SUBSTATION EQUIPMENTS

INDEX

INTRODUCTION:

A substation is an assemblage of electrical apparatus. It receives electrical power from generating station via incoming transmission lines and delivers electrical power via the outgoing transmission lines. Substations are integral parts of a power system and form important links between the generating stations, transmission systems, distribution system and the load points.

In every electrical substation, there are various indoor and outdoor equipments. Each equipment has certain functional requirements. The choice of equipment depends on technical considerations, rated voltage, rated MVA, and the type of substation.

Function of substation equipment:

Outdoor Equipments

The following are the various EHV outdoor equipments and their functions are here under.

Power Transformer: It is used to step-up or step-down a.c voltages and to transfer electrical power from one voltage level to another. The choice of KVA rating of transformers in a particular installation depends upon the KVA load.

Shunt Reactor: It is used for long EHV transmission lines to control voltage during low-load period. To compensate shunt capacitance of transmission line during low load periods.

Circuit-breaker: A device capable of making and breaking an electrical circuit under normal and abnormal conditions such as short circuits. It can operate automatically/ manually and clear fault currents safely and quickly.

Isolator (Disconnecting switch): A switching device which can be opened or closed only under no current conditions. It provides isolation of a circuit for the purpose of maintenance.

Earthing switch: It is a switch which connects a conductor to the earth so as to discharge the charges on the conductor to earth. Earthing switches are generally installed on frames of the isolators.

Current transformer (CT): The Current ratio of current transformer is generally high and volt ampere capacity is relatively low as compared with that of the power transformers. It step downs the current for measurement, protection and control.

Voltage transformer (VT): The volt ampere capacity is relatively low and the voltage ratio is high. The protective relays are connected in secondary circuits of CTs and VTs. It step downs the voltage for measurement, protection and control.

Lightning arrester (surge arrester): It discharges the over-voltage surges to earth and protect the equipment insulation from switching surges and lightning surges. The equipment connected between the conductor and ground, to discharge the excess voltages to earth.

Capacitor Voltage Transformers (CVT): Capacitor potential transformer, in which the primary voltage is applied to a series capacitor group. The voltage across one of the capacitor is taken to auxiliary voltage transformer. The secondary of auxiliary voltage transformer is taken for measurement of protection.

Shunt Capacitor: It is used for compensating reactive power of lagging power factor. To improve power factor and voltage control during heavy lagging power factor loads.

Series Capacitor: It is used for some long EHV a.c lines to improve power transferability.

Carrier Equipment: It consists of line trap unit, coupling capacitor, electronic equipment and it is used for protection and communication signaling, voice communication, protection signaling, telex channel, control and monitoring signals.

Marshalling Kiosks: It is used to mount monitoring instruments, control equipment and to provide access to various transducers. Control and protective cables are laid between Marshalling Kiosks located in switchyard and corresponding indoor control panels.

Insulators: - It provides mechanical support to the conductor and subject to the normal operating voltage and transient over voltages. It should have sufficient mechanical strength to withstand the maximum wind-loading, ice-loading, dead load, etc., and should not flash over under any conditions of humidity, dirt, salt contaminates, etc. The materials used in the manufacturing of insulators are porcelain, glass and Epoxy type.

Indoor Equipments:

The following are the various indoor equipments and their functions are here under. These are installed inside a separate building near the switchyard.

Protective Relay: An electrical relay is a device designed to produce sudden, pre-determined changes in one or more electrical output circuits, when certain conditions are fulfilled in the electrical input circuits controlling the device.” The function of any faulty section of the power system from service.

Medium and low voltage A.C. Switchgear (In-door): It is used to provide a.c. power to auxiliaries, station lightning system, etc. at respective voltage levels.

Control and Protection Panels: Control and protection panels have a functionally important role. They perform the following functions:

a. They provide facility for centralized control.
b. They provide a point for centralized supervision at which all vital information relating to controlled equipment is received and assimilated.
c. They provide for necessary protection and isolation facility of all power circuits like generators, feeders, transformers, bus-coupler, reactors, etc. The control and protection panels provide alarm and trip commands under abnormal conditions and hence function like a watchdog for the system.

Metering Panels: Electrical parameters like current, voltage, active power, reactive power, frequency, etc. are monitored for the convenience of the operator. For transmission lines, energy is monitored at high accuracy of the order of class 0.2 for the purpose of tariff metering. Load profile data is also recorded for the purpose of analysis of energy flowing through the line of protective relay is to affect disconnection .

1. POWER TRANSFORMER

Specifications to be referred

Sl. No.	Standards	Topic
1.	IS-335-1972	Specification for New insulating oil for transformer and switch gear
2.	IS-2026 (Part-1)-1977	Specification for power transformers-General
3.	IS-2026 (part-2)-1977	Specification for power transformers-Temperature rise
4.	IS-2026 (part-3)-1977	Specification for power transformers-Insulation levels and dielectric tests
5.	IS-2026 (part-4)-1977	Specification for power transformers-Terminal markings & Tapping connections
6.	IS-2026 (part-5)-1977	Specification for power transformers- Bushings
7.	IEC:60-1973	High voltage test techniques
8.	IEC:71-1976 Part 1 Part 2	Insulation coordination Terms, definitions, principles and rules. Application guide.
9.	IS-3639	Fitting & accessories for Transformers

Principles of Power Transformer:

Transformers are Static piece of Electrical equipment Transferring Power from one winding at one voltage to another winding at another voltage. The Transformer is one of the most efficient machines with 95% efficiency, generally in lower capacities while even 99% efficiency is also achievable in higher ranges. The fundamental principle on which the Transformer works is the Electromagnetic Induction (self and mutual). Physically, a winding called Secondary is wound around a Magnetic core and over that another winding called Primary is wound round. Application of an Alternating voltage V1 to the primary winding results in flow of a current and production of a self induced emf (or

Counter emf) whose direction is in opposition to the one producing it. The flow of current in the Primary produces a magnetic flux which links the secondary winding and results in the production of a secondary emf called mutually induced emf. This emf is in phase opposition to the primary applied voltage V1 and its magnitude depends upon the rate of change of flux and the secondary number of turns. It can be seen that the more the primary and secondary circuits are linked together, the more direct is the exchange of energy between them. Thus when the Transformer is on No Load, the current drawn by the primary is expended to meet the Iron Losses in the core (Hysterisis and Eddy Current Losses). In fact, the No Load Current which is the resultant of the active current and the magnetizing current actually lags behind the applied Voltage at an angle less than 90 degrees. It can be seen that $E1 = 4.44 * f * N1 * Bmax * A$ and $E2 = 4.44 * f * N2 * Bmax * A$ from which it can be derived that $V2 / V1 = N2 / N1 = E2 / E1 = K$.

If $K > 1$, the Transformer is a Step up Transformer and if $K < 1$ it is a Step down Transformer. It can also be shown when a Load is connected to the Transformer secondary, that on account of the Load, a separate loss of energy occurs and that the No Load Loss is independent of the Load Loss (it is called the Fixed Loss) where as the Load Loss is a Variable Loss. The ideal condition for maximum efficiency of a Transformer is worked out to be when the No Load Losses equal the Load Losses

Types of transformers:

The Transformers are largely divided into Power and Distribution Transformers and Step up or step down Transformers. Depending upon utility, the following other types of classification is also in use:

(1) Generator Transformer

(2) Unit Auxiliary Transformer

(3) Station Transformer

(4) Transmission Sub-Station Transformers

(5) Auto Transformers

(6) HVDC Converter Transformer

(7) Arc Furnace Transformers

(8) Traction Transformers

(9) Earthing Transformer or the Zig-Zag

(10) Generator Neutral earthing Transformer

(11) Series and Shunt Reactors (strictly not a transformer)

Constructional features of a transformer:

About 70% of the material used is (1) Core (2) Winding (3) Insulating Oil

Others are : (1) Structural Steel (2) Electrical grade paper such as kraft/crepe paper, (3) Press Board (4) Wood and laminated wood (5) Paper covered conductor / PVC cable (6) Insulating tapes such as cotton/Glass woven/ Polyester resin (7) Gaskets such as Neoprene/ Nitrile Rubber/Synthetic Rubber (8) Low Loss CRGO (H1B-0.23, H1B-0.27, Laser Grade ZDMH-0.23, Amorphous Metal core (9) Copper (high conductivity, sheet, strip, foil, rod, tube, tinned, flexible, braided, flat, and insulated conductors (10) Aluminum conductors-insulated, plates, alloys etc.

Core:

Core provides a high permeability closed path for Flux. It supports the winding. It consists of laminated sheet steel (CRGO or Amorphous).The vertical member of the core is called the Limb /Leg and the Horizontal member of the core is called the Yoke. Core plates or laminations are very thin and coated with insulating varnish. There are two types of construction of the core viz; Core Type and Shell type. Generally in India, Core type of construction with Two/Three/Five limbed cores is used. Generally five limbed cores are used where the dimensions of the Transformer is to be limited due to Transportation difficulties. In three limbed core the cross section of the Limb and the Yoke are the same where as in five Limbed cores, the cross section of the Yoke and the Flux return path Limbs are very less (58% and 45% of the principal Limb). Shell type of construction of the core is widely used in USA. In the construction of the core the laminations of the Limb and Yoke are interleaved. The joint where these laminations meet could be Butt or Mitred. In CRGO, the Mitered Joint is preferred as it reduces the Reluctance of the Flux path and reduces the No Load Losses and the No Load current (by about 12% & 25% respectively).The Limb and the Yoke are made of a number of Laminations in Steps. Each step comprises of some number of laminations of equal width. The width of the central strip is Maximum and that at the circumference is Minimum. The cross section of the Yoke and the Limb are nearly circular. Mitred joint could be at 35/45/55 degrees but the 45 one reduces wastage. The assembled core has to be clamped tightly not only to provide a rigid mechanical structure but also required magnetic characteristic. Top and Bottom Yokes are clamped by steel sections using Yoke Studs. These studs do not pass through the core but held between steel sections. Of late Fiber Glass Band tapes are wound round the Limbs tightly up to the desired tension and heat treated. These laminations, due to elongation and contraction lead to magnetostriction, generally called Humming which can be reduced by using higher silicon content in steel but this makes the laminations become very brittle.

Windings:

Types of Windings:

(1) Distributed: Used for HV windings of small Distribution Transformers where the current does not exceed 20 amps using circular cross section conductor.

(2) Spiral: Used up to 33 kV for low currents using strip conductor. Wound closely on Bakelite or press board cylinders generally without cooling ducts. However, multi layer windings are provided with cooling ducts between layers. No Transposition is necessary.

(3) Helical: Used for Low Voltage and high currents .The turns comprising of a number of conductors are wound axially. Could be single, double or multi layer winding. Since each conductor is not of the same length, does not embrace the same flux and of different impedances, and hence circulating currents, the winding is transposed.

(4) Continuous Disc: Used for 33kv and 132 kv for medium currents. The coil comprises of a number of sections axially. Cooling ducts are provided between each section.

(5) Interleaved Disc: used for voltages above 145 kV . Interleaving enables the winding withstand higher impulse voltages.

(6) Shielded Layer: Used up to 132 kV in star connected windings with graded insulation. Comprises of a number of concentric spiral coils arranged in layers grading the layers. The longest at the Neutral and the shortest at the Line Terminal. The layers are separated by cooling ducts. This type of construction ensures uniform distributed voltages.

Distribution transformers:

Distribution Transformers are normally Three Phase. These are generally rated at 11kv on the HV side and 415/433volts on the LV side. Some Distribution Transformers are rated at 33kv on HV side and 415/433 volts on LV side. The normal Ratings of the Distribution Transformers are: 25, 50, 75,100, 250,315,500,630 & 1000kva.The Standard Frequency of operation in India is 50Hz.

The Types of Distribution Transformers are:

(1) Conventional Non CSP

(2) Conventional CSP

(3) Sealed Non CSP

(4) Sealed CSP

(5) Hermetically sealed.

All the above types of Transformers are Oil Filled. The Core could be made of CRGO or Amorphous. Amorphous core provides low No Load Losses, No Load Current, Low Eddy Current Losses; the Core can be very thin, suitable up to Flux Density of 1.58T against 1.92T of CRGO.The Insulation materials used are Press Board, Kraft Paper, and Perma wood and Mineral Oil. The Winding Material is Copper, or Aluminum.

The cooling is generally natural. The cooling is done by one or more layers of Tubes, or Pressed Steel Radiators, or Corrugated Fins. The Transformers are suitable for Structural Mounting, Plinth Mounting (or Pad Mounted).

High voltage single phase distribution transformers:

These are generally connected between Phases on HV side and between phase and Neutral on LV side. These have the advantage of: Reducing Isq.R Loss, and Lines, prevent Failures of Transformers, provide quality supply, and prevent unauthorized Energy usage, Low Maintenance, and Easy to mount. Normally Stacked, CORE type construction with Mitred joint is used. Shell type core can also be used. The Core can be AMORPHOUS Metal or CRGO.

The conductor of the winding could be DPC or SE Aluminum or Copper. The transformer can have a LT MCCB and a HV Fuse Link and LA on HV side for

Protection. The Transformer Tank could be Round, Elliptical or Rectangular but generally round. The Transformer is suitable for Pole Mounting or Plinth Mounting.

After Extensive cleaning, the Tank is sprayed with Powder Coated Paint which is extremely Hard, Scratch Free and Glossy. These Transformers when used for Agricultural Pump sets in Rural areas can ensure Quality, Trouble Free, Reliable, Dedicated Power supply to the consumer and protect him from the Adverse Effects of unauthorized Tapping of supply.

Dry Type Resin Cast Transformers:

These are Transformers, in which the insulating medium is Gas or Dry compound without insulating oil. These can be single phase or three phase, ventilated or non-ventilated, sealed with primary voltage greater than 600 volts. These have special applications. These are used in place of Transformers filled with Mineral Oil /PCB/ SF6 in:

(1) Chemical / Cement Industries
(2) Hospitals
(3) Hydro/Thermal/Nuclear Power Stations
(4) Multi storied Buildings
(5) Indoor Installations

The Advantages are:

(1) Fire Resistant
(2) Maintenance Free
(3) High Short Circuit With Stand Capability
(4) Excellent Insulation against Moisture Absorption.

The Transformer has the following Accessories:

(1) Off Circuit Tap Changing links
(2) Winding Temperature Scanners
(3) Neutral CT & Earthing
(4) Inter Locks for Doors
(5) Cable Box & Bus Duct
(6) Limit Switches for Doors.

There are three types of Transformers:

(1) Cast Resin

(2) Vacuum Resin Impregnated

(3) Vacuum Varnish impregnated

Amorphous metal transformers:

The use of Amorphous Metal Core instead of Silicone sheet steel reduces the No Load Losses by about 80%. A proprietary molten alloy of Iron, Boron, and Silicone is cooled rapidly at a rate of one million degrees centigrade per second such that Crystals are not formed. The Metal can be drawn very thin (0.025mm) and so exhibits very low eddy current loss. It is non-crystalline and it has a random molecular structure.

When AC Magnetic field is applied, the random atomic structure causes less friction and hence lesser Hysterisis Loss. However, it has a Low Space Factor of 80% as compared to 96% in respect of CRGO. Space Factor is defined as the Ratio of Core Cross sectional Area to the Area available for the Core, which means the weight, and cost (by about 30%) is more. The high initial cost however is compensated by the Lower No Load Losses which is advantageous when the Total Owning Cost over the life period of the Transformer is considered. This advantage helps in efficient use of available generation, better Demand side Management, Low Noise level, Lesser Temperature rise, reduction in Emissions at generating stations, etc.

Completely Self Protected (CSP) Transformers:

These transformers have primary protective fuse mounted inside the HV Bushings. A circuit breaker is provided immersed in the oil in the Tank for LV protection. This LT Circuit breaker trips for over loads and alerts the operator against over loads. The loads can be reduced and the CB taken back into service. However, it allows the CB to be closed in emergency by means of the external control for emergency restoration. It limits the temperature to 110 degrees Centigrade.

An external indication gives a warning of over load. A surge arrestor provided on the HV Bushings protects the Transformer against external surges. The Top cover of the Transformer Tank is welded. This transformer requires less maintenance and does not allow outsiders to meddle with.

Power Transformers:

The Basic Material used in the construction of the Transformer are:

(1) Structural Steel

(2) Silicon Steel

(3) Hard Drawn copper/Aluminum conductor

(4) Solid Insulation

(5) Insulating Oil

The Limits of Temperature rise as per IS 2026 (Part2):

(1) Maximum Ambient Temperature: --- 50^0C

(2) Maximum Daily Average Air Temperature: --- 40^0C

(3) Max. Yearly weighted average Air Temp: --- 32^0C

(4) Minimum Ambient Air Temperature: --- 05^0C

For Water Cooled Transformers, the Maximum Temperature of cooling water should not be more than 30C and the average daily temperature should not be more than 25^0C As long as the Hot Spot Temperature based on Maximum yearly weighted average temperature is within 98^0C, the Transformer can have an expected life of 25 years. The Normal Vector Groups are: Yd1, Yd11, Yyo, Dy11, Dd0, Dy1, and Dzo. Depending on the application, the following other vector groups are also being used: Dz10,Yz11,Dd4,Dz4,Yz1,Dy5,Dd2,Dz2,Yd5,Yz5,Yd7,Dz0,Dd6,Dd8,Dz6,Dd10,Dy7,Yy6,Yz7.

Accessories & Fittings:

The Transformers have the following Accessories & Fittings:

(1) The HV & LV Bushings

(2) Neutral and Body Earthing Terminals

(3) Tank and its Lifting Lugs

(4) Top Cover with its Lifting Lugs

(5) Drain, Sampling and Filling Valves.

(6) Oil Level Gauge

(7) Explosion Vent Diaphragm

(8) Silica Gel Breather

(9) Off Circuit Tap Changer

(10) Conservator Tank

(11) Thermometer Pocket

(12) Base Channels for Mounting.

The Vector Group of the Three Phase Transformer is generally Dy11.

Bushing: A structure carrying one or several conductors through a partition such as a wall or tank, and insulating it or them there from, incorporating the means of attachment (flange or other fixing device) to the partition. The conductor may form an integral part of the bushing or be drawn through.

3.7.1.1 Liquid Filled Bushing — A bushing in which the space between the inside surface of the insulating envelope and the solid major insulation is filled with oil or another insulating liquid.

