deviations from normal consumption and their causes and reasons. The overall check would also be possible by adopting the population of each class of consumer and applying the sample data for estimation of consumption to validate T&D losses. Finally, we would like to present the major obstacles to energy accounting by utilities and give some suggestions about how to overcome them.



Some Problems in Energy Accounting

Overcoming the Problems in Energy Accounting

Lack of meters, inadequate workforce, insufficient numbers of computers are some of the issues that need to be dealt with by the utility management in order to implement energy accounting. In addition, there is the problem of corruption and inefficiency of the workforce of the utility, which is largely responsible for insufficient revenue realization. The technical problem of time parallax in data collection also needs to be addressed.

In Table, we give some suggestions for taking care of these problems. Obviously, it is for the management of the power utilities to take action along these lines for effective implementation of the energy accounting procedure.

Role of the Management in Overcoming the Problems in Energy Accounting

Problem	Solutions
Lack of meters	Present to the company the business case (economic study) that the company will lose less money when meters are installed. Acknowledge that collections will not be 100%. Even with less than 100% collections, the business case is probably positive.
Lack of workforce	Make the business case for more staff.
Lack of computers	This business case is easy, since the cost of computers is low, especially when compared to the lost revenue.

Employees take bribes or extort money from customers	Pay them a compensation package (salary, bonus incentives, retirement, medical plans, education support, etc.). Then discipline them. Discharge those that are found and proven to be corrupt; adhere to the company's disciplinary procedures. Then, prosecute the special cases under the Civil Laws and if needed under the Criminal Laws.
Time parallax in data collection	Read all the meters on one feeder at the same time, on the same day. Create meter reading routes that are based on feeders and not on geography. Use the load survey data recording function in the meter on the DT to time slice the energy flow into the feeder to coincide with the day of the route meter reading.

We now acquaint you with certain technological requirements and advances in the energy accounting procedure that should be adopted by utilities to reduce their losses.

Shutdown of Substation

In the Indian grid system following procedure are followed stepwise incase of availing a shutdown.

1 Approval is sought form the load dispatch centre by explaining the reason, period and nature of the shutdown (planned/emergency)/

2 The load despatch centre studies the request and approves it if found valid.

3 The shutdown operation is executed with the required men and material. Moreover, incase of an emergency shutdown, the competent authorities on the area have to be informed about supply disruption, if there is any/ Mostly it is tried to avoid supply disruptions.

The shutdown procedure

The shutdown procedure in an electrical substation typically involves the following steps:

1 Isolate the substation by opening the appropriate circuit breakers and disconnecting any transmission lines.

2 De-energize all equipment in the substation by opening the appropriate switchgear.

3 Ventilate all enclosed spaces to ensure that they are safe to enter.

4 Conduct a visual inspection of the substation to ensure that all equipment is in a safe and secure condition.

5 Turn off all substation lighting and lock all substation gates.

6 Notify the appropriate personnel that the substation has been shut down and that it is safe to enter.

It's important to note that the specific shutdown procedure will vary depending on the type of substation and the equipment that it contains. It's also important to follow all safety protocols and guidelines when shutting down a substation.

1 Maintenance Work Permit

Maintenance work permit is a safety guidelines templates which provides a permit for start working. Different types permit are used according work nature. (Model) of work permit is attached'.

2 Types of Work Permit

The types of work permit details are below mentioned.

- Cold or general work permit
- Hot work permit
- Height work permit
- Confined space work permit
- Chemical work permit

CONFINED SPACE WORK PERMIT

Date of Work:	Initiator:		Permit No.:
Description of work:			
Name of person supervising:		Dept./Function:	
Names of workmen involved in the job:			
1		2	
3		4	
Exact Location of Work:			
JSA Referance No.			
Job Instruction & Confirmation Sheet Ref. No			
Valid From: Time .... Date:		To Time: ....Date:	
Other relevant information (if any)			
Initiated by Engineer / Supervisor of Agency		Checked by Agency Safety Representative	
Name		Name	
Signature		Signature	
Date		Date	
Check list for Authorization of Work Permit			
Minimum and Mandatory Precautions			Y/N/NA
1	Permit form filled in completely?		
2	Have wind, atmospheric, and work area conditions (e.g. cold, hot, snow, poor lighting & Ventilation etc.) been considered throughout the job so that work can be done safely?		
3	All necessary Personnel Protective Equipment like Breathing Set, Waist Rope, Light Mounted Helmet etc. is put on by all the workmen?		
4	A lifeline, a rope tied on the safety belt of the person entering the confined space is provided?		
5	All practicable measures are taken to ensure that the atmosphere inside is not deficient in oxygen and does not contain flammable vapors and no hazardous gases like H2S. (Open at least 2 manholes & keep for 2 hours)?		
6	One fully trained person is stationed at ground level/outside to assist the inside workers and emergency contact No's available?		
7	All the workers trained for emergency?		
8	Safe means of access and egress provided?		
9	Is the suitable fire extinguisher available at work location?		
10	Are they Using only 24V lamps & working tools inside the confined space?		

Following additional precautions need to be taken before the start of the work		
Permit Issued By:		
	Approved by Principal Agency work in charge	Endorsed by Principal Agency HSE Dept
Name		
Signature		
Date		
Permit Close Out by: Name & Signature (Principal Agency)		
Date:		Time:
Note: All extra information on preparation and precautions to be provided on the reverse side of this PTW.		

HOT WORK PERMIT

Date of Work:	Initiator:	Permit No.:
Description of work:		

Name of person supervising:	Dept./Function:
Names of workmen involved in the job:	
1	2
3	4
Exact Location of Work:	
JSA Referance No.	
Job Instruction & Confirmation Sheet Ref. No	
Valid From: Time .... Date: .... To Time: ....Date:	
Other relevant information (if any)	

Initiated by Engineer / Supervisor of Agency		Checked by Agency Safety Representative	
Name		Name	
Signature		Signature	
Date		Date	
Exact Location of Work:			
Relevant information:			
Check list for Authorization of Work Permit			

Minimum and Mandatory Precautions		Y/N/NA
1	Permit form filled in completely?	
2	Form filled in correctly and in full.	
3	Has the work area been inspected for any abnormalities- specify on wind, atmosphere, surroundings, etc.	
4	Are the necessary PPE provided and do the workmen know their use?	
5	Is the fitter, experienced and knowledgeable enough to carry out the job?	
6	Area has to be cleared of any flammables and combustible material.	
7	Electrical equipment to be protected and grounded.	
8	Are fire-fighting equipment- extinguishers, water, sand buckets etc, located nearby for ready in case of any mishap?	
9	Gas cylinders in upright state/ trolleys/ flash-back arrestors/hose condition/ NRVs, etc.	
10	Is the area easily accessible?	

Additional precautions to be taken:		
This permit is valid only for one week. A fresh hot work permit has to be taken for continued works for the next week.		
Permit Issued By:		
	Approved by Principal Agency work in charge	Endorsed by Principal Agency HSE Dept
Name		
Signature		
Date		
Permit Close Out by: Name & Signature (Principal Agency)		
Date:		Time:
Note: All extra information on preparation and precautions to be provided on the reverse side of this PTW.		

PERMIT FOR LIFTING OF MATERIAL

Date of Work:	Initiator:	Permit No.:
Description of work:		

Name of person supervising:	Dept./Function:
Names of workmen involved in the job:	
1	2
3	4
Exact Location of Work:	
JSA Referance No.	
Job Instruction & Confirmation Sheet Ref. No	
Valid From: Time .... Date:	To Time: ....Date: ....
Other relevant information (if any)	
Initiated by Engineer / Supervisor of Agency	Checked by Agency Safety Representative

Name		Name	
Signature		Signature	
Date		Date	

Check list for Authorization of Work Permit		
Minimum and Mandatory Precautions		Y/N/NA
1	Details of type of crane(s) to be used?	
2	Name of Lift Co-ordinator, Rigger/Crane Operator?	
3	Adequate and suitable lifting gears available and in good condition.	
4	Have soil, wind, atmospheric, and work area conditions (e.g. cold, hot, snow, poor lighting & Ventilation etc.) been considered throughout the job so that work can be done safely?	
5	Lifting Equipments, Lifting gears and Slings are tested and certified?	
6	Are all operators trained, competent and healthy (Having Licenses/ Experience Certificate)?	
7	Are all the examinations and tests carried out on the equipment (Crane) and certified by competent persons?	
8	Is the safe working load (SWL) marked on all lifting tools & tackles?	
9	Lifting area cordoned off?	
10	Tag lines provided to control the swing of load?	
11	Load tied properly and secured against toppling and falling?	
12	Signalman/Rigger is provided and competent?	
13	Proper communication available between operator and rigger?	
14	Is the vehicle for transportation adequate for the load?	

Following additional precautions need to be taken before the start of the work		
Permit Issued By:		
	Approved by Principal Agency work in charge	Endorsed by Principal Agency HSE Dept
Name		
Signature		
Date		
Permit Close Out by: Name & Signature (Main Agency)		
Date:	Time:	
Note: All extra information on preparation and precautions to be provided on the reverse side of this PTW.		

WORKING AT HEIGHT PERMIT

Date of Work:	Initiator:		Permit No.:
Description of work:			
Name of person supervising:		Dept./Function:	
Names of workmen involved in the job:			
1		2	
3		4	
Exact Location of Work:			
JSA Referance No.			
Job Instruction & Confirmation Sheet Ref. No			
Valid From: Time .... Date:		To Time: ....Date:	
Other relevant information (if any)			
Initiated by Engineer / Supervisor of Agency		Checked by Agency Safety Representative	
Name		Name	
Signature		Signature	
Date		Date	

Check list for Authorization of Work Permit		
Minimum and Mandatory Precautions		Y/N/NA
1	Permit form filled in completely?	
2	Work area below is temporarily cordoned barricaded.	
3	The scaffold erected has pipes and clamps in good condition.	
4	Diagonal/lateral bracings pipes are provided to ensure stability.	
5	Access ladder is provided to reach the week location.	
6	Planks/sheet used in temporary platform are in good condition.	
7	Planks sheets are tied properly using binding wire.	
8	Temporary platform is having temporary side railing.	
9	Workers are wearing Helmet, Shoes & Safety belt in good condition.	
10	For Anchoring of safety belt at height rigid support/ life rope line is provided	
11	Experienced workers are engaged for work	
12	Portable elect equip fibre body checked for its healthiness including earthing	
13	The sling/pulley blocks/ropes are tested for fitness	
14	Workers are briefed on Safety Precautions to be taken Power hand tools used at tight are connected through 30mA, ELCB.	

Following additional precautions need to be taken before the start of the work		
Permit Issued By:		
	Approved by Principal Agency work in charge	Endorsed by Principal Agency HSE Dept
Name		
Signature		
Date		
Permit Close Out by: Name & Signature (Principal Agency)		
Date:	Time:	
Note: All extra information on preparation and precautions to be provided on the reverse side of this PTW.		

Isolator, Circuit breaker, Earth switch

Objectives: At the end of this lesson you shall be able to
- **describe Isolator, Circuit breaker, and earth swich**
- **usage of earth switch**
- **explain the working principle and mechanism of earth switch.**

Isolator , Circuit breaker - Refer related theory of Ex. No. 147 to 154

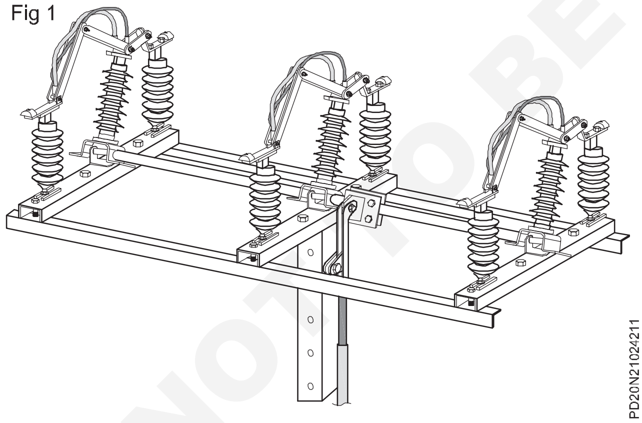
Earth Switch - Every electrical power distribution system must have protective devices that safeguard appliances and equipment from unfortunate occurrences. Among these protective devices are earth switches, which are connected to components of switchgear for keeping electrical equipment safe and preventing further harm, such as fire outbreak or injury to users.

An earth switch is a mechanical switching device for protecting parts of a circuit. It is capable of sustaining currents for a specific time under abnormal conditions such as short circuits. During normal circuit conditions, it doesn't carry any current. It's only called into action when there is an abnormal condition. An earth switch is a must-have in every electrical installation as it protects the technicians and switchgear during abnormal current conditions.

We will further explain what an earthing switch is, and we will discuss everything you need to know about the protective device.

Earthing Switch

Fig 1



An earthing switch is also known as a grounding switch. Earthing switch and grounding switch are used interchangeably. It's a protective device that's included in switchgear components like circuit breakers and isolators. When circuit breakers are removed and racked out, earthing switches automatically ground the part of the bus bar adjacent to the circuit breakers. For isolators, the earthing switches make contact with the bus bar when the isolator isolates the circuits, discharging any charges that may have gathered there.

An earth switch in switchgear is used to ground the remaining change in a power line after the power line has been removed from its source. A residual charge always remains in the circuit after it has been severed or opened by the circuit breaker and isolator. An earthing switch is usually used to discharge the charge.

Earthing switches have a snap action closing mechanism. They protect technicians and staff when there is an abnormal current. They are designed to withstand short circuits; they can also be motorized. Examples are the high voltage earthing switch and the high speed grounding switch. An earth switch in a substation has the ability to create short circuits in order to safeguard other electrical devices from damage. It's used with several high-voltage switchgear and it also serve as a protective device in the overhaul of high-voltage electrical equipment.

Earthing switches, circuit breakers, and isolators are all connected in the Ring Main Unit (RMU) substation. If there is a need for the circuit to be opened or broken for maintenance or any other reason, the right sequence for the operation of these three devices (earthing switches, circuit breakers, and isolators) must be followed. If the right steps are not followed, you won't just be causing damage to your circuit and equipment, but you will also be putting yourself in danger. To perfectly house these components, you can contact Elecspare, one of the gis switchgear manufacturers for a reliable insulating medium for your devices.

Earthing switches and isolating switches are often combined into a single device. In this case, in addition to the main contact, the isolating switch also has an earthing switch for grounding one end of the isolating switch after opening. The main contacts and the earthing switch are usually mechanically interlocked in such a way that the earthing switch cannot be closed when the isolating switch is closed, and the main contacts cannot be closed when the earthing switch is closed.

The grounding switch can be divided into two types: open type and closed type. The conduction system of the former is exposed to the grounding switch similar to the disconnector in the atmosphere, and the conduction system of the latter is enclosed in the charging SF. or insulating medium, such as oil.

Earth switch in switchgear closes short-circuit current and has certain short-circuit making ability and dynamic and thermal stability. It doesn't have an arc quenching device as it does not need to break the load current and short-circuit current. The lower end of the blade is usually connected to the grounding point through a current transformer. Current transformers can give signals for relay protection.

Earthing switches have several structures. We have the single-pole, the double-pole, and the three-pole earthing switches. The single-pole is only used when you're dealing with the neutral point grounding system. The double-pole and three-pole structures are used for the neutral point ungrounded system, and share an operating mechanism for operation.

Earthing Switch in Low-voltage Systems

The fundamental purpose for the design of grounding switches in low-voltage systems, which deliver electric power to the broadest class of end-users, is the safety of customers who use electric products and their protection against electric shocks.

The grounding system, in conjunction with other switchgear protection components like load break switch and residual current devices, ensures that a person does not touch a metallic object whose potential relative to the person's potential exceeds a safe threshold, which is normally set at 50 volts.

From the safety point of view, an earthing switch is also necessary for low-voltage electricity networks with a phase to neutral voltage exceeding 240 to 690 volts, which is typically utilized in industries, mining equipment, and machinery rather than publicly accessible networks.

Earthing Switch in High-voltage Systems

The focus of an earth switch in substation, which is significantly less accessible to the general public, does not prioritize safety as it does in the low-voltage system. Rather, it focuses more on supply dependability, protection reliability, and impact on equipment in the event of a short circuit. Because the current channel is mostly blocked through the earth, only the amplitude of phase-to-ground short circuits, which are the most prevalent, is considerably affected by the choice of earthing system.

What is Earthing Switch Used for

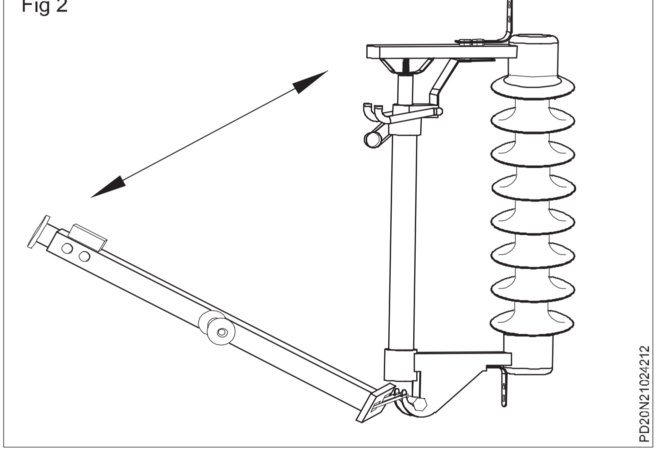
- Earthing switch is used to provide a ground line to an underground or delta-connected system.
- Earthing switch allows the connection of phase-to-phase loads.
- The earthing switch in substation is grounded to give a low-impedance link to the ground, which keeps the system neutral.
- The earthing switch in switchgear ensures that the magnitude of transient over voltage is limited during a re-striking ground fault.
- When there are line-to-ground problems, a ground fault current source is provided by an earthing switch.
- It is used to ground electrical devices to meet the protection requirement.

What is the Function of Earthing Switch

- An earth switch in switchgear primary's function is to protect technicians and switchgear from an inadvertent operation. It can be reliably closed against short-circuit currents.
- It is connected to circuit breakers, and when they are cleared and racked out, the bus bar that is adjacent to the circuit breakers is grounded through earthing switches automatically. This process protects technicians, maintenance personnel, and users from any unfortunate accidental voltages.
- It is used for static electricity and electromagnetic induction current. In two or more overhead transmission lines with the same tower or adjacent parallel arrangement, when one or several lines are out of power, due to the electromagnetic induction and electrostatic induction between it and the adjacent live lines, the outage circuit will generate induced voltage and induced current. Hence, the grounding switches for this type of line.
- It's used to close short-circuit current. An earthing switch with a rated short-circuit making current shall be able to close at any applied voltage including its rated voltage and any current including its rated short-circuit making current. The earthing switch has a rated short-circuit making the current equal to the rated peak withstand current.
- An earthing switch in a substation performs cogent functions in a big or heavy-duty power transformer as it allows the electrical grid to have a consistent point of reference for voltage. Otherwise, voltages may vary from one place to another. It guarantees safety for both the transformer and people to use power.

An Isolator with earth switch

Fig 2



Introduction to Emergency Lighting

Emergency lighting legislation

The Regulatory Reform (Fire Safety) Order (RRFSO) 2005, which came into force in October 2006, charges the responsible person in control of non-domestic premises and the common areas of a House in Multiple Occupancy (HMO) with the safety of everyone in the building, whether working, visiting or living there. This duty of care includes the provision of emergency lighting. Article 14 (2) (h) of the RRFSO states:

“Emergency routes and exits requiring illumination must be provided with emergency lighting of adequate intensity in the case of failure of their normal lighting”.

Emergency lighting is part of the fire safety provision of a building and cannot be ignored: as noted by the Industry Committee for Emergency Lighting (ICEL), which is the foremost UK authority on emergency lighting and provides third party accreditation for components and products for emergency light fittings under the auspices of the Lighting Industry Association (LIA):

“The legal requirement is that non-domestic buildings must be safe at all times, even if mains power failure occurs. Therefore, nearly all such buildings must have emergency lighting fitted”.

1 There are two main types of emergency lighting:

   i Emergency escape lighting;

   ii Standby lighting.

Emergency escape lighting is defined as “that part of emergency lighting that is provided to enable safe exit in the event of failure of the normal supply”.

Standby lighting is defined as “that part of the emergency lighting provided to enable normal activities to continue in the event of failure of the normal mains supply”.

From the point of view of fire safety provision, emergency escape lighting is the significant type of emergency lighting.

Emergency escape lighting

There are three main aspects of emergency escape lighting:

1 Escape route lighting;

2 Open area / anti-panic area lighting;

3 High risk task area lighting.

1 Escape route lighting is the part of an emergency lighting system provided to enable the swift and safe evacuation of a building by illuminating its escape routes, such as corridors and stairways, and also the location of fire-fighting equipment, e.g. fire extinguishers and safety / security equipment such as key-boxes holding emergency keys to exit doors. As such, escape route lighting can be seen to be a fundamental requirement of fire safety provision in all non-domestic premises and public areas of HMOs, whatever their use or occupancy levels.

2 Large public buildings such as shopping malls, museums and exhibition halls, etc., attract significant numbers of visitors who will not be familiar with the layout of the premises. Panic may therefore ensue should emergency evacuation be triggered by the sounding of the fire alarm. Open area / anti-panic lighting is relevant in such situations to aid in the identification of escape routes and exits and the guidance of people towards them.

3 High risk task lighting is a specific type of emergency lighting provided to ensure the safety of people involved in a potentially dangerous process or situation. It must be sufficient to enable the requisite shut-down procedures to be implemented. This type of lighting will only apply across a limited range of scenarios.

Where is emergency escape lighting necessary

- Each exit door
- Escape routes
- Intersection of corridors
- Outside each final exit and on external escape routes
- Emergency escape signs
- Stairways so that each flight receives adequate light
- Changes in floor level
- Windowless rooms and toilet accommodation exceeding 8m²
- Fire-fighting equipment
- Fire alarm call points
- Equipment that would need to be shut down in an emergency
- Lifts
- Areas in premises greater than 60m²

LED emergency lighting:

With the focus increasingly on protecting the environment as well as energy and cost saving, the LED (light emitting diode) is becoming an increasingly popular choice of light source for emergency lighting luminaires.

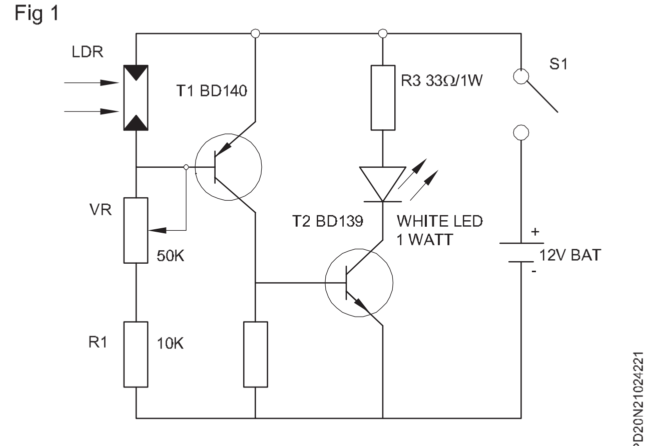
LEDs contain no mercury and their low energy consumption, high efficiency and long life (typically 10 years) mean they are more environmentally sound than almost any other type of light source. They come on instantly, unlike some energy saving bulbs, and the fact that they are much smaller than, for example, the traditional fluorescent tube means that there is scope for much more stylish designs in emergency luminaires.

There are different kinds of lights available in the market in different sizes and shapes. Each light is designed based on the application. There are some common emergency lighting systems used in buildings are Exit Lights.

- Batten Lights
- Oyster Lights
- Spotfire Lights

Emergency Light Circuit using 12v Battery (Fig 1)

Fig 1



LOTO (Lockout /Tagout)

Objectives: At the end of this lesson you shall be able to
- **define LOTO, 6 steps of LOTO**
- **describe colour coding of Tags and Locks,different types of Locks.**

LOTO (Lockout/Tagout)

Lockout Tagout (LOTO) is a system that prevents the unexpected start-up of equipment or machinery during service or maintenance procedures. A successful lockout/ tagout program safeguards workers from injury by blocking incoming energy and releasing stored energy, making it impossible for devices to turn on, run or move.

