INTRODUCTION

An electrical substation is a part of an electricity generation, transmission and distribution system where voltage is transformed from high to low or in reverse using transformers. It also serves as a point of connection between various power system elements such as transmission lines, transformers, generators and loads. To allow for flexibility in connecting the elements, circuit breakers are used as high power switches. Electric power may flow through several substations between generating plant and consumer, and may be changed in voltage in several steps. There are different kinds of substation such as Transmission substation, distribution substation, collector substation, switching substation and some other types of substation. The general functions of a substation may include:

- voltage transformation
- connection point for transmission lines
- switchyard for network configuration
- monitoring point for control center
- protection of power lines and apparatus
- Communication with other substations and regional control center

The first step towards the design of a 400/220/132 KV substation is to determine the load that the substation has to cater and develop it accordingly. The substation is responsible for catering bulk power to various load centres distributed all around through 220 KV and 132 KV substations. The substation is fed 1316 MW power from 3 generating stations A,B,C through 400 KV single circuit lines working at around 87% loading. The power is received on 400 KV busbar (double main and transfer bus scheme). 636 MW power is dispatched to a 400 KV substation ‘a’ catering an area having diversity factor 1.1 through 400 KV double circuit lines working at 70% loading.

The remaining 680 MW is fed to three 315 MVA (=3 x 105 MVA units) autotransformers working at an average 80% loading and 0.9 power factor. The 315 MVA transformers step down the voltage from 400 KV to 220 KV. 6% of the input power 680 MW i.e. around 40 MW power is lost in the transformers.
The rest i.e. 640 MW is fed to the 220 KV busbar (double main and transfer bus scheme). To increase the reliability of the system the 220 KV busbar is also fed from 2 other substations. A single circuit line from station E working at 68% loading supplies 85 MW while a double circuit line from station D working at 70% loading supplies 175 MW power to the busbar. This ensures continuity of supply to certain extent even when an entire 315 MVA transformer unit fails to operate. Thus total incoming power on 220 KV bus is (640+175+85 =)900 MW. From the 220 KV bus two 220 KV single circuit lines are drawn at 90% loading to supply power to 220KV substations ‘b’and ‘c’ working at a diversity factor of 1.35 to cater 112.5 MW each. Three 220 KV double circuit lines working at 80% loading feeds substations ‘d’,‘e’,‘f’ working at a diversity factor of 1.35 to meet a demand of 200 MW each.

The remaining 288 MW is fed to three 160 MVA autotransformers working at an average 75% loading and 0.8 power factor. The 160 MVA transformers step down the voltage from 220 KV to 132 KV. 6% of the input power 288 MW i.e. around 17 MW power is lost in the transformers. The rest i.e.271 MW is fed to the 132 KV busbar(double main bus scheme). To increase the reliability of the system the 132 KV busbar is also fed from another substation. A 132 KV double circuit line working at 54% loading delivers 54 MW power to the 132 KV bus. This arrangement similar to the one for 220 KV bus and ensures that the substation is not inconvenienced to a great extent if somehow a 160 MVA transformer goes out. Total incoming power on 132 KV bus is (271+54 =)325 MW. From the 132 KV bus five 220 KV double circuit lines working at 90% loading feeds substations ‘g’,‘h’,‘i’,‘j’,‘k’ working at a diversity factor of 1.45 to meet a demand of 90 MW each.

After dispatching 310 MW power, the remaining 15 MW power available from 132 KV bus is stepped down using 132/33 KV & 33/0.415 KV two winding transformers. This power is used for auxiliary purposes like pumping, lighting, ac and ventilation.
purposes within the substation to ensure its smooth functioning.

To compensate for any reactive power deficit or to balance excess reactive power of lightly loaded lines Static VAR Compensators (SVCs) are used.

SURGE IMPEDENCE:

The characteristic impedance or surge impedance of a uniform transmission line, usually written $Z_0$, is the ratio of the amplitudes of voltage and current of a single wave propagating along the line; that is, a wave travelling in one direction in the absence of reflections in the other direction. Characteristic impedance is determined by the geometry and materials of the transmission line and, for a uniform line, is not dependent on its length.

The general expression for the characteristic impedance of a transmission line is:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

where

$R$ is the resistance per unit length, considering the two conductors to be in series,
\( L \) is the inductance per unit length, 
\( G \) is the conductance of the dielectric per unit length, 
\( C \) is the capacitance per unit length, 
\( j \) is the imaginary unit, and 
\( \omega \) is the angular frequency.

For a lossless line, \( R \) and \( G \) are both zero, so the equation for characteristic impedance reduces to:

\[
Z_0 = \sqrt{\frac{L}{C}}
\]

The imaginary term \( j \) has also canceled out, making \( Z_0 \) a real expression, and so is purely resistive.

**SURGE IMPEDANCE LOADING:**

In electric power transmission, the characteristic impedance of a transmission line is expressed in terms of the surge impedance loading (SIL), or natural loading, being the power loading at which reactive power is neither produced nor absorbed:

\[
SIL = \frac{V_{LL}^2}{Z_0}
\]

in which \( V_{LL} \) is the line-to-line voltage in

Loaded below its SIL, a line supplies reactive power to the system, tending to raise system voltages. Above it, the line absorbs reactive power, tending to depress the voltage. The Ferranti effect describes the voltage gain towards the remote end of a very lightly loaded (or open ended) transmission line. Underground cables normally have a very low characteristic impedance, resulting in an SIL that is typically in excess of the thermal limit of the cable. Hence a cable is almost always a source of reactive power.
Figure below is a graphic illustration of the concept of SIL. This particular line has a SIL of 450 MW. Therefore is the line is loaded to 450 MW (with no Mvar) flow, the Mvar produced by the line will exactly balance the Mvar used by the line.

**SUBSTATION LOAD DISTRIBUTION DIAGRAM**
SURVEY AREA

LOAD BALANCE SHEET
### Incoming power (MW) to Outgoing power (MW)

<table>
<thead>
<tr>
<th>From 3 generating stations A,B,C</th>
<th>1316</th>
<th>To 400 KV substation through 400 KV double ckt line</th>
<th>636</th>
</tr>
</thead>
<tbody>
<tr>
<td>From substation D through 220 KV double ckt line</td>
<td>175</td>
<td>To 220 KV area through 5 220 KV substations</td>
<td>612</td>
</tr>
<tr>
<td>From substation E through 220 KV single ckt line</td>
<td>85</td>
<td>To 132 KV area through 5 132 KV substations</td>
<td>310</td>
</tr>
<tr>
<td>From substation F through 132 KV double ckt line</td>
<td>54</td>
<td>To Internal loading</td>
<td>15</td>
</tr>
<tr>
<td>As loss in 3 315 MVA transformers</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As loss in 3 160 MVA transformers</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1630</strong></td>
<td><strong>Total</strong></td>
<td><strong>1630</strong></td>
</tr>
</tbody>
</table>

### SELECTION OF SITE:

Selection of site for construction of a Grid Sub Station is the first and important activity. This needs meticulous planning, fore-sight, skillful observation and handling so that the selected site is technically, environmentally, economically and socially optimal and is the best suited to the requirements.

The site should be:

(a) As near the load centre as possible.

(b) As far as possible rectangular or square in shape for ease of proper orientation of bus- bars and feeders.
(c) Far away from obstructions, to permit easy and safe approach / termination of high voltage overhead transmission lines.

(d) Free from master plans / layouts or future development activities to have free line corridors for the present and in future.

(e) Easily accessible to the public road to facilitate transport of material.

(f) As far as possible near a town and away from municipal dumping grounds, burial grounds, tanneries and other obnoxious areas.

(g) Preferably fairly levelled ground. This facilitates reduction in levelling expenditure.

(h) Above highest flood level (HFL) so that there is no water logging.

(i) The site should have as far as possible good drinking water supply for the station staff.

(j) The site of the proposed Sub Station should not be in the vicinity of an aerodrome. The distance of a Sub Station from an aerodrome should be maintained as per regulations of the aerodrome authority. Approval in writing should be obtained from the aerodrome authority in case the Sub Station is proposed to be located near an aerodrome.

**REQUIREMENT OF LAND AREA**

The requirement of land for construction of Sub Station including staff colony is as under:

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Voltage Level</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>132kV</td>
<td>4 Hectare</td>
</tr>
<tr>
<td>2</td>
<td>220kV</td>
<td>6 Hectare</td>
</tr>
<tr>
<td>3</td>
<td>400kV</td>
<td>20</td>
</tr>
</tbody>
</table>
CIVIL WORKS FOR SUBSTATION

GENERAL:

All structures, buildings, foundations etc., layout & other details shall be designed and developed keeping in view the functional requirement of the line and sub-station facilities to meet the major technical parameters and project parameter.

LICENSED PREMISES (SUBSTATIONS SITES):

1. Formation Levels: Formation Level (FL) of substations should be fixed minimum 600 mm higher than the surroundings on the basis of the drainage conditions and the Highest Flood Level in the area.

2. Site Preparation: Necessary earth cutting/filling(spreading), leveling, compaction and dressing should be done. Backfilled earth should be free from harmful salts; viz, Sulphates, Chlorides and/or any Organic / Inorganic materials and compacted to minimum 95% of the Standard Proctor's Density (SPD) at Optimum Moisture Content (OMC). The subgrade for the roads and embankment filling shall be compacted to minimum 97% of the SPD at OMC.

3. Site Surfacing in Switchyard Area: Site surfacing should be carried out to provide

   ➢ safe & hazard free high earth resistivity working area (switchyard)
   ➢ prevent growth of weeds & grass within the working area.
- The site surfacing will be restricted up to 2.0 m beyond the last structure/equipment foundation.
- A 100 mm thick base layer of lean concrete of 1:4:8 using coarse aggregate of 20 mm nominal size shall be provided in the areas with covering with M-20 concrete layer with minimum thickness of 50mm in the switchyard excluding roads, drains, cable trenches etc.
- 30-40 mm Stone/Gravel spreading shall be done in areas presently in the scope of the scheme.
- No stone spreading shall for the time being done in the areas (bays) kept for future expansion.
- To hold the stone (gravel) from spreading out of the surfaced/gravel filled area, a 115 mm thick and 300 mm deep toe wall 25 mm above top of gravel shall be provided.
- All visible portions of toe-wall shall be plastered & cement painted.

4. Outside Switchyard Area: Areas lying outside the switchyard should be landscaped, developed and maintained in a clean and presentable fashion.

**WATER SUPPLY, SEWERAGE & DRAINAGE SYSTEM:**

Water Supply & Sewerage: Water supply & sewerage system shall be designed to meet the total water requirement of the substations, facilities and emergency reserve for complete performance of the works. The design and construction of septic tanks and soak pits shall be suitable for a minimum 100 users with a minimum 10 years span.

1. Design of Drainage: The concessionaire shall obtain rainfall data and design the storm water drainage system including culverts, drains etc. to accommodate the most intense rainfall (in one hour period on an average of once per ten years.)

2. Slope of Drainage System: Invert level of drainage system at outfall point shall be decided in such a way that any water over flow from water harvesting recharge shafts can easily be discharged outside the substation boundary wall. For easy drainage of water:

- Minimum slope of 1:1000 shall be provided from the ridge to the nearest drain.
- Maximum spacing between two drains shall be less than 100 meter within the switchyard
- Side wall(s) of the drains shall be 25mm above the gravel level & covered with CI grating;
- Pipe drains shall be connected through manholes within intervals of maximum 30m;
- Two portable pumps of adequate discharge capacity shall be provided for drainage of water;
- A sump pit of suitable capacity to hold water of at least 5 minutes discharge shall be constructed at a suitable point.

**RAINWATER HARVESTING:**

Arrangements shall be made for rainwater harvesting in case the depth of water table is more than 8.0 m from finished ground level. Rainwater harvesting shall be done by providing two numbers recharge structures with bore wells suitably located within the sub-station with a suitable arrangement to connect the overflow from these structures with sump-pit.

**ROADS, CULVERTS & PCC PAVEMENT / PARKING:**

- All internal roads, culverts and PCC pavements / parking within the sub-station area and approach road from main PWD road to the sub-station main entry gate(s) should be constructed as per state PWD specifications and as per layout in the Project.
- All external / internal substation roads should be constructed to permit transportation of heaviest of the substation equipment that can ever roll over the concerned road.
- The main road leading to control room / switch yard / colony shall have a minimum 6 m width with shoulder on either side.

1. **Shoulders, Footpaths, & Side-walks:** The shoulders / footpath / side-walk shall be provided with C.C. (M-15) pre-cast kerbs on either side of the road. The top edge of the kerbs shall be battered. The kerb stones with top 20 cm wide shall be laid with their length running parallel to the road edge, true in line and gradient at a distance of 30 cm from the road edge to allow for the drainage channel and shall project about 12.5 cm above the latter as per PWD specifications.
2. Road Drainage: Adequate provision shall be made for road drainage. The channel stones with top 30 cm wide shall be laid in position in camber with finished road surface and with sufficient slope towards the road gully chamber.

3. Base Sub-Grade & Soling: Sub grade shall be compacted to achieve the density in accordance with IS: 2720. The base course shall be extended on either side to at least 15 cm (for switch yard roads) beyond the edge of the concrete pavement. The coarse aggregate used shall be crushed or broken stone or any naturally occurring aggregates.

4. Surfacing: The concrete to be placed shall conform to M-20 grade design mix using approved materials & methods as per IS: 10262. The concrete shall be distributed to such depth that when consolidated and finished, the slab thickness obtained is as per site requirement; but not less than 50 mm and equal at all points.

5. Paving/ Parking: Cement concrete paving / parking shall be provided as per layout.

**TRANSFORMER FOUNDATION:**

1. General Scope:

- RCC foundations & plinths shall be designed having minimum Grade M-20 laid on base concrete (1:4:8) of minimum thickness 100 mm along with a pylon support system for supporting the fire fighting system for placing 315 MVA & 160 MVA Transformers.
- The foundations of transformers and circuit breakers should be of block type.
- Suitable arrangement for shifting the transformer from trailer like jacking etc. wherever required should be made in plinth and in front of plinth on the road.
- Adequate drainage outlets shall be provided and necessary slopes given to drain off rain water/oil.
- Suitable foundations shall be provided for all auxiliary equipment of the transformer like radiators, fan supports etc. as required and the transformer plinth foundation shall match the equipment drawings.
If trench / drain crossings are required then suitable R.C.C. culverts shall be provided in accordance with RRC standards / relevant IS.

2. Emergency Oil Evacuation System: Design & construction of Emergency Oil Evacuation System should be suitable to the type of fire protection & emergency oil drainage system.