3.7.1.2 Liquid Insulated Bushing — A bushing in which the major insulation consists of oil or another insulating liquid.

NOTE: The definitions in **3.7.1.1** and **3.7.1.2** also include bushings which are intended to form an integral part of liquid insulated equipment, the liquid of the equipment being in communication with that of the bushing.

3.7.1.3 Gas Filled Bushing — A bushing in which the space between the inside surface of the insulating envelope and the solid major insulation is filled with gas (other than ambient air) at atmospheric or higher pressure.

NOTE: The definition includes bushings which are intended to form an integral part of gas insulated equipment, the gas of the equipment being in communication with that of the bushing.

3.7.1.4 Gas Insulated Bushing — A bushing in which the major insulation consists of gas (other than ambient air) at atmospheric or higher pressure.

NOTE:

1. This definition includes bushings which are intended to form an integral part of gas insulated equipment, the gas of the equipment being in communication with that of the bushing.

2. A bushing which contains solid insulating materials other than the envelope containing the gas (for example, support for conducting layers or insulating cylinder) is a composite bushing.

3.7.1.5 Oil Impregnated Paper Bushing — A bushing in which the major insulation consists of a core wound from untreated paper and subsequently impregnated with an insulating liquid, generally the transformer oil. The core is contained in an insulating envelope; the space between the core and the insulating envelope being filled with the same insulating liquid as that used for impregnation.

3.7.1.6 Resin Bonded Paper Bushing — A bushing in which the major insulation consists of a core wound from resin coated paper. During the winding process, each paper layer is bonded to the previous layer by its resin coating and the bonding is achieved by curing the resin.

NOTE: A resin bonded paper bushing may be provided with an insulating envelope, in which case the intervening space may be filled with an insulating liquid or another Insulating medium.

3.7.1.7 Resin Impregnated Paper Bushing — A bushing in which the major insulation consists of a core wound from untreated paper and subsequently impregnated with a curable resin.

NOTE: A resin impregnated paper bushing may be provided with an insulating Envelope, in which case the intervening space may be filled with an insulating liquid or another insulating medium.

3.7.1.8 Ceramic, Glass or Analogous Inorganic Material Bushing —A bushing in which the major insulation consists of a ceramic, glass or analogous inorganic material.

3.7.1.9 Cast Resin Insulated Bushing — A bushing in which the major insulation consists of a cast organic material with or without an inorganic filler.

3.7.1.10 Composite Bushing — A bushing in which the major insulation consists of a combination of different insulating materials.

3.7.1.11 Capacitance Graded Bushing — A bushing in which metallic or non-metallic conducting layers are arranged within the insulating material for the purpose of controlling the distribution of the electric field of the bushing.

NOTE:

1. Generally, the major insulation of a capacitance graded bushing is constituted of one of the following:

a) Oil impregnated paper,

b) Resin bonded paper,

c) Resin impregnated paper,

d) Cast resin,

e) Gas or other insulating fluid, and

f) Composite.

2. A capacitance graded bushing may be provided with an insulating envelope, in which case the intervening space may be filled with an insulating liquid or another insulating medium.

3.7.1.12 Indoor Bushing — A bushing, both ends of which are intended to be in ambient air but not exposed to external atmospheric conditions.

NOTE:

1. In indoor installations, moisture condensation on the surface of the bushing is to be prevented, if necessary by ventilation or heating.

2. This definition includes bushings operating in air at temperatures above ambient, such as occurs with air-insulated ducting.

3.7.1.13 Outdoor Bushing — A bushing, both ends of which are intended to be in ambient air and exposed to external atmospheric conditions.

3.7.1.14 Outdoor-Indoor Bushing — A bushing, both ends of which are intended to be in ambient air. One end is intended to be exposed to external atmospheric conditions and the other end is intended not to be so exposed

3.7.1.15 Indoor-Immersed Bushing — A bushing, one end of which is intended to be in ambient air but not exposed to external atmospheric conditions and the other end to be immersed in an insulating medium other than ambient air (for example, oil or gas)

3.7.1.1.16 Outdoor-Immersed Bushing — A bushing, one end of which is intended to be in ambient air and exposed to external atmospheric conditions and the other end to be immersed in an insulating medium other than air (for example, oil or gas).

3.7.1.17 Completely Immersed Bushing — A bushing both ends of which are intended to be immersed in insulating media other than ambient air (for example, oil or gas).

3.7.2 Earthing:

The Core of the Transformer is clamped to a Frame, which is in turn connected to the Tank. The Transformer is provided with two separate Earthing Terminal connections. These must be connected to two distinct Earthing Electrodes in the Substation. The Earth Resistance of these Electrodes must be less than 0.5 ohms. The Combined earth resistance shall be less than 0.1 ohm.

For Distribution Transformers, normally Dy11 vector Group, the LT Neutral is earthed by a separate Conductor section of at least half the section of the conductor used for phase wire and connected to a Separate Earth whose Earth Resistance must be less than 1 ohm. The Body of the Tank has two different earth connections, which should be connected to two distinct earth electrodes by GI flat of suitable section.

For Large Power Transformers, Neutral and Body Connections are made separately but all the Earth Pits are connected in parallel so that the combined Earth Resistance is always maintained below 0.1 ohm. The individual and combined earth resistance is measured periodically and the Earth Pits maintained regularly and electrodes replaced if required.

3.7.3 Lifting Lugs: Two or Four Lifting Lugs are provided depending upon the size of the weight / size, for lifting the Transformer. The core also similarly provided with two or Four Lifting Lugs.

3.7.4 Drain, Sampling and Filling Valves:-There are two different types of Valves. (1) Wheel Valve (2) Butterfly Valve. The Wheel Valves are generally made of Cast Iron or gunmetal. These are used as Bottom Drain/Filter Valve, Top Filter Valve, and Isolating Valve between the Main Tank and the Conservator. The Butterfly Valves are used between the Main tank and the Radiators.

3.7.5 Off Circuit Tap Changer: These are provided on the side of the Transformer. These have to be operated only when the Transformer is de-energized. This can be manually operated with a Cranking Handle. A Lock is provided to lock the Tap Changer in any Tap Position but not at any intermediate position. Interlocks can also be provided to trip off the Transformer if this mechanism is meddled when the Transformer is energised.

3.7.6 Ratio Changing Links: Some times, a Transformer will be required to function as a Common Standby for two different Power Transformers with separate LV voltages like 11 kV and 33kv. It is possible, for instance to manufacture and use a Power Trasformer with two different Ratios like 132/33-11kv.This Transformer can be used as 132/33 or 132/11 kv by changing the Ratio Changing the Links.

For changing the Links, the Transformer has to be de-enrgised; oil has to be drained below the inspection cover for the Links. After changing the Ratio by the Links, the Ratio has to be tested before taking back the unit into service.

3.7.7 On Load Tap Changer:

The Tap Changer has a Motor Drive Mechanism. The Motor rotes in the clockwise or anti clock wise direction when the taps raised or lowered either manually or electrically. The Tap changer operation is Step by Step. Limit switches provided cut off the OLTC at the End Taps. The Total operation by Motor takes about 40 to 70 milli seconds. A Bank Of Energy Storing Springs are provided , whose stored energy will be released for a very fast completion of Tap changing operation even when the drive motor supply is interrupted. In some cases the Transformer will be isolated if the Tap is stuck in an intermediate position.

The OLTC can be in One Compartment for 33kv Transformers and in two compartments to provide the selector Switch inside the Main tank and the Diverter outside the Main Tank. Make before Break switches, and Transition Resistors are provided in Diverter. The OLTC can be of a three phase Type or three Single-phase type. A separate Bucholtz relay or surge relays are provided to take care of any faults inside the OLTC gear. A separate Conservator Tank is provided for 33kv Transformers where as the Main Conservator Tank is partitioned for OLTC in large Power Transformers. The Contacts, Oil in divertor have to be maintained periodically for good performance.

3.7.8 Conservator Tank: This takes care of volumetric expansions of Oil in the Transformer. Its capacity is about 5% of the Main Tank. The Pipe from the Main Tank projects about 3 cm above the bottom of the Conservator Tank to collect sludge/moisture.

The Oil level in the Main Conservator is indicated by a Magnetic Oil Level Indicator which has also provision for Low Oil Level alarm or Trip. Generally the OLTC conservator has a prismatic oil level indicator.

A Silica Gel Breather is also provided for each of the Conservator Tanks. In case of large Power Transformers, a synthetic rubber made expansion bellow Barrier or a Diaphragm Barrier is provided to which the Breather is connected. This arrangement eliminates the contact of Transformer oil with Air.

3.8 Cooling equipment:

For Distribution Transformers, one or two sets of radiators are welded to the Tank. For Power Transformers, Detachable Radiators to accommodate Transport dimensions and weight are provided. These are provided with blanking plates. Lifting Lugs are provided for each Radiator and Valves are provided at the Top and also bottom. Provision for cooler fans and pumps are also made. Bracing straps are provided to prevent vibration of the radiators.

3.8.1 Transformer Cooling: The Heat in a transformer is produced due to I square R in the windings and in the core due to Eddy Current and Hysterisis Loss. In Dry type Transformer the Heat is directly dissipated into the atmosphere but in Oil filled Transformer, the Heat is dissipated by Thermosyphon and transmitted to the top and dissipated into the atmosphere through Radiators naturally or by forced cooling fans or by Oil pumps or through Water Coolers. The following Standard symbols are adopted to denote the **Type of Cooling:**

A…………………………….Air Cooling

N…………………………….Natural Cooling by Convection

B…………………………….Cooling by Air Blast Fans

O…………………………….Oil (mineral) immersed cooling

W……………………………Water Cooled

F……………………………. Forced Oil Circulation by Oil Pumps

S……………………………. Synthetic Liquid used instead of Oil

G…………………………… Gas Cooled (SF6 or N2)

3.9 Parallel Operation:

The condition required for paralleling two Transformers is:

(1) Same Polarity

(2) Same Voltage Ratio

(3) Same Percentage Impedance.

(4) Same Vector Group

(5) Same Phase sequence.

(6) Compatibility of Taps if OLTC is fitted for both the Transformers.

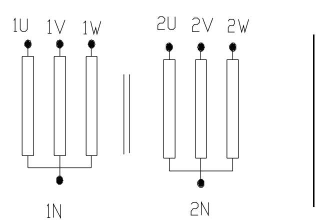
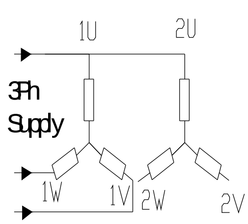
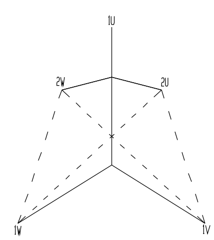
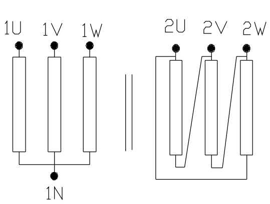
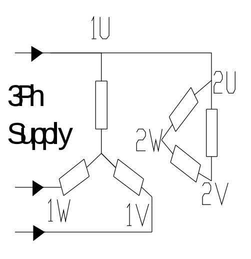
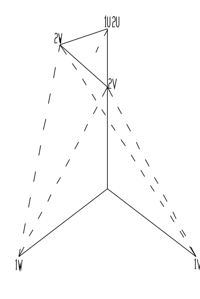
The Transformers Vector Connections are normally divided into four groups:

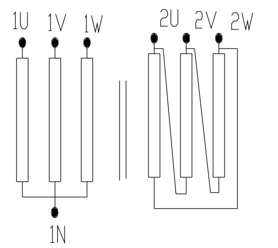
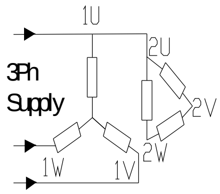
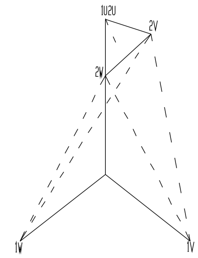
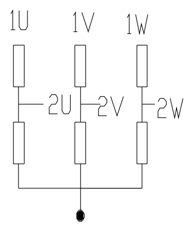
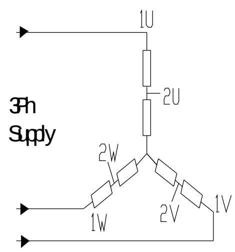
Group 1 … Dd0, Yyo, Dzo (Time indices of 0, 4 and 8)

Group 2 … Dd6, Yy6, Dz6 (Time Indices of 6, 12 and 2)

Group 3 … Dy5, Yd5, Yz5 (Time indices of 1 and 5)

Group 4 … Dy11, Yd11, Yz11 (Time indices of 7 and 11)

vector symbol	winding arrange ment HV	LV	Connection diagram for test	vector diagram	acceptable condition
Yy0					1V2V=1W2W=V1 1V2W=1W2V=V2 V2>V1
Yd 1					1V2V=1W2V=1W2W 1V2W>1W2W

Yd II				1V2W=1W2W=1V2W 1W2V>1V2V
Ya0				1V2U=1W2U 2V2U=2W2U

Note: Transformers of Group 1 and 2 can only be paralleled with Transformers of their own group while Transformers of Group 3 &4 can be interconnected for parallel operation. Within the same group, Transformers of different time indices can be connected in parallel by connecting their primaries to corresponding terminals and by phase rotation of the connections to the secondary terminals of one of the Transformers.

While conditions 1, 2 and 5 for parallel operation cannot be deviated, conditions 3 & 6 can be tolerated to some extent within limits of circulating currents. Condition 4 has to be satisfied to the extent as in the above Para.

3.10 Protection (Internal and External) of Transformer:

3.10.1 Internal protection:

a. Bucholtz Relay: This Gas operated relay is a protection for minor and major faults that may develop inside a Transformer and produce Gases. This relay is located in between the conservator tank and the Main Transformer tank in the pie line which is mounted at an inclination of 3 to 7 degrees. A shut off valve is located in between the Bucholtz relay and the Conservator. The relay comprises of a cast housing which contains two pivoted Buckets counter balanced weights. The relay also contains two mercury switches which will send alarm or trip signal to the breakers controlling the Transformer.

In healthy condition, this relay will be full of oil and the buckets will also be full of oil and is counter balanced by the weights. In the event of a fault inside the transformer, the gases flow up to the conservator via the relay and push the oil in the relay down. Once the oil level falls below the bottom level of the buckets, the bucket due to the weight of oil inside tilts and closes the mercury switch and causes the Alarm or trip to be actuated and isolate the transformer from the system.

b. Oil Surge/ Bucholtz Relay for OLTC: This relay operating on gas produced slowly or in a surge due to faults inside the Diverter Switch of OLTC protects the Transformer and isolates it from the system.

c. Pressure Relief Valve for Large Transformers: In case of a serious fault inside the Transformer, Gas is rapidly produced. This gaseous pressure must be relieved immediately otherwise it will damage the Tank and cause damage to neighboring equipment. This relay is mounted on the top cover or on the side walls of the Transformer. The valve has a corresponding port which will be sealed by a stain less steel diaphragm .The diaphragm rests on a O ring and is kept pressed by two heavy springs. If a high pressure is developed inside, this diaphragm lifts up and releases the excessive gas. The movement of the diaphragm lifts the spring and causes a micro switch to close its contacts to give a trip signal to the HV and LV circuit breakers and isolate the transformer. A visual indication can also be seen on the top of the relay. For smaller capacity transformer, an Explosion vent is used to relieve the excess pressure but it can not isolate the Transformer.

d. Explosion Vent Low & Medium Transformers: For smaller capacity Transformers, the excessive pressures inside a Transformer due to major faults inside the transformer can be relieved by Explosion vents. But this cannot isolate the Transformer.

e. Winding/Oil Temperature Protection: These precision instruments operate on the principle of liquid expansion. These record the hour to hour temperatures and also record the Maximum temperature over a period of time by a reset table pointer. These in conjunction with mercury switches provide signals for excessive temperature alarm annunciation and also isolate the Transformer for very excessive temperatures. These also switch on the cooler fans and cooler pumps if the temperature exceeds the set values. Normally two separate instruments are used for oil and winding temperatures. In some cases additional instruments are provided separately for HV, LV and Tertiary winding temperatures. The indicator is provided with a sensing bulb placed in an oil pocket located on the top cover of the Transformer tank. The Bulb is connected to the instrument housing by means of flexible connecting tubes consisting of two capillary tubes. One capillary tube is connected to an operating Bellow in the instrument. The other is connected to a compensating Bellow .The tube follows the same path as the one with the Bulb but the other end; it does not end in a Bulb and left sealed. This compensates for variations in Ambient Temperatures. As the temperature varies, the volume of the liquid in the operating system also varies and operates the operating Bellows transmitting its movements to the pointer and also the switching disc. This disc is mounted with mercury float switches which when made provides signals to alarm/trip/cooler controls. Oil and winding temperature indicators work on the same principles except that the WTI is provided with an additional bellows heating element. This heating element is fed by a current transformer with a current proportional to the load in the winding whose temperature is to be measured/monitored. The temperature increase of the heating element is proportional to the temperature rise of winding over top oil temperature. The operating bellow gets an additional movement simulating the increase of winding temperature over top oil temperature and represents the Winding Hot Spot. This is called Thermal Imaging process.

f. Conservator Magnetic Oil Level Protection: Inside the conservator tank, a float is used to sense the levels of oil and move. This is transmitted to a switch mechanism by means of magnetic coupling. The Float and the Magnetic mechanism are totally sealed. The pointer connected to the magnetic mechanism moves indicating the correct oil level and also provision is made for Low oil level alarm by switch.

g. Silica gel Breather: This is a means to preserve the dielectric strength of insulating oil and prevent absorption of moisture, dust etc. The breather is connected to the Main conservator tank. It is provided with an Oil seal. The breathed in air is passed through the oil seal to retain moisture before the air passes through the silica gel crystals which absorbs moisture before breathing into the conservator tank. In latest large transformers, Rubber Diaphragm or Air cells are used to reduce contamination of oil.

h.

3.10.2 External protection:

(1) Lightning Arrestors on HV & LV for Surge Protection

(2) HV / LV Over Current Protection(Instantaneous /IDMT- Back up)

(3) Earth Fault Protection (Y connected side)

(4) REF (HV & LV) (For internal fault protection)

(5) Differential Protection (for internal fault protection)

(6) Over Fluxing Protection (against system Kv & HZ variations)

(7) HG Fuse Protection for Small Capacity Transformers.