Training employees on detailed LOTO protocol is vital to protect everyone who works in an industrial environment. We created this comprehensive guide to lockout tagout systems to help you understand and implement an effective program that protects your employees from potentially dangerous equipment.

Lockout/Tagout Overview and Background

Lockout/Tagout refers to safety procedures that ensure dangerous machines do not experience unexpected energy bursts that cause injuries to workers during maintenance tasks. It requires the isolation of all energy sources to render equipment inoperable when service is necessary. A detailed, written plan protects employees from severe injuries or fatalities on-the-job.

What Is "Lockout/Tagout" and What Does It Mean?

Lockout/Tagout (LOTO) refers to the protocol for correctly shutting down equipment when repairs or maintenance are necessary. These procedures and systems protect employees from potential injuries or death by ensuring machines are inoperable and do not have any stored energy that may cause unintended start-ups.

Lockout devices lock machinery with a key or combination to block potential hazardous energy release, preventing unintentional start-ups.

Tagout systems alert workers and others in the area that they may not use or operate equipment until authorized personnel removes the warnings.

What Is Hazardous Energy?

Any power source that poses a potential danger to workers is hazardous energy. Failure to effectively manage stored energy within machines can cause an unexpected discharge of power, leading to workers' injuries or fatalities. Some types of hazardous energy include: If not correctly discharged, hazardous energy can release suddenly, causing a power surge that turns on or moves equipment. An unexpected start-up during maintenance activities can result in severe or fatal injuries to people working on or near the machinery, including:

- Electrocutions
- Burns
- Fractures
- Lacerations
- Amputations
- Crushing injuries
- Paralysis

Lockout is the most reliable method to protect industrial workers from dangerous power sources. The use of a lockout device puts systems in a zero energy state, eliminating the potential hazards of stored energy. Authorized managers must identify all energy sources and discharge any dangerous remaining power to keep workers safe from perilous equipment or machines.

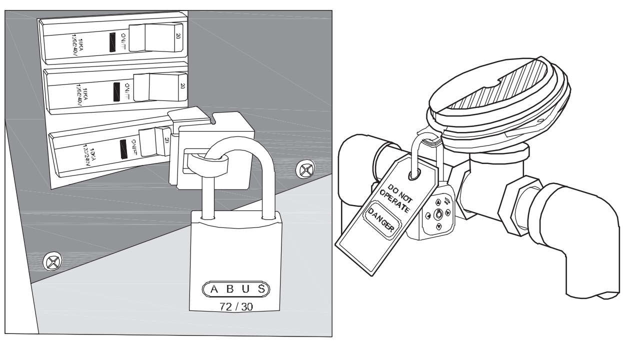
A lockout/tagout procedure aims to protect employees from harm while performing service or maintenance tasks on machines. An effective plan ensures the release of stored energy that could unexpectedly start equipment while workers perform repairs.

Employers must train all employees on the necessary processes and tasks involved with LOTO safety procedures.

Workers must employ LOTO procedures under the following circumstances:

- The equipment requires repair, cleaning or service.
- Operators must work near the hazardous areas of the machinery.
- Someone must set up or install new equipment.
- A worker needs to replace a machine part.
- A supervisor must perform an equipment inspection.

Fig 1



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Six Steps of LOTO Safety & Lockout/Tagout Procedures

A lockout/tagout procedure should include the following six steps:

1 Preparation

2 Shutdown

3 Isolation

4 Lockout/tagout

5 Stored energy check

6 Isolation verification

Let's look at each of these steps of LOTO safety more closely in the sections below.

Lockout/Tagout Step 1: Preparation

The first step of locking and tagging out equipment for service and maintenance is to prepare. During the preparation phase, the authorized employee must investigate and gain a complete understanding of all types of hazardous energy that might be controlled. In addition, it's important to identify the specific hazards and of course means for controlling that energy.

Lockout/Tagout Step 2: Shut Down

With planning complete, the actual process of powering down and locking out machines begins.

At this point, it's time to shut down the machine or equipment that will be serviced or maintained. Another important part of this step is to inform any employee affected by the shutdown, even if they won't play a role in the service or maintenance. An example of affected employees include machine operators who need to know that their machine should not be operated, or any other employees, visitors, or contractors who would be working in the area.

Lockout/Tagout Step 3: Isolation

The next step of the lockout/tagout procedure is to isolate the machine or equipment from any source of energy.

This may mean any number of things, such as turning off power at a breaker or shutting a valve.

Lockout/Tagout Step 4: Lockout/Tagout

With the machine or equipment isolated from its energy source the next step of lockout/tagout is to actually lock and tag out the machine. It's fair to say that this entire six-step process takes its name from this step.

During this step, the authorized employee will attach lockout and/or tagout devices to each energy-isolating device. The point is to apply the lockout device on the energy-isolating device in a way so it says in the "safe" position and cannot be moved to the unsafe position except by the person performing the lockout.

Tagout refers to applying a tag on the device as well. This tag includes the name of the person who performed the lockout and additional information.

Lockout/Tagout Step 5: Stored Energy Check

Even after the energy source has been disconnected, in step 3 of the lockout safety process, and the machine has been locked out, in step 4, that doesn't entirely guarantee that there's no hazardous energy still stored within the machine or that it's safe to perform maintenance.

At this time, it's important to look for any hazardous energy that's been "stored" within the machine, or any "residual" energy. During this phase, any potentially hazardous stored or residual energy must be relieved, disconnected, restrained, or made non-hazardous in some other way.

Lockout/Tagout Step 6: Isolation Verification

This last step is all about making sure.

Yes, you've shut down the machines, isolated them from their source of power, locked them out, and checked for hazardous stored energy. But now's the time to double-check that you did it all right and it's now safe to work on the machine or equipment.

At this point, an authorized employee verifies the machine has been properly isolated and de-energized.

Colour coding of Tags and Locks

Fig 1

Orange: Use orange for warning signs.

Yellow: Signs and safety tags in this color designate caution.

Red: Use devices in this color to indicate danger.

Fluorescent orange: Choose this color for safety signs and markers to label biological hazards.

Another colour code suggestion

- **Red:** for machine maintenance
- **Blue:** for contractors
- **Yellow:** for electrical
- **Orange:** for external employees

To sum up, there are no standard rules regarding the colour of Lockout-Tagout locks. Any Lockout-Tagout safety programme can specify its own Lockout-Tagout padlock colour coding.

SafeKey Lockout Padlocks — SafeKey Lockout Padlocks feature a patent-pending locking mechanism that includes six precision steel tumbler blades and more unique key possibilities, making it ideal for large organizations using hundreds of thousands locks. The innovative design makes for an extra smooth key insertion and removal — even when wearing gloves! It's linear, low-friction lock mechanism helps maintain key integrity, helping the padlock last longer.

Color-coding — Larger organizations have benefited from color-coding locks by trade or location to help keep equipment organized. Color-coded locks can also tell you who is still working on a machine at a glance, improving the visibility of the lockout process. Some facilities have even opted to color code their locks by location to reduce losses when internal maintenance teams are working with outside contractors

Selecting the right key system for your needs

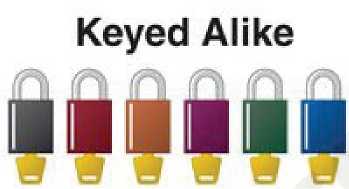
Finding the right key system for your lockout tagout program ensures the right people have access to lockout equipment during maintenance. The guidelines below will help you determine the right keyed alike or keyed different option for your unique needs:

Fig 2

Keyed different padlocks

Each padlock has its own unique key. Ideal for ensuring there is no potential key duplication when multiple maintenance personnel need to lockout equipment.

Fig 3



Keyed alike padlocks

Each padlock can be opened with the same key. This option is beneficial when multiple locks are assigned to a single employee. However, it's important to remember that under OSHA regulations no employee should be able to open a lock applied by someone else. Therefore, keyed alike locks from the same set should never be distributed to multiple employees.

This type of lock is mostly used when a maintenance individual is responsible for multiple machines or isolation points. It makes it easier to find the right key and reduces the number of keys on a key ring.

Fig 4

Master keyed padlocks

The master key can open all locks including keyed alike and keyed different locks. This allows supervisors to easily remove a lock in the event of an emergency. In order for employees to retain exclusive control, master keys should be kept in a secure location that is only accessible to management.

Fig 5

Grand master keyed padlocks

The grand master key can open all locks grouped into two or more master keyed systems. This option is best for applications with larger teams requiring multiple levels of supervisory access. In order for employees to retain exclusive control, grand master keys should be kept in a secure location that is only accessible to management.

LOTO padlock keys

LOTO padlocks are opened and closed with a standard flat key. As they are not designed to prevent theft, the lock does not require security pins. They do, on the other hand, include a security mechanism that retains the key in the lock when the padlock is open. This prevents the padlock from being closed without a key, forcing the worker in charge of the padlock to close it.

- Another interesting aspect regarding the keys is that LOTO padlocks can be supplied keyed alike, or even with a master key, in addition to standard LOTO padlocks with different keys.
- Having the same key is useful when a worker needs to handle numerous padlocks in a particular facility. However, it is important to note that according to OSHA regulations, a single set of padlocks with the same key cannot be distributed among different workers, as each worker must be responsible for their own padlocks.

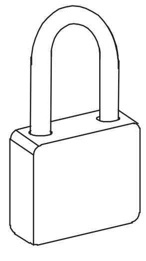
- In addition, master keys are ideal when dealing with large teams that work on a significant number of machines with multiple locking points. By using master keys, team managers can remove any padlock if necessary. The team managers are also responsible for storing the master keys in a place which only they can access

Types of Lockout/Tagout Devices

There are numerous different kinds of lockout/tagout devices available for use. Of course, the style and type of LOTO device can vary depending on the type of work that is being done, as well as any applicable federal or state guidelines that must be followed during the lockout/tagout process. The following is a list of some of the most common LOTO devices that can be seen being used within facilities.

- **Padlocks–** Padlock style LOTO devices are placed on the plug or another part of the electrical system to ensure that it physically can't be used. There are a number of different sizes and types of padlock that can be used, so make sure to choose one that will be able to be secured to the area where it will be used in your facility. This, and all lockout devices, should say "LOCKED OUT" and "DANGER" right on them so people know why they are there.

Fig 1

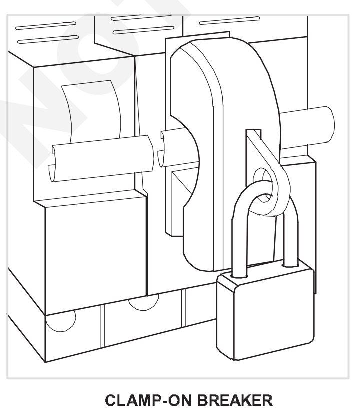


PADLOCKS

PD20N21024331

- **Clamp-On Breaker–** A clamp-on breaker style LOTO device will open up and then clamp down onto the electrical points to ensure power can't be restored while in place. This option often fits a wider range of different electrical system, which is why it is quite popular in many facilities. This kind of device is usually red in color so it will easily stand out.

Fig 2

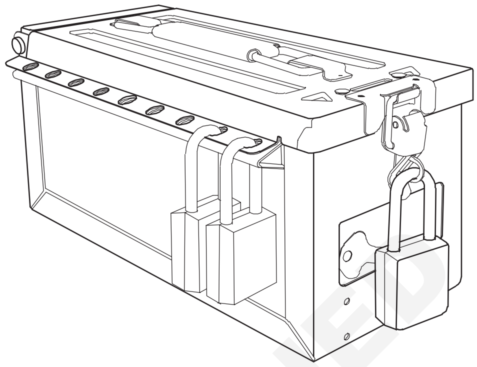


CLAMP-ON BREAKER

PD20N21024332

- **Lockout Box–** A LOTO box style device simply fits around the electrical plug and closes around the cord. The box is then locked so that it can't be opened. Unlike many other styles, this one doesn't fit snugly on the actual prongs of the power cord, but rather isolates it in a large box or tube structure that can't be opened without the key.

Fig 3

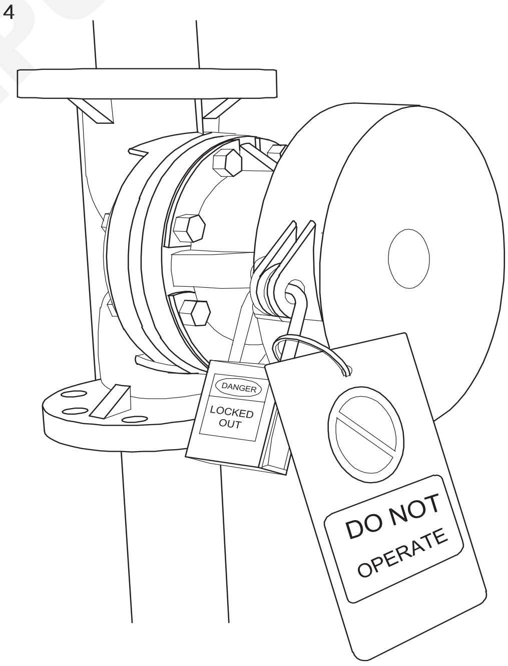


LOCKOUT BOX

PD20N21024333

- **Valve Lockout –** These devices can lockout a wide range of pipe sizes to prevent workers from being exposed to dangerous chemicals. It works by securing the valve in the off position. This may be necessary for pipe maintenance work, pipe replacement, and simply shutting off pipelines to prevent them from being accidentally opened.

Fig 4

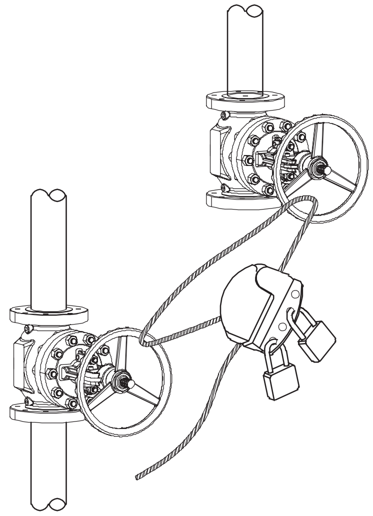


PD20N21024334

- **Plug Lockout –** Electrical plug lockout devices are normally shaped as a cylinder that allow for the plug to be removed from its socket and placed inside the device, preventing employees from plugging in the cord.
- **Adjustable Cable Lockout –** This lockout device is unique in that it is favorable for unique situations that call for multiple lockout points. The adjustable cable is fed into the lockout points and then back through

the lock itself to prevent harm coming to those who are working on the equipment.

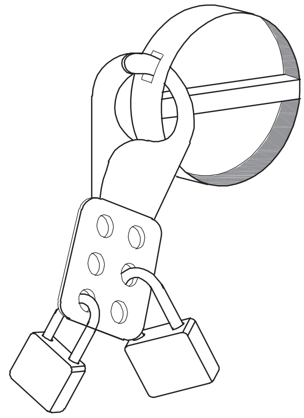
Fig 5



ADJUSTABLE CABLE LOCKOUT

- **Hasp –** Unlike the adjustable cable which is more concerned with the number of sources of energy that have to be locked, utilizing a hasp involves only one machine but with multiple people performing individual tasks. This is a useful type of lockout device because it allows every person a lock. Once they are finished with their task, then they can go over and take their lock and tag away. This keeps every last worker safe inside a particularly dangerous environment.

Fig 6



HASP

- **Other Styles of LOTO Devices –** There are a variety of other types and styles of lockout/tagout devices that are available too. Some companies even have custom devices built so they fit the exact situation where they will be used. No matter what type of device you are using, you'll want to make sure that it is able to physically prevent a power cord or other power source from being plugged in. When these devices are used properly, they can help to keep everyone in the facility safer.

Remember, lockout/tagout devices are visual reminders that also physically restrict access to an energy source. If not used properly in accordance with OSHA's regulations, those devices may not work as well as they should. This means all employees must follow all facility protocol that should have been gone over in training. Lastly, simply being aware of your surroundings gives you the chance to avoid endangering yourself, and the people around you.

Energy Flow Diagram, Fuses

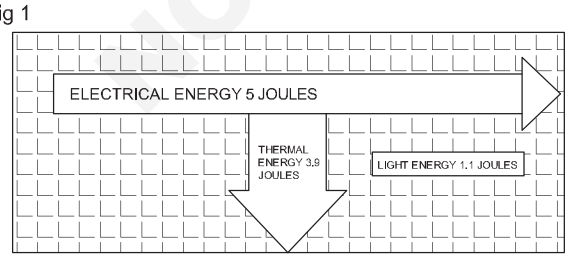
Objectives: At the end of this lesson you shall be able to
- **explain Energy Flow Diagram,Sankey diagram**
- **describe about fuses, the necessity , Advantages/Disadvantages**
- **distinguish different types of IT/HT Fuses, DO Fuse sets**
- **state Rupturing capacity & recommended sizes of fuse elements**
- **know about the installation and maintenance of fuses.**

Energy flow diagram

Energy Flow Diagrams (often also referred to as Energy Flow Charts) are used to show energy and energy transformation visually and quantitatively. This may include primary energy used as raw fuels to feed into a system, energy supply, conversion or transformation, losses and energy being used.

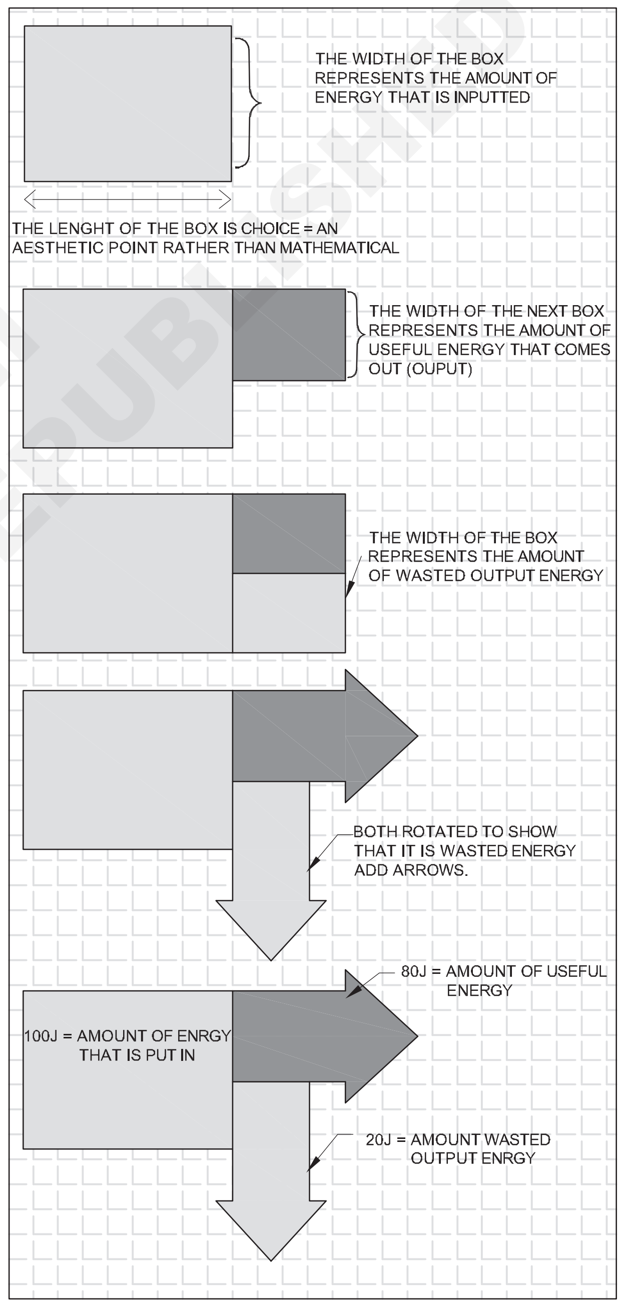
Sankey diagrams represent the flow of energy visually by identifying energy stores, energy transfers, and points where energy could be wasted. It is important that the energy we use is not wasted, and knowing the energy transfer helps us to determine the efficiency of a device. Students may be familiar with various graphic representations of data such as bar charts, pie charts and scatter graphs. However, these representations often depend on the interpretation of the reader as well as the quantity of data used. In 1898 an Irish man called Captain Matthew Sankey used a flow chart to show the energy efficiency of a steam engine. This type of flow chart is now referred to as a Sankey diagram, and is used to investigate the energy efficiencies of systems as well as the cash flow of businesses. The diagrams are constructed from data and represent the energy transfers involved, quantifying these transfers and thus highlighting the efficiency of the system in question. A Sankey diagram is shown in Figure 4. The width of the arrows represents the quantity of energies involved, and their directions indicate where the energy flows. In Figure 4, the arrow to the right represents useful output and the downward arrow represents output of wasted energy. It also shows the conservation of energy: an input of 5 J results in a total output of 3.9 J + 1.1 J.

Fig 1



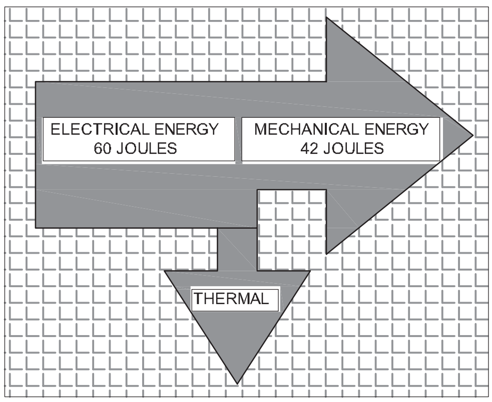
Constructing A Sankey Diagram

Fig 2



Reading A Sankey Diagram

Fig 3



1 How much thermal energy does the motor produce/

a 62 joules

b 18 joules

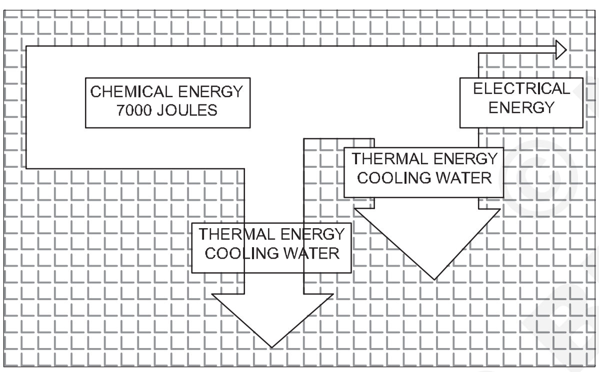
c 60 joules

d 42 joules

Answer: [ ]

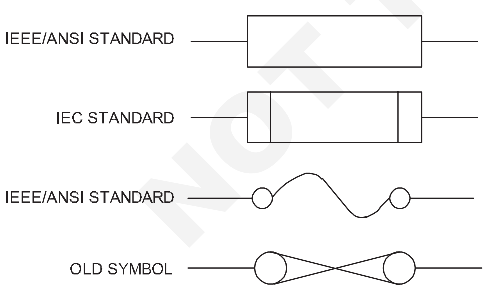
2 How much useful energy is produced by this power station? (Hint: check the scale)

Fig 4



Fuses

Fig 1



DIFFERENT SYMBOL OF USE

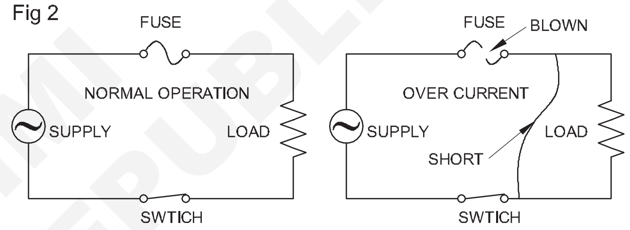
A fuse is an electric/electronic or mechanical device, which is used to protect circuits from over current, overload and ensure the protection of the circuit. Electric fuse was invented by Thomas Alva Edison in 1890. There are many types of fuses, but the function of all these fuses is the same. In this article, we will discuss the different types of fuses, its construction, working and operation and their application in various electronics and electrical systems.