FIRE PROTECTION WALLS:

- Fire protection walls are designed in order to protect 105 MVA single phase Transformers of the 315 MVA unit against the effects of radiant heat and flying debris from an adjacent fire in accordance with Tariff Advisory Committee (TAC) stipulations.
- The partitions reduce the noise level of the transformers & should have adequate fire resistance.
- A minimum of 2m clearance shall be provided between the equipments and fire walls.
- The building walls which act as fire walls shall extend at least 1 m above the roof in order to protect it.

CABLE & PIPE TRENCHES:

1. General Scope: The top of trenches should be kept at least 25 mm above the gravel level so that rain water does not enter the trench. Trench walls shall not foul with the foundations and shall be designed for the following loads:
   - Dead load of 155 kg/m length of cable support +75 kg on one tier at outer edge of tier
   - Earth pressure + uniform surcharge pressure

Trenches shall be constructed in RCC of M-20 grade. All metal parts inside the trench should be connected to the earthing system.

2. Outdoor Cable Trenches: RCC cable trenches shall be constructed in the switchyard and fibre glass/pre-cast RCC removable covers with lifting arrangement, edge
protected with suitable galvanized angle iron designed to withstand self weight of top slab.

3. Indoor Cable Trenches: RCC indoor cable trenches shall be provided with 50X50X6 mm GI angles grouted on the top edge of the trench wall for holding minimum 7 mm thick mild steel checkered plate covers (600 mm in length except at ends & bends) with lifting arrangement. ISMC GI channels of 75x40 mm shall also be grouted at distances of 600 mm across the indoor cable trenches to support the checkered plates.

4. Trench Drainage: The trench bed shall have a slope of 1/500 along the run & 1/250 perpendicular to the run. In case straight length exceeds 30 m, suitable expansion joint shall be provided at appropriate distances. The expansion joint shall run through vertical wall and base of trench. All expansion joints shall be provided with approved quality PVC water stops of approx. 230x5 mm size. Man holes shall be provided at interval of not more than 30 meters. Sumps, as necessary, shall be provided at suitable places and at the dead end of all trenches. Sumps shall be provided with drainage pumps of adequate discharge capacity with all accessories for pumping out water collected in the cable trenches. Cable trenches shall not be used as storm water drains.

5. Trench - Road Crossings: Suitable box culvert (Single span or multi spans) shall be provided for any road crossing. The box culvert shall extend 1.5 m on each side of road and shall have 230-mm wide, 500 mm high brick parapet wall at ends.

FOUNDATIONS FOR CONSTRUCTION WORKS:

1. General: All the foundations except walls of switch house administrative and fire handling building shall be of Reinforced Cement Concrete.

2. Design Standards & Procedure: The design and construction of foundations and other RCC structures shall be carried out as per IS specification. 2 layers of reinforcement – one each on inner and outer side of wall and slabs having thickness of 150 mm and above shall be provided. The tower and equipment foundations shall be checked for a factor of safety for normal condition and 1.65 for short circuit condition against sliding, overturning and pullout.

3. Sliding & Overturning Stability: All sub-structures shall be checked for sliding and overturning stability both during construction and operating conditions for various combinations of loads.
4. Depth of Foundations: In switchyard area, deeper foundation shall be constructed first. For the foundations resting on filled up soil, earth filling is involved due to high fixation of formation level. All foundations shall rest below virgin ground level and minimum depth excluding lean concrete of all foundations <= 500 mm.

5. Height of Foundations: The Switch Yard foundations shall be at least 100 mm above the finished ground level or as per the manufacturers’ design. Excavation shall extend minimum 150 mm around foundation (from RCC portion and not from lean concrete). If the site is on a gradient / slope, the foundation height will be adjusted to maintain the exact level of the top of structures to compensate such slopes.

6. Plinth Levels: The plinth level of the Control Room-cum-Administrative building should be minimum 500 mm above the finished ground level.

7. Reinforcement steel: Reinforcement steel (including TMT Bars) of the designed grade and manufactured by primary steel producers and conforming to IS: 1786 should only be used.

8. Foundation Bolts: All the foundation bolts used for equipment foundations & for main gantry tower foundations should be galvanized and embedded in concrete during concreting.

9. Water Tanks: Minimum grade of concrete shall be M-25 for any water retaining structure or any member submerged in water. The RCC storage tank shall be designed for minimum 0.65 million litre water storage capacities preferably in two compartments.

**BUILDINGS:**

1. Design Criterion: The buildings shall be designed to withstand the earth quake pressure as per the requirements of the National Building Code of India.

2. Design Loads:
   - Building structures shall be designed for the most critical combinations of dead loads, superimposed loads, equipment loads, crane loads, wind loads, seismic loads, short circuit loads and temperature loads.
   - Dead loads shall include the weight of structures complete with finishes, fixtures and partitions and should be taken as per IS: 1991.
Super-imposed loads in different areas shall include live loads, minor equipment loads, cable trays, small pipe racks/hangers and erection, operation and maintenance loads.

Equipment loads shall constitute, if applicable, all load of equipments to be supported on the building TAC or other relevant code.

For crane loads an impact factor of 30% and lateral crane survey of 10% of (lifted weight + trolley weight) shall be considered in the analysis of frame according to provisions of IS: 875. The horizontal surge shall be 5% of the static wheel load.

The wind loads and seismic forces shall be computed. Response spectrum method shall be used for the seismic analysis using at least first five modes of vibration. Wind and Seismic force shall not be considered to act simultaneously.

For temperature loading, the total temperature variation shall be considered as 2/3 of the average maximum annual variation in temperature. The average maximum annual variation in temperature for the purpose shall be taken as the difference between the mean of the daily minimum temperature during the coldest month of the year and mean of daily maximum temperature during the hottest month of the year. The structure shall be designed to withstand stresses due to 50% of the total temperature variation.

Floors / slabs shall be designed to carry loads imposed by equipment, cables, piping, travel of maintenance trucks and equipment and other loads associated with the building. In general, floors shall be designed for live loads as per relevant IS and cable and piping loads of no less than 5kN / sq. m. hanging from the underside. For consideration of loads on structures, IS: 875, “Code of practice for structural safety of buildings” shall be followed. The following minimum superimposed live loads shall, however, be considered for the design:

i) Roof 150kg / m² for accessible roofs & 75kg / m² for non accessible roofs

ii) RCC floors 500 kg /m² for non-accessible roofs. 2 for offices and minimum 1000 kg/m² for equipment floors or actual, if higher than 1000 kg / m²

iii) Toilet Rooms 200 kg / m².

iv) Walkways 300 kg / m²

3. DG Building Cum Fire Fighting Pump House and RCC Water Storage Tank:

➢ The DG and FF buildings designed to accommodate up to [two (2)] DG sets, motors /pumps and a permanent crane, hoist and service trucks mounted on suitable steel structure below the ceiling for servicing, lifting and maintenance of the heavy equipment shall be constructed

➢ Arrangement shall be made to drain the spill oil from oil diesel operated equipment along the periphery for collection. Piping shall be provided for conveying oil from the storage tank (common for all diesel / engines) to individual fuel tank of engine.
4. Storm Water Drainage for Buildings: The building drains shall be provided for the collection of storm water from the roofs in junction boxes and these boxes shall drain to the main drainage system of the station. Cast iron / PVC rain water down comers (minimum 100mm diameter) with water tight joints shall be provided to drain off the rain water from the roof. These shall be suitably concealed with masonry work or cement concrete or cladding materials. All drains inside the buildings shall have minimum 40 mm thick grating covers.

5. Brick Work: All brickwork shall strictly be done according to the P.W.D. specifications.

6. Damp Proof Course: On outer walls horizontal DPC shall be provided at level with plinth protection and on inner face vertical DPC 20 mm thick shall be provided. On all inner walls horizontal DPC shall be provided at floor/plinth level. In earth quake resistant structures DPC may be substitute by 230mm x230mm thick M-20 RCC plinth beams

7. Painting and Finishing: All paints & allied materials shall be of superior quality, conform to the relevant Indian Standards and of approved brands and shades.

**FLOORING:**

- The flooring of Control Room-cum-Administrative building except conference room, control room, reception hall & reception stairs shall be made of Kota stone.
- Pre-polished granite stone slabs, 19 mm thick (3/4”) flooring shall be provided in reception hall, stairs of reception hall, control room and conference rooms.
- Anti-skid tiles 300 x 300 x 7.7 mm flooring in toilets and pantry.
- Anti skid floor tiles of reputed makes having minimum 300 x 300 mm nominal size and 7.7 mm thick preferably in Beige colour shall be provided in the toilets.
- Heavy duty ironite concrete floor hardener shall be provided in DG Building cum Fire Fighting Pump House.
**Entire area around the Control Room-Cum-Administrative building, DG- cum-fire fighting building, Security Hut and the Driver’s room shall be provided with PCC paving.**

**DOORS AND WINDOWS:**

Aluminium frames / doors / windows / ventilators (single & double leaf) consisting frame work including vertical styles, top rails, lock (middle) rails and bottom rails with metal fastener & screws shall be fitted with nuts & bolts or using plastic plugs & screws. The Aluminium doors & windows shall be fitted with minimum 5.5 mm thick glass of reputed make with high-class rubber gaskets & beading complete so to make the glass airtight. The toilet doors shall, however, be fitted with prelaminated board panels of appropriate size with Aluminium beading to make it airtight.

**ROLLING SHUTTERS:**

Rolling shutters with suitable operating arrangement according to size & weight shall be provided in buildings to facilitate handling and transportation of equipment.

**TOILET & PANTRY SANITARY FITTINGS:**

All the water closets, wash basins, squatting pans etc. shall be of vitreous China clay in white color, (first quality) as per IS: 2556. The water closet in officer’s toilet shall be European type with single / double siphon and low-level cistern. The toilets & pantry shall be provided with the best Indian make 20 mm diameter, 600 mm long towel rails and other normal fixtures, firmly fixed in position with plastic plugs and CP brass screws. All fixtures / fittings shall be chromium plated of good durable quality. The pantry shall be provided with reputed make white vitreous chinaware sink of size 600 x 450 x 250 mm or more with complete fittings including 40 mm CP brass waste and PVC pipe chromium plated brass tap etc.
SWITCH - YARD FENCING AND GATES:

Fencing & Gates shall be provided for Switchyard area as per General Electrical Layout Plan. Chain link fence fabric shall have size 75 mm; coated wire shall be of 3.15 mm diameter having zinc galvanizing after weaving. The barbed wire shall be of 12 SWG galvanized steel with its weight 155-186 gm/m length of wire. Maximum distance between two barbs shall be 75mm. The barbs should carry four points and shall be formed by twisting two point wires, each two turn tightly round one line wire making altogether 4 complete turns. The barbs shall have a length of not less than 13 mm and not more than 18 mm. The points shall be sharp and well pointed and single strand galvanized steel wire.

BOUNDARY AND RETAINING WALLS:

A Boundary wall shall be constructed all around the entire substation land. The front wall shall be 1.4 m. high and in addition 0.600 m galvanized iron grill & the boundary wall on the other three sides shall be 1.8 m with 0.600 m U/C barbed wire fencing over the wall.

SAFETY CLEARANCES

“Safety Working Clearance” is the minimum clearance to be maintained in air between the live part of the equipment on one hand and earth or another piece of equipment or conductor (on which it is necessary to carry out the work) on the other.

The various equipments and associated / required facilities have to be so arranged within the substation that specified minimum clearances are always available from the point of view of the system reliability and safety of operating personnel. These include the minimum clearances from live parts to earth, between live parts of adjacent phases and sectional clearance between live parts of adjacent circuits / bays. It must be ensured that sufficient clearance to ground is also available within the Sub Station so as to ensure safety of the personnel moving about within the switchyard.

The Table below gives the minimum values of clearances required for Sub Stations upto 400 kV:
### Nominal System Voltage vs. Insulation Co-ordination

<table>
<thead>
<tr>
<th>Nominal System Voltage</th>
<th>Highest System Voltage</th>
<th>Lightning Impulse Level</th>
<th>Switching Impulse Level</th>
<th>Minimum Clearances (mm) between phase and earth</th>
<th>Safety Clearances (mm) between phases</th>
<th>Ground Clearances (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>12</td>
<td>70</td>
<td>-</td>
<td>178</td>
<td>229</td>
<td>2600 3700</td>
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<td>1900 2100</td>
<td>4300 4600 5500 5500</td>
</tr>
<tr>
<td>400</td>
<td>420</td>
<td>1425</td>
<td>1050 (Ph – E) 1575 (Ph – Ph)</td>
<td>3400 --</td>
<td>4200</td>
<td>6400 8000</td>
</tr>
</tbody>
</table>

### Insulation Co-ordination

Insulation co-ordination is the correlation of insulation of electrical equipments and circuit with the characteristic of protective devices such that the insulation is protected from excessive over-voltages.

The requirements need to be satisfied:

(i) a suitable basic insulation level (BIL) is to be selected.
(ii) it is to be ensured that the breakdown voltage of all insulation in the station will exceed the BIL.
(iii) choosing proper protective devices providing good protection at a viable cost.
BUS BAR SCHEMES

There are several ways in which the switching equipments can be connected in the electrical layout of substation. The selection of the schemes is in general affected by following aspects:

1. Degree of flexibility of operations desired.
2. Importance of load and local conditions. Freedom from total shutdown and its period desired.
3. Economic consideration, availability and cost.
4. Provision of extension.
5. Maintenance, safety of personnel.

The commonly used bus bar schemes at Sub Stations are:

1. Single bus bar.
2. Main and Transfer bus bar.
3. Double bus bar.
4. Double main and transfer bus bar.
5. One and a half breaker scheme.

SINGLE BUS-BAR ARRANGEMENT:

This is the simplest switching scheme in which each circuit is provided with one circuit breaker. This arrangement offers little security against bus bar faults and no switching flexibility resulting into quite extensive outages of bus bar and frequent maintenance of bus bar isolator(s). The entire Sub Station is lost in case of a fault on the bus bar or on any bus bar isolator and also in case of maintenance of the bus bar. Another disadvantage of this switching scheme is that in case of maintenance of circuit breaker, the associated feeder has also to be shutdown.

MAIN AND AUXILIARY BUS ARRANGEMENT:

This is technically a single bus bar arrangement with an additional bus bar called “Auxiliary bus” energized from main
bus bars through a bus coupler circuit, i.e., for ‘n’ number of circuits, it employs ‘n + 1’ circuit breakers. Each circuit is connected to the main bus bar through a circuit breaker with isolators on both sides and can be connected to the auxiliary bus bar through an isolator. The additional provision of bus coupler circuit (Auxiliary bus) facilitates taking out one circuit breaker at a time for routine overhaul and maintenance without de-energizing the circuit controlled by that breaker as that circuit then gets energized through bus coupler breaker.