Normally Each Power Transformers will have a LV Circuit Breaker. For a Group of Transformers up to 5 MVA in a substation, a Group control Circuit Breaker is provided. Each Transformer of 8 MVA and above will have a Circuit Breaker on the HV side.

3.11 Drying of Transformers:

3.11.1 Distribution Transformers: These are thoroughly dried at the Factory and filled with New Filtered and Tested Transformer Oil before dispatch. When it is received at site, the IR values and the Oil Tests (Dielectric and Acidity) are checked. If OK, the Transformer can be commissioned if all the pre-commissioning Tests are satisfactory.

3.11.2 Power Transformers: These are also thoroughly dried at the Factory before dispatch. However, large Transformers are sent without oil with Conservator, Radiators, Bushings, Protective devices etc packed separately and the Transformer filled with Nitrogen. All the Manholes, etc is blanked off. Under such circumstances, the drying out in the field will take very less time.

The real drying is not so much for the Oil but for the winding, which might have absorbed moisture. Vacuuming, and oil Filtration is necessary and the process may take more than a month. The criteria to determine that the drying out is completed are the satisfactory IR values of windings, satisfactory oil tests, and moist free exhaust from the vacuum pump outlet

3.12 Technical specifications of power transformer:-

3.12.1 33kV power transformer:

Three phase rating MVA	Voltage ratio	Cooling
1.0	33/11	ONAN
1.6	33/11	ONAN
3.15	33/11	ONAN
4.0	33/11	ONAN
5.0	33/11	ONAN
6.3	33/11	ONAN
8.0	33/11	ONAN
10.0	33/11	ONAN

Vector Group: Dy11

3.12.2 66kV power transformer:

Three phase rating MVA	Voltage ratio	Cooling
6.3	66/11	ONAN/ONAF
8.0	66/11	ONAN/ONAF
10.0	66/11	ONAN/ONAF
12.5	66/11	ONAN/ONAF
20.0	66/11	ONAN/ONAF

Vector group:Yy 0

3.12.3 145kV power transformer:

Three phase rating MVA	Voltage ratio	Impedance voltage (percent)	Cooling
(a) Two winding			
16	132/33,132/11 kV	10	ONAN/ONAF
25	132/33,132/11 kV	10	ONAN/ONAF
31.5,50	132/33,132/11 kV	12.5	ONAN/ONAF

Vector group: YNyn 0 *or* YNd 11

(b) Interconnecting Auto-transformer			
50	132/66kV	10	ONAN/ONAF
63	132/66 kV	10	ONAN/ONAF

Vector group: YNa0

3.12.4 245 kV Power transformers:

(a) Two winding			
Three phase rating MVA	Voltage ratio	Impedance voltage (percent)	Cooling
50	220/66 kV	12.5	ONAN/OFAF (or) ONAN/ODAF
100	220/66 kV	12.5	ONAN/OFAF (or) ONAN/ODAF
100	220/33 kV	15.0	ONAN/OFAF (or) ONAN/ODAF
(b)Inter Connecting Auto Transformers			
35,50	220/33	10	ONAN/OFAF
50	220/132	10	ONAN/OFAF
100	220/132	12.5	ONAN/ONAF/OFAF (or) ONAN/ONAF/ODAF
160	220/132	12.5	ONAN/ONAF/OFAF (or) ONAN/ONAF/ODAF
200	220/132	12.5	ONAN/ONAF/OFAF (or) ONAN/ONAF/ODAF

Vector group: YNaod11

3.12.5 Auto Transformers(420 Kv Level)Constant Percentage Impedance:

Three-phase HV/IV/LV	**Voltage ratio**	**Tapping range per cent**	**Per cent impedance voltage**			**Cooling**
MVA			**HV-IV**	**HV-LV**	**IV-LV**	
100/100/33.3	400/132/33	+10% to -10% 16 steps of 1.25%	12.5	27	12	ONAN/ONAF
200/200/66.7	400/132/33	+10% to -10% 16 steps of 1.25%	12.5	36	22	ONAN/ONAF or ONAN/ONAF
2580/250/83.3	400/220/33	+10% to -10% 16 steps of 1.25%	12.5	45	30	ONAN/ONAF or ONAN/ONAF

315/315/105	400/220/33	+10% to -10% 16 steps of 1.25%	12.5	45	30	ONAN/ONAF or ONAN/ONAF
500/500/166.7	400/220/33	+10% to -10% 16 steps of 1.25%	12.5	45	30	ONAN/ONAF or ONAN/ONAF
630/630/210	400/220/33	+10% to -10% 16 steps of 1.25%	12.5	45	30	ONAN/ONAF or ONAN/ONAF

3.12.6 Auto transformers (800 kV level):-

Three phase rating HV/IV/LV MVA	**Voltage ratio KV**	**Tapping range(percent)**	**Percent impedance voltage**			**Cooling**
			HV-IV	**HV-LV-IV-LV**		
315/315/105	765/220/33	+4.5% -7.5% 24 steps	12.5	40	25	ONAN/ONAF or ONAN/ODAF or ODAF
630/630/210	765/400/33	-do-	12.5	60	40	-do-
750/750/250	-do-	-do-	-do-	-do-	-do-	-do-
1000/1000/333.3	-do-	-do-	14	65	45	-do-
1500/1500/500	-do-	-do-	-do- tolerance	-do- ±10%	-do- ± 15%	± 15%

SAMPLE CHECK LIST IN TRANSFORMER ERECTION:

1. Testing of Oil samples for BDV in Main Tank and OLTC.
2. Oil level in Main Conservator and OLTC Conservator
3. Capacitance and Tan Delta values of all the HV Bushings
4. Oil level in HV Bushings
5. Cleanliness of Bushings and Tightness of connections
6. Tightness of Bushing Test tap plugs
7. Locking in of Main/ OLTC Bucholtz relays released
8. Locking in of MOG is released
9. Test switch of Bucholtz relay kept in S (service) position
10. All the Radiator valves (Top & Bottom) Opening ensured
11. Release air from Bushings and close the valve
12. Release air fro the Bucholtz relays and close
13. Test Bucholtz relay for proper operation by air injection
14. Shut off valve of Main/OLC Bucholtz/Surge relays are opened
15. Oil seal is ensured for the Breather
16. Silica gel for the Breather is Blue in color
17. All Radiator Top and Bottom valves are opened
18. All Filter/ sampling/ drain valves are properly closed
19. Main/OLTC Conservator Oil filling caps are tight.
20. Oil filling in OTI and WTI pockets/ Calibration of WTI/OTI
21. No oil leaks any where
22. Explosion vent diaphragm top and bottom are in place
23. Release air from top cover
24. Tank Double point earth and connected to two different earths
25. Earth Resistance of Earth pits
26. HV/ LV neutrals are earthed
27. Bi directional Rollers are locked
28. Alarm and indications and trip connections ensured after operating the concerned relays

CIRCUIT BREAKERS

Specifications to be referred:-

IEC-62271-100	High voltage alternating current circuit breakers
IEC-60427	Synthetic testing of high voltage alternating current circuit breakers
IEC-61264	Pressurized hollow column insulators
IS-13947(PART-2)	Specification for low voltage switch gear and control gear –Circuit breakers
IS-2516 (PART-1,2,3,4&5)	Circuit breakers

High voltage circuit breaker technology has changed radically in the past 15 years. Most utility systems are having mix population of bulk oil, minimum oil, vacuum, air blast, SF6 two-pressure, and SF6 single-pressure circuit breakers.

Arcing phenomena

Arcs in ac circuit breakers occur in two ways. When the current carrying contacts are being separated, arcing is possible even when the circuit e.m.f. is considerably below the minimum cold electrode breakdown voltage because of the ions neutralizing the electronic space charge and thus allowing large currents to flow at relatively low voltage gradients. This way of occurrence of an arc is common to both dc and ac circuit breakers. Another way of occurrence of arc happens only in ac circuit breakers. In this case, the arc is extinguished every time the current passes through zero and can re-strike only if the transient recovery voltage across the electrodes, already separated and continuing to separate, reaches a sufficiently high value causing break down. The function of an a.c.circuit breaker is to prevent re-striking of the arc, which depends upon the following important factors.

- The nature and pressure of the medium of arc;
- The external ionizing and de-ionising agents present;
- The voltage across the electrodes and its variation with time;
- The material and configuration of the electrodes; and
- The nature and configuration of the arcing chamber.

Arc extinction process

The final extinction of the arc requires a rapid increase of the dielectric strength in the medium between the circuit breaker contacts, which is achieved by either de-ionisation of the arc path or by the replacement of the ionised gas by cool fresh gas. The various de-ionisation processes include high pressure, cooling by conduction, forced convection and turbulence.

Circuit Breaker Operating Mechanisms

The primary function of a circuit breaker mechanism is to provide the means for opening and closing the contacts. These are generally three types of mechanisms to choose from, viz. spring operating, pneumatic and hydraulic mechanisms. Originally, the spring mechanisms were usually confined to MOCBs (which require about 3500 / 4500 NM per pole of a 420 kV circuit breaker) and SF6 circuit breakers for 36 kV to 145 kV voltages. For HV circuit breakers of 420 kV and above, especially for faster ones with total break time of two cycles, the choice is generally limited to pneumatic or hydraulic mechanisms. However, in the recent past, spring mechanisms have also been used with HV range of SF6 gas circuit breakers up to 550 kV. Spring operated mechanisms are preferred for almost all voltage class of circuit breakers due to their simple design and cost advantage over other mechanisms.

Technical Particulars of a Circuit-breaker

A circuit-breaker is identified by the following particulars:

1. Type of medium for arc-extinction.
2. Rated voltage. This corresponds to highest power-frequency voltage between phase to phase, e.g., 3.6 kV, 7.2 kV, 12 kV, 36 kV, 72.5 kV, 245 kV, 420 kV, 800 kV.
3. Rated breaking circuit, e.g. 40 kA.
4. Type of construction
5. Type of construction
   - Indoor metal-clad type
   - Outdoor type
   - Metal-clad SF_6 gas insulated type
6. Type of operating mechanism. E.g. Pneumatic, spring, Hydraulic.
7. Total break-time, e.g., 2 cycles, 3 cycles, 5 cycles.
8. Structural form:
   - Live tank type (Interrupters housed in porcelain)
   - Dead tank type. (Interrupters housed in metallic tank at earth potential)
9. Other rated characteristics

S.No	Description	145 kV	245 kV	420 kV
1	Nominal system voltage, kV	132	220	400
2	Highest system voltage, kV	145	245	420
3	Rated continuous current, A	2000	2000	3000
4	Frequency, Hz	50	50	50
5	Power frequency test voltage 1 min, 50 H_z	300 220	545 445	810 665
6	Impulse withstand voltage 1.2/50 u.s. kV peak	650	1300	1800
7	Short circuit breaking current kA, rms.	31.5	40	40
8	Short time current, 1 sec	31.5	40	40
9	Total break time, ms	60	60	50
10	Recovery voltage, first peak, first pole to		420	720

	clear, kV peak			
11	Reinsertion resistor, Ω / ph	-	-	400
12	Operating sequence 0 – 0.3S – CO-3m-CO	√	√	√

Selection of Circuit-breakers

As per IEC specifications the following specifications must be considered while selecting circuit-breakers.

The following circuit breakers are preferred for EHV A.C. sub-station:

Type	Medium	Range
Air break circuit-breaker Miniature C.B	Air at atmospheric pressure Air at atmospheric pressure	Low voltage Up to 100V "
Tank type oil circuit-breaker	Dielectric oil	Up to 11 kV
Minimum oil circuit-breaker	Dielectric oil	36 kV, 1500 MVA 132 kV, 3000 MVA
Air-blast circuit-breaker	Compressed air (20-30) kgf/cm^2	132 kV, 220 kV 400 kV, 765 kV
SF_6 circuit-breaker - Single pressure puffer type	SF_6 gas at 5 to 6 bar	132 kV, 220 kV 400 kV, 765 kV
Vacuum circuit-breaker	Vacuum	11 kV, 33 kV
H.V.D.C Circuit-breaker system	Vacuum or SF_6	300 A DC at 20 kV. For Metallic Return Transfer Beater (MRTB)

Duties for all Circuit-Breakers

- rated voltage
- rated insulation level
- rated normal current

- rated frequency
- rated breaking capacity symmetrical and asymmetrical
- rated making capacities
- rated short-time current
- rated maximum duration of short-circuit
- rated operating duties
- opening time
- Closing time and Operating mechanism type of features.

Special Duties:

- Reactor switching, Low inductive current switching.
- Line charging (line off load) breaking capacity.
- Cable charging (cable, off load) breaking capacity.
- Repeated operations duty.
- DC current switching.
- Switching higher frequency currents.
- Switching lower frequency currents.
- Parallel capacitor switching.
- Short-Line fault switching.
- Single capacitor breaking capacity.
- Out-of phase making and breaking capacities.
- Breaking capacity for terminal faults.
- Breaking capacity for short line faults.
- Conditions of TRV, transient recovery voltage etc.

ISOLATORS

Specifications to be referred

Sl.No.	Standard	Topic
1.	IEC -60129	Alternating current disconnections
2.	IEC-1129	Alternating current earth switches induced current switching
3.	IEC-60265 (PART 1& PART 2)	High voltage switches
4.	IS-9921(PART 1)	Specification for alternating current disconnectors and earth switches -general and definitions
5.	IS-9921(PART 2)	Specification for alternating current disconnectors and earth switches-rating
6.	IS-9921(PART 3)	Specification for alternating current disconnectors and earth switches-design and construction
7.	IS-9921(PART 4)	Specification for alternating current disconnectors and earth switches- Type tests & Routine tests
8.	IS-9921(PART 5)	Specification for alternating current disconnectors and earth switches-Information

		for tenders
9.	IS-1818	Alternating current Isolators
10.	IS-2607	Air break isolators for Voltages not exceeding1000 V

Introduction:

A mechanical switching device which provides, in the open position, an isolating distance in accordance with specified requirements. A disconnector is capable of opening and closing a circuit when either negligible current is broken or made, or when *no* significant change in the voltage across the terminals of each of the poIes of the Disconnector occurs. It is also capable of carrying currents under normal circuit conditions and carrying, for a specified time, currents under abnormal conditions such as those of short-circuit.

NOTE:

1. “Negligible current” implies currents such as the capacitance c*urrents* of bushings, busbars. Connections with very short lengths of cables, currents of permanently connected grading impedances of circuit-breakers and currents of voltage transformers and dividers. %or rated voltages of 420 kV and below, a current not exceeding 0.5 A is deemed to be a negligible current for the purpose of this definition; for rated voltages above 420 kV, the manufacturer shall be consulted.

2. “No significant change in voltage” refers to such applications as the by passing of induction voltage regulators or circuit-breakers.

Divided Support Disconnect or Earthing Switch

A disconnect or earthing switch whose fixed and moving contacts of each pole are not fixed on a common base or frame.

NOTE - A pantograph disconnector is an example.

Earthing Switch

A mechanical switching device for earthing parts of a circuit capable of withstanding for a specified time currents under abnormal conditions such as those of short-circuit, but not required to carry current under normal conditions of the circuit.

NOTE: 1. An earthing switch may have a rated short-circuit-making current.

2. Earthing switches may be combined with disconnectors.

Indoor Disconnector or Earthing Switch

A disconnector or earthing switch designed solely for installation within a building or other housing where the disconnector or earthing switch is protected against wind, rain, snow, abnormal dirt deposits, abnormal condensation, ice and hoar-frost.

Outdoor Disconnector or Earthing Switch:

A disconnector or earthing switch suitable for installation in the open air that is capable of withstanding wind, rain, snow, dirt deposits, condensation, ice and hoar.

Types of isolators:

1. Horizontal centre break
2. Double break
3. Pantograph-Semi & Full
4. Vertical break

Design Criteria of Isolators:

Operating conditions

- Ambient Temperature (-40 deg to 50 deg.C)
- Icing Conditions
- Wind loads
- Seismic factor
- Higher Altitudes
- Short Circuit Forces
- Pollution Factors, Corrosive Environment

Base Frame and Mechanical Bearings

(a) Rigidity of Base Frame

(b) Bearing Housing and Bearings

Bearing	---	To be sealed against ingress of agents
Bearing Housing	---	Should avoid internal condensation and Accumulation of moisture
Grease	---	Should with stand Temperature Limits

Inter Phase Linkages and Mechanical Motion Transfer Arrangement

i. Lost Motion on Linkages to be reduced.
ii. Corrosion Resistant material for Roll pins.
iii. Friction to be reduced. Movements required after long gaps of time.

Main Current Path

(a) Current Carrying Arms, Material and Current densities

(b) Contacts, Material and Surface Coating.

(c) Springs for Contact Pressure

(d) Contact Pressure

(e) Rated Current Carrying Capability – Temperature Rise.

(f) Short Circuit Current Carrying Capability.