Construction & Working of a Fuse

A general Fuse consists of a low resistance metallic wire enclosed in a non combustible material. It is used to connect and install in series with a circuit and device which needs to be protected from short circuit and over current, otherwise, electrical appliance may be damaged in case of absence of the fuse and circuit breaker as they are unable to handle the excessive current according to their rating limits.

The working principle of a fuse is based on the "Heating effect of Current" i.e. Whenever a short circuit, over current or mismatched load connection occurs, then the thin wire inside the fuse melts because of the heat generated by the heavy current flowing through it. Therefore, it disconnects the power supply from the connected system. In normal operation of the circuit, fuse wire is just a very low resistance component and does not affect the normal operation of the system connected to the power supply.

Fig 2



WORKING OF A FUSE

Necessity of Fuse in an Electric Circuit: If no fuse or other similar device is provided in the circuit then a dangerous situation would be created on developing of faults such as overload, short circuit or earth faults In case of overload, short circuit and heavy earth faults a heavy current will continue to flow through the Consuming apparatus, current carrying cables or wires and other current carrying equipment. Due to continuous flow of heavy current through the cables or wires, apparatus etc., these will get heated up and so get damaged The fire may also break out.

In case of earth leakage fault, (i.e. on the body of the electrical apparatus becoming alive), the body of the electrical apparatus will continue to be alive and at much higher potential above that of the earth. In such circumstances any person coming in contact with the metal body of the apparatus is liable to get an electric shock, even if it is earthed.

The main function of a fuse is to blow out under a fault and isolate the faulty section from the live side. If the fuse is provided on neutral wire, in place of live wire, then in abnormal conditions though the fuse will blow out but the lamp or other apparatus still remains connected to the live wire and in case of leakage some trouble will arise and cause a considerable damage. In case the earth fault takes on the neutral wire between lamp and fuse provided in it, the fuse will blow out because the neutral wire is slightly at a higher potential with respect to earth and so the fault current flows through the neutral wire and fuse melts itself. The current will flow through the live wire, lamp, neutral wire and earth fault, even after the fuse has blown out and this may cause serious damage to the wiring, the apparatus connected or building itself.

If fuses of same capacity are provided on the phase wire and neutral, then in case of short-circuit fault, one of them will blow out first. If the fuse on neutral wire blows out first, the fuse in phase line remains intact and faulty apparatus still remains connected to the live. If some person comes in contact with the faulty apparatus, he is liable to get electric shock. In case the installation is connected to 3-phase 4-wire supply system, and fuses are provided on both live and neutral wire and fuse on neutral wire blows out then voltage of each phase to neutral will become considerably different, which is not desirable. Hence the fuse is provided only in phase or live pole, never on neutral pole.

Select Proper Rating Size of Fuse?

While selecting the proper fuse and its rated size for electrical appliances is based on different factors and environments. But the following basic formula shows

How to choose the right size of fuse?

Fuse Rating = (Power / Voltage) x 1.25

For example, you have to find the right size of fuse for 10A two pin socket.

(1000W / 230V) x 1.25 = 5.4A

In the above example, 1kW is the power rating which can be controlled through the 2 pin socket and the main supply voltage is single phase 230V AC (120V AC in US).

But you should go for the max i.e. 6A fuse rating instead of 5.4A for safe and reliable operation of the circuit.

Characteristics of a Fuse

Different types of fuses can be categories on the following characteristics.

- Current Rating & Current Carrying Capacity of Fuse
- Voltage Rating of Fuse
- Breaking Capacity of a Fuse
- I^2t Value of Fuse
- Response Characteristic
- Rated voltage of Fuse
- Packaging Size

Below is the brief explanation of the above categories.

Fuse Current Carrying Capacity

Current carrying capacity is the amount of current which a fuse can easily conduct without interrupting the circuit.

Breaking capacity:

The value of maximum current that can safely be interrupted by the Fuse is called Breaking Capacity and should be higher than the prospective short circuit current.

Rated Voltage of Fuse

Expect the current capacity of current, there is the maximum voltage rating a fuse can handle safely. Each fuse has maximum allowed voltage rating, for example, if a fuse is designed for 32 volts it cannot be used with 220 volts, different amounts of isolation is required in different fuses working on different voltage levels. Bases of voltage rating, a fuse can be HV (High Voltage) LV (Low Voltage), and Miniature Fuses.

I^2t Value of Fuse

The I^2t terms related to fuse normally used in short circuit condition. It is the amount of energy which carries the fuse element when the electrical fault is cleared by the fuse element.

Response Characteristic of a Fuse

The speed at which the fuse blows, depends on the amount of current flowing through its wire. The higher the current flowing through the wire, faster will be the response time.

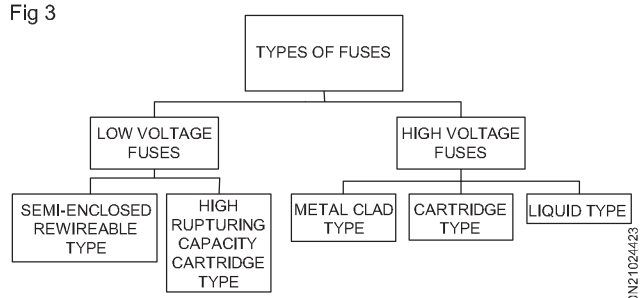
Response characteristic shows the response time for an over-current event. Fuses which respond rapidly to the over current situation is called ultra fast fuses or Fast fuses. They are used in Many semiconductor devices because semiconductor devices are damaged by over current very rapidly.

There is another fuse which is called a slow burn fuse, switch fuses do not respond rapidly to the over current event, but blow after several seconds of over current occurrence. Such fuses found their application in motor control electronics systems because motors take a lot more current at starting than running.

Types of Fuses

Fuses can be divided into two major categories, AC fuses, and DC fuses. The below block diagram illustrates the different types of the fuse under each category. We will discuss each fuse in brief in our article.

Fig 3



TYPES OF FUSES

Low Voltage Fuses:

a Semi Enclosed Rewireable Type:

- It is also known as kit-kat type.
- It is used where low value of fault current are to be interrupted.

It has two parts :

1 A base

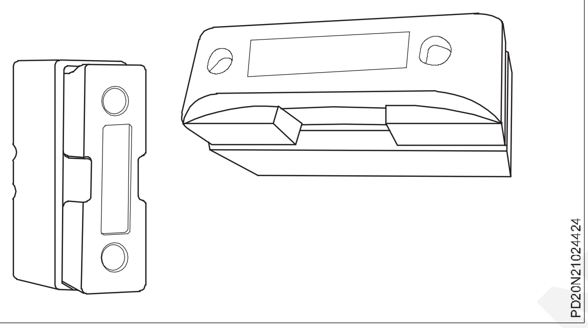
2 A fuse carrier

both base and fuse carrier are made up of porcelain, base is fixed while fuse carrier (which carries the fuse element) is moving, fuse carrier is taken out when the fuse blows out and after replacing it with the new fuse wire , it is again placed over base.

Semi enclosed rewireable fuse are made upto 500A rated current but their breaking capacity is low.

So they are used only for domestic or small loads.

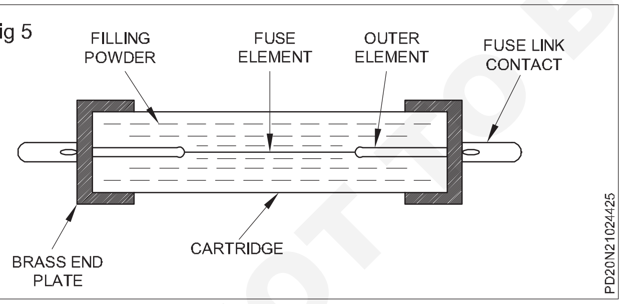
Fig 4



b High Rupturing Capacity (H.R.C) Cartridge Fuse:

As the breaking capacity of semi- enclosed rewire able fuses is very low , so H.R.C fuse are developed which high breaking capacity. The function of every fuse to trip the circuit as discussed earlier in this section.

Fig 5



H.R.C FUSE

- It has a heat resisting ceramic body having metal end caps to which is welded silver current carrying element.
- The space surrounding the element is completely filled with filling powder. E.g. chalk, sand, Plaster of Paris
- filling powder is filled because when the arc generates it has to be extinguished as soon as possible, so this filling powder helps to finish the generated arc.

Dropout Types of Fuses

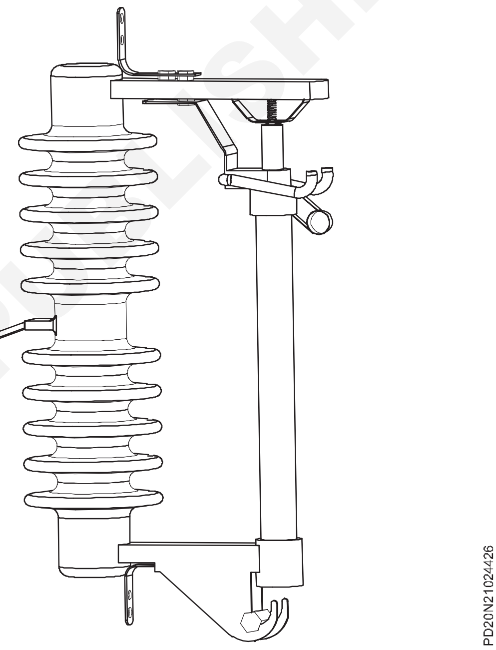
In this fuse type, fuse melting creates the element to drop down below gravity regarding to its minimal assistance. These kinds of fuses are employed for safeguarding external transformers.

Highly demanded in power generation plants and substations, this Drop Out Fuse Set is used for swinging out surge current that is occurred in troubles and faults. The offered set is extensively used as a switchgear protection devices in power system in order to protect connected devices. As we have the ability to meet bulk demands, the offered set in manufactured in a variety of sizes and specifications. The offered fuse is featured with high-quality contacts to ensure the high-pressure multi-line connection and surge cleaning action.

Key Points:

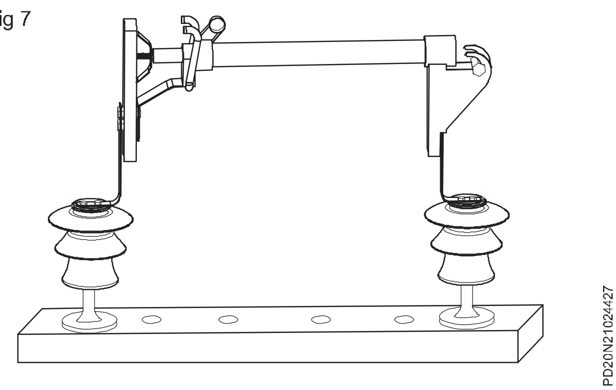
- Protects transformers in an effective manner
- Reliable working
- Easy to install

Fig 6



Drop Out Fuse Set

Fig 7



Advantages

- They are capable of clearing high and low fault currents.
- No deterioration with age
- No maintenance required

- Reliable discrimination
- High speed of operation.

Disadvantages

It has to be replaced and heat produced may affect nearby switches. This is the major disadvantage but still it's advantages are more valuable than it's disadvantage.

High Voltage Fuse

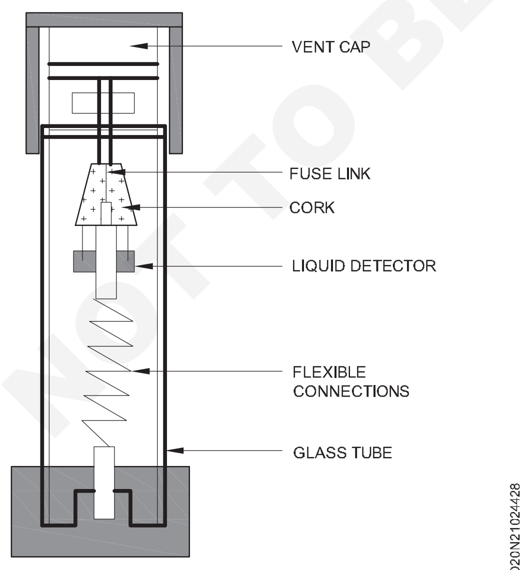
- **Cartridge Type:** it has same construction as of the low voltage cartridge type fuse, but it has two wires one is of fuse element which is to melted after fault in the circuit and second one is tungsten wire (which has very high resistance). so when the normal current flows through the circuit, the current goes through silver wire but when the fault occurs in the circuit, the silver wire gets melted and the short circuit current starts flowing through the tungsten wire and due to it's high resistance , the current finally reaches to zero.

  High voltage cartridge type fuse are use upto 33kV with breaking capacity of 8700A at that voltage, rating of the order of 200A at a voltage 6.6kV.

- **Liquid Type:** In liquid type high voltage fuse, the fuse element is fixed at one side and connected with the spring on other side with a level detector, the spring is enclosed in a glass chamber which is filled with the oil. when the fuse element blows out , the spring shrinks and pulls the level detector inside the glass chamber. so that some oil move upside and this oil will extinguish the arc generated during blowing out of the fuse. for understanding this phenomena in a better way please visit my youtube channel .

  They may be used upto about 100A on 132kV systems.

Fig 8



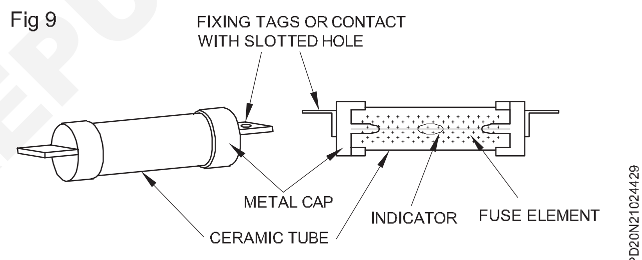
- **Metal Clad Type:** These also have similar function only difference is that they are enclosed in a metal clad.

Sizes of fuse element (Plain or tinned-copper wire):

Current rating of fuse	Nominal diameter of fuse wire
5A	0.15mm
5A	0.2mm
10A	0.35mm
15A	0.5mm
20A	0.6mm
25A	0.75mm
30A	0.85mm
45A	1.25mm
60A	1.53mm
80A	1.8mm
100A	8.0mm

High Rapturing Capacity (H.R.C) Fuse: It consists of a pure silver fuse element totally enclosed in a ceramic tube which is filled with fireproof materials such as 'silica' and it is capable or interrupting a circuit under a heavy fault current at the shortest period of time.

Fig 9



Standard rating of H.R.C. or H.B.C. fuse: 5A, 10A, 15A, 20A, 25A, 32A, 40A, 50A, 63A, 80A, 100A, 125A, 160A, 200A, 250A, 315A, 400A, 500A, 630A, 800A.

Rating of Fuse

1 Fuse current rating (in Amperes).
2 Fuse voltage rating (in Volts).
3 Fusing Factor (F.F.) (no unit).
4 Rupturing capacity (R.C.) (in Kiloamperes).

Rapturing Capacity: It is the maximum amount of fault current the fuse can withstand without destroying itself. Eg. 20kA, 200kA…..etc.

Safety Precautions When Replacing Fuses

The following safety precautions will prevent injury to personnel and damage to equipment. These are the MINIMUM safety precautions for replacing fuses. Be sure the power is off in the circuit and the circuit is discharged before replacing a fuse. Use an identical replacement fuse if possible. Remove any corrosion from the fuse holder before replacing the certain the fuse properly fits the fuse holder.

Preventive maintenance of fuses consists of checking for the following conditions and correcting any discrepancies.

1 **Improper Fuse:** Check the fuse installed against that recommended in the technical manual for the equipment. If an incorrect fuse is installed, replace it with the correct fuse.

2 **Corrosion:** Check for corrosion on the fuse holder terminals or the fuse itself. If corrosion is present, remove it with fine sandpaper.

3 **Improper Fit:** Check for contact between the fuse and fuse holder. If a piece of paper will fit between the fuse and the clips on a clip-type fuse holder, there is improper contact. If the fuse is not held in the cap of a plug-type fuse holder, the contacts are too loose.

4 **Open Fuses:** Check fuses for opens. If any fuse is open, repair the trouble that caused the open fuse and replace the fuse.

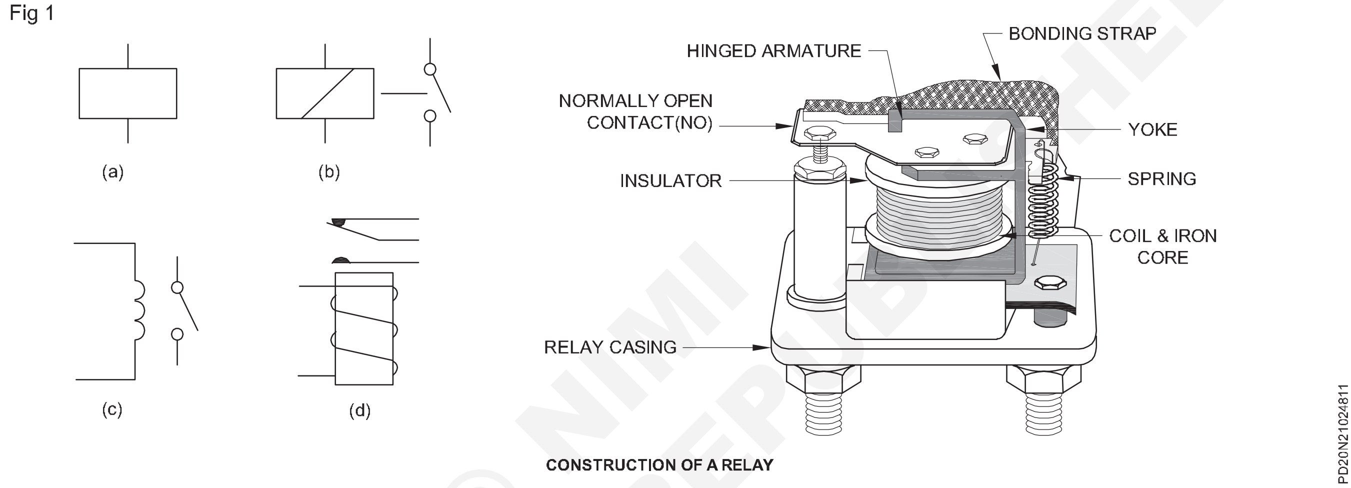
Relays, High Power Rectifier System, SCADA, GIS

Objectives: At the end of this lesson you shall be able to
- **define relays and describe its operations**
- **distinguish different types of relays and its applications**
- **describe High Power Rectifier system, SCADA and GIS mapping.**

Introduction To Relay and Different Types of Relays | Its Terminals, Working and Applications

Relays are the essential component for protection and switching of a number of the control circuits and other electrical components. All the Relays react to voltage or current with the end goal that they open or close the contacts or circuits. A relay is an electrical switch that control (switch on and off) a high voltage circuit using a low voltage source. A relay completely isolates the low voltage circuit from the high voltage circuit.

Fig 1



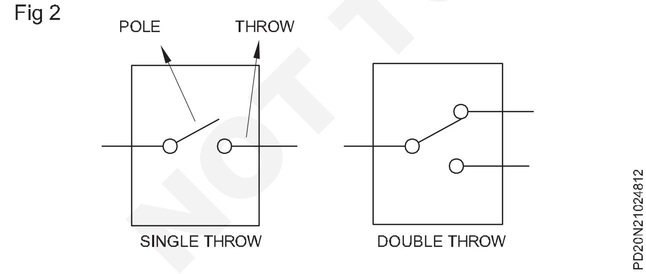
Poles and Throw:

Poles refer to the switches inside a relay.

The numbers of Switches inside a relay is called the poles of the relay.

The number of circuits being controlled per pole is called the throw of a relay.

Fig 2



Types of Relay:

There are various types of relays and they are classified into different categories according to their properties. Each of these types of relays is used for a specific application and it is necessary to select the appropriate relay before using in any circuit.

Based on Poles and Throw:

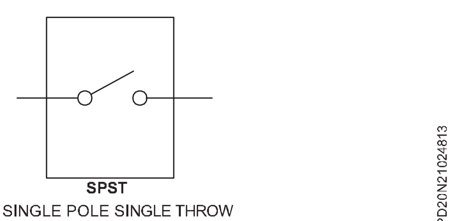
These following types of relays are classified by the numbers of poles and throw inside a relay.

SPST Relay

SPST refers to single pole single throw relay.

The single pole means that it can control only one circuit while the single throw means its pole has only one position in which it can conduct. SPST diagram is given below.

Fig 3

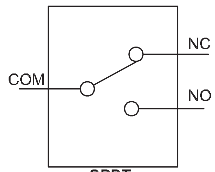


SPDT Relay

SPDT refers to single pole double throw relay.

The single pole means it can control only one circuit at a time. The double throw means its pole has two positions in which it can conduct. The SPDT relay has two states and in each state, its one circuit remains closed while the other remains open and vice versa.

Fig 4



SPDT

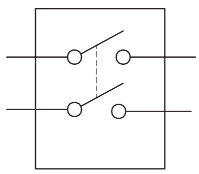
SINGLE POLE DOUBLE THROW

DPST Relay

DPST refers to double pole single throw.

The double pole means it can control two completely isolated individual circuits. The single throw means that each pole has one position in which it can conduct.

Fig 5



DPST

DOUBLE POLE SINGLE THROW

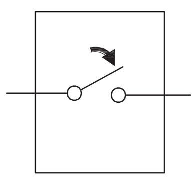
The DPDT relay can be interpreted as two SPDT relays but their switching is simultaneous.

A relay can have as many as 12 poles.

Types of relays are also classified based on its configuration known as **"Forms".**

"Form A" is an SPST relay with normally open **(NO)** default state.

Fig 6

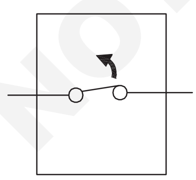


"FROM A"
"SPST NO"

It has NO terminal that connects the circuit when the relay is activated and disconnects the circuit when the relay deactivates.

Form B relay is SPST relay with normally closed **(NC)** default state.

Fig 7

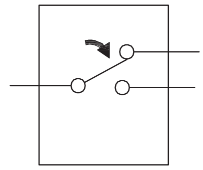


"FROM B"
"SPST NC"

The NC terminal connects the circuit while the relay is inactive and it disconnects the circuit when the relay activates.

Form C relay is SPDT relay with double throw contact terminals known as **NC and NO.**

Fig 8

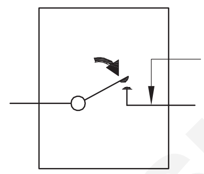


"FROM C"
"SPDT (BBM)"

It controls two circuit i.e. one circuit remain open while the other remains closed. It is also known as **"break-before-make"** relay because it breaks open one circuit before closing the other circuit.

Form D relay is also an SPDT relay and has the same principle as Form C relay but it is "make-before-break" contact relay.

Fig 9



"FROM D"
"SPDT (MBB)"

Based On Operation Principles:

These following types of relays are classified based on their different operation principles.

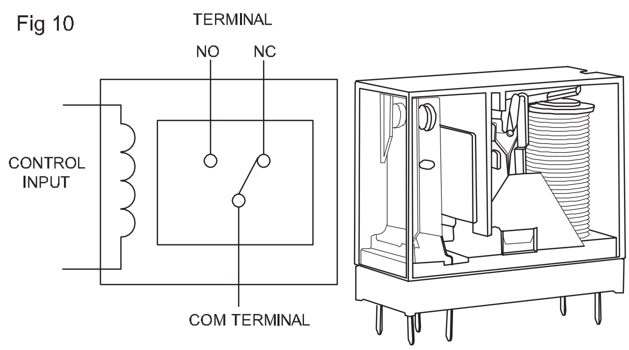
EMR (Electromechanical Relay)

Electromechanical relays are the most basic type of relay. They function using the standard electromagnetic coil that can manipulate the moveable contact. However, this physical motion can take longer and leads to internal arcing, which can degrade the relay over time.