As in the case of single bus arrangement, this scheme also suffers from the disadvantages that in the event of a fault on the main bus bar or the associated isolator, the entire substation is lost. This bus arrangement has been extensively used in 132 kV Sub Stations.
DOUBLE BUS BAR ARRANGEMENT:

In this scheme, a double bus bar arrangement is provided. Each circuit can be connected to either one of these bus bars through respective bus bar isolator. Bus coupler breaker is also provided so that the circuits can be switched on from one bus to the other on load. This scheme suffers from the disadvantage that when any circuit breaker is taken out for maintenance, the associated feeder has to be shutdown. This Bus bar arrangement was generally used in earlier 220 kV sub stations.
DOUBLE MAIN AND AUXILIARY BUS BAR ARRANGEMENT:

The limitation of double bus bar scheme can be overcome by using additional Auxiliary bus, bus coupler breaker and Auxiliary bus isolators. The feeder is transferred to the Auxiliary bus during maintenance of its controlling circuit breaker without affecting the other circuits.
This Bus bar arrangement is generally used nowadays in 220 kV sub stations.

ONE AND A HALF BREAKER ARRANGEMENT:
In this scheme, three circuit breakers are used for controlling two circuits which are connected between two bus bars. Normally, both the bus bars are in service. A fault on any one of the bus bars is cleared by opening of the associated circuit breakers connected to the faulty bus bar without affecting continuity of supply. Similarly, any circuit breaker can be taken out for maintenance without causing interruption. Load transfer is achieved through the breakers and, therefore, the operation is simple. However, protective relaying is somewhat more involved as the central (tie) breaker has to be responsive to troubles on either feeder in the correct sequence. Besides, each element of the bay has to be rated for carrying the currents of two feeders to meet the requirement of various switching operations which increases the cost. The breaker and a half scheme is best for those substations which handle large quantities of power and where the orientation of outgoing feeders is in opposite directions. This scheme has been used in the 400 kV substations.
### Bus-bar Materials

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>Description</th>
<th>Bus Bar and Jumper Material</th>
</tr>
</thead>
</table>

TYPICAL ONE AND HALF BREAKER ARRANGEMENT
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400 kV Main Bus</td>
<td>114.2 mm dia. Aluminium pipe</td>
</tr>
<tr>
<td>2</td>
<td>400 kV equipment interconnection</td>
<td>114.2 mm dia. Aluminium pipe</td>
</tr>
<tr>
<td>3</td>
<td>400 kV overhead bus &amp; droppers in all bays</td>
<td>Twin ACSR Moose</td>
</tr>
<tr>
<td>4</td>
<td>220 kV Main Bus</td>
<td>Quadruple / Twin ACSR Zebra / Twin AAC Tarantula</td>
</tr>
<tr>
<td>5</td>
<td>220 kV Auxiliary Bus</td>
<td>ACSR Zebra</td>
</tr>
<tr>
<td>6</td>
<td>220 kV equipment interconnection</td>
<td>Twin ACSR Zebra / Single ACSR Zebra</td>
</tr>
<tr>
<td>7</td>
<td>220 kV overhead bus &amp; droppers in all bays</td>
<td>Twin ACSR Zebra / Single ACSR Zebra</td>
</tr>
<tr>
<td>8</td>
<td>132 kV Main Bus</td>
<td>ACSR Zebra</td>
</tr>
<tr>
<td>9</td>
<td>132 kV Auxiliary Bus</td>
<td>ACSR Panther</td>
</tr>
<tr>
<td>10</td>
<td>132 kV equipment interconnection</td>
<td>ACSR Zebra / ACSR Panther</td>
</tr>
</tbody>
</table>

**BAY LAYOUT OF A 440 kV SUBSTATION:**
Details about numbers of bays and numbers of equipments required:
<table>
<thead>
<tr>
<th>Component</th>
<th>400 kV SIDE</th>
<th>220 kV SIDE</th>
<th>132 kV SIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of bays</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incoming</td>
<td>3</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Outgoing</td>
<td>5</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Bus coupler</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Bus Tie</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Power transformer</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Autotransformer</td>
<td>3 (400/220 KV)</td>
<td>3 (220/132 KV)</td>
<td>-</td>
</tr>
<tr>
<td>Auxiliary transformer</td>
<td>-</td>
<td>-</td>
<td>1 (132 KV/415V)</td>
</tr>
<tr>
<td>Wave trap</td>
<td>12</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td>CVT</td>
<td>12</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td>Current transformer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential transformer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circuit Breakers</td>
<td>30</td>
<td>57</td>
<td>51</td>
</tr>
<tr>
<td>Isolators</td>
<td>33</td>
<td>168</td>
<td>138</td>
</tr>
<tr>
<td>Earth switch</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

MAIN DATA OF A TYPICAL 400/220 KV OUTDOOR AC SUBSTATION:-

<table>
<thead>
<tr>
<th>OPERATING VOLTAGE</th>
<th>400 KV</th>
<th>230 KV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated current</td>
<td>2000A</td>
<td>2000A</td>
</tr>
<tr>
<td>Maximum short circuit current in bus bar</td>
<td>40 KA</td>
<td>40 KA</td>
</tr>
<tr>
<td>Minimum phase to phase clearance</td>
<td>5.75 m</td>
<td>2.5 m</td>
</tr>
<tr>
<td>Minimum phase to earth clearance</td>
<td>3.65 m</td>
<td>2.0 m</td>
</tr>
<tr>
<td>Number of horizontal bus bar of first level above ground</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Height of tubular bus bar of first level above ground</td>
<td>7 m</td>
<td>6 m</td>
</tr>
<tr>
<td>Height of tubular bus bar of second level above ground</td>
<td>13 m</td>
<td>4 m</td>
</tr>
<tr>
<td>Tubular aluminum bus bar A1 ASTM B241</td>
<td>4”IPS</td>
<td>4”IPS</td>
</tr>
</tbody>
</table>

**SWITCHYARD:**

Switchyard may be defined as the combination of various switching, measuring and protecting devices, supported with structures & hardwares that meant to establish the flow of power in an electrical network.

**FUNCTIONS OF A SWITCHYARD:**

1. Providing a link between Generating Plant and Transmission System.
2. Stepping up or stepping down voltage as required
3. Controlling reactive power which has effect on quality of power.
4. Protection of substation and its components.
MAIN COMPONENTS OF A SWITCHYARD:

- Transformer.
- Circuit Breaker.
- Current Transformer (CT).
- Voltage Transformer (VT).
- Capacitor Voltage Transformer (CVT).
- Isolators.
- Earthing Switch.
- Lightning Arrester.
- Wave Trap.
- Bus Bar & Clamp Fitting.

TRANSFORMERS

Transformer is a static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power.

Normally during the design of a substation a few types of transformers are needed for smooth and flexible operation. They are:

1. **Power Transformers**
   a. Auto Transformers (with tertiary winding and OLTC)
   b. Two winding Transformers (mainly for auxiliary purposes)

2. **Transformers for metering and protection**
   a. Current Transformers (C.T.)
   b. Potential Transformers (P.T.)
   c. Capacitive Voltage Transformers (C.V.T)

Two Winding Transformers :

The two-winding power transformer has two separate electrical windings. It is used to interconnect two electrical networks with
typically different voltage levels. Two-winding power transformers with rating bigger than 5MVA are typically star (wye) connected or delta connected, and less frequently, zigzag connected. Such power transformers introduce a fixed phase angle displacement (i.e. phase angle shift) $\Theta$ between the two windings. The commonly used two winding connections are shown below:-

**Dd6 or Dd0 (delta/delta):** This is an economical connection for large low voltage transformers in which insulation problem is not urgent as it increases the number of turns per phase and reduces the necessary sectional area of conductors. But it can meet large unbalanced load with ease as the third harmonic currents are damped out in closed mesh.

**Dy or Yd (Delta/star or Star/delta):** It is the most common connection for power supply transformers. It has the advantage of star point for mixed loading and delta to carry the third harmonic currents.

**Yy (star/star):** This is the most economical connection for small high voltage transformers and as the number of turns per phase is minimum the amount of insulation is minimum. But this type of connection is favorable for shell type transformer and in other cases presence of tertiary winding is essential for stabilizing the neutral.

**Yz or Zy (star/zigzag or Zigzag/star):** This type of connection is done where delta connection is mechanically weak on account of large no. of turns for small copper cross sections.
**AUTO TRANSFORMERS:**

An auto-transformer is a power transformer in which at least two windings have a common part. Auto-transformers are most often used to interconnect EHV and/or HV networks. It can be shown that they are less expensive than normal two-winding transformers if the voltage difference between the two windings (e.g. networks) is relatively small. For power system applications auto-transformers are typically used with a third, delta connected winding. With voltage ratio of 2:1 there may be a 30-35% saving of cost from that of a two-winding transformer. But they are not used when the voltage ratio exceeds 3:1 as the disturbances in one side will affect the other side pretty dangerously due to the direct electrical connection between two sides.
315 MVA 400 KV autotransformer

The autotransformers are provided with a tertiary winding for a few reasons. They are :-

a. For additional load which for some reason must be kept insulated from the secondary.
b. To supply phase compensating devices whose voltage may not be equal to primary or secondary voltage and operated at different voltages.
c. To suppress harmonic voltages (when connected in delta) and to limit voltage unbalance where load is asymmetrical.

Due to unbalance loading and presence of triplen harmonics transformer operation may be affected considerably. Thus the tertiary winding is connected in delta to suppress th harmonic voltage and to detain the flow of triplen harmonic currents in the lines. (If both primary and secondary are star connected then harmonic currents are divided according to relative impedance).
CURENT TRANSFORMER

This instrument transformer is connected to ac power circuit. The secondary winding of the CTs are fed to indicating, metering instrument & and protective relays. CTs are connected to power circuit to watch over current flow & over power load. In CT primary Winding is directly connected in series with the power circuit & it is single turn. In the secondary winding number of turns is more if the measuring current is more. The ratio of primary & secondary current is known as CT transformation ratio. The main purpose of use CTs:

1. Differential Protection
2. Bus bar protection
3. Backup protection for over current and earth fault
4. Metering

VOLTAGE TRANSFORMER

Potential transformers serve a number of functions in a power system. They are mainly used for stepping down of high magnitude voltage to a safe value for incorporate measuring and protection logics. They are used for metering and instrumentation purposes in power system. These are also used in relay protective system. In conjunction with current transformers (CTs) they can be used in measuring power.
CAPACITIVE VOLTAGE TRANSFORMER

The CVT is used for line voltage meter, synchroscope, protective relays and tariff meters. The performance of CVT is inferior to electromagnetic voltage transformer. Performance of CVT is greatly affected by variation of frequency.

CIRCUIT BREAKERS

A circuit breaker is a mechanical device designed to close or open contact members, thus, closing or opening an electrical circuit breaker, under normal or abnormal conditions. It consist of fixed & moving contacts which touch each other under normal conditions i.e. when CB is closed, considerable amount of energy is stored in the spring contacts which are held together by toggles. CB is provided with trip coil connected to a
relay designed to open automatically under fault condition. Only small pressure is required to be applied on protective relay. It trips & the potential energy of the springs is released & contacts open in fraction of seconds.

Various types of C.B are used:

1. **SF6 circuit breaker**
2. **Oil circuit breaker**
3. **Air blast circuit breaker**
4. **Vacuum circuit breaker**

**MODES OF ARC EXTINCTION**

1) **HIGH RESISTANCE INTERRUPTION** - In this process the arc is increased by lengthening and cooling to such an extent that the system voltage is no longer able to maintain the arc and the arc gets extinguished. This technique is employed in air break circuit breakers and D.C circuit breaker.

2) **LOW RESISTANCE OR ZERO POINT INTERRUPTION** - In this process the arc gets extinguished at natural current zero of the alternating current wave and is prevented from restriking again by rapid build-up of dielectric strength of the contact space. This process is employed in almost all A.C circuit breakers.

**SF6 Circuit Breaker**
Principle of operation:

In the closed position of the breaker, the contacts remain surrounded by SF$_6$ gas at a pressure of about 2.8 kg/cm$^2$. When the breaker operates, the moving contact is pulled apart and an arc is stuck between the contacts. The movement of the moving contact is synchronized with the opening of a valve which permits SF$_6$ gas at 14 kg/cm$^2$ pressure from the reservoir to the arc interruption chamber. The result is that the medium between the contacts quickly builds up high dielectric strength and causes extinction of arc.

**OILCIRCUITBREAKER:**

The oil in OCBs serves two purposes:

1. It insulates between the phases and between the phases and the ground

2. It provides the medium for the extinguishing of the arc. When electric arc is drawn under oil, the arc vaporizes the oil and creates a large bubble that surrounds the arc. The gas inside the bubble is around 80% hydrogen, which impairs ionization. The decomposition of oil into gas requires energy that comes from the heat generated by the arc. The oil surrounding the bubble conducts the heat away from the arc and thus also contributes to deionization of the arc.
Main disadvantage of the oil circuit breakers is the flammability of the oil, and the maintenance necessary to keep the oil in good condition (i.e. changing and purifying the oil).

Two main types of oil circuit breakers are:
(a) **Bulk oil circuit breaker**: no special means is available for controlling the arc and the contacts are directly exposed to the whole of the oil in the tank.
(b) **Low oil circuit breaker**: use minimum amount of oil. Oil is used only for arc extinction. Insulation is provided by air or porcelain or organic insulating material.

**Air Blast circuit breaker**

These breakers employs a high pressure air blast as an arc quenching medium. The contacts are opened in a flow of air blast established by the opening of blast valve. The blast cools the arc and sweeps away the arcing products to the atmosphere. This rapidly increases the dielectric strength of the medium between the contacts and prevents from re-establishing the arc. Consequently, the arc is extinguished.

Types of Air blast circuit breakers:
(a) **Axial blast type**: air-blast directed along the arc path.
(b) **Cross blast type**: air blast directed at right angles to the arc path.
(c) **Radial blast type**: air blast directed radially to arc path.

**Vacuum circuit breaker**:

When the breaker operates, the moving contact separate from the fixed contact and an arc is struck between the contacts. The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc diffuse in a short time and seized by the surface of moving and fixed members and shields. Due to fast rate of recovery of dielectric strength of vacuum, arc extinction occurs.
**ISOLATORS**

An isolator/disconnecting switch is used to open some given parts of a power circuit after switching off the load by means of a CB. This isolator serves only for preventing the voltage from being applied to some given section of the bus bars in a switchgear installation or to one or another piece of apparatus in the installation.

In some cases isolators are used as a circuit breaking device but their purposes are strictly limited.

**EARTHING SWITCH**

Earth switch discharges the capacitive voltage stored in line on generator side in the isolated system just after opening of CB & isolator. When earth switch is connected to the isolated but charged system it discharges the stored energy to earth, so that maintenance work can be carried out either in line on generator side. Earth switches should be operated only when the isolators are open.

All earth switches can be operated manually. Semaphore indicator can be seen for position feedback (on/off) in switchyard control panel.

