STANDARDS / MANUALS / GUIDELINES FOR
SMALL HYDRO DEVELOPMENT

SPONSOR:
MINISTRY OF NEW AND RENEWABLE ENERGY
GOVERNMENT OF INDIA

GUIDELINES FOR
ELECTRICAL DESIGNS OF SHP PLANTS
INCLUDING SWITCHYARD

LEAD ORGANISATION:
ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE
GUIDELINES FOR ELECTRICAL DESIGNS OF SHP PLANTS INCLUDING SWITCHYARD

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SECTION–1

TURBINE

1.0 TURBINE

The turbine converts the potential and kinetic energies available in the water column into mechanical energy to drive a generator which converts the mechanical energy into electrical energy.

2.0 Terminology

2.1 Gross Head ($H_g$)
It is the difference in elevation between the water levels of the fore-bay and the tailrace.

2.2 Net head ($H_n$)
It is the gross head less all hydraulic losses except those chargeable to the turbine. Intake and penstock losses are to be considered while calculating net head. Spiral case and draft tube losses are considered chargeable to the turbine and are not included while calculating net head.

Hydraulic losses depends upon water velocity. Penstock velocities should be based on economic studies but should not exceed 9 meter per second. The normal penstock water velocity in micro / mini / small hydro power station is 3-4 meter per second

2.3 Maximum Head
It is the gross head resulting from the difference in elevation between the maximum forebay level and the tail water level without spillway discharge with one unit operating at no load speed minus losses

Turbine discharge at no load speed is approximately 5% of rated flow. Under this condition hydraulic losses are negligible and may be disregarded.

2.4 Minimum Head
It is the net head resulting from the difference in elevation between the minimum forebay level and the tailrace level minus hydraulic losses with all turbines operating at full gate.

2.5 Rated Discharge
It is the volume ($m^3/sec$) of water required by the turbine to generate rated output while operating at rated head and speed.

2.6 Rated Head
It is the net head at which the full gate output of the turbine produces the rated output. The turbine name plate rating usually is given at this head.
3.0 Specific speed

It is the speed in revolution per minute at which the given turbine would rotate, if reduced homologically in size so that it would develop unit power under unit head at full gate.

Low specific speeds are associated with high heads and high specific speed are associated with low heads. The selection of a high specific speed for a given head will result in a smaller turbine and generator with saving in capital cost. However, the turbine will have to be placed lower for which the cost may offset the saving. Also at high specific speed lower efficiency is expected.

Specific speed is given by the formula

\[ \eta_s = \frac{\eta \sqrt{P}}{H^{5/4}} \]

Where
- \( \eta_s \) = Specific speed in r.p.m
- \( \eta \) = Speed of turbine in r.p.m
- \( P \) = output power of turbine in metric horsepower
  - 1 metric HP = .736 KW
- \( H \) = Net head in meter

A set of curves showing specific speed versus head of Francis, propeller, and Pelton turbines are shown in Fig-1 given below. Curves for cavitation coefficient \( \sigma \) for francis and Kaplan turbines are also shown in the same figure.
Power output of turbine – generator set.

\[ P = 9.81 \times Q \times H \times \eta_t \times \eta_g \times \eta_d \]

Where

- \( P \) = Power output in KW
- \( Q \) = Discharge in m\(^3\)/second
- \( H \) = Net head in meter
- \( \eta_t \) = Efficiency of turbine
- \( \eta_g \) = Efficiency of generator
- \( \eta_d \) = Efficiency of gear box or belt if provided
4.0 Type of Turbines, Computation of Runner diameter and other parameters of turbine

The head and the flow rate dictate the type of turbine.

Hydraulic turbines have two general classifications-
- Reaction
- Impulse

Reaction turbines – Reaction turbines are propeller and francis

Impulse turbine – These are classified as
- Perpendicular jet – (Pelton)
- Diagonal jet – (Turgo)
- Cross flow.

4.01 Propeller Turbine – A propeller turbine is one having a runner with four, five or six blades in which the water passes through the runner in an axial direction with respect to shaft. The runner blades may be fixed or movable. The Turbines are mounted with a vertical, horizontal or slant shaft.

The efficiency curve of a fixed blade propeller turbine forms a sharp peak. For movable blade units, called Kaplan turbine, the efficiency curve is broad and flat.

Propeller turbines are designed to operate effectively between approximately 8 feet (2.4 m) and 120 feet (36.6 m) of head. Four blades designs may be used up to 35 feet of head, five blades designs to 65 feet and six blades designs to 110 feet.

The approximately head range for satisfactory operation is from 85% to 110 % for fixed blades and from 65 % to 125 % for adjustable blades.

Propeller turbine may be operated using flow ranges from 40% to 105 % of the design flow for adjustable blades units and 50 % to 105 % for fixed blades units.

The specific speed ranges from 375 to 1100 rpm. In general, the peak turbine efficiency at rated head ranges approximately from 88 % to 90%. The efficiency loss at higher heads drops 2 to 5% below peak efficiency at the design head and as much as 15% at lower head.

Water supply case is generally concrete. Either an open flume or a closed conduit type of construction may be used. Open flume construction may be economical when heads are below 35 feet. At capacity above 1500 KW, wicket gate and guide bearing loading are such that an open flume may not be a satisfactory choice.

4.011 Tubular Turbine – Tubular turbines are horizontal or slant mounted unit with propeller runners. The generators are located outside of the water passage way. These are equipped with fixed or variable pitch runner (movable blades) and with or without wicket gate assemblies.
Performance characteristic of tubular turbine are similar to the performance characteristics of propeller turbine. The efficiency of a tubular turbine will be one to two percent higher than for a vertical propeller turbine of the same size since water passage way has less change in direction.

4.012 Bulb Turbine – Bulb turbines are horizontal units which have propeller runners directly connected to the generator. The generator is enclosed in a water tight enclosure (bulb) located in the turbine water passage-way. The bulb turbine is available with fixed or movable blades and with or without a wicket gates assemblies. Performance characteristics are similar to vertical and tubular type turbines. The efficiency of bulb turbine is higher of approximately 2% over a vertical unit and one percent over a tubular unit because of straight water passage way. Due to compact design, power house floor space and height for bulb turbine installations are minimized.

4.013 Rim type Turbine – It is a turbine in which the generator rotor is mounted on the periphery of the turbine runner blades. These turbines are also named straflo. Rim turbines are available with or without wicket gates and are also available with partial closure of wicket gates. The compact design of the rim type turbine provides the smallest power house dimensions of all the turbine.

Performance characteristics of Rim type turbine are similar to those of the bulb unit.

4.014 Runner Diameter of Propeller turbine

The actual runner size is determined by the manufacture in accordance with model tests and design criteria. For preliminary layout following formula may be used to determine runner diameter.

\[ D_3 = \text{Discharge diameter of runner.} \]
\[ h_d = \text{design head} \]
\[ \eta = \text{rotational speed} \]
\[ \eta_s = \text{specific speed} \]
\[ \Phi_3 = \text{velocity ratio at } D_3 \]

\[ \Phi_3 = 0.0233 (\eta_s)^{2/3} \text{ metric} \]

\[ D_3 = \frac{84.47 \phi_s (hd)^{1/2}}{\eta} \text{ meter} \]

**Shaft size** – Turbine shafts are made of forged carbon or alloy steel which has been properly heat treated. Shafts are provided with flanged couplings. Shafts more than 15 inches in diameter are hollow bored. The diameter of shaft is estimated from the following formula

Shaft diameter = \((70 \text{ P/n})^{1/3}\) inches.

\[ P = \text{Turbine output in metric horse power} \]
\[ n = \text{Rotational speed in RPM} \]
Flange diameter = 1.75 × shaft diameter
Flange thickness = 0.20 × shaft diameter

Other dimensions
Other salient dimensions of the propeller turbine can be assessed from the discharge diameter of the runner with the help of multiplying factors shown on the drawings given in Fig. 2 to Fig. 8 at the end of this chapter.

Fig. 2 - Typical dimensions of tube turbine
Fig. 3 - Power house layout – vertical propeller / francis
Fig 4 - Power house layout – open flume turbine
Fig. 5 - Power house layout – tubular turbine, multiple units.
Fig. 6 - Power house layout – bulb turbine
Fig. 7 - Typical dimensions of tube turbines as recommended by M/s Alli’s Chambers
Fig. 8 - Schematic layout of Jyoti Tubular turbine power plant

4.02 FRANCIS TURBINE - Francis turbine is one having a runner with fixed blades, usually nine or more to which the water enters the turbine in a radial direction, with respect to the shaft and is discharged in axial direction. This is also called mixed flow turbine.

Francis turbine may be operated over range of discharge from approximately 40% to 105% of rated discharge. Below 40% rated discharge, there can be area of operation where vibration may occur. The approximate head range for operation is from 65% to 125% of design head.

The efficiency or francis turbine is approximately 88 to 90%. The efficiency at 60% of rated head will drop to nearly 75%. The specific speed ranges form 80-400RPM.

Francis turbine may be mounted with vertical or horizontal shafts. Vertical mounting allows a smaller plan area and permits a deeper setting of the turbine with respect to tail water elevation without locating the generator below tail water. Generator costs for vertical units are higher than for horizontal units because of the need for a large thrust bearings. Horizontal units are often more economical for small higher speed applications where standard horizontal generators are available.

Francis turbines are generally provided with a 90% elbow draft tube which has venture design to minimize head loss.

4.021 Diameter of Francis turbine

\[ \phi_3 = 0.0211 \left( \frac{n}{s} \right)^2 \]

\[ D_3 = \frac{84.47 \phi_3 (hd)^{1/2}}{n} \]
4.022 Other Dimensions –

Other salient dimensions of the small francis turbine can be assessed from the discharge diameter of the runner with the help of multiplying factors shown in the drawings given in Fig.9, Fig.10 and Fig.11.

Fig.9 - Dimensions and arrangement of francis
Fig 10 - Power house layout – vertical francis turbine
Fig.11 - Power house layout – Horizontal francis unit.

4.03 Impulse turbine – An impulse turbine is one having one or more free jets discharging into an aerated space and impinging on the bucket of the runner. Impulse turbines may be mounted horizontal or vertically. Pelton turbines are installed with a horizontal shaft with one or two jets or with a vertical shaft up to six jets. The buckets are shaped in such a way that the ridge in the middle divides the free jet into two equal parts which are reversed by almost 180°.

Control of the turbine is maintained by hydraulically operated needle nozzles in each jet. In addition a deflector is provided for emergency shutdown and variation of load. The deflector diverts the water jet from the buckets to the wall of the pit liner. This feature figures provides surge protection for the penstock without the need for a pressure release valve.

Runners of impulse turbine are preferred in one piece casting.

The maintenance costs for an impulse turbine are less than for reaction turbine as they are free of cavitations. Excessive silt or sand in water, however, will cause more wear on the runner of an impulse turbine than on the runner of reaction turbine.

Draft tubes are not required for impulse turbines. The runner should be located above maximum tail water to permit operation at atmosphere pressure. This causes an additional head loss in a impulse turbine.

Horizontal shaft units are normally provided with one or two jets for lower capacity sizes. Vertical units are often used for large capacity multi nozzle units.

The number of buckets should not be less than 16 to ensure that all the water of the jet may hit a bucket. The number of buckets influences the efficiency of the turbine but has no influence on the optimal speed of the runner.

The buckets are made of cast steel with 13% chrome and 4% Nickel.

The operating head for impulse turbine is between approximately 60m to 1500 meter. These turbine may be operated over a range of flow from approximately 40% to 115% of rated flow. The head range of operation can be 90% to 110% of design head. The peak turbine efficiency range is approximately 88% to 92%. The specific speed ranges from 12 to 80RPM.
### 4.031 Dimensioning of Pelton Turbine

Following are the necessary formulas for the design and the layout of Micro and mini Pelton Turbines:

$$ c_t = k_c \sqrt{2gH_n} $$

- $c_t = $ absolute velocity of water jet [ms$^{-1}$]
- $k_c =$ nozzle coefficient ($k_c = 0.96 \ldots 0.98$)
- $g = $ gravitational constant = 9.81 [ms$^{-2}$]
- $H_n = $ Net head [m]

$$ d = \sqrt{\frac{4Q}{\pi c_i}} $$

- $d = $ optimal jet diameter [m]
- $Q = $ water discharge [m$^3$s$^{-1}$]

$$ u_i = k_u \sqrt{2gH_n} $$

- $u_i = $ optimal peripheral velocity [ms$^{-1}$] (at the pitch circle diameter)
- $k_u = $ coefficient ($k_u =0.45 \ldots 0.49$)

$$ b = (2.5 \ldots 3.2)d $$

- $b = $ bucket width [m]

$$ h = (2.1 \ldots 2.7)d $$

- $h = $ bucket height [m]

$$ t = 0.9d $$

- $t = $ bucket depth [m]

$$ D = \frac{60u_i}{\pi n_G} $$

- $D = $ pitch circle diameter (PCD) [m]

$$ n_G = \frac{60u_i}{\pi D} $$

- $n_G = $ rotational speed of driven machine (RPM) [min$^{-1}$]
- $i =$ transmission ratio (RPM of driven machine / RPM of turbine)
  - (i=1 if a generator is coupled directly)

$$ k = (0.1 \ldots 0.17)D $$

- $k = $ offset of bucket

$$ z = \frac{D\pi}{2d} $$

- $z = $ approximate number of buckets

$$ D_a = D + 1.2h $$

- $D_a = $ outside diameter of runner [m]

### 4.032 Layout of Pelton Turbine

The layout and dimensions of Pelton Turbine are based on pitch circle diameter and may be assessed with the help of multiplying factors shown on the drawings given in Fig. 12).
4.04 CROSS FLOW TURBINE

A cross flow turbine may be described as an impulse turbine with partial air admission. The main characteristics of the cross flow turbine is the broad water jet of rectangular cross section which twice passes through the turbine blading at right angles to the shaft. The water flows through the runner blading first from the periphery towards the centre and then, after crossing the open centre space, from the inside to out wards.

Performance characteristics of this turbine are similar to an impulse turbine and consist of a flat efficiency curve over a wide range of flow from 30% to 100% of rated discharge and head condition.

Cross flow turbines are equipped with a conical draft tube creating a pressure below atmosphere in the turbine chamber. Therefore, the difference between the turbine center line elevation and the tail water is not lost to an cross flow turbine as is the case for an impulse turbine. Air is admitted into the chamber through an adjustable air inlet valve used to control the pressure.

Cross flow turbines are free from cavitations but are susceptible to wear when excessive silt or sand particles are in the water. Runners are self cleaning, maintenance is less complex than for other types of turbines.

Floor space requirements are more than for the other turbine types, but a less complex structure is required and a saving in cost might be realized.

It covers a head range of 1 to 100 m, the turbine speed varies between 60 to 1500 r.p.m. The specific speed lies usually between 40 and 200 (metric). The efficiency range of foreign make varies from 82% to 86%, while of Indian make 70-75%.

4.041 Parameters of cross flow turbines

- Runner Diameter $D = \frac{39.819 \sqrt{H}}{\eta}$

  Where $D = \text{Diameter of runner in meter}$
  $H = \text{Net head in meter}$
  $\eta = \text{speed of turbine in r.p.m.}$

- Width of runner $b_o = \frac{Q \times 2.0}{D \times \sqrt{H}}$

  Where $b_o = \text{width of runner in meter}$
  $Q = \text{discharge in m}^3/\text{second}$
  $D = \text{Diameter of runner in meter}$
  $H = \text{Net head in meter}$
4.042 Layout of cross flow turbine

The layout and salient dimensions of cross flow turbine can be assessed from the diameter and width of runner with the help of multiplying factors shown in the drawings given in Fig. 13, 13A & 13 B.

Fig. 13 - Plan lay out of cross flow turbine
Fig. 13A - Section A-A of Fig. 13
Fig. 13B - Section B-B of Fig. 13.

5.0 Turbine Efficiency Curves

Typical efficiency curves of the various type of turbines are shown for comparison in Fig. below. These curves are shown to illustrate the variation in efficiency of turbine through the load range at the design head. Rated efficiency will increase as the size of the turbine increases. The bottom curves shows the relationship of efficiency to throat diameter. The rated efficiency for turbines with throat diameters larger than one foot may be calculated in accordance with this curve.

The efficiency curves shown are typical expected efficiencies. Actual efficiency vary with manufacturer and design.
Fig.– Turbine – efficiency curve

Source – A guide manual, feasibility studies for Small scale Hydro Power July-79 by U.S. Army corps of Engineers.
6.0 Average Turbine Performance Characteristics

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Turbine Type</th>
<th>Specific speed range RPM</th>
<th>Efficiency %</th>
<th>Head Application (m)</th>
<th>Head Variation %</th>
<th>Flow Variation %</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>I IMPULSE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(i) Pelton</td>
<td>12-30</td>
<td>88-92</td>
<td>60</td>
<td>1500</td>
<td>90</td>
<td>110</td>
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<tr>
<td>(ii) Turgo Impulse</td>
<td>20-70</td>
<td>70-85</td>
<td>40</td>
<td>200</td>
<td>90</td>
<td>110</td>
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<tr>
<td>(iii) Cross flow</td>
<td>40-200</td>
<td>70-86</td>
<td>1</td>
<td>100</td>
<td>60</td>
<td>125</td>
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<td>II REACTION (Mixed Flow)</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>1. Francis horizontal</td>
<td>80-400</td>
<td>88-90</td>
<td>10</td>
<td>250</td>
<td>65</td>
<td>125</td>
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<td>2. Francis vertical</td>
<td>80-400</td>
<td>88-90</td>
<td>10</td>
<td>250</td>
<td>65</td>
<td>125</td>
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<td>3. Francis open flume</td>
<td>80-400</td>
<td>88-90</td>
<td>2</td>
<td>10</td>
<td>90</td>
<td>110</td>
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<tr>
<td>III REACTION (AXIAL FLOW)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(i) vertical fixed blade with fixed gate (Propeller)</td>
<td>375-1100</td>
<td>88-90</td>
<td>2</td>
<td>36</td>
<td>85</td>
<td>110</td>
</tr>
<tr>
<td>(ii) vertical fixed blade with wicket gate (Propeller)</td>
<td>375-1100</td>
<td>88-90</td>
<td>2</td>
<td>36</td>
<td>85</td>
<td>110</td>
</tr>
<tr>
<td>(iii) Tubular with adjustable blade and fixed gate (semi Kaplan)</td>
<td>375-1100</td>
<td>89-91</td>
<td>2</td>
<td>36</td>
<td>65</td>
<td>125</td>
</tr>
<tr>
<td>(iv) Tubular with fixed blades with wicket gates (horizontal propeller)</td>
<td>375-1100</td>
<td>89-91</td>
<td>2</td>
<td>36</td>
<td>85</td>
<td>110</td>
</tr>
<tr>
<td>(v) Tubular with adjustable blades and with wickets gates (Horizontal Kaplan)</td>
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<td>90-92</td>
<td>2</td>
<td>40</td>
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<td>125</td>
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<tr>
<td>(vi) Bulb</td>
<td>375-1100</td>
<td>90-92</td>
<td>2</td>
<td>40</td>
<td>65</td>
<td>125</td>
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</tbody>
</table>

7.0 Selection of turbine type

- Calculate the specific speed of the turbine from the following formula

\[
n_s = \frac{3.65 \sqrt{Q}}{H^{3/4}}
\]
\[
n_s = \frac{n \sqrt{p}}{H^{3/4}}
\]

Where \( Q = \) discharge in \( \text{m}^3/\text{second} \)
\( H = \) Net head in meter
\( n = \) speed in r.p.m.
\( p = \) Turbine output in metric horse power.

- Determine the turbine type by using the diagram of fig. 14.

Following figures may also be used for determination of the type and diameter of turbine.

(a) Fig. – 15. Functional range of different water turbines source (Escher – Wyss)
(b) Fig. – 16. Turbine operating regimes source IEC 1054/92
(c) Fig. – 17. Summary chart of commercially available turbines.
(d) Fig. – 18. Tubular Turbines Performance chart as recommended by M/s Jyoti.
8.0 Typical Examples
Typical examples for calculation of speed, specific speed and runner diameter of following turbines are given in following Annexures.
- Francis turbine - - - - - - - - - - - - Annexure–1
- Kaplan turbine - - - - - - - - - - - - Annexure–2
- Pelton Turbine - - - - - - - - - - - - Annexure–3
- Cross flow turbine - - - - - - - - - - Annexure–4

9.0 Governor
- For units up to 100 KW Electronic load controller is recommended.
- For units above 100 KW PLC based speed and water level control digital governor is recommended.

Electronic Load controller
Each turbine shall be equipped with suitable non flow control digital shunt load governor (electronic load controller), which switches/ adjust load so as to match available generation.

Digital shunt load governor shall be digitally controlled (Micro processor based controller) electronic governor for following control:
- Speed Control
- Fore bay water level control
- Unit control
- Suitability for Isolated Operation
- Suitability for Parallel Operation
- Suitability for Grid Operation

The governor controls the output load only. Standard controllable load (like Water Heater) shall be provided along with governing system. The load on the machine will be maintained constant using these loads in such a way, so that user gets stable voltage and frequency. The governor shall be of proven design, capable of maintaining control of speed under all conditions of head, discharge and load. Parallel operation with grid is achieved by dead band in ELC operation between 48.5 Hz & 51.5 Hz frequency. Time delayed over speed protection is provided for inlet valve closing.

- PLC based speed and water level control digital governor
Each turbine shall be provided with PLC based digital electronic governor with manually operated back up system for integrated unit and plant control. The governor shall be of proven design controlling the turbine by speed sense and upstream water level. The governor should provide flexibility in control, alarming, sequence of even recording and providing graphic display. The PLC should be of standard make, open architectural system allowing expansion. The governing system shall be complete-with actuator unit comprising of hydraulic pressure system, water level sensor, restoring mechanism, load adjustment with level, load limiting device, start stop capability and emergency closure. The hydraulic pressure system shall comprise of two motors driven pumping unit, pressure tank, sump tank and piping etc.
Electronic governor shall provide following control:

a. Speed Control
b. Unit Control
c. Suitability for Isolated Operation
d. Suitability for Parallel operation
e. Suitability for Grid Operation

Governor shall be fail safe on the failure of the speed sensing element, loss of oil pressure or defects in actuating system, so that under any of these conditions, the machine shall be automatically shut down with alarm and indication. Hand control device for stroking governor shall be provided.
Annexure-1

TYPICAL COMPUTATION OF SPEED, SPECIFIC SPEED AND RUNNER DIAMETER OF FRANCIS TURBINE

- Basic data
  - Net head: 60 meter
  - Discharge: 1.22 m³/sec
  - Efficiency of turbine: 88%
  - Efficiency of generator: 95%

Calculations

Power output at generator terminal

\[ kW = 9.8 \times Q \times H \times \eta_g \times \eta_t \]

Where
- \( Q \) = discharge in m³/sec
- \( H \) = Net head in meter
- \( \eta_g \) = Efficiency of generator
- \( \eta_t \) = Efficiency of turbine

\[ kW = 9.81 \times 1.22 \times 60 \times 95 \times 0.88 \]
\[ = 600 \text{ kW} \]

Method – I

Trial specific speed of francis turbine

\[ N_s = \frac{1583}{\sqrt{H}} \times \frac{2854}{\sqrt{P}} \]

\[ = \frac{1583}{\sqrt{60}} \times \frac{2854}{\sqrt{60}} \]

\[ = 200.49 \text{ to } 303.90 \text{ (i)} \]

Now

\[ N_s = \frac{n \sqrt{P}}{N_{7/4}} \]

Where
- \( N_s \) = specific speed
- \( n \) = speed of turbine
- \( P \) = Power output of turbine in metric HP.
- \( H \) = Net head

\[ P = \frac{600}{0.95 \times 0.756} \]

\[ = 858.12 \text{ metric H.P.} \]

\[ N_s = \frac{n \sqrt{858.12}}{60^{7/4}} \]
\[ \eta = \frac{200.49}{175} \text{ to } \frac{303.90}{175} = 1145.65 \text{ to } 1736.57 \]

Adopted speed = 1000 RPM
Adjusted specific speed = \( \eta \times 1000 \)
\[ \frac{175}{175} \]

**Method – 2:**

From Fig. 1 the specific speed at 60 meter head for Francis turbine = 210 RPM.

From equation (ii) \( N_s = \eta \)
Trial speed \[ \frac{210}{175} \]
\[ = 1200 \text{ RPM} \]
Adopt speed = 1000 RPM
Adjusted specific speed \( N_s = \eta \times 1000 \)
\[ \frac{175}{175} \]

**Diameter of Runner**

\[ \phi_3 = \text{Velocity ratio} = \frac{0.211}{(\eta_0)^{2/3}} \]
\[ = \frac{0.211}{(175)^{2/3}} \]
\[ = 0.6578 \]

\[ D_3 = \text{Discharge diameter of runner} \]
\[ = \frac{84.47 \phi_3 (H)^{1/2}}{\eta} \]
\[ = \frac{84.47 \times 0.6578 \times 60^{1/2}}{1000} \]
\[ = 431 \text{ mm.} \]

Adopted Diameter = 450 mm.

**Note** – Similar calculations may be done by adopting speed 1500 RPM but in practice speeds are generally kept limited to 1000 RPM.
Annexure-2

TYPICAL COMPUTATION OF SPEED, SPECIFIC SPEED AND RUNNER DIAMETER OF KAPLAN TURBINE.