This type of relay has an electromagnetic coil and a mechanical movable contact.

When the coil is energized it produces a magnetic field. This magnetic field attracts the armature (movable contact). When the coil is de-energized the coil loose magnetic field and a spring retract the armature to its normal position.

Fig 10

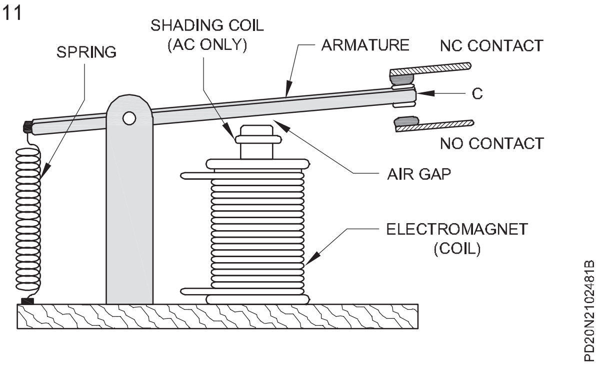


ELECTRO MECHANICAL RELAY

The EMR relay is designed for AC or DC source depending on the application it is used for. The structure of AC and DC EMR relay differs from each other by having a slight difference in its coil construction. The DC coil has a freewheeling diode for protection against back EMF and de-energizing the coil.

The polarity of the source in EMR relay does not matter, it energizes the coil in either way but if there is a back EMF diode installed then polarity should be considered.

Fig 11



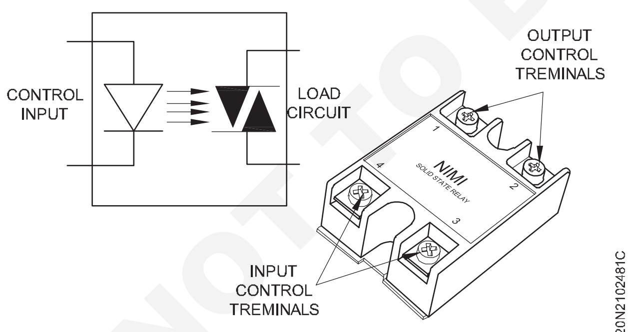
The main disadvantage of EMR relay is that its contacts produce arc during breaking which leads to increasing its resistance over time and decreasing the lifespan of the relay.

SSR (Solid State Relay)

A solid-state relay operates using a semiconductor that controls the relay's switching mechanism. This is done using a low-voltage optical signal from the semiconductor which, when triggered, allows the operation of the controlled higher-voltage load. Solid-state relays are known for their quick operation and comparably long life compared to electromechanical alternatives. The main downside of solid-state relays is the additional heat they generate through the operation of the semiconductor, which can cause issues or require built-in solutions to prevent overheating.

SSR relay is made up of semiconductors instead of mechanical parts and it works on isolating the low voltage circuit from high voltage circuit using an optocoupler.

Fig 12



SOLID STATE RELAY(SSR)

When the control input is applied to a solid state relay, an LED lights up which produce infrared light. This light is received by a photosensitive semiconductor device which converts the light signal into an electrical signal and switches the circuit.

SSR operates on relatively high speed and has very low power consumption as compared to EMR relay. It has a longer lifespan because there are no physical contacts to burn out.

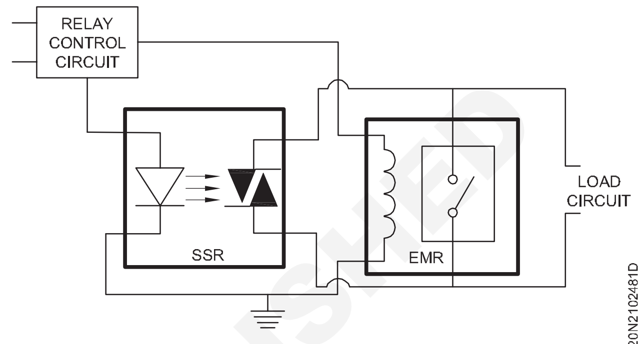
The main disadvantage of SSR relay is its nominal voltage drop across the semiconductor which wastes power in the form of heat.

Hybrid Relay:

Hybrid relays are made using both SSR and EMR relays.

As we know that the SSR wastes power in form of heat and EMR has contact arcing problem. The hybrid relay uses both SSR and EMR to overcome their disadvantages.

Fig 13



HYBRID RELAY

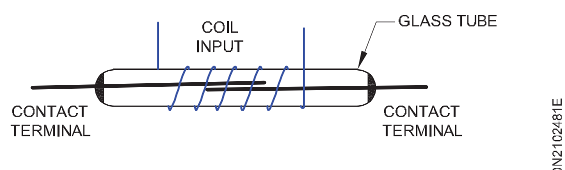
In Hybrid relay, SSR and EMR are used in parallel. A relay control circuit is used for switching the SSR first. The SSR takes the load current. So it eliminates the arching problem. Then the control circuit energizes the EMR coil and its contact closes but there is no arching since the SSR is taking the load in parallel. After some time, when the EMR contact settles down, the control input of SSR is removed. The EMR conducts the entire load current without any loss. Since there is no current flow throw SSR and the EMR takes the entire load, there is no power loss in form of heat. Thus, it eliminates the heat problem too.

Reed Relay

Reed relays also operate on an electromechanical basis at their core but use a modified design to reduce or eliminate common EMR problems. They're made up of two magnetic metal blades suspended inside a tube of inert gas with a coil. When the coil energizes, the two blades are attracted to one another, completing the circuit. This prevents some of the wear and tear that shortens the lifespan of typical EMR relays. Still, they're slower and can't handle as high a current as SSR switches.

Reed relay is made up of a reed switch and an electromagnetic coil with a diode for back EMF.

Fig 14

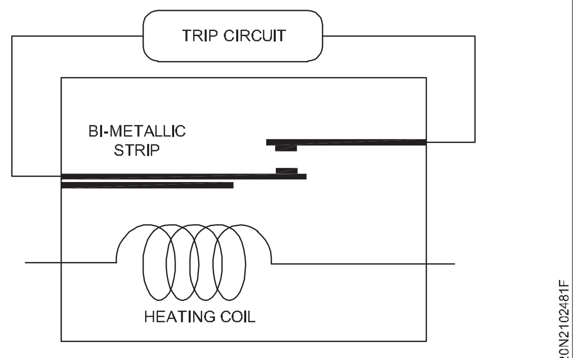


REED RELAY

Electrothermal Relay (Thermal Relay):Over load relay

An electrothermal relay is made up of bimetallic (made up of two metals having different thermal expansion coefficients) strip.

Fig 15



THERMAL RELAY(OVERLOAD RELAY)

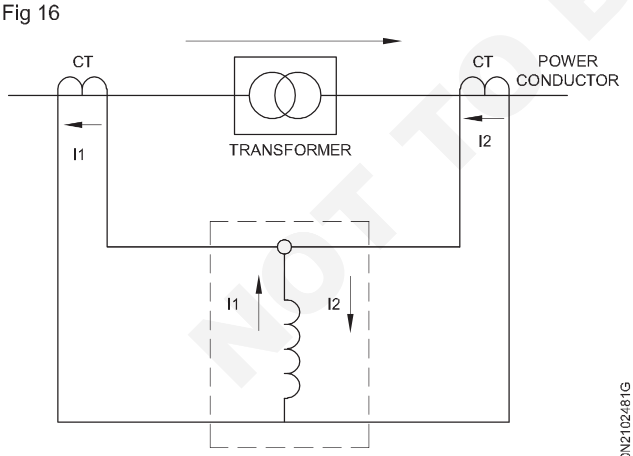
When the current flow through the conductor, it produces heat. Due to which the temperature of the bimetallic strip rises and expands. The metal having high thermal expansion coefficient expands more than the other metal. Due which the strip bends and closes the contacts to usually activate the trip circuitry.

Thermal relays are usually used for electric motor protection.

Differential Relays

As the name suggests, Differential Relays are those relays which work on the 'difference' of the controlling (or actuating) signals. Differential Relays operate when the phasor difference of two or more similar electrical quantities exceeds a predetermined value. A current differential relay operates based on the result of comparison between the magnitude and phase difference of the currents entering in and leaving out of the system to be protected.

Fig 16



DIFFERENTIAL RELAYS

Under normal operating condition, the currents entering and leaving are equal in magnitude and phase so the relay is inoperative. But if a fault takes place in the system, these currents are no longer equal in magnitude and phase. This type of relay is connected in such that the difference between the current entering and current leaving flows through the operating coil of the relay. Hence the relay coil is energized under fault condition due to the difference quantity of the current. Thus, the relay operates and opens the circuit breaker so as to trip the circuit.

The above figure shows the principle of differential relays in which there are two CTs connected either side of the power transformer i.e., one CT on the primary side and the other at the secondary side of the power transformer. The relay compares the currents on both sides and if there is any unbalance then relay tends to operate. The differential relays can be current differential relays, voltage balance differential relays and biased differential relays.

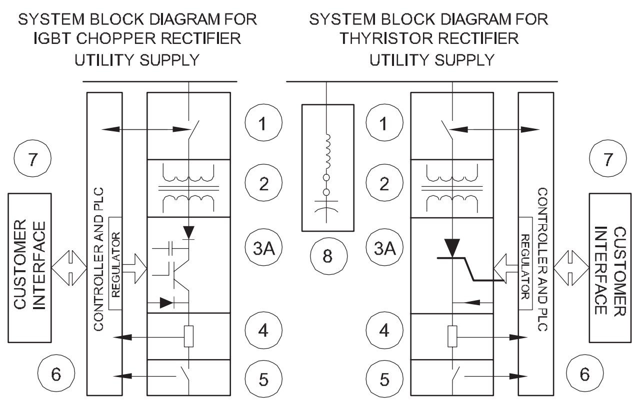
Application Of Relay

- Relays are used for isolating a low voltage circuit from high voltage circuit.
- They are used for controlling multiple circuits.
- They are also used as automatic change over.
- Microprocessors use relays to control a heavy electrical load.
- Overload relays are used for protection of motor from overload and electrical failure.

High Power Rectifier Systems

High Power Rectifier Systems are used in many heavy industrial processes such as electrowinning, electrochemical, electrorefining, electroplating and other specialized applications. High Power Transformer Rectifier System – inclusive of fully integrated operator interfaces and control systems for a single unit or entire multi-unit SCADA network. We can evaluate the impact of the rectifier system on the incoming power grid and design power factor correction and harmonic filtering as required.

Fig 17



DYNAPOWER HIGH POWER RECTIFIER SYSTEMS CONSIST OF THE FOLLOWING SECTIONS

1.HV SWITCHGEAR
2.RECTIFIER TRANSFORMES
3.THYRISTOR RECTIFIER
3A.IGBT CHOPPER RECTIFIER
4.DC CURRENT MEASUREMENT
5.DC NO-LOAD SWITCHES
6.CONTROLLER, PLC AND REGULATOR
7.CUSTOMER/OPERATOR INTERFACE
8.POWER FACTER CORRECTION & HARMONIC FILTER NETWORK

Types of Rectifiers

There are a wide variety of industrial rectifiers, including SCR, powerstat, tapswitch, switch mode, IGBT chopper, and thyristor rectifiers. Tapswitch and powerstat rectifiers offer little to no control for operators. They have a very low ripple reading, low amperage, and low cost, yet they are typically very expensive to repair.

Alternatively, SCR, SMPS, and IGBT chopper rectifiers offer seemingly infinite control for operators; they can easily control voltage from top to bottom between zero and 100 percent.

SCR Rectifiers

An SCR rectifier is a semiconductor power supply that meters electricity by opening electrical “valves” that work together to rectify electricity. The longer the “valve” is open, the higher the voltage leaving the rectifier will be.

Thyristor & Igbt Chopper Rectifiers

Thyristor rectifiers and fast switching IGBT chopper rectifiers for large applications are available in 6, 12, 18 and 24 pulse sets with higher order combined systems available. Each multi-pulse arrangement is in an ANSI configuration that is selected for the voltage/current values of the application. The multi-pulse criteria is selected to reduce the supply side harmonic content, reduce output DC ripple, and provide improved regulation.

Both Rectifier Technologies Feature:

- Conservative design margins
- Electrolytic pure Copper bus work
- Heavy gauge construction
- Sub-system integration
- High reliability and maintainability
- Deep hole drilled copper heat sink (water cooled systems)

Our system designs may also be provided with auxiliary equipment as required by the specification, including switchgear, power factor correction and harmonic filters, heat exchangers and free-standing cooling systems.

Chopper Rectifiers

The chopper rectifier designs consist of high frequency switching technology in a modular design package that converts the secondary AC voltage to a regulated output DC voltage. Larger power systems are constructed of multiple chopper modules to obtain the specified current requirements. Each section of modules has a separate set of sensing and protection and receives directions from the main chopper controller. This chopper conversion process has minimal effect on the incoming power system and a high power factor is maintained at the level of a fixed diode converter. The transformer section is configured to optimize the harmonics. The total module count results in a 12 pulse configuration as seen by the utility. The load sees a very smooth low ripple DC over the total range due to compact high frequency output filtering.

IGBT Chopper rectifiers are designed for high power factor and low harmonic distortion, eliminating the need for power factor correction equipment and harmonic filters. They also have inherently low ripple (typically <2%) at full output so ripple filters are not needed.

Compared to standard thyristor rectifiers, the Chopper offers a modular approach to rectification, resulting in simplified transformer designs and systems that are easier to install, have a lower total cost of ownership, and save valuable space. Its modular design also makes repairs fast and easy should a module fail.

AC Input

Up to 69kV, 3Ph, 50/60Hz

DC Output

- Up to 100,000ADC (higher current available on request)
- Up to 2000VDC (higher voltage available on request)

IGBT chopper and thyristor rectifiers may also be provided with auxiliary equipment as required by the specification—including switchgear, power factor correction, harmonic filters, heat exchangers and free-standing cooling systems. The chopper rectifier designs consist of high-frequency switching technology in a modular design package that converts the transformer secondary AC voltage to a regulated output DC voltage. Larger power systems are constructed of multiple chopper modules to obtain the specified current requirements.

SCADA

Supervisory control and data acquisition (SCADA) is a control system architecture comprising computers, networked data communications and graphical user interfaces for high-level supervision of machines and processes. It also covers sensors and other devices, such as programmable logic controllers, which interface with process plant or machinery.

One of the most commonly used types of industrial control system, SCADA can be used to manage almost any type of industrial process.

SCADA systems include hardware and software components. The hardware gathers and feeds data into field controller systems, which forward the data to other systems that process and present it to a human-machine interface (HMI) in a timely manner. SCADA systems also record and log all events for reporting process status and issues. SCADA applications warn when conditions become hazardous by sounding alarms.

Components of a SCADA system

SCADA systems include components deployed in the field to gather real-time data, as well as related systems to enable data collection and enhance industrial automation. SCADA components include the following:

- **Sensors and actuators:** A sensor is a feature of a device or system that detects inputs from industrial processes. An actuator is a feature of the device or system that controls the mechanism of the process. In simple terms, a sensor functions like a gauge or meter, which displays the status of a machine; an actuator acts like a switch, dial or control valve that can be used to control a device. Both sensors and actuators are controlled and monitored by SCADA field controllers.

- **SCADA field controllers:** These interface directly with sensors and actuators. There are two categories of field controllers:

  1 Remote telemetry units, also called remote terminal units (RTUs), interface with sensors to collect telemetry data and forward it to a primary system for further action.

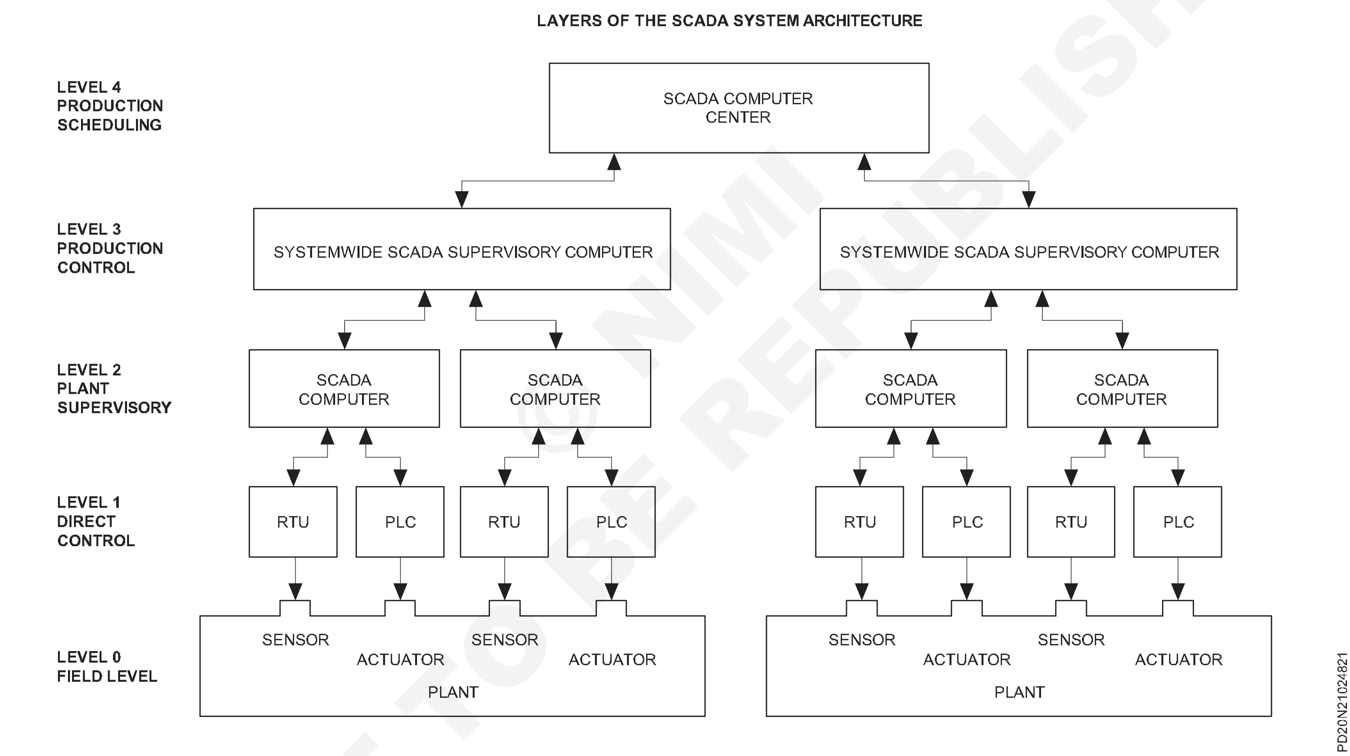
  2 Programmable logic controllers (PLCs) interface with actuators to control industrial processes, usually based on current telemetry collected by RTUs and the standards set for the processes.

- **SCADA supervisory computers:** These control all SCADA processes and are used to gather data from field devices and to send commands to those devices to control industrial processes.

- **HMI software:** This provides a system that consolidates and presents data from SCADA field devices and enables operators to understand and, if needed, modify the status of SCADA-controlled processes.

- **Communication infrastructure:** This enables SCADA supervisory systems to communicate with field devices and field controllers. This infrastructure enables SCADA systems to collect data from field devices and to control those devices.

Fig 1



SCADA is sometimes compared with the industrial internet of things (IIoT), and while there is considerable overlap, the two terms are different. SCADA vendors tend to provide more complete, monolithic systems with tight integration across levels and devices, while IIoT vendors are likely to provide greater interoperability and more options for deploying systems and devices across an organization.

Features of SCADA systems

Although SCADA systems may include special features for specific industries or applications, most systems support the following features:

- **Data acquisition** is a foundation of SCADA systems; sensors collect data and deliver it to field controllers, which, in turn, feed data to the SCADA computers.

- **Remote control** is achieved through the control of field actuators, based on the data acquired from field sensors.

- **Networked data communication** enables all SCADA functions. Data collected from sensors must be transmitted to SCADA field controllers, which, in turn, communicate with the SCADA supervisory computers; remote control commands are transmitted back to actuators from the SCADA supervisory computers.

- **Data presentation** is achieved through HMIs, which represent current and historical data to the operators running the SCADA system.

- **Real-time and historical data** are both important parts of the SCADA system, as they enable users to track current performance against historical trends.

- **Alarms** alert SCADA operators to potentially significant conditions in the system. Alerts can be configured to notify operators when processes are blocked, when systems are failing, or when other aspects of SCADA processes need to be stopped, started or adjusted.
- **Reporting** on SCADA system operations can include reports on system status, process performance and reports customized to specific uses

Benefits of modern SCADA

The benefits of updating legacy SCADA systems include the following:

- **Scalability:** Modern SCADA systems are more scalable than legacy systems for several reasons, including better availability of supported hardware and software and use of cloud computing to meet workload demand.
- **Interoperabilit:** Legacy SCADA systems rely on proprietary hardware and software, resulting in vendor lock-in.
- **Communication:** Modern SCADA systems support more widely supported and modern communications protocols, which enable greater accessibility to SCADA data and controls.
- **Support:** Legacy SCADA systems may have limited options for support, while modern systems are more likely to be well supported by vendors. Use of commercial off-the-shelf hardware, open networking standards and modern software development platforms makes third-party support more accessible as well.

GIS (Geographic Information System)

A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface.

A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. By relating seemingly unrelated data, GIS can help individuals and organizations better understand spatial patterns and relationships.

GIS technology is a crucial part of spatial data infrastructure, which the White House defines as "the technology, policies, standards, human resources, and related activities necessary to acquire, process, distribute, use, maintain, and preserve spatial data."

GIS can use any information that includes location. The location can be expressed in many different ways, such as latitude and longitude, address, or ZIP code.

Many different types of information can be compared and contrasted using GIS. The system can include data about people, such as population, income, or education level. It can include information about the landscape, such as the location of streams, different kinds of vegetation, and different kinds of soil. It can include information about the sites of factories, farms, and schools, or storm drains, roads, and electric power lines.

With GIS technology, people can compare the locations of different things in order to discover how they relate to each other. For example, using GIS, a single map could include sites that produce pollution, such as factories, and sites that are sensitive to pollution, such as wetlands and rivers. Such a map would help people determine where water supplies are most at risk.

Data Capture

Data Formats

GIS applications include both hardware and software systems. These applications may include cartographic data, photographic data, digital data, or data in spreadsheets.

Cartographic data are already in map form, and may include such information as the location of rivers, roads, hills, and valleys. Cartographic data may also include survey data and mapping information that can be directly entered into a GIS.

Photographic interpretation is a major part of GIS. Photo interpretation involves analyzing aerial photographs and assessing the features that appear.

Digital data can also be entered into GIS. An example of this kind of information is computer data collected by satellites that show land use—the location of farms, towns, and forests.

Remote sensing provides another tool that can be integrated into a GIS. Remote sensing includes imagery and other data collected from satellites, balloons, and drones.

Finally, GIS can also include data in table or spreadsheet form, such as population demographics. Demographics can range from age, income, and ethnicity to recent purchases and internet browsing preferences.

GIS technology allows all these different types of information, no matter their source or original format, to be overlaid on top of one another on a single map. GIS uses location as the key index variable to relate these seemingly unrelated data.

Putting information into GIS is called data capture. Data that are already in digital form, such as most tables and images taken by satellites, can simply be uploaded into GIS. Maps, however, must first be scanned, or converted to digital format.

The two major types of GIS file formats are raster and vector. Raster formats are grids of cells or pixels. Raster formats are useful for storing GIS data that vary, such as elevation or satellite imagery. Vector formats are polygons that use points (called nodes) and lines. Vector formats are useful for storing GIS data with firm borders, such as school districts or streets.

Spatial Relationships

GIS technology can be used to display spatial relationships and linear networks. Spatial relationships may display topography, such as agricultural fields and streams. They may also display land-use patterns, such as the location of parks and housing complexes.