**LIGHTNING ARRESTER**
Lighting arrestor is a device, which protects overhead lines and other electrical apparatus viz, transformer, and generator against lightning. Basically it consists of an arc gap and a non-linear resistor. Whenever there is a lightning, the voltage strikes the transmission line and the surge voltage begins to flow along the line. Under this condition the value of non-linear resistor decreases to a low value thus providing a low resistance path for the voltage wave. Thus the surge wave directly passes to the earth without affecting any equipment in the line. It is also seen that if there is a positively charge cloud over a transmission line, then it will produce a negative charge by electrostatic induction. This negative charge will however remain right under the cloud and portion of the line away from that cloud will be positively charged. This positive charge will flow gradually to earth slowly through insulator and metallic parts. Thus the charge that remains is the negative charge. This charge then flows along the transmission line as surge wave
and damages the equipment. Thus the lightning arrester provides protection against this wave.

**WAVE TRAP**

Wave trap is used for protection of the transmission line and communication between the Substations:

- VHF signal is transmitted from one end to another through the same power line.
- Sends inter-trip signal to the other end CBs so that fault can be isolated at the earliest time.

**Protection of Busbars**

Busbars in the substation form important link between the incoming and outgoing circuits. If a fault occurs on a busbars, considerable damage and disruption of supply will occur unless some form of quick-acting automatic protection is provided to isolate the faulty busbar.

The busbar zone, for the purpose of protection, includes not only the busbars themselves but also the isolating switches, circuit breakers and the associated connections.
The two most commonly used schemes for busbar protection are

1. Differential protection
2. Under voltage protection.
3. Over- current protection with directional element.
5. Frequency relay.

1. **Differential protection**: The basic method for busbar protection is the differential schemes in which current entering and leaving the bus are totalised. During normal load condition, the sum of these currents is equal to zero. When a fault occurs, the fault current upsets the balance and produces a differential current to operate a relay.

![Differential Protection Diagram]

Under normal load condition or external fault condition, the sum of the current entering the bus is equal to those leaving it and no current flows through the relay. If a fault occurs within the protective zone, the currents entering the bus will no longer be equal to those leaving it. The difference of these currents will flow through the relay and cause the operation of the each of the circuit breaker.

2. **Combined earth fault and phase fault protection**: It is convenient to incorporate phase fault and earth fault relay in a combined phase fault and earth fault protection. The earth relay has low current setting and operates under
earth or leakage faults only. The overload relays have high current setting and are arranged to operate against faults between the phases.

In the absence of earth fault the vector sum of three line currents is zero. Hence the vector sum of three secondary currents is also zero.

\[ I_a + I_b + I_c = 0 \]

so during normal condition no current flows through earth fault relay and the relay will not operate. However in the presence of earth fault the condition is disturbed and \[ I_a + I_b + I_c \neq 0 \], so the current flows through earth fault relay and if this current is above the pickup value, relay operates.

For any phase-phase fault the increase in current of phase cause corresponding increase in respective secondary current. If the current becomes more than pick up current, relay operates.

3. **Under voltage relays**: under voltage protection is provided for bus-bars, rectifiers, transformers etc. such protection is given by means of under voltage relays. Under voltage relays are necessary for voltage control anr reactive power control of network buses and load buses. Under voltage relays can have instantaneous characteristic or inverse characteristic depending upon the construction and design. Inverse time undervoltage relays have inverse characteristic, their operating time
reduces with reduction in voltage. Induction disc type construction is used for inverse undervoltage relay.

4. **Directional power relay**: this type of relay operates when power in the circuit flows in a specific direction. A directional power relay is so designed that it obtains its operating torque by the interaction of magnetic fields derived from both voltage and current source of the circuit it protects.

In this type of relays
Torque developed $\alpha VI \cos \phi$
$\alpha$ power in the circuit.

When the power in the circuit flows in the normal direction, the driving torque and the restraining torque help each other to turn away the moving contact from the fixed contacts. Consequently, the relay remains inoperative. However reversal of current in the circuit reverses the direction of driving torque on the disc.
NEGATIVE SEQUENCE RELAY:

Negative sequence overcurrent relays are used to detect unbalanced load on a generator which may cause excessive rotor heating. The relay is also used to detect unbalanced load currents in motor.

The advantage of the negative sequence current over zero sequence current is that mutually coupled parallel line currents are not influencing the measurement and that only the three phase currents are used as inputs, i.e. the neutral current is not needed.

HARMONIC RESTRAINT RELAY:

1. The relay is used to delay earth fault protection in solidly earth power system.

2. The most typical application is as a sensitive back-up protection in a transformer neutral or at a power line.

3. When a transformer is switched in and energized, a high inrush current usually appears. It can reach a peak value of several times the transformer’s rated current, and it is gradually damped to a normal magnetizing current of some percent of rated current.

4. The transformer inrush current is heavily distorted and has a high percentage of second harmonic, which prevents relay operation.

- Rated frequency 50 or 60 Hz
- Operation blocked by 2nd harmonic component >20% of the fundamental current
- Operate time 50 - 70 ms at 3 x pick-up
- Reset ratio >90%
Variants available with definite or inverse time delayed output.

**Transformer Failures:**

Failures in transformers can be classified into,

- winding failures due to short circuits (turn-turn faults, Phase-phase faults, phase-ground, open winding)
- Core faults (core insulation failure, shorted laminations)
- Terminal failures (open leads, loose connections, short Circuits)
- On-load tap changer failures (mechanical, electrical, short Circuit, overheating)
- Abnormal operating conditions (over fluxing, overloading, overvoltage)
- External faults

**Types of abnormal conditions:**

- Incipient faults below oil level resulting in decomposition of oil. Faults between phase and between phases to ground.
- Large internal faults phase to phase. Phase to ground below oil level.
- Faults in tap changer.
- Saturation of magnetic circuit.
- Earth faults.
- Over loads.
- High voltage surges due to lighting switching.
Protection against Internal fault:-

**Buchholz relay (gas actuated relay):**

Buchholz relay is a gas-actuated relay installed in oil immersed transformers for protection against all kinds of faults. Named after its inventor, Buchholz, it is used to give an alarm in case of incipient (i.e. slow-developing) faults in the transformer and to disconnect the transformer from the supply in the event of severe internal faults. It is usually installed in the pipe connecting the conservator to the main tank. It is a universal practice to use Buchholz relays on all such oil immersed transformers having ratings in excess of 750 kV.
- Local winding overheating - alarm
- Local core overheating (short circuited laminations)
- Bad contacts or joints
- Partial discharge
- Broken down core bolt insulation

Operation. The operation of Buchholz relay is as follows:

(i) In case of incipient faults within the transformer, the heat due to fault causes the decomposition of some transformer oil in the main tank. The products of decomposition contain more than 70% of hydrogen gas. The hydrogen gas being light tries to go into the conservator and in the process gets entrapped in the upper part of relay chamber. When a predetermined amount of gas gets accumulated, it exerts sufficient pressure on the float to cause it to tilt and close the contacts of mercury switch attached to it. This completes the alarm circuit to sound an alarm.

(ii) If a serious fault occurs in the transformer, an enormous amount of gas is generated in the main tank. The oil in the main tank rushes towards the conservator via the Buchholz relay and in doing so tilts the flap to close the contacts of mercury switch. This completes the trip circuit to open the circuit breaker controlling the transformer.

Advantages

(i) It is the simplest form of transformer protection.

(ii) It detects the incipient faults at a stage much earlier than is possible with other forms of protection.

Disadvantages

(i) It can only be used with oil immersed transformers equipped with conservator tanks.
(ii) The device can detect only faults below oil level in the transformer. Therefore, separate protection is needed for connecting cables.

**EARTH FAULT PROTECTION:-**

An earth-fault usually involves a partial breakdown of winding insulation to earth. The resulting leakage current is considerably less than the short-circuit current. The earth-fault may continue for a long time and cause considerable damage before it ultimately develops into a short-circuit and removed from the system. Under these circumstances, it is profitable to employ earth-fault relays in order to ensure the disconnection of earth-fault or leak in the early stage. An earth-fault relay is essentially an overcurrent relay of low setting and operates as soon as an earth-fault or leak develops. One method of protection against earth-faults in a transformer is the core-balance leakage protection shown in figure below:

![Diagram of Earth Fault Protection](image)

The three leads of the primary winding of power transformer are taken through the core of a current transformer which carries a single secondary winding. The operating coil of a relay is connected to this secondary. Under normal conditions (i.e. no fault to earth), the vector sum of the three phase currents is zero and there is no resultant flux in the core of current transformer no matter how much the load is out of balance. Consequently, no current flows through the relay and it remains
inoperative. However, on the occurrence of an earth-fault, the vector sum of three phase currents is no longer zero. The resultant current sets up flux in the core of the C.T. which induces e.m.f. in the secondary winding. This energises the relay to trip the circuit breaker and disconnect the faulty transformer from the system.

RESTRICTED EARTH FAULT PROTECTION

Conventional earth fault protection using overcurrent elements fails to provide adequate protection for transformer windings. This is particularly the case for a star-connected winding with an impedance-earthed neutral. The degree of protection is very much improved by the application of restricted earth fault protection (or REF protection). This is a unit protection scheme for one winding of the transformer (mainly for secondary winding phase to earth fault). It can be of the high impedance type, or of the biased low impedance type. For the high-impedance type, the residual current of three line current transformers is balanced against the output of a current transformer in the neutral conductor. In the biased low-impedance version, the three phase currents and the neutral current become the bias inputs to a differential element. The system is operative for faults within the region between current transformers, that is, for faults on the star winding in question. The system will remain stable for all faults outside this zone. Restricted earth fault protection is often applied even when the neutral is solidly earthed. Since fault current then remains at a high value even to the last turn of the winding, virtually complete cover for earth faults is obtained. This is an improvement compared with the performance of systems that do not measure the neutral conductor current. Earth fault protection applied to a delta-connected or ungrounded star winding is inherently restricted, since no zero sequence components can be transmitted through the transformer to the
other windings. Both windings of a transformer can be protected separately with restricted earth fault protection, thereby providing high-speed protection against earth faults for the whole transformer with relatively simple equipment. A high impedance relay is used, giving fast operation and phase fault stability.

**Combined Leakage and overload protection:**

The core-balance protection described above suffers from the drawback that it cannot provide protection against overloads. If a fault or leakage occurs between phases, the core-balance relay will not operate. It is a usual practice to provide combined leakage and overload protection for transformers. The earth relay has low current setting and operates under earth or leakage faults only. The overload relays have high current setting and are arranged to operate against faults between the phases.
In this system of protection, two overload relays and one leakage or earth relay are connected as shown. The two overload relays are sufficient to protect against phase-to-phase faults. The trip contacts of overload relays and earth-fault relay are connected in parallel. Therefore, with the energising of either overload relay or earth relay, the circuit breaker will be tripped.

Biased Differential Protection:-

A simple rule of thumb is that the CT’s on any wye winding of a power transformer should be connected in delta, and the CT’s on any delta winding should be connected in wye. This rule may be broken, but it rarely is; for the moment let us assume that it is inviolate. Later, we shall learn the basis for this rule. The remaining problem is how to make the required interconnection between the CT’s and the differential relay.

Two basic requirements that the differential-relay connections must satisfy are:

(1) the differential relay must not operate for load or external faults; and

(2) the relay must operate for severe enough internal faults.
Biased differential protection is used in case of low fault settings and high operating speeds are to be obtained when the following condition exist in a power transformer:-

1. On Load Tap Changing.
2. Magnetising Inrush Current
3. Unmatched CTs.

To take account of magnetizing inrush current, a high speed biased differential relay incorporating harmonic restraint feature is used.

Percentage(Biased) differential protection scheme

**Overcurrent Protection:-**

The over current protection is needed to protect the transformer from sustained overloads and short circuits. Induction type over current relays are used which in addition to providing overload protection acts as back up relays for protection of transformer winding fault. The arrangement is such that the relay does not respond to any out of balance
current between windings caused by tap changing arrangement.

Auto transformer Protection:-

In this substation 400/220KV and 220/132KV transformers are autotransformers. Their protection scheme is almost same with that of a two winding Transformer.

**Overflux Protection:-**

Overfluxing arises principally from the following system conditions:-

a. high system voltage

b. low system frequency

c. geomagnetic disturbances

The latter results in low frequency earth currents circulating through a transmission system. Since momentary system disturbances can cause transient overfluxing that is not dangerous, time delayed tripping is required. The normal protection is an IDMT or definite time characteristic, initiated if a defined V/f threshold is exceeded. Often separate alarm and trip elements are provided.

**SUBSTATION EARTHING SYSTEM**
EARTHING : In power system grounding or earthing means connecting frame of electrical equipment (non current carrying part) or some electrical part of the system (e.g. neutral point in a star connected system, one conductor of the secondary of a transformer etc.) to earth i.e. soil. This connection to earth may be through a conductor or some other circuit element (e.g. through a resistor, circuit breaker etc).

SUBSTATION EARTHING : Substation earthing is very important for safety of personnel and needs careful attention while designing, erection and routine maintenance. The function of substation earthing is to provide a grounding mat below ground surface in and around the substation which will have uniformly zero potential with respect to ground and lowest earth resistance. The neutral points of all the transformers and generators as well as the non current carrying metal parts should be connected to this earth mat through risers.

OBJECTIVE OF SUBSTATION EARTHING

- All the non-current carrying parts connected to the earthing system shall be uniformly at zero potential with respect to ground.
- The floor on which the operation and maintenance staff moves shall be at ground potential (safe step potential).
- During any earth fault in the substation, the potential of structures, tanks and other non current carrying parts does not rise to unsafe values. (safe touch potential).

REQUIREMENT OF GOOD EARTHING

- Good earth should have low resistance
- It should stabilize circuit potential with respect to ground and limit overall potential rise.
- It should protect men, material from injury or damage due to over voltage.
- It should provide low impedance path to fault currents to ensure prompt and consistent operation of protective relays, circuit breakers etc.
- It should keep maximum potential gradient along the surface of the sub-station within safe limits during ground fault.

**FUNCTION OF EARTHING IN A SUBSTATION**

- It shall be capable of passing maximum earth fault current
- The passage of fault current does not result in any thermal or mechanical damage to the insulation of the connected plant/equipment
- Every exposed conductor part or extraneous conductive part may be connected to earth.
- There is no danger to the personnel
- Ensure equi-potential bonding within the power system
- No dangerous potential gradients (step, touch or transfer potential) shall occur under normal or abnormal conditions.
- To minimize interference between power & control/communication system.
DESCRIPTION OF AN EARTHING SYSTEM

1. EARTH ELECTRODES:

Earth electrode is a metal plate or metal pipe or metal conductors driven vertically into earth at several locations. These electrodes are connected to earth mat. Large number of earth electrodes give lower earth resistance. Materials used as earthing electrode:

- Copper
- Aluminium
- Mild steel
- Galvanized iron

Size of earth electrodes:

<table>
<thead>
<tr>
<th>Type of electrode</th>
<th>Minimum diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium pipes</td>
<td>12.5 mm</td>
</tr>
<tr>
<td>Galvanized iron pipes</td>
<td>16 mm</td>
</tr>
<tr>
<td>Mild steel rods</td>
<td>40 mm dia (used in India)</td>
</tr>
</tbody>
</table>
2. **EARTHING RISERS:**

Earthing risers are used for connection between the structures, equipment bodies and the earthing mat. These are usually clamped or welded or brazed.