- ❖ Peak and R.M.S. Currents
- ❖ Dynamic and Thermal Effects

Insulators

(a) Type of Insulators

- Cap and Pin type
- Solid core
- Poly cone Or Multi Cone

(b) Mechanical Strength

- Cantilever or Bending Strength
- Torsion and Compression

(c) Electrical Values

- Basic Insulation Level
- RIV and Corona

(d) Pollution Characteristics

- Creepage Distance
- Shed Profiles as per IEC etc.
-

Operating Mechanism (Drives)

- ✓ Hand Operated mechanism (Manual Drive)
- ✓ Motor Operated Mechanism (Motor Drive)

- ✓ Inter Locking Requirements

Technical Particulars of Isolators:

S.No	Description	145 kV	245 kV	420 kV
1	Rated voltage (kV, rms)	`145	245	420
2	Rated frequency (H_z)	50	50	50
3	No. of poles	3	3	3
4	Design ambient temperature (^{0}C)	50	50	50
5	Rated Insulation levels:			
	a. Full wave impulse withstand voltage (1.2/50 micro sec)	±650kVp	±1050kVp	±1425 kVp
	- between line terminals and ground			±1425kVp
	- between terminals with circuit breaker/Isolator open	±750kVp	±1200kVp	On one terminal & 240 kVp power frequency voltage of opposite polarity on other terminal
	b. Switching impulse withstand voltage (250/2500 micro-second dry and wet)	…..	….	± 1050 kvp on one terminal& 345 kvp on opposite polarity on other terminal
	- between line terminals and ground			
	- between terminals with circuit breaker/Isolator open			
	c. One minute power frequency dry and wet withstand voltage		460kv rms	275kv rms
	- between line terminals and ground		530 kv rms	315kv rms

	- between terminals with circuit breaker/Isolator open	275kv rms		.
	- Corona extinction voltage (kV rms) with Circuit Breaker / Isolator in all position	315 kv rms		
	Max. radio interference voltage (micro volts) for frequency between 0.5 MH_z and 2 MH_Z at 266 kV rms. In all positions.	500(at 92kv rms)	1000(at 156 kv rms)	1000
6	Minimum Creepage distance:			
	a. Phase to ground (mm)	3625	6125	10500
	b. Between CB Terminals (mm)	3625	6125	10500
	- Phase to phase spacing			6000mm
7	Seismic acceleration	0.3 g horizontal	0.3 g horizontal	0.3 g horizontal
8	Thermal Rating of Auxiliary Contacts	10A at 220v DC	10A at 220v DC	10A at 220v DC
9	Breaking Capacity of auxiliary contacts	2A DC with circuit time constant not less than 20 ms	2A DC with circuit time constant not less than 20 ms	2A DC with circuit time constant not less than 20 ms
10	System neutral earthing	Effectively earthed	Effectively earthed	Effectively earthed

4.Current Transformers

Specifications to be referred:

- current transformers- specification(general requirements)---
  IS: 2705(part 1):1992
- current transformers – specification(measuring current transformers)----
  IS: 2705(part 2):1992
- current transformers – specification(protective current transformers)----
  IS: 2705(part 3):1992
- current transformers – specification(protective current transformers for special purpose applications)----**IS: 2705 (part 4):1992**

4.1 Definitions:

a. **Rated Primary current:** The value of primary current on which the primary performance of the current transformer is specified by the manufacturer.
b. **Rated short-time current (primary):**It is defined as R.M.S. value of a.c. component which the CT can carry for rated time without damage due to thermal or electrodynamic stresses.
c. **Rated secondary current:** The value of secondary current marked on the rating plate.

d. Rated existing current: The R.M.S. value of current of taken by the secondary-winding of a C.T. when sinusoidal voltage of rated frequency is applied to secondary with primary winding open circuited.

e. Rated Burden: The burden assigned by manufacturer at which the C.T. performs with specified accuracy.

f. Current error or Ratio error: The percentage error in the magnitude of the secondary current is defined in terms of current error.

g. Phase angle error: The phase angle between primary current vector and the reversed secondary current vector.

h. Composite error: The r.m.s. value of the difference ($K_n i_s - I_p$) integrated over one cycle under steady condition, given by

$$\text{Composite error} = \frac{100}{I_p}\sqrt{\frac{1}{T}\int_{0.}^{T}(K_{nis} - i_p)^2\,dt}$$

Where K_n = Rated transformation ration

I_P = Primary current, r.m.s.

i_P = Primary current, instantaneous

i_s = Secondary current, instantaneous

T = Time of one cycle, in sec.

i. Accuracy class: The class assigned to the current transformer with the specified limits of ratio error and phase angle error.

j. Over-current factor: The ratio of rated short-time current to rated primary current.

k. Insulation level (primary). Insulation level of the C.T. refers to the withstand values of

- Power frequency withstand voltage.
- Impulse withstand voltage.
-

4.2 Types of CT's

A. According to construction:

Instrument transformer in which the secondary current, in normal conditions of use, is substantially proportional to the primary current and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections.

Current Transformer (Wound Type): A current transformer having a primary winding of more than one full turn wound on the core (s).

Current Transformer (Bar Type): A current transformer in which the primary winding consists of a bar of suitable size and material forming an integral part of the current transformer.

Current Transformer (Dry Type): A current transformer which does not require the use of any liquid or semi-liquid material.

Current Transformer (Liquid Immersed): A current transformer which requires the use of oil or other suitable liquid of suitable characteristics as insulating and/or cooling medium.

Hermetically Sealed Current Transformer: A liquid immersed current transformer which is sealed and does not communicate with atmospheric air.

Current Transformer (Ring Type): A current transformer which has an opening in the center to accommodate a primary conductor through it.

Multi-Core Current Transformers: A current transformer having more than one secondary core and winding with a common primary winding.

Multi-Ratio Current Transformer: A current transformer in which more than one ratio is obtainable by reconnection, or tappings, in primary or secondary windings.

B.According to application:

Metering CT's: verify that they are measuring the ratio error &phase displacement for metering CT's having accuracy class 0.2, 0.5&1.0.

- If it is 0.2 or 0.1 class then we have to take the values at 120%, 100%, 20%&5% of rated current with 100%, 25%of the rated burden.
- If it is 0.5, 1.0 class then we has to take the values at 120%, 20% of rated current with 100%, 25%of the rated burden.

Protective CT's (class "p"): verify that they are measuring the ratio error &phase displacement for protective CT's having accuracy class '5p' or '10p' at rated current with rated burden connected.

Protective CT's class 'ps': turns ratio error of the special protection core can be measured directly by turns ratio meter .check that error is within limits or not.

4.3 Accuracy class. It is the class assigned to the current transformer with the specified limits of ratio error and phase angle error.

4.3.1 Limits of Error and Accuracy Class:

Accuracy class	**Current error rated primary current**	**Phase displacement at rated current**	**Composite error rated accuracy limit primary current**
	Per cent	Minutes	Per cent
5P	± 1	± 60	5
10P	± 3	-	10
15P	± 5	-	15

The current transformers are marked as follows:

[E.g. 30/5P 10]

First number: Output in VA (e.g. 30)

Second number: Accuracy class (e.g. 5 P)

Last number: Composite error (e.g. 10)

4.4 Burden:-

Impedance of secondary circuit expressed in ohms, power factor angle is called burden. But it is usually expressed in terms of apparent power in kVA and rated secondary current at specified power factor. This power factor is not the power factor of secondary current of CT.

Rated ‘Burdens’ of CTs and VTs refer to the maximum load in volt-amperes (VA) which may be applied across the secondary terminals, without the ratio and phase angle errors exceeding the permissible limits. The burden depends upon the number of instruments or relays connected and their individual burdens typical values are:

We may express the burden in the following two forms. e.g., 0.5 ohm impedance or 12.5 volt-amperes at 5 amperes. Let rated burden B volt-amperes at rated secondary I_s amperes. Then the ohmic impedance the burden Z_b can be calculated as follows:

$$Z_b = \frac{B}{I_s^{\,2}} ohms$$

4.4.1 Burdens of Individual Instruments/Relays:

	Potential (110 V)	Current (5 A)
Indicating voltmeter/ammeter	2 to 10 VA	0.5 to 5 VA
Watt-hour meters and recording instruments	3 to 5 VA	5 to 7.5 VA
Thermal over current relays	-	2 to 12 VA

4.4.2 The Standard VA Burdens Ratings for CTs and VTs:

	Potential (110 V)	Current (5 A)
Instrument transformers	10, 15, 50, 100, 200	2.5, 5, 7.5, 15, 30
Protective transformers	50, 100, 200	2.5, 5, 7.5, 10, 15, 30 p.f. 0.7 lag

Example: if A CT has to feed an indicating ammeter (1.0 VA), a record-wattmeter (5 VA) and over current relay (6 VA) the total burden would be 12 VA. If the resistances of the connecting leads (go and return) is 0.2 ohm, its burden would be

$$= I^2R, \text{ i.e., } 5^2 \times 0.2 = 5 \text{ VA}$$

Therefore, the total burden on the CT would be 17 Va.

The rated burden could also be expressed in terms of impedance in ohms instead of volt-amperes. Thus a 15 VA burden would be equivalent to a 0.6 ohm impedance burden with respect to 5 amperes secondary or 15 ohm impedance in return to a one ampere secondary.

If burden power factor is $\text{Cos}\,\phi$, B = VA burden

$$R_b = Z_b \text{ Cos}\,\phi \text{ ohms}$$

$$X_b = \sqrt{Z_b^2 - R_b^2} \text{ ohms.}$$

4.5. Terminal Marking: The terminal marking shall identify:

a) The primary and secondary windings;

b) The winding sections, if any;

c) The relative polarities of windings and winding sections; and

d) The intermediate tappings, if any.

4.5.1 Method of Marking

1. The terminals shall be marked clearly and indelibly either on their surface or in their immediate vicinity.

2. The marking shall consist of letters followed, or preceded, where necessary, by numbers. The letters shall be in block capitals.

3. The marking of current transformers shall be as indicated in Fig. 1 to 4.

4. All the terminals marked P1, S1 and C1 shall have the same polarity at any instant.

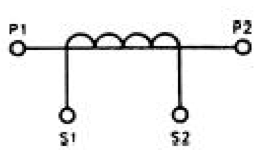


Fig. 1 Single ratio transformer

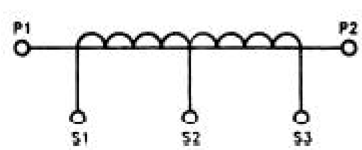
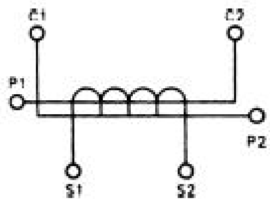


Fig. 2 Transformer with an intermediate Tapping on secondary winding



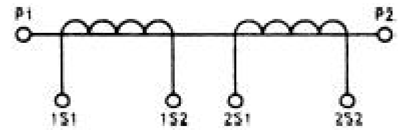


Fig. 3 Transformer with primary winding in Two sections intended for connection Either in series or parallel

Fig.4 Transformer with two secondary windings

4.5 Magnetization curve:-

Magnetization curve of CT shows the excitation characteristic curve of typical oriented electrical steel. The excitation curve may be sub-divided into four main regions (*i)* from origin to ankle point (ii) from ankle point to knee (iii) knee region (iv) saturation region. Knee point is defined as where a 10% increase in flux density cause 50% increase to exciting ampere turns.

Protective current transformer generally operate over-working range of flux density extending from the ankle-point to the knee-region of above, while the measuring current transformer has the flux density in the region of ankle-point only.

Prior to saturation, the flux density in core is proportional to ampere-turns. On reaching saturation, magnetizing inductance becomes low and the total primary current is utilized in exciting the core alone and, therefore, the secondary output of CT disappears. The saturation continues till the primary transient current is reduced below saturation level. On energy in saturation zone, the CT behaves an open circuited. It is difficult to avoid saturation during short circuit condition. The effect of saturation is the reduced output, hence reduced speed of over-current relays. In differential relays the saturation disturbs the balance and stability of protection is affected.

Current transformer saturation curve is generally plotted in secondary volts *vs.* exciting current measured in secondary. For the required magnitude of secondary voltage, the degree of saturation can bee seen from the curve and is also indicated by magnitude of exciting current to produce this voltage.

4.6 CT current setting:-

(a). The rated primary current should be selected from standard values. The value should be so chosen that it is suitable for all normal currents and permissible over load currents in the primary circuit.

Current transformer operating a high-set instantaneous over-current relay may be selected for higher rated primary current; thereby the required accuracy limit may be reduced.

Referring values of rated primary currents : 0.5 – 1 – 2.5 – 5 – 10 - 12.5 – 15 – 20 – 25 - 30 – 40 – 50 – 60 – 75 – 100 – 125 – 150 – 200 – 250 – 300 - 400 – 500 – 600 – 750 – 800 – 1000 – 1250 – 3000 – 4000 – 5000 – 6000 – 7500 - 10000 Amperes.

Reference values of rated secondary currents: 1-2-5 Amperes.

Reference values of rated output: 2.5-5-7.5-10-15-30 VA and up.

(b) Rated short time current and its duration example:

750 A for 0.5 sec., 525 for 1 sec., 300 for A for 3 sec.

4.7 Classification of Tests

4.7.1 *Type Tests:*

The following shall constitute the type tests:

a) Short-time current tests

b) Temperature-rise test.

c) Lightning impulse test for current transformers for service in electrically exposed installation

d) Switching impulse voltage tests for current transformers of 420 kV and above

e) High voltage power-frequency wet withstand voltage tests on outdoor current transformers up to and including 245 kV

f) Determination of errors or other characteristics according to the requirements of the appropriate designation or accuracy class.

4.7.2 *Routine Tests:*

The following shall constitute the routine tests:

a) Verification of terminal marking and polarity

b) Power frequency dry withstand tests on primary windings.

c) Power frequency dry withstand tests on secondary windings

d) Over-voltage inter-turn test

e) Partial discharge tests in accordance with

f) Determination of errors or other characteristics according to the requirements of the appropriate designation or accuracy class.

4.7.3 *Optional Tests:*

The following tests where applicable, shall be carried out by mutual agreement between the purchaser and the manufacturer:

a) Chopped lightning impulse test as a type test

b) Measurement of dielectric dissipation factor for oil immersed current transformers of 72.5 kV and above

c) Commissioning tests on new current transformers up to and including 36kV.

4.8 Technical specifications of Current Transformer:-

S.No	Nominal system voltage	33 kV	66 kV	110 kV	132 kV	220 kV	400 kV	765 kV
1	Highest system voltage	36 kV	72.5 kV	123 kV	145 kV	245 kV	420 kV	800 kV
2	Frequency	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz
3	Basic insulation level (kV peak)	170	325	550	650	1050	1425	2100
4	Power frequency withstand strength (kV rms)	70	140	230	275	460	630	830
5	Rated primary current		400A/ 200A		800A/ 600A	800 A/ 600A	2000-1000-500 A	3000-2000-1000 A
6	Rated burden for metering	20 VA	20 VA	20 VA	20 VA	20 VA	20 VA	20 VA

7	Rated short time current for 1 sec	25 kA	31.5 kA	31.5 kA	31.5 kA	40 kA	40 kA	40 kA
8	Secondary current amps	1	1	1	1	1	1	1
9	No. of cores	3	3	3	3	5	5	5
10	Max. Temperature rise over design ambient temp	As per IEC : 60044-1						
11	Type of insulation	Class A						
12	Instrument safety factor	<10	<10	<10	<10	<10	<10	<10

5. Voltage Transformer

Specifications to be referred:-

IS-3156(Part-1) Voltage Transformers Specification - General requirements

IS-3156(Part-2) Voltage Transformers Specification-Measuring voltage transformers

IS-3156(Part-3) Voltage Transformers Specification –Protective voltage transformers

IS-3156(Part-4) Voltage Transformers Specification-Capacitive voltage transformers

5.1 Definitions:

a) **Rated Voltage.** The voltage marked on the rating plate of the voltage transformer. The method of connection of primary winding to system and system voltage should be considered while selecting the VT of correct primary voltage rating. There are several values of standard primary voltages. These have a reference to standard system voltages.

b) **Rated Transformation Ratio**. The ratio of rated primary voltage to rated secondary voltage.

c) **Rated Secondary Voltage**. E.g., 130/√3 = 63.5 V or 110/√3 = 190 V. It is the value of secondary voltage marked on the rating plate.

d) **Residual Voltage.** Vector sum of three lines to earth voltages, i.e.

$$V_{RES} = V_{RN} + V_{YN} + V_{ZN}$$

e) Residual VT. A three-phase VT or a group of 3 single phase residually connected VTs in which residual voltage appears across secondary terminals when three-phase voltage are applied to primary windings.

f) Ratio Error. Percentage ratio error sometimes called percentage voltage error is given by

$$\% \text{ R.E} = \frac{100(K_n V_s - V_s)}{V_p}$$

Where K_n = Normal ratio

V_s = Secondary voltage

V_p = Primary voltage

An alternate method describe the ratio is to specify the voltage ratio factor (V.R.F.)

$$\text{V.R.F.} = \frac{K_v}{K_n}$$

K_n = Normal ratio $\frac{V_p}{V_s}$

K_v = Voltage ratio $\frac{V_p}{V_s}$ actual.

$$\text{V.R.F} \cong 1 - \frac{\%R.E}{100}$$

5.2 Types of Voltage Transformer:

An instrument transformer in which the secondary voltage, in normal conditions of use, is substantially proportional to the primary voltage and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections.

5.2.1 Hermetically Sealed Voltage Transformer: A liquid immersed voltage transformer which is sealed and does not communicate with atmospheric air.

5.2.2 Electromagnetic Voltage Transformer: A voltage transformer which transforms the primary voltage to the secondary voltage entirely by electromagnetic phenomena.

5.2.3 Auxiliary Voltage Transformers: A voltage transformer for matching the rated Secondary voltage of the main voltage transformer to the rated voltage of the burden.

5.2.4 Capacitor Voltage Transformer: A voltage transformer comprising a capacitor divider unit and an electromagnetic unit so designed and interconnected that the secondary voltage of the electromagnetic unit is substantially proportional to and in phase with the primary voltage applied to the capacitor divider unit.

5.2.5 Measuring Voltage Transformer: A voltage transformer intended to supply Indicating instruments, integrating meters and similar apparatus.

5.2.6 Protective Voltage Transformer:A voltage transformer intended to provide a supply to electrical protective relays and similar apparatus.

5.2.7 Dual Purpose Voltage Transformer: A voltage transformer having one magnetic core intended to serve the dual purpose of measuring and protection. It may have one or more secondary windings.

5.2.8 Residual Voltage Transformer:A 3-phase voltage transformer or a group of three single-phase voltage transformers having windings connected in broken delta so as to produce between the appropriate terminals a voltage representative of the residual voltage existing in the 3-phase voltage applied to the primary terminals.

5.2.9 Unearthed Voltage Transformer:A voltage transformer which has all parts of its Primary winding, including terminals, insulated from earth to a level corresponding to its rated insulation level.

5.2.10 Earthed Voltage Transformer: A single-phase voltage transformer which is Intended to have one end of its primary winding directly earthed or a three phase voltage Transformer which is intended to have the star point of its primary winding directly earthed.