Linear networks, sometimes called geometric networks, are often represented by roads, rivers, and public utility grids in a GIS. A line on a map may indicate a road or highway. With GIS layers, however, that road may indicate the boundary of a school district, public park, or other demographic or land-use area. Using diverse data capture, the linear network of a river may be mapped on a GIS to indicate the stream flow of different tributaries.

GIS must make the information from all the various maps and sources align, so they fit together on the same scale. A scale is the relationship between the distance on a map and the actual distance on Earth.

Often, GIS must manipulate data because different maps have different projections. A projection is the method of transferring information from Earth's curved surface to a flat piece of paper or computer screen. Different types of projections accomplish this task in different ways, but all result in some distortion. To transfer a curved, three-dimensional shape onto a flat surface inevitably requires stretching some parts and squeezing others.

A world map can show either the correct sizes of countries or their correct shapes, but it can't do both. GIS takes data from maps that were made using different projections and combines them so all the information can be displayed using one common projection.

GIS Maps

Once all the desired data have been entered into a GIS system, they can be combined to produce a wide variety of individual maps, depending on which data layers are included. One of the most common uses of GIS technology involves comparing natural features with human activity.

For instance, GIS maps can display what man-made features are near certain natural features, such as which homes and businesses are in areas prone to flooding.

GIS technology also allows users to "dig deep" in a specific area with many kinds of information. Maps of a single city or neighborhood can relate such information as average income, book sales, or voting patterns. Any GIS data layer can be added or subtracted to the same map.

GIS maps can be used to show information about numbers and density. For example, GIS can show how many doctors there are in a neighborhood compared with the area's population.

With GIS technology, researchers can also look at change over time. They can use satellite data to study topics such as the advance and retreat of ice cover in polar regions, and how that coverage has changed through time. A police precinct might study changes in crime data to help determine where to assign officers.

One important use of time-based GIS technology involves creating time-lapse photography that shows processes occurring over large areas and long periods of time. For example, data showing the movement of fluid in ocean or air currents help scientists better understand how moisture and heat energy move around the globe.

GIS technology sometimes allows users to access further information about specific areas on a map. A person can point to a spot on a digital map to find other information stored in the GIS about that location. For example, a user might click on a school to find how many students are enrolled, how many students there are per teacher, or what sports facilities the school has.

GIS systems are often used to produce three-dimensional images. This is useful, for example, to geologists studying earthquake faults.

GIS technology makes updating maps much easier than updating maps created manually. Updated data can simply be added to the existing GIS program. A new map can then be printed or displayed on screen. This skips the traditional process of drawing a map, which can be time-consuming and expensive.

GIS Jobs

People working in many different fields use GIS technology. GIS technology can be used for scientific investigations, resource management, and development planning.

Many retail businesses use GIS to help them determine where to locate a new store. Marketing companies use GIS to decide to whom to market stores and restaurants, and where that marketing should be.

Scientists use GIS to compare population statistics to resources such as drinking water. Biologists use GIS to track animal-migration patterns.

City, state, or federal officials use GIS to help plan their response in the case of a natural disaster such as an earthquake or hurricane. GIS maps can show these officials what neighborhoods are most in danger, where to locate emergency shelters, and what routes people should take to reach safety.

Engineers use GIS technology to support the design, implementation, and management of communication networks for the phones we use, as well as the infrastructure necessary for internet connectivity. Other engineers may use GIS to develop road networks and transportation infrastructure.

Power and control circuits of outdoor substation

Objectives: At the end of this lesson you shall be able to
- **describe schematic drawings of power and control schematic diagram with interlocks**
- **describe isolator - earth switch wiring and its scheme of operation**
- **describe PT, CT, Marshalling box wiring**
- **describe CB closing and tripping circuit.**

What is Electrical Interlocking?

Electrical interlocking is a mechanism of electrical controls and devices designed to ensure the safe and orderly operation of electrical circuits, machinery, or equipment by preventing certain actions or conditions unless specific prerequisites are met. For example, when we need to perform a motor reverse-forward operation controlled by two contactors, only one contactor should be operational at a time to prevent damage to the circuit

It relies on the use of logic-based controls, such as relays, contactors, and sensors, to create dependencies between different electrical components or processes.

The primary purpose of electrical interlocking is to enhance safety and prevent accidents or damage by enforcing predefined sequences of operatión, ensuring that equipment or systems operate in a coordinated and controlled manner. This technique is commonly applied in industrial settings, automation systems, and power distribution networks to mitigate risks and maintain operational integrity.

In practical applications, electrical interlocking is commonly used in scenarios where multiple motors, machines, or equipment need to operate in a specific sequence or under particular conditions. By interconnecting these devices and employing logical control strategies, electrical interlocking ensures that actions occur in a safe and coordinated manner, adhering to established operational protocols. This technique is widely used in various industries, including manufacturing, automation, and power distribution, to enhance safety and system reliability.

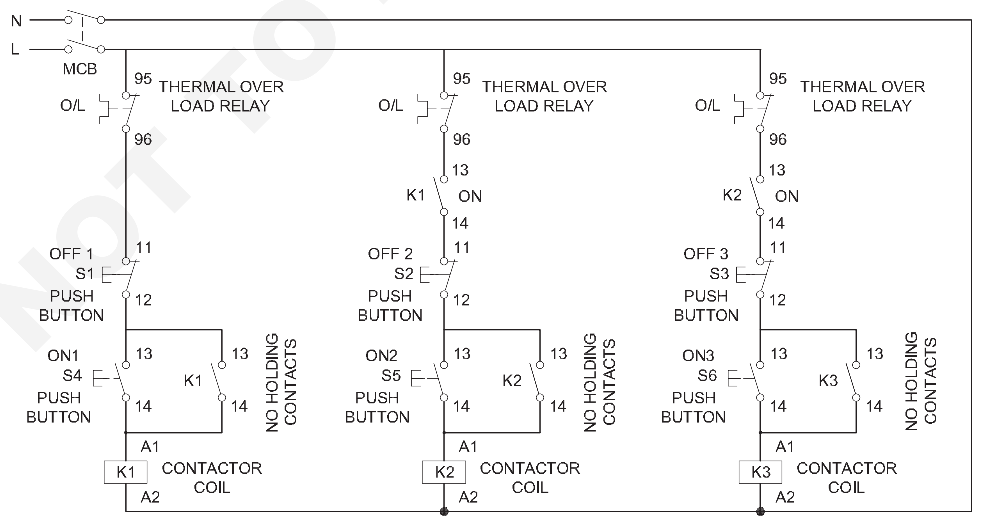
Contactor Interlocking

Contactor interlocking is a system in which only one contactor is functional and performs a single operation at a time to prevent damage to the overall circuit. For example, in the case of a motor controlled by a star-delta starter, the motor can only run in either the star or delta configuration because the interlocking system of contactors prevents both contactors from operating simultaneously.

To interconnect the motor circuit in such a way that the second motor will not start until the first one runs, and likewise, the third motor will not run unless the second one runs, and so on (same like sequential operation of motors). This type of motor circuit connection is called interlocking.

A simple electrical interlocking control circuit diagram is shown below.

Fig 1



ELECTRICAL INTERLOCKING

PD20N21125011

1 When we push the ON-1 button to energize the M1 Contactor (or start the M1 Motor), the circuit completes through the Fuse, the Overload relay's trip link, OFF Push -1, and ON Push 1. Motor M1 then starts to run.

2 As Contactor M1 energizes, all its normally closed (NC) contacts open, while the normally open (NO) contacts close.

3 When M1 energizes, the normally open (NO) contact immediately closes, which is in parallel with ON-Push 1. This is called the Holding circuit, as it keeps the motor in the starting condition. Now, the motor will continue to run even if we release (disconnect) ON-Push 1.

4 A normally open (NO) contact is also used in line 2. When M1 energizes, this link (NO M1 in line 2) also closes, causing M1 Motor to start running. Consequently, the supply also reaches ON-Push 2. If we press ON-Push 2, the second motor, M2, will start to run. Additionally, the normally open (NO) contacts of the connected contactor M2 in the circuit will also close immediately. Holding will occur through the M2 link, which is in parallel with ON-Push 2. Consequently, Motor 2 will start running.

5 It's important to note that Motor 2 will not start running until Motor 1 runs, meaning that Motor 1's link M1 must close. Similarly, Motor 3 will not start until Motor 2 runs. In other words, Motor 3 will start running (by pressing the ON-Push for Motor 3, denoted as M3) after Motor 2 has started.

In each control circuit, fuses, circuit breakers and overload relays are connected for short circuit and overload protection, respectively.

Modification in the Electrical Interlocking Control Circuit

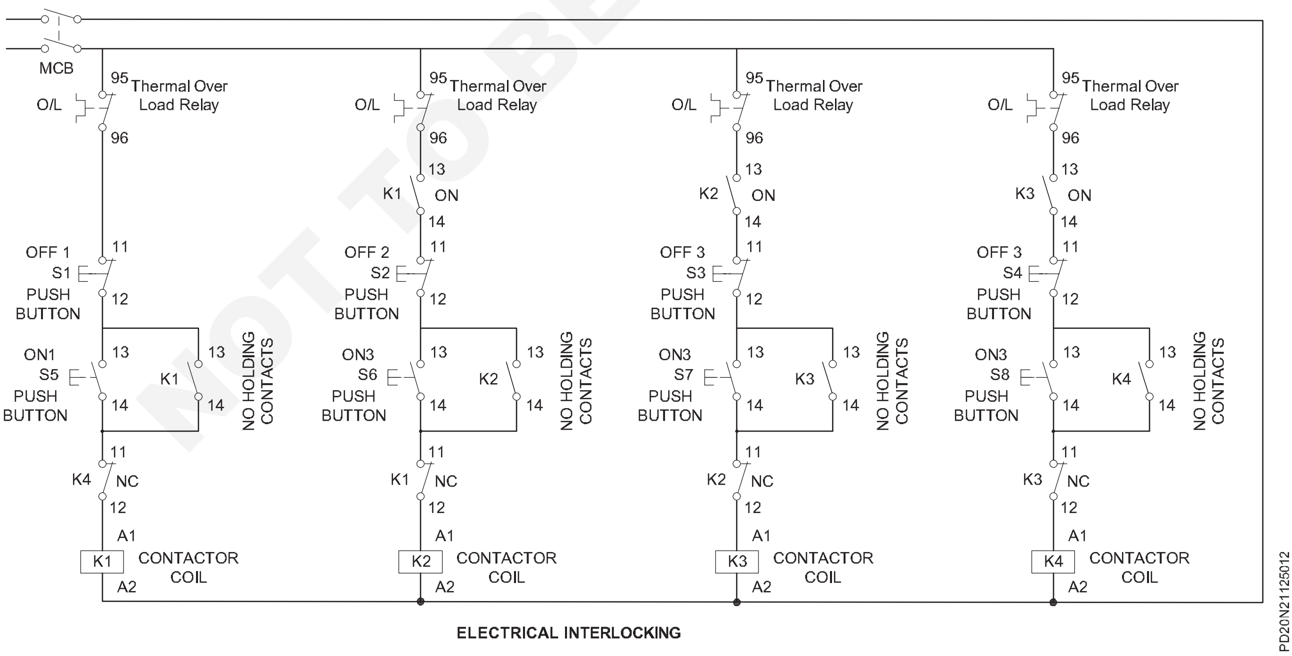
This is a straightforward electrical interlocking circuit, and many similar circuit are employed across various industries. The specific interlocking configuration depends on the nature of the task motors are required to perform. Consequently, creating and utilizing various interlocking circuits for different purposes is easily achievable

This is a basic electrical interlocking circuit, and many similar circuits can be designed by using some modification in this circuit. The specific interlocking configuration depends on the nature of the task motors are required to perform. Consequently, creating and utilizing various interlocking circuits for different purposes is easily achievable. For example, let's see the following scenario,

We can modify the operation and control of the motors in the above simple electrical interlocking control circuit diagram. For instance, if we want Motor-1 to stop when Motor- 3 starts running, we can use a Normally Closed (NC) link of K3 in line 1. When Contactor K3 energizes and Motor-3 starts running, the Normally Closed (NC) link of Motor-1 connected in line 1 will immediately open (after K3 Contactor energizes). This action de- energizes the K1 contactor, causing Motor-1 to stop. (Fig 2)

With a few minor modifications, we can configure the above electrical interlocking control circuit to start and run each motor individually as shown in the following control diagram.

Fig 2



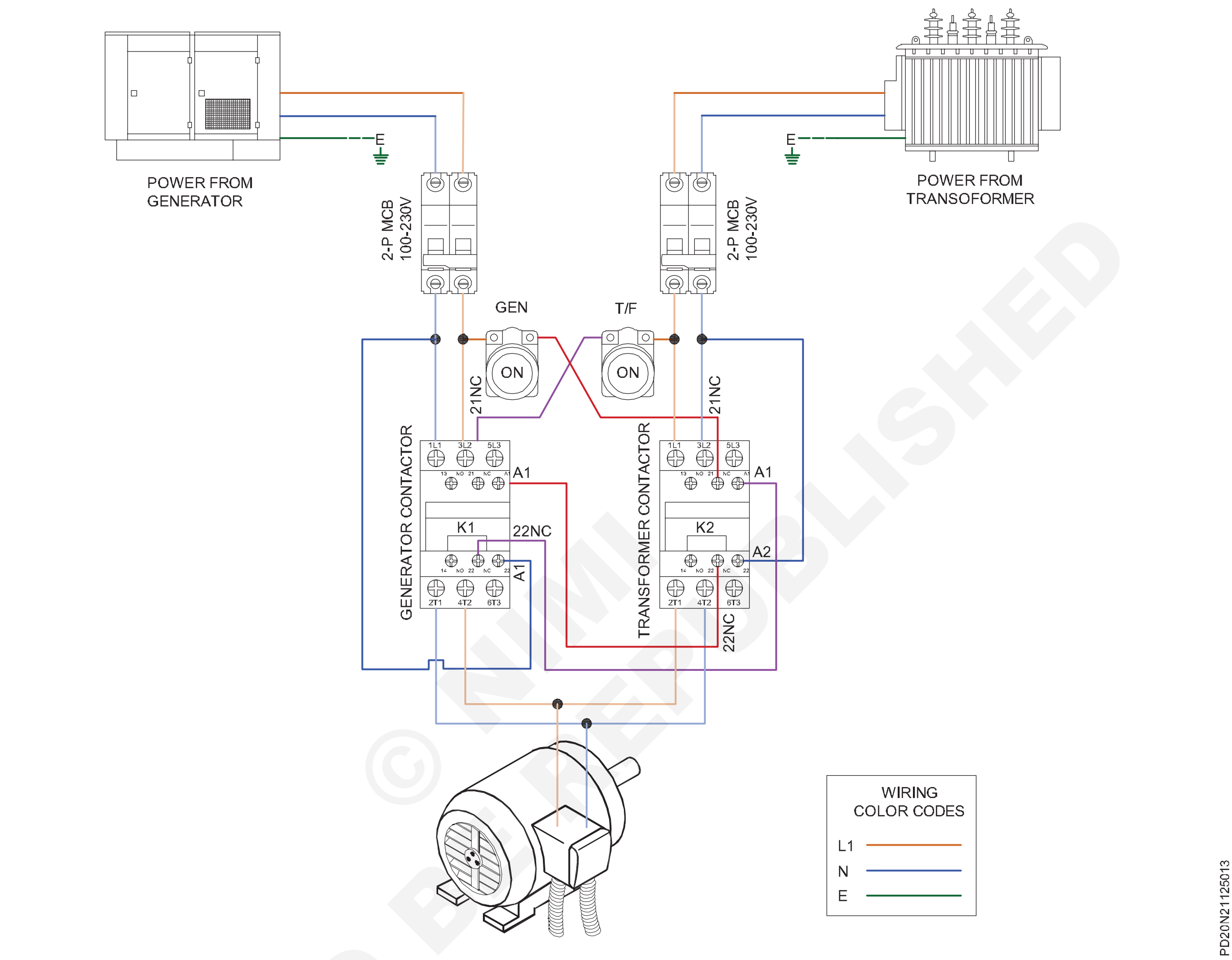
Power & Control Wiring Diagrams of Interlocking

Interlocking for Single Phase Motor Connected to 2 Power Supplies.

The automatic ATS wiring diagram below ilustrates the connection of a single-phase motor to two different power supply sources: the main supply and a backup generator

The two contactors in this setup are electrically interlocked, allowing only one contactor to be operational at any given time, whether it's the contactor for the main supply or the contactor for the generator supply. This arrangement effectively prevents damage to connected appliances. (Fig 3)

Fig 3



Interlocking for Three-Phase Motor Designed for Two Directions:

The following diagram illustrates the connection of a three-phase motor through a Direct Online starter. This connection offers both forward and reverse operations using a DOL starter, which is based on contactors and a thermal overload relay. Both contactors (1) and 2) are interlocked, ensuring that only one of them can operate at any given time. Contactor 2 is used for forward operation, while contactor 1 is used for reverse operation.

Thanks to the interlocking feature, as this arrangement effectively prevents short circuits and serious damage to the connected machinery, thanks to the interlocking feature (Fig 4)

For further interlocking tutorials and wiring diagrams, we have used the same mechanism of holding and interlocking for Two-Speed. One-Direction. Two-Speed Two- Direction, Reverse-Forward Motor Control,

Sequential Operation of Motors and Star- Delta Starter using Timer for three-phase induction motors.

In the Substations circuit breakers, isolators, and earthing switches are connected. For the maintenance or any other purpose if we need to open of break the circuit then we should follow a proper sequence for the operations of circuit breakers, isolators, and earthing switches. If we follow the wrong sequence then it will be a danger for us as well as equipment and circuits

The sequence of operation of the Isolator, Circuit Breaker, and Earthing Switch:

While we opening a circuit we should follow the below sequence, (Fig 5)

Fig 5

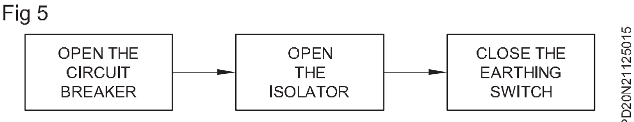
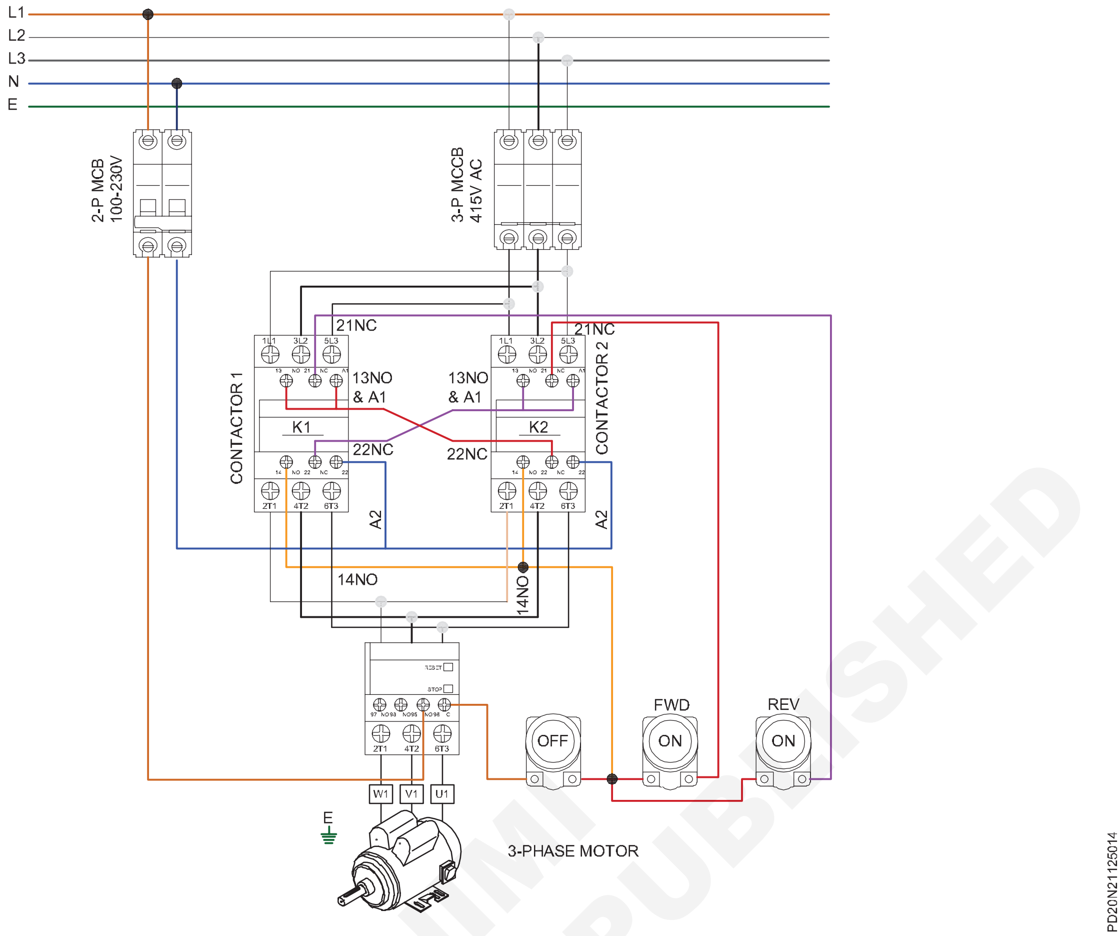


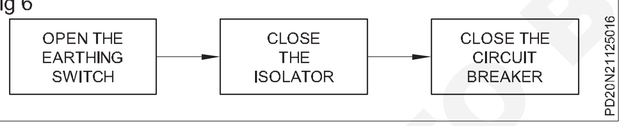
Fig 4



So, First, the Circuit Breaker should be open, then the isolator should be open and at last, the earthing switch is to be closed.

While we closing a circuit we should follow the below sequence. (Fig 6)

Fig 6



So, first, the Earthing Switch is to be open, then the isolator is to be closed and al last, the circuit breaker is to be closed.

What happened if we open the isolator before the circuit breaker?

We know that the Isolator is designed to operate under no load conditions, so if we open the isolator before the circuit breaker, that means we open the isolator under live conditions. So there will be huge sparking between the contacts of the Isolator which is very dangerous for us.

Understanding the sequence with an Example:

Here a circuit diagram of 11KV/400V substation is shown. Here is one incoming line and two outgoing lines. Suppose we need to the maintenance of the Transformer of the second outgoing line. (Fig 7)

So for the maintenance, first the transformer is to be disconnected from the circuit. So below sequence should be followed,

1 First circuit breakers A, B should be open.

2 Then the isolators C and D should be open.\

3 Then the earthing switches E and F should be closed.

Now after completing the maintenance, to connect again the Transformer to the line we should follow the below sequence.