Basic Data

Net Head (H) = 18 m
Discharge = 10.4 m$^3$/sec
Unit – output = 1500 KW
Efficiency of turbine = 88%
Efficiency of generator = 95%

Method – I

Trial specific speed of Kaplan turbine

$$N_s = \frac{2088}{\sqrt{H}} \times \frac{2702}{\sqrt{H}}$$

$$= \frac{2088}{\sqrt{18}} \times \frac{2702}{\sqrt{18}}$$

$$= 492.14 \text{ to } 636.86 \ldots \ldots \ldots (i)$$

$$N_s = \frac{n\sqrt{P}}{H^{3/4}}$$

$$P = \frac{1500}{.95 \times .736}$$

$$= 2145.31$$

$$N_s = \frac{n\sqrt{2145.31}}{18^{3/4}}$$

$$= 1.249 n \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (ii)$$

Trial speed of turbine from (1)

$$\eta = \frac{492.14}{1.249} \times \frac{636.86}{1.249}$$

$$= 394 \text{ to } 509.89$$

Adopting speed of turbine 400 RPM, the specific speed of turbine $N_s = 1.249 \times 400$

$$= 499.6 \text{ RPM}$$

$$= 500 \text{ RPM (Say)}$$

It may be noted that from Fig.1 the specific speed is also 500 RPM.
**Diameter of Runner**

\[
\phi_3 = \text{velocity ratio} = 0.0233 \left( \frac{N_s}{s} \right)^{2/3} = 0.0233 \left( 500 \right)^{2/3} = 1.467
\]

\[
D_3 = \text{discharge diameter of runner} = \frac{84.47 \phi_3 (H)^{1/2}}{\eta} = \frac{84.47 \times 1.467 \times 18^{1/2}}{400} = 1314 \text{ mm}
\]

Adopt \( D_3 = 1325 \text{ mm} \)
TYPICAL COMPUTATION OF SPEED, SPECIFIC SPEED RUNNER DIAMETER AND OTHER PARAMETERS OF PELTON TURBINE

Basic Data
Net Head (H) = 86.0 meter
Discharge = 0.02 m³/sec
Power output = 10 kW
Over all efficiency = 60%
Of T.G. Set (η)

Calculation

Discharge for 10 kW = \( \frac{KW}{9.81 \times H \times \eta} \)
\[ Q = \frac{10}{9.81 \times 86.0 \times 0.6} = 0.01975 \]
\[ = 0.020 \text{ m}^3/\text{sec} \]

Absolute velocity of water Jet \( C_1 = K_c \sqrt{2gH} \)
Where \( K_c = \text{Nozzle coefficient} = (0.96 \ldots 0.98) \)
\[ C_1 = 0.97 \sqrt{2 \times 9.81 \times 86} \]
\[ = 39.84 \text{ m/second} \]

Optimal Jet diameter \( d = \frac{4Q}{\pi C_1} \text{ meter} \)
\[ = \frac{4 \times 0.02}{\pi \times 39.84} \]
\[ = 0.0253 \text{ m} \]
\[ = 25.3 \text{ mm} \]

Optimal peripheral velocity at the pitch circle diameter
\( \mu_t = k_u \sqrt{2gH} \)
Where \( k_u = \text{coefficient} = 0.45 \ldots 0.49 \)
\[ \mu_t = 0.46 \sqrt{2 \times 9.81 \times 86} \]
\[ = 18.9 \text{ m/s} \]

Pitch circle diameter of Runner \( D = \frac{60 \mu_t T}{\pi \eta} \)
Where \( T = \text{Transmission Ratio} \)
\[ \frac{RPM \text{ of } \text{generator}}{RPM \text{ of } \text{Turbine}} = 1.0 \text{ if generator is coupled directly} \]

\[ \eta = \text{speed of generator} \]

Case – I – When speed of generator = 1500 RPM

\[ D = \frac{60 \times 18.9}{\pi \times 1500} \]
\[ D = 240.6 \text{ mm} \]

Bucket Width (b) = 2.5 \ldots \ldots 3.2) d
\[ = 2.85 \times 25.3 \]
\[ = 72.1 \text{ mm} \]

No. of buckets \( z \) = \[ \frac{D \pi}{2d} \]
\[ = \frac{240.6 \times \pi}{2 \times 25.3} \]
\[ = 14.94 \]

Since minimum number of buckets should be atleast 16.0, therefore pelton turbine will have two jets.

Discharge per jet = \[ \frac{\text{Total discharge}}{\text{No. of Jets}} \]
\[ = \frac{.02}{2} \]
\[ = .01 \text{ m}^3/\text{sec} \]

\( C_1, \mu \) and \( D \) will remain the same because net head has not changed.

\[ d = \sqrt{\frac{4Q}{\pi C_1}} \]
\[ = \sqrt{\frac{4 \times .01}{\pi \times 39.84}} \]
\[ = .0179 \text{ m} \]
\[ = 17.9 \text{ mm} \]

\[ b = 2.85 \times d \]
\[ = 2.85 \times 17.9 \]
\[ = 51.0 \text{ mm} \]

No. of buckets \( z \) = \[ \frac{D \pi}{2d} \]
\[ = \frac{240.6 \times \pi}{2 \times 17.9} \]
\[ = 21.12 \text{ bucket} \]
\[ = 21.0 \text{ bucket (say)} \]
Case – II – If speed of generator is adopted 1000 RPM.

Pitch circle diameter of runner \( D = \frac{60 \mu T}{\pi \eta} \)
\[
= \frac{60 \times 18.9 \times 1}{\pi \times 1000} \\
= 360.8 \text{ mm}
\]

No. of bucket \( z = \frac{D \pi}{2d} \)
\[
= \frac{360.8 \times \pi}{2 \times 25.3} \\
= 22.40 \\
= \text{Say 22 buckets}
\]
Annexure-4

TYPICAL COMPUTATION OF SPEED, SPECIFIC SPEED AND RUNNER DIAMETER OF CROSS FLOW TURBINE

Basic DATA

- Net Head (H) = 46.0 meter
- Discharge = .85 m³/s
- Power output at generator terminal = 250 kW
- Efficiency of Turbine (ηₜ) = .70
- Efficiency of generator (η₉) = .95

Calculation

Rated discharge 

\[ Q = \frac{kW}{9.81 \times H \times \eta_t \times \eta_g} \]

\[ = \frac{250}{9.81 \times 46 \times .70 \times .95} \]

\[ = .833 \text{ m}^3/\text{sec} \]

Specific speed (ηₜ)

\[ = \frac{n\sqrt{P}}{H^{5/4}} \]

\[ = \frac{n\sqrt{250}}{.95 \times .736 \times 46^{3/4}} \]

\[ = .1578 \eta \]

Specific speed when η = 750 RPM = 118.38

Runner Diameter \( D \)

\[ = \frac{39.819 \sqrt{H}}{n} \]

\[ = \frac{39.819 \sqrt{46}}{750} \]

\[ = 360 \text{ mm} \]

Adopted Runner diameter = 375 mm

Width of runner \( b_o \)

\[ = \frac{Q \times 2.0}{D \times \sqrt{H}} \]

\[ = \frac{.833 \times 2.0}{.375 \times \sqrt{46}} \]

\[ = 655 \text{ mm} \]

Adopted runner diameter = 650 mm.
Fig. 2 Typical Dimensions of Tubular Turbine
Source - IS 12800 (Part 3) : 1991
Equipment

1. Generator
2. Turbine
3. Governor
4. Generator breaker
5. Control panel
6. Neutral ground cubicle
7. Cooling pumps
8. Sump pumps
9. Air compressor and tank

NOTES
1. Arrangement and equipment are schematic.
2. Layout, equipment and dimensions shown may vary according to site specific power plant conditions.

FIG. 3 POWER HOUSE LAYOUT—VERTICAL PROPELLER/FRANCIS TURBINE
Source - IS 12800 (Part 3) : 1991
Equipment
1. Generator
2. Turbine
3. Governor
4. Generator breaker
5. Control panel
6. Neutral ground cubicle
7. Cooling pumps
8. Sump pumps
9. Air compressor and tank

NOTES
1. Arrangement and equipment are schematic.
2. Layout, equipment and dimensions shown may vary according to site specific power plant conditions.

FIG. 4 POWER HOUSE LAYOUT — OPEN FLUME TURBINE

Source - IS 12800 (Part 3) 1991
Equipment
1 Generator
2 Turbines
3 Governor
4 Generator breaker
5 Control panel
6 Neutral ground cubicle
7 Speed increaser
8 Sump pumps
9 Pressure set

NOTES
1 Arrangement and equipment are schematic.
2 Layout, equipment and dimensions shown may vary according to site specific power plant conditions.

FIG. 5  POWER HOUSE LAYOUT — TUBULAR TURBINE, MULTIPLE UNITS

Source - IS 12800 (Part 3) : 1991
Equipment

1. Generator
2. Turbine
3. Governor
4. Generator breaker
5. Control panel
6. Neutral ground cubicle
7. Surge and protection cubicle
8. Sump pumps
9. Air compressor and tank

NOTES

1. Arrangement and equipment are schematic.
2. Layout, equipment and dimensions shown may vary according to site specific power plant conditions.

Fig. 6 Power House Layout — Bulb Turbine

Source - IS 12800 (Part 3) : 1991
### BASIC DIMENSIONS

A = Runner Diameter in millimeters (inches) = 1.00

All Other Dimensions Are In Proportion From Runner Diameter

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<td>K</td>
<td>1.49</td>
<td>1.49</td>
<td>1.49</td>
<td>1.49</td>
<td>1.49</td>
<td>1.49</td>
<td>1.49</td>
<td>1.49</td>
<td>1.49</td>
<td>1.49</td>
</tr>
<tr>
<td>L</td>
<td>0.93</td>
<td>0.90</td>
<td>0.88</td>
<td>0.87</td>
<td>0.80</td>
<td>0.78</td>
<td>0.77</td>
<td>0.77</td>
<td>0.76</td>
<td>0.73</td>
</tr>
<tr>
<td>M</td>
<td>1.33</td>
<td>1.30</td>
<td>1.28</td>
<td>1.25</td>
<td>1.26</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
<td>1.17</td>
</tr>
<tr>
<td>N</td>
<td>3.00</td>
<td>2.75</td>
<td>2.60</td>
<td>2.50</td>
<td>2.43</td>
<td>2.38</td>
<td>2.33</td>
<td>2.30</td>
<td>2.27</td>
<td>2.25</td>
</tr>
</tbody>
</table>

Fig. 7 - Allis Chalmers standard tube turbine dimensions
FIG. 8-
SCHEMATIC LAYOUT OF JYOTI TUBULAR TURBINE POWER PLANT

The dimensions — related to D₁ may be used for preliminary planning purposes. All dimensions are indicative only and may vary for specific applications.

A  Stop log
B  Trash rack
C  Intake
D  Turbine
E  Bearing
F  Gear box
G  Flywheel
H  Generator
I  Crane (In case of large units only)
J  Switch board panel
K  Governor
Equipment

1. Generator
2. Turbine
3. Governor
4. Generator breaker
5. Control panel
6. Neutral ground cubicle
7. Cooling pumps
8. Sump pumps
9. Air compressor and tank

NOTES
1. Arrangement and equipment are schematic.
2. Layout, equipment and dimensions shown may vary according to site specific power plant conditions.

Fig. 10 Power House Layout — Vertical Francis Turbine, Multiple Units

Source - IS 12800 (Part 3): 1991
Equipment
1 Generator
2 Turbine
3 Governor
4 Generator breaker
5 Control panel
6 Neutral ground cubicle
7 Cooling pumps
8 Sump pumps
9 Air compressor and tank

NOTES
1 Arrangement and equipment are schematic.
2 Layout, equipment and dimensions shown may vary according to site specific power plant conditions.

FIG. 11 Power House Layout — Horizontal Francis Turbine
Source - IS 12800 (Part 3) : 1991
Fig. 12 Dimension & arrangement of Pelton turbine
Source - CBIP Publication 280
PLAN OF LAYOUT OF CROSS FLOW TURBINE

Fig. 13A – Section A-A

B = width of runner
D = diameter runner
Fig. 13 B – Section B-B
Fig. 15: Functional range of different water turbines (source Escher-Wyss)
Figure -16 Turbine operating regimes (approximate)
Source – IEC 1116
Fig. 17-Summary Chart of Commercially Available Turbines
Source – IS 12800 (Part 3) : 1991
FIG. 18 - TUBULAR TURBINES PERFORMANCE CHART

Calculation Example

- Head (net) = 8 M
- Discharge = 6 M³/sec.
- Power Turbine Output = 400 Kw
- Runner Diameter = 1050 mm
- Max. Suction Head = +2 M
- Turbine speed = 428 r.p.m.
- Turbine Setting = \( H_s + (H_b - 10) \)

WHERE \( H_b \) IS THE LOCAL ATMOSPHERIC PRESSURE IN METERS OF WATER.

Note: Beyond 2500 KW Jyoti offers tailor made units.

Source – M/s Jyoti Publication
SECTION – 2

GENERATOR

1.0 GENERATOR

Synchronous generator of natural air-cooled self ventilated with brush less excitation will be used. The generator shall be capable of delivering 10% continuous over load. The generator shall be star connected complete with stator, rotor, bearings, stator temperature detector, oil coolers for bearings, brush less excitation system, AVR and protection equipment.

The generator shall be designed to withstand the runaway speed of the turbine for 30 minutes without any detrimental effect. The generator shall be able to operate in parallel with other generator and with grid also. The generator stator and rotor shall have class F insulation Class B temperature rise and designed for continuous operation at 10% over load with screen-protected enclosure. The generators are designed to conform to IS 4722/1968/IEC-34/BS 4999.

The six terminals from three main windings shall be brought out to the terminal box. The generator neutral shall be directly or through resistor / transformer connected to earth through disconnecting link. The generator shall be capable to operate with either leading or lagging power factor by control of excitation. The power factor commonly ranges between .80 and 1.0.

The synchronous generator will be capable to establish its own operating voltage and maintain frequency while operated isolated. Thus if interconnection to the power system is severed, the generator may continue supplying the station and local load.

2.0 Basic Parameters of generator

- Rated output \( \text{kVA} \)
- Rated terminal voltage \( \text{kV} \)
- Power factor .8 to 1.0
- Frequency 50 Hz
- No. of phases 3
- Speed RPM
- Range of voltage variation \( \pm 10\% \)
- Range of frequency variation \( \pm 3\% \)
- Short circuit ratio \( > .8 \)
- Inertia constant \( > 1.0 \)

3.0 Rated voltage of generator

Followings are recommended rated voltages for generators of different rated output.

- Up to 500 KW \( 415 \, \text{V} \)
• 501 to 2500 KW  3.3 KV
• 2501 to 5000 KW  6.6 KV or 11 kV
• More than 5000 KW  11 KV

3.01 Range of voltage variation

The generators are normally manufactured to ± 5% voltage variation range. The voltage variations at the location of mini/small Hydro Power Station is very much higher to the range of say ± 10% to ± 15%. The higher voltage variation range call for much higher sized machine and more pertinently, a special design machine. It is therefore desirable to use standard design machine and try to adopt means to deal with voltage variation in, for instance, by changing taps of transformer.

4.0 Speed of generator

The generators are manufactured having standard speed of 500, 750, 1000 or 1500 RPM. In case the speed of turbine is low than the speed of standard generator, gear/ belt drive may be used to match with the speed of standard generator.

5.0 NOISE LEVEL

The noise level shall not exceed 90 dB when measured at a distance of 1.0 Meter from any component of the generator.

6.0 INSULATION AND TEMPERATURE RISE

Insulation shall be provided as follows:

(i) Stator winding material corresponding to class F
(ii) Rotor winding material corresponding to class F

The generator shall be capable of delivering rated output continuously at any voltage and frequency in the operating range at rated power factor without exceeding the following values of temperature rise over ambient temperature of 40 deg C. For ambient temperature higher than 40 degree C the temperature rise shall be reduced correspondingly.

(a) Stator winding  80°C
(b) Rotor winding
   (i) Single layer  90°C
   (ii) Multi layer  80°C
   (iii) Core  75°C

Each generator terminal shall be brought out of the stator frame for insertion of current transformers for protection, metering and surge protection apparatus. The generator neutral shall be grounded suitably and the generators shall be designed to safely withstand any mechanical / magnetic stresses resulting from either a three or a single phase fault.
7.0 BRAKES

For stopping the generating units quickly, generator shall be provided with suitable braking arrangement preferably compressed air operated brakes which will be operated automatically at predecided speed.

8.0 Stator

**The stator frame shall be of cast iron/ fabricated steel construction.** The frame shall be designed to withstand bending stresses and deflections due to its self weight and weight of the complete core to be supported by it. The stator core shall be built up of segmental punchings of low loss, non-oriented steel sheets and end plates. Each punching shall be carefully debarred and insulated on both sides with high quality varnish to reduce losses in the core.

The stator winding shall be of multi-turn or single turn type and shall be insulated with Class ‘F’ insulation. The stator winding shall be star connected with both ends of conductors of each phase out of the stator.

Six nos. embedded temperature detectors of resistance type shall be provided for stator winding located symmetrically.

8.01 Rotor

The design and construction of rotor shall be in accordance with the best modern practice. The factor of safety at maximum runaway speed based on yield point of material shall not be less than 1.5.

Necessary flywheel effect shall be incorporated into the rotating parts of the generator and shall be determined in consultation with turbine manufacturer. In case requisite moment of inertia is not available from the rotor, a separate flywheel shall be provided, to furnish the additional flywheel effect required.

8.02 Shaft

The generator shaft shall be made of the best quality carbon steel properly heat treated. The shaft shall be of adequate size to operate at all speeds including maximum runaway speed and shall be able to withstand short circuit stresses without excessive vibrations or distortion. The generator shall be accurately machined all over and polished where it passes through the bearings and accessible points for alignment checks. Generator shaft shall have suitable provision for coupling to turbine through gear box/belt drive.

8.03 Bearings

The generator bearings can be the

(a) Pad type or sleeve type with Babbitt lined. Bio-degradable oil lubricated either self lubrication or forced lubrication type.
(b) Anti-friction ball/ roller bearings oil or grease lubricated. These bearings shall be guaranteed for minimum continuous working for 100,000 (one hundred thousand) hours and shall be of proven design and performance.

8.04 Ventilation

The generator shall be provided with screen-protected enclosures for open ventilated type machines.

8.05 Heaters

Space heaters of adequate rating shall be provided for maintaining stator surrounding air temperature above the ambient during prolonged shutdown period.

8.06 The Flywheel

A separate flywheel of ample dimensions shall be supplied in case the required movement of inertia for limiting the speed rise/ runaway speed is not available from the generator rotor exciter, etc. The flywheel shall be coupled to the generator directly and to the turbine (through the speed increaser, if envisaged). Necessary provision for receiving the piston of the brake cylinder on application of brakes shall be made in the flywheel.

8.07 Neutral Grounding

The generator may be solidly grounded, through isolating link, if earth fault current does not exceed the three phase short circuit current. The resistance or transformer grounding may be used if earth fault current exceeds the three phase short circuit current.

9.0 Monitoring and Protection

9.01 Turbine

a. Speed of rotation
b. Oil level in the bearing
c. Bearing Temperature
d. Oil level of governing system
e. Oil pressure of governing system
f. Oil level of speed increaser
g. Oil temperature of speed increaser
h. Circulation of cooling water
i. Circulation of lubricants
j. Oil temperature of governing system
k. Penstock water pressure

Speed monitoring system is provided in two stages. First stage – Electromechanical sensor with speed indicator and over speed relay Second stage – Mechanical over speed switch
Immediate tripping is required for items a, i, e, k and h, other items b, c, d, f, g, j may have an alarm annunciated first allowing corrective action to be taken but in the absence of corrective action, tripping will follow.

9.02 Generator
a. Over current (stator & rotor)
b. Earth fault (stator & rotor)
c. Over/under voltage
d. Over/under frequency
e. Power reversal
f. Phase unbalance
g. Stator temperature
h. Bearing temperature
i. Oil level in bearing sump
j. Cooling air temperature

Immediate tripping is required for items a, b, c, d and e. Items f, g, h, i, and j may have an alarm annunciated allowing corrective action to be taken, but in the case of corrective action, tripping will eventually follow.

The differential protection is to be considered when the size of generator is large, normally more than 1000 kW.

9.03 Instrumentation

Following parameters may be monitored
- Voltage
- Current
- Watt
- Energy
- Reactive (KVAR) energy
- Power factor
- Speed
- Forebay water level
- Turbine opening
- Penstock pressure
- Frequency
- Stator temperature
- Turbine and generator bearings temperature
- Oil temperature of speed increaser
- Oil level of OPU
- Oil pressure of OPU
SECTION – 3

TRANSFORMER

1.0 TRANSFORMER

The function of power transformer is to convert electrical power from one voltage level to another. The power transformers are broadly classified as step up and step down transformers according as they are used for raising or lowering the voltage. The transformers are usually star/star, star/delta and delta star type. The principal components and accessories of a transformer are steel tank, core, windings, transformer oil, tap changing switch, conservator, breather, pressure relief or explosion vent pipe, oil and winding temperature thermometer and buchholz relay.

In hydropower station, step up transformers are generally used which perform the task of delivering power produced by the generators to the transmission system. Most of these transformers are connected directly to the generator with or without a generator breaker.

The transformers shall be designed as per requirements given in IS: 2026 – 1977.

1.1 Service Conditions

1.1.1 Ambient temperatures – The reference ambient temperatures assumed for the design of transformers are as follows:

- Maximum ambient air temperature    50°C
- Maximum daily average ambient air temperature  40°C
- Maximum yearly weighted average ambient temperature  32°C
- Minimum ambient air temperature    -5°C
- When cooling medium is water, the temperature of water will not exceed 30°C and that the average cooling water temperature will not exceed 25°C in any day.

1.1.2 Altitude

The transformers conforming to this standard are suitable for operation at an altitude not exceeding 1000 meters above mean sea level.

For altitude exceeding 1000 meters above mean sea level an adjustment of the temperature rise shall be necessary in accordance with IS 2026 (Part II) – 1977.

1.1.3 Temperature – Rise – The T/F shall conform to the requirements of temperature rise specified in IS2026 (Part-II)- 1977 and given below.
### TEMPERATURE-RISE LIMITS FOR OIL-IMMERSED TYPE TRANSFORMERS

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Part</th>
<th>Temperature-Rise External Cooling Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Air (°C)</td>
</tr>
<tr>
<td>1. (i)</td>
<td>Windings (temperature-rise measured by resistance method)</td>
<td>55°C</td>
</tr>
<tr>
<td></td>
<td>When the oil circulation is natural or forced non-directed</td>
<td></td>
</tr>
<tr>
<td>(ii)</td>
<td>Temperature class of insulation A</td>
<td>60°C</td>
</tr>
<tr>
<td></td>
<td>When the oil circulation is forced directed</td>
<td></td>
</tr>
<tr>
<td>(iii)</td>
<td>Top oil (temperature-rise measured by thermometer)</td>
<td>50°C</td>
</tr>
<tr>
<td></td>
<td>When the transformer is equipped with a conservator or sealed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45°C</td>
<td>50°C</td>
</tr>
<tr>
<td></td>
<td>When the transformer is neither equipped with a conservator nor sealed</td>
<td></td>
</tr>
<tr>
<td>(iv)</td>
<td>Cores, metallic parts, and adjacent materials</td>
<td>The temperature shall in no case reach a value that will damage the core itself, other parts or adjacent materials</td>
</tr>
</tbody>
</table>

**NOTE:** The temperature-rise limits of the windings (measured by resistance method) are chosen to give the same hot-spot temperature-rise with different types of oil circulation. The hot-spot temperature-rise cannot normally be measured directly. Transformers with forced directed oil flow have a difference between the hot-spot and the average temperature-rise in the windings which is smaller than that in transformers with natural or forced but not directed oil flow. For this reason the windings of transformers with natural or forced but not directed oil flow. For this reason the windings of transformers with forced directed oil flow can have temperature-rise limits (measured by resistance method) which are 5°C higher than in other transformers.

#### 1.1.4 Highest Voltage for T/F –
This is the maximum value of the voltage of a system to which winding of a transformer may be connected. It is denoted by $U_m$.

#### 1.1.5 Insulation levels –
The insulation levels shall be in accordance with IS 2026 (Part-III) − 1977.
The rated with stand voltages for the winding which constitutes its insulation level shall be varified by a set of following dielectric tests.

- The rated lightning impulse and one minute power frequency with stand voltages for transformers operating at highest voltages $U_m$ lower than 300 kV.
- The rated lightning impulse, one minute power frequency with stand voltage and switching impulse with stand voltages (Phase to earth) for transformer with $U_m$ greater than 300 kV.

The value of rated lightning impulse (LI) switching impulse (SI) and Power Frequency with stand voltages for one minute (AC) are given below.
### RATED WITHSTAND VOLTAGES FOR TRANSFORMER WINDINGS WITH HIGHEST VOLTAGE FOR EQUIPMENT

<table>
<thead>
<tr>
<th>Highest Voltage for Equipment $U_m$</th>
<th>Rated short duration power frequency withstand voltage</th>
<th>Rated lightning impulse withstand voltage</th>
<th>Rated switching impulse withstand voltage (phase to neutral)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) kV rms</td>
<td>(2) kV rms</td>
<td>(3) kV peak</td>
<td>(4)</td>
</tr>
<tr>
<td>1.1</td>
<td>3</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3.6</td>
<td>10</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>7.2</td>
<td>20</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>12</td>
<td>28</td>
<td>60</td>
<td>75</td>
</tr>
<tr>
<td>17.5</td>
<td>38</td>
<td>75</td>
<td>95</td>
</tr>
<tr>
<td>24</td>
<td>50</td>
<td>95</td>
<td>125</td>
</tr>
<tr>
<td>36</td>
<td>70</td>
<td>145</td>
<td>170</td>
</tr>
<tr>
<td>52</td>
<td>95</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>72.5</td>
<td>140</td>
<td>325</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>185</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td></td>
<td>230</td>
<td>550</td>
</tr>
<tr>
<td>123</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>230</td>
<td>550</td>
</tr>
<tr>
<td>145</td>
<td></td>
<td>275</td>
<td>650</td>
</tr>
<tr>
<td></td>
<td></td>
<td>275</td>
<td>650</td>
</tr>
<tr>
<td>170</td>
<td></td>
<td>325</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td></td>
<td>325</td>
<td>750</td>
</tr>
<tr>
<td>245</td>
<td></td>
<td>360</td>
<td>850</td>
</tr>
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<td></td>
<td></td>
<td>395</td>
<td>950</td>
</tr>
<tr>
<td>300</td>
<td></td>
<td>395</td>
<td>950</td>
</tr>
<tr>
<td></td>
<td></td>
<td>460</td>
<td>1050</td>
</tr>
<tr>
<td>362</td>
<td></td>
<td>460</td>
<td>1050</td>
</tr>
<tr>
<td></td>
<td></td>
<td>510</td>
<td>1175</td>
</tr>
<tr>
<td>420</td>
<td></td>
<td>570</td>
<td>1300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>630</td>
<td>1425</td>
</tr>
</tbody>
</table>

Note – The underlined values are preferred in IS: 585 – 1962 Specification for voltages and frequency for ac transmission and distribution systems (revised).
The choice between list 1 and list 2 for $U_m < 52$ kV and the choice between alternative rated withstand voltages for $U_m = 123, 145, 170$ and $245$ kV depends on the severity of overvoltage conditions to be expected in the system and on the importance of particular installation. Guidance may be obtained from IS: 2165–197.

2.0 **Rating** – Following are the standard ratings of the three phase transformer.