5.3 Accuracy Class and Limits and Phase Errors for Voltage Transformers

Accuracy Classes	0.9 to 1.1 times rated primary voltage 0.5 to 1.0 times rated output at 0.8 lag p.f	Applications

	Voltage error % (+ or -)	Phase error (minutes) (+ or -)	
1.2 0.2 0.5 1.00	0.1 0.2 0.5 1.0	5 10 20 40	Measurement
3.0 5.0	3.00 5.00	120 300	Protection
10.0	10.00	- only	Residual VT

5.3.1 Applications of VTs Depending upon Accuracy Class

Accuracy Classes	**Applications**
0.1	Precision testing in standard laboratories
0.2	Sub-standard instruments in laboratories
0.5 – 1.00	Industrial metering
3.00	Voltmeters
5.00	Under voltage relays, over voltage relay other relay where phase angle is not important
10.0	Directional relay where phase angle is important

Note. (1) Class 3.0 and 5.0 VTs are recommended for protection.

(2) Class 5.00 and 10.00 is recommended only in residual VTs.

5.4 Terminal Markings:

a. Marking shall be in accordance with Fig. 1 to 10 as appropriate. Capital *A*, *B*, *C* and *N d*enote the primary winding terminals and the lowercase letters *a*, *b*, *c* and *n* the corresponding secondary winding terminals.

b. The letters *A*, *B*, *C* denote fully insulated terminals and the letter *N* denotes a terminal intended to be earthed, and the insulation of which is less than that of the other terminals.

c. Letters *da* and *dn* denote the terminals of windings intended to supply a residual voltage.

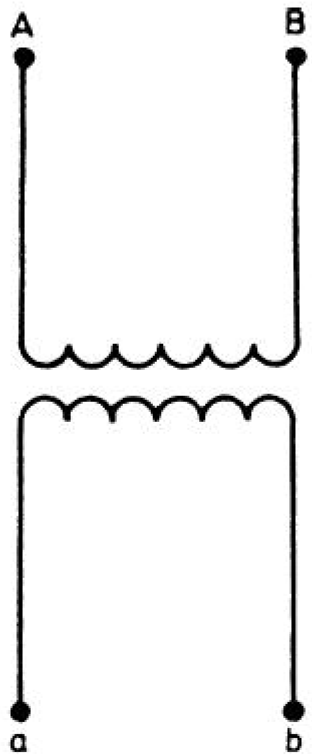


Fig. 1 Single phase transformer with fully Insulated terminals and a single secondary

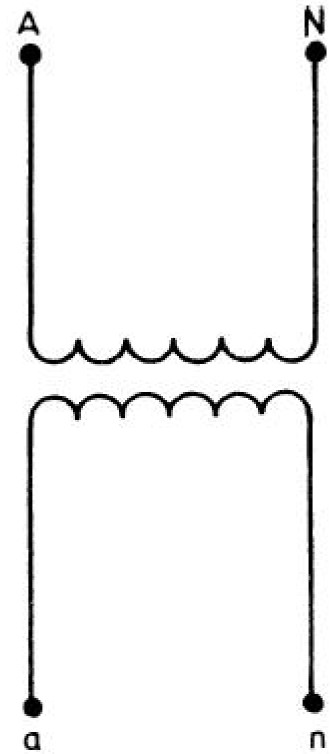


Fig. 2 Single phase transformer with neutral Primary terminal and a single secondary

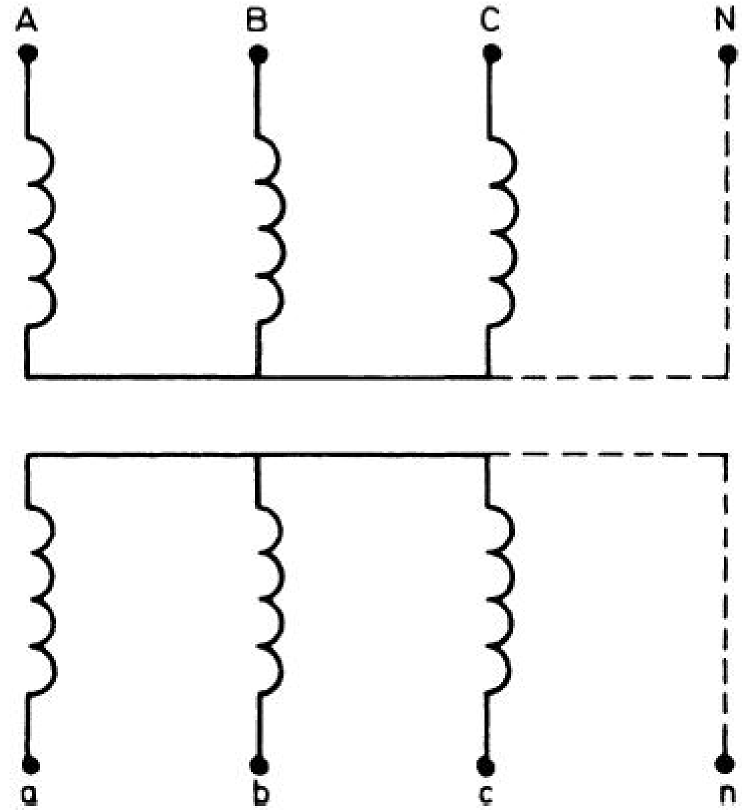


Fig. 3 Three-phase assembly with a single Secondary

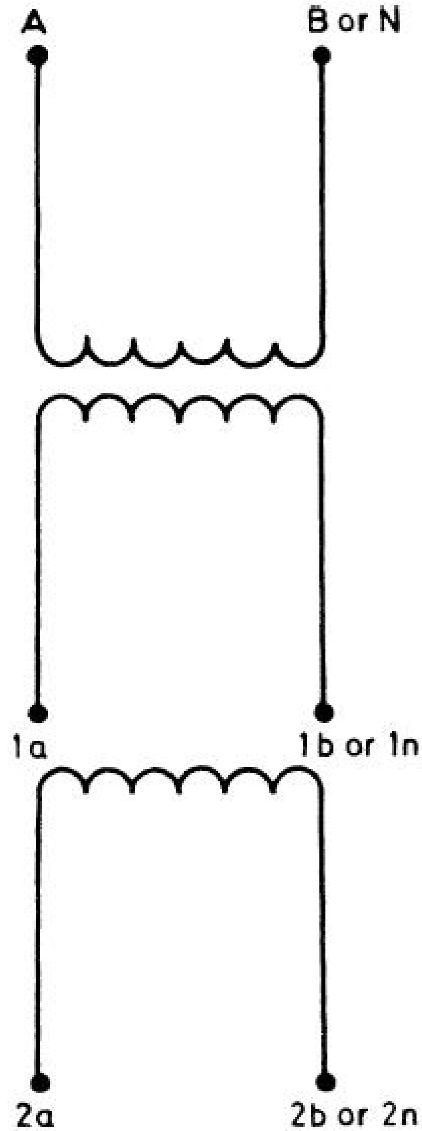


Fig. 4 Single-phase transformer with two
Secondaries

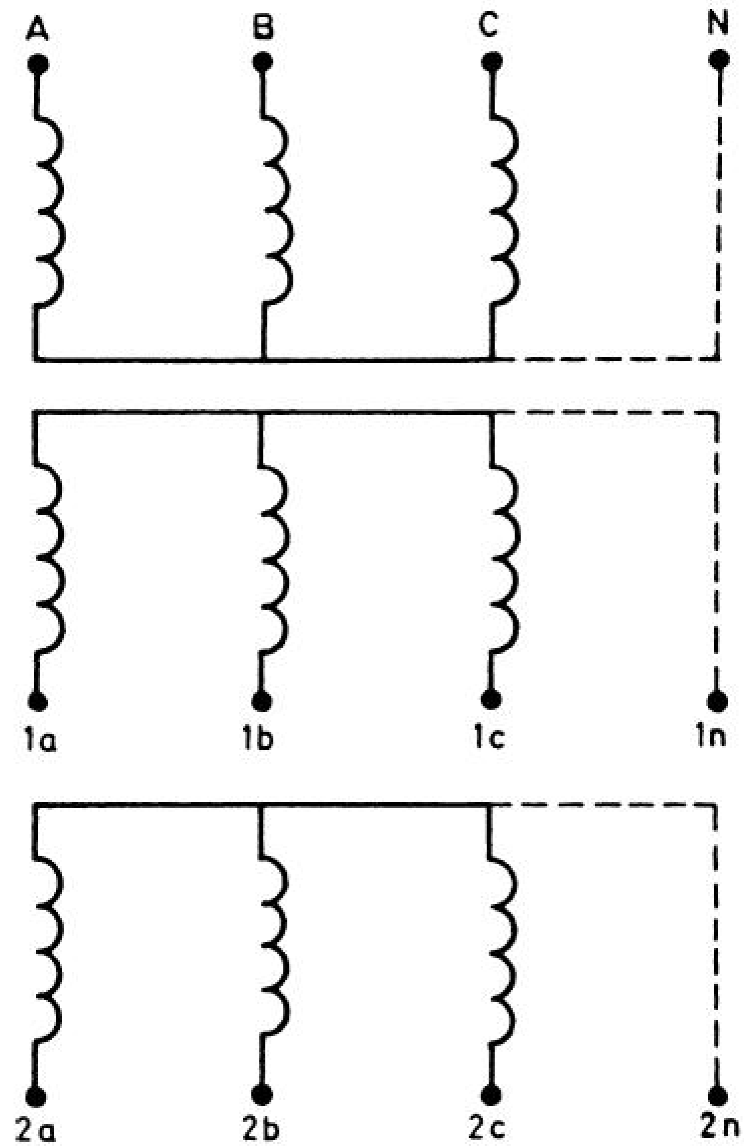


Fig. 5 Three-phase assembly with two Secondaries

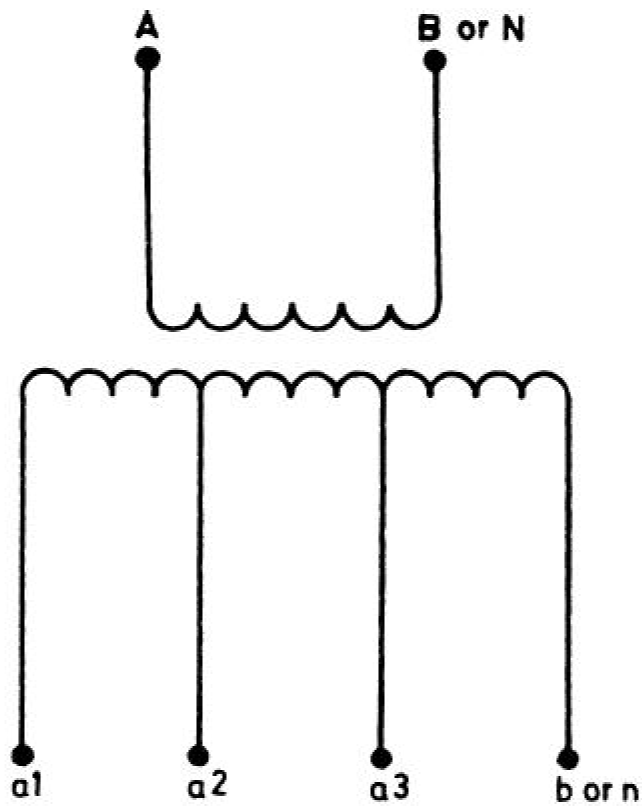


Fig. 6 Single-phase Transformer with One
multi-tap secondary

5.4 Connections of VT:

There are three types of connections, V-V, Star-Star and Star-Open Delta, Residually Connected VT.

1. **V-V Connection:** This connection is used only for measurement and generally not for protection. Two VTs are used. Primaries are connected in V, secondary, also in V. There is no path for zero sequence voltages arising from earth faults.
2. **Star-Star Connection**: Either three separate transformers or a single three limb transformer are used. Primaries are connected in star; secondaries are also connected in star. Each primary phase winding is connected to phase to earth voltage of supply circuit which is transformed into secondary.

The neutral point of load is connected to neutral point of secondaries. The neutral point of primary is solidly earthed with such connections. If primary neutral is not earthed, the zero sequence components of voltages (due to earth fault) cannot flow through primary windings. Hence phase to earth voltages of system which contain zero sequence component do not get truly transformed.

Hence the earth fault on the system cannot be sensed on the secondary side of VT. In voltage restrained over current fault protection impedance protection for earth faults.

5.5 Classification of Tests

5.5.1 ***Type Tests:*** The following shall constitute the type tests:

a) Temperature rise test

b) Lightning impulse test for voltage transformers for service in electrically exposed installation.

c) Switching impulse voltage tests for voltage transformers of 420 kV and above

d) High voltage power frequency wet withstand voltage tests on outdoor voltage transformers up to and including 245 kV

e) Determination of errors or other characteristics according to the requirements of the appropriate designation or accuracy class

5.5.2 ***Routine Tests:*** The following shall constitute the routine tests

a) Verification of terminal marking and polarity

b) Power frequency dry withstand tests on primary windings

c) Power frequency dry withstand tests on secondary windings

d) Partial discharge measurement in accordance with IS 11322 : 1985.

e) Determination of errors or other characteristics according to the requirements of the appropriate designation or accuracy class

5.5.3. Optional *Tests*

The following tests, where applicable, shall be carried out by mutual agreement between the purchaser and the manufacturer:

a) Chopped lighting impulse test as a type test

b) Short circuit withstand capability test as a type test

c) Commissioning test on non-earthed voltage transformers of up to and including 36 kV.

5.6 Technical specifications of Voltage Transformers

S.No	**Type**	**Single phase, oil filled, Natural oil cooled**				
1	Nominal system voltage	33 kV	66 kV	110 kV	132 kV	220 kV

2	Highest system voltage	36 kV	72.5 kV	123 kV	145 kV	245 kV
3	Insulation level (a). Rated one min. Power frequency withstand voltage kV (rms) HV Terminal to earth (b). Impulse withstand voltage (1.2/50 micro sec. wave shape) kV (Peak)	70 170	140 325	230 550	275 650	460 1050
4	Over voltage factor (a). Continuous (b). 30 sec	1.2 1.5	1.2 1.5	1.2 1.5	1.2 1.5	1.2 1.5
5	No. of secy. winding	Three	Three	Three	Three	Three
6	Voltage ratio	33 kV/√ 3 110 V/√ 3	66 kV/ √3 110 V/√ 3	110 kV/ √3 110 V/√ 3	132 kV/√ 3 110 V/ √3	220 kV/√3 110 V/√ 3
7	Rated burden (not less than)					
	(a). Core I (Metering)	100/50 VA	100/50 VA	100/50 VA	100/50 VA	100/50 VA
	(b). Core II (Protection)	100/50 VA	100/50 VA	100/50 VA	100/50 VA	100/50 VA
	(c). Core III (Open Delta)	100/50 VA	100/50 VA	100/50 VA	100/50 VA	100/50 VA
8	Connection	Y/Y/open delta				
9	Class of accuracy					
	(a) Core I (Metering)	0.2	0.2	0.2	0.2	0.2
	(b) Core II (Protection)	3P	3P	3P	3P	3P
	(c) Core III (Open Delta)	3P	3P	3P	3P	3P

6. Capacitor Voltage Transformer

Specifications to be referred:-

IS:3156 (PART 4)-1967	Capacitive voltage transformers
IS:8263-1976	Method for radio interference test on high voltage insulators
IEC-60358	Coupling capacitors and capacitor dividers.
IEC-358-1971	Coupling capacitors and capacitor dividers
IS-5547	Application Guide for CVT
IEC-60481	Coupling devices for power line carrier system

6.1 Introduction:

A voltage transformer comprising a capacitor divider unit and an electromagnetic unit so designed and interconnected that the secondary voltage of the electromagnetic unit is substantially proportional to and in phase with the primary voltage applied to the capacitor divider unit. Capacitor voltage transformers are used for line voltmeters, synchroscopes, protective relays, tariff-meter, etc.

The performance of capacitor voltage transformer is interior to that of electromagnetic voltage transformer. Its performance is affected by the supply frequency, switching transients, magnitude of connected burden, etc. The capacitor voltage transformer is more economical than an electromagnetic voltage transformer when the nominal system voltage increases above 66 KV.

The carrier current equipment can be connected via the capacitor of the capacitor Voltage Transformers. Thereby there is no need of separate coupling capacitors.

Capacitor type VT is used for voltages 66 KV and above. At such voltages cost of electromagnetic type PTs tends to be too high.

6.2 Definitions:

6.2.1 Voltage Divider: A device comprising resistors, capacitors or inductors by means of which it is possible to obtain between two points a voltage proportional to the voltage to be measured.

6.2.2 Capacitor (Voltage) Divider: A voltage divider comprising only capacitors.

6.2.3 High-Voltage (or Line) Terminal: Terminal to be connected to the power line.

6.2.4 Low- Voltage Terminal: Terminal to be connected to the carrier frequency transmission circuit or to the earth terminal.

NOTE - The high voltage and low voltage terminals are the primary terminals.

6.2.5 Intermediate (Voltage) Terminal: Terminal to be connected to an intermediate circuit such as the electromagnetic unit of a capacitor voltage transformer.

6.2.6 High Voltage Capacitor (C): Capacitor connected between the high-voltage terminal and the intermediate-voltage terminal.

6.2.7 Intermediate-Voltage Capacitor (C): Intermediate-voltage terminal and the low-voltage terminal or the earth terminal.

6.2.8 Electromagnetic Unit: The component of a capacitor voltage transformer, connected across the intermediate terminal and the earth terminal of the capacitor divider (or possibly directly coquetted to earth when a carrier-frequency coupling device is used) which supplies the secondary voltage.

NOTE - An electromagnetic unit comprises essentially a transformer to reduce the intermediate voltage to the required value to secondary voltage, and an inductive reactance, approximately equal, at rated frequency, to the capacitive reactance of the two parts of the divider connected in parallel (CI+ CJ).The inductive reactance may be incorporated wholly or partially in the transformer.

6.2.9 Intermediate Voltage: The voltage to earth at the intermediate voltage terminal of the capacitor divider unit when primary voltage is applied between the primary and earth terminals.

6.2.10 Voltage Ratio (of a Capacitor Divider): Ratio between the sum of the capacitances of the high-voltage and intermediate-voltage capacitors and the capacitance of the high voltage capacitor.