3. **EARTHING CONDUCTORS:**

The earth mat is made from earthing conductors. The design of the cross section of earthing conductors depends on:

- Fault current through the earth conductor
- Duration of fault current
- Permitted final temperature for the earth conductor
- Permitted voltage drop in earth conductor

**Duration of earth fault current**

- Main (primary protection) : 0.5 s
- Back-up protection : 1.0 s

4. **EARTH MAT**:

An earth mat or earth grid is formed by copper or mild steel bars or bare cables placed in the ground at a depth of about 0.5m in a horizontal plane. The crossings are welded. The grid covers the entire substation area and sometimes a few metres beyond the fencing. The earthing rods are also run along the border of the fencing of the substation.
REFERENCE DATA FOR TYPICAL EARTHING SYSTEM

| Earthing electrodes   | • 25 mm / 40 mm dia steel bars  
|                       | • 2 to 3m long                  |
| Earthing mat          | • 75*10 mm² mild steel placed 3 to 4m apart in mesh form  
|                       | • Distance between parallel strips= 2m  
|                       | • Depth 0.5m below surface  
|                       | • Joints by electric arc welding welded joints , covered by 2mm thick bitumen paint  |
| Risers                | • 75 * 10 mm² MS flats connected to equipment structures and welded to earth-mat.  |
| Overhead shielding wire (earthed) | • Level 30m above ground level , with adequate clearances.  
|                       | • 7/9 SWG steel wire.  
|                       | • Shielding angle=45°  |

CLASSIFICATION OF EARTHING

Earthing can be classified into the following categories based on the purpose for which the part of the equipment connected to the general mass of earth.

* SYSTEM EARTHING
* EQUIPMENT EARTHING

SYSTEM EARTHING

Earthing associated with current carrying parts of the equipment is called System Earthing. The system security, reliability, performance, voltage stabilization, all depends only on the System Earthing.

Eg. Earthing Neutral of Transformer, Surge arrester Earthing
**SYSTEM EARTHING METHODS:**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Earthing</td>
<td>The neutral is directly connected to ground without any intentional impedance between neutral and ground. The coefficient of earthing is less than 80% for such systems.</td>
</tr>
<tr>
<td>Resistance Earthing</td>
<td>Resistance is connected between neutral and ground</td>
</tr>
<tr>
<td>Reactance Earthing</td>
<td>Reactance is connected between neutral and ground</td>
</tr>
<tr>
<td>Resonant earthing</td>
<td>An adjustable reactor of correctly selected value to compensate the capacitive earth current is connected between neutral and earth. The coil is called Arc suppression coil or earth fault neutralize.</td>
</tr>
</tbody>
</table>

**EQUIPMENT EARTHING**
Equipment earthing (also called safety earthing or body earthing) relates to the manner in which the frames, enclosures, structures and other non-current carrying exposed metallic parts in the substation are interconnected and earthed.

**Example**: Motorbody, switchgear metal enclosure, transformer tanks, conduits of wiring, support structures, tower, poles, sheaths of metals etc.

**BASIC OBJECTIVES**:

1) To ensure freedom from exposure to dangerous electrical shocks to persons working in the substation.
2) To provide current carrying capability for flow of earth fault current of specified magnitude and duration, thus permitting overcurrent protection; without any fire, damage or explosive hazards.

**NECESSITY OF EQUIPMENT EARTHING**:

- Equipment earthing ensures safety. The potential or earthed body does not rise to dangerously high values above earth since it is connected to the ground.
- Earth fault current flows through the earthing and may rapidly cause operation of a fuse or an earth fault relay.
## CONNECTION OF ELECTRICAL EQUIPMENTS TO STATION EARTHING SYSTEM

<table>
<thead>
<tr>
<th>Apparatus</th>
<th>Parts to be earthed</th>
<th>Method of connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Support of bushing insulators,</td>
<td>Device flange or base plate</td>
<td>1. Connect the earthing bolt of the device to station earthing system. In the absence of earthing bolt or in case of connection to non-conducting structures, connect device fastening bolt to earth.</td>
</tr>
<tr>
<td>▪ lightning arrestor,</td>
<td>Each terminal of each pole of 3 phase surge arrestor</td>
<td>2. When the device is mounted on a steel structure, weld the structure, mounting the device flange; each supporting structure of apparatus is connected to earthing mesh via separate conductor</td>
</tr>
<tr>
<td>▪ fuse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>▪ Cabinets of control &amp;</td>
<td>Frameworks of switchgear &amp; cabinets</td>
<td>Weld the framework of each separately mounted board and cabinet minimum at 2 points to the earth conductor of earthing system.</td>
</tr>
<tr>
<td>relay panel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>▪ HV circuit breakers</td>
<td>Operating mechanism, frame</td>
<td>Connect the earthing bolt on the frame and to the operating mechanism of C.B. to the earthing system</td>
</tr>
<tr>
<td>▪ Isolator</td>
<td>Isolator base(frame) operating mechanism bedplate</td>
<td>Weld the isolator base frame, connect it to the bolt on the operating mechanism base plate and station earth.</td>
</tr>
<tr>
<td>▪ Surge arrestor</td>
<td>Lower earth point</td>
<td>To be directly connected to earth mat</td>
</tr>
</tbody>
</table>
|                         | Potential transformer tank, LV neutral, LV winding phase lead | 1. Connect the transformer earthing bolt to earthing system  
2. Connect LV neutral of phase lead to case with flexible copper conductor |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Current transformer</td>
<td>Secondary winding &amp; metal case</td>
<td>Connect secondary winding to earthing bolt on transformer case with flexible copper conductor, the case being earthed in the same way as support insulators.</td>
</tr>
<tr>
<td></td>
<td>Transformer tank</td>
<td>Connect the earthing bolt on the transformer tank to station earth. Connect the neutral to earthing system.</td>
</tr>
<tr>
<td></td>
<td>Door or guard steel mount</td>
<td>Weld the mount of each door and guard to earth system.</td>
</tr>
<tr>
<td></td>
<td>Each post of the fence</td>
<td>A grounding rod/bare cable is run parallel to the fence at a distance of about 1m and at a depth of 0.5 m to which fence is connected</td>
</tr>
</tbody>
</table>
Indoor Equipments

The indoor equipments inside a sub-station are of vital importance. These consist of communication systems, relays and other protection schemes, backup power arrangement, DC power supply equipments etc.

DESIGN OF CONTROL AND RELAY PANEL COMPLETE WITH PROTECTION FOR 132/33 KV SUBSTATION

This section covers design, engineering, manufacture, installation, testing and commissioning of control and relay panels (Complete with protective relays, measuring and indicating equipments along with visual and audible alarm, interlocking schemes) inclusive of internal wiring and external connection to various switchyard equipments.

In a 220/132KV substation the control panels are corridor type (also called duplex type). In this type the front and rear walls are erected independent with a common cover. The sides are open except the end panels, which are provided with doors and door switch for internal illumination. In between front and rear there is adequate space to move for inspection and wiring. In this type, the protective relays are mounted on rear board and the control and indication equipments on the front panels.
The standard size of individual panel is Depth – 1983mm, width- limited to 1000mm, height – 2312 mm. the corridor is 762mm wide and access doors on end panels are 1900mm high.

Panels are dust, moisture and vermin proof. These are free standing, floor mounting type but grounded with foundation bolts.

Cable entries to panel are from bottom. The bottom plates of the panel are fitted with removable gland plates and fixed with cable glands. The cable glands are screwed type made of brass and suitable for PVC armoured cable.

The control switches for central breakers and isolators are located on the mimic diagram corresponding to their exact position of the control equipment in the single line drawing. The locations of switches are within working height from the floor level for easy and comfortable operation.

Colored mimic diagram and symbols showing exact representation of the system are provided in the front panel. Mimic diagram are made of anodized aluminum or plastic, screwed to panel. The mimic buses are generally 2mm thick; width of mimic bus is 10mm for bus bar and 7mm for other connections. Indicating lamp, one for each phase for each bus is provided on mimic of bus coupler panel to indicate bus charged condition.

Color scheme for mimic diagram

<table>
<thead>
<tr>
<th>VOLTAGE CLASS</th>
<th>COLOUR</th>
<th>SHADE INDEX OF IS</th>
</tr>
</thead>
<tbody>
<tr>
<td>220KV</td>
<td>LIGHT ORANGE</td>
<td>557</td>
</tr>
<tr>
<td>132KV</td>
<td>SIGNAL RED</td>
<td>537</td>
</tr>
<tr>
<td>66KV</td>
<td>Golden Brown</td>
<td>414</td>
</tr>
<tr>
<td>33KV</td>
<td>Brilliant Green</td>
<td>221</td>
</tr>
</tbody>
</table>
Semaphore indicators for each earth switches, control switch width on, off indicating lamps for isolators, and discrepancy type control switch with built-in indicating lamp, flush type for circuit breakers are mounted along mimic diagram at appropriate location in panel.

Control Switches for Circuit Breakers shall be of three position spring return type with pistol grip handle and sequence device to ensure that manual pumping of closing solenoid not possible. The switches shall be robust construction and shall have four effective contact positions. “At after Close‖ position the switches shall have a maintained contact for using with Circuit Breaker Auto-Trip Indication Lamp Circuit

L.E.D. Type Indicating Lamps shall be provided on the Control Panel to indicate the following:

<table>
<thead>
<tr>
<th>Functions</th>
<th>Quantity</th>
<th>Colour of Lens</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 C.B. Spring charged indication</td>
<td>1 No.</td>
<td>Blue</td>
</tr>
<tr>
<td>2 C.B. Spring Circuit healthy indication</td>
<td>1 No.</td>
<td>White</td>
</tr>
<tr>
<td>3 C.B. Auto tripped indication (where necessary)</td>
<td>1 No.</td>
<td>Amber</td>
</tr>
<tr>
<td>4 Panel D.C. Fall indication (for Common Equipment Panel)</td>
<td>1 No.</td>
<td>Amber</td>
</tr>
<tr>
<td>5 P.T. Supply indicating</td>
<td>2 sets</td>
<td>Red/ Yellow/ Blue</td>
</tr>
<tr>
<td></td>
<td>Lamp (where necessary)</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----------------------</td>
<td>---</td>
</tr>
<tr>
<td>6</td>
<td>C.B. ―ON‖ indication</td>
<td>1 No.</td>
</tr>
<tr>
<td>7</td>
<td>C.B. ―OFF‖ indication</td>
<td>1 No.</td>
</tr>
</tbody>
</table>

All system equipments, relays are provided with name plates for easy identification. The specifications, serial number etc are written on these plates.

10mm wide plastic name plates are used for push buttons, equipment numbers, control devices. For other equipments like transformers 50mm wide brass or plastic boards are used.

Apart from these the panels are also provided with microprocessor based Annunciator. Microprocessor based electronic annunciator is provided in each panel to indicate over current and earth fault protection operated. In addition to above, each electronic annunciator of Transformer Control Panel has provision to indicate Transformer trouble trip/alarm function operated. Also one window of the Annunciator is used for Non-Trip A.C. Fail Alarm Indication and one window for Trip Circuit unhealthy indication. Each Electronic Annunciator has provision for connection with accept/reset/lamp test/mute Push buttons for proper functions. Electronic annunciator shall have provision for connection with Electronic Buzzer/Electronic Bell for Trip & Non-Trip Audio Alarm of common annunciation scheme. Electronic Annunciation has provision for flashing illuminating display with inscription for operation of respective Protection Relay. The Micro-Processor based Electronic Annunciator has separate coloured windows for Trip & Non-Trip Annunciation for easy detection. The annunciators are often connected to alarms. The Alarm Scheme comprises of separate D.C. operated common buzzer/alarm bell mounted inside the panel for Trip Alarm & another for Non-Trip Alarm. The wiring is such that single set of buzzer/bell will be sufficient and cover in common with all the
alarm actuating device. Alarm Scheme has facility for bell and is suitable for self reset as well as hand reset type initiating contact.

The control panels also consist of metering equipments. The equipments have to fulfill the following requirements:

1. Zero adjuster capable of being safely handled while the instrument is in service. The adjustments above mark and below the zero point shall not be less than 3% of the full scale length and need not exceed 6%. It shall have sufficient friction to keep the adjustment in position.

2. The dials shall be made of such materials as to ensure freedom from warping, fading, discoloring etc. during full life of instruments. Marking of Scale shall be black on white background.

3. The limits of error shall be of class 1.0 type. The calibration of the instruments shall function satisfactorily when mounted on steel panels or alternatively magnetically.

4. Instruments shall be capable of indicating freely when operated continuous at any temperature from 0 to 50 degree C.
5. All circuits of instruments shall be capable of withstanding applied load of 20% greater than the rated capacity for a period of eight hours.
6. The instruments shall be capable of withstanding the effect of shock vibration and a di-electric test of 2000 Volts r.m.s. to ground for one minute as per relevant ISS.

The meters that are used are:

1. Voltmeter: AC voltmeter are generally moving coil type, 96mm X 96mm size, 240°scale, with range of 0-300 KV(for 220 KV) and 0-15 KV(for 132KV)

2. Ammeter: Ammeters are moving coil type, 96mm X 96mm size, 240°scale and generally with dual scale.

3. Frequency Meter: Bus coupler/bus transfer panel is provided with indicator type frequency meter. The range is 45Hz-55Hz. The accuracy class is 0.5Hz

4. MVA and MVAR meter: MW meter/MVAR meter are dynamo meter type, 3phase, 4wire, 3 element, centre zero, 96 mm X 96mm size, 240° dual scale. The meter shall be provided with separate transducer having dual output -10mA – 0 – 10mA. One output for metering and other telemetering.

- Watt hour meter and VAR hour meter are 3phase, 3element type suitable for measurement of unbalanced loads in 3phase, 3wire system. They are static trivector meter with digital reading.
- The meters are suitable for operation from the secondaries of CT and PT. they are provided with a separate 3phase, 4wire type-test blocks for testing the meters without disturbing the CT and PT connections.
- The accuracy class of KWhour/KVAR meter is 0.5 and it has the facility for display of
  1. KWH export
  2. KWH import
3. KVARH export
4. Leading/lagging VAR
- Display of reading shall be at regular interval of time and also on demand.