(a) **415 V/ 11000 Volt class**

<table>
<thead>
<tr>
<th>KVA</th>
<th>KVA</th>
<th>KVA</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>31.5</td>
<td>200</td>
<td>ONAN</td>
</tr>
<tr>
<td>6.3</td>
<td>40</td>
<td>250</td>
<td>ONAN</td>
</tr>
<tr>
<td>8</td>
<td>50</td>
<td>315</td>
<td>ONAN</td>
</tr>
<tr>
<td>10</td>
<td>63</td>
<td>400</td>
<td>ONAN</td>
</tr>
<tr>
<td>12.5</td>
<td>80</td>
<td>500</td>
<td>ONAN</td>
</tr>
<tr>
<td>16</td>
<td>100</td>
<td>630</td>
<td>ONAN</td>
</tr>
<tr>
<td>20</td>
<td>125</td>
<td>800</td>
<td>ONAN</td>
</tr>
<tr>
<td>25</td>
<td>160</td>
<td>1000</td>
<td>ONAN</td>
</tr>
</tbody>
</table>

(b) **33 kV / 11 kV Class**

<table>
<thead>
<tr>
<th>MVA</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>ONAN</td>
</tr>
<tr>
<td>1.6</td>
<td>ONAN</td>
</tr>
<tr>
<td>3.15</td>
<td>ONAN</td>
</tr>
<tr>
<td>4.0</td>
<td>ONAN</td>
</tr>
<tr>
<td>5.0</td>
<td>ONAN</td>
</tr>
<tr>
<td>6.3</td>
<td>ONAN</td>
</tr>
<tr>
<td>8.0</td>
<td>ONAN</td>
</tr>
<tr>
<td>10.0</td>
<td>ONAN</td>
</tr>
</tbody>
</table>

(c) **66 kV / 11 kV Class**

<table>
<thead>
<tr>
<th>MVA</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3</td>
<td>ONAN</td>
</tr>
<tr>
<td>8.0</td>
<td>ONAN</td>
</tr>
<tr>
<td>10.0</td>
<td>ONAN</td>
</tr>
<tr>
<td>12.5</td>
<td>ONAN/ ONAF</td>
</tr>
<tr>
<td>15.0</td>
<td>ONAN/ ONAF</td>
</tr>
<tr>
<td>20.0</td>
<td>ONAN/ ONAF</td>
</tr>
</tbody>
</table>

(d) **132/ 11 kV Class**

<table>
<thead>
<tr>
<th>MVA</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>ONAF</td>
</tr>
<tr>
<td>25</td>
<td>ONAF/ OFAF</td>
</tr>
<tr>
<td>31.5</td>
<td>ONAF/ OFAF</td>
</tr>
<tr>
<td>50</td>
<td>ONAF/ OFAF</td>
</tr>
</tbody>
</table>
(e) **220/ 11 kV Class**

<table>
<thead>
<tr>
<th>MVA</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>ONAF</td>
</tr>
<tr>
<td>50</td>
<td>OFWF</td>
</tr>
<tr>
<td>70</td>
<td>OFWF</td>
</tr>
<tr>
<td>100</td>
<td>OFWF</td>
</tr>
</tbody>
</table>

**SYMBOL**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONAN</td>
<td>Oil immersed natural air cooled</td>
</tr>
<tr>
<td>ONAF</td>
<td>Oil immersed forced air cooled</td>
</tr>
<tr>
<td>OFAF</td>
<td>Oil immersed with forced Oil circulation forced air cooled.</td>
</tr>
<tr>
<td>OFWF</td>
<td>Oil immersed with forced oil circulation, forced water cooled.</td>
</tr>
</tbody>
</table>

### 3.0 Operation at other than rated voltage and frequency

- The transformer shall be designed so that it may be operated at its rated kVA at any voltage within ±10% of the rated voltage of that particular tap.
- The transformer shall be capable of delivering rated current at a voltage equal to 105% of the rated voltage.
- The T/F shall be capable to operate at its rated kVA at 50Hz frequency with tolerance of ±3%

Transformer should be capable of remaining in operation at full load for 10 minutes after failure of blowers with out the calculated winding hot spot temperature exceeding 150°C. Transformer fitted with two coolers each capable of dissipating 50% of the losses at continuous maximum rating (CMR) should be capable of remaining in operation for 20 minutes in the event of failure of the blower associated with one cooler without the estimated winding hot spot temperature exceeding 150°C.

### 4.0 Requirement with regard to ability to withstand short circuit

The T/F shall be designed and constructed to withstand without damage the thermal and dynamic effects of external short circuit.

External short circuits are not restricted to three phase short circuit. They include line to line, double line to earth and line to earth fault.

The symmetrical short circuit current (rms value) shall be calculated using the short circuit impedance of the transformer plus the system impedance for transformers.

### 5.0 Typical values of short circuit impedance of Transformer

Typical values for the short circuit impedance of transformer expressed as the impedance voltage at rated current are given below.
### Rated Power (kVA) vs Impedence Voltage (%)

<table>
<thead>
<tr>
<th>Rated Power (kVA)</th>
<th>Impedence Voltage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 630 kVA</td>
<td>4.0</td>
</tr>
<tr>
<td>631 – 1250</td>
<td>5.0</td>
</tr>
<tr>
<td>1251 – 3150</td>
<td>6.25</td>
</tr>
<tr>
<td>3151 – 6300</td>
<td>7.15</td>
</tr>
<tr>
<td>6301 – 12500</td>
<td>8.35</td>
</tr>
<tr>
<td>12501 – 25000</td>
<td>10.00</td>
</tr>
<tr>
<td>25001 – 200000</td>
<td>12.5</td>
</tr>
</tbody>
</table>

### 6.0 Load Rejection on generator T/F

Transformer connected directly to generator may be subjected to load rejection conditions shall be able to withstand 1.4 times the rated voltages for 5 seconds at the transformer terminal.

### 7.0 Flux density

The maximum flux density in any part of the core and yoke at normal voltage and frequency should be such that the flux density in over voltage conditions does not exceed 1.9 tesla / 19000 lines per cm².

### 8.0 Construction Features of Transformer

#### 8.01 Insulation Liquid

Mineral oil if used shall comply with IS 335-1972.

#### 8.02 Bushings- The bushing used shall comply with IS 2099-1973 and IS 3347.

<table>
<thead>
<tr>
<th>L.V. Side</th>
<th>H.V. Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

- L.V. bushing should be mounted on turrets suitable for connection to bus bar in bus duct. If cables are used, the cable boxes may be provided.

- Solid porcelain / oil communicating and other type of bushing up to 36 kV voltage Class in accordance with IS 3347
- Oil impregnated paper (OIP) type condenser bushings for voltage above 36 kV to 220 kV in accordance with IS 2099 and IEC 137.

#### 8.03 Transformer Tank

The transformer tanks and covers are to be fabricated from good commercial grade, low carbon steel suitable for welding and of adequate thickness. The tank cover shall be bolted to the tank. All bolted connections to the tank shall be fitted with suitable oil tight gaskets. The tank shall have sufficient strength to withstand distortion developed during filling the oil by vacuum.
8.04 Core
The core shall be built with high grade, non-ageing, low loss, high permeability cold rolled, grain oriented silicon steel, thick laminations specially suitable for transformer core. Laminations shall be coated with a durable baked enamel insulation coating. The core shall be rigidly clamped and bolted to ensure adequate mechanical strength and to prevent vibrations during operation. The bolts used in the assembly of the core shall be suitably insulated. The core shall be provided with lugs suitable for lifting the complete core and coil assembly of the transformer. The design and construction of the core shall ensure-free operation.

8.05 Windings
The windings shall be pre-shrunk during manufacture. Clamping rings with adjustable screws shall be provided so that the necessary pressure can be brought to bear on the windings during assembly and that they shall not be damaged or deformed during shipment or by mechanical stresses induced by short circuits. All coil assemblies of identical voltage rating shall be interchangeable and field repairs to the windings can be made readily without special equipment. All leads from the windings to the terminal bushings shall be rigidly supported to prevent injury due to vibrations. Disc or helical type windings shall be used. The assembled core and winding shall be vacuum dried and suitably impregnated before removal from the treating tank.

The insulation used for windings shall be of adequate quality and electrical properties. The main insulation used shall be class ‘A’ for oil-immersed transformers and class ‘F’ for dry type transformers as specified in IS: 1271-1958.

8.06 Cooling Method
Identification Symbols – Transformers shall be identified according to the cooling method employed. Letter symbols for use in connection with each cooling method shall be as given in Table 1.

<table>
<thead>
<tr>
<th>Table 1 – Letter Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>i) Kind of Cooling Medium</strong></td>
</tr>
<tr>
<td>a) Mineral oil or equivalent flammable synthetic insulating liquid</td>
</tr>
<tr>
<td>b) Non-flammable synthetic insulating liquid</td>
</tr>
<tr>
<td>c) Gas</td>
</tr>
<tr>
<td>d) Water</td>
</tr>
<tr>
<td>e) Air</td>
</tr>
<tr>
<td><strong>ii) Kind of Circulation</strong></td>
</tr>
<tr>
<td>a) Natural</td>
</tr>
<tr>
<td>b) Forced (Oil not directed)</td>
</tr>
<tr>
<td>c) Forced (directed oil)</td>
</tr>
</tbody>
</table>

Arrangement of Symbols – Transformers shall be identified by four symbols for each cooling method for which a rating is assigned by the manufacturer.

Dry-type transformers without protective enclosure are identified by two symbols only for the cooling medium that is in contact with the windings of the surface coating of windings with an overall coating (for example, epoxy resin).
The order in which the symbols are used shall be as given in Table 2. Oblique strokes shall be used to separate the group symbols for different cooling methods.

For example, an oil-immersed transformer with forced directed oil circulation and forced air circulation shall be designated ODAF.

For oil-immersed transformers in which the alternatives of natural or forced cooling with non-directed oil flow are possible, typical designations are:

ONAN/ONAF  ONAN/OFAF

The cooling method of a dry-type transformer without a protective enclosing or with a ventilated enclosure and with natural air cooling is designated by:

AN

For a dry-type transformer in a non-ventilated protective enclosure with natural air cooling inside and outside the enclosure the designation as:

ANAN

**Table 2 ORDER OF SYMBOLS**

*(Clause 2.2.2)*

<table>
<thead>
<tr>
<th>1st Letter</th>
<th>2nd Letter</th>
<th>3rd Letter</th>
<th>4th Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kind of cooling medium indicating the cooling medium that is in contact with the windings</td>
<td>Kind of circulation</td>
<td>Kind of cooling medium indicating the cooling medium that is in contact with the external cooling systems</td>
<td>Kind of circulation</td>
</tr>
</tbody>
</table>

**8.07 FITTINGS AND ACCESSORIES**

The transformer shall have the following in addition to any other fittings recommended by the manufactures on transformer as required:

1. One set of H.V. bushings / cable box
2. One set of L.V. bushings/ cable box
3. Buchholz’s relay with alarm and trip contacts
   a) Size of buchholz’s relay up to 10 MVA – 50mm
   b) 10 MVA and above – 80 mm.
4. Oil sampling valves at the top and bottom of transformer tank and at the conservator bottom.
5. Air release devices
6. One silica gel breather
7. One externally operated off-load tap changing gear with locking arrangements
8. Conservator with oil filling hole, cap and drain plug size 19 mm nominal pipe and with one oil level gauge with low level alarm contacts.
9. a) plain oil level gauge for all transformer upto and including 1.6 MVA
   b) Magnetic type oil gauge for transformers above 1.6 MVA with low oil level alarm contact.
10. Explosion vent
11. Two earthing terminals, one on either side of the base.
12. One set of lifting lugs.
14. A set of four rollers suitable for moving the transformer along with fixing arrangements.

**Type of Rollers**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Rating</th>
<th>Type</th>
<th>Gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shorter Axis</td>
</tr>
<tr>
<td>1</td>
<td>Up to 5 MVA</td>
<td>Flat unidirectional</td>
<td>As per manufacturer’s practice, however not to exceed 1000 mm</td>
</tr>
<tr>
<td>2</td>
<td>6.3 MVA</td>
<td>Flanged bi-directional</td>
<td>1435 mm</td>
</tr>
<tr>
<td>3</td>
<td>10 MVA and above</td>
<td>Flanged bi-directional</td>
<td>1676 mm</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

15. Cooling accessories (ONAN/ONAF Cooling)
   - Radiators with shut off valves and air release plugs
   - Fans
   - Filter valves
   - Drain and sampling device
16. Skids
17. Compound necessary for filling cable boxes
18. Winding temperature indicator with two step contact for alarm and tripping
19. One dial type mercury thermometer mounted on the top cover to measure the temperature of the oil.
20. Cable boxes/ bushings on HV and L.V. sides of suitable size for accommodating aluminium cable of adequate sizes.
21. One oil-filling valve
22. One oil drain valve
23. Marshalling box – For housing control equipments and terminal connectors.
   Wiring up to marshalling box with PVC copper cable 2.5 sq. mm 660/1100 volts grade.
24. Weather proof cubicle to accommodate control equipment, terminal blocks etc.
25. Neutral CT for earth fault protection.
26. A Rating plate bearing the data specified in the standards.
27. A diagram plate showing internal connections & vector relationship of windings.
28. Metal Enclosure
29. One set of tools and tackles required for the transformer
30. Clamping device to take care of earthquake forces.
31. Other accessories as may be required.

All the accessories furnished, shall be suitably mounted on the transformer. All valves shall be provided either with blind companion flange or with pipe plugs for protection.
The above fittings as given below shall be provided.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Item</th>
<th>Transformers to which fitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Inspection Cover</td>
<td>Above 1 600 kVA</td>
</tr>
<tr>
<td>2.</td>
<td>Rating plate</td>
<td>All</td>
</tr>
<tr>
<td>3.</td>
<td>Terminal-marking plate</td>
<td>All</td>
</tr>
<tr>
<td>4.</td>
<td>Two earthing terminals</td>
<td>All</td>
</tr>
<tr>
<td>5.</td>
<td>Lifting lugs</td>
<td>All</td>
</tr>
<tr>
<td>6.</td>
<td>Drain valve with plug or cover plate</td>
<td>25 kVA and above</td>
</tr>
<tr>
<td>7.</td>
<td>Dehydrating breather</td>
<td>25 kVA and above for rated voltage 11 kV and below, and all ratings above 11 kV.</td>
</tr>
<tr>
<td>8.</td>
<td>Oil-level indicator with minimum</td>
<td>All</td>
</tr>
<tr>
<td>9.</td>
<td>Marking</td>
<td>All</td>
</tr>
<tr>
<td>10.</td>
<td>Thermometer pocket</td>
<td>All</td>
</tr>
<tr>
<td>11.</td>
<td>Oil-filling hole with cover</td>
<td>All</td>
</tr>
<tr>
<td>12.</td>
<td>Conservator</td>
<td>50 kVA and above for rated voltage 11 kV and below, and all ratings above 11 kV.</td>
</tr>
<tr>
<td>13.</td>
<td>Air release device</td>
<td>All transformers fitted with conservators</td>
</tr>
<tr>
<td>14.</td>
<td>Jacking lugs</td>
<td>Above 1 600 kVA</td>
</tr>
<tr>
<td>15.</td>
<td>Filter valve</td>
<td>Above 1 600 kVA</td>
</tr>
</tbody>
</table>

Note: When filter valves are required, the drain valve should be used as one of these.

8.08 RATING PLATES
Each transformer shall be provided with a rating plate of weather-proof material, fitted in a visible position, showing the appropriate items given below. The entries on the rating plate shall be indelibly marked (for example, by etching, engraving or stamping).

**Information to be given in all cases**
- Kind of transformer (for example, transformer, auto-transformer, booster transformer, etc);
- Number of this standard, Ref IS: 2026;
- Manufacturer’s name;
- Manufacturer’s serial number;
- Year of manufacture;
- Number of phases;
- Rated kVA (for multi-winding transformers the rated kVA of each winding shall be given. The loading combinations shall also be indicated unless the rated power of one of the windings is the sum of the rated powers of the other windings);
- Rated frequency;
- Rated voltages;
- Rated currents;
- Connection symbol;
- Percent impedance voltage at rated current (measured value corrected to 75°C)
m) Type of cooling (if the transformer has several methods of cooling, outputs that differ from the rated power may be shown as percentages of the rated power, for example, ONAN/ONAF 70/100 percent;

n) Total mass; and

o) Mass and volume of insulating oil.

9.0 CRITERIA FOR SELECTION OF GENERATOR TRANSFORMERS

Ratings – The MVA rating of the generator transformer should be at least equal to the full generator output without considering reduction for unit auxiliary requirements. The no-load voltage of the secondary winding should be specified about 5 percent more than the nominal value to compensate the transformer regulation partly.

Taps – The generator transformer more normally provided with off-circuit tap changers except in cases where the system conditions warrant use of on-load tap changers. The standard range for off-circuit tap changer is 2.5 percent to 7.5 percent in steps of 2.5 percent.

Connection Symbol – The preferred connection symbol for two winding transformers is YNd 11 or YNd 1 with the star neutral solidly earthed.

Impedance – The standard impedances are as given in IS:2026 (Part 1)-1977. The exact value is to be specified based on short-circuit level.

Termination Arrangement – The generator side LV terminals should be suitable for bus duct or cable connection. The HV side should have bare bushings suitable for out door installation. For 66 kV and above oil-filled condenser type bushings should be specified. For installation in polluted atmospheres, the bushings shall be specified with extra creepage distance as given in IS: 2099-1973.

Cooling – The type of cooling may be ONAN, OFAF or OFWF. The temperature-rise limits should be as given in IS:2026(Part2)-1977 (Section 5.6). Following cooling arrangements are recommended:

- Upto 10 MVA up to 66 KV ONAN
- Above 10 MVA up to 66 KV ONAN/ONAF

To
- 20 MVA 132 kV ONAF/OFAF
- 50 MVA 132 kV/220 kV OFAF/OFWF

Fittings and Accessories – The fittings and accessories should be as specified in Appendix C of IS: 2026 (Part 1) – 1977. The following should, in addition, be specified:

a) Magnetic oil level gauge
b) Gas and oil actuated relay
c) Explosion vent
d) Winding temperature indicator with electrical contacts for alarm/ trip and controlling fans and pumps  
e) Skids and hauling lugs  
f) Rollers (bidirectional, if required). If flanged rollers are required, rail gauge should be specified and  
g) Accessories for cooling arrangement

10.0 Criteria for selection of auxiliary and station transformers

Rating – The voltage rating should be specified in such a manner that the secondary voltages are about 5 percent more than the nominal voltages to compensate the transformer regulation.

The number of unit auxiliary transformers (UAT) is one or two depending upon the capacity of unit. The number of station transformers depends on the total number of generators in a power station. It is normal practice to provide one station transformer up to two units and two station transformers for two to five units.

The capacity of the unit auxiliary transformers is based on the total actual running auxiliary load of the particular unit with a 10% margin. If there are two auxiliary transformers per unit, each unit transformer should be rated for minimum 55 percent of the actual running auxiliary load of the unit.

The capacity of the station transformers should meet the following requirements:

a) All running auxiliaries for station service at full station load;  
b) The running auxiliaries of one unit bus at full load in the event of outage of one UAT at a time in the power station; and  
c) The auxiliary starting or coasting of another unit which may be taken as 40% of the normal auxiliary load.

Taps – The UATs are normally provided with off-circuit taps with ± 2.5 percent and ± 5 percent on HV side.

The station transformers are preferably provided with OLTC with ± 10 percent in steps of 1.25 percent on HV side.

Connection Symbol – The UATs are connected in delta/ star or delta/ delta. In case of delta/ star, the star neutral is earthed through a resistor.

The station transformers are connected in star/ delta or star/ star. In case of star/star, neutral on LV side is earthed through a resistor.

Impedance – The impedance is specified taking into consideration the fault level of the auxiliary switchgear and the voltage dip during starting of large motors. Also for station transformers with two secondaries, the impedance shall be specified to limit the fault levels.
**Termination Arrangement** – The HV and LV terminals of the UATs should be suitable for bus duct or cable connection.

The HV terminals of the station transformer are to be bare bushings suitable for outdoor installation. For rating 66 kV and above, oil filled condenser type bushings should be specified. For installation in polluted atmosphere, bushings should be specified with extra creepage distance in accordance with IS: 2090-1973. The LV terminals should be suitable for cable or bus duct connection.

The LV neutrals of UAT and station transformers wherever applicable, should be brought out for connection to neutral earthing resistor.

**Cooling** – The UATs may be ONAN.

The station transformers may be ONAN

**Fittings and Accessories** – The fittings and accessories should be as specified in Appendix C of IS: 2026 (Part 1)-1977.

11.0 **Magnetizing in rush current in a transformer**

When a T/F is energized, initially there is no induced emf. The resistance being low a large inrush of magnetizing current takes place. This current may reach 6-8 times of full load current. Consequently there is a spill current in the differential circuit which can cause differential relays to mal operate.

The magnetize in rush current has a predominantly second harmonic content and fifth harmonic content during over fluxing.

The second harmonic content is filtered and used as bias quantity in all harmonic restraint differential relays. As far as fifth harmonic is concerned the practice varies in some design, the fifth harmonic is also filtered and used for biasing against relay operation.

Under heavy internal fault condition, a poor CT can go under saturation due to DC component of fault current, residual flux in the core and A.C. component of fault current. The CT output in such cases is unsymmetrical and contains large second harmonics which can bias the relay against operation the time of operation of relay increases inordinately. Unless large CT cores are employed, this problem can not be overcome totally.

On examination of the wave form of magnetizing inrush current and over excitation current, it has been four that there is a substantial period of half cycle when current remains zero unlike in a fault current wave form. Deduction of these zero crossing is made uses in distinguishing fault current, magnetizing current and over excitation current. This is the approach taken in new T/F differential relay.
Harmonic content in Magnetizing in rush current | Amplitude as a % of fundamental
---|---
2<sup>nd</sup> | 63
3<sup>rd</sup> | 26.8
4<sup>th</sup> | 5.1
5<sup>th</sup> | 4.1
6<sup>th</sup> | 3.7
7<sup>th</sup> | 2.4

12.0 Over fluxing of a transformer
The flux density in a core is directly proportional to the applied voltage and inversely proportional to the frequency. Modern core material has a sharp saturating characteristic. Due to its low inherent losses and economy considerations, the working, flux density could be too close to the saturation value. Thus slight increase in voltage and lower frequency, the core is driven into saturation resulting higher excitation current which could be sufficient to cause relay – mal operation. The increased excitation current is made up of higher harmonic. The fifth harmonic is in phase with fundamental.

At 125% of rated voltage, the rms value of excitation current is 10% of rated current of T/F. At 143% of rated voltage, the excitation current is 100% rated current of T/F.

![Magnetizing inrush current wave in a transformer](image)
Sustained fault current wave

Magnetizing current with T/F over flux
SECTION – 4
CIRCUIT BREAKERS

1.0 CIRCUIT – BREAKERS
A mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also under specified abnormal circuit conditions such as those of short circuit etc.

Basically a circuit breaker comprises a set of fixed and movable contacts. The contacts can be separated by means of an operating mechanism. The separation of current carrying contacts produces an arc. The arc is extinguished by a suitable medium such as dielectric oil, air, vacuum, air blast SF-6 gas. The extinguishing media of the arc classifies the circuit breaker as oil circuit breaker, air circuit breaker, vacuum circuit breaker air blast circuit breaker and gas circuit breaker.

2.0 TYPE OF CIRCUIT BREAKER AND THEIR APPLICATION

2.1 Oil circuit breaker – A circuit breaker in which the movable and fixed contacts open and close in insulating oil. These breakers are bulky in size, requires lot of maintenance and are now not in use.

2.2 Air circuit breaker – A circuit breaker in which the contacts open and close in air at atmospheric pressure. These breakers are normally used upto 1000V supply voltage system. These breakers are equipped with overload and short circuit releases for protection. The releases may be thermal magnetic or static type.

The normal current rating of ACB are 400A, 630A, 800A, 1000A, 1250A, 1600A, 2000A, 2500A, 3200A.

The short circuit breaking capacity of these breakers are 8 KA, 10 KA, 12.5 KA, 16 KA, 25 KA, 40 KA, 50 KA and 80 KA.

2.3 Vacuum circuit breaker – A circuit breaker in which the contacts open and close within a highly evacuated envelope. These are generally used for 11 KV and 33 KV supply system.

2.4 Air blast circuit breaker – A circuit breaker in which the contacts open and close in a high pressure air. High pressure air is forced on the arc through a nozzle at the instant of contact separation.

These breakers were used in the past for system voltages above 33 kV. On account of high maintenance cost, the use of these breakers in new substation have not been preferred.

2.5 Gas circuit breaker - A circuit breaker in which the contacts open and closed in a gas medium other than air. These are generally for supply system above 33 KV to 760 KV.
SF-6 (sulphur hexafluoride) circuit breakers (Gas circuit breaker)
Sulphur hexafluoride (SF-6) is an inert, heavy gas having good dielectric and arc extinguishing properties. The dielectric strength of the gas increases with pressure and is more than that of insulating oil and 2.4 times that of air at a pressure of 3 kg/cm². The gas remains in a gaseous state up to a temperature of 9°C at 15kg/cm² pressure. Its density is about five times of air and the free heat convection is 1.6 times as much as that of air.

It is non inflammable, nonpoisonous and odourless. When arcing takes place through the gas, some by-products arc produced due to break down of gas which are a hazard to the health of maintenance personnel therefore should be properly taken care of.

The arc extinction process in SF-6 circuit breaker is different from that in Air-Blast circuit breakers. During the arcing period, SF-6 gas is blown axially along the arc. The gas removes the heat from the arc by axial convection and radial dissipation. As a result, the arc diameter reduces during the decreasing mode of the current wave. The diameter becomes small during current zero and the arc is extinguished.

The single flow pattern and double flow pattern arc used for arc extinguishing in single pressure puffer type and double pressure puffer type SF-6 breaker.

Single flow pattern has limited quenching ability and is used for lower breaking currents. Double flow pattern gives almost one and a half times the breaking capacity compared with single flow.

SF-6 Circuit breakers are of following types/ design.

- **Double pressure puffer type** – In this breaker, the gas from high pressure system is released into the low pressure system through a nozzle during the arc extinguishing process. This design is very complicated and has become obsolete.

- **Single pressure puffer type** – In this breaker, the gas is compressed by the moving cylinder system and is released through a nozzle while extinguishing the arc. This design is most popular. This is a sealed unit filled with SF-6 gas at a pressure of 5kg/cm². Both double pressure and single pressure puffer design have been developed in following two types of design.

  (a) **Live Tank Design** - In this breaker the interrupters are supported on porcelain insulators.

  (b) **Dead Tank Design** - In this breaker, the interrupters are installed on SF-6 gas filled tank at earth potential.

Single pressure puffer type live tank breakers are preferred for conventional outdoor switchyard.

2.6 **Moulded case circuit breakers** – It is a circuit breaker having a supporting housing of moulded insulating material forming an integral part of the circuit breaker. This is basically an air circuit breaker and used in system voltage up to 1000 V.

The current breaking capacity of these breakers are 10KA, 16KA, 25KA, 35KA, and 50KA, 70 KA.

3.0 Standard
- The low voltage circuit breakers upto 1000V shall conform to IS 13947-1993.
- The high voltage circuit breaker for system voltage exceeding 1000V shall conform to IS 13118-1991.