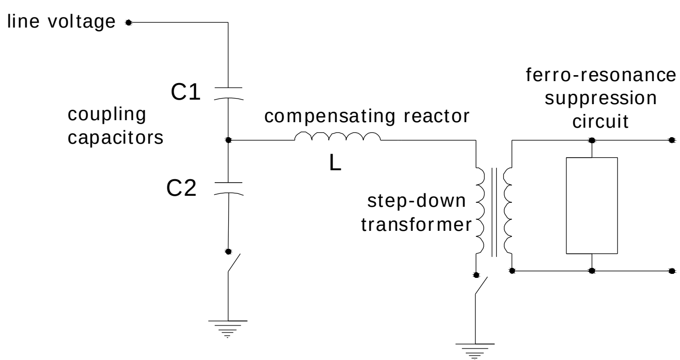
6.2.11 Rated Open Circuit Intermediate-Voltage: The voltage across the intermediate-voltage capacitor when the rated voltage is applied between the high-voltage and low-voltage terminals and both the high-voltage and the intermediate-voltage capacitors have the capacitance value for which they have been designed.

6.2.12 Reference Range of Frequency: The range of frequency value within which a capacitor voltage transformer complies with the relevant accuracy requirements.

6.2.13 Reference Range of Temperature: The range of ambient temperature values within which a capacitor voltage transformer complies with the relevant accuracy requirements.

6.2.14 Protective Device: A device incorporated in a capacitor voltage transformer for the purpose of limiting over-voltage which may appear across one or more of its components, and/or to prevent sustained ferro-resonance.

6.3 Capacitor Voltage Transformer (CVT) basic circuit:



CVT basic circuit

6.4 Accuracy Requirement:

The standard accuracy classes for capacitor voltage transformers shall be:

a) For measurement: 0.2, 0.5, 1.0 and 3.0 and

b) For protection 3P and 6P

6.5 Construction:-

The capacitors connected in series act like potential dividers provided the current taken by the burden is negligible compared with the current passing through the series connected capacitors. However the burden current becomes relatively large and ratio error and also phase error is introduced. Compensation is carried out by 'tuning'. The reactor connected in series with the burden is adjusted to such a value that at supply frequency it resonates with the sum of two capacitors. This eliminates the error. The construction of capacitor type VT depends on the form of capacitor voltage divider. Generally, h.v.capacitors are enclosed in a porcelain housing. A large metal sheet box at the base encloses the tuning coil intermediate transformer.

6.6 Capacitive voltage transformer failures (CVTs):-Though life expectancy of CVTs is about 25-35 years, many premature failures of CVTs have been reported by various power utilities. The rate of failures is about 2.6% per year, which is high as compared to international data on CVT failures (0.30-0.40% per year).

The reasons of failures generally reported are given below:

- Shorting of capacitor elements and subsequent blasting of CVT stacks
- Moisture entry from bellows due to pin holes
- Moisture entry from lower flange of bottom stack due to water accumulation and rusting
- Loosening of core bolts causing humming sound
- Failures of varistors across secondary winding.
- Wrinkles on aluminum foil
- Poor soldering quality
- Poor quality of paper (local source)
- Snapping of bellow connection
- Overheating of damping resistor
- Shorting of transformer cores
- Failures of FT circuit components

6.7 Preventive Measures for avoiding CVT Failures:-

Design modifications

- Modification of damping resistors

- Modification of metallic bellows
- Modifications of capacitor stack bottom flange.
- Strengthening of Standard Manufacturing Quality Plan (SMQP)

Stringent quality checks during manufacturing to be incorporated for quality inspection of vulnerable components/assemblies:

- Springing test on metallic bellows
- Dielectric strength of capacitor paper
- Conductivity of aluminum foil
- Resistance measurement of damping resistors
- Temperature rise test on damping resistors
- Temperature rise test on damping resistors
- Capacitor assembly: DC over potential test
- Capacitance and tangent delta measurement after voltage test (at rated voltage)
- Testing of transformer oil for BDV, moisture content, specific resistivity and tangent delta per IS – 335

6.8 Tests on Capacitive voltage transformer:

6.8.1 Type Tests

- Temperature Rise Test
- Impulse Test
- Ferro-resonance Tests
- Transient Response Tests
- Test for Accuracy

6.8.2 Routine Tests

- Power-Frequency Tests
  - Capacitor voltage divider
  - Low-voltage terminal of the capacitor voltage divider
  - Electromagnetic unit
- Tests for Accuracy

6.9 Condition Monitoring of CVTs at Site:-

Condition assessment techniques for testing healthiness of CVTs are given below:

- Capacitance and Tan delta measurement of capacitor dividers.
- Secondary voltage measurement

The norms for secondary voltage measurement are tabulated below:

6.9.1 Secondary Voltage Measurement Norms:-

S.No	Drift in secondary voltages	Condition of CVT	Measurement Frequency	Remarks
1	Up to ± 0.5 volts	Healthy	Six monthly	Secondary voltage measurement by 0.2/0.5 class meter
2	± 0.5 to ± 0.8 volts	Needs monitoring	Three monthly	
3	+0.8 to +1.2 volts	Needs close monitoring	Monthly	CVTs may not fail immediately. If there is increasing trend, then to be removed
4	+1.2 to +2.0 volts	Needs close monitoring	15 days	
5	Above + 2.0 volts	Needs close monitoring	Needs replacement	Not safe to keep in service
6	-0.8 to -4.0 volts	Needs close monitoring	15 days	--
7	Less than -4.0	Alarming	Needs replacement	--

6.10 Technical particulars of CVT:

S.no	Voltage	132 kV	220 kV	400 kV	765 Kv
1	Transformation ratio	132/√3 kV	220/√3 kV	400/√3 kV	765/√3 kV

		110/√3 V	110/√3 V	110/√3 V	110/√3 V
2	No. of secondary winding	3	3	3	3
3	Voltage factor		1.2 Continuous & 1.5 for 30 seconds		
4	Rated capacitance	4400 pF	4400 pF	4400 PF/8800 pF	4400/8800 pF
5	Rated burden	100 VA/50VA	100 Va/50 VA	100 VA/50 VA	50 VA
6	Insulation Level (a). Rated one minute power frequency withstand voltage kV (rms) (b). Impulse withstand voltage (1.2/50) micro second wave shaped kV (Peak) (c) . Switching Impulse withstand voltage (250/2500 micro secs)	275 650 ---	460 1050 ---	630 1425 1050	830 2100 1550
7	Class of accuracy (a). Core I (Metering) (b). Core II (Protection) (c) . Core III (Open Delta)	0.2 3P 3P	0.2 3P 3P	0.2 3P 3P	0.2 3P 3P

7. SURGE ARRESTERS

Specifications to be referred:

IS-3070(part-1)	Specification for surge arresters-Non-linear resistor type surge arresters
IS-3070(part-3)	Specification for surge arresters-Metal oxide lightning arresters without Gaps
IS: 8263-1976	Method for radio interference Test on high voltage insulators
IS-4004	Application guide for non-linear resistor type surge arrester
IS-4850	Application guide for expulsion type lightning arrester

7.1 Introduction:

Over voltages are due to

(i) Switching over voltage

(ii) Temporary over voltage.

The term temporary over voltage means over voltages essentially of power frequency or a frequency close to it. It is mainly due to load rejection and/or to one phase to ground faults or resonance and ferro resonance.

Protection with Surge arrester:-

Surge diverters: (i) Non- linear resistor type

(ii) Expulsion type

(iii) Spark gaps.

In order to ensure that an apparatus is not subjected to a surge voltage exceeding that which appears across a surge arrester, it is general rule to locate the arrester as close as possible to the apparatus. In particular, surge arresters should preferably be either installed on the transformer tank or its high voltage and earth terminals should be connected to the transformer by shortest possible connections.

Similarly surge arresters should be fitted close to cable terminations, if they need protection, with shortest possible connections between the terminals of surge arrester and the phase conductor and the cable sheath respectively.

a) In Substations, station type arresters should be installed on the L.V. and H.V. sides of power transformers. The arrester may be installed either on the bus or near the transformers so as to limit the distances to the values specified.

Distribution or line type arresters should be provided on all feeders rated 33KV below..

b) i) The station type arresters employed for protecting transformers should be installed as close as possible to the transformers.

ii) Long cables from the station to exposed overhead lines should be protected by arresters installed at the junction of the cable to the overhead line. The arrester should be effectively grounded at the base of the cable terminal structure and the arrester grounded terminal should also be connected to the cable sheath.

7.2 Surge Arrester Specifications and Terms:-

Surge Arrester: It **is** a device deigned to protect electrical equipment from high voltage surges and to limit the duration and amplitude of the follow current.

Non linear resistor: The part of the arrester which offers a low resistance to the flow of discharge currents thus limiting the voltage across the arrester terminals and high resistance to power frequency voltage, thus limiting the magnitude of follow current.

Rated voltage of the arrester: Maximum permissible R.M.S. voltage between the line terminal and earth terminal of the arrester as designated by the manufacturer.

Surge counter is connected in series with the earth terminal and the earthing riser. Surge counter is a part of the surge arrester pole. Readings are regularly monitored.

Follow current: The current which flows from connected power source through Surge arrester following the passage of discharge current.

Normal discharge current: Surge current which flows through the surge arrester after the spark over, expressed in crest value (peak value) for a specified wave.

Discharge current: The surge current which flows through the arrester after the spark over.

Power frequency spark over voltage: R.M.S.value of power frequency 50 c/s voltage applied between the line and earth terminals of arrester and earth which causes spark over of the series gap.

Impulse spark over: Highest value of voltage attained during an impulse of given polarity, of specified wave shape applied between the line and earth terminal of an arrester before the flow of discharge current.

Residual voltage (discharge): The voltage that appears between the line terminals of an arrester during the passage of the discharge current.

Rated current: Maximum impulse current at which the peak discharge residual voltage is determined.

7.3 Identification and Standard Ratings:

Arrester Identification:

Metal oxide surge arresters shall be identified by the following minimum .information which shall appear on a name plate permanently attached to the arrester:

- Continuous operating voltage
- Rated Voltage
- Rated Frequency, If Other Than The Standard Frequency
- Nominal Discharge Current
- Pressure Relief Rated Current in Ka R.M.S.
- (for arresters fitted with pressure relief devices)
- The manufacturers name or trade-mark, type and identification of the complete arrester
- Identification of The Assembling Position of the unit (for multi-unit arresters)
- The year of the manufacture
- Serial number (only for arresters of 60 kV and above).

Arrester section requirements:

This clause specifies a thermal model of the arrester section and shall be followed when thermal prorating is required:

1. The model must electrically and thermally represent a sliced portion of the active part of the arrester being modelled.
2. The housing must meet the following requirements.
   - i) Material shall be the same as that of the arrester housing.
   - ii) Inside diameter shall be the same as that of the arrester within ± 5 percent.

iii) The total mass of the porcelain must not be more than 10 percent greater than the mass of the average porcelain section of the arrester being modelled.

iv) The housing must be long enough to enclose the arrester section and the amount of insulation at the two ends shall be adjusted so as to meet the thermal requirements.

3. Maximum conductor size used for electrical connections within the sample Shall be 3 mm diameter copper wire.

7.4 Tests on surge arresters:

7.4.1 Type Tests:

- Insulation Withstand Test
- Residual Voltage Tests
- Long Duration Current Impulse Withstand Test
- Operating Duty Tests
- Pressure Relief Test
- Tests Of Arrester Disconnector
- Artificial Pollution Test on Porcelain Housed Arresters
- For Porcelain Housed Arresters
  - a) Temperature Cycle Test.
  - b) Porosity Test
- Galvanizing Test on Exposed Ferrous Metal Parts

7.4.2 Routine tests and acceptance tests

7.4.2.1 Routine Tests:

The minimum requirement for routine tests to be made by the manufacturer shall be:

a) Measurement of reference voltage.

b) Residual voltage test.

c) Satisfactory absence from partial discharges and contact noise shall be checked on each unit by any sensitive method adopted by the manufacturer.

d) For arrester units with sealed housing leakage check shall be made on each unit by any sensitive method adopted by the manufacturer.

e) Current distribution test for multi-column arrester.

7.4.2.2 Acceptance Tests

1. Standard Acceptance Test: When the purchaser specifies acceptance tests in the purchase agreement the following tests shall be made on the nearest lower whole number to the cube root of the number of arresters to be supplied:

a) Measurement of power frequency reference voltage.

b) Lightning impulse residual voltage

c) Partial Discharge Test.

7.5 Guide for selection of Surge arrester:-

Before selecting the L.A. it should be ascertained whether the system is effectively earthed, non-effectively earthed or having isolated neutral.

The L.As are usually procured along with the surge counters and leakage current ammeters if available.

The L.A.voltage ratings corresponding to the system voltage s normally adopted are indicated below:

Rated system voltage KV	**Highest system voltage KV**	**Arrester ratings in KV Effectively earthed system**
11	12	9
33	36	30
66	72.5	60

132	145	120
220	245	198
400	420	336

7.6 Location of Surge arresters:-The L.A.s employed for protecting transformers should be installed as close as possible to the transformer. The electrical circuit length between L.A. and the transformer bushing terminal should not exceed the limits given below:

Rated system voltage kV	**BIL kV (peak)**	**Max. distance between L.A. & Transformer Bushing terminal(in meters) Effectively earthed system**
11	75	12.0
33	200	18.0
66	325	24.0
132	550 650	35.0 43.0
220	900 1050	Close to transformer
400	1425 1550	Close to transformer

Station type L.A.s should be installed on the H.V. and L.V. side of power transformers in sub-stations. Line type L.A.s should be provided on all feeders rated 33KV and below.

Protection against traveling waves entering the station as a result of strokes on unshielded transmission lines or on ground wires or on adjacent objects provided by the installation of lightening arresters at the stations.

7.7 Technical specification of Surge arresters:-

7.7.1 Suggested over- voltage envelope for the arresters in 230KV and 400KV Sub-station:-

S.No.	Description	230KV system		400KV system	
		Transmission SS --KV rms	Power stans. & Vital Trans. SS --KV rms	Transmission SS --KV rms	Power stans. & Vital Trans. SS --KV rms
1.	Nominal system voltage	230	230	400	400
2.	Highest system voltage (L.L.) (L.G.)	245 198	260 214	420 336	450 360
3.	Max. continuous operating voltage withstand level	168	184	286	306
4.	Temporary over voltage i) 0.1 Sec. ii) 1.0 Sec. iii) 10 Sec.	 243 233 224	 281 276 259	 325 326 318	 335 326 318

7.7.2 Comparison between conventional gapped and gapless arrester:

S.No.	**Description**	**230KV system**		**400KV system**	
		Conventional gapped	**Gapless arrester**	**Conventional gapped**	**Gapless arrester**
i) System data					

1.	Max.system voltage for equipment kV rms	245	245	420	420
2.	BILof the protected equipment KVP	900	900	1300	1300
3.	BSLofthe protected equipment	765	765	1050	1050
ii) **Arrester characteristics**					
4.	Arrester rated Voltage KV rms	198	Not specified	360	Not specified
5.	Max.continuous operating voltage	Not defined.	184	Not defined.	306.
6.	Temporary over voltage i) 0.1 Sec. ii) 1.0 Sec. iii) 10 Sec	Not defined.	281 276 259	Not defined.	335 320 318
7.	Nominal discharge Current 8/20 micro sec. (KA)	10	10	10	20
8.	impulse surge current withstand 4/10microsec. (KA)	100	100	100	100
9.	Switchingsurge current(square wave strength) (KA) 2000 micro sec	1	1	2	2
10.	Energy absorption capacity	BIS class ii (2.2KJ/KV)	BIS class iii (4.3KJ/KV)	BIS class iii (4.1KJ/K	BIS class iv (6KJ/KV)

				V)	
11.	Lightning impulse residual voltage at rated discharge current 8/20 micro sec. (KVP)	550	525	875 (at 10KA)	850 at 10KA 950at 20KA
12.	Lightning surge wave 1:2/50 Micro sec. (KVP)	550	525	875 (at 10KA)	850 at 10KA 960at 20KA
13.	Steep current impulse residual voltage KVP	630	612	1050 (at 10KA)	952 at 10KA 960at 20KA
14.	Max.switching surge wave (KVP) Residual voltage	550	446	850	720
15.	Percentage rating of the arrester	80	75	80	73
16.	Pressure relief class	Class-A	Class-A	Class-A	Class-A
17.	Creepage distance of outer porcelain housing In polluted regions polluted free zones	9800 6400	9800 6400	10000 10000	10500 10500
18.	Insulation withstand of external housing Impulse (KVP) P.F.withstand KV	1050 480	1050 480	1450 685	1450. 685.
19.	Ambient temperature	50°c	50°c	50°c	50°c

7.7.3 Technical Parameters of Surge Arresters:

S.No	Item	66kv	132kv	220kv	400kv	765kv
1	System voltage kv	66	132	220	400	765
2	Highest system voltage kv	72.5	145	245	420	800
3	Rated voltage arrestor kv	60	120	198/216	390/360/336	624
4	Nominal discharge current	-------------------------------10 KA--------------------------------				20 KA
5	Class	class3	class3	class3	class 3	class 5
6	Pressure relief class	--A--				

8. CAPACITORS

Specifications to be referred:

IS-1980 Ceramic dielectric capacitors,Type-1

IS-2786(Part-2)	Ceramic dielectric capacitors,Type-2
IS-2834	Shunt capacitors for power systems
IS-9835	Series Capacitors for power systems
IS-11548	Capacitors for Surge protection for voltage levels above 650Volts & up to 33kV
IS-11530	Voltage Grading capacitors

8.1 Introduction:

Capacitors are widely used in distribution systems to achieve power and energy loss reduction, system capacity release and to maintain a voltage profile within permissible limits. The extent of these benefits depends on the location, type and number of capacitors.

Series capacitors are used to allow higher power transfer over a long distance. The shunt capacitor banks are used at the receiving end of heavily loaded transmission lines. The series and shunt capacitors are used to control the reactive power during lightly loaded/over load conditions.

8.2 Shunt Capacitors:-

Shunt capacitors are meant only to compensate the VAR needs of the load and the system. This means that the load should not need any VAR from the source through transmission lines i.e. the reactive component of the load is generated locally through shunt capacitors and there will not be any reactive component current dispatched by generators if the capacity of capacitors is properly quantified and located. Thus, there will not be any voltage drop in the line due to reactive component of the load current. This in turn brings back the voltages at the load end almost to the unloaded line voltage level and this is considered as increase by engineers.

(a) Reduce the line current by nullifying the inductive reactance current component through the capacitive reactance current. This helps
  - Reduce the line losses.
  - Increase the MW loading capability of lines.

- Reduce the line voltage drop there by bringing the receiving end voltage nearer to sending end voltage.