Control and Relay panels also have AC and DC circuits. They are described as below:

**DC CIRCUIT**

There shall be only one DC incoming (220V) for the C&R board through a 32Amp switch-fuse unit. One HRC fuse-unit both at positive and negative side shall be provided for the DC incomer at the bus coupler panel. The said DC incoming bus shall run continuously in the total C&R board.

DC annunciation bus shall also be teed off from the incomer DC bus through 6A HRC fuse at positive and a link in the negative side with necessary DC supervision relay.

DC supply to each individual panel thus teed off and distributed within the panel as below

1. C.B. remote and local closing through HRC fuse and link.
2. C.B. remote and protection trip to trip coil 1 with trip circuit supervision relay through a separate HRC fuse and link.
3. C.B. remote and protection trip to trip coil 2 with trip circuit supervision relay through a separate HRC fuse and link.
4. Protective relay and PT selection circuit with DC supervision relay.
5. Indication circuit through 6A HRC fuse and link.
6. Isolator control circuit through 10A HRC fuse and link.

Bus bar protection and LBB protection DC shall be teed off from the 220KV C&R board.

**AC CIRCUIT**
A 220KV single phase AC supply to the entire C&R board will be fed from AC distribution board through a 32A switch-fuse unit. The supply shall be provided in bus coupler/ bus transfer panel.

AC circuit for incoming DC and annunciation DC fail alarm scheme is provided in bus coupler panel. The above bus is teed off to each panel through separate switch-fuse unit.

One supervision relay for incoming AC fail with test push button and reverse flag indication shall be provided for monitoring of AC supply healthiness through DC operated fascia annunciation of bus coupler panel.

Power and Control Cables

**CABLE**: An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cable. The auxiliary power for substation is supplied through underground cables.
## CONSTRUCTION OF CABLES:

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Cores or conductors**    | • A cable may have one or more core(conductor) depending on the service for which it is required.  
                               • The conductors are tinned copper or aluminium  
                               • Usually stranded in order to provide flexibility to the cable |
| **Insulation**             | • Each conductor provided with suitable thickness of insulation  
                               • Thickness depends on the voltage to be withstood  
                               • Impregnated paper, varnished cambric or rubber mineral compound. |
| **Metallic sheath**        | • Made of lead or aluminium  
                               • Protects cable from moisture, gases, acids or alkalis. |
### Bedding
- Applied over metallic sheath
- Consists of fibrous material like jute or Hessian tape
- Protects metallic sheath against corrosion and from mechanical injury due to armouring.

### Armouring
- Consists of one or two layers of galvanized steel wire or tape
- Applied over bedding
- Protects the cable from mechanical injury while laying it and during course of handling

### Serving
- Layer of fibrous material like jute provided over armouring
- Protects armouring from atmospheric conditions.

---

**POWER CABLES**
The function of the power cables in the substation is to transfer power from auxiliary transformer to various auxiliary loads. The power cables are used for various voltages up to 11 KV. The power cables are laid on cable racks supported on cable trenches. The underground distribution system in a substation is generally at two or three ac voltages such as 11 KV, 3.3 KV, 415 rms. For voltages from 3.3 KV to 33 KV, insulated, lead covered three or four conductor cables are extensively used. Single conductor plastic insulated cables are used for secondary circuits. Formerly copper conductors were used, but now aluminium conductors are used wherever possible.

[A high-voltage cable designed for 400 kV. The large conductor in the center carries the current, smaller conductors on the outside act as a shield to equalize the voltage stress in the thick polyethylene insulation layer.]

Power cables are manufactured with 1, 2, 3 or 4 cores. The conductor is either copper or aluminium. The conductor is either solid or stranded. Each core of the cable is provided with insulation. The insulation may be of impregnated paper or rubber or plastic. Over the core insulation, a sheath of lead or rubber or plastic is provided. Protective covering and armour made up of plastic or
steel is provided over the sheath. To reduce electrostatic & electromagnetic interference the power cables are shielded and earthed. Thus a power cable is made up of the following basic components:

(1) conductor
(2) core insulation
(3) sheath
(4) protective covering & armouring.

**TYPES OF CONVENTIONAL POWER CABLES:**

- Paper insulated cables.
- Plastic insulated cables (PVC)
- Oil filled cables
- Gas filled cables

At present PVC insulated and PVC sheathed cables are commonly manufactured for laying in the cable trenches (underground) and in case the power cables are to be directly laid in the aggressive ground, cables with metal sheath are necessary. Cross linked poly ethelene (XLPE) cables developed during 1970’s are being preferred for voltages upto 245 KV.

**LAYING OF POWER CABLES:**

Power cables should be laid preferably in separate trenches or ducts. However, a well shielded power cable might be laid in the ducts having measuring cables and control cables. A minimum distance of 0.3m (12 inches) should be kept between power & control cables. The power cable should be supported on racks placed at an interval of 0.8 to 1.0m. Heavy power cables should be supported on cable trays.

\[ D = \text{diameter of cable} \]

<table>
<thead>
<tr>
<th>Rating</th>
<th>Upto 11 KV</th>
<th>22 KV</th>
<th>33 KV, 3 core</th>
<th>33 KV, single core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>12D</td>
<td>15D</td>
<td>20D</td>
<td>30D</td>
</tr>
</tbody>
</table>
METHODS OF LAYING CABLES:

- Cables supported on brackets above ground level
- Cables laid in trenches below ground level
- Cables laid in pipes.
- Cables laid in RCC ducts & supported on galvanized slotted steel fabricated trays.

PERMISSIBLE LOADING & TEMPERATURE RISE OF CONTROL CABLES:

The maximum load on a power cable is determined for maximum ambient temperature and permissible temperature rise for the particular cable. The maximum load is determined by conducting temperature rise test on a 10m long power cable. When the loads on a cable are less than the rated load, the cables may be temporarily overloaded for a period suggested by the manufacturer.
Control cables are used in substations for connecting control system, measurement, signaling devices protection & communication circuits. They are generally at low voltage. (220V AC, 110V AC, 48V AC, 110V DC, 48V DC). They have copper conductors. They may have another rubber or PVC insulation. Control cables have several cores, each having independent insulations. The cross-sectional area of control cables is comparatively less. The colours of various core insulations of cables are different.

Control cables are wired between the control panels in the control room, and the various equipments in the switchyard. The various measurements, protection, control communication functions are dependent on control cables. The control cables are also laid on cable racks inside the cable trenches. The CT’s are provided in the switchyard and control room building. To avoid interference due to stray-magnetic fields, the control cables should be properly laid and their sheeths should be properly earthed so that protection and control functions are performed without disturbance. Control cables having several cores are laid over large distances. To check the continuity of cable a battery and telephone set is connected and installed at both the ends. If the core is continous then the telephones at both the ends will be in communication.
LAYING OF CONTROL CABLES:

The main current current in these conductors being low, these cables may be laid in a common duct, without separation. However they should be separated from power conductors. Highly sensitive measuring cables are sometimes laid in separate steel pipes totally away from other cables.

**SENSITIVITY OF VARIOUS LOADS TO INTERFERENCE**

<table>
<thead>
<tr>
<th>Application</th>
<th>Type of cable</th>
<th>Sensitivity of load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power cable</td>
<td>Multi core with one shield &amp; protection conductor</td>
<td>Low</td>
</tr>
<tr>
<td>Control cable</td>
<td>Multi core with one shield</td>
<td>Sensitive</td>
</tr>
<tr>
<td>Measuring cable</td>
<td>Double shielded multi conductor</td>
<td>Sensitive</td>
</tr>
<tr>
<td>Measuring cables</td>
<td>Shielded pairs common external shielded</td>
<td>Highly sensitive</td>
</tr>
</tbody>
</table>
Power Line Carrier Communication

PLCC, Power Line Carrier Communication, is an approach to utilize the existing power lines for the transmission of information. In today’s world every house and building has properly installed electricity lines. By using the existing AC power lines as a medium to transfer the information, it becomes easy to connect the houses with a high speed network access point without installing new wirings.

This technology has been in wide use since 1950 and was mainly used by the grid stations to transmit information at high speed. Now a days this technology is finding wide use in
building/home automation as it avoids the need of extra wiring. The data collected from different sensors is transmitted on these power lines thereby also reducing the maintenance cost of the additional wiring. In some countries this technology is also used to provide Internet connection.

**Operating Principle**

The communication device used for the communication over the power lines is a MODEM, commonly known as MODERN. It works as both transmitter and receiver, i.e., it transmits and receives data over the power lines. A power line modem not only modulates the data to transmit it over the power lines and but also demodulates the data it receives from the power lines. By using modulation techniques, binary data stream is keyed on to a carrier signal and then coupled on to the power lines by Modem. At the receiver end another Modem detects the signal and extracts the corresponding bit stream.
The above image shows the working of a PLCC system. Data is processed before transmission on power lines according to the above figure. First data is modulated & filtered and then by using couplers, it is sent over the power lines.

**Important Technical Parameters in PLC Communication**

**Noise on Residential Power Circuit (RPC):**

A variety of noises may occur during the communication caused by the home appliances. Following are some of the types:
1. Noise synchronous to the power system frequency (50Hz or 60 Hz) – This type of noise is generated because of different kind of switching devices.

2. Noise with a smooth spectrum – The sources of such type of noise are the appliances that are not operating synchronously with the power line frequency. For example the small motors with several windings can generate such type of noise.

3. Single Event Impulse Noise – Switching of devices, that contain a capacitor, generates such type of noise. The reason is sudden discharge of the capacitor in the RPC.

4. Periodic Noise – The type of noise is generated by fluorescent lights, television receivers etc.

These are some ways to reduce the noise in between the communication over power lines:

a. Implementation of Forward Error Correction (FEC) codes with interleaving can reduce the noise in category 1, 2 and 3.

b. Frequency Hopping with the FEC coding can be implemented to deal with the unknown frequencies.
While modulating the signal on to the power lines, television line frequencies should be avoided.

**Signal to Noise Ratio:**

Signal to Noise Ratio (SNR) is a measurement of quality of the signal. It indicates the amount of the noise in a signal. SNR can be formulated in the following way:

\[
SNR = \frac{Received \ Power}{Noise \ Power}
\]

Increasing SNR means increasing the performance of the communication system. By applying noise filters on household appliances, the noise entering into the power system can be reduced. However it will increase the cost of the appliances but is a better solution to improve overall performance.

**Signal Attenuation:**

Signal attenuation is basically the reduction in strength of the signal. A signal attenuation of about 100dB/Km occurs for low voltage power lines and 10dB/km for high voltage lines. It creates a need of continuous repeaters over a fixed distance. A
number of factors that are responsible for signal attenuation include distance, time, frequency of the signal, etc

**PLCC SYSTEM:** The frequency range over which PLC frequencies are transmitted is usually 15 KHz to 500 KHz. Power line itself is the medium for transmission of carrier frequencies apart from transmission of those within the power frequency range. Since both the frequencies are transmitted simultaneously over the same power line, some essential outdoor equipments are required to discriminate the said two frequencies at the transmitting or receiving substation. These are line traps and coupling capacitors. A line trap also called a ‘Wave Trap’, offers high impedance to carrier frequency (15 KHz to 500 KHz) current and thus prevents it from entering into the power equipments in the switch yard. The high inductance of the line traps at high frequency itself accounts for this property, and hence, the line trap offers very low impedance to the power frequency current. On the other hand, a coupling capacitor because of its high capacitive reactance offers high impedance to power frequency current and at the same time offers low impedance to carrier frequency current.

a> **Channel Description** : A PLC channel connecting two stations includes the following equipment at either end.

i> Indoor Carrier Terminal (Carrier Set)

ii> Signal path including co-axial cable

iii> Outdoor coupling equipment and tuner (line matching equipment between transmission line and the co-axial cable).

The channels must be so planned that the signals are confined to the desired path and unwanted signals are excluded. As mentioned earlier these functions can be achieved through the use of line traps and coupling capacitors.
The arrangement of outdoor coupling equipment is shown in the following fig.

**Methods of Coupling**: Usually there are two types of coupling

1. **Phase to Ground Coupling** and
2. **Phase to Phase Coupling**.

The arrangements are shown in the following figure.

1. **Phase to Ground Coupling**: Coupling to the power line is effected between the conductor of one phase of the power line and the earth. Earth return path is employed.

---

**PLC CHANNEL**

---

**COUPLING ARRANGEMENTS**
for the communication circuit for communication between two stations.

2. **Phase to Phase Coupling**

Coupling to the power line is effected between the conductor of one phase and the conductor of another phase of the same power line. The two phases may belong to the same circuit or to different circuits of the same power line (Inter Circuit Coupling).

Although for reasons of economy, phase to ground coupling is employed between substations of less importance, phase to phase coupling is essentially recommended for all practical purposes for all power lines of 132 kV, 220 kV and 400 kV system with the idea that in the case of a broken conductor or snapping of conductor, communication can still be carried out over the healthy phase conductor, though at a higher attenuation. Besides, phase to phase coupling has also got the advantage of lower signal attenuation over phase to ground coupling under normal conditions. Thus, phase to phase coupling is applicable not only for speech communication and express channels, but also for telemetering and teleprotection networks, where reliability of operation is an important factor.

**Channel Equipments**

**Line Trap**: As discussed earlier, the function of a line trap is to present a high

blocking impedance to the carrier frequency currents, while introducing negligible impedance to the power frequency components. The carrier frequency characteristics of the line trap are determined by the inductance of the trap and the impedance it offers to carrier frequency components. Line traps generally fall into two categories. One is the resonant or tuned trap and the second is the Wide Band trap.

Resonant trap blocks only one or two components and have very low inductance less than 0.5 mH (generally 0.2 mH). Wide
Band trap blocks the available carrier frequency range completely or a larger portion thereof have typically inductance up to 2mH (generally 1 mH).

Wave traps are generally rated for line operating current (power frequency) with permissible overload capacity. Wave traps are generally inserted in series with the power lines. However the IEC recommends a certain grading as to the rated currents and associated short circuit resistance. Thus rated short duration current related to the line trap refers to the maximum value of the rms currents stated in KA, whose effect the wave trap will withstand for a period of 1 second, following a continuous loading with rated current under standardized temperature condition. Besides the wave trap must be able to withstand the first current amplitude, which is 2.55 times the rated short duration current.

For the purpose of blocking carrier frequency/ range of carrier frequencies resonant tuning is done with tuning capacitor, also called tuning pot. In some wave traps the tuning pot are accommodated inside the cylindrical coil. Other designs provide for a housing protected against rain to be installed close to the trap. A simplified diagram is shown for a wide band wave trap.