4.0 RATED CHARACTERISTICS OF CIRCUIT BREAKER

The following rated characteristics are generally specified for all high voltage AC circuit breakers rated above 1000V.

4.1 Rated Voltage
The rated voltage of a circuit breaker corresponds to the highest system voltage for which the circuit breaker is intended for use. The standard values of rated voltages are given below.

<table>
<thead>
<tr>
<th>Nominal System Voltage V rms</th>
<th>Rated Voltage of circuit breaker KV rms</th>
</tr>
</thead>
<tbody>
<tr>
<td>.240</td>
<td>.264</td>
</tr>
<tr>
<td>.415</td>
<td>.440</td>
</tr>
<tr>
<td>3.3</td>
<td>3.6</td>
</tr>
<tr>
<td>6.6</td>
<td>7.2</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>33</td>
<td>36</td>
</tr>
<tr>
<td>132</td>
<td>145</td>
</tr>
<tr>
<td>220</td>
<td>245</td>
</tr>
<tr>
<td>400</td>
<td>420</td>
</tr>
<tr>
<td>500</td>
<td>525</td>
</tr>
<tr>
<td>750</td>
<td>765</td>
</tr>
</tbody>
</table>

4.2 Rated Insulation Level
It is the combination of rated voltage, the corresponding impulse withstand voltage and corresponding power frequency with stand voltage and are given below.
Table 1 – Power frequency voltage withstand test and Impulse voltage withstand test For Voltage upto 72.5 kV (Reference Values)

<table>
<thead>
<tr>
<th>Circuit Breaker Rated Insulation Level</th>
<th>One Minute Power Frequency Withstand Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage of Circuit-Breakers kV (r.m.s.)</td>
<td>Standard impulse withstand voltage positive or negative polarity kV (peak)</td>
</tr>
<tr>
<td>3.6</td>
<td>45</td>
</tr>
<tr>
<td>7.2</td>
<td>60</td>
</tr>
<tr>
<td>12</td>
<td>75</td>
</tr>
<tr>
<td>17.5</td>
<td>95</td>
</tr>
<tr>
<td>24</td>
<td>125</td>
</tr>
<tr>
<td>36</td>
<td>170</td>
</tr>
<tr>
<td>52</td>
<td>250</td>
</tr>
<tr>
<td>72.5</td>
<td>325</td>
</tr>
</tbody>
</table>

Table – 2 (Above 72.5 kV Reference Values)

<table>
<thead>
<tr>
<th>Circuit breaker Rated Insulation Level</th>
<th>One Minute Power Frequency Voltage Withstand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Impulse Withstand Voltage</td>
<td>For type and Routine Tests</td>
</tr>
<tr>
<td>Rated Voltage kV (r.m.s.)</td>
<td>Full insulation kV (r.m.s.)</td>
</tr>
<tr>
<td>100</td>
<td>450</td>
</tr>
<tr>
<td>123</td>
<td>550</td>
</tr>
<tr>
<td>145</td>
<td>650</td>
</tr>
<tr>
<td>170</td>
<td>750</td>
</tr>
<tr>
<td>245</td>
<td>1050</td>
</tr>
<tr>
<td>300</td>
<td>-</td>
</tr>
<tr>
<td>420</td>
<td>1425</td>
</tr>
</tbody>
</table>

4.3 Standard Frequency

The standard frequency for a three pole circuit breaker is the frequency of the power system (50 Hz). The frequency of the power system influences the circuit breaker behaviour as follows.

- The temperature rise of current carrying parts and neighboring metallic parts is influenced by eddy current heating. The increase in frequency results in increased eddy currents and thus high temperature of current carrying parts and neighboring metallic parts. Hence with specified limits of temperature rise, the rated current of circuit breaker needs derating for application on higher frequency.
- The breaking time of a circuit breaker increases with reduction in frequency.
- The increase in frequency influences the TRV and rate of rise of TRV.
Hence a circuit breaker designed and tested for a certain frequency can not be recommended for other frequencies.

4.4 **Rated Normal Current**

The rated normal current of a circuit breaker is the r.m.s. value of the current which the circuit breaker can carry continuously and with temperature rise of the various parts with in specified limits.

Preferred values of rated normal currents, Ampere r.m.s.

400, 630, 800, 1250, 1600, 2000, 2500, 3150, 4000

The design of contacts and other current carrying parts in the interrupter of the circuit-breaker are generally based on the limits of temperature rise. For a given cross-section of the conductor and a certain value of current, the temperature rise depends upon the conductivity of the material. Hence, high conductivity material is preferred for current carrying parts. The cross-section of the conductors should be increased for materials with lower conductivity.

### Permissible Temperature Rise

<table>
<thead>
<tr>
<th>Item</th>
<th>Maximum value of temperature °C</th>
<th>Temperature rise at ambient air temperature of 40°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Copper contacts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) In air with silver plating</td>
<td>105</td>
<td>65</td>
</tr>
<tr>
<td>(b) In air without silver plating</td>
<td>75</td>
<td>35</td>
</tr>
<tr>
<td>(c) In oil with silver plating</td>
<td>90</td>
<td>50</td>
</tr>
<tr>
<td>(d) Without silver plating in oil</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>2. Oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In oil circuit-breakers</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>3. Terminals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) With silver plating</td>
<td>105</td>
<td>65</td>
</tr>
<tr>
<td>(b) Without silver plating</td>
<td>90</td>
<td>50</td>
</tr>
<tr>
<td>4. Metal part in contact with class E insulation in oil.</td>
<td>100</td>
<td>60</td>
</tr>
</tbody>
</table>

The use of magnetic materials in close circuits should be avoided to prevent heating due to hysteresis loss and eddy currents. The rated current of a circuit-breaker is verified by conducting temperature-rise tests.

4.5 **Rated Short Circuit Breaking Current**

The rated short-circuit breaking current of a circuit-breaker is the highest value of short-circuit current which a circuit-breaker is capable of breaking under specified conditions of transient recovery voltage and power frequency voltage.

The short-circuit current has a certain value at the instant of contact separation.

Breaking current refers to value of current at the instant of the contact separation.
Determination of breaking current.

The transient recovery voltage refers to the transient voltage appearing across the circuit-breaker pole immediately after the arc interruption. The rated values of transient recovery voltage are specified for various rated voltages of circuit-breakers. For specified conditions of rated TRV and rated power frequency recovery voltage, a circuit-breaker has a certain limit of breaking current. This limit is determined by conducting short-circuit type tests on the circuit-breaker. The waveforms of short-circuit current are obtained during the breaking test. The evaluation of the breaking current is explained in Fig. above.

The breaking current is expressed by two values:

1. The r.m.s. value of the a.c. component at the instant of contact separation EE, given by
   \[ \frac{I_{AC}}{\sqrt{2}} \]

2. The percentage d.c. component at the instant of contact separation, given by
   \[ \frac{I_{DC} \times 100}{I_{AC}} \]

The R.M.S. values of a.c. component are expressed in kA, the standard values being

8.0, 10, 12.5, 16, 20, 25, 31.5, 40, 45, 63, 80 and 100 kA

---

**Legend:**

- **AA'** Envelope of current wave
- **BB'** Normal zero axis of wave
- **CC'** Displaced zero axis of wave
- **EE** Instant of contact separation
- **I_{AC}** Peak value of A.C. component at EE
- **I_{DC}** D.C. component of current at EE
- \( \frac{I_{DC} \times 100}{I_{AC}} \) Percentage of D.C. component at the instant EE
- \( \frac{I_{AC}}{\sqrt{2}} \) = R.M.S. value a.c. component.
The earlier practice was to express the rated breaking capacity of a circuit-breaker in terms of MVA given as follows:

\[ MVA = \sqrt{3} \times kV \times kA \]

Where

- \( MVA \) = Breaking capacity of a circuit-breaker
- \( kV \) = Rated voltage
- \( kA \) = Rated breaking current

This practice of specifying the breaking capacity in terms of MVA is convenient while calculating the fault levels. However, as per the revised standards the breaking capacity is expressed in kA for specified conditions of TRV, and this method takes into account both breaking current and TRV.

While selecting the circuit-breaker for a particular location in the power system, the fault level at that location is determined. The rated breaking current can then be selected from the standard range.

4.6 Rated short-circuit Making current

It may so happen that circuit-breaker may close on an existing fault. In such cases the current increases to the maximum value at the peak of first current loop. The circuit-breaker should be able to close without hesitation as contacts touch. The circuit-breaker should be able to withstand the high mechanical forces during such a closure. These capabilities are proved by carrying out making current test. The rated short-circuit making current of a circuit-breaker is the peak value of first current loop of short-circuit current \( (I_{pk}) \) which the circuit-breaker is capable of making at its rated voltage.

The rated short-circuit making current should be at least 2.5 times the r.m.s. value of a.c. component of rated breaking current.

\[
\text{Rated making current} = 1.8 \times \sqrt{2} \times \text{Rated short-circuit breaking current} \\
= 2.5 \times \text{Rated short-circuit breaking current}
\]

In above equation the factor \( \sqrt{2} \) converts the r.m.s. value to peak value. Factor 1.8 takes into account the doubling effect of short-circuit current with considerations to slight drop in current during the first quarter cycle.

4.7 Rated duration of short-circuit

The short time current of a circuit-breaker is the r.m.s. value of current that the circuit-breaker can carry in a fully closed position during a specified time under prescribed conditions of use and behaviour. It is normally expressed in terms of kA for a period of one second.

The rated duration of short-circuit is generally 1 second and the circuit-breaker should be able to carry short-circuit current equal to its rated breaking-current for one second. During the short-time current test, the contacts should not get damaged or welded. The current carrying parts and insulations should not get deteriorated. Generally, the cross-section of conductors based on normal current rating requirement is quite adequate for carrying the rated short-circuit current for the duration of 1 second.
4.8 **Rated Operating Sequence**

The opening sequence denotes the sequence of opening and closing operations which the circuit-breaker can perform under specified conditions. The operating mechanism experiences severe mechanical stresses during the auto-reclosure duty. As per IEC, the circuit-breaker should be able to perform the operating sequence as per one of the following two alternatives:

(i) \[O - t - CO - T - CO\]

Where. 
- **O** = opening operation
- **C** = closing operation
- **CO** = closing followed by opening
- **t** = 3 minutes for circuit-breaker not to be used for rapid auto-reclosure
- **T** = 3 minutes

**Note** – Instead of **T = 3 minutes**, other values: **T= 15 seconds** (for voltages less than or equal to 52 KV) and **T = 1 minute** are also used for circuit breakers intended for rapid auto reclosing.

(ii) \[CO - t' - CO\]

Where, 
- **t'** = 15 second for circuit-breaker not to be used for rapid-auto-reclosure.

4.9 **TRANSIENT RECOVERY VOLTAGE OR RESTRIKING VOLTAGE**

In alternating current circuit breakers, the current interruption takes place invariably at the natural zero of the current wave.

After a current zero, the arc gets extinguished if the rate of rise of transient recovery voltage between the contacts is less than the rate of gain of the dielectric strength. The voltage appearing across contacts after current zero is a transient voltage of higher natural frequency (called restriking voltage) superimposed on the power frequency system voltage (power frequency recovery voltage).

Thus transient recovery voltage also called transient restriking voltage refers to the voltage across the poles immediately after arc extinction. This voltage consists of two components, an oscillatory transient component plus a power frequency component called power frequency recovery voltage.

The transient oscillatory components subsides after a few microseconds and the power frequency component continues. The frequency of transient component is given by

\[f_n = \frac{1}{2\pi\sqrt{LC}} \text{ Hz}\]

\[f_n = \text{frequency of transient recovery voltage}\]
\[L = \text{equivalent inductance, henry}\]
• Effect of natural frequency on transient recovery voltage
The rate of rise of TRV increases with increase in natural frequency. The increased rate of rise of TRV causes more voltage stress on the contact-gap tending to continue the arc. Thus breaking capacity of a circuit breaker reduces with increase in natural frequency.

• Effect of Power factor on TRV
The arc gets extinguished at current zero. At unity P.F., the voltage and current are in phase and both are zero at the same instant. For zero power factor currents, the peak value of the system voltage ($E_{\text{max}}$) is impressed on the circuit breaker poles at the instant of current zero. Such sudden application of high voltage give rise to severe transient and has a high rate of rise of TRV.

Hence interrupting current of low P.F. is a difficult switching duty.

• Effect of the first pole to clear on TRV
In three phase AC circuit breaker, the arc extinction in the three poles is not simultaneous as the currents in three phases are mutually 120° out of phase. Hence the power frequency recovery voltage of the phase in which the arc gets extinguished first, is about 1.5 times the phase voltage.

To consider the effect of the first pole clear on the power frequency component of TRV, the following factor has been defined in the standards.

The first pole to clear factor = $\frac{\text{voltage between healthy and faulty line ($V_{RN}$)}}{\text{Normal phase to Neutral voltage ($V_{RN}$)}}$

For non effective earthing, the value of first pole to clear factor is 1.5 and for effective earthing 1.3.
• Amplitude factor = \[
\frac{\text{Highest peak value of TRV}}{\text{Peak value of power frequency recovery voltage}}
\]

• Representation of rated TRV
  The following parameters are used for the representation of rated TRV:

a) Four-parameter reference line (see figure below)
   \( u_1 = \) first reference voltage, in kilovolts
   \( t_1 = \) time to reach \( u_1 \), in microseconds
   \( u_c = \) second reference voltage (TRV peak value), in kilovolts
   \( t_2 = \) time to reach \( u_c \), in microseconds

b) Two-parameter reference line (see figure below)
   \( u_c = \) reference voltage (TRV peak value), in kilovolts
   \( t_3 = \) time to reach \( u_c \), in microseconds
c) Delay line of TRV

\[ t_d = \text{time delay, in microseconds} \]

\[ u' = \text{reference voltage in kilovolts} \]

\[ r' = \text{time to reach } u' \text{ in microseconds} \]

The delay line starts on the time axis at the rated time delay and runs parallel to the first section of the reference line of rated TRV and terminates at the voltage \( u' \) (time-coordinate \( t' \)).

- **Standard values of rated TRV**

  Standard values of rated TRV for three-pole circuit-breakers of rated voltages below 100 kV, make use of two parameters. Values are given in Table IIA for rated voltages series I.

  For rated voltages of 100 kV and above, four parameters are used. Values are given in Table IIC for a first-pole-to-clear factor of 1.3 for rated voltages from 100 kV to 170 kV. Table IID gives values appropriate to a first-pole-to-clear factor of 1.5 for this range of rated voltages. Table IIE gives values for rated voltages of 245 kV and above.

  For rated breaking currents greater than 50 kA and voltages 100 kV and above, it may be justified and more economical to use circuit-breakers having lower capabilities in terms of rate of rise of the TRV.
### Table- IIA

**Standard values of rated transient recovery voltage**  
**Rated voltages Series-I**  
**Representation by two parameters – First-pole-to-clear factor 1.5**

<table>
<thead>
<tr>
<th>Rated voltage U (kV)</th>
<th>TRV peak value $U_c$ (kV)</th>
<th>Time $t_3$ (μs)</th>
<th>Time delay $t_d$ (μs)</th>
<th>Voltage $u'$ (kV)</th>
<th>Time $t'$ (μs)</th>
<th>Rate of rise $u'_c/t_3$ (kV.μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.6</td>
<td>6.2</td>
<td>40</td>
<td>6</td>
<td>2.1</td>
<td>19</td>
<td>0.15</td>
</tr>
<tr>
<td>7.2</td>
<td>12.3</td>
<td>52</td>
<td>8</td>
<td>4.1</td>
<td>25</td>
<td>0.24</td>
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<tr>
<td>12</td>
<td>20.6</td>
<td>60</td>
<td>9</td>
<td>6.9</td>
<td>29</td>
<td>0.34</td>
</tr>
<tr>
<td>17.5</td>
<td>30</td>
<td>72</td>
<td>11</td>
<td>10</td>
<td>35</td>
<td>0.42</td>
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<tr>
<td>24</td>
<td>41</td>
<td>88</td>
<td>13</td>
<td>14</td>
<td>42</td>
<td>0.47</td>
</tr>
<tr>
<td>36</td>
<td>62</td>
<td>108</td>
<td>16</td>
<td>21</td>
<td>52</td>
<td>0.57</td>
</tr>
<tr>
<td>52</td>
<td>89</td>
<td>132</td>
<td>7</td>
<td>30</td>
<td>51</td>
<td>0.68</td>
</tr>
<tr>
<td>72.5</td>
<td>124</td>
<td>166</td>
<td>8</td>
<td>41</td>
<td>64</td>
<td>0.75</td>
</tr>
</tbody>
</table>

$u'_c = 1.4 \cdot 1.5 \sqrt{\frac{2}{3}} U$ : $t_d = 0.15 t_3$ for $U < 52$ kV.

$u' = \frac{1}{3} u'_c$ : $t_d = 0.05 t_3$ for $U \geq 52$ kV.

### Table- IIC

**Standard values of rated transient recovery voltage**  
**Rated voltages 100 kV to 170 kV**  
**Representation by four parameters – First-pole-to-clear factor 1.3**

<table>
<thead>
<tr>
<th>Rated voltage U (kV)</th>
<th>First reference voltage $u_1$ (kV)</th>
<th>Time $t_1$ (μs)</th>
<th>TRV peak value $u_c$ (kV)</th>
<th>Time $t_2$ (μs)</th>
<th>Time delay $t_d$ (μs)</th>
<th>Voltage $u'$ (kV)</th>
<th>Time $t'$ (μs)</th>
<th>Rate of rise $u_1/t_1$ (kV.μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>106</td>
<td>53</td>
<td>149</td>
<td>159</td>
<td>2</td>
<td>53</td>
<td>29</td>
<td>2.0</td>
</tr>
<tr>
<td>123</td>
<td>131</td>
<td>65</td>
<td>183</td>
<td>195</td>
<td>2</td>
<td>65</td>
<td>35</td>
<td>2.0</td>
</tr>
<tr>
<td>145</td>
<td>154</td>
<td>77</td>
<td>215</td>
<td>231</td>
<td>2</td>
<td>77</td>
<td>40</td>
<td>2.0</td>
</tr>
<tr>
<td>170</td>
<td>180</td>
<td>90</td>
<td>253</td>
<td>270</td>
<td>2</td>
<td>90</td>
<td>47</td>
<td>2.0</td>
</tr>
</tbody>
</table>

$u_1 = 1.3 \sqrt{\frac{2}{3}} U$ : $t_2 = 3 t_1$ ; $u_c = 1.4 u_1$ ; $u' = \frac{1}{2} u_i$
Table- II D

Standard values of rated transient recovery voltage
Rated voltages 100 kV to 170 kV
Representation by four parameters – First-pole-to-clear factor 1.5

<table>
<thead>
<tr>
<th>Rated voltage</th>
<th>First reference voltage</th>
<th>Time</th>
<th>TRV peak value</th>
<th>Time</th>
<th>Time delay</th>
<th>Voltage</th>
<th>Time</th>
<th>Rate of rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>U (kV)</td>
<td>u₁ (kV)</td>
<td>t₁ (μs)</td>
<td>u₂ (kV)</td>
<td>t₂ (μs)</td>
<td>t₃ (μs)</td>
<td>u' (kV)</td>
<td>t' (μs)</td>
<td>u₁/t₁ (kV.μs)</td>
</tr>
<tr>
<td>100</td>
<td>122</td>
<td>61</td>
<td>171</td>
<td>183</td>
<td>2</td>
<td>61</td>
<td>33</td>
<td>2.0</td>
</tr>
<tr>
<td>123</td>
<td>151</td>
<td>75</td>
<td>211</td>
<td>225</td>
<td>2</td>
<td>75</td>
<td>40</td>
<td>2.0</td>
</tr>
<tr>
<td>145</td>
<td>178</td>
<td>89</td>
<td>249</td>
<td>267</td>
<td>2</td>
<td>89</td>
<td>46</td>
<td>2.0</td>
</tr>
<tr>
<td>170</td>
<td>208</td>
<td>104</td>
<td>291</td>
<td>312</td>
<td>2</td>
<td>104</td>
<td>54</td>
<td>2.0</td>
</tr>
</tbody>
</table>

\[ u₁ = 1.5 \sqrt{\frac{2}{3}} U : \quad t₂ = 3t₁ : u₂ = 1.4 u₁ : u' = \frac{1}{2} u₁ \]

Table- II E

Standard values of rated transient recovery voltage
Rated voltages from 245 kV and above
Representation by four parameters – First-pole-to-clear factor 1.3

<table>
<thead>
<tr>
<th>Rated voltage</th>
<th>First reference voltage</th>
<th>Time</th>
<th>TRV peak value</th>
<th>Time</th>
<th>Time delay</th>
<th>Voltage</th>
<th>Time</th>
<th>Rate of rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>U (kV)</td>
<td>u₁ (kV)</td>
<td>t₁ (μs)</td>
<td>u₂ (kV)</td>
<td>t₂ (μs)</td>
<td>t₃ (μs)</td>
<td>u' (kV)</td>
<td>t' (μs)</td>
<td>u₁/t₁ (kV.μs)</td>
</tr>
<tr>
<td>245</td>
<td>260</td>
<td>130</td>
<td>364</td>
<td>390</td>
<td>2</td>
<td>130</td>
<td>67</td>
<td>2.0</td>
</tr>
<tr>
<td>300</td>
<td>318</td>
<td>159</td>
<td>446</td>
<td>477</td>
<td>2</td>
<td>159</td>
<td>82</td>
<td>2.0</td>
</tr>
<tr>
<td>362</td>
<td>384</td>
<td>192</td>
<td>538</td>
<td>576</td>
<td>2</td>
<td>192</td>
<td>98</td>
<td>2.0</td>
</tr>
<tr>
<td>420</td>
<td>446</td>
<td>223</td>
<td>624</td>
<td>669</td>
<td>2</td>
<td>223</td>
<td>113</td>
<td>2.0</td>
</tr>
<tr>
<td>525</td>
<td>557</td>
<td>279</td>
<td>780</td>
<td>837</td>
<td>2</td>
<td>279</td>
<td>141</td>
<td>2.0</td>
</tr>
<tr>
<td>765</td>
<td>812</td>
<td>406</td>
<td>1137</td>
<td>1218</td>
<td>2</td>
<td>406</td>
<td>205</td>
<td>2.0</td>
</tr>
</tbody>
</table>

\[ u₁ = 1.3 \sqrt{\frac{2}{3}} U : \quad t₂ = 3t₁ : u₂ = 1.4 u₁ : u' = \frac{1}{2} u₁ \]

The tables also indicate values of rate of rise, taken as u₂/t₃ and u₁/t₁, in the two-parameter and four-parameter cases respectively, which together with TRV peak values u₂ may be used for purposes of specification of TRV.

The values given in the tables are prospective values. They apply to circuit-breakers for general transmission and distribution in three-phase systems having service frequencies of 50 Hz or 60Hz and consisting of transformers, overhead lines and short lengths of cable.
5.0 Selection of circuit breaker.

- Calculate the normal current of the system.
- Calculate the short circuit breaking current of the system.
- Select the breaker based on rated voltage, rated short circuit breaking current and rated normal current from the following table-1.

<table>
<thead>
<tr>
<th>Rated Voltage $U$ (kV)</th>
<th>Rated short-circuit breaking current $I_{sc}$ (kA)</th>
<th>Rated Normal Current $I_n$ (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 630 1 250 1 250 1 600 2 500 4 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 630 1 250 1 250 1 600 2 500 4 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 630 1 250 1 250 1 600 2 500 4 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 630 1 250 1 250 1 600 2 500 4 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 630 1 250 1 250 1 600 2 500 4 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 630 1 250 1 250 1 600 2 500 4 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 630 1 250 1 250 1 600 2 500 4 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>72.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>800 1 250 1 250 1 600 2 000 4 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>123</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 250</td>
</tr>
<tr>
<td>Voltage (kV)</td>
<td>Current (A)</td>
<td>Nominal Voltage (V)</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>145</td>
<td>2 000</td>
<td>1 250</td>
</tr>
<tr>
<td>170</td>
<td>2 000</td>
<td>1 250</td>
</tr>
<tr>
<td>245</td>
<td>2 000</td>
<td>1 250</td>
</tr>
<tr>
<td>300</td>
<td>2 000</td>
<td>1 250</td>
</tr>
<tr>
<td>362</td>
<td>2 000</td>
<td>1 250</td>
</tr>
<tr>
<td>420</td>
<td>2 000</td>
<td>1 250</td>
</tr>
<tr>
<td>525</td>
<td>2 000</td>
<td>1 250</td>
</tr>
<tr>
<td>765</td>
<td>2 000</td>
<td>1 250</td>
</tr>
</tbody>
</table>

**6.0 Name Plate Information**

Following informations are to be given on the name plate of a circuit breaker.
### Nameplate Information

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Unit</th>
<th>Circuit-breaker</th>
<th>Operating device</th>
<th>Condition: Marking required only if</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Manufacturer</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type designation and serial number</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated voltage</td>
<td>U</td>
<td>kV</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage</td>
<td>U&lt;sub&gt;l&lt;/sub&gt;</td>
<td>kV</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage</td>
<td>U&lt;sub&gt;s&lt;/sub&gt;</td>
<td>kV</td>
<td>y</td>
<td>Rated voltage 300 kV and above</td>
</tr>
<tr>
<td>Rated frequency</td>
<td>f</td>
<td>Hz</td>
<td>y</td>
<td>Rating is not applicable at both 50 Hz and 60 Hz</td>
</tr>
<tr>
<td>Rated normal current</td>
<td>I&lt;sub&gt;n&lt;/sub&gt;</td>
<td>A</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Rated duration of short-circuit</td>
<td>I&lt;sub&gt;th&lt;/sub&gt;</td>
<td>s</td>
<td>y</td>
<td>Different from 1 Second</td>
</tr>
<tr>
<td>Rated short-circuit breaking current</td>
<td>I&lt;sub&gt;sc&lt;/sub&gt;</td>
<td>kA</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>First-pole-to-clear factor</td>
<td></td>
<td></td>
<td>y</td>
<td>Different from 1.3 for rated voltages 100 kV to 170 kV</td>
</tr>
<tr>
<td>Rated out-of-phase breaking current</td>
<td>I&lt;sub&gt;d&lt;/sub&gt;</td>
<td>kA</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Rated line-charging breaking current</td>
<td>I&lt;sub&gt;l&lt;/sub&gt;</td>
<td>A</td>
<td>y</td>
<td>Rated voltage 72.5 kV and above</td>
</tr>
<tr>
<td>Rated cable-charging breaking</td>
<td>I&lt;sub&gt;c&lt;/sub&gt;</td>
<td>A</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Rated single capacitor bank breaking current</td>
<td>I&lt;sub&gt;sb&lt;/sub&gt;</td>
<td>A</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Rated back-to-back capacitor bank breaking current</td>
<td>I&lt;sub&gt;sb&lt;/sub&gt;</td>
<td>A</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Rated capacitor bank inrush making current</td>
<td>I&lt;sub&gt;bi&lt;/sub&gt;</td>
<td>kA</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Rated gas pressure for operation</td>
<td>P&lt;sub&gt;op&lt;/sub&gt;</td>
<td>MPa or bar</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Rated gas pressure for interruption</td>
<td>P&lt;sub&gt;cb&lt;/sub&gt;</td>
<td>MPa or bar</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Rated supply voltage of closing and opening devices</td>
<td>V</td>
<td>(X)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated supply frequency of closing and opening devices</td>
<td>f</td>
<td>Hz</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Rated supply voltage of auxiliary circuits</td>
<td>U&lt;sub&gt;a&lt;/sub&gt;</td>
<td>V</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Rated supply frequency of auxiliary circuits</td>
<td>f</td>
<td>Hz</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Mass (including oil for oil circuits-breakers)</td>
<td>m</td>
<td>kg</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>Rated operating sequence</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year of manufacture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature class</td>
<td>y</td>
<td>y</td>
<td>Different from - 5°C indoor - 25°C outdoor</td>
<td></td>
</tr>
</tbody>
</table>
X = the making of these values is mandatory; blanks indicate the value zero.
(X) = the marking of these values is optional
y = the marking of these values to the conditions in column (6)

Note – The abbreviations in column (2) may be used instead of the terms in column (1). When terms of column (1) are used the word “rated” need not appear.