1 First Open the earthing switches E and F

2 Then close the isolators C and D

3 Then close the circuit breakers A and B

During opening of circuit breaker (Fig 8)

shows the sequence of operations as

1 Opening C.B

2 Opening Isolator

3 Closing earth switch.

During closing circuit breaker (Fig 9)

shows the sequence of operations as

1 Opening earth switch

2 Closing Isolator

3 Closing C.B.

Fig 7

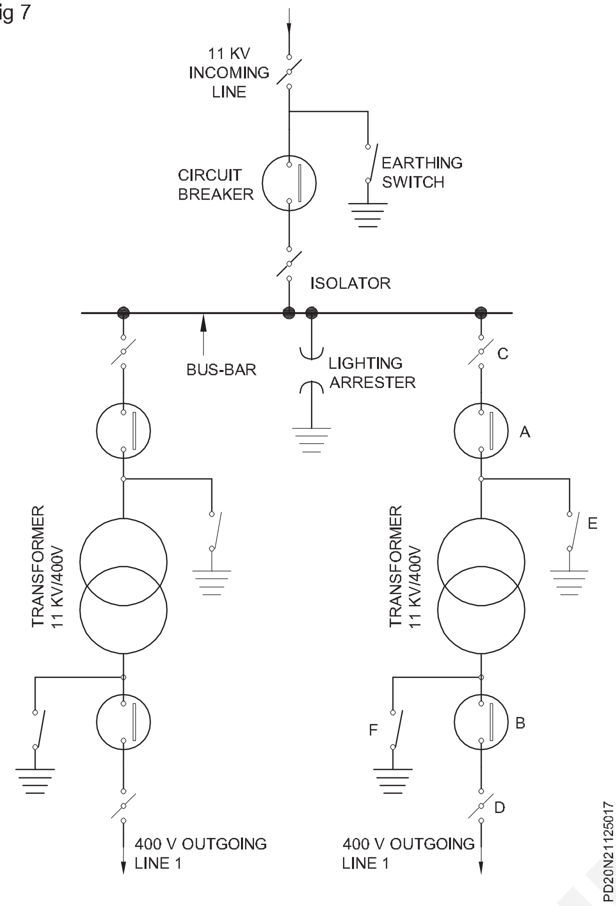


Fig 8

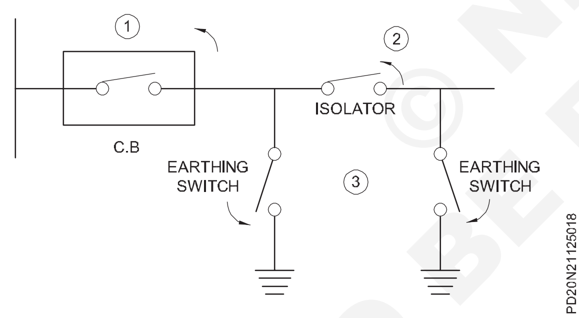
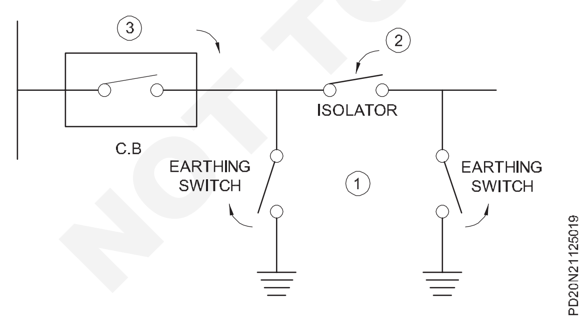


Fig 9



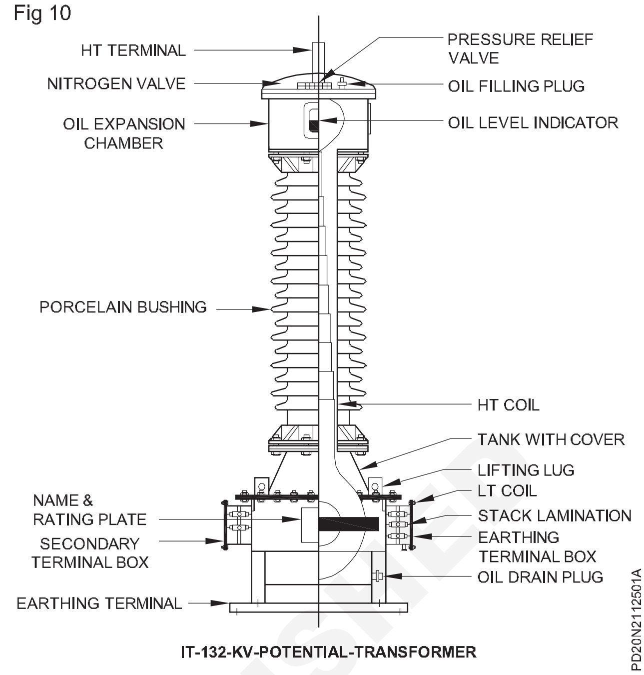
Secondary Terminal Box:

All secondary terminals shall be brought out in a compartment on one side of each Potential Transformer for easy access.

The exterior of this terminal box shall be hot-dip galvanized/painted with weather proof paint.

Potential transformer terminal Box (Fig 10)

Fig 10



The secondary terminal box shall be provided with a removable cable gland plate at bottom for mounting cable glands of 1.1 KV grade steel wire armored, PVC insulated PVC sheathed 4 core (4 sq.mm.) stranded copper conductor cables. The cable glands shall be included within the scope of supply. The number of cable glands are equal to number of cores in the PT.

The terminal box shall be provided with a detachable cover plate in front so as to have easy access of secondary terminals. The cover shall have a sealing arrangement and shall be suitable to prevent ingression of moisture and rain water. The sealing arrangement shall be done by drilling holes in the tightening bolts of the cover. The degree of protection shall be not less than IP-55 as per IS-2147. 9.5. All terminals shall be clearly marked with identification number to facilitate connection to external wiring with sufficient space in between.

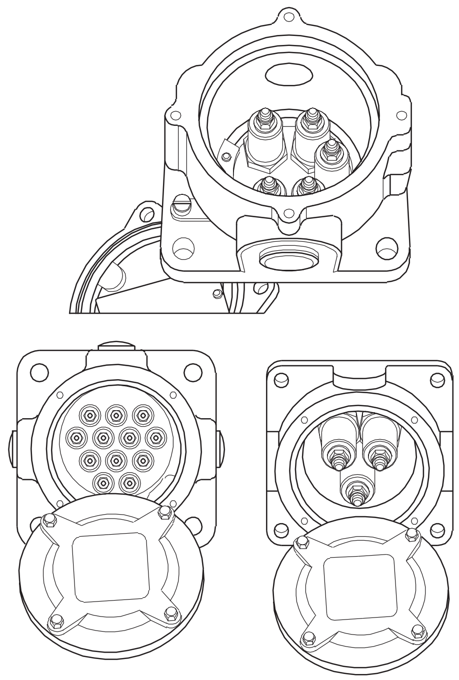
Current transformer terminal box

Features

- CT Terminal Box and Core grounding terminal box
- CT terminal box available upto 12 terminals in two sizes
- Core Grounding terminal box available upto 3 terminals
- Die cast aluminium body & cover assembly is rust proof, Compact and light weight
- Moulded terminal and studs with rellable O-ring sealing
- Any terminal can be replaced by user
- Fool proof mechanism with rotation protection
- Individually tested for leak, IR and HV

- IP67/IPX7 enclosure protection (Fig 11)

Fig 11



TERMINAL BOXES

PD20N2112501B

CT terminal box upto 12 terminals

Application

CI. Terminal box is meant for connecting internal Circuits to External Circuits in oil filed Transformers They are primarily used to connect CT to internal wiring in the transformer

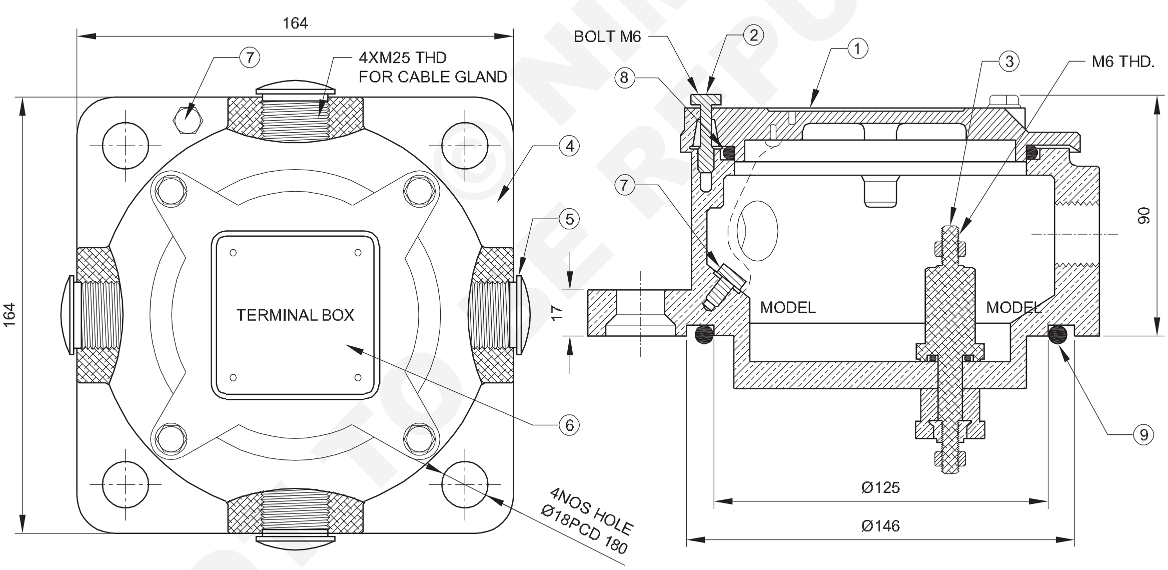
Variety Available

- 4.6.98 12 terminal options
- Shorting link supplied on demand

Specific Features

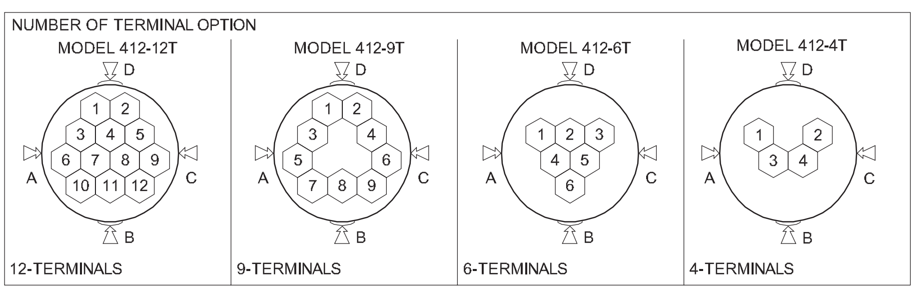
- Four M25 cable gland entries available at every 50 degrees for easy connection of external CT wiring to terminal box contacts
- 4.6.9 & 12 terminals all have same mounting for design simplicity
- Extra cable gland entries have milable O-ring sealed entry protection
- MG terminals (Fig 12)

Fig 12



PARTS LIST	
SL	DESCRIPTION
1	TERMINAL BOX COVER
2	COVER ASSEMBLY BOLT
3	TERMINAL
4	TERMINAL BOX BODY
5	CAPS M25X1.5
6	NAME PLATE
7	GROUND CONNECTION BOLT OR SCREW (M6)
8	COVER O-RING
9	MOUNTING O-RING

VARITY AND CODING



CT TERMINAL BOX : UPTO 12 TERMINALS

PD20N2112501C

CT terminal box upto 6 terminals

Application

C.T. Terminal box is meant for connecting Internal Circuits to External Circuits in oil filled Transformers. They are primarily used to connect CT to internal wiring in the transformer

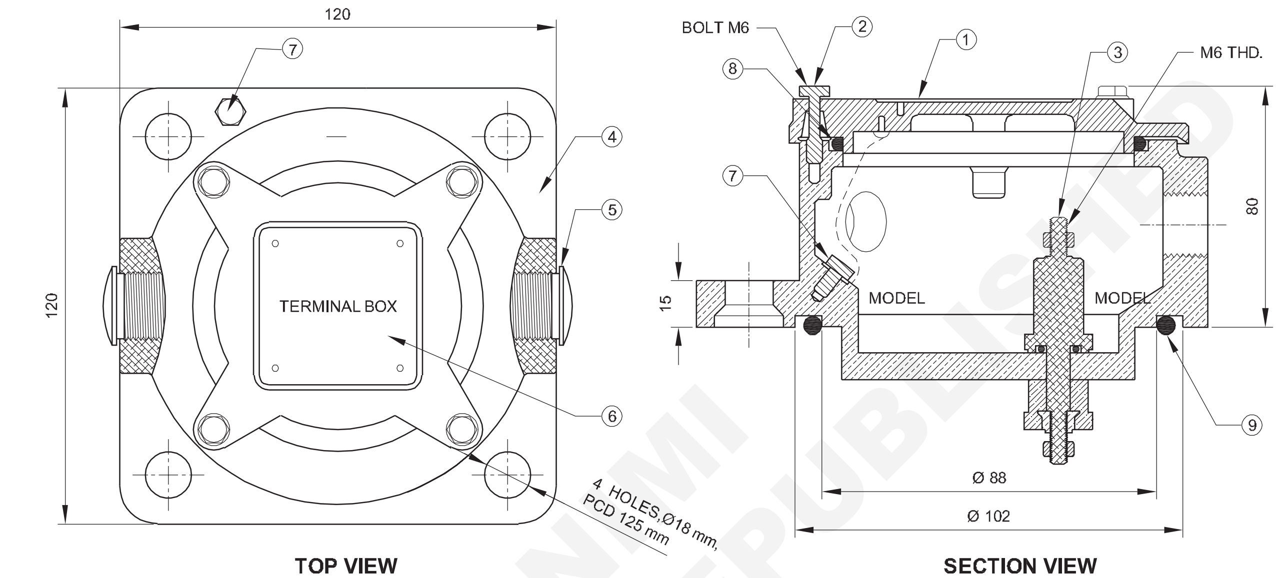
Variety Available

- 2.3.4.5 and 6 terminal options
- Shorting link supplied on demand

Specific Features

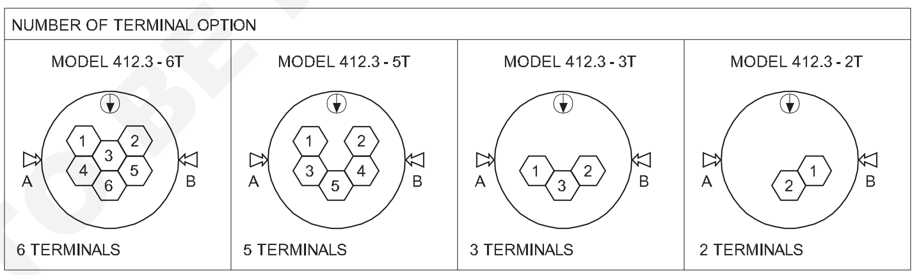
- Two M25 cable gland entries available for easy connection of external CT wiring to terminal box contacts
- 2,3,4,5,6 terminals all have same mounting for design simplicity
- M6 terminals
- Smaller box than 12 terminals enables smaller footprint on transformer (Fig 13)

Fig 13



PARTS LIST	
SL	DESCRIPTION
1	TERMINAL BOX COVER
2	COVER ASSEMBLY BOLT
3	TERMINAL
4	TERMINAL BOX BODY
5	CAPS M25X1.5
6	NAME PLATE
7	GROUND CONNECTION BOLT OR SCREW (M6)
8	COVER O-RING
9	MOUNTING O-RING

VARITY AND CODING



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Circuit breaker closing and tripping circuit

Before explaining what each device in the scheme does, understanding the different forms of auxiliary contact is necessary. Every breaker comes fitted with an auxiliary switch. It is mechanically linked to the breaker's trip-close mechanism. Within the auxiliary switch case you can have either form a contact (a.k.a. 52a per ANSI) or form 'b' (aka. 52b).

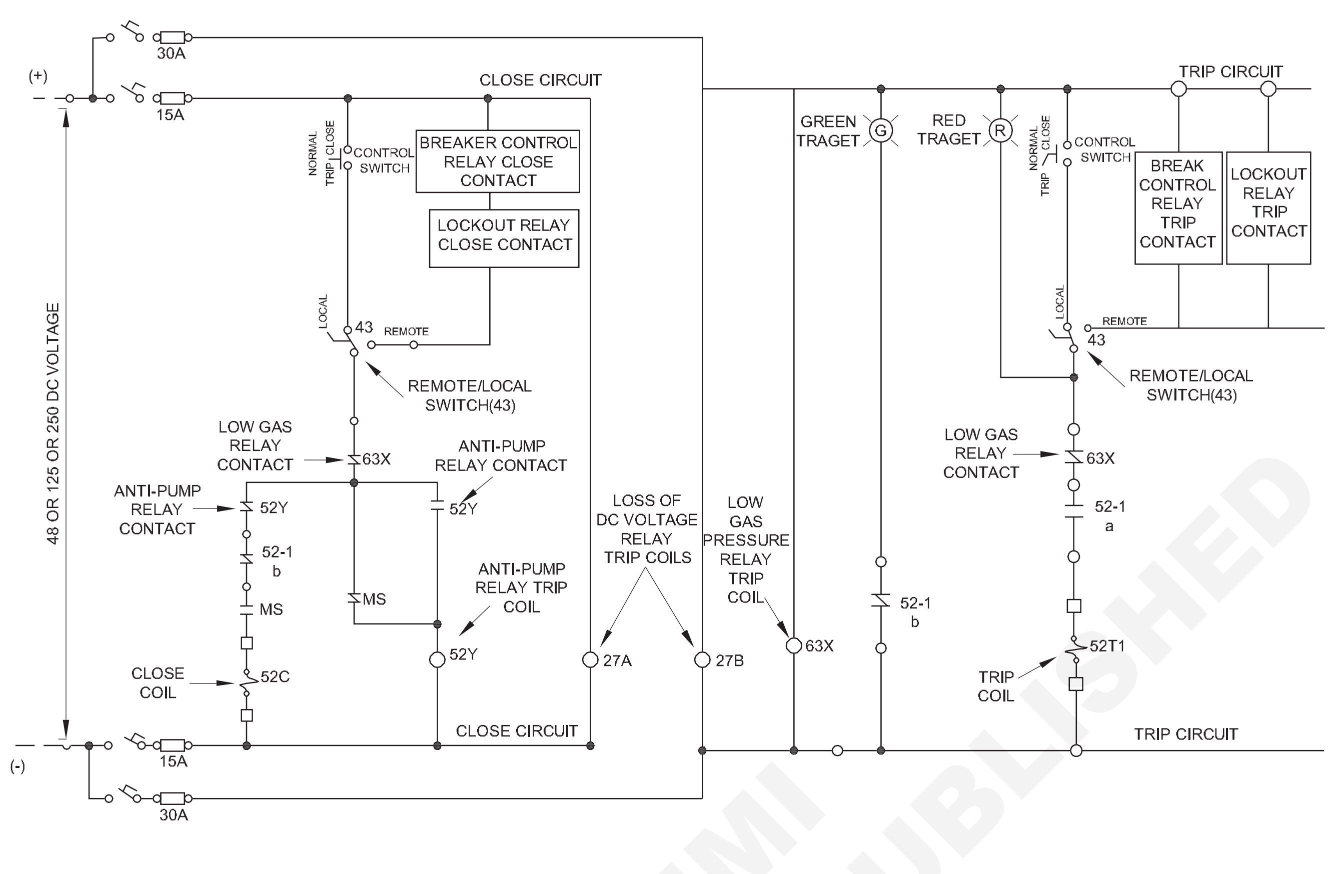
A form 'a' contact represents a Normally Open (N.O.) contact. Thus when the breaker is open, its 52a contacts are open. When the breaker is closed, the 52a contacts are closed. The 52a contact follows the status of the breaker.

A form 'b' contact represents a Normally Closed (N.C.) contact. It operates exactly opposite of what an 'a' does. When the breaker is open, the 52b contacts are closed. When the breaker is closed, the 52b contacts are open.

With the 52a contact in the trip circuit (as shown in the scheme above), once the breaker opens, this contact opens too. Now no matter what the relays do, the trip coil is isolated. On the flip side, with the breaker open, the 52b contact in the close circuit is closed - allowing the close operation when desired.

Apart from breaker auxiliary switch contacts, you will see relays such as anti-pump relay 52Y, low gas relay 63X, under voltage relay 27, etc in the breaker scheme. The 'a' and 'b' contacts from each of these relays are interlocked with other relays or switches such that they either permit or not permit the breaker operation. (Fig 14)

Fig 14



For the trip circuit, you must wire the tripping relays 'a' contact in parallel. See Figure 15. Therefore when any one relay or switch contact closes, thus completing the circuit, the breaker trips. The only exception to the parallel wiring of contacts is the low-gas auxiliary relay contact (63X in the figure). This one is wired in series. Why? Modern power circuit breakers employ Sulfur Hexa-Flouride (SF6) gas to extinguish an arc. Without adequate gas i.e. reduced interrupting capability, a flash-over can occur inside the tank. To prevent flash-overs due to low gas, breakers are fitted with ANSI '63' relay. Tripping of breaker is cut out by this relay's contact.

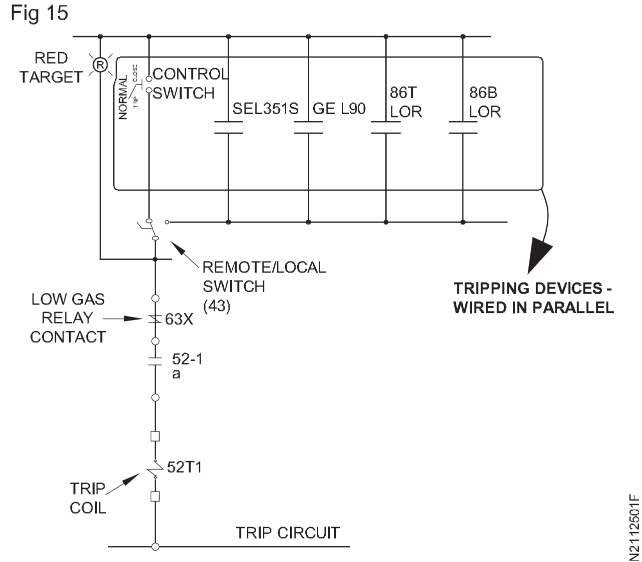
Most modern circuit breakers are specified with two trip coils. Energizing either one trips the breaker. Since a good amount of redundancy is built into the protection and control of a power system, it is not uncommon to see all primary relaying in the system tripping trip coil 1 and the back-up tripping trip coil 2.

At this point, I hope the reader has grasped the strategy of series-parallel placement of relay contacts.

Let's look at other relays and switches from the trip circuit of our breaker. The 278 under- voltage relay trip coil is connected across the same DC source as the one feeding the trip circuit. When this supply is interrupted, the 27B relay coil is de-energized, operating its contacts.