8.2.1 Shunt capacitors installations at substations provide the following advantages:-

(i) They ensure that the transmission of inductive KVAR to the load area from the generating source is kept at reasonable limits.

(ii) They avoid over loading of circuits and/or release circuit load carrying capacity.

(iii) By avoiding over loading they release spare MVA, capacity on the generators.

(iv) They reduce system I^2 R losses. A unit saved is 2 units generated.

(v) They improve the voltage regulation and or restore it to an acceptable level for a given load.

8.2.2 Negative effect of over usage of shunt capacitors:-

"Shunt capacitors applied to correct the power factor of a composite load adversely affect its stability. The stability margin goes on decreasing with increasing rating of shunt capacitors."

8.3 LT Capacitors:-

Shunt capacitors may also be used on LT lines to improve the line voltage and also to reduce the line losses. They can be used either on the secondary side of the transformers or at the load points.

Normally LT capacitors are used by the LT consumers to improve their power factors and the series capacitors by the suppliers to suppress the flickering in line voltages.

8.4 Series capacitors:-

Series capacitors which are connected in series with the circuit, introduce negative or leading reactance in the line. Current through negative reactance causes voltage drop that leads the current by 90 degrees. This drop is opposite in nature when compared to that across an inductive reactance. Thus, a series capacitor compensates for the drop or part of the drop through the inductive reactance of the feeder. The main advantage of series capacitor is that the quantum of compensation is dependent on load current and is given by QS = IXc. Hence the series capacitor can be kept in service during the complete load angle without causing the adverse effect of over voltages during light load period.

The series capacitor is not a reactive power compensation device but a reactance compensation device. Since the series capacitors greatly influence the reactive power conditions of transmission system, it is, however, proper to include also them in the description of reactive power compensation devices.

Series capacitors are mainly installed in EHV transmission systems for one or more main reasons. One of these is to increase the transmission load capability as determined by transient stability limits. The other reason is to obtain a desired load division among parallel circuits. Further, series capacitors favorably influence the control of both the voltage and the reactive power balance. The reason for this is that the reactive power generated in a series capacitor increases with increased transmitted load; a series capacitor is to some extent a self regulating device in this respect.

Series capacitors are employed for long EHV lines in several countries, on a large. The degree of compensation usually lies between20 and 70 percent, as referred to the line inductive reactance. EHV series capacitor installations usually range in size between 100 and 800 MVAR.

8.4.1 Location of Series Capacitor:-the effect of a series capacitor on a circuit is from its point of location towards load end. Hence on a radial feeder, series capacitor must be located at source and load whose voltage is to be improved. if there are number of tapped loads distributed throughout, the rule of thumb for the best location of series capacitors is at, about one third of electrical impedance of the feeder from source bus.

8.4.2 Rating of series capacitors:-

The ratings have to be determined for series capacitors i.e. KVAR, voltage and current. As series capacitor has to carry full line current in the circuit where it is inserted, its continuous current rating should be at least equal to peak line current and preferably greater than the peak line current for the purpose of catering further load growth. The value of Xc depends on the percentage of compensation required. The voltage rating is (IXc) and KVAR rating per phase is ($3I^2R$)

8.5 Shunt Reactors

Specifications to be referred:

IS-5553(PART-1) Reactors-General Requirements

IS-5553(PART-2) Reactors-Shunt reactors

IS-5553(PART-3) Reactors-current limiting &neutral earthing reactor

IS-5553(PART-4) Reactors-Damping Reactor

IS-5553(PART-5) Reactor-Tuning Reactor

IS-5553(PART-6) Reactor- Earthing Transformer

IS-5553(PART-7) Reactor- Arc suppression

IS-5553(PART-8) Reactor- Smoothing reactor

The purpose of reactor is to compensate the capacitive charging power of three-phase high voltage lines. With the growth of 400KV lines and 765KV AC lines the need for shunt compensation reactors increases.

8.5.1 Types of construction of shunt reactors

(i) oil-immersed with gapped core
- single phase unit
- three phase unit

(ii) Oil-immersed coreless.
- single phase unit
- Three phase unit.

(iii) Air core reactors
- outdoor
- Indoor.

8.5.2 Constructional features of shunt reactors:-

Shunt reactors may be of the dry type or oil-immersed type. They may be constructed with or without magnetic core or electro magnetic shield or magnetic shield.

There are basically two different kinds of high voltage shunt reactor, namely with or without a magnetic core in the centre of the winding. The magnetization characteristic of both types is not exactly linear.

In the case of an air- core reactor, however, saturation occurs at a higher voltage and is less pronounced than in a reactor which has a magnetic core. It has therefore become customary to speak of linear characteristics (air core reactor) and non-linear characteristics (reactors with magnetic cores).

For a low voltage reactor intended for connection to the tertiary winding of a transformer, the magnetization characteristics is of no practical significance. The study of H.V. transmission systems indicates that it is better to use reactors with a non-linear characteristic. Their main advantage is that reactance drops as voltage increases, and so the reactive power absorbed i.e. the degree of compensation is higher.

For compensation of EHV-AC lines, oil-immersed shunt reactors with gapped magnetic core in the centre are generally preferred.

8.5.3 Types of cooling:-

- ONAN (oil natural air natural)
- ONAF (oil natural air forced)
- OFAF (oil forced air forced)

8.5.4 Different types of Shunt reactor connections and their applications:-

Application	**connection**	**Remarks**
1.Shunt compensation	Direct	For a long EHV lines
	through C.B.	At sending end
	Via Tertiary	At receiving-end
		At intermediate substation

(i) Shunt reactor connected to line/bus bars:-

Shunt reactors in 400KV systems are connected directly to line/bus bar without circuit breaker for switching due to following reasons.

- While switching on the transmission line circuit breaker, the shunt reactor is essential to limit switching surges and power frequency over voltage within permissible limits.
- Conventional circuit breakers used for 400KV systems do not have reactor switching capability to switch such compensating reactors. Special circuit breakers with proven reactor current breaking capacities with switching over voltage within specified limits would be necessary for reactor switching.
- The direct connection of shunt reactor has techno-economic advantages.

(ii) Shunt reactor connected with a switching device:- The switching device capable of reactor switching must be available. Reactor switching is a difficult duty for circuit-breakers due to:

- High stored energy in rector corresponding to the chopping current.
- High switching over voltage factor above 3 p.u. which is not permissible.

For voltage levels below 245KV, SF_6 circuit-breakers have been developed to meet the above requirements.

(iii) Shunt reactor connected to tertiary terminals:-

The advantages are

- A circuit breaker can be incorporated at lower voltage level.
- Cost of shunt reactor is reduced. However the choice between three schemes is finalized after detailed technical and economic feasibility studies.

8.5.5 Technical particulars of Shunt reactor:

For 400 KV Shunt Reactors:-

Rated voltage (KV)	420 (1.0 pu)
System fault level (KA)	40
(a) lightning impulse 1.2/50µs Withstand voltage (Kvp)	1300
(b) Switching surge impulse 20/200/500µs voltage (Kvp)	1050

Insulation level of neutral

(a)Impulse withstand voltage (Kvp)	550
(b)Power frequency voltage (rms)	230

9. INSULATORS

Specifications to be referred:

IS-8765	Ceramic insulating material for electrical purpose
IS-8704	Methods for artificial pollution test on High voltage Insulators
IS-3188	Dimensions for disc Insulators
IS-5350	Dimensions of Indoor & Outdoor porcelain Post Insulators

IS-2486	Insulator fittings for over head power line with nominal voltage >1000 Volts
IS-7935	Insulator fittings for over head power line with nominal voltage <1000 Volts
IS-4318	Solid core porcelain Insulators

9.1 Introduction:

The operating performance of a substation depends upon insulators. All the current carrying parts in a substation are supported on insulators. The insulators provide mechanical support to the conductors and are subjected to normal operating voltage and transient over voltages. The insulators should not fail due to mechanical load or over voltages. Porcelain is very widely used for insulators.

The electric stresses applied to an insulator are:

1) internal stresses resulting from

(a) Normal power frequency voltage,

(b) Power frequency over voltage caused by faults or abnormal conditions, and

(c) Switching impulse over voltage and

(2) Externally applied stresses due to lightning.

9.2 Definitions:

Insulator String — One or more string insulator units intended to give flexible support to an overhead line. The insulator string is intended to be stressed only in tension.

Suspension Insulator Set — One insulator string or two or more strings suitably connected together, complete with fittings for flexible attachment to a supporting structure and to carry a line conductor or conductors at its lower end. The term 'set' includes all other metal parts and accessories as required in service.

Tension Insulator Set — One insulator string, or two or more strings suitably connected together, complete with fittings for flexible attachment to a supporting structure and to secure a line conductor or conductors in tension. The term 'set' includes all other metal parts and accessories as required in service.

Rigid Insulator — An insulator intended to give rigid support to an overhead line and to be stressed mainly by bending and compressive loads.

Pin Insulator — A rigid insulator consisting of a single piece of porcelain or of two or more porcelain components permanently connected together, and intended to be mounted rigidly on a supporting structure by an insulator pin passing up inside the insulator. Unless otherwise stated, this term excludes the insulator pin.

Line Post Insulator — A rigid insulator consisting of a porcelain part permanently secured in a metal base and intended to be mounted rigidly on a supporting structure by means of a stud attached to the base. Unless otherwise stated, this term includes the stud.

Shell — A single insulating member without cement or other connecting devices.

Lot — All the insulators of the same type and design manufactured under similar conditions of production, offered for acceptance; a lot may consist of the whole or part of the quantity ordered.

Flashover — A disruptive discharge external to the insulator, connecting those parts which normally have the operating voltages between them.

Puncture — A disruptive discharge passing through the solid insulating parts of an insulator.

NOTE — A fragment breaking away from the rim of a shed or damage to the insulator due to the heat of a surface discharge is not considered a puncture.

Dry Impulse Withstand Voltage — The specified impulse voltage which the insulator shall withstand, under the conditions without flashover or puncture.

Fifty-Percent Dry Impulse Flashover Voltage — The impulse voltage which, under the conditions has a 50 percent probability of producing a flashover on the insulator.

Wet Power-Frequency Withstand Voltage — The specified power-frequency voltage which the insulator shall withstand (wet) under the conditions prescribed for the specified time (one minute) without flashover or puncture.

Wet Power-Frequency Flashover Voltage — The arithmetic mean value of the measured power-frequency voltages which cause flashover of the insulator under

Electromechanical Failing Load — The maximum load which can be reached when a string insulator unit is tested under the conditions prescribed

Mechanical Failing Load — The maximum load which can be reached when a string insulator unit or a rigid insulator is tested under the conditions prescribed

Puncture Voltage (of a String Insulator Unit or a Rigid Insulator) — The voltage which, under the conditions prescribed causes puncture.

Creepage Distance (of an Insulator) — The shortest distance or the sum of the shortest distances along the contours of the external surfaces of the porcelain insulating parts of the insulator between those parts which normally have the operating voltage between them. A distance over a cement surface shall not be considered as forming part of the creepage distance. If high-resistance coatings are applied to parts of the insulator, such coatings shall be considered effective creepage surfaces and the distance over them is included in the creepage distance (*see* Fig. 1).

NOTE 1 — The surface resistivity of such high-resistance coatings is usually about 10^5 ohms, but may be as low as 10^4 ohms.

NOTE 2 — If high-resistance coatings are applied to the whole surface of the insulator (the so-called stabilized insulator), the questions of surface resistivity and creepage distance should be subject to agreement between the user and the manufacturer.

Protected Creepage Distance — That part of the creepage distance on the illuminated side of the insulator which would lie in shadow if light were projected on to the insulator in a direction at 90° to the longitudinal axis of the insulator (*see* Fig. 1).

Highest Voltage of a System — The highest rms line-to-line voltage which can be sustained under normal operating conditions at any time and at any point on the system. It excludes temporary voltage variations due to fault conditions and the sudden disconnection of large loads.

9.3 Construction of insulator:

The following three materials are used in the manufacture of substation insulators.

(i) Porcelain
(ii) Glass
(iii) Synthetic resin.

(i) Ceramics: - These are used for bushings, enclosures, supporting insulators, and strain insulators. The ceramic insulators are used in circuit breakers, CT's, PT's, isolators and almost all electrical equipment. The most used ceramic materials are electrical porcelain and steatite.

(ii) Porcelain: - Porcelain is a ceramic material. A good electrical porcelain is free from internal laminations, laminations, holes, cooling stresses, cracks.

The porcelain insulators are used for the following components.

- Support insulators.
- Enclosures for interruption chambers.
- Hollow insulators for passage of gas/air.
- Insulators bushings.

(iii) Glass insulators: - These are available in pin type for voltage up to 66KV. Toughen glass suspension insulators are available for all transmission voltages.

(iv) Synthetic insulators: - These have been developed for various applications. They consist of fiber glass bonded high strength core with sheds of synthetic porcelains silicon rubber,PRFA,cycle alphabetic,risen,etc.synthetic resin insulators have high strength to weight ratio. Most synthetic resin insulators have poor ageing properties when subjected to sunlight. They are not suitable for outdoor applications.

For indoor busbars, indoor bushings, etc epoxy resin cast insulators are used. They are cheaper, stronger and lighter than the porcelain insulators.

9.4 Technical requirements of insulators:-

- The insulator shall conform to IS: 2544 and/or IEC-168.The porcelain of the insulator shall conform to the requirements stipulated under part-1 general Technical requirements and shall have minimum cantilever strength of 800/800/600 Kgs, For 420/245/145 KV insulators respectively.
- Pressure due to contact shall not be transferred to the insulators after the main blades are fully closed.
- The parameters of the insulators should meet the requirements specified under part- general Technical requirements.
- Insulators shall be type and routine tested as per IEC-168.besides following additional tests shall also be conducted.
  - Bending load testing four directions at 50% of minimum bending load guaranteed on all insulators, as a routine test.
  - Bending load testing four directions at 100% of minimum bending load as a sample test on each lot.
  - Tensional test on sample insulators of a lot.
  - Ultrasonic test as a routine test.

9.5 Types of insulators used in substations:-

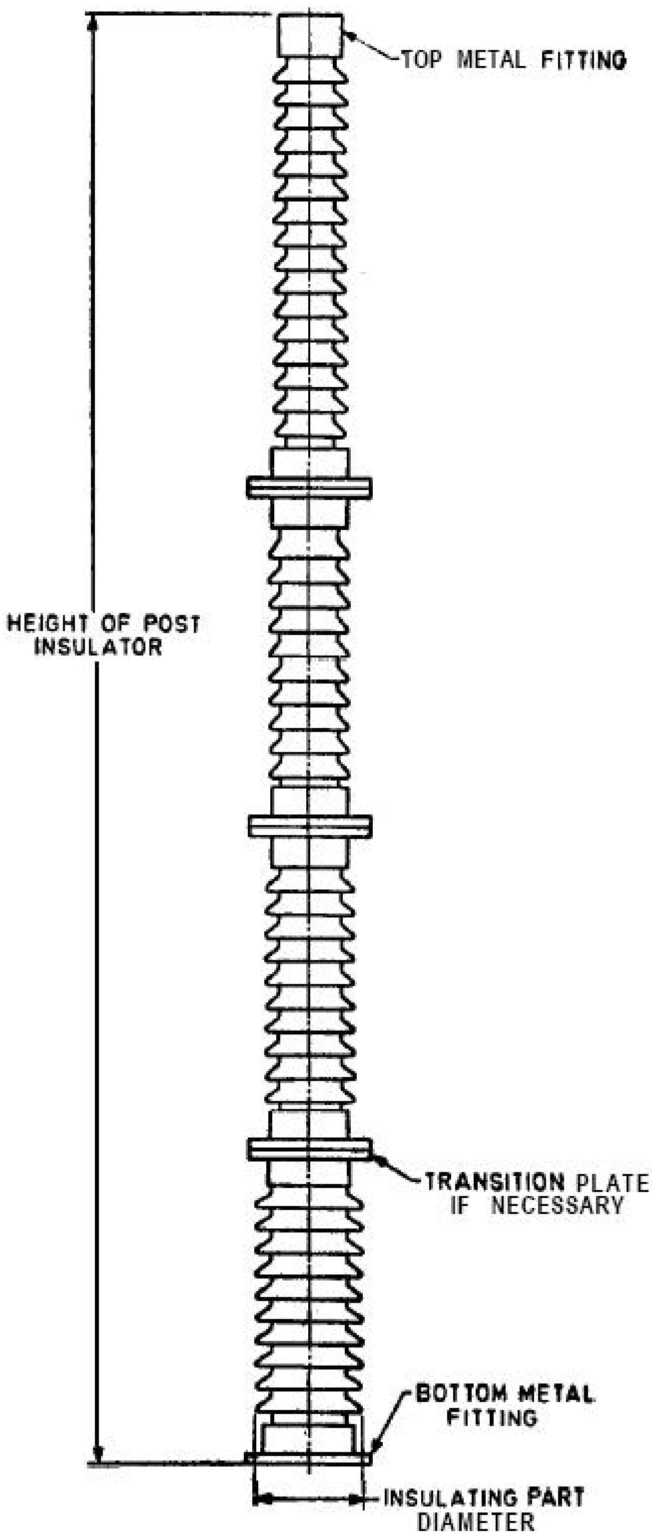
In a substation, several types of insulators are used. These include the following:

(i) Pin insulators
(ii) Post insulators
(iii) Strain insulators
(iv) Suspension insulators
(v) Hollow apparatus insulators
(vi) Dead-end insulators
(vii) Solid core insulators.

The insulators have certain insulation level. The insulation level is characterized by the following.

- Nominal voltage and highest system voltage
- One minute power frequency withstand voltage
- Standard lightning impulse withstand level
- Standard switching impulses withstand level

9.5.2 Post Insulators:



Post insulators are standardized in mechanical strength classes based on Values of the specified failing load in the bending test, chosen to conform as far as possible with current practice. Unless otherwise agreed, it is assumed that a post insulator is to be mounted in the upright position, that is, with the live end at the top.

It is also assumed that the load is applied at the top surface. Where insulators are to be mounted under hung, the standard values of bending strength may not be applicable. Other positions of mounting (for example, horizontal) may also affect the strength if the weight of the Post insulator is not negligible. The appropriate strength rating for methods of mounting other than upright shall be subject to agreement between the manufacturer and the purchaser.