**7.0 CONSTRUCTION REQUIREMENT OF INDOOR TYPE 415V, 11 KV AND 33 KV CIRCUIT BREAKERS**

In micro, mini and small hydro power stations, the most commonly used circuit breakers are of indoor type 415V ACB, 11 KV VCB and 33 KV VCB. The salient features of these breakers are given below:

- The C.B. shall be horizontal withdraw, metal clad pattern, indoor, free standing, complete with spring closing mechanism by manual and motorized both.
- The cubicle shall be provided with suitable louveres covered with perforated mild steel sheets and so located as to direct the hot gases away from operating personnel.
- Sheet steel, hinged, lockable doors shall be provided at the front for CT chamber.
- The C.B. shall have a rupturing capacity of not less than _____ kA at _____ kV at less than 0.15 p.F. and a peak making capacity of 2.55 times the breaking capacity.
- Technical specification

<table>
<thead>
<tr>
<th>Type</th>
<th>415V breaker</th>
<th>11 kV breaker</th>
<th>33 kV breaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of poles</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Class</td>
<td>Indoor</td>
<td>Indoor</td>
<td>Indoor</td>
</tr>
<tr>
<td>Current rating</td>
<td>_______ Amps</td>
<td>- Amps.</td>
<td>- Amps</td>
</tr>
<tr>
<td>Rated voltage</td>
<td>415 V</td>
<td>11 kV</td>
<td>33 kV</td>
</tr>
<tr>
<td>Higher rated voltage</td>
<td>660 V</td>
<td>12 kV</td>
<td>36 kV</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 c/s</td>
<td>50 c/s</td>
<td>50 c/s</td>
</tr>
<tr>
<td>Impulse with stand voltage</td>
<td>_______</td>
<td>75 kV</td>
<td>170 kV</td>
</tr>
<tr>
<td>One minute power frequency with stand voltage</td>
<td>3 kV</td>
<td>28 kV</td>
<td>70 kV</td>
</tr>
<tr>
<td>Rated short circuit breaking capacity</td>
<td>- - kA</td>
<td>- kA</td>
<td>- kA</td>
</tr>
<tr>
<td>Rated short circuit making capacity</td>
<td>- - kA</td>
<td>- kA</td>
<td>- kA</td>
</tr>
<tr>
<td>Operating cycle</td>
<td>0- 3 min-CO</td>
<td>0-3 min-CO-3 min-CO</td>
<td>0-3 min-CO-3 min-CO</td>
</tr>
</tbody>
</table>
Operating Mechanism

- It shall be possible to close and trip the circuit breaker without opening the circuit breaker compartment door. A mechanical ‘ON-OFF’ indicator, appropriately marked shall be provided at the front. Electrical indication through red/green lamps for indicating the ON-OFF position shall also be provided.
- The closing springs shall be charged through manually and electrically both. Electrical indication through AMBER lamp shall be provided to indicate ‘READY FOR ON’ position of the breaker.
- The C.B. shall be manually and electrically closed
- The tripping shall be done through 2 Nos. shunt trip coil from reliability view point suitable for DC control voltage.
- The auxiliary device shall operate satisfactorily at all voltage between 80% to 110% of the D.C. control voltage. The trip coils shall operate satisfactorily at all voltages between 50-110% of D.C. control voltage.
- The circuit breaker shall be electrically and mechanically trip free in all positions.
- The circuit breaker shall be closed & tripped electrically from the circuit breaker panel.
- The breaker shall be provided with suitable anti-pumping device to ensure that when closing on to a fault, it does not re-close automatically, after tripping, even if the closing impulse is maintained by manual command.
- Trip circuit healthy supervision lamp for preclosing and after closing supervision.
- 415V circuit breaker shall be equipped with over load and short circuit releases.

Annunciation System

A multipoint microprocessor based annunciator with suitable number of ways for projecting visual signals and audible alarm, in case of fault, shall be provided. The annunciator shall be back connected flush mounting with audible warning device suitable for operation on DC supply.

The annunciator shall have minimum suitable number of points complete with alarm, accept, test and cancellation push button.

Cradle

The cradle shall be so designed and constructed as to permit the smooth withdraw and insertion of the breaker into it. The movement shall be free of jerks, easy to operate and shall preferably be on steel balls / rollers. Preferably there shall be 4 distinct and separate position of the circuit breaker on the cradle:

<table>
<thead>
<tr>
<th>Service</th>
<th>Test</th>
<th>Isolated</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Both main and secondary isolating contacts in service.</td>
<td>Main isolating contacts separated and secondary isolating contacts in service.</td>
<td>Both main and secondary isolating contacts isolated.</td>
<td>Circuit breaker fully outside the cubicle on self supporting telescopic rails which are integral with the draw out mechanism.</td>
</tr>
</tbody>
</table>
The first three positions shall be positively achieved only through the turning/racking motion of the draw out mechanism and not by trial and error. There shall be mechanical indicator clearly shown in the above 3 position and visible preferably from the front door. The fourth position may be achieved by manually drawing out the circuit breaker beyond the isolated position.

- The secondary isolating contacts shall be rated for not less than 15 A,
- The switch-gear shall have interlocks against:
  a) A closed circuit breaker from being withdrawn.
  b) Tripping by attempted isolation (access to the raising or lowering mechanism should be automatically prevented when circuit breaker is closed in fully raised position).
  c) Closing of circuit breaker except when correctly located in service, earth or isolated position or alternatively, when the circuit breaker is withdrawn from the cubicle.
  d) Withdrawing or replacing of circuit breaker except when it is isolated and is in the appropriate position for withdraw or replacement.
  e) Closing circuit breaker in the service position when the secondary circuit between the fixed and moving portions are not completed.
- There shall be provision for locking the breaker in isolated position for complete safety and interlocking.
- The drawout portion of the circuit breaker shall be effectively connected to the earth bus-bar through scraping contacts. Earth continuity shall be automatically broken when the circuit breaker is withdrawn to isolated position.

**Metering Equipment**

The following metering equipment shall be provided on breaker panel.

1. kW Meter
2. kWh Meter
3. KVAR Meter
4. KV Meter
5. Ampere Meter
6. P.F. Meter
7. Frequency Meter

**Protective Devices** – Relays as required for protection of generator equipments & feeders.

**Current Transformer**

The CTs will be mounted on circuit breaker. The current transformer should be suitable for metering and protection single phase, epoxy cast resin, class ‘F’ insulation. The accuracy class for metering shall not be less than class 0.50 and 5P10 for protection. It shall confirm to the latest IS-2705 (1992).
Potential Transformer

The VTs will be mounted on circuit breaker. The VT should be suitable for metering and protection, 3 Phase, epoxy cast resin, class ‘F’ insulation. The accuracy class for metering shall not be less than 0.50 for metering and class 3 P for protection.

Earthing

Copper flats of atleast 25×6 mm with adequate earthing eyes shall be provided in panel for earthing.

8.0 Preferred Rating of Voltage Circuit Breaker – These are given in the following table as guidance.

<table>
<thead>
<tr>
<th>Preferred Ratings of Voltage Circuit-breakers; Selection Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rated Voltage kV, rms</strong></td>
</tr>
<tr>
<td>1 Minute p.f. withstand kV rms</td>
</tr>
<tr>
<td>Impulse withstand kV peak</td>
</tr>
<tr>
<td>Rated normal current A rms</td>
</tr>
<tr>
<td>Rated S.C. making current KA, peak</td>
</tr>
<tr>
<td>Rated duration of S.C. Sec</td>
</tr>
<tr>
<td>Rated operating sequence</td>
</tr>
</tbody>
</table>

Reference standards: (1) IS 2516, IEC 56 for rating and testing of High Voltage a.c. current breakers. 
(2) IEC 60, IEC 71 for High Voltage Testing and Insulation Co-ordinations.
(3) ICE 157 for low Voltage Switchgear and Controlgear.
Total break time varies between 80-120 ms for circuit breakers upto 12 kV and 40-80 ms for circuit breakers above 36 kV. It is less than 60 ms for 145 kV, less than 50 for 420 kV circuit breakers.

NOTE:
* Not to be used for auto reclosing
** For auto reclosing
9.0 Typical calculation of rating of circuit breaker

Calculate the rating of circuit breaker for the following system.

**Basic Data**
- System voltage = 33 kV
- The continuous current the breaker has to carry = 150A
- 3 phase short circuit fault current at 33 kV for one second = 13 KA
- Breaker is not intended for rapid auto reclosing

**Calculation**

From the table-1, the breaker will have following specification.
- Type of breaker – VCB / SF-6 breaker
- Voltage rating – 36 kV
- Rated normal current = 630A
- Rated short circuit breaking current = 16 KA
- Operating sequence
  - O – 3 min – CO – 3 min – CO
  - or
  - CO – 15 second – CO
SECTION – 5
CABLES

1.0 Types of Cables

Cables are of two types based on the insulation of conductor.

1.1 PVC Cable – These cables are designed to conform IS 1554-1988. These cables are suitable for use where the combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding the following.

<table>
<thead>
<tr>
<th>Type of PVC Cable</th>
<th>Normal Continuous Operation</th>
<th>Short Circuit Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Purpose</td>
<td>70°C</td>
<td>160°C</td>
</tr>
<tr>
<td>Heat Resisting</td>
<td>85°C</td>
<td>160°C</td>
</tr>
</tbody>
</table>

1.2 Cross linked polyethylene insulated PVC sheathed (XLPE) cables.

These cables are designed to conform IS 7098 – 1988. These cables are suitable for use where combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding 90°C under normal operation and 250°C under short circuit conditions.

2.0 Features of Cables

- The both type of cables are armoured, unarmoured, single, twin, three, four and multicore cables for electric supply and control purposes.
- The conductor used in cables are composed of plain copper or aluminium wires complying with IS 8130 – 1984.
- Cables For Fire Risk Areas – Flame Retardant Low Smoke (FRLS) cables are used.
- The outer sheath of FRLS cables has following properties
  - Minimum oxygen index = 29
  - Maximum acid gas generation during fire – 20% by weight
  - Smoke density rating – 60%
- **Armour** – The following types of armour may be applied.
  - (a) Galvanised round steel wires
  - (b) Galvanised flat steel strips
  - (c) Non magnetic armour of aluminium alloy or copper wires for single core cables in AC circuit

Armouring is required for mechanical strength of cables and reduce induce voltage in the cable during phase to ground fault. The both ends of the armours are earthed.
3.0 **Minimum Permissible Bending Radius for Cables**
Installation radius should be as large as possible. However the minimum installation radius for cables as recommended in IS 1255 – 88 are given below.

<table>
<thead>
<tr>
<th>Voltage Rating</th>
<th>Single Core</th>
<th>Multicore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 1.1 kV</td>
<td>15D</td>
<td>12D</td>
</tr>
<tr>
<td>Above 1.1 to 11kV</td>
<td>15D</td>
<td>15D</td>
</tr>
</tbody>
</table>

Where D is diameter of the cable.

4.0 **Determination of size of cables**

Following parameters should be considered while deciding the size of the cable.
- Voltage of the system
- Whether cable is to used in earthed or unearthed system.
- Current – direct or alternating
- Short circuit current of the system
- Ambient temperature
- Method of laying – in air, duct or in ground
- Number of cables grouped together and their spacing
- Thermal resistivity of soil for cables land directly in soil
- Depth of laying of cables in ground

5.0 **Continuous Current Rating, Rating factor, Short circuit Rating of Cables**

- Continuous Current Ratings of PVC cables – Table 1 to 6.
- Rating Factors for PVC cables - Table 7 to 13.
- Short circuit ratings of PVC cables - Table 14.
- Rating factors for XLPE cables - Tables 15-20.
- Continuous current ratings of XLPE cables - Tables 21-22.

6.0 **Typical example for calculating size of cable – Annexure-1**
Continuous Current Ratings of PVC Cables

The Current Ratings of PVC Cables given in the subsequent tables are based on the following assumptions and calculated in accordance with the recommendations of IS 3961-Part II.

**BASIC ASSUMPTIONS:**
- Maximum Conductor Temperature at Continuous Load*: 70°C/85°C
- *70°C for PVC and 85°C for HR-PVC Cables
- Ambient Air Temperature: 40°C
- Ground Temperature: 30°C
- Thermal Resistivity of the Soil: 150°C cm/W
- Thermal Resistivity of PVC: 650°C cm/W
- Depth of laying (to the highest point of Cable laid direct in ground or to top surface of ducts): 750 mm
- 1 kV Cables: 950 mm
- 3.3 to 11 kV Cables: 900 mm

**METHOD OF INSTALLATION**

1) Multicore Cables: Installed Singly
2) Single Core Cables:
   - Type of installation
     a) Laid direct in the ground
     b) In ducts
     c) In air

**Method of Installation**
- 1) Three in close trefoil formation, or
- 2) Two touching in horizontal formation
- 1) Three in trefoil formation, or
- 2) Two in horizontal formation.
- i) Two single-core cables are installed one above the other fixed to a vertical wall as follows; the distance between the wall and the surface of the cable being 25 mm in each case.
- ii) Cables of sizes up to and including 185 mm² are installed at a distance between centres of twice the overall diameter of the cable.
- iii) Cables of sizes 240 mm² and above are installed at a distance between centres of 90 mm.

**NOTE**—The ratings for two cables may be applied with safety in cases where such cables are installed in horizontal formation, on brackets fixed to a wall, or spaced as indicated above or touching throughout.

2) Three single-core cables are installed in a trefoil formation touching.

**Rating Factors:** For other conditions of installation, given in these tables.

**NOTE**—For Single Core screened/magnetic armoured Cables, ratings are given with screens bonded at both ends of the Cables.

**CURRENT RATINGS**

**TABLE 1**

**COPPER CONDUCTOR CONTROL CABLES**

**PVC INSULATED ARMOURED/UNARMOURED**

**850/1100 V**

(Max Conductor Temp-70°C)

<table>
<thead>
<tr>
<th>NO. OF CORES</th>
<th>NOMINAL AREA OF CONDUCTOR</th>
<th>NOMINAL AREA OF CONDUCTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.5 Sq.mm</td>
<td>2.5 Sq.mm</td>
</tr>
<tr>
<td></td>
<td>In the ground amp</td>
<td>In single way duct amp</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>17</td>
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<td>6</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
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<td>10</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>12</td>
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</tr>
<tr>
<td>14</td>
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<td>9</td>
</tr>
<tr>
<td>16</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>19</td>
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</tr>
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<td>24</td>
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<td>30</td>
<td>9</td>
<td>7</td>
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<td>37</td>
<td>8</td>
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<td>44</td>
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<td>6</td>
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<tr>
<td>52</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>61</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>
## CURRENT RATINGS

**TABLE 2**

**ALUMINIUM CONDUCTOR PVC INSULATED ARMOURED/UNARMOURED 650/1100V**

(MAX CONDUCTOR TEMP: 70°C)

<table>
<thead>
<tr>
<th>Nominal area of conductor</th>
<th>Single Core</th>
<th>Twin Core</th>
<th>3½ or more</th>
<th>Single Core</th>
<th>Twin Core</th>
<th>3½ or more</th>
<th>Single Core</th>
<th>Twin Core</th>
<th>3½ or more</th>
<th>Single Core</th>
<th>Twin Core</th>
<th>3½ or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm²</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>17</td>
<td>21</td>
<td>21</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>19</td>
<td>19</td>
<td>16</td>
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## COPPER CONDUCTOR CABLES

**PVC INSULATED ARMOURED/UNARMOURED 650/1100V**

(MAX CONDUCTOR TEMP: 70°C)

<table>
<thead>
<tr>
<th>Nominal Area of conductor</th>
<th>Single Core</th>
<th>Twin Core</th>
<th>3½ or more</th>
<th>Single Core</th>
<th>Twin Core</th>
<th>3½ or more</th>
<th>Single Core</th>
<th>Twin Core</th>
<th>3½ or more</th>
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<tbody>
<tr>
<td>(Sq m)</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
<td>amp</td>
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AHEC/MNRE/ShP Standards/E&M Works – Guidelines For Electrical Works of SHP Plants Including Switchyard
85
### CURRENT RATINGS

**ALUMINIUM CONDUCTOR CABLES—HR PVC INSULATED ARMOURED/UNARMOURED CABLES**

**650/1100 V**

**MAX CONDUCTOR TEMPERATURE-85°C**

<table>
<thead>
<tr>
<th>Nominal area of conductor (Sq mm)</th>
<th>Laid in the Ground</th>
<th>In Single Duct</th>
<th>In Air</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Single core (3 Nos.)</td>
<td>Twin core (Single)</td>
<td>3.3/3 or 4 core (Single)</td>
</tr>
<tr>
<td></td>
<td>amp</td>
<td>amp</td>
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</tr>
<tr>
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**TABLE 5**

**COPPER CONDUCTOR CABLES—HR PVC INSULATED ARMOURED/UNARMOURED**

**650/1100 V**

**MAX CONDUCTOR TEMPERATURE-85°C**

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<th>Nominal area of conductor (Sq mm)</th>
<th>Laid in the Ground</th>
<th>In Single Duct</th>
<th>In Air</th>
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<td>Single core (3 Nos.)</td>
<td>Twin core (Single)</td>
<td>3.3/3 or 4 core (Single)</td>
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AHEC/MNRE/SHP Standards/E&M Works – Guidelines For Electrical Designs Of SHP Plants Including Switchyard 86
### CURRENT RATINGS

#### COPPER/ALUMINIUM CONDUCTOR CABLES,

**PVC INSULATED, 3.3kV AND ABOVE**

(Max Conductor Temperature: 70°C)

<table>
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<th>Nominal Area of Conductor (sq. mm)</th>
<th>Single Core</th>
<th>Multi (3) Core</th>
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</tr>
<tr>
<td></td>
<td>Ground</td>
<td>Air</td>
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Note: General Guidance: VDE/0208.

### RATING FACTORS

#### TABLE-7

**RATING FACTORS FOR DEPTH OF LAYING FOR CABLES LAID DIRECTLY IN THE GROUND**

[General Ref.: IS 3861 (Part III) – 1967]

<table>
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<th>Depth of Laying (mm)</th>
<th>850/1100 V</th>
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<td>Upto</td>
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<tr>
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<tr>
<td>1800 or MORE</td>
<td>0.85</td>
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#### TABLE-8

**RATING FACTORS FOR VARIATION IN THERMAL RESISTIVITY OF SOIL FOR CABLES LAID DIRECTLY IN THE GROUND (AVERAGE VALUES)**

<table>
<thead>
<tr>
<th>Type and Size of Cable</th>
<th>Soil Thermal Resistivity in °C cm/w</th>
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<td>Single Core Cables:</td>
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<td>(3 Cables in Trefoil Touching)</td>
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<td>From 16 to 50</td>
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<td>From 70 to 300</td>
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<td>Multi Core Cables:</td>
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<td>up to 10</td>
<td>1.10</td>
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<td>From 16 to 50</td>
<td>1.14</td>
</tr>
<tr>
<td>From 70 to 150</td>
<td>1.17</td>
</tr>
<tr>
<td>From 185 to 400</td>
<td>1.18</td>
</tr>
</tbody>
</table>

AHEC/MNRE/SHP Standards/E&M Works – Guidelines For Electrical Designs Of SHP Plants Including Switchyard 87
### TABLE-9

**RATING FACTORS FOR DEPTH OF LAYING MULTI-CORE CABLES IN SINGLE-WAY DUCTS**

*As per IS 3961 (Part II) – 1987 – Table 10*

<table>
<thead>
<tr>
<th>DEPTH OF LAYING mm</th>
<th>RATING FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>1.00</td>
</tr>
<tr>
<td>900</td>
<td>0.99</td>
</tr>
<tr>
<td>1050</td>
<td>0.98</td>
</tr>
<tr>
<td>1200</td>
<td>0.97</td>
</tr>
<tr>
<td>1500</td>
<td>0.95</td>
</tr>
<tr>
<td>1800</td>
<td>0.95</td>
</tr>
<tr>
<td>2700</td>
<td>0.92</td>
</tr>
<tr>
<td>3600</td>
<td>0.91</td>
</tr>
<tr>
<td>4500</td>
<td>0.90</td>
</tr>
<tr>
<td>5400 or MORE</td>
<td>0.89</td>
</tr>
</tbody>
</table>

### TABLE-10

**RATING FACTORS FOR THREE SINGLE-CORE CABLES (ac) IN FLAT FORMATION IN AIR**

*TO BE APPLIED TO THE CORRESPONDING RATINGS FOR TREFOIL GROUPS IN AIR*

*As per IS 3961 (Part II) – 1987 – Table 19*

<table>
<thead>
<tr>
<th>NOMINAL AREA OF CONDUCTOR S&lt;sub&gt;0&lt;/sub&gt;,mm&lt;sup&gt;2&lt;/sup&gt;</th>
<th>RATING FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPTO AND INCLUDING</td>
<td></td>
</tr>
<tr>
<td>185</td>
<td>1.07</td>
</tr>
<tr>
<td>240</td>
<td>1.10</td>
</tr>
<tr>
<td>300</td>
<td>1.08</td>
</tr>
<tr>
<td>400</td>
<td>1.04</td>
</tr>
<tr>
<td>500 and above</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### TABLE-11

**RATING FACTORS FOR VARIATION IN AMBIENT AIR TEMPERATURE**

*As per IS 3961 (Part II) – 1987 – Table 17*

<table>
<thead>
<tr>
<th>AIR TEMPERATURE °C</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC CABLES (Max. Conductor Temp. 70°C)</td>
<td>1.25</td>
<td>1.16</td>
<td>1.09</td>
<td>1.00</td>
<td>0.90</td>
<td>0.80</td>
<td>0.69</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR PVC CABLES (Max. Conductor Temp. 85°C)</td>
<td>1.10</td>
<td>1.05</td>
<td>1.00</td>
<td>0.94</td>
<td>0.88</td>
<td>0.82</td>
<td>0.74</td>
<td>0.67</td>
<td>0.58</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE-12

**RATING FACTORS FOR VARIATION IN GROUND TEMPERATURE**

*For Cables laid directly in ground or in duct*

*As per IS 3961 (Part II) – 1987 – Tables 7 & 11*

<table>
<thead>
<tr>
<th>GROUND TEMPERATURE °C</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC CABLES (Max. Conductor Temp. 70°C)</td>
<td>1.17</td>
<td>1.12</td>
<td>1.06</td>
<td>1.00</td>
<td>0.94</td>
<td>0.87</td>
<td>0.79</td>
<td>0.70</td>
<td>0.60</td>
</tr>
<tr>
<td>HR PVC CABLES (Max. Conductor Temp. 85°C)</td>
<td>1.13</td>
<td>1.09</td>
<td>1.04</td>
<td>1.00</td>
<td>0.95</td>
<td>0.89</td>
<td>0.85</td>
<td>0.80</td>
<td></td>
</tr>
</tbody>
</table>
GROUP RATING FACTORS FOR PARAMITE CABLES

[Ref. IS 3961 (Part II) – 1967]

Fig. 1
Group rating factors for twin and multi-core cables in horizontal formation, laid direct in the ground.

Fig. 2
Group rating factors for twin and multi-core cables in tier formation, laid direct in the ground.

Fig. 3
Group rating factors for circuits of two single-core cables side by side and touching, horizontal formation, laid direct in the ground.