The requirements imposed on tuning capacitors are stringent. They must be deigned to withstand very high test voltages, because a high voltage drop occurs across the coil in the event of short circuit currents and also travelling waves might damage the tuning capacitor. To replace the defective tuning capacitor the power system must be inserted between the terminals of the coil of the line trap. The arc over voltage of
these surge arrestors, lies, on one hand below the voltage for
which the tuning capacitors are rated and on the other hand,
above the voltage produced across the coil in the event of a
short circuit current surge. The tuning capacitors are thereby
protected against the momentary over voltages entailed by the
travelling waves. Sustained over voltage for a short duration
resulting from a short circuit current surge are not sufficiently
high to cause the arrestor to arc over. This eliminates the
danger of destruction of the arrestor. The station arrestors
meant for the protection of the power lines and equipments
have got a different characteristic from the surge arrestor
associated with the line traps. To prevent the small arrestors of
the line trap from being destroyed by the arcing over of the
station arrestors, both type of surge arrestors must be designed
for the same surge current discharge capacity although they
are rated for greatly different arc over voltages. In case of its
replacement afore said criteria must be given due
consideration.

**SERVICE CONDITIONS**

- Operating Point: Outdoor
- Ambient Temperature: -40°C to +45°C
- Altitude: Not greater than 1000m
- Power Frequency: 50/60Hz
- Atmospheric Condition: Free of damaging gas or excessive
dust.
- Abnormal Condition: Above or below the specified
temperature range, salt, spray, industrial
pollution, or other environmental factors which could seriously
affect the operating conditions

**MOUNTING OPTIONS**

**a. Suspension line traps** are provided with one, two, or four
suspension points and eyenut(s),
which must be turned tightly during assembly to mount the line
trap in a vertical state. Generally these types are used for
voltages less or equal to 132KV, where size and weight of wave trap is small.

b. For **pedestal mounted line traps**, aluminum pedestal(s) should be mounted to the lower spider first, then connected to the post insulator. For large line traps with three or four supports, every support point shall be levelled to prevent insulators or line traps from carrying undue force. Generally these types are used for voltages greater or equal to 220KV, where size and weight of wave trap is quite large.

![SPECIFICATIONS](image)

Application chart for line traps with a blocking impedance of 800 Ohms. The blocking resistance is not less than 570 Ohms for wide-band traps, and is at least 800 Ohms for single-frequency traps. (Line Traps with other blocking impedances, such as 400, 600 or 1000 Ohms, are also available.)
### Specification of wave traps used for 400KV, 220KV and 132 KV outgoing or incoming lines

<table>
<thead>
<tr>
<th>Voltage Class</th>
<th>400KV</th>
<th>220KV</th>
<th>132KV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Inductance (mH)</td>
<td>2mH</td>
<td>1mH</td>
<td>0.5mH</td>
</tr>
<tr>
<td>Rated Continuous Current (A)</td>
<td>2000A</td>
<td>1000A</td>
<td>630A</td>
</tr>
<tr>
<td>Rated short-time Current, r.m.s./Duration (KA/s)</td>
<td>63KA</td>
<td>40KA</td>
<td>25KA</td>
</tr>
<tr>
<td>Assymetric Peak Current (KA)</td>
<td>161KA</td>
<td>102KA</td>
<td>63.8KA</td>
</tr>
<tr>
<td>Power Loss</td>
<td>27.6KW</td>
<td>9.68KA</td>
<td>3.81KW</td>
</tr>
</tbody>
</table>

*Figure 2* Tuning circuits and their characteristics
<table>
<thead>
<tr>
<th></th>
<th>Height</th>
<th>Outer diameter including anti-corona ball or anti-corona ring</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1626mm</td>
<td>1860mm</td>
<td>1610kg</td>
</tr>
<tr>
<td></td>
<td>1084mm</td>
<td>1190mm</td>
<td>395kg</td>
</tr>
<tr>
<td></td>
<td>874mm</td>
<td>830mm</td>
<td>146kg</td>
</tr>
</tbody>
</table>

(Figure 5) Outline for line trap (suspension mounting)

(Figure 9) Outline for line trap (pedestal mounting)
**Coupling Capacitor & Capacitive Voltage Transformer (CVT)**: As stated earlier, the coupling capacitor blocks the power frequency currents and at the same time allow to pass the high frequency signals. For 66KV and 132 KV the ratings of the coupling capacitors are normally 8800PF and 5575PF respectively, whereas for 220 KV and 400 KV systems they are usually rated for 4400PF and 2200 PF respectively. Coupling capacitors are invariably connected at the end of the line i.e. ahead of the first disconnecting switch or line isolator at the switchyard end so as to maintain voice/data communication even when the power line is disconnected by the line isolator.

**Line Matching Unit (L.M.U)**: Transition from overhead line to power cable results in substantial mismatch loss across the cable input, primarily due to the mismatch of characteristic impedance of the overhead transmission line and the high frequency co-axial cable. The characteristic impedance (also called the surge impedance) usually varies between 300 and 350 ohms for 132, 220 and 400 KV depending upon the tower configuration and conductor spacing. The characteristic impedance of the high frequency co-axial cable usually lies within the range of 500ohms and 150 ohms. It is therefore necessary to arrange for matching equipment at the transition point. The equipment is called Line Matching Unit (L.M.U), which consists of a special matching circuit (mainly an impedance matching transformer) that is inserted between the power line/ equipment and the high frequency co-axial cable, thus minimizing to the extent
possible, the mismatch loss from the power line to the communication equipment. In case of phase to phase coupling, apart from installation of LMU on one phase another such equipment called the Line Matching and Distribution Unit (LMDU) is installed on another phase with the same idea to avoid the mismatch loss. However, the L.M.D.U consisting usually of a matching transformer of opposite polarity to that of L.M.U serves to cancel out the noise in the line to a great extent. L.M.U and L.M.D.U are interconnected through a HF coaxial cable, but HF cable is finally drawn from the LMDU terminal upto the indoor PLC terminal and hence supports the distributing function of L.M.D.U.

The schematic diagram of outdoor coupling arrangement is shown in the following figure

![Diagram](image)

**Protective Device**: A three-element protective device is also an outdoor equipment comprising of 3 separate independent small units mounted on C.C/C.V.T structure. The protective device is used to protect the communication system from dangerous over voltages. It usually consists of

a. Drainage Coil
b. Surge arrestor &
c. Earthing switch.

The charging current of the coupling capacitor increases with the operating voltage and with the coupling capacitances. This is safely conducted to ground by the drainage coil. If the line side of the coupling capacitor is interrupted, over voltage up to the magnitude of the operating voltage may occur on the equipment side of the capacitor. Great stress is therefore placed on optimum reliability and a copper conductor of atleast ¼” diameter is used in connection with 10KV support although the conductor carries normally only a small current and theoretically no voltage against the ground.

The surge arrestor is rated for an arc over voltage of approx. 2 KV and is provided to initiate in case of travelling waves or in case of an interruption of the ground conductor, immediate grounding at the point where over voltage occurs. Here also to prevent this arrestor from being destroyed by the station arrestor arcing over, they are rated for greatly different arc over voltages. Since the main purpose of this small surge arrestor is to protect the outdoor communication equipment, particularly the L.M.U/L.M.D.U and its delicate components like the tuning capacitor etc. the arc over voltage should be below the voltage ratings of the said equipments. This insulation co-ordination feature should be taken care while replacing the tuning capacitor or the L.A itself, particularly if the puncture of the capacitor is caused by the high level switching surge or lightning surge at 400KV substation or power station.

A ground switch permits the entire outdoor circuit to be grounded behind the coupling capacitor without interruption of the transmission during maintenance of the outdoor communication equipment.

v> **H.F Co-Axial Cable**: The co-axial cable is of single centre conductor type. The wire serving for carrier energy transmission and the cable sheath as the return path. The HF co-axial cable is normally used for low impedance inter
connection between the outdoor L.M.U/L.M.D.U and the indoor carrier terminal end. If both the shield ends are grounded, large surge currents can flow under certain conditions and this can cause saturation of the impedance matching transformer of the L.M.U/L.M.D.U resulting in an inoperative carrier channel. A co-axial cable consists of a single copper conductor having polythene insulation, which is enclosed in copper shielding braid and in turn in a polyvinyl plastic jacket. The nominal characteristic impedance of the co-axial cable is 50/75/125 ohms.

Indoor Communication Equipment:

a. PLC Terminals (Carrier Sets) : For telephone conversation only single purpose carrier terminals were first in use, utilizing 300 to 2000 Hz for speech band. Carrier bands were subsequently developed for simultaneous transmission of speech, telemetry and supervisory control signals for SCADA, utilizing (300-2000) Hz for speech and (2160 – 3400) Hz band for super imposed tele-signalling purpose. These entire bands lying within the AF range of frequencies having band width from 0 to 4 KHz also called side band. Modulation of the carrier with the A.F band results in two side bands in the carrier range covering the upper side band of 0 to 4 KHz and lower side band from 0 to -4 KHz. The mode of transmission is based on “amplitude modulation” (AM) with “Single Side Band” (SSB) transmission. PLC terminals are usually suitable for operation on 48V D.C, with the positive terminal of the battery connected to the solid earth.

b. Trunk Dialing System through EPAX : Recent trend is to use digital EPAX for trunk dialing system. The EPAX usually serves as terminating exchange for carrier telephones. EPAX handles both local and long distance traffic on different trunk routes by enabling fully automatic operation among the local subscribers of the exchange and any outgoing direction or trunk line over carrier channel. The EPAX is usually a combination of PAX of modular design along with modular cards
containing the features of FGS (Four wire Group Selector) for direction discrimination of trunk PLCC routes, both the PAX and the FGS being housed in the same cabinet, which is on floor mounting type. The EPAX is suitable for operation on (-)48 V.D.C

c. Telemetering : The function includes telemetering of measurements (e.g. Active power in MW, Reactive power in MVar, line currents in amp, Bus voltage in KV) and tele indicating of the position of different power switching equipment e.g. circuit breakers etc from various remote power stations/ sub stations to the data concentrator computer (Personal Computer) at the Central Load Dispatch Station for Data acquisition and processing and thereby effecting supervisory control of the power system network.

CARRIER AIDED DISTANCE PROTECTION

Protective relaying should be provided for all EHV transmission lines to automatically disconnect the faulted line sections within few milliseconds. For high speed protection, particularly to ensure simultaneous operation of both the circuit breakers at the two ends of the line, the most natural solution is to provide carrier aided protection so that inter tripping occurs almost at the same instant on the other end on receipt of the transmitted tripping signal from the sending end. The distant relay being closer to the point of fault of the first zone will transmit the tripping signal and immediately a coded pulse train or certain sinusoidal frequencies in the AF band are sent out from the protective coupler in the carrier set and transmitted over PLC to the other end for decoding and reception in the AF band in the counterpart protective coupler for inter tripping the circuit breaker through operation of the associated relay. The contactor unit, which is a part of the protective coupler housed inside the carrier terminal, interfaces the protective coupler with the relaying system at either end of the line. Transmission of the said coded signal or the sinusoidal frequencies in the AF
band is however effected on simultaneous fulfillment of two conditions.

i. Tripping command for direct tripping must be sensed. And

ii. Pilot frequency transmission should either be absent during the momentary period or should fall below the threshold level.

Exclusive PLC terminals with associated protection couplers are earmarked at both the ends for this purpose. In case of 400KV transmission line, carrier protection involves two such exclusive PLC terminals with associated protection couplers at both ends of the line for the sake of reliability. In case of 220 KV and mostly in 132 KV power lines, permissive mode of tripping is also employed, where in addition to the conditions mentioned above, tripping command is transmitted only when it is permitted by the starter relay on operation of the associated relay contact. In case of 400 KV system however the standard practice is to employ both tripping features as well as permissive tripping in the protective coupler for carrier aided distance protection.

Auxiliary DC Power Supply System

The most critical component of a protection, control, and monitoring system is the auxiliary dc control power system. Failure of the dc control power can render fault detection devices unable to detect faults, breakers unable to trip for faults, local and remote indication to become inoperable, etc.
The auxiliary dc control power system consists of the battery, battery charger, distribution system, switching and protective devices, and any monitoring equipment. Proper sizing, design, and maintenance of the components that make up the auxiliary dc control system are required. Many references for stationary battery system design address only a specific battery technology, making it difficult to compare different types of batteries for their overall suitability to substation application. Also, most references do not address the particular requirements of the electrical substation environment and duty cycle. This paper provides an overall review of things to consider in designing the auxiliary dc control power system for an electrical substation.

**BATTERY AND BATTERY CHARGER:**

**INTRODUCTION:**

**BATTERY 220 V DC:**

The storage batteries are installed in special room. The battery room should have adequate ventilation and lighting. The floor and walls should be acid resistance tiles. The battery cells are placed on racks. The racks are placed on porcelain insulators. The D.C bus bars are flat copper sections or tubular copper sections. The connections are made by soldering or brazing. The conductors are covered by grease or electrolyte resistance varnish. The positive leads are painted red and negative leads blue. Only acid-proof cables must be used upon D.C switchboard.
Without battery the relay will not operate and also C.B the D.C. supply is used for automatic control telemetering equipment, communication equipments, Interlocking equipment and emergency lighting system.

**TYPES OF BATTERIES:-**

**TWO TYPES OF BATTERIES AT SOJA are:-**

- **P.L.C.C**
- **STATION BATTERY**
  - **SUBSTATION BATTERY** (for 400 K.V two sets)
    - **MAKE:** auto bat
    - **CAP:** 250 A.H
    - **VOLTAGE:** 220 V
    - **NO. OF CELL:** 108*2

1. **P.L.C.C:-**
MAKE: - Standard
CAP: - 600 A.H
VOLTAGE: - 220 V
NO. OF CELL: - 25*2

Battery Set:-
⇒ Battery is considered as the heart of sub-station.
⇒ Sub-station battery sets

220 V D.C
⇒ Single or double

110 V DC
⇒ Single or double

48 V DC
⇒ Single or double

Battery specifications:-
Generally.. Telecom DC source.. 48 V DC.
PLCC.. 1 extra cell to compensate cable drop
50 V-200 AH means Battery set is having 25 nos. of 2-Volts cells that can deliver..
20 Amps for 10 Hrs 20Ax10H=200 AH at 100% efficiency

Battery structure
- Hard rubber container
- Positive terminal post. Lead peroxide
- Negative terminal post. Sponge lead
- Vent plug
- Float level indicator
- Inter-cell connector strips
Electrolyte... $H_2SO_4$

**Chemical reaction:-**

\[
Pb + PbO_2 + H_2SO_4 \rightarrow 2PbSO_4 + H_2O
\]

**Battery charger:-**

**MAIN PARTS:-**

1. FLOAT CHARGER
2. BOOST CHARGER

**Functions of Float Charger:-**

- Converts 3-Ph AC into 48 V DC (Rectifier)
- Normally it delivers load & give trickle charging to battery bank
- Works on ‘Auto’ or ‘Manual’ mode

In ‘Auto’ mode, o/p DC voltage is controlled by ECU card to predefined value irrespective of amplitude of AC voltage.