In our breaker, we are not blocking trip for this abnormal condition. It is typical in the industry to only annunciate locally and forward the alarm to a remote operator via SCADA. The breaker is also fitted with a 43 switch that toggles between local-trip and remote-trip. Positioning it in local allows the persons at the breaker junction box to trip the breaker by closing the Control Switch (CS). Switching it to the remote position permits the relays in the control house to trip the breaker. (Fig 15)

Fig 15



CIRCUIT BREAKER TRIP SCHEME

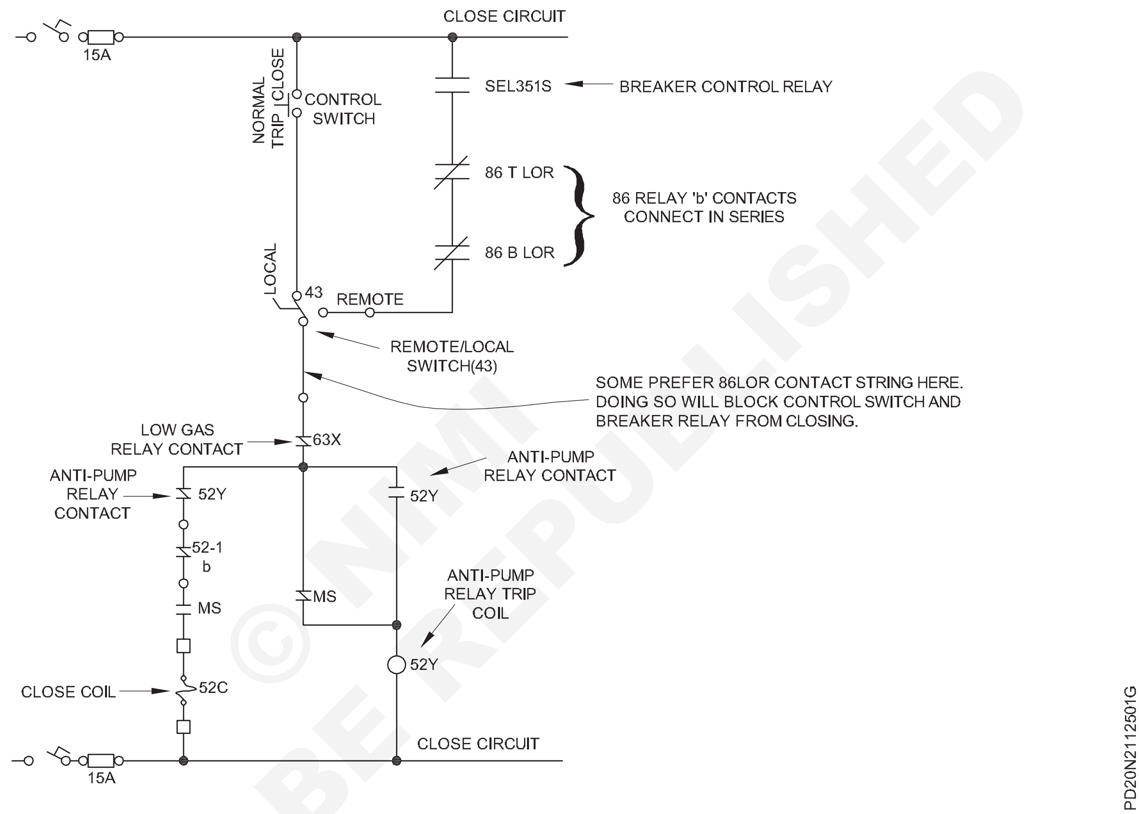
Target lamps are used in circuits to convey certain conditions. With the breaker closed and energized, the red lamp illuminates to indicate a live breaker. When the breaker opens the green lamp illuminates - the circuit complete with 52b contact switching from open to close

Now, you may notice the red target lamp is connected in a way that will essentially short out the tripping relays and trip the breaker. Not surprisingly, this is not the case. The target lamps have enough resistance in them (-200 ohms for a 125VDC circuit), limiting the current that can energize the coil.

Circuit Breaker Close Scheme

For this circuit, you must wire breaker control relay's 'a' contact in series with a string of 86 lockout relay 'b' contacts before you hit the anti-pump relay in the close circuit. Why? Well, would you want to close a breaker into a faulted circuit? See figure 16. In this example, you have 86T (transformer LOR) and 86B (bus LOR) 'b' contacts in series with 'a' contact of SEL351S breaker control relay. Therefore when either a transformer or a bus fault occurs, its corresponding LOR will block the SEL3515 from completing the circuit

Fig 16



Modern breaker control relays are programmed to check for synchronism. That is, before the breaker is closed, the relay checks the phase angle of source and load side voltage of any one phase. If the angles are out of sync, the relay logic will not allow its close control contact to operate.

The close circuit also has contacts from the Motor Switch (MS). The motor is used to charge the spring that trips-closes. The motor switch contacts don't allow the breaker to close until it finishes its job.

Marshalling Cabinet

The marshalling cabinet acts as an interface between the system cabinet and field junction boxes. The main cables are laid from the field junction boxes to the marshalling cabinet The prefab cables from the system cabinet 10 cards are also terminated in the marshalling cabinet.

The marshalling cabinet is used for the primary termination point for incoming field cables. Further, the other ends of wires are internally connected to system cabinets wherein the I/O modules and controllers are installed.

In the below picture, there are three cabinets (or panels). The middle one is system cabinet and the left & right side are marshalling cabinets. (Fig 17)

As you can see from the below pictures, a conventional cabling work contains field inputs and output to a field junction box, then using a home run (Multipair/ Multi-core) cable to bring the signals from the field junction box to a marshalling panel in a control room/Instrument Technical Room, and then using cross-wiring to route the signals to respective termination assemblies.(Fig 18)

In simple terms, Marshalling cabinets are located between junction boxes and control system. Within the marshalling cabinets, field cables are connected and cross-wiring is performed to order the signals according to the I/O modules. In this way, it is possible to use prefabricated cables to interconnect the marshalling cabinets with the I/O modules.

Fig 17

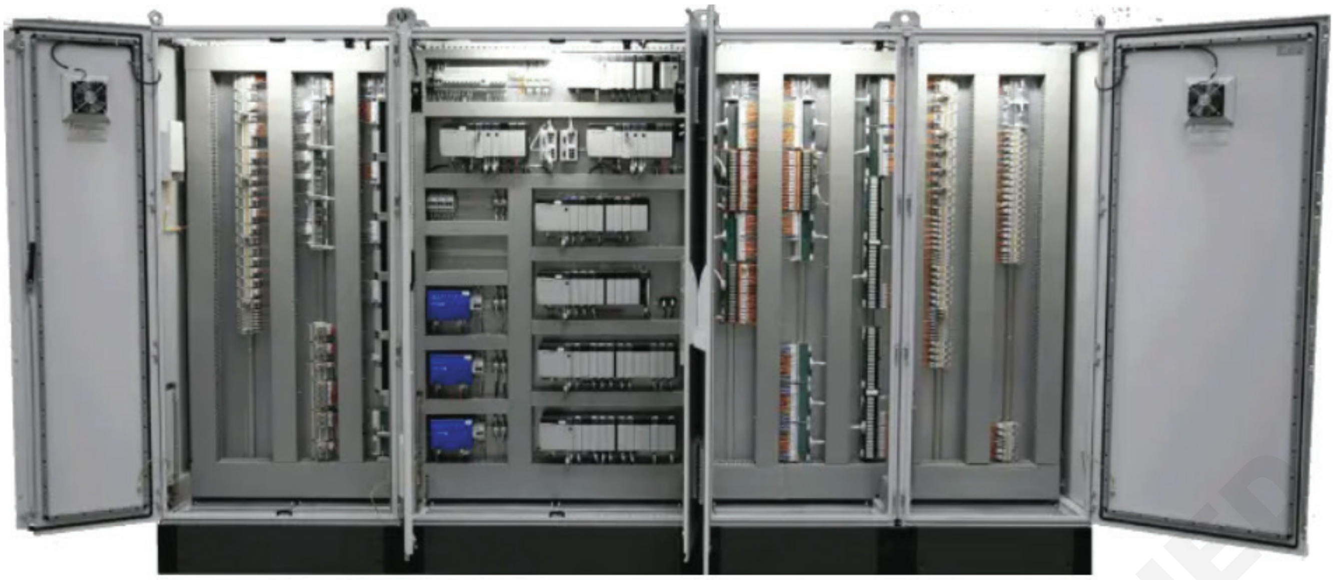
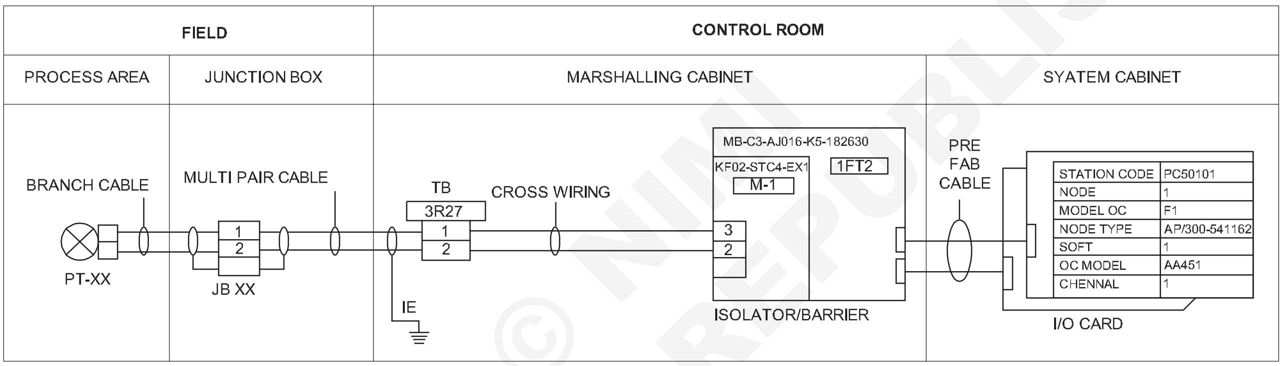


Fig 18



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The major components of marshalling cabinet are Isolators/ Barrier, Relays, Terminal bocks for field home run cables, shield terminals, Terminal board for cross-wiring. Power supply modules, Diode O-ring.

Dedicated marshalling cabinet is used for large I/O systems. When separate marshalling cabinets are used, these cabinets can be sent to site at the early phase of the project so that field cables are terminated. Later when system cabinets are available then prefabricated cables are installed between marshalling and system cabinets. Separate cabinets have the advantage of staged Factory acceptance tests and staged delivery.

Relay and Control panel wiring, RTCC, OLTC, Mimic

Objectives: At the end of this lesson you shall be able to
- **Describe and Interpret Relay and control panel wiring**
- **Describe RTCC panel wiring**
- **Describe OLTC,Mimic panel wiring.**

Control & Relay Panel (CRP)

Control and Relay panel is most important equipment of the substation as it work as shield guard for all substation equipments and electrical network. Moreover, these panels are useful to control the flow of electricity as per the Voltage class and detect the faults in transmission lines.

A control & relay panel is designed to provide to control the associated line or transformer through outdoor switchgear at various 11KV and 33KV zonal substations. The control & Relay panels are complete in themselves with all main and auxiliary relays, annunciation relay, fuses, links, switches, wiring, labels, terminal blocks, earthing terminals, base frame, foundation bolts, illumination, cable glands etc. These panels are used for the control & monitoring of electrical equipments such as transformers, generators and circuit breakers. Indoor Control panel for Outdoor VCB includes IDMT Numerical relay, Master Trip Relay, Trip circuit Supervision Relay, Indications & meters etc. These control & Relays panels are available in various combinations as single circuit or multi-circuit depending upon the customer requirements.

Scope

Used for protection, control. measurement & monitoring of electrical equipment such as transformers, generators, motors, bus bars, cable or line feeders, bus couplers, capacitor banks, voltage protection etc.

Benefits

- Fully designed, manufactured, and tested as per customer philosophy
- Factory engineered and tested
- Fast commissioning and deployment at customer site

Features of Control Relay Panel

- Complete protection of Generator, transformer, motor and line feeder
- Alarm & Annunciation features
- Simple Construction
- Multiple Construction Choice (front door or rear door type)
- Also available with Communicable Relays
- Multiple scheme configurations in a Single panel
- Compact
- CPRI tested
- Graphics

Designing and manufacturing of Control and Relay panel depend on the requirement of utilities and these can broadly be classified as follows;

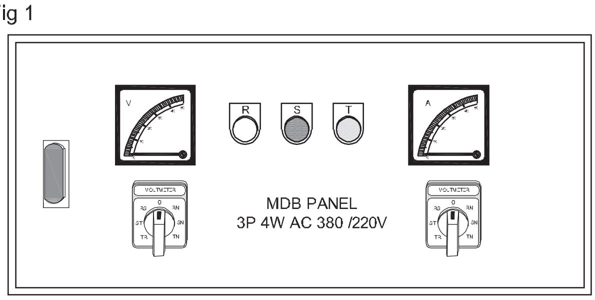
- Line Protection
- Transformer Protection
- Bus Bar Protection
- Tie Breaker
- Bus Coupler
- Reactor

In this panel, varieties of numerical & electromechanical relays are installed to provide damage protection to equipments. Meters, Semaphore indicators, Control Switches, Indicating lamps, Push Buttons, Annunciator, Test Blocks and Test Plugs are among of major equipments installed as per designing requirements.

The Control & relay panels are designed & manufactured as per voltage class of substations like 11KV, 33KV, 66KV, 132KV, 220KV and 400KV etc. However DC voltage or supply voltage may differ according to the panel requirement such as 30V DC, 110V DC, 220V DC etc. Use of Control & relay panel is not only limited in Substations owned and operated by electrical utilities, but also essential in industrial and commercial sector where power consumption is very high.

Modern Control & Relay panels are widely being manufactured as per international standards and strictly following IEC -61850 communication protocol, which is well compatible to SCADA application. (Fig 1)

Fig 1



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There are major two types of control panels are being manufactured for substations;

- Simplex type
- Duplex type

In simplex type panel, all control and relay instruments are equipped/mounted in the same panel. On the other hand, control & relay unit fitted separately in duplex type, wherein relay installed in relay section and other equipments like Meters, Switches, Semaphores, Annunciator, indicating lamps and Push Buttons in control section.

Furthermore, design of Panel can be categorized in two types as per customer requirements and location feasibility ;

- Corridor type
- Rack mounting type

Panel is made of CRCA sheet having thickness from 2mm to 3mm. Rack mounting type panel is design with front glass door and corridor type is simple panel which do not have front glass door. (Fig 2 & 3)

Fig 2

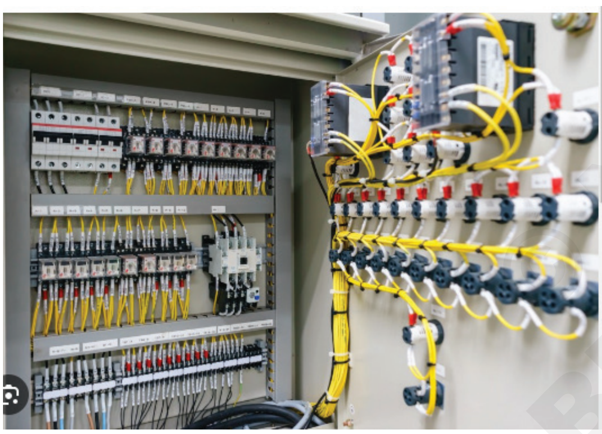


Fig 3

Remote Tap Changer Control Panel

RTCC is "Remote Tap Changer Control "which is a Programmable device to control the output of the transformer through OLTC unit fitted in the transformer through control cables. The desired voltage will be achieved accordingly by controlling the OLTC with respect to the tap position through RTCC system. The output voltage of the transformer is been maintained through an inbuilt AVR (Automatic Voltage Regulator), which continuously verifies the output power with the set/programmed reference voltage, which triggers the OLTC accordingly. Hence, by above said phenomena, the consistency of the transformer output is been maintained.

RTCC is a panel consisting of the AVR, Display for Tap Position, Voltage, LEDs for Raise & Lower of Taps relays, Selector Switches for Auto Manual Selection etc. In AUTO Mode the voltage is controlled by the AVR. In MANUAL Mode the operator can

Increase / decrease the voltage by changing the Taps manually through the Push Button in the RTCC. Normally RTCC panel will be installed in Main panel room and will be connected to OLTC (On load tap changer) of the transformer through control cable. There will be AVR in RTCC Panel to control the secondary voltage of the transformer and AVR output will control OLTC motor in Clock wise or Anti clock wise directions.

RTCC is installed with transformer HT Panel. Automatic OLTC Panel consists of a LCP and a RTCC. System uses an AVR (AVR-MA9) to sense the LV Voltage and a comparator circuit to compare the sensing voltage with a preset value. Any difference in two sends a corresponding signal to OLTC Panel to lower or raise the LV Voltage of transformer. The OLTC Control Panel also has a provision to operate two or more transformer in parallel. One transformer is taken as the master and the remaining as followers so that they follow the Master's LV Voltage set values.

Parts of RTCC Panel:

1 Indicators.

Two indicators are used for as one is taping process and other is panel supply on or off. When taping process is working then show on condition. If the control supply of panel is available or not available then it shows the status.

2 Tap control relay.

Tap control relay is a voltage monitoring and default voltage maintaining relay. It works on auto mode. First it senses on line voltage if the voltage is low or high in comparison of default line voltage then it sends a commands to OLTC motors which is moved reverse or forward.

3 Tap status counter.

Tap status counter is a tap counting current status monitoring device. The status supply is received from tap control monitoring relay and then it shows the status of taping on display. Mostly seventeen nos taping are used for voltage variation.

4 Push buttons.

- Tap Up. When the voltage is increased then the push button of tap up is pressed continued till to get default line voltage.

- Tap Down. When the voltage is decreased then the push button of tap down is pressed continued till to get default line voltage.

5 Selector switch.

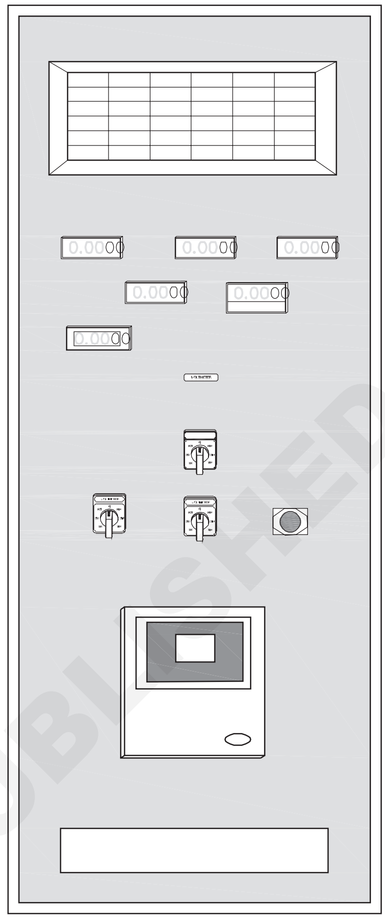
Three type selector switch are used as per below mentioned.

- Auto/ Manual selector switch: -It is used for selecting the RTCC panel in auto or manual mode. If the selector switch is selected in auto mode then RTCC panel is controlled by tap monitoring relay. If the selector switch is selected in manual mode then the tap can be controlled by push button increase or decrease.
- Panel heater selector switch: - When humidity is more then a heater is used in panel for removing moisture. Heater selector switch is used for ON and OFF.
- Control Supply selector switch: - Single phase control supply is used for tap monitoring and control relay as auxiliary supply, push button, selector switches and tap counter.

OLTC Control Panel

- Nowadays almost all the large transformer is provided with on-load tap changer.
- Users can easily check the Winding temperature and Oil temperature, Tap Position of transformer through the panel status.
- OLTC control panel includes Annunciator (SEL, 36windows), WTI, OTI, TPI, VM, Key switch for Auto – Manual and Individual – Parallel operation, AVR and etc.
- Any modification and designs can be negotiate upon prior request (Fig 1)

Fig 1



OLTC CONTROL PANEL

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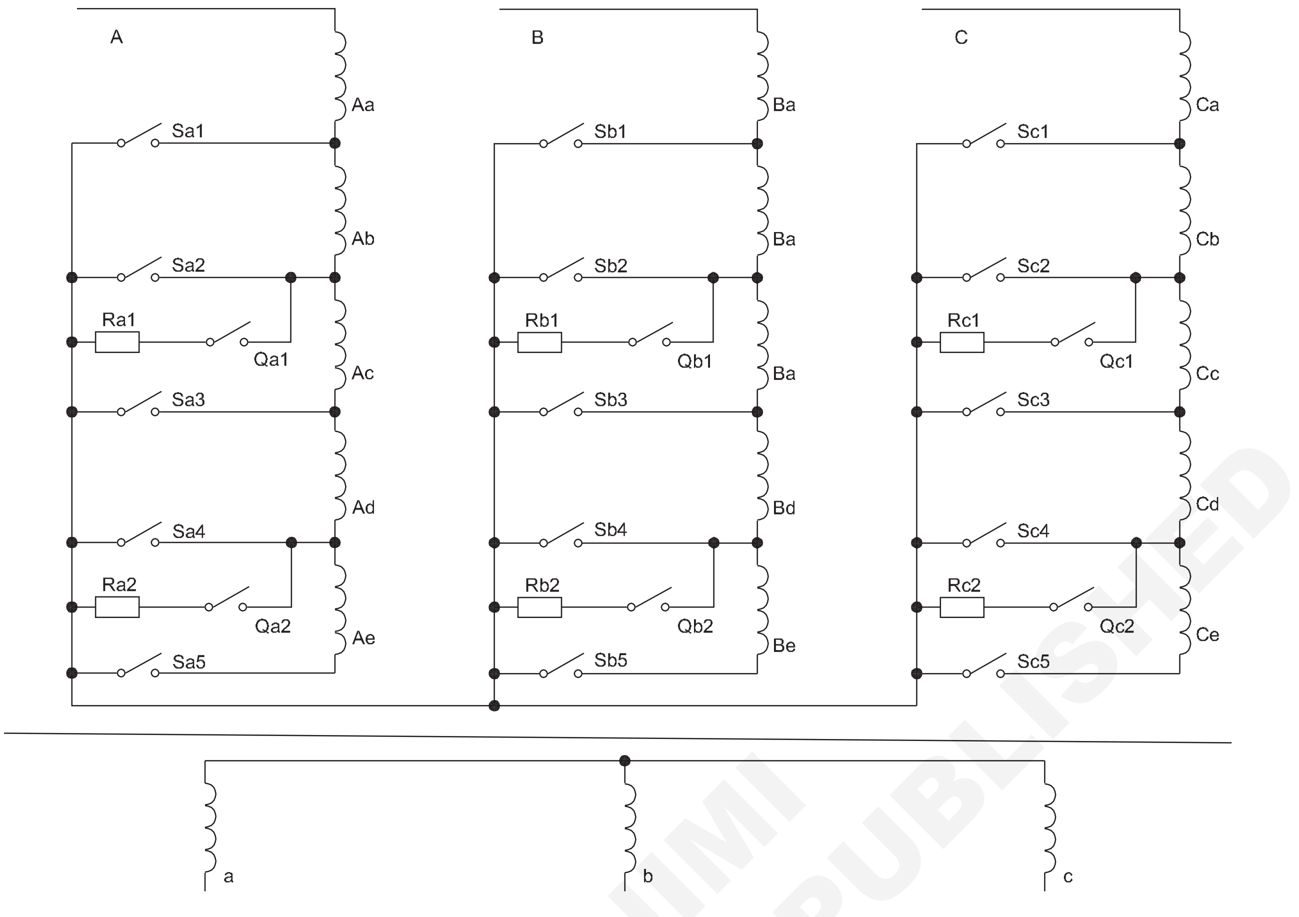
Panel Type	OLTC Control Panel
Panel Size (Indoor)	600W x 2150H x 600D mm 800W x 2350H x 850D mm (Standard)
Panel size can be changed depending on the environment in which it is applied.	
Method of installation	Self-standing (With Panel Base)
Door handle	Handle with key
Wiring mark (Hot mark)	Black letter and white background
Ground Bus	Copper (5tx30 mm)
Control Voltage	220/110V DC
Control cable	0.6/1.0kV, XHHW/SIS XLPE Insulated, PVC/Cu
Metal Thinkness	1.8mm~2.5mm
Painting Thickness	More than 80μm
Metal Type	EGI (Electro Galvanized Iron) Sheet
Degree of Protection	IP43
Colour	RAL7032, RAL7035, RAL7033Z
Cable Entry	Bottom
Installation Type	Indoor
Applied Standard	IEC 60529

Fig 2



The schematic diagram of OLTC

Taking phase A, for example, Aa to Ae are primary coils. Sa1 to Sa5 are vacuum interrupters controlled by PMA and connect with transformer taps respectively, as the current paths during the OLTC is working. Ra1 and Ra2 are transition resistors. Qa1 and Ra1 constitute a transition circuit, and Qa2, Ra2 make up another. When different coils and different vacuum interrupters are connected to the circuit, the secondaryvoltage will range from 0.95 to 1.05 times the value of rated voltage, accomplishing the voltage regulating task. In practical

application, it must be ensured that there is only one interrupter among Sa1 to Sa5 close at the same time, or it will cause a serious short-circuit accident.

A whole switching process contains following four steps.