Fig. 4
Group rating factors for circuits of three single-core cables in trefoil and touching, horizontal formation, laid direct in the ground.
### TABLE 13
RATING FACTORS FOR MULTI-CORE PVC/HR PVC CABLES LAID ON RACKS IN AIR (WITH SPACING BETWEEN CABLES EQUAL TO DIAMETER OF THE CABLE)

Ref: IS 3861 (Part II) – 1967

<table>
<thead>
<tr>
<th>ARRANGEMENT</th>
<th>No. of Racks</th>
<th>Number of Cable per Rack</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### TABLE 14
RATING FACTORS FOR MULTI-CORE PVC/HR PVC CABLES LAID ON RACKS IN AIR (WITH CABLES TOUCHING)

Ref: IS 3861 (Part II) – 1967

<table>
<thead>
<tr>
<th>ARRANGEMENT</th>
<th>No. of Racks</th>
<th>Number of Cable per Rack</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### TABLE 15
PERMISSIBLE MAXIMUM SHORT CIRCUIT RATINGS FOR PVC AND HR PVC CABLES

Ref: IEC 724

<table>
<thead>
<tr>
<th>Nominal area of Conductor (sq. mm.)</th>
<th>Aluminium</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PVC Cables in Kilo amps</td>
<td>HR-PVC Cables in Kilo amps</td>
</tr>
<tr>
<td>1.5</td>
<td>0.114</td>
<td>0.102</td>
</tr>
<tr>
<td>2.5</td>
<td>0.190</td>
<td>0.171</td>
</tr>
<tr>
<td>4</td>
<td>0.304</td>
<td>0.274</td>
</tr>
<tr>
<td>6</td>
<td>0.456</td>
<td>0.411</td>
</tr>
<tr>
<td>10</td>
<td>0.760</td>
<td>0.680</td>
</tr>
<tr>
<td>16</td>
<td>1.216</td>
<td>1.097</td>
</tr>
<tr>
<td>25</td>
<td>1.800</td>
<td>1.715</td>
</tr>
<tr>
<td>35</td>
<td>2.56</td>
<td>3.40</td>
</tr>
<tr>
<td>50</td>
<td>3.89</td>
<td>3.89</td>
</tr>
<tr>
<td>70</td>
<td>5.26</td>
<td>5.26</td>
</tr>
<tr>
<td>100</td>
<td>8.33</td>
<td>8.33</td>
</tr>
<tr>
<td>150</td>
<td>11.40</td>
<td>11.40</td>
</tr>
<tr>
<td>200</td>
<td>14.06</td>
<td>14.06</td>
</tr>
<tr>
<td>250</td>
<td>18.24</td>
<td>18.24</td>
</tr>
<tr>
<td>300</td>
<td>22.50</td>
<td>22.50</td>
</tr>
<tr>
<td>350</td>
<td>27.44</td>
<td>27.44</td>
</tr>
<tr>
<td>400</td>
<td>33.10</td>
<td>33.10</td>
</tr>
<tr>
<td>450</td>
<td>38.80</td>
<td>38.80</td>
</tr>
<tr>
<td>500</td>
<td>44.88</td>
<td>44.88</td>
</tr>
<tr>
<td>550</td>
<td>50.80</td>
<td>50.80</td>
</tr>
<tr>
<td>600</td>
<td>56.80</td>
<td>56.80</td>
</tr>
<tr>
<td>650</td>
<td>62.80</td>
<td>62.80</td>
</tr>
<tr>
<td>700</td>
<td>68.80</td>
<td>68.80</td>
</tr>
<tr>
<td>750</td>
<td>74.80</td>
<td>74.80</td>
</tr>
<tr>
<td>800</td>
<td>80.80</td>
<td>80.80</td>
</tr>
<tr>
<td>850</td>
<td>86.80</td>
<td>86.80</td>
</tr>
<tr>
<td>900</td>
<td>92.80</td>
<td>92.80</td>
</tr>
<tr>
<td>950</td>
<td>98.80</td>
<td>98.80</td>
</tr>
<tr>
<td>1000</td>
<td>104.80</td>
<td>104.80</td>
</tr>
</tbody>
</table>

Initial Temperature: 70°C (PVC) & 85°C (HR PVC)
Final Temperature: 160°C (PVC) & 160°C (HR PVC)

For durations other than One Second, the Short Circuit Current may be calculated from the following formula:

\[
I_{sc} = \frac{I}{\sqrt{t}}
\]

where
- \( I_{sc} \) = Short Circuit Current during time \( t \) – ampere
- \( I \) = Short Circuit Current during the time "One Second" as given in the Table – ampere
- \( t \) = Short Circuit Current duration – Seconds

Note: For Large Currents, the force between the Conductors must be considered, especially when Single Core Cables are used.
CONTINUOUS CURRENT RATING OF XLPE CABLES

The current rating given in Table 8 to 19 are based on the following assumptions:

(i) Maximum conductor temperature for continuous operation : 90°C
(ii) Ambient air temperature : 30°C
(iii) Ground temperature : 20°C
(iv) Thermal resistivity of soil : 150°C cm/w
(v) Depth of laying (to the highest point of cables laid direct in ground)
   (a) 3.3 kV, 6.6 kV & 11 kV cables : 900mm
   (b) 22 kV & 33 kV cables : 1050mm
(vi) Type of installation
   (a) Multicore cables : Installed singly
   (b) Single core cables : Three cables in trefoil touching formation

In actual practice, conditions of installation may differ from the standard installation conditions given above. Hence, to determine the continuous current rating for actual conditions, the current ratings should be multiplied by the appropriate rating factor/factors given in Table 15 to 20.

RATING FACTORS FOR XLPE CABLES

(1) CABLES LAID DIRECTLY IN GROUND
(2) Rating factors for variation in Ground temperature

Table – 15

<table>
<thead>
<tr>
<th>Ground Temperature (°C)</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating Factors:</td>
<td>1.04</td>
<td>1.00</td>
<td>0.96</td>
<td>0.93</td>
<td>0.89</td>
<td>0.5</td>
<td>0.81</td>
<td>0.76</td>
</tr>
</tbody>
</table>

(b) Rating factors for depth of laying

Table – 16

<table>
<thead>
<tr>
<th>Depth of laying (cm)</th>
<th>3.3 kV, 6.6 kV &amp; 11 kV Cables</th>
<th>22 kV &amp; 33 kV Cables</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>150</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>120</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>150</td>
<td>0.96</td>
<td>0.97</td>
</tr>
<tr>
<td>180 and above</td>
<td>0.95</td>
<td>0.96</td>
</tr>
</tbody>
</table>

(b) Rating factors for variation in thermal resistivity of soil

Table – 17

<table>
<thead>
<tr>
<th>Thermal Resistivity of soil °C cm/w</th>
<th>100</th>
<th>120</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating factors</td>
<td>1.20</td>
<td>1.11</td>
<td>1.00</td>
<td>0.89</td>
<td>0.80</td>
<td>0.73</td>
</tr>
</tbody>
</table>
(c) Group rating factors

TABLE -18

<table>
<thead>
<tr>
<th>Number of Cables / Circuits in group</th>
<th>Multicore cable in horizontal formation</th>
<th>Multicore cables in tier formation</th>
<th>Single core cables in trefoil touching formation (three cables per circuit)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Touching</td>
<td>s=15cm</td>
<td>s=30cm</td>
</tr>
<tr>
<td>2</td>
<td>0.79</td>
<td>0.82</td>
<td>0.86</td>
</tr>
<tr>
<td>3</td>
<td>0.69</td>
<td>0.72</td>
<td>0.76</td>
</tr>
<tr>
<td>4</td>
<td>0.62</td>
<td>0.66</td>
<td>0.72</td>
</tr>
<tr>
<td>6</td>
<td>0.54</td>
<td>0.59</td>
<td>0.65</td>
</tr>
<tr>
<td>8</td>
<td>0.50</td>
<td>0.54</td>
<td>0.62</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.46</td>
<td>0.51</td>
<td>0.59</td>
</tr>
</tbody>
</table>

(2) CABLES LAID ON RACKS IN AIR
(a) Rating factors for variation in air temperature

Table -19

<table>
<thead>
<tr>
<th>Ambient air temperature (°C)</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating factors</td>
<td>1.07</td>
<td>1.04</td>
<td>1.00</td>
<td>0.95</td>
<td>0.91</td>
<td>0.86</td>
<td>0.82</td>
</tr>
</tbody>
</table>

(b) Group rating factors

Table -20

<table>
<thead>
<tr>
<th>Number of Cables/ circuits per rack</th>
<th>Multicore Cables (touching)</th>
<th>Multicore Cables (Spacing between cables equal to diameter of cable)</th>
<th>Single core Cables in trefoil touching formation (Spacing between circuits equal to twice the diameter of cable)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Touching</td>
<td>s=15cm</td>
<td>s=30cm</td>
</tr>
<tr>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>0.84</td>
<td>0.80</td>
<td>0.78</td>
</tr>
<tr>
<td>3</td>
<td>0.80</td>
<td>0.76</td>
<td>0.74</td>
</tr>
<tr>
<td>6</td>
<td>0.76</td>
<td>0.71</td>
<td>0.70</td>
</tr>
<tr>
<td>9</td>
<td>0.73</td>
<td>0.69</td>
<td>0.68</td>
</tr>
</tbody>
</table>
### TABLE 21
**CURRENT RATINGS FOR THREE, THREE AND HALF AND FOUR CORE 650/1100 VOLTS ARMoured OR UNARMoured 1.1 KV XLPE CABLES ACCORDING TO IS:7098 (Part 1)**

<table>
<thead>
<tr>
<th>NOMINAL AREA OF CONDUCTOR</th>
<th>LAID DIRECT IN THE GROUND</th>
<th>IN DUCTS</th>
<th>IN AIR</th>
<th>SHORT CIRCUIT RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Copper</td>
<td>Aluminium</td>
<td>Copper</td>
<td>Aluminium</td>
</tr>
<tr>
<td>mm²</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>1.5</td>
<td>25</td>
<td>20</td>
<td>23</td>
<td>18</td>
</tr>
<tr>
<td>2.5</td>
<td>34</td>
<td>27</td>
<td>31</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>44</td>
<td>34</td>
<td>40</td>
<td>31</td>
</tr>
<tr>
<td>6</td>
<td>55</td>
<td>43</td>
<td>50</td>
<td>39</td>
</tr>
<tr>
<td>10</td>
<td>73</td>
<td>57</td>
<td>66</td>
<td>51</td>
</tr>
<tr>
<td>16</td>
<td>97</td>
<td>73</td>
<td>87</td>
<td>66</td>
</tr>
<tr>
<td>25</td>
<td>122</td>
<td>94</td>
<td>110</td>
<td>85</td>
</tr>
<tr>
<td>35</td>
<td>146</td>
<td>113</td>
<td>131</td>
<td>102</td>
</tr>
<tr>
<td>50</td>
<td>172</td>
<td>133</td>
<td>155</td>
<td>120</td>
</tr>
<tr>
<td>70</td>
<td>211</td>
<td>164</td>
<td>190</td>
<td>148</td>
</tr>
<tr>
<td>95</td>
<td>253</td>
<td>196</td>
<td>228</td>
<td>176</td>
</tr>
<tr>
<td>120</td>
<td>287</td>
<td>223</td>
<td>258</td>
<td>201</td>
</tr>
<tr>
<td>150</td>
<td>321</td>
<td>249</td>
<td>289</td>
<td>224</td>
</tr>
<tr>
<td>185</td>
<td>361</td>
<td>282</td>
<td>325</td>
<td>254</td>
</tr>
<tr>
<td>240</td>
<td>416</td>
<td>326</td>
<td>374</td>
<td>293</td>
</tr>
<tr>
<td>300</td>
<td>464</td>
<td>367</td>
<td>418</td>
<td>330</td>
</tr>
<tr>
<td>400</td>
<td>521</td>
<td>418</td>
<td>469</td>
<td>376</td>
</tr>
<tr>
<td>500</td>
<td>582</td>
<td>470</td>
<td>524</td>
<td>423</td>
</tr>
<tr>
<td>630</td>
<td>644</td>
<td>529</td>
<td>580</td>
<td>476</td>
</tr>
</tbody>
</table>

### TABLE 22
**CURRENT RATINGS FOR THREE SINGLE CORE 1.9/3.3 KV & 3.3/3.3 KV XLPE CABLES ACCORDING TO IS:7098 (Part 2)**

<table>
<thead>
<tr>
<th>NOMINAL AREA OF CONDUCTOR</th>
<th>LAID DIRECT IN THE GROUND</th>
<th>IN DUCTS</th>
<th>IN AIR</th>
<th>SHORT CIRCUIT RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Copper</td>
<td>Aluminium</td>
<td>Copper</td>
<td>Aluminium</td>
</tr>
<tr>
<td>mm²</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>25</td>
<td>125</td>
<td>97</td>
<td>113</td>
<td>87</td>
</tr>
<tr>
<td>35</td>
<td>149</td>
<td>115</td>
<td>134</td>
<td>104</td>
</tr>
<tr>
<td>50</td>
<td>176</td>
<td>136</td>
<td>158</td>
<td>122</td>
</tr>
<tr>
<td>70</td>
<td>214</td>
<td>166</td>
<td>193</td>
<td>149</td>
</tr>
<tr>
<td>95</td>
<td>256</td>
<td>198</td>
<td>230</td>
<td>178</td>
</tr>
<tr>
<td>120</td>
<td>289</td>
<td>225</td>
<td>260</td>
<td>203</td>
</tr>
<tr>
<td>150</td>
<td>326</td>
<td>253</td>
<td>293</td>
<td>228</td>
</tr>
<tr>
<td>185</td>
<td>365</td>
<td>285</td>
<td>329</td>
<td>257</td>
</tr>
<tr>
<td>240</td>
<td>422</td>
<td>330</td>
<td>380</td>
<td>297</td>
</tr>
<tr>
<td>300</td>
<td>476</td>
<td>373</td>
<td>428</td>
<td>336</td>
</tr>
<tr>
<td>400</td>
<td>539</td>
<td>427</td>
<td>485</td>
<td>384</td>
</tr>
<tr>
<td>500</td>
<td>605</td>
<td>485</td>
<td>545</td>
<td>437</td>
</tr>
<tr>
<td>630</td>
<td>678</td>
<td>551</td>
<td>610</td>
<td>495</td>
</tr>
<tr>
<td>800</td>
<td>753</td>
<td>625</td>
<td>678</td>
<td>570</td>
</tr>
<tr>
<td>1000</td>
<td>818</td>
<td>692</td>
<td>736</td>
<td>623</td>
</tr>
</tbody>
</table>
Annexure-1

Calculation of the size of cable

Calculate the size of the cables for the following conditions.

(a) Voltage of the system - 415 V
(b) Continuous current the cable has to carry - 150 A, 3 Phase 4 wire system
(c) Ambient temperature - 45°C
(d) Short circuit current the cable has to carry for one second - 30 KA
(e) FIRE RISK AREA
(f) Method of cable laying – The cables are laid on racks in trench in air covered with chequered plates. Total number of cables on the racks are three numbers touching each other.
(g) Max permissible conductor temperature - 70°C

Calculations

The cables are laid on racks in trench in air covered with chequered plates. This is equivalent to cable laying in duct. The rating of the cables applicable for ducts are to be considered.

- 1100 V 3½ core Aluminium Conductor armoured PVC insulated cable is selected.
- Rating factor for ambient air temperature from table 12 = .79
- Rating factors for method of laying of cables from table 13 = .80
- The desired current rating of cable = 150A / .79×.80 = 237.34.
- From table 2.0, the size of the cable = 240 sq. mm.
- The short circuit with stand current of 240 sq. mm cable from table 14 is 18.24 KA against the requirement of 30 KA, therefore 240 sqmm cable is not suitable.

The short circuit with stand current of 400 sqmm cable is 30.40KA from table 14.0. Therefore 400 sqmm cable is the correct size of cable for the conditions given in above example.

Specification of cable

400 sqmm 3½ core 1100 V aluminium conductor PVC insulated armoured PVC over all FRLS Cable.
SECTION – 6

VOLTAGE TRANSFORMER

1.0 VOLTAGE TRANSFORMER

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

2.0 Type of voltage transformer

2.01 Measuring voltage transformer – A voltage T/F intended to supply the indicating instruments, integrating meters and similar apparatus.

2.02 Protective voltage transformer – A voltage T/F intended to provide a supply to Electrical protective relays and similar apparatus.

2.03 Dual Purpose voltage Transformer – A voltage transformer having one magnetic core intended to serve the dual purpose of measuring and protection. It may have one or more secondary winding.

3.0 Terminology

3.01 Actual Transformation Ratio – The ratio of the actual primary voltage to the actual secondary voltage.

3.02 Rated Transformation Ratio – The ratio of the rated primary voltage to the rated secondary voltage.

3.03 Voltage Error (Ratio Error)

The error which a transformer introduces into the measurement of a voltage and which arises when the actual transformation ratio is not equal to the rated transformation ratio.

This is expressed by the following formula

\[ Voltage\ error = \frac{K_n U_s - U_p}{U_p} \times 100 \text{ Percent} \]

\( K_n \) = Rated transformation ratio
\( U_p \) = the actual primary voltage
\( U_s \) = the actual secondary voltage

3.04 Phase Displacement

The difference in phase between the primary voltage and the secondary voltage vector in the reverse direction.
This phase displacement is said to be positive when the secondary voltage vector leads the primary voltage vector and negative when it lags. It is usually expressed in minutes.

3.05 **Burden**

It is the impedance of secondary circuit expressed in ohm and power factor.

The burden is usually expressed in volt Ampere as the apparent power absorbed at the specified power factor at the rated secondary voltage.

3.06 **Rated output**

The value of apparent power (in volt – amperes at a specified power factor) which the voltage transformer is intended to supply to the secondary circuit at the rated secondary voltage and with rated burden connected to it.

3.07 **Rated Voltage Factor**

It is the ratio of the maximum voltage to the rated primary voltage at which a transformer must comply with the relevant thermal requirements for a specified time and with relevant accuracy requirement.

\[
RVF = \frac{\text{Maximum Voltage at which VT comply with thermal requirement & accuracy class}}{\text{Rated Primary Voltage}}
\]

The standard rated voltage factors appropriate to the different earthing conditions are given in table below:

**Table 1- Rated Voltage Factor**

<table>
<thead>
<tr>
<th>Method of connecting the primary winding and system earthing condition (1)</th>
<th>Rated Voltage Factor (2)</th>
<th>Rated Time (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between lines in any network between transformer star point and earth in any network</td>
<td>1.2</td>
<td>Continuous</td>
</tr>
<tr>
<td>Between line and earth in any effective earthed neutral system</td>
<td>1.2 &amp; 1.5</td>
<td>Continuous 30 Seconds</td>
</tr>
<tr>
<td>Between line and earth in a non-effective earthed neutral system with automatic earth fault tripping)</td>
<td>1.2 &amp; 1.9</td>
<td>Continuous 30 Seconds</td>
</tr>
<tr>
<td>Between line and earth in an isolated neutral system without automatic earth-fault tripping or in a resonant earthed system without automatic earth fault tripping</td>
<td>1.2 &amp; 1.9</td>
<td>Continuous 8 hours</td>
</tr>
</tbody>
</table>
3.08 Rated insulation level

It is defined by the power frequency and the lightning impulse with stand voltage and is given in the tables given below.

Table 2A- Rated Insulation Levels for Highest System Voltages Up to and Including 72.5 kV.

<table>
<thead>
<tr>
<th>Nominal System Voltage (1)</th>
<th>Highest System Voltage (2)</th>
<th>Power Frequency Withstand Voltage (3)</th>
<th>Lightning Impulse Withstand Voltage (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>kV (rms)</td>
<td>kV (rms)</td>
<td>kV (rms)</td>
<td>kV (Peak)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.60</td>
<td>0.66</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>3.3</td>
<td>3.6</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>6.6</td>
<td>7.2</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>11</td>
<td>12.0</td>
<td>28</td>
<td>60</td>
</tr>
<tr>
<td>15</td>
<td>17.5</td>
<td>38</td>
<td>75</td>
</tr>
<tr>
<td>22</td>
<td>24.0</td>
<td>50</td>
<td>95</td>
</tr>
<tr>
<td>33</td>
<td>36.0</td>
<td>70</td>
<td>145</td>
</tr>
<tr>
<td>45</td>
<td>52.0</td>
<td>95</td>
<td>250</td>
</tr>
<tr>
<td>66</td>
<td>72.5</td>
<td>140</td>
<td>325</td>
</tr>
</tbody>
</table>

Notes:
1. Underlines values are preferred
2. The choice between lists 1 and 2 should be made by considering the degree of exposure to lightening and switching overvoltages, the type of system neutral earthing and the kind of the overvoltage protection. Some guidance is given in IS 2165 (Part 1): 1977.

Table 2B- Rated Insulation Levels for Highest System Voltages of 123 kV and above Up to and including 245 kV

<table>
<thead>
<tr>
<th>Nominal System Voltage (1)</th>
<th>Highest System Voltage (2)</th>
<th>Power Frequency Withstand Voltage (3)</th>
<th>Lightning Impulse Withstand Voltage (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>kV (rms)</td>
<td>kV (rms)</td>
<td>kV (rms)</td>
<td>kV (Peak)</td>
</tr>
<tr>
<td>110</td>
<td>123</td>
<td>185</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td></td>
<td>230</td>
<td>550</td>
</tr>
<tr>
<td>132</td>
<td>145</td>
<td>230</td>
<td>550</td>
</tr>
<tr>
<td></td>
<td></td>
<td>275</td>
<td>650</td>
</tr>
<tr>
<td>220</td>
<td>245</td>
<td>360</td>
<td>850</td>
</tr>
<tr>
<td></td>
<td></td>
<td>395</td>
<td>950</td>
</tr>
<tr>
<td></td>
<td></td>
<td>460</td>
<td>1050</td>
</tr>
</tbody>
</table>

Note – Underlined values are preferred.
3.09 Rated Output

The rated output at a power factor of .8 lagging expressed in volt-amperes shall be one of the value given below.

10, 15, 25, 30, 50, 75 & 100

3.10 Accuracy Class

(a) For measuring voltage transformer

The standard accuracy classes for measuring voltage transformers shall be 0.1, 0.2, 0.5, 1.0 and 3.0

Limit of voltage Error and phase displacement

The voltage error and phase displacement at rated frequency shall not exceed the value given in table below, at any voltage between 80% and 120% of rated voltage and with burden of between 25% and 100% of rated burden at a power factor of .8 lagging.

Table 3A– Limits of voltage errors and phase displacement

<table>
<thead>
<tr>
<th>Class</th>
<th>Ratio Error percentage voltage</th>
<th>Phase displacement (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.1</td>
<td>± 0.1</td>
<td>± 5</td>
</tr>
<tr>
<td>.2</td>
<td>± 0.2</td>
<td>± 10</td>
</tr>
<tr>
<td>.5</td>
<td>± 0.5</td>
<td>± 20</td>
</tr>
<tr>
<td>1.0</td>
<td>± 1.0</td>
<td>± 40</td>
</tr>
<tr>
<td>3.0</td>
<td>± 3.0</td>
<td>-</td>
</tr>
</tbody>
</table>

(b) For Protective Voltage T/F.

The standard Accuracy classes for protective voltage transformers are 3P and 6P

Limit of voltage error and phase displacement

The voltage error and phase displacement at rated frequency shall not exceed the values in table given below at 5 percent rated voltage and at rated voltage multiplied by the rated voltage factor (1.2,1.5 or 1.9) with burdens of between 25% and 100% of rated burden at a power factor of .8 lagging

Table 4 - Limit of voltage Error and phase displacement

<table>
<thead>
<tr>
<th>Accuracy Class</th>
<th>percentage voltage Error</th>
<th>Phase displacement (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3P</td>
<td>± 3.0</td>
<td>± 120°</td>
</tr>
<tr>
<td>6P</td>
<td>± 6.0</td>
<td>± 240°</td>
</tr>
</tbody>
</table>

At 2% of the rated voltage, the limit of error and phase displacement with burdens between 25% and 100% of rated burden at a power factor of .8 lagging shall be twice as high as those given in above table.
(c) Dual purpose voltage transformer

Where the voltage transformer has two or more separate secondary windings, one for measurement and the other for protection, having the same or different transformation ratios, they shall respectively comply with the requirement of both measuring VT and protection VT.

Where the transformer has one secondary winding which is intended to serve a dual purpose, that is, both for measurement as well as protection, it shall comply with the requirement of both measuring and protection VT.

(d) For a voltage transformer intended to produce a residual voltage.

The accuracy class for a residual voltage winding shall be 5PR& 10 PR.

The voltage error and phase displacement at rated frequency shall not exceed the values given in table below, with burdens of any value between 25% and 100% of the rated burden at a power factor of .8 logging.

<table>
<thead>
<tr>
<th>Accuracy class</th>
<th>Voltage error percent</th>
<th>Phase Displacement (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5PR</td>
<td>± 5.0</td>
<td>± 200</td>
</tr>
<tr>
<td>10PR</td>
<td>±10.0</td>
<td>± 600</td>
</tr>
</tbody>
</table>

4.0 Marking

All voltage transformers shall carry at least the following markings.

a) The manufacturer’s name and country of origin.
b) Year of manufacture;
c) A serial number and a type designation;
d) The rated primary and secondary voltage (for example, 66/0.11kv);
e) Rated frequency;
f) Rated output and the corresponding accuracy class (for example, 50 VA, class 1.0 or 50 VA/1.0);
g) Highest system voltage (for example, 72.5 kV);
h) Rated insulation level (for example, 140/325kV);
i) Rated voltage factor and corresponding rated time (for example, 1.9/30s);
j) Number of phases and method of connection (if 3-phase);
k) Earthed or unearthed
l) Reference to the standard

NOTE – When more than one separate secondary windings are provided, the marking should indicate the output range of each secondary winding in VA, the corresponding accuracy class and the rated voltage of each winding.

g) Highest system voltage (for example, 72.5 kV);
h) Rated insulation level (for example, 140/325kV);
i) Rated voltage factor and corresponding rated time (for example, 1.9/30s);
j) Number of phases and method of connection (if 3-phase);
k) Earthed or unearthed
l) Reference to the standard

NOTE: The items (g) and (h) may be combined into one marking (for example, 72.5/140/325 kV).
5.0 Application Guide for measuring voltage transformer

The accuracy classes recommended below are intended as a guide in the selection of measuring voltage transformer.

<table>
<thead>
<tr>
<th>Application</th>
<th>Class of accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>For precision testing or as substandard for testing laboratory voltage transformers</td>
<td>0.1</td>
</tr>
<tr>
<td>For laboratory and test work in conjunction with high accuracy indicating instruments, integrating meters and also for substandard for testing industrial voltage transformers</td>
<td>0.2</td>
</tr>
<tr>
<td>For precision industrial metering and for use with substandard indicating wattmeters</td>
<td>0.5 or 1.0</td>
</tr>
<tr>
<td>For commercial industrial metering and for use with indicating and graphic wattmeters and voltmeters</td>
<td>1</td>
</tr>
<tr>
<td>For purposes where the phase angle is of less importance, for example, voltmeters</td>
<td>3</td>
</tr>
</tbody>
</table>

Typical values of VA burden imposed by different meters are given below:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Burden VA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltmeters</td>
<td>5</td>
</tr>
<tr>
<td>Voltage coils of wattmeters and power factor meters</td>
<td>5</td>
</tr>
<tr>
<td>Voltage coils of frequency meters (Pointer type or read type)</td>
<td>7.5</td>
</tr>
<tr>
<td>Voltage coils of kWH, K VAR meters</td>
<td>7.5</td>
</tr>
<tr>
<td>Recording voltmeters</td>
<td>5</td>
</tr>
<tr>
<td>Voltage coils of recording power factor meters and wattmeters</td>
<td>7.5</td>
</tr>
<tr>
<td>Voltage coils of synchroscopes</td>
<td>15</td>
</tr>
</tbody>
</table>

**NOTE:** The measuring voltage transformer need to maintain its accuracy from 80% to 120% of rated voltage. It is not required to maintain its accuracy within specified limit during the fault conditions.

6.0 Application Guide for Protective Voltage Transformers

- A protective VT is required to operate under system fault conditions. The faults are generally associated with voltage dips, a protective VT is required to maintain its accuracy within specified limits from 5% to the rated voltage factor of the rated voltage.

- Under voltage relay, over voltage relay, voltage restrained over current relay–class 6P

  The operation of above relays does not depend on the phase relationship between the voltage and current, the phase error is of little importance and accuracy class of 6P is quite adequate.
• Directional over current, reverse power, directional distance protection – class 3P.

The operation of above relays depend upon the phase relationship between the voltage and current, voltage transformer of class 3P should be used.
SECTION – 7

CURRENT TRANSFORMERS

1.0 CURRENT TRANSFORMER

Current transformers are required for measurement of electrical current and electrical protective devices. These comply to IS 2705.