- In ‘Manual’ mode, o/p DC voltage to be controlled manually by external control

**Functions of boost charger:-**

- Converts 3-Ph AC into 48 V DC (Rectifier)
- Normally it is made OFF
- Works on ‘CC’ or ‘CV’ mode.
- In ‘CC’ mode, battery can be charged at constant current.
- In ‘CV’ mode battery can be charged at constant voltage.

Need for boost charger:-
- Boost charging is required only if whole battery bank is drained considerably. At that time, Float charger will deliver the load.
- Boost charger is made on when Float charger is out of order. In this case, Boost section will charge the battery bank and battery bank output from tap-cell will deliver load.

Battery capacity can be calculated from the following equations :-

1. Battery (kw) = Load KVA*Power-Factor/Inverter Efficiency
2. Number of Cells = Minimum allowable battery voltage/Final voltage per cell
3. Cells capacity(kw/per cell) = Battery kw/Number of cells

Capacity of the Battery
The capacity of a battery is expressed in ampere hour (AH). The rating tells us about how much amount of current the battery can supply for 1 hour. Capacity of a battery depends on the following factors:
1. Rate of Discharge
AH rating decreases with increase in rate of discharge. Due to rapid rate of discharge cell potential falls significantly, due to internal losses. Weakling of acid at higher discharge rate in porous plate is also greater at higher discharge rates. This also affects the capacity adversely.

2. Temperature:-
Capacity of a battery increases with increase in temperature.

(Include empirical correction formula)

3. Density of Electrolyte
As the density of electrolyte affects the internal resistance and the vigor of the chemical reaction, it has an important effect on the capacity. Capacity increases with density.

Efficiency of the Battery

There are two different values of the battery efficiency:-

1. Ampere-Hour Efficiency
2. Watt-Hour Efficiency

1. AH Efficiency:-
The ampere-hour efficiency is defined as the ratio of ampere hour taken from battery to ampere hour supplied to it while charging.

\[ \text{AH Efficiency} = \frac{\text{AH during discharge}}{\text{AH input while charging}} \]

The typical value of AH efficiency is 90 to 95%. 5 to 10% reduction is due to losses taking place in the battery. The ampere hour efficiency takes into account only the current and time but it does not consider the battery terminal voltage.

2. Watt-Hour Efficiency:-

The Watt-Hour efficiency is defined as follows:-

\[ \text{WH-Efficiency} = \frac{\text{AH efficiency} \times \text{Avg. cell voltage by discharging}}{\text{Avg. cell voltage while charging}} \]

\[ = 70-80\% \text{ usually} \]

If the charging volts increase or decrease then WH-efficiency will also decrease. High charging and discharging rates will usually do this and hence are not recommended.
- Maintain input AC voltage with specified band. Normally it should be around 415 V AC +/- 10% / 230 V AC +/- 10%
- Keep the batteries away from heat source, sparks etc.
- Charge the batteries once every six months, if stored for long periods
- After a discharge recharge the batteries immediately
- Note down module voltage readings once every month.
- Charge the batteries only at 13.5 V per module.
- Do not add water or acid
- Do not attempt to dismantle the battery
- Do not boost charge the batteries for more than 12 hours
- Do not mix the batteries of different capacities of makes

**SUB-STATION AND SWITCHYARD SUPPORT FACILITIES**

**Illumination and Lighting:**

The Concessionaire shall design, provide & maintain at all times a good lighting & illumination system in a substation both for normal and emergency situations and to facilitate operation and maintenance activities and ensure safety of the working personnel.

**Lighting Systems:** The illumination & lighting systems shall comprise of the following:
- AC Normal Lighting: AC lights shall be connected to Main Light Distribution Boards.

- AC Emergency Lighting: Emergency lighting system with about 50% points connected to auto tart generators shall be available in Control room building, Fire fighting pump house, DG Set building & Switchyard. The emergency lighting system shall be kept normally ‘ON’.

- D.C. Emergency Lighting: Strategically located lights in places like, Staircases, Corridors, Fire control Rooms, Battery Room, DG Set building and Control Room building shall be connected to DC emergency lighting system. These lights shall be kept normally 'OFF' and will be switched 'ON' automatically on AC failure.

- Portable Lighting Fixtures: At least three (3) number battery powered portable lighting fixtures hall be kept at easily accessible points in the Control room building and one (1) each in DG Set Building and Fire fighting pump house.

**Illumination Levels:** Average illumination levels shall be as per CBIP manual on Substation. Adequate lighting is necessary for safety of working personnel and O&M activities

- **Control & Relay panel area -** 350 Lux (at floor level)
- **Test laboratory -** 300 Lux
- **Battery room -** 100 Lux
- **Other indoor area -** 150 Lux
- **Switchyard -** 50 Lux (main equipment)
  - **20 Lux (balance Area / road @ ground level)**

**Air Conditioning System:**
Air Conditioning (AC) requirement shall be met using individual split C units of 2TR each. AC units for control room building shall maintain DBT 24.40°C +/- 2°C

- Control room
- S/ S Engineer’s room
- Battery room
- Conference Room
- Electronics test lab

Color scheme for Air Conditioning systems shall be as given below:

C. The following facilities, in addition to any other deemed necessary by the Concessionaire shall also be air conditioned:

**Air Conditioning System**

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>Pipeline</th>
<th>Base colour</th>
<th>Band colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Refrigerant gas pipeline - at compressor suction</td>
<td>Canary Yellow</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Refrigerant gas pipeline - at compressor discharge</td>
<td>Canary Yellow</td>
<td>Red</td>
</tr>
<tr>
<td>3</td>
<td>Refrigerant liquid pipeline</td>
<td>Dark Admiralty Green</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Chilled water pipeline</td>
<td>Sea Green</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Condenser water pipeline</td>
<td>Sea Green</td>
<td>Dark Blue</td>
</tr>
</tbody>
</table>

Direction of flow shall be marked by (arrow) in black color

**Oil Evacuating, Filtering, Testing and Filling Apparatus:**

To monitor the quality of the oil for satisfactory performance of transformers and shunt reactors, and for periodical maintenance, necessary oil evacuating, filtering, testing and filling apparatus shall be provided at a new sub-station or new switchyard or for a cluster of sub-stations and switchyards. Oil
tanks of adequate capacities for storage of pure and impure transformer oil shall be provided.

**SF6 Filling, Evacuation, Filtering, Drying & Recycling Plant:**

SF6 filling, evacuation, filtering, drying and recycling plant with adequate storage capacity shall be provided at a new substation or new switchyard or for a cluster of sub-stations and switchyards along with trolley for filling or evacuation of SF6 circuit breaker or gas insulated switchgear (in case of GIS installation) and to monitor the purity, moisture content, decomposition product etc. of SF6 gas.

**Fire Safety Issues**

**FIRE-FIGHTING SYSTEM**

Fire and outbursts of oil filled equipment like power transformers, reactors, are not uncommon in electrical substations. Fire causes extensive damage to the equipment, civil works, control and protection cabling. The objective of modern fire extinguishing system is to extinguish the fire very quickly and to prevent spreading of fire. The fire fighting system should be automatic and adequate. The system is designed such that the fires are sensed by the detectors and the water-sprays in that zone are immediately actuated. The high velocity water spray is followed by sprinkling of water for a long duration (about 30 minutes)

**FIRE PROTECTION SYSTEM :**

- Emulsifier system for transformers and reactors
- Hydrant system for transformers, reactors and buildings.
- Fire extinguishers
- Fire alarm system
- Fire bucket

**EMULSIFIER SYSTEM:**
- Used to protect transformers/reactors from fire
- Around transformer/reactor spray lines and fire detection lines are provided
- In spray line nozzles are provided for spray on fire
- In detection lines quartz bulbs are provided which blows at 79 °C.
- Deluge valve is provided between main line and detection line
- Balance across deluge valve is made under normal conditions which stops water from entering the spray line.
- Whenever fire occurs, quartz bulb blows and it releases water or air of detection line. This operates deluge valve & high velocity water spray starts.

**HYDRANT SYSTEM**:

- The hydrant is a fitting which allows the fireman to connect his hose or standpipe to the water mains and also to control the flow of water as he requires.
- It consists of a short length of flanged pipe connected to water mains, a valve and an outlet.
- A hose box is provided near hydrant. In hose box branch pipes and hose pipes of required length are provided.
Whenever fire occurs branch pipes and hose pipes are taken out and connected to the hydrant. The valve is opened to extinguish the fire.

**FIRE FIGHTING PUMP HOUSE:**

In the fire fighting pump house building following system is provided to maintain pressurized water system in the pipeline for hydrant spray and high velocity water spray system.

- Diesel engine
- HVW motor (3 phase, 400/440V)
- Jockey pump(1 running, 1 standby)
- Pressure switches
- Air vessel
- Strainers

**PRESSURE IN FIRE FIGHTING PIPELINE:**

- Normal pressure maintained in fire fighting pipeline is 8.0 kg/cm².
- Whenever pressure reduces to 6.0 kg/cm² the reduced pressure is sensed by the pressure switch which starts the jockey pump and after 8.0 kg/cm² is achieved it stops automatically.
- Generally 2 jockey pumps are provided. One of these acts as standby.
- When fire occurs and hydrant/HVW system operates pressure in the pipeline goes below 4.5 kg/cm², electric motor operates and build pressure to keep pressurized water supply continous. Motor is stopped manually after use of water for extinguishing fire.
- If any problem with electric motor develops pressure in pipeline reduces to 3.5 kg/cm² and the diesel engine starts to make up the supply of water.
- Pressure switches are very important as the entire operation depends on them.
- Strainers are provided to strain foreign materials from water.
**FIRE EXTINGUISHERS**:  
Fire extinguishers are portable fire extinguishing equipments placed in fire prone areas to extinguish small fires that can develop into big fires and bring about huge damages. They have different types of medium for different kinds of fire.

<table>
<thead>
<tr>
<th>TYPES</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water type extinguisher</td>
<td>Contains water and CO₂ cartridge. Before operation nozzle blockage is necessary to be checked</td>
</tr>
<tr>
<td>Foam extinguisher</td>
<td>AISO₄ and NaHCO₃ mixture makes CO₂ and foam which extinguishes fire.</td>
</tr>
<tr>
<td>Dry powder extinguisher</td>
<td>Uses NaHCO₃ or KHCO₃ powder in combination with gas cartridges, for extinguishing fire.</td>
</tr>
<tr>
<td>CO₂ type extinguisher</td>
<td>CO₂ gas under pressurized conditions is used for extinguishing fire.</td>
</tr>
</tbody>
</table>
**USES:**

<table>
<thead>
<tr>
<th>CLASS OF FIRE</th>
<th>FIRE PRONE MATERIALS</th>
<th>FIRE EXTINGUISHERS USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>Solids like paper</td>
<td>Water, foam type</td>
</tr>
<tr>
<td>Class B</td>
<td>Liquids like petrol</td>
<td>Dry powder, CO₂, Foam type</td>
</tr>
<tr>
<td>Class C</td>
<td>Gases like methane, propane</td>
<td>Dry powder, CO₂ type</td>
</tr>
<tr>
<td>Class D</td>
<td>Metals like sodium</td>
<td>Metal powder type</td>
</tr>
<tr>
<td>Electrical fire</td>
<td></td>
<td>CO₂ type</td>
</tr>
</tbody>
</table>

**FIRE ALARM DETECTORS:**

The fire alarm system comprises fire-detectors of the following types:

- Fixed temperature heat detector
- Ionization smoke detector
- Break glass push button detector for indoor and outdoor use.

**WORKING PROCEDURE:**

- Fixed temperature detectors are distributed throughout the buildings and are connected in parallel with the manual push buttons for fire alarms.
- The substation buildings (control room building, switchgear building, stores etc.) are divided into several fire alarm zones. A fire alarm control panel is installed in the control room. The control panel indicates
  1) General fires
  2) Faults
3) Alarms for water spray control panel
- In case of fire, the optical indication is obtained on corresponding alarm zone in the fire alarm control panel and also a buzzer is sounded inside the fire alarm control panel.
- The fire-horns are sounded in respective zone.
- The ac supply is switched off area-wise by respective relays and contactors.
- The 11 KV auxiliary ac switchgear, low voltage ac switchgear battery room and low voltage dc switchgear are provided with fixed temperature heat detector and response indicators.
- The response indicators sound an alarm and provide indication on the fire alarm on the fire control panel located in the control room.

**FIRE BUCKET**

A fire sand bucket or fire bucket is a steel bucket filled with sand which is used to put out fires. Typically, fire buckets are painted bright red and have the word 'Fire' stencilled on them in white lettering. They are placed in prominent positions in rooms or corridors. They are a low-technology method of fighting small fires. The main advantages of fire buckets are that they are cheap, reliable and easy to use. The fire buckets are usually made round bottom so that they cannot be used for other purposes. Fire buckets are hung on fire bucket stands.
Sometimes used as a suppressant for class D fires. The sand must be completely dry or the intense heat of the burning metal will quickly flash the moisture into steam, splattering the burning metal on surrounding material and the operator.

Sand cannot reliably be used to extinguish burning magnesium, sodium, lithium, or other strongly reducing metals. These metals have the ability to strip oxygen from the sand, resulting in an even more intense fire.

**PRECAUTIONS AGAINST STARTING OF FIRE:**

All personnel must become familiar with the safety rules and be careful to avoid fires. The rules recommended by the insurance companies, loss prevention board etc are followed for:

1) Design of substation
2) Storage of equipment for erection
3) Portable fire fighting sets and fire hydrant locations
4) Removal of rubbish, packing wood.
5) Special care, strict watch and ward to ensure no smoking, no warning up fires, no loose connections of cables etc.
6) Training of personnel and rehearsals
7) No storage of inflammables in general stores.

**PROTECTION AGAINST SPREADING OF FIRE:**
FIRE WALL

In case of fire the transformer may outburst, causing damage to other substation equipments. The transformer oil may spread everywhere causing the spreading of fire in the cable trenches. Besides emulsifier protection, the power transformers in the outdoor yard are provided with barrier walls. The dimension of these walls should be such that the HT bushings are covered. The spreading of fire from one transformer to another is prevented by the wall. The walls are covered with refractory bricks.

OIL SUMP FOR TRANSFORMERS AND REACTORS:

The transformers are placed on specially designed foundations. An oil sump is provided in the switchyard at a lower level than the transformer foundation. The oil from the transformer foundation cavity flows into the sump through a well designed trench having good gradient with tile finish. The sump is underground. In the event of fire in the transformer, the oil from the transformer is drained quickly into the underground sump and the spreading of fire in the switchyard is prevented.