1 Closing the vacuum interrupter of transition circuit in order to connect transition resistors to the main circuit.

2 Disconnecting the tap in which the current is flowing.

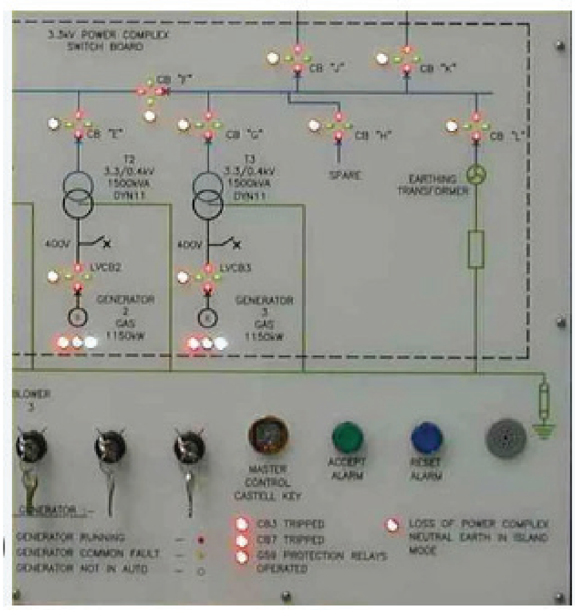
3 Connecting the tap in need to the main circuit.

4 Breaking the transition circuit being working.

Mimic Panel Wiring: (Fig 3 & 4)

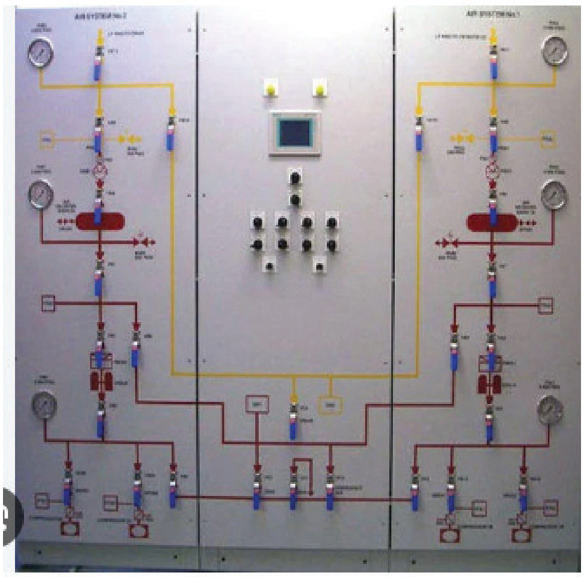
Suitably painted mimic diagram will be reproduced on the panels. Automatic semaphore indication for indicating OPEN and CLOSE position of circuit breakers, isolators and earth switches shall be suitably incorporated in the mimic diagram as per SketchI(enclosed). The operating coil of the semaphore relays shall be suitable for use on 24VD.C.

Fig 3



Following colour scheme shall be used for mimic representation on the panels against this specification:

Fig 4



Voltage panel	Colour	Shade No.(According to ISS- 1961)
33KV	Brilliant green	221
11KV	Signal	537

The mimic diagram provides the operator with an overview of the status of the power system. The dynamic data shown on the mimic is updated automatically with telemetered, calculated and manually updated data from the database.

The mimic diagram can also accommodate analog meters, digital displays, directional power flow indicators and chart recorders.

The mimic diagram control equipment, Mimic Controller 300, is used together with dedicated software, normally residing in the application servers, as the mimic driver unit.

Benefits

- The operator is able to scan the overall status of the complete power system at a glance.
- The mimic diagram provides a pictorial view of the power system network

Functions

The mimic diagram shows and overview comprising static and dynamic information. The static information shows devices such as transmission lines, bus-bars and transformers. The dynamic information shows the current state of the devices such as breakers, isolators and for example the direction of power flow on a line.

Indications in the power system are presented on the mimic diagram with LEDs. The value and the status of the indication determine the status of the LEDs. Indications can be presented with one or two LEDs.

Calculated indications are presented on the mimic diagram in the same way as indications. The value of a calculated indication is recalculated whenever any of the component indications change status. Summary Alarms are presented on the mimic diagram with single LED representing the alarm condition in a station or a subsystem. The status of the LED is updated when the status of the alarm summary indication changes.

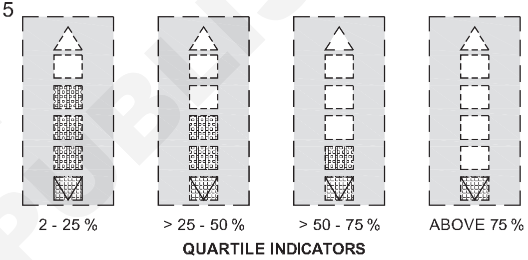
Measurements can be displayed on the mimic diagram using analogue meters, digital displays with fixed decimal point, chart recorders, or quartile indicators. Measurements are updated cyclically.

For analogue meters, digital displays and chart recorders, the values are recalculated to utilize the full-scale range of the instruments.

Functions continued

Measurements can also be presented by so called quartile indicators. These indicators are used to show loads in power lines and transformers as illustrated above. A quartile indicator com-prises a set of lamps that show the sign and percentage of the measurement relative to a predefined reference value. (Fig 5)

Fig 5



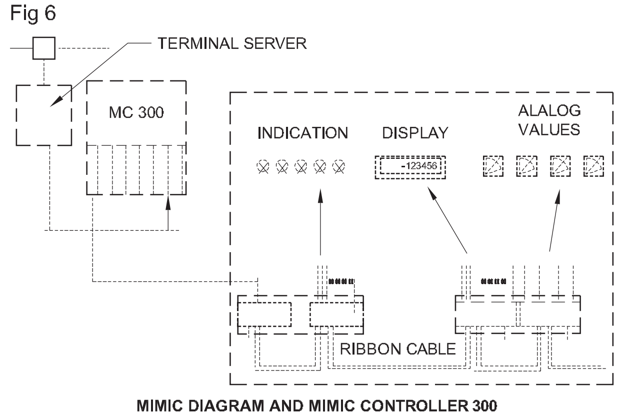
Technology

Different alternatives are available for the communication between the mimic diagram and the SPIDER system. The mimic diagram is normally connected to an application server. (Fig 6)

The communication to the mimic diagram is continuously supervised from the master system and any permanent interrupt is immediately reported.

The supervision function also generates events for errors detected locally and reported by the mimic driver. The mimic diagram can be divided into logical sections, where each section then can be tested separately from an operator's console.

Fig 6



Categories of fire and fire fighting equipments

Objectives: At the end of this lesson you shall be able to
- **describe categories of Fire, equipments for various categories of Fire**
- **describe Origin and preventive measures of electrical fire**
- **define Do's and Don'ts for electrical safety.**

Classification of Fires

Fires are classified in six groups A, B, C, D, F and electrical:

- **Class A fires –** are fires involving organic solids like paper, wood, etc
- **Class B fires –** are fires involving flammable liquids
- **Class C fires –** are fires involving flammable gasses
- **Class D fires –** are fires involving burning metals (e.g. aluminium swarf)
- **Class F fires –** are fires involving fats such as used in deep fat fryers
- **Electrical fires (the letter E is not used. Instead the symbol of an electric spark is displayed) –** are fires caused by electrical equipment.

Electrical Fires

Electrical fires are not given their own full class, as they can fall into any of the classifications. After all it is not the electricity burning but surrounding material that has been set alight by the electric current.

The first step when fighting a fire caused by electricity is to switch the equipment off. In addition, any water based extinguishers used on electrical equipment should be dielectrically tested and certified to ensure that you can extinguish the fire safely, even if the power supply is left on. It must be remembered that certain electrical apparatus maintain a lethal charge for some time after they have been switched off.

The Regulatory Reform (Fire Safety) Order 2005 requires premises to supply adequate fire safety equipment relevant to the risks of the premises. For example, a commercial kitchen or restaurant would be obligated to keep fire extinguishers suitable for Class F fires where an office would not. This is where a fire risk assessment becomes so important as it allows premises to identify which classes of fire they are most at risk of and, as a result, be able to install suitable fire safety measures. Some settings are at greater risk of certain types of fire than others and each class of fire requires a specific type of fire extinguisher to be present.

Different types of fire extinguisher

Each class of fire requires a certain type of fire extinguisher. You can quickly identify a suitable fire extinguisher by its label. The list below concisely highlights which classes of fire various fire extinguishers are suitable for.

Water fire extinguisher – Class A

Foam fire extinguisher – Class A and B

Powder fire extinguisher – Class A, B, C and electrical fires (under 1000v)

CO_2 fire extinguisher – Class B and electrical fires

L_2 fire extinguisher – Class D

Wet Chemical fire extinguisher – Class A and F

MultiCHEM fire extinguisher – Class A, B and F

Water Mist fire extinguisher – Class A and F

For more detailed information about fire extinguisher applications, **download our free fire extinguisher application guide.**

Class A (combustible materials)

Class A fires are generally caused by a naked flame or items of high temperatures coming into contact with combustible, carbonaceous materials.

Almost all premises are at risk of Class A fires due to the widespread use of such materials. This includes offices, schools, warehouses, hospitals, and anywhere that uses or contains paper, cardboard, wood, etc.

There are several types of fire extinguishers that can be used on Class A fires. These are: water, foam, MultiCHEM, powder and wet chemical, water mist.

Class B (flammable liquids)

Class B fires occur when flammable liquids, such as petrol and spirits, are exposed to a source of ignition. These types of liquid are flammable by design and extremely volatile, if not stored safely.

Many settings, including restaurants, bars, garages, construction sites, laboratories, hospitals and petrol forecourts, are at particular risk of Class B fires and must keep suitable fire extinguishers onsite and mandatory fire safety signage to highlight the proper safety procedures of everyone onsite.

Fire extinguishers suitable for Class B fires are: MultiCHEM, foam, powder and CO2.

Class C (flammable gases)

Fires involving flammable gases, such as propane and butane, are known as Class C. Flammable gases must be stored correctly in sealed containers and only operated by a competent person.

Manufacturing and industrial warehouses, chemical plants or anywhere that stores large quantities of flammable gases are at particular risk of Class C fires.

Class C fires must be tackled using a powder fire extinguisher.

Class D (burning metals)

Class D fires occur when combustible metals, such as magnesium, lithium and sodium, ignite and are more prevalent in laboratories, warehouses and metal fabricators.

Only specialised fire extinguishers are suitable for use on Class D fires, such as the L_2 fire extinguisher.

Electrical fires

Electrical, or Class E, fires are a risk to all premises that use electricity.

They occur when live electrical equipment is involved in a fire and must not be tackled by a liquid-based fire extinguisher. This is because water is a conductor and will spread the current across a greater area if used, potentially endangering the user of the fire extinguisher.

As a result, only powder (for electrical currents under 1000v) and CO_2 fire extinguishers are suitable here, as they do not rely on a liquid agent.

Class F (cooking oils and fats)

Class F fires pose a risk to restaurants and kitchens. Fires from cooking oils and fats can be made significantly worse by using a liquid-based agent to extinguish it.

As a result, specialised MultiCHEM, water mist and wet chemical fire extinguishers are essential in settings that use cooking oils and fats.

Extinguisher is used for each class of fire

Type (Fire / Extinguisher)	CLASS A	CLASS B	CLASS C	CLASS D	Electrical	CLASS F	Comments
	Combustible materials (e.g. paper & wood)	Flammable liquids (e.g. paint & petrol)	Flammable gases (e.g. butane and methane)	Flammable metals (e.g. lithium & potassium)	Electrical equipment (e.g. computers & generators)	Deep fat fryers (e.g. chip pans)	
Water	✓	✗	✗	✗	✗	✗	Do not use on liquid or electric fires
Foam	✓	✓	✗	✗	✗	✗	Not suited to domestic use
Dry Powder	✓	✓	✓	✓	✓	✗	Can be used safely up to 1000 volts
CO2	✗	✓	✗	✗	✓	✗	Safe on both high and low voltage
Wet Chemical	✓	✗	✗	✗	✗	✓	Use on extremely high temperatures

The following factors should also be considered when siting fire extinguishers:

- Extinguishers should normally be sited on escape routes on all floors at what is called 'fire points'.
- They should be fixed in a location where the extinguisher can be reached quickly. The best place is near a door leading to a place of safety or near a specific fire risk.

- They should be fixed where they can be easily seen. Fixing them inside cupboards or behind doors will waste valuable time if a fire breaks out.
- Do not place them over cookers or heaters or in places of extreme temperatures, hot or cold.
- Extinguishers should be fixed at an elevated height, so that the carrying handle is 1m from the floor for heavier units (heavier than 4kg) and 1.5m for smaller units.
- Extinguishers should be within reasonable distance from any fire risk:

1 Class A: 30m

2 Class B: 10m

3 Class E: 30m

4 Class D: case-by-case basis, by expert advice

5 Class F: 10m

- If you have to travel through doorways, the maximum travel distances need to be reduced.
- The method of operation should be similar for all extinguishers, where possible.
- The occupiers should be capable of handling all the types and sizes recommended.
- Where different types of extinguishers for different risk types are sited together they must be properly labelled to prevent confusion.
- Extinguishers should be fitted with suitable jet or spray nozzles or flexible hoses to suit the risk involved.

Types of Fire Fighting Equipment

Depending on the type of fire and amount of risk, these equipment are divided into two categories:

1 Portable

2 Fixed

Portable fire fighting equipment

These types of fire fighting equipment are used to deal with small fires that are detected as soon as the fire ignites. It serves the purpose of protection and prevention.

1 Fire Blankets

Also known as fire-retardant blankets, these are used to protect human bodies from burning. Small fires in the house, garage, boat, caravan, kitchen, etc. can be smothered by fire blankets. Due to their simplicity, they can be used by anyone without any special training and can be carried by the user to different places.

2 Fire Extinguisher

As its name suggests, it is used to extinguish the fire in case of an emergency. Almost every commercial and non-commercial buildings have a fire extinguisher installed in it. Being portable, it is used to deal with small fires rather than fires that are out of control and would require the help of a fire brigade. To deal with different types of fire, extinguishers come with different types of extinguishing agents that are filled inside the cylinder.

3 Fire Bucket

The simplest equipment that can be used by anyone to deal with small fires is fire buckets. The user can fill it with water or fire smothering powders and dump it on the fire. It is usually red in color and has FIRE written on it.

4 Flamezorb

It is a type of fire fighting powder used in areas prone to fire like a garage. Being a non-toxic chemical, it smothers the fire very easily. These powders come in different types of packaging as per the need of the consumers.

Fixed fire fighting equipment

These types of fire fighting equipment are installed at places of higher risks or areas that are prone to catch fire easily. They are not movable and work only for the area where they are installed, for example, engine rooms.

1 Fire Hydrants

They are used to provide a large amount of water supply in emergencies. The firefighters plug the hose or pipe into the hydrant and open the valve to deal with the fire. Fire hydrants are connection points by which water can be thrown directly onto the fire or to fill fire engines. The pressure of the water flow helps firefighters to smother out of control fires. Because of high water pressure, these hydrants are used only by trained firefighters to avoid injuries.

2 Automatic Sprinkler System

Often regarded as the most reliable equipment for fire fighting, the sprinkler system has evolved highly. It consists of a water supply via a pipe that is connected to a sprinkler head. Whenever a fire is detected, the sprinkler starts functioning by sprinkling high-pressure water on the fire.

With technological advancements, these fire fighting equipment can detect heat and sprinkle water in a room before it turns into fire. This has also increased its demand not only in factories and commercial buildings but also in residential societies. Sprinkler systems are mainly used to deal with uncontrollable fires.

3 Water Mist System

A water mist fire fighting system makes the use of nozzles and very fine water mists that create a foggy effect. The purpose of this fire fighting solution is to deal with two fire-causing elements i.e. heat and oxygen. Fire can be suppressed and controlled before it grows by the fine mist. It cools the flames and evaporates the gas. Due to their high efficiency in dealing with fire these systems are used in data centers, museums, and theaters. Consumers also prefer using it because it saves water.

4 Hose Reel System

To combat fires the hose reel system is connected permanently to a water supply. It consists of a nozzle at the end of the hose, an on/off valve and a hose guide.

The main usage of this type of fire fighting equipment is to deal with fires that can be smothered by a pressurized water supply. The nozzle, in the end, is used to control the flow and direction of the water.

Electrical Fires

Class E Fire Extinguishers and Electrical Fires

Knowing fire classifications is an essential part of any fire safety plan, particularly in commercial settings where electrical, chemical, or flammable liquid fires can occur. Different kinds of fires are fought with different approaches and require specific types of extinguishers. Class E fires, sometimes referred to as electrical fires, require their own Class E fire extinguishers. There are also certain precautions that must be taken when confronting a Class E fire. Understanding the distinct qualities of Class E fires and how to prevent and extinguish them is vital for keeping your commercial and residential buildings safe.

A Class E fire is an energized electrical fire. "Energized" in this case means that it is fed by a power source. Class E fires may begin from a short circuit, faulty wiring, power cord damage, overcharged devices, or overloaded electrical outlets. Any place where electrical equipment is used or electrical wiring is present is a potential site for a Class E fire.

When a fire occurs in an electrical unit such as a kitchen appliance, power panel, computer, or other media device, the electricity powering the equipment acts as a constant source of spark or ignition. Water and water-based foams are not capable of putting out Class E fires because they cannot counteract the constant, electrical ignition source. Because water conducts electrical currents, using water on a Class E fire can result in a spread of the electricity and therefore the fire's source of ignition.

"Class E" is a term that distinguishes a fire from Class A and Class B fires. Class A is a category for fires consuming a source like fire or wood that can be extinguished with water, and Class B fires are fueled by flammable liquids like gasoline.

How to Fight a Class E Fire

A Class E fire can become a class A fire if the material in flames is cut off from the main power source (i.e. a computer on fire is unplugged from the electrical outlet). However, this is not always safe or possible and sometimes it's unclear if an appliance is completely cut off from its source of power. If water is used on a Class E fire that continues to be fueled by an electric power source, dangerous and even fatal results can occur. The person fighting the fire may be electrocuted if a water-based extinguisher is utilized in an attempt to control a Class E fire.

This is why having a Class E fire extinguisher and knowing how to use it properly is so important for comprehensive fire safety. Class E fire extinguishers are the only type suitable for smothering the flames of a fire that is still connected to an electrical source. Once it becomes clear the burning object is completely disconnected from any electrical sources, a Class E extinguisher may be switched out for an extinguisher appropriate for fighting Class A fires. However, often times a dry chemical fire extinguisher can be used on Class A, B, and C fires.

Fire Extinguishers For Class E Fires

A Class E fire requires an agent that can break apart the elements that feed a fire: oxygen, heat, and fuel. Carbon dioxide (CO_2) extinguishers smother a fire by eliminating the oxygen. They also suppress the fire's heat because their discharge is very cold. Similarly, dry chemical extinguishers work to separate the elements of a fire. The fire dies when the oxygen and fuel can no longer interact due to the chemicals introduced by a dry chemical extinguisher. These Class E fire extinguishers may contain monoammonium phosphate, potassium bicarbonate, or potassium chloride, all of which are suitable for putting out Class E fires.

Fire extinguishers of any type can only work to extinguish a fire when used properly. It is important to review fire extinguisher instructions regularly so you are familiar with its proper use should a fire ever occur. Additionally, make sure to test your fire extinguisher periodically to ensure it's in proper working condition.

Preventing Class E Fires

The best fire-fighting strategy is prevention. For Class E fires, make sure all your wiring, appliances, and electrical components are up to code and in good working condition at all times. Avoid overloading outlets and improperly charging electrical devices. Still, fires can happen even in the best maintained environments.

Make sure you have an up-to-date fire extinguisher designed specifically for putting out Class E fires near any place where an electrical fire may occur. Know your fire safety equipment and how to use it so you can be fully prepared in the event of a Class E fire. As always, consult with local fire-fighting authorities on the best safety procedures for your building.

Fire Protection.

The layout of the plant and the design of the building play a major part in reducing the spread of fire and the effect of explosions.

For example, equipment and buildings should be arranged to have vents which rupture rather than allowing an explosion to damage the main fabric. Site supervisors should ensure that these vents are never obstructed. In the prevention of fire, cleanliness and tidiness are very important, as is the careful maintenance of tools.

Most fires are caused either by carelessness or faulty equipment.

The choice of fire-fighting equipment is dependent on its suitability for electrical fires but also on cost and the importance of the electrical supplies at the point in question. Portable manual types are as follows: halon gas of various kinds, carbon dioxide chemical foam and powder.

Fixed systems use water sprinklers, carbon dioxide and halon gas. Both halon gas and carbon dioxide can suffocate personnel trapped in the discharge area.

Strict precautions must therefore be taken to lock-off the equipment when staff are present. There is also the used of sand, blankets and fire hoses. Fire doors are a very important means of limiting the spread of fire, and ventilating systems should also be provided with automatic shut-down if not with automatic dampers in the event of fire. Fire drill is also important and should not be neglected on a building site.

Cabling may also be a cause of serious fires with risks of extensive damage to the installation and danger to personnel. Low smoke and fume (LSF) cables are now available in a number of forms, most of which will reduce the flammability as well as causing less poisonous gas to be released when they are heated.

The DC supplies (UPS batteries) are a particularly important and vulnerable part of any installation. They are generally derived from stationary batteries which give off flammable and toxic gases.

Batteries should be in a separate room with an acid-resistant floor, special lighting fittings, a suitable sink and adequate water supplies. It is wise to have an acid-resistant drainage system. The room must be properly ventilated but sunlight must not be allowed to shine directly on to the cells.

Fire Safety Considerations in Substations

The major fire risks and detection difficulties within Substations arise as a result of the following:

- Electrical arcing and the build-up of static electrical charge within equipment.
- Overheating of electrical control equipment, switchgear and cabling.
- Once initiated, a fire may rapidly spread due to the presence of large amounts of combustible material in the form of hydrocarbons contained in cabling and insulation.
- The environment within uninterrupted power supply areas (i.e. battery room) may become explosive from the build up of high concentrations of hydrogen gas.
- Substations are usually unmanned, thus, early intervention by staff may not be possible in the event of a fire.
- High air movement, caused by air-conditioning dilutes and disperses the smoke.
- Much of the mission critical equipment is housed within equipment cabinets and incabinet fires may take some time to be detected by ceiling mounted detection devices, especially since in-cabinet fires will usually have prolonged incipient (smouldering) stages.
- Underground cable trenches linking the main areas of the substation are considered hostile environments. High levels of background pollution present in these areas will affect the reliable operation of conventional detectors as well as being a source of false (nuisance) alarms.

Design for Effective Fire Protection

Areas		Essential	Recommended
Switch/Relay Room	Ceiling		√
	In/On Cabinet	√	
Control Room	Ceiling	√	
	In/On Cabinet	√	
	Floor Void	√	
	Return air vent/Duct		√
Battery Room	Ceiling	√	
	Return air vent/Duct		√
Cable Trench		√	

The Switch Room

The Switch Room accommodates high density of electronic equipment housed in cabinets and automated switch-gear. In-cabinet equipment maintain the primary functions of the facility and form the switching interface between the Control Room and the field equipment.

The area may also accommodate a significant amount of metering and logging equipment. Due to the high volume of critical electronic equipment, it is essential that a fire event be detected before the operation of the plant is compromised.

Control Room

The control room is the main command centre of the substation. The entire operation of the site is monitored and controlled from this central location.

A control room may range from a small, seldom manned, non-ventilated room to a large, air conditioned area containing numerous staff members and electronic equipment (PCs, control panels/consoles, electrical and electronic switching devices, underfloor cabling, etc.).

Battery Room

The Battery Room houses lead acid or nickel cadmium batteries for uninterrupted power supply (UPS) to the substation.

Battery rooms may consist of a slightly corrosive atmosphere (sulphuric acid). It is recommended that a polymeric sampling pipe network is used to eliminate the potential for corrosion. In addition there may be a need to incorporate a 'Chemical Filter' – a special filter designed to absorb corrosive gaseous contaminants.

Cable Trench

A Cable Trench is located under the Switch/Relay Room, Control Room and Battery Room to house the communication, control and power cables between the substation's operational areas as well as transport power to external high voltage switching towers.

The most efficient way to protect a Cable Trench is to install sampling pipe network at the top 10% of the trench's height.