2.0 Types of current transformers

- **Wound Type CT** – A current transformer having a primary winding of more than one full turn wound on the core.
- **Bar Type Current Transformer** – A current transformer in which the primary winding consists of a bar of suitable size and material forming an integral part of the CT.
- **Ring Type Current Transformer** – A current transformer which has an opening in the centre to accommodate a primary conductor through it.
- **Dry Type Current Transformer** – A current transformer which does not require the use of any liquid or semi liquid material.
  These are epoxy (Resin) cast dry type unit suitable for both indoor and outdoor applications.
- **Liquid immersed current transformer** – A current transformer which uses insulating oil or other suitable liquid as insulating and or cooling medium.
- **Multicore current transformer** – A current transformer having more than one secondary core and winding with a common primary winding.
- **Multi Ratio Current Transformer** – A CT in which more than one ratio is obtainable by reconnection or tappings in primary or secondary winding.
- **Hermetically sealed current transformer** – A liquid immersed current transformer which is sealed and does not communicate with atmospheric air.
- **Measuring Current T/F** – A current transformer intended to supply indicating instruments integrating meters and similar apparatus.
- **Protective Current T/F** – A current transformer intended to supply protective relays and similar apparatus.
- **Dual purpose Current T/F** – A current transformer intended to serve the dual purpose of measuring and protection.

3.0 Terminology

3.01 **Actual Transformation Ratio** – It is the ratio of the actual primary current to the actual secondary current.

3.02 **Rated Transformation Ratio** – It is the ratio of the rated primary current to the rated secondary current.

3.03 **Burden** – The value of load connected across the secondary of CT, expressed in VA or Ohm at rated secondary current at specified power factor.
3.04 **Rated Primary Saturation Current** – The maximum value of primary current at which the required accuracy is maintained.

3.05 **Ratio Error** – It arises from the fact that the actual transformation ratio is not equal to the rated transformation ratio.

The current error expressed in percentage is given by the formula.

\[
\text{Ratio error} = \left( \frac{K_a I_s - I_p}{I_p} \right) \times 100
\]

Where
- \( K_a \) = Rated transformation ratio
- \( I_s \) = Actual secondary current
- \( I_p \) = Actual primary current

3.06 **Phase Displacement Error** – The difference in phase between the primary and secondary current vectors, the direction of vectors being so chosen that the angle is zero for a perfect transformer. It is usually expressed in minutes.

The phase displacement is said to be positive when the secondary current vector leads the primary current vector.

3.07 **Composite Error** – (For measuring and protection CT)

**Under steady state conditions, the rms value of the difference between**

(a) The instantaneous values of the primary current

(b) The instantaneous values of the actual secondary current multiplied by the rated transformation ratio.

Integrated over one cycle under steady condition.

The composite error is expressed by the following formula.

\[
E_c = \frac{100}{I_p} \sqrt{\int_0^T (k_a i_s - i_p)^2 \, dt}
\]

Where
- \( E_c \) = composite error in percent
- \( k_a \) = rated transformation ratio
- \( i_s \) = instantaneous value of the actual secondary current
- \( i_p \) = instantaneous value of the primary current
- \( I_p \) = rms value of the primary current
- \( T \) = duration of one cycle.

3.08 **Accuracy Limit Factor** – It is the ratio of the rated accuracy limit primary current to the rated primary current.

The accuracy limit factors shall be 5, 10, 15, 20 & 30.

3.081 **Rated accuracy limit primary current**
The value of the highest primary current up to which the CT will comply with the specified limits of composite error.

3.09 **Exciting current** –
The rms value of the current taken by the secondary winding of a current transformer when a sinusoidal voltage of rated frequency is applied to the secondary terminals, the primary and any other windings being open circuited.

3.10 **Accuracy Class** –
(a) **Protective current transformer**
The accuracy class is designated by the highest permissible percentage composite error at the rated accuracy limit primary current, followed by the letter ‘P’.

The standard accuracy classes for protective current transformers shall be 5P, 10P, 15P. Protective current T/Fs are designated by accuracy class followed by the accuracy limit factor. For example 5P10, 15P30.

The current error, composite error and the phase displacement at the rated frequency and with rated burden connected shall not exceed the values given below.

<table>
<thead>
<tr>
<th>Accuracy class</th>
<th>Ratio Error at rated primary current (percent)</th>
<th>Phase displacement at rated primary current (minutes)</th>
<th>Composite Error at rated accuracy limit primary current (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5P</td>
<td>+1</td>
<td>+60</td>
<td>5</td>
</tr>
<tr>
<td>10P</td>
<td>+3</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>15P</td>
<td>+5</td>
<td>-</td>
<td>15</td>
</tr>
</tbody>
</table>

(b) **Measuring current transformer**
The accuracy class shall be designated by the highest permissible percentage current error at rated current for that accuracy class.

The standard accuracy class for measuring current transformer shall be: 0.1, 0.2, 0.5, 1, 3 and 5.
Limits of Error for Standard Accuracy Classes 0.1, 0.2, 0.5 and 1

<table>
<thead>
<tr>
<th>Accuracy Class</th>
<th>± Percentage Current (Ratio) Error at Percentage of Rated Current</th>
<th>± Phase Displacement in Minutes at Percentage of Rated Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>0.1</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>0.2</td>
<td>0.75</td>
<td>0.35</td>
</tr>
<tr>
<td>0.5</td>
<td>1.5</td>
<td>0.75</td>
</tr>
<tr>
<td>1.0</td>
<td>3.0</td>
<td>1.5</td>
</tr>
<tr>
<td>3.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5.0</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

3.11 Rated short time thermal current –

The rms value of primary current which the CT will stand for a rated time, with their secondary winding short circuited without suffering harmful effects.

3.12 Rated continuous thermal current or rated primary current –

The value of the current which can be permitted to flow continuously in the primary winding, the secondary winding being connected to the rated burdens without the temperature rise exceeding the specified limits.

3.13 Rated dynamic current –

It is the peak value of rated short time thermal current. It is normally 2.5 times the rated short time, thermal current unless otherwise specified.

3.14 Rated instrument limit primary current –

The value of minimum primary current at which the composite error of measuring CT is equal to or greater than 10 percent, the secondary burden being equal to the rated burden.

The composite error should be greater than 10 percent in order to protect the apparatus supplied by the CT against the high currents produced in the event of system fault.

3.15 Instrument Security Factor (SF) –

It is the ratio of instrument limit primary current to the rated primary current.

For measuring CT, SF < 5
For protective CT, SF > 10, 15, 20

The safety of apparatus (Ampere meter, energy meter) supplied by CT is greatest when the value of instrument security factor (SF) is small.
3.16 **Rated short time factor or over current factor** –

It is the ratio of the rated short time thermal current to the rated primary current.

\[
\text{STF} = \frac{\text{Rated short time thermal current}}{\text{Rated primary current}}
\]

4.0 **Service conditions** –

- Unless otherwise specified, CT shall be suitable for the following service conditions.

(a) **Standard ambient conditions**

- Standard reference ambient temperature – 40°C
- Maximum ambient air temperature – not exceeding 45°C
- Maximum daily average ambient air temperature – 35°C
- Maximum yearly average ambient air temperature – 30°C
- Minimum ambient air temperature – 5°C

(b) **Altitude**

- Upto 1000m above mean sea level.

(c) **Atmospheric Conditions**

Atmospheres which are not heavily polluted and atmospheres not conducive to the growth of fungi and condensation of atmosphere.

5.0 **Limits of Temperature-Rise**

The temperature-rise of a current transformer winding when carrying a primary current equal to the rated continuous thermal current, at a rated frequency and with a unity power factor burden corresponding to rated output connected to the secondary windings, shall not exceed the appropriate values given in Table below. The temperature-rise of the windings is limited by the lowest class of insulation either of the winding itself or of the surrounding medium in which it is embedded.

**Table 1 - Limits of Temperature-rise of Windings**

<table>
<thead>
<tr>
<th>Class of Insulation</th>
<th>Maximum Temperature-rise (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All classes immersed in oil</td>
<td>55</td>
</tr>
<tr>
<td>All classes immersed in oil and hermetically sealed</td>
<td>60</td>
</tr>
<tr>
<td>All classes immersed in bituminous compound</td>
<td>45</td>
</tr>
<tr>
<td>Classes not immersed in oil or bituminous compound</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>40</td>
</tr>
<tr>
<td>A</td>
<td>55</td>
</tr>
<tr>
<td>E</td>
<td>70</td>
</tr>
<tr>
<td>B</td>
<td>80</td>
</tr>
<tr>
<td>F</td>
<td>105</td>
</tr>
<tr>
<td>H</td>
<td>30</td>
</tr>
</tbody>
</table>
The values given in table are based on the standard reference ambient temperature conditions. For higher reference ambient temperature, the permissible temperature rise in Table shall be reduced by an amount equal to the difference between such reference ambient temperature and 40°C.

If a transformer is specified for service at an altitude in excess of 1000 m and tested at an altitude below 1000m, the limits of temperature-rise given in Table shall be reduced by the following amounts for each 100m, the altitude at the operating site exceeds 1000m.

a) Oil-immersed transformers – 0.4 percent, and
b) Dry-type transformers – 0.5 percent.

When the transformer is fitted with conservator tank or has any gas above the oil, or is hermetically sealed, temperature-rise of the oil at the top of the tank or housing shall not exceed 50 K.

When the transformer is not fitted with conservator tank or has any gas above the oil or is hermetically sealed the temperature-rise of the oil at the top of the tank or housing shall not exceed 45 K.

The temperature-rise measured on the external surface of the core and other metallic parts in contact with or adjacent to, insulation (if accessible) shall not exceed the appropriate value in Table-1.

6.0 Rated insulation level

The rated insulation levels of CTs is defined by the power frequency and the lightning impulse withstand voltage given in table below.

Table 2A- Rated insulation Levels for highest System Voltages Up to and including 72.5 kV

<table>
<thead>
<tr>
<th>Nominal System Voltage (1) kV (rms)</th>
<th>Highest System Voltage (2) kV (rms)</th>
<th>Power Frequency Withstand Voltage (3) kV (rms)</th>
<th>Lightning Impulse Withstand Voltage (4) kV (peak)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>List 1</td>
</tr>
<tr>
<td>Up to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.60</td>
<td>0.66</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>3.3</td>
<td>3.6</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>6.6</td>
<td>7.2</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>11</td>
<td>12.0</td>
<td>28</td>
<td>60</td>
</tr>
<tr>
<td>15</td>
<td>17.5</td>
<td>38</td>
<td>75</td>
</tr>
<tr>
<td>22</td>
<td>24.0</td>
<td>50</td>
<td>95</td>
</tr>
<tr>
<td>33</td>
<td>36.0</td>
<td>70</td>
<td>145</td>
</tr>
<tr>
<td>45</td>
<td>52.0</td>
<td>95</td>
<td>250</td>
</tr>
<tr>
<td>66</td>
<td>72.5</td>
<td>140</td>
<td>325</td>
</tr>
</tbody>
</table>
NOTES:
1. Underlined values are preferred.
2. The choice between lists 1 and 2 should be made by considering the degree of exposure to lightning and switching over voltages, the type of system neutral earthing and the kind of the over voltage protection. Some guidance is given in IS 2165 (Part 1): 1977.

The rated insulation levels of current transformers having highest system voltages of 123 kV and above, up to and including 245 kV, defined by the power frequency and lightning impulse withstand voltages, shall be one of the values given in Table 2B.

Table 2B- Rated Insulation Levels for Highest System Voltages of 123 kV and above, Up to Including 245 kV.

<table>
<thead>
<tr>
<th>Nominal System Voltage (kV (rms))</th>
<th>Highest System Voltage (2) kV (rms)</th>
<th>Power Frequency Withstand Voltage (3) kV (rms)</th>
<th>Lightning Impulse Withstand Voltage (4) kV (peak)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>123</td>
<td>185</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td></td>
<td>230</td>
<td>550</td>
</tr>
<tr>
<td>132</td>
<td>145</td>
<td>230</td>
<td>550</td>
</tr>
<tr>
<td></td>
<td></td>
<td>275</td>
<td>650</td>
</tr>
<tr>
<td>220</td>
<td>245</td>
<td>360</td>
<td>850</td>
</tr>
<tr>
<td></td>
<td></td>
<td>395</td>
<td>950</td>
</tr>
<tr>
<td></td>
<td></td>
<td>460</td>
<td>1050</td>
</tr>
</tbody>
</table>

NOTE – Underlined values are preferred.

7.0 MARKING

7.01 Rating Plate

All current transformers shall carry at least the following markings:

a) The manufacture’s name and country of origin;
b) Year of manufacture;
c) A serial number and a type designation;
d) The rated primary and secondary currents (for example, 200-100/1-1A);
e) Rated frequency; and
f) Rated output and the corresponding accuracy class (for example (i) 10 VA, class 1 or 10VA/1 (ii) 30VA class 5P/10 or 30VA/5P10

Note – When more than one separate secondary windings are provided, the marking should indicate the output of each secondary winding in VA, the corresponding accuracy class and the rated current of each winding.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
g) Highest system voltage (for example, 72.5kV);
h) Rated insulation level (for example, 140/325 kV);
Note – The items (g) and (h) may be combined into one marking (for example, 72.5/140/325 kV).

i) Rated short-time thermal current or short-time factor with rated time (if different from 1 second) (for example 13.1kA/0.5 or STF 100/0.5)
j) Rated dynamic current if different than 2.5 times the rated short-time thermal current;
k) Reference to the standard.

7.02 Terminal Marking

The terminal marking shall identify:

a) The primary and secondary windings;
b) The winding sections, if any;
c) The relative polarities of windings and winding sections; and
d) The intermediate tappings, if any;

7.03 Method of Marking

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

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

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

![Fig. 1 Single Ratio Transformer](image1)

![Fig. 2 Transformer with an Intermediate Tapping on Secondary Winding](image2)

![Fig. 3 Transformer with Primary Winding in Two Sections Intended for Connection Either in Series or Parallel](image3)

![Fig. 4 Transformer with Two Secondary Winding](image4)

All the terminals marked P1, S1, and C1 shall have the same polarity at any instant.
8.0 **Correlation of Burden and Accuracy Limit Factor**

For economic design of CT, the product of connected burden and accuracy limit factor should not exceed 150, otherwise the CT may be uneconomical or of unduly large dimensions.

The ALF and burdens are inter related, that is a decrease in the burden will automatically increase its ALF and vice-versa. For example the burden of an inverse time over current relay will reduce by changing its setting from 100 to 200 percent. This will enable the current transformer to supply a higher secondary current without its composite error exceeding the limit of its accuracy class.

9.0 **Application of Measuring CT.**

- A current transformer with a rated output considerably in excess of required output may result in increased errors under operating conditions.
- The burden is composed of the individual burdens of the instrument and connecting leads. When the length of the connecting leads is such that the impedance of leads at 5 ampere secondary current would be excessive, consideration should be given to the use of a rated secondary current of lower value (say 1.0 ampere).

The accuracy classes recommended below are intended as a guide in selection of measuring transformer.

<table>
<thead>
<tr>
<th>Application</th>
<th>Class of accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) For precision testing, or as a sub-standard or testing laboratory current transformers</td>
<td>0.1</td>
</tr>
<tr>
<td>b) For laboratory and test work in conjunction with high accuracy indicating instruments, integrating meters and also sub-standard for testing industrial current transformer</td>
<td>0.2</td>
</tr>
<tr>
<td>c) For precision industrial metering</td>
<td>0.5</td>
</tr>
<tr>
<td>d) For commercial and industrial metering</td>
<td>0.5 or 1</td>
</tr>
<tr>
<td>e) For use with indicating and graphic wattmeters and ammeters</td>
<td>1 or 3</td>
</tr>
<tr>
<td>f) For purpose where the ratio is of less importance, for example ammeters where approximate values are required</td>
<td>3 or 5</td>
</tr>
</tbody>
</table>

Typical values of VA burden imposed by different meters are given below:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>VA Burden</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Ammeters</td>
<td>3</td>
</tr>
<tr>
<td>b) Current coils of wattmeter and power factor meters</td>
<td>5</td>
</tr>
<tr>
<td>c) Current coils of kWh, kVar meters</td>
<td>5</td>
</tr>
<tr>
<td>d) Recording ammeters</td>
<td>3</td>
</tr>
<tr>
<td>e) Current coils of recording power factor meters and wattmeters</td>
<td>5</td>
</tr>
</tbody>
</table>
10.0 Application of Protective current transformer

- The burden on a protective current transformer is composed of the individual burdens of relays and the connected leads.
- When the individual burdens are expressed in ohmic values, the total burden may be computed by addition. This total ohmic burden should then be converted to a VA burden at the rated secondary current.
- When the individual burdens are expressed in terms of VA, convert at a common base before they may be added together to form the total computed burden. The common base shall be the rated secondary current of CT.
- When the relays having following characteristics are set to operate at current differing from the rated secondary current of CT, the VA burden (Pe) which is effectively imposed on the CT at rated secondary current is given by the following formula.

\[
P_e = P_r \left( \frac{I_s}{I_r} \right)^2
\]

- The impedance of relay is constant, regardless of current setting (example – untapped relay (oil)).
- Impedance changes with the current setting

\[
P_e = P_r \left( \frac{I_s}{I_r} \right)^2
\]

- The accuracy class required for protective current transformer depend upon the particular application and is given below for guidance.

  - Instantaneous overcurrent relays and Tripcoil – Class 10P
  - Over current relays with inverse and definite minimum time lag characteristic (Both directional and non-directional)
    (a) Class 10P where phase fault stability and accurate time grading is not required.
    (b) Class 5P where accuracy, phase fault stability and accurate time grading is required. The product of rated burden of CT and rated accuracy limit factor should not exceed 150.

The CT should not saturate – up to at least 20 times the relay setting. This may be achieved by choosing a relay with low VA burden or a CT with a higher ratio.

- Earth fault Relays with inverse and definite minimum time lag characteristics (Both directional and non directional).
  (a) Class 10P in which phase fault stability and accurate time gradings are not required. It may also be ensured that
    - The product of rated burden of CT and rated accuracy limit factor should not exceed 150.
    - The earth fault relay is not set below 20% of the rated secondary current of CT.
    - The burden of relay at its current setting does not exceed 4 VA.
  (b) Class 5P in which phase fault stability and accurate time grading are required. It may also be ensured that
• The product of rated burden of CT and rated ALF should not exceed 150.
• The earthfault relay is not set below 30% of the rated secondary current of CT.
• Burden of relay at its current setting should not exceed 4 VA.
• Phase burden effectively imposed on each CT does not exceed 50% of its rated burden.

Note: In case, it is not possible to select a CT with a higher accuracy limit factor, then the same result may be obtained by imposing a phase burden on each CT not exceeding 50% of its rated burden, thereby increasing the ALF indirectly twice the value.

• Differential protection, distance measuring protection, directional relays where CT phase error are important up to the maximum through fault current, restricted earth fault protection, instantaneous earth fault protection.
  (a) Class 5P provided CT maintains its class accuracy up to maximum through fault current.
  (b) Class PS where more accuracy than that provided by class 5P is required.

11.0 Affect of saturation of CT on the performance of relays.
• A CT may saturate from both AC and DC component of fault current. On saturation, the secondary current supplied by CT would contain a considerable proportion of harmonics, the most predominant being the third harmonics. The harmonic current flowing in the induction disc relay causes incorrect tripping (higher operating time) of the relay.

Thus desired time discrimination and times of operation may not be obtained even if satisfactory nominal setting are used on the relays. While selecting CT and where fault current is adequate, it should be ensured that CTs do not saturate up to at least 20 times the relay setting. This may be achieved by choosing a relay with a low VA burden or a CT with a higher ratio.

12.0 Affect of large magnetizing current of CT on the performance of relays

Current transformer should not consume excessive magnetizing current. If magnetizing current is high, it may result in higher primary fault settings in case of current operated relays and may use under reaching in case of distance relays. However a very low value of magnetizing current should not be specified as it may result in larger and costly current transformer.

13.0 Affect of knee point of voltage on the performance of relays

It CTs are not of adequate knee point voltage, if may result in higher operating time of the relays for distance protection due to saturation of CT on fault current.
14.0 **Protective current transformers for special purpose application**

These CTs are for special purpose application such as balanced protective systems and distance protection scheme. These CTs are designated “Class PS”.

“Class PS” CTs are of low reactance and their performance are specified in terms of the following characteristics.

- Turn ratio – the error in turn ratio shall not exceed ± .25 percent.
- Minimum knee point voltage – it is specified by the following formula.

\[
V_k = K I_s (R_{CT} + R_b)
\]

where:

- \( V_k \) = minimum knee point voltage in volts
- \( K \) = a parameter which depends on the system fault level and the characteristics of the relay.
- \( I_s \) = Rated secondary current of CT (or the secondary current as derived from a specified turn ratio and primary current).
- \( R_{CT} \) = Resistance of secondary winding of CT corrected to 75°.
- \( R_b \) = impedance of secondary circuit.

**Maximum exciting current at the rated knee point voltage or at any specified fraction of the rated knee point voltage.**

The exciting current should not exceed the value stipulated, otherwise it will affect the primary fault settings of the protection scheme.

14.01 **Knee Point Voltage**

The sinusoidal voltage of rated frequency applied to the secondary terminals of the CT, all other windings being open circuited, which when increased by 10%, causes the exciting current to increase by 50 percent.

14.02 **Requirement of current transformer for special purpose**

- A current transformer should have identical turn ratio
- All CTs must be operated on full winding (No tap connection)
- The knee point voltage of CT should be at least twice the relay setting voltage.
- The CT should be of low leakage type i.e. low resistance type. The CT should have following characteristic to be of low reactance type.
- The core is of jointless ring type
- The secondary turns are substantially evenly distributed along the whole length of magnetic circuit.
- The primary conductor passes through approximate centre of the core.
- The CT have flux equalizing winding such an arrangement ensures substantially even flux distribution within the core.

15.0 **Typical examples on CTS have been given in Annexure- 1, 2 & 3.**
Example – 1

(i) Calculate the VA output required for a CT of 5A rated secondary current when burden consists of relay requiring 10VA at 5A, plus loop lead resistance 0.1 ohm.

\[ \text{Total VA output of CT} = 5^2 \times 0.1 \text{ ohm} + 10 \text{VA} \]
\[ = 2.5 \text{ VA} + 10 \text{VA} \]
\[ = 12.5 \text{VA} \]

Hence a CT rating of 15VA and secondary current 5A will be used.

(ii) The rated secondary current of a current T/F is 5A.

The plug setting of a relay is 2.5A. The power consumption of the relay at 2.5A plug setting is 2VA. Calculate the effective VA burden of the relay on the CT at 5A secondary current.

\[ P_e = P_r \left( \frac{I_s}{I_r} \right)^2 \]
\[ = 2 \left( \frac{5}{2.5} \right)^2 \]
\[ = 8 \text{VA} \]

The CT of 10VA burden should be selected.
Example–2

A 1000 kVA, 415V, 3φ generator is supplying power to an industrial load. The sub transient reactance of generator is 8%. Find the rating of measuring and protection CT. The VA burden of relay is 3VA, the impedance of lead loop is 0.5 ohm. The VA burden of kWh and ampere meter is 3VA and 1VA respectively.

![Diagram of Lead Loop Resistance 0.5 OHM](image)

**Rated current of generator**

\[ I_{\text{Rated}} = \frac{1000 \times 415}{\sqrt{3} \times 415} \]

\[ = 1392.85 \text{A} \]

**3 phase short circuit current**

\[ I_{\text{CS}} = \frac{I_{\text{Rated}}}{0.85} \]

\[ = \frac{1392.85}{0.85} \]

\[ = 17410.68 \text{A} \]

**Rating of Protection CT**

- **Rated accuracy limit primary current** = 17410.68
- **Accuracy limit factor** = \( \frac{17410.68}{1392.85} \)
- **Accuracy limit factor** = 12.5
- **Adopt accuracy limit factor** = 15
- **CT Ratio** = \( \frac{1500}{5} \)
- **Rated generator current in secondary of CT**

\[ I_s = \frac{1392.85 \times 5}{1500} \]

\[ = 4.643 \text{A} \]

**Burden connected to secondary of protective CT**

\[ P = I_s^2 \times \text{impedance of lead} + \text{VA burden of relay} \]

\[ = 4.643^2 \times 0.5 + 3 \]

\[ = 10.78 + 3 \]

\[ = 13.78 \text{VA} \]
Adopt rated output of CT = 15VA
Rating of protection CT 1500/5, 15VA, 10P/15

• **Rating of measuring CT**

Standard accuracy classes for measuring CT
= 0.1, 0.2, 0.5, 1, 3, 4, 5

For kWH measurement adopt 0.5 accuracy class.

VA burden on secondary of CT

\[ P_e = I_s^2 \times \text{impedance of lead} + \text{VA burden of kWh} + \text{VA burden of Ampere-meter} \]
\[ = 4.643^2 \times 0.5 + 3VA + 1VA \]
\[ = 10.78 + 4VA \]
\[ = 14.78VA \]

Adopt rated output of measuring CT = 15VA

Rating of measuring \( CT = \frac{1500}{5} = 15VA / .5 \)
Example – 3

Find the kneepoint voltage and value of stabilizing resistance in the following differential protection scheme of generator. The one side lead resistance from CT to relay is .4 ohm.

Generator full load current

\[
I_f = \frac{24 \times 1000}{\sqrt{3} \times 11 \times 0.9} = 1401 \text{ A}
\]

Three phase short circuit transient current.

\[
= \frac{1401}{X_{d''}} = \frac{1401 \times 100}{10} = 14010 \text{ A}
\]

Assumption for calculation of stabilizing resistance.

- One set of current transformer is completely saturated.
- Whole of the primary fault current is perfectly transformed by the remaining CTs.
- Maximum loop lead burden between the relay and CT is used.