The mechanical strength classes for outdoor cylindrical post- insulators are as follows :

Strength Class 2	2 000 N
Strength Class 4	4 000 N
Strength Class 6	6 000 N
Strength Class 8	8 000 N
Strength Class 10	10 000 N

Mechanical strength in tension, compression and torsion are also given in Table 1. However, tension and compression values are for general guidance where these are important for special applications. A failing load Px may also be specified and will refer to a load applied at x mm above the top face of the insulator. The value of such loads shall be subject to agreement between the purchaser and the manufacturer.

9.5.5 Hollow Insulator:

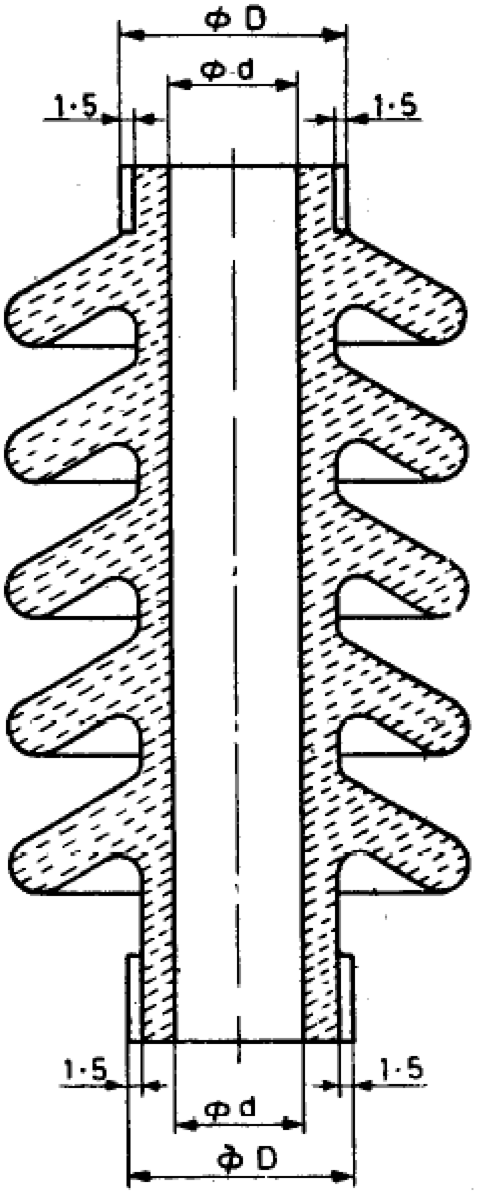


Fig: Hollow Insulator

A hollow insulator consists of a single insulating element or of several parts permanently joined together.

The hollow insulators consist of hollow bodies, open from end to end with or without sheds, intended for use in electrical equipment such as of the following types:

a) Instrument transformers,

b) Lightning arresters,

c) Capacitors,

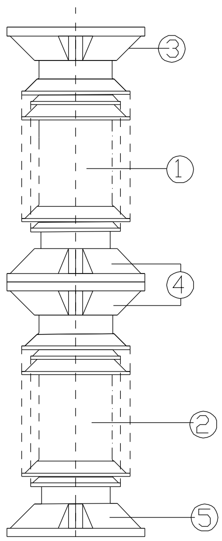
d) Bushings,

e) Cable sealing ends,

f) Circuit-breakers, and

g) Cable sealing boxes.

9.5 Solid core insulators: The porcelain long rod insulators are used as suspension and tension insulators. Both single and multiple suspension strings as well as single and multiple tension strings are used.



Power lines equipped with single or multiple strings consisting of long rod insulators have proved their superiority under the most arduous mechanical, electrical and climatic conditions.

Our Principals, SIEMENS and in house technical experts assist our clients in choosing long rod insulators, especially with regard to their electrical qualities, the necessary creepage distances and the required fittings.

9.5.1 Ideally Suited for Insulated Cross-arm

To meet the increasing requirement of power everywhere, more electrical energy needs to be transmitted on the existing lines. This requires upgradation of the operating voltage of the existing transmission lines. This is an area where long rod insulators find their most important and latest applications.

Parts:

1&2 ---- Insulator Body

2 ----Brown Glazed

3, 4&5 ---Cap& Flange

4 --- Hot-Dip Galvanized

Because of their superior design, it is possible to have long rod insulators of suitable length and high mechanical strength. Such long rod insulators have opened up the possibility of their use as insulated cross arm where line conductors can be attached directly to the cross arm without having the necessity to increase the tower length and also, without requirement of wider right-of-way, the insulated cross arm made of long rod insulators gives us the necessary clearances for updating the existing transmission lines to higher voltage levels.

9.5.2 Flexible Configurations Possible

Only with long rod insulators, it is possible to have the flexibility of various configurations in their installation in overhead lines. Extensive research and experience of use of long rod insulators have resulted in their use as single, multiple V-, inverted V-, Y-, or t-shaped string arrangements depending upon the kind of requirement.

The importance of the use of long rod insulators in various configurations, both in single as well as multiple strings manifests its importance in the situations where the necessary right-of-way needs to be shortened. Possibility of their use in narrow right-of-way reduces the required tower cross arm length and thus cost reduction is also possible.

9.5.3 Strings

Long rod insulators are gaining greater importance as the need to shorten the necessary right-to-way increases. In place of the standard suspension strings. V-or Y-shaped arrangements can be fixed to voltage lines of 110 kV and above.

A necessary clearance between the line conductors and the tower itself must be allowed for when wind pressure causes the insulators to swing out. The swinging of the suspension insulator requires a longer cross arm and thus a wider right-of-way. Swinging motion is considerably reduced in the case of insulator chains by the use of a Y-shaped arrangement and therefore shorter cross arm can be installed. The conductors cannot swing towards the tower body if V-shaped chains are applied. This reduces the width of the right-of-way and therefore makes the design of the overhead line more economical the long rod insulators can fix to each other by special intermediate flanges to achieve a rigid connection between the single parts of a long rod chain.

9.5.4 Absolutely puncture proofs

The long rod insulators are not prone to puncture because of their shortest puncture path which is approximately equal to shortest arcing distance. Moreover, the electric field distribution of an energized long rod insulator is completely free from extremely high peaks, thereby offering substantial advantages. There is electrical stress of approximately 0.70 kV/cm on the surface of long rod insulator, which is far below its puncture resistance.

In contrast to this, cap and pin type insulators have electrical field of about 5 kV/cm on the insulator surface which is slightly higher compared to puncture resistance of air. Therefore, while long rod insulators are impossible to be punctured the corresponding string of conventional cap and pin type insulators are penetrable.

9.5.5 Regular Inspection Unnecessary

Cap and pin type insulators are penetrable because of the existence of intermediate fittings and therefore, it is essential to have regular inspection as such lines to be carried out and maintenance undertaken wherever required. This exercise can save considerable time, effort and cost on the part of the owner organization and its engineers. In the case of long rod insulators are totally puncture proof. This advantage offers significant overall savings and facilitates uninterrupted transmission of power.

9.5.6 Excellent Anti Pollution Performance

During the service life of overhead lines, the insulators are subjected to severe weather conditions such as wind, thunderstorm, desert conditions which contaminate the insulator surface and may affect its performance. This problem can be alleviated by having a suitable shed profile of the insulator. Strings of cap and pin type insulators have their own inbuilt limitations in this regard because of their intermediate fittings.

In comparison to this, long rod insulators can be produced with various types of optimal shed profiles such as:

- Overhead and steep sheds (“open” or “protected” design)
- Sheds with drop late rims
- Plain sheds without drop late rims
- Sheds with under ribs

In addition, the creepage path is enhanced in the axial direction in the case of long rod insulator, thereby providing many more possibilities of shed configurations in the radial direction. These shed profiles have resulted from extensive research conducted to increase the anti-pollution performance in various conditions.

Moreover, while operating in contaminated environment, long rod insulators have extremely low leakage current which results in considerable energy savings as compared to cap and pin type insulator.

9.5.7 Good Self Cleaning Ability

The wind and rain are disadvantageous for cap and pin type insulators because of their intermediate fittings and their under sheds easily attach dust and prevent their self cleaning. In comparison to this, the possibility of superior shed profile facilitates self cleaning process in ling rod insulators.

For long rod insulators, plain sheds have been highly successful because of their excellent self cleaning properties. Operating mostly under solid contamination (such as industrial and desert), the she3ds should have low inclination (aerodynamic shed design). Long rod insulators which this shed design have been successful in desert contamination by preventing concentrated deposition of salts and dust. Similarly plain sheds with steeper inclination are advantageous is liquid contamination areas (such as salt fog) because of attainment of larger protected creepage distance.

9.5.8 Less Radio and Television Interference

In conventional disc insulators, the existence of very high peaks of electric field on the pin very often leads to incidents of gliding or corona discharges accompanied by high frequencies. This phenomenon results in disturbances from radio and television transmission.

In long rod insulators, because of their superior design, the electric field distribution is highly homogeneous both within and outside the insulator surface. In such a situation field concentrations, which are responsible for radio and television interference due to electrical discharges are minimized. Moreover, in long rod insulators, further reduction in radio and television disturbances can be achieved by having protected fittings.

9.5.9 No Cascade Flashover

In homogeneous electric field distribution in cap and pin type insulators strings resulting from their intermediate fittings leads to frequent occurrences of cascade flashover. This never happens in long rod insulators even under non-uniform contamination due to their favorable electric field distribution.

Salient Features

- Absolutely puncture proof
- Regular inspection unnecessary
- Excellent anti-pollution performance
- Good self cleaning ability
- Low radio and television interference
- No cascade flashover
- Lower partial discharges hence less power loss
- Fully protected against power arcs
- No cement growth problem
- No ball pin shearing due to aeoline – vibrations
- Immunity against thermal puncture Lower dead-weight
- Low vandalism losses
- Flexible configurations possibility
- Ideally suited for insulated cross-arm
- Experience-based reliability and stability

9.5.10 Lower Partial Discharges Hence Less Power Loss

In disc insulators, the pin tends to attract the creep flashover towards the string, consisting of multiple disc insulators which, when accumulated, may possibly result in an internal explosion of the surrounding cemented area as well as porcelain and metal caps. The probability of this happening is increased where short circuit capability of the network is higher. Happenings such as this can severely damage one or more discs and thereby irreversibly diminish the insulator performance.

Because of uniform electric field distribution on the surface of long rod insulators, possibility of occurrence of creepage discharges is minimized. This ensures the continued mechanical safety and insulating capability of the long rod insulator. Therefore, the long rod insulator certainly offers less power loss and thus superior performance.

9.5.11 Fully protected Against Power Arcs

Long rod insulators can be easily protected against onslaught of power arcs. This is possible since there are either no intermediate caps or, if there are any these caps are equipped with arc protective fittings. Task of arc protective fittings is to safeguard the long rod insulators against power arcs and at the same time limit RIV.

On cap and pin type insulator string protective fittings are not installed on all the intermediate fittings but put only at the ends due to economic considerations. Therefore, there is possibility of partial power arcs getting developed towards any or all metal parts of the string. Overall impact of such partial power arcs can result in destruction of one or more discs. Moreover, the unprotected pins may melt under the stress of multiple flashovers and cause the break-down of the insulator string.

9.5.12 Mechanical advantages:

No cement Growth Problem

Because of their superior design, it is possible to manufacture single piece long rod insulators of larger lengths and this reduces the number of units per string to only 1,2 or 3 for 132, 220 and 400 kV respectively. In such a situation the number of metals parts required to be cemented between individual units of the overall insulator string of the required voltage is reduced. Thus there is no cement growth problem in long rod insulators.

No Ball Pin Shearing Due To Aeoline-Vibrations

In order to fasten the conductor safely to the earthed tower with disc insulators, ball pins are utilized. The occurrence of aeoline vibrations causes shearing of these ball pins thereby impairing the functioning of the insulator string. This problem does not exist in long rod insulators since no ball pins are required in their assembly.

Immunity against Thermal Puncture

Thermal punctures are impossible with long rod insulators made of alumina porcelain in contrast to cap and pin type insulators where these occur frequently. The reasons are low-tan x value and the long insulating path through the porcelain which is nearly the same as the arcing distance.

Lower Deadweight

The number of long rod insulators used in one string is limited to one, two or three and therefore, these reduce the overall weight of the complete string in comparison to the corresponding string consisting of cap and pin type disc insulators. This reduction is possible mainly due to elimination of intermittent metal parts. This greatly lowers the overall deadweight on the towers.

Low Vandalism Losses

Vandalism is a serious and increasing problem in many countries; the experience has shown that generally vandalism is caused by small caliber rifles or pebbles. Because of slim shaped superior design and higher impact resistance, such kind of vandalism can hardly damage long rod insulators.

Guaranteed technical particulars of Solid core insulators:
General:
1. Standards applicable IS: 2544-1973/IEC: 168-1984
2. Types of insulators : Solid core post type
3. No. of units per Stack: 2
4. Min.nom. Crrepage distance mm 6125
5. Net weight approx. KG 130

Mechanical values:

1. Ultimate cantilever strength	KN	6
2. Ultimate torsinol strength	KN.M	4.5
3. Ultimate tensile strength	KN	110
4. Ultimate compression strength	KN	270

Electrical values:

1. Nominal system voltage		kV (rms)	220
2. Highest system voltage		kV (rms)	245
3. Dry power frequency withstand voltage		kV (rms)	510
4. Wet power frequency withstand voltage		kV (rms)	480
5. Lightning impulse withstand voltage		kV (peak)	1050
6. Dry power frequency flash over voltage		kV(rms)	575
7. Wet power frequency flash over voltage		kV(rms)	525
8. Impulse flash over voltage			
	Positive	kV (peak)	1150
	Negative	kV (peak)	1100
9. Visible discharge voltage		kV(rms)	156

9.5 Technical particulars:

9.5.1 Test voltages:-

(i) Post insulators for busbars and switches

Insulator Nominal Voltage(3-ph) KV	Impulse withstand Test KV	Power frequency momentary withstand dry test KV	Power frequency withstand wet test KV	Power frequency withstand puncture test on units	Visible discharge test KV
3.3	50	20	16	1.3 times the actual dry flashover voltage of the unit.	3
6.6	75	30	22		5.5
11	95	40	30		9
22	150	75	55		18
33	200	110	80		27
66	350	190	150		53
110	450	245	195		88
132	550	300	240		105
220	900	470	385		154

(ii) Power frequency and impulse test voltages for line insulators (BSS 137-1960):-

Insulator nominal Voltage (3-phase) KV	Impulse withstand test voltage KV	One minute dry test KV	One minute wet test KV	Over-voltage test		Visible discharge test KV
				Pin or line post insulators KV	String insulator unit KV	
3.3	50	36	16	68	1.3 times the actual dry flashover voltage of the unit.	3
6.6	75	42	22	80		5.5
11	95	50	30	95		9
22	150	70	50	130		18
33	200	90	70	170		27
66	350	152	130	290		53
110	450	200	170			88
132	550	240	210			105
220	900	380	340			154
380	1425	670	600			266

(iii) String flashover characteristics of suspension insulators:-

(10’’ diameter and 5$^{3/4}$’’ spacing)

Barometer: 29.92 inches, **Temperature**: 77F **Vapour pressure**: 0.6085 inch

Number of units	60 cycles flash over KV		Impulse flashover KV 1.5 x 40 µs positive
	Dry	Wet	
1	80	50	125
2	155	90	255
3	215	130	355
4	270	170	440
5	325	215	525
6	380	255	610
7	435	295	695
8	485	335	780
9	540	375	860
10	590	415	945
11	640	455	1025
12	690	490	1105
13	735	525	1185
14	785	565	1265
15	830	600	1345
16	875	635	1425
17	920	670	1505
18	965	705	1585
19	1010	740	1665
20	1055	775	1745

(iv) Test voltages for all insulators up to and including 72.5 KV rated voltage and for insulators for non-effectively earthed system above 72.5 KV

Highest system voltage KV (rms)	Visible discharge test (power frequency voltage) KV(rms)	Dry-one minute power frequency withstand test KV(rms)	wet-one minute power frequency withstand test KV (rms)	Power frequency puncture withstand test on units KV (rms)	Impulse voltage withstand test KV (peak)
3.6	3	21	21	1.3 times the actual dry flashover voltage for the unit	45
7.2	5.5	27	27		60
12	9	35	35		75
24	18	55	55		125
36	27	75	75		170
72.5	53	140	140		325
123	88	230	230		550
145	105	275	275		650
245	154	510	460		1050

(v) Test voltages for insulators for use on effectively earthed systems above 72.5 KV

Highest system voltage KV (rms)	Visible discharge test (power frequency voltage) KV(rms)	Dry-one minute power frequency withstand test KV(rms)	wet-one minute power frequency withstand test KV (rms)	Power frequency puncture withstand test on units KV (rms)	Impulse voltage withstand test KV (peak)
123	88	185	185	1.3 times the actual dry flashover voltage for the unit	450
145	105	230	230		550
245	154	395	395		900
420	266	630/680	630/680		1425/1550

(vi) Minimum creepage distances for post and line insulators (BSS 137-1960 and 3297-1960)

Nominal system voltage (3 phase) KV	Minimum creepage distance		
	Moderately polluted atmosphere	Heavily polluted area	
		total	protected
3.3	3	5	--
6.6	5	9	--
11	9	12.5	--
22	17	22	--
33	23	33	16.5
66	44	66	33
110	72	110	55
132	88	132	66
220	147	220	110
380	255	380	190

(vii) Mechanical characteristic and dimensions

System voltage	Mechanical characteristics			dimensions	
	H (lb.)	Te (lb.)	To (inch-lb.)	Axial length	Max. diameter
11	500	3000	3000	9	6.375
22	500	4000	3000	9	7.5
33	650	5000	4000	13	10.75
66	600	6000	10000	24	14
110	600	10000	14000	36	14
230	900	20000	40000	72	17

(viii) Dimensions and loading of post type insulators

Minimum failing loads (BSS 137-1960)

	Minimum failing load in KG		
	(Type 1)	(Type 2)	(Type 3)
Pin insulators	540	1080	
Insulator pins	69	540	1080
Line post insulators	2400		
String insulator units With pin dia 11mm.	2250		
String insulator units With pin dia 16mm.	4500	6750	9000.
String insulator units With pin dia 20mm.	11250	12600	
String insulator units With pin dia 24mm.	16300	18900	