Voltage developed across the relay circuit also called Relay Setting Voltage

\[
V = \frac{I_f}{N} \left( R_s + 2R_s \right)
\]

Where

- \( I_f \) = Maximum through fault current
- \( N \) = CT Ratio
- \( R_s \) = CT internal resistance (say 1 ohm)
\[ R_b = \text{loop lead burden} \]

\[ V = \frac{14010 \times 5}{2000} \left[ 1 + 2 \times 0.4 \right] \]

\[ = 63 \text{ V} \]

The relay therefore can be set at 70V. Let relay setting is 0.5A in case of 5A relay and has a burden of 1VA at 0.5A setting.

\[ Z_{\text{relay}} = \text{impedance of relay} = \frac{V_A}{I_s^2} \]

\[ I_s = \text{Relay current setting} = \frac{1}{0.5 \times 0.5} = 4 \text{ ohm} \]

Total relay circuit impedance \( Z_{\text{total}} = \frac{V}{I_s} \)

\[ = 63V \]

\[ \text{relay} \]

\[ .5 \text{ A} \]

\[ = 126 \text{ ohm} \]

Stabilizing resistor required \( = Z_{\text{Total}} - Z_{\text{relay}} \)

\[ = 126 - 4 \]

\[ = 122 \text{ ohm} \]

- Knee Point voltage of CT.

\[ V_k = \frac{2I_f}{N} (R_{CT} + 2R_L) \]

Where

\[ I_f = \text{Maximum through fault current} \]

\[ N = \text{CT Ratio} \]

\[ R_{CT} = \text{CT Secondary resistance in ohm at 75°C} \]

\[ R_L = \text{one way lead resistance in ohm at 75°C} \]

\[ V_k = \frac{2 \times 14010 \times 5}{2000} \left[ 1 + 2 \times 0.4 \right] \]

\[ = 126 \text{ Volt} \]

It may be noted that knee point voltage should be at least twice the relay setting voltage. Therefore to be on safer side knee point voltage is adopted 200V.

**Magnetizing current drawn by CT**

It should not be more than 1 mA per volt of relay setting.

The magnetizing current at relay setting

or \( \frac{V_k}{2} \leq 70mA \)
SECTION – 8
LIGHTNING ARRESTOR

1.0 LIGHTNING ARRESTOR

It is a device designed to protect electrical apparatus from high transient voltage and to limit the duration and frequently the amplitude of follow current.

2.0 Type of Lightning Arrestor

• Non linear Resistor Type Arrestor (Valve Type)

A lightning arrestor having a single or a multiple spark gap connected in series with one or more non linear resistors. The resistor has non linear voltage current characteristics which offers low resistance to over voltages thus limiting the voltage across the arrestor terminals with flow of high discharge current and as a high resistance at normal power frequency voltage thus limiting the magnitude of follow current.

For important installation valve type LA is not usually recommended.

• Non Linear Metal Oxide Lightning Arrestor without gaps

It is a lightning arrestor having non linear metal oxide resistors with out any series or parallel spark gaps

A lightning arrestor is normally connected between phase and earth.

3.0 Terminology

3.01 Rated Voltage of an arrestor

The maximum permissible r.m.s. value of power frequency voltage between its terminals at which its is designed to operate correctly under temporary over voltage condition for a duration of 10 seconds.

The following causes of temporary over voltage should be considered.

(a) Earth fault voltage

For effectively earthed system the coefficient of earthing is less than 80%. 75% is the reasonable value. The duration of over voltages is generally less than 1 sec.

For non effectively earthed system, the coefficient of earthing is more than 80% and duration of over voltages is generally less than 10 seconds. In system without earth fault clearing the duration may be several hours.
(b) Load Rejection

A full load rejection can give rise to phase to earth over voltages with amplitude below 1.2 PU. The duration of over voltages depends on the operation of voltage control equipment and may be up to several minutes.

For load rejection of generator transformer, the temporary over voltages may reach amplitude upto 1.5 PU for hydro generators.

(c) Calculation of amplitude of temporary voltages with a duration of 10 seconds

The approximate amplitude of temporary over voltages (the duration of which is between 1 seconds to 100 seconds or more) can be converted to an equivalent amplitude with a duration of 10 seconds by the following formula.

\[ U_{eq} = U_t \left( \frac{T_t}{10} \right)^m \]

Where,

- \( U_t \) = amplitude of temporary over voltages
- \( T_t \) = duration of temporary over voltages in seconds
- \( m \) = an exponent describing the power frequency voltage vs time characteristics of the arrestor, the average value of .02 may be used.

The power frequency voltage vs time characteristic of the arrestor should exceed the temporary over voltage.

3.02 Continuous operating voltage of an arrestor

It is the r.m.s. value of power frequency voltage that may be applied continuously between the arrestor terminals

3.03 Impulse

An unidirectional wave of voltage or current which without appreciable oscillations rises rapidly to a maximum value and falls usually less rapidly to zero.

The parameters that defines a voltage or current impulse are polarity, peak value, front time and time to half value on the tail.

An 8/20 10 KA current impulse is shown as below
3.04 Steep Current Impulse (1/20)

A current impulse with a virtual front time of 1µs and time to half value on current tail not longer than 20 µs.

A 1/20 5 KA steep current impulse is shown below:

![Steep Current Impulse Diagram]

3.05 Lightning Current Impulse

An 8/20 current impulse is called lightning current impulse.

3.06 Discharge current of an arrester

The impulse current which flows through the arrestors.

3.07 Nominal discharge current of an arrester

The peak value of discharge current having 8/20 wave shape which is used to classify an arrester.

3.08 High current impulse of an arrester (4/20)

The peak value of discharge current having a 4/10 impulse shape which is used to test the thermal stability of the arrester.

3.09 Switching current impulse of an arrester

The peak value of discharge current having a virtual front time greater than 30µs but less than 100 µs and a virtual time to half value on the tail of roughly twice the front time.

Ex. A 35/70 10KA switching current impulse is shown below:

![Switching Current Impulse Diagram]
3.10 **Continuous current of an arrestor**

It is the current flowing through the arrestor when energized at the continuous operating voltage.

The continuous current consists of a resistive and a capacitive components. It is expressed by its r.m.s. or peak value.

3.11 **Standard lightning voltage impulse (1.2/50)**

An impulse voltage having a wave shape designation of 1.2/50.

3.12 **Residual Voltage (Discharge Voltage) of an arrestor**

The peak value of voltage that appears between the terminals of an arrestor during the passage of discharge current.

3.13 **Power frequency voltage withstand Vs time characteristic of an arrestor**

This characteristics shows the maximum time durations for which corresponding power frequency voltage may be applied to arrestor without damage or ensuing thermal instability.

![Voltage vs Time Graph](image)

3.14 **Protective characteristics of an arrestor**

It is the combination of the following

(a) Residual voltage for steep current impulse
(b) Residual voltage for switching impulse
(c) Residual voltage Vs discharge current characteristic for lightning impulses (8/20)

3.15 **Pressure Relief Device**

It is a device for relieving internal pressure in an arrestor and preventing violent shattering of the housing following prolonged passage of fault current or internal flash over of the arrestor.

3.16 **Arrestor Disconnector**

A device for disconnecting an arrestor from the system in the event of arrestor failure.

3.17 **Standard Nominal Discharge Current**

Standard nominal discharge currents are 1.5 KA, 2.5 KA, 5KA, 10KA, 20KA having an 8/20 impulse wave shape.
4.0 Rated Insulation level of housing of an arrester
It is defined by the power frequency and lightning impulse with stand voltage and is given in table below:

Table 1- Voltage Withstand Tests on Arrester Housing

<table>
<thead>
<tr>
<th>Highest System Voltage kV rms</th>
<th>Power Frequency Test Voltage kV rms</th>
<th>Lightning Impulse Test Voltage kV Peak</th>
<th>Switching Impulse Test Voltage kV Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>0.440</td>
<td>2.5</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>1.0</td>
<td>3.5</td>
<td>14</td>
<td>-</td>
</tr>
<tr>
<td>3.6</td>
<td>10</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>7.2</td>
<td>20</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td>12.0</td>
<td>28</td>
<td>75</td>
<td>-</td>
</tr>
<tr>
<td>24.0</td>
<td>50</td>
<td>125</td>
<td>-</td>
</tr>
<tr>
<td>36</td>
<td>70</td>
<td>170</td>
<td>-</td>
</tr>
<tr>
<td>72.5</td>
<td>140</td>
<td>325</td>
<td>-</td>
</tr>
<tr>
<td>123</td>
<td>230</td>
<td>550</td>
<td>-</td>
</tr>
<tr>
<td>145</td>
<td>275</td>
<td>650</td>
<td>-</td>
</tr>
<tr>
<td>245</td>
<td>460</td>
<td>1,050</td>
<td>-</td>
</tr>
<tr>
<td>420</td>
<td>-</td>
<td>1,425</td>
<td>1,050</td>
</tr>
<tr>
<td>800</td>
<td>-</td>
<td>2,400</td>
<td>1,550</td>
</tr>
</tbody>
</table>

5.0 Maximum Protection Level of surge arrestors.

The maximum protection levels of surge arrestors are given below:

Table 2- Maximum Protection Levels of surge arrestors

<table>
<thead>
<tr>
<th>Rated Voltage kV</th>
<th>Maximum Residual Voltage at steep current impulse 1/20µs at 10KA (KV peak) or steep current protection level</th>
<th>Maximum Residual Voltage at nominal discharge current of 8/20 µs impulse wave (KV peak) or lightning impulse protection level.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1.5KA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5KA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10KA</td>
</tr>
<tr>
<td>0.175</td>
<td>3.0</td>
<td>2.2</td>
</tr>
<tr>
<td>0.280</td>
<td>3.5</td>
<td>2.5</td>
</tr>
<tr>
<td>0.50</td>
<td>4.5</td>
<td>3.0</td>
</tr>
<tr>
<td>0.660</td>
<td>6.0</td>
<td>5.0</td>
</tr>
<tr>
<td>1.000</td>
<td>9.0</td>
<td>6.0</td>
</tr>
<tr>
<td>3.0</td>
<td>12.0</td>
<td>-</td>
</tr>
<tr>
<td>4.5</td>
<td>18.0</td>
<td>-</td>
</tr>
<tr>
<td>6.0</td>
<td>24.0</td>
<td>-</td>
</tr>
<tr>
<td>7.5</td>
<td>30.0</td>
<td>-</td>
</tr>
<tr>
<td>9.0</td>
<td>35.0</td>
<td>-</td>
</tr>
<tr>
<td>10.5</td>
<td>40.0</td>
<td>-</td>
</tr>
<tr>
<td>12.0</td>
<td>45.0</td>
<td>-</td>
</tr>
</tbody>
</table>

AHEC/MNRE/SHP Standards/E&M Works – Guidelines For Electrical Designs Of SHP Plants Including Switchyard 123
6.0 System Earthing

6.01 Effectively Earthed Neutral System – System neutral is earthed in such a manner that coefficient of earthing does not exceed 80 percentage or earth fault factor does not exceed 1.4. This condition is met when
\[
\frac{X_0}{X_1} < 3
\]
\[
\frac{R_0}{X_1} < 1
\]
Reduced insulation level is normally applicable to this condition.

Note:
(i) Star point of power T/F directly connected to earth is regarded as effectively earthed
(ii) The inclusion of bar primary current T/F between between the T/F neutral and earth is regarded as effectively earthed.
(iii) A System in which some of the star point of T/F are not solidly earthed or have delta connected winding may be considered as effectively earthed provided coefficient of earthing of system is less than 80%.
(iv) The inclusion of multi turn primary current transformer between the transformer neutral and earth regarded as effectively earthed provided coefficient of earthing as less than 80%.

6.02 Non Effectively Earthed System –

System Neutral is earthed through resistor or reactor or earthed directly at a limited number of points such that coefficient of earthing may be exceed 80% or earth fault factor exceed 1.4.

Full insulation level appropriate to highest system voltage is applicable.

6.03 Resonant Earthed System (System earthed through an Arc suppression coil)

A system earthed through a reactor, the reactance being of such value that during a single phase to earth fault, the power frequency inductive current passed by this
reactor substantially neutralizes the power frequency capacitive component of the earth fault current, resulting arcing fault in air self extinguishing.

Full insulation level is normally applicable. It is usually the intention that line to earth fault shall be either
1. Self clearing without interruption of supply or cleared by automatic disconnection with in a few seconds
2. Cleared by manual disconnection but allowed to persist until it is convenient to locate and isolate.

It is contemplated that system will be operated with one line earthed for a period exceeding 8 hours in any 24 hours or an aggregate of 125 hours per annum.

6.04 System Neutral Isolated – In such a system no intentional connection to earth is made except through indicating, measuring or protective devices of very high impedance.

It requires adoption of an insulation level higher than that would normally be selected for full insulation. In such system earthing factor may be 100% or higher at the point of arrestor installation.

6.05 Earth Fault Factor –
It is the ratio of highest RMS phase to phase power frequency voltage on a sound phase during phase to earth fault on one or two phases to RMS phase to earth power frequency voltage at the same location with the fault removed.

6.06 Coefficient of Earthing –
It is the ratio of highest RMS phase to earth voltage of healthy phase during phase to earth fault on one line to line to line normal RMS voltage.

Earth fault factor = \( \sqrt{3} \times \text{coefficient of Earthing} \)

Note: For effectively earthed system, the coefficient of earthing is less than 80%. On high voltage transmission system, the coefficient of earthing does not exceed 75%.

7.0 Application Guide for Selection of Lightning Arrestor

10000A (8/20\(\mu\)s) discharge current lightning arrestor provides the best protective level. 5000 A arrestors are the next, and 2500A and 1500A arrestors are the last.

7.01 Effectively / non effectively shielded installation
It depends on the degree of shielding against direct lightning strokes to lines and substation. Such installations are devided into two classes, namely, effectively shielded installation and non effectively shielded installation.

Experience shows that shielding is not very effective for lines below 100 KV and these are treated non effectively shielded installation.
7.02 **Magnitude and wave shape of discharge current for effectively shielded installation** –
In these installation the protective angle of earth wires is of the order of 30° or less and earthing resistance of each tower does not exceed 10 ohm.

The maximum surge arrestor discharge currents in such a case vary from 4000A at 110 KV to about 10000 A at 400 KV. Substations, lines and bundled conductor may attain a discharge currents between 5000A and 10000A. These discharge currents correspond to 8/20 µs wave shape used for surge arrestor testing.

The rate of rise of discharge current current is dependent on the rate of rise of voltage. The maximum rate of rise of voltage when it enters the sub-station from an effectively shielded line is estimated to be 500 KV/ µs.

7.03 **Magnitude and wave shape of discharge current for non effectively shielded installations**
The maximum surge arrestor discharge currents in such a case vary from 5000A to 2000A (8/20 µs wave shapes)

The maximum rate of rise of voltage when it enters the substation from a non effectively shielded line is estimated to be 1000 KV/ µs.

**As a general rule**
(a) 10000A arrestors are applied to high voltage system (100 KV and above)
(b) 10000A or 5000A arrestors are used on less than 100 KV transmission lines and sub stations, higher ratings for important installations.
(c) 5000A, 2500A and 1500A arrestors on distribution system and small transformers.

7.04 **Determination of arrestor voltage rating**
The voltage rating of arrestor should be chosen at least equal to the highest phase to earth voltage of healthy phase during phase to earth fault on one line.

Arrestor voltage rating = Coefficient of Earthing × Highest System Voltage

7.05 **Protection Level**
It is the ratio of lightning impulse with stand strength of the equipment to the lightning impulse protective level of the arrestor.

Lightning impulse protective level is the maximum residual voltage at nominal discharge current (1.5A, 2.5KA, 5KA, 10 KA, 20 KA of 8/20 impulse wave.

Protection Level = \[
\frac{\text{B.I.L. of the equipment to be protected}}{\text{Lightning impulse protection level of Lightning arrester}}
\]

The recommended minimum protection level is 1.2.
7.06 Location of Arresters

7.061 Cable connected equipment for single line installation

Cable connected equipments involves a substation or individual apparatus connected to a cable which in turn is connected to overhead line that may or may not be effectively shielded at the line-cable junction.

Arrestors are installed at the equipment or at the overhead line cable junction or at both the equipment and the junction if necessary.

In the case of unshielded lines, it may be advantageous to mount additional LA a few span before the over head line cable junction.

7.062 For non effectively shielded installations with a single incoming overhead line

The arrestor should be installed right at the transformer.

7.063 For non effectively shielded installations with several incoming lines

A set of arrestors is installed at or close to the transformer.

The arrestors are also installed at the respective line entrances.

7.064 For effectively shielded installation

In the case of effectively shielded installations, separation between the arrestor and equipment to be protected is permissible.

(a) For small installations with one incoming over head line.

One set of arrestors is installed at a point which provides protection to all equipment.

(b) For large installations with several incoming overhead lines, transformers, switch gear etc.

The location of arrestor and number of arrestors which will give the required degree of protection will be determined by model studies and digital computer programming method.

7.065 Protection of Rotating Machines

(a) For machines connected to over head lines either directly or through a short length of cable.

The capacitors (.1 to .3 µf) shall be installed at the machine terminals between line and earth as close as possible to the machine terminals to slope off the wave front to approximately 10µs or more and the arrestors shall be used to provide additional protection.

The arrestors shall also be installed on the over head lines ahead of the machine location or at an overhead line-cable junction point.
(b) **For machines connected to over head lines through transformer.**
- If lightning arrestors have been installed on the transformer and if the machine is connected to transformer by sufficiently long cables no LA protection is required on the machine.
- If LA have been installed on the transformer and a capacitor of the value .1 to .3µF are installed between phase and earth of the rotating machine no LA protection is required on the machine.
- For machines connected to star-delta transformer, improved protection can be achieved by additional phase-to-phase arrestors.

8.0 **Arrestor Identification**
Metal oxide surge arrestors shall be identified by the following minimum information which shall appear on a name plate permanently attached to the arrestor
(a) Continuous operating voltage
(b) Rated voltage
(c) Rated frequency
(d) Nominal discharge current
(e) Pressure Relief Rated current in KA r.m.s.
(f) Manufactures name or trade mark
(g) Year of manufacturing
(h) Serial Number

9.0 **Typical examples for calculations of the ratings of lightning Arrestors – Annexure 1, 2, 3.**
Annexure-1

Example 1- Calculate the temporary over voltage for 10 seconds in healthy phase on account of earth fault in the other phase. The rated voltage of the LA may also be calculated.

- System – effectively earthed 11KV system. \( \frac{X_0}{x_1} < 3 \) and \( \frac{R_0}{X_1} < 1 \)
- Duration of temporary voltage = 1 sec
- Highest system voltage = 12 K.g.
- Coefficient of earthing = .75

Solution

\[
\text{Coefficient of earthing} = \frac{\text{During earth fault on one phase.}}{\text{Line to line r.m.s. Voltage}}
\]

\[.75 = \frac{\text{Highest r.m.s. phase to earth voltage of healthy phase}}{11 \text{ KV}}\]

Highest r.m.s. phase to earth voltage = 11 K.V. \( \times .75 = 8.25 \text{ KV} \)

Amplitude of the temporary over voltage (\( U_{eg} \))

\[
U_{eg} = U_t \left( \frac{T_t}{10} \right)^m
\]

\( U_t = 8.25 \text{ K.V} \)
\( T_t = 1 \text{ Sec} \)
\( m = .02 \)

\[
U_{eg} = 8.25 \text{ KV} \left( \frac{1}{10} \right)^{.02}
\]

\[= 7.87 \text{ KV} \]

The rated voltage of LA should be more than 7.87 KV. It is taken as 9.0 KV.
Example-2

Calculate the protective margin of the following system.

- Highest system voltage = 12 KV, non effectively shielded installation
- Residual Voltage of arrestor at steep current impulse $\frac{1}{20}$ $\mu$s at 10 KA= 35 KV peak.
- Maximum Rate of Rise of Voltage when it enters the substation
  From a non effectively shielded line = 1000 KV/$\mu$s
  From a effectively shielded line = 500 KV/$\mu$s
- B.I.L. of T/F = 75 KV.
- Distance of T/F from LA = 2 meter
- Lightning impulse protection level = 30 KV

Calculation:

The voltage stress $V_2$ on the protected object (T/F) is given by the formula

$$V_2 = V_1 + \frac{2 \times S \times L}{V}$$

When

- $V_1$ = Residual voltage of arrestor at = 35 KV peak
- Steep current impulse 1/20 $\mu$s at 10 KA
- $L$ = distance between arrestor and object including leads
  = $d + d_1 + d_A + d_2$
  = 2 meter

Where

- $d$ = The distance between the high voltage terminal of the protected equipment and the connection point of the arrestor with high voltage conductor.
- $d_1$ = length of arrestor high voltage conductor
- $d_2$ = length of arrestor earth conductor
- $d_A$ = length of arrestor
S = steepness of incoming wave or maximum rate of rise of voltage when it enters the substation = 1000 KV/µs

V = Velocity of wave propagation (approximately equal to velocity of light for overhead line) = 300 m/micro second.

\[ V_2 = 35 + \frac{2 \times 1000 \times 2}{300} \]
\[ = 35 + 13.33 \]
\[ = 48.33 \]

The voltage at the T/F will be 48.33KV.

The protective margin = \[ \left( \frac{75 - 48.33}{48.33} \right) \times 100 \]
\[ = 55.18\% \]

Protection Level = \[ \frac{B.I.L. \ of \ equipment \ to \ be \ protected}{Lightning \ impulse \ protection \ level} \]
\[ = \frac{75KV}{30KV} \]
\[ = 2.5 \]
Example 3.0

Typical example for 415V, 11KV, and 33 KV system.

**System Data**

<table>
<thead>
<tr>
<th></th>
<th>415 V</th>
<th>11 KV</th>
<th>33 KV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage of system (KV rms)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.I.L. of T/F (KV Peak)</td>
<td>10 KV</td>
<td>75 KV</td>
<td>170 KV</td>
</tr>
<tr>
<td>Characteristic of Surge arrester rated voltage</td>
<td>280 V</td>
<td>9 KV</td>
<td>30 KV</td>
</tr>
<tr>
<td>Maximum Residual Voltage at nominal discharge current of 8/20 µs impulse wave (KV peak) or lightning impulse protection level (KV peak)</td>
<td>2.5 KV</td>
<td>30 KV</td>
<td>100 KV</td>
</tr>
<tr>
<td>Maximum residual voltage at steep current impulse 1/20 µs at 10KA (KV peak) or steep current protection level</td>
<td>3.5 KV</td>
<td>35 KV</td>
<td>110 KV</td>
</tr>
<tr>
<td>B.I.L. of T/F also called lightning impulse 1/50 µs wave (KV peak)</td>
<td>10 KV</td>
<td>75 KV</td>
<td>170 KV</td>
</tr>
<tr>
<td>Protection Level</td>
<td>10 KV</td>
<td>75 KV</td>
<td>170 KV</td>
</tr>
<tr>
<td></td>
<td>2.5 KV</td>
<td>30 KV</td>
<td>100 KV</td>
</tr>
<tr>
<td></td>
<td>4.00</td>
<td>2.5</td>
<td>1.7</td>
</tr>
</tbody>
</table>
SECTION – 9
EXCITATION SYSTEM FOR SYNCHRONOUS GENERATOR

1.0 General

There are two loads on the generator, the apparent load (KVAR) and the real load (KW). The KW load is derived from the input of the prime mover. The speed governor characteristic (speed Vs KW) called speed droop characteristic determine the KW load sharing between generators.

KVAR load is derived from the generator, the excitation control characteristic (Voltage Vs KVAR or P.F.) determine the KVAR sharing between generators.

It is to be noted that change of excitation of an alternator operating in parallel with other machines has no effect upon the real load (KW) delivered by that machine. It merely affects the P.F. of the machine or the load in KVAR delivered by it. This is unlike D.C. generators operating in parallel, where change in excitation is accompanied by variation in KW load delivered by that machine.

An alternator is said to be over excited or under excited according as its field current is more or less than that required for delivering the load at unit P.F. An over excited machine will deliver reactive power (lagging) while under excited machine will deliver leading P.F. reactive power.

The behavior of an alternator connected to constant voltage bus bar is quite different from its behavior when it is operating independently (solo). In the former case the change in excitation has no effect on bus voltage. It merely effects the reactive load and P.F. of the machine. In the latter case, the change of excitation is accompanied by a change in voltage.

1.01 Control of bus bar voltage

When a number of alternators are running in parallel, the bus bar voltage can be regulated by regulating the excitation of all the machines. Change of excitation of any one machine will merely affect the reactive load delivered by that machine.

1.02 Control of bus frequency -

The frequency of the bus can be regulated by regulating the power input to all the machines. Increase of power input to any one machine will merely cause it to take more load at the expense of other machines, with possibility of damage to itself.

2.0 Capability of excitation system

The excitation system should have features which will enable the alternator to operate.

(a) In isolation (solo)
(b) Parallel with other alternators
(c) Parallel with the grid
3.0 **Main features of excitation system**

- It should have manual and auto channel.
- It should have field flashing unit to provide excitation power to build up voltage during starting of the machine. Field flash gets disconnected after a set time delay (0-6 seconds). Field flash takes the voltage up to about 70% of Vnominal. AVR takes over at about 45% of Vnominal. The overlap provided thus, ensures positive and smooth build up of voltage.
- **VAR / PF Control** – This control provides generator PF or VAR Constant (depending on the mode selected) against variation in grid voltage and KW variation, Thus reactive power from the generator is fixed. **The PF at when generator functions is fixed.** The generator output voltage through PT and generator out-put current through CT is connected to VAR/PF control module.
- **Maximum – Minimum excitation limiter:**
  When there is large voltage fluctuation in grid voltage coupled with failure of VAR/PF controller or saturation of VAR/PF controller, the Maximum- Minimum excitation limiter comes into picture to decrease or increase the excitation as desired.

  This limiter provides two functions

  As maximum excitation limiter, it senses the field current output of the voltage regulator and limits any further increase in excitation current (field current) to prevent over heating of the rotor field.

  As minimum excitation limiter, it senses the leading Volt – Ampere – reactive output of the generator and limits any further decrease in excitation to prevent loss of synchronism and iron heating during parallel operation.

  Over excitation limiter provides a limit on field current at a pre-selected high level (allowing for motor starting, 3 phase short circuit) for a fixed period. After a set period of time (0-60 seconds) the limit will drop to a low value to prevent & rotor field over heating.

- **Droop or (quadrature droop) CTS** – It is the most commonly method of KVAR sharing between generators. It permits parallel operation of two generators.

  This is achieved by an additional CT in Y-phase. The CT provides a signal depending on PF. The droop circuit creates a generator voltage that falls with decreasing P.F. The device permits to share correctly the total reactive power depending on the droop characteristic of two generators.

- **Short Circuit Maintenance (SCM) CTS**

  The voltage of stator drops due to sudden over load (such as due to starting of motor or short circuit). SCM CT is inserted in circuit when stator voltage drops below 70% of rated voltage. The SCM CT provides an output current proportional to load current. This output current is rectified and then added to the current given by AVR.
The SCM System permits to maintain the three phase short circuit current over 2.5 times the rated current.

- **Follow up control (Auto Tracking unit)** –

  When the excitation system works in Auto mode, the manual mode is arranged to track the outputs of auto mode. The ATU after comparing the outputs of auto and manual mode, generates up & down commands for the variac motor of potentiometer of manual mode with a view to increase or decrease the excitation. The variac motor therefore rotates clock wise or anti-clock wise till the output of manual mode is made slightly slower in order not to track transients or faults. The null meter shows at any point of time the difference between the Auto & Manual modes.

  Thus ATU keeps the output of Manual mode always equal to that of Auto mode.

- **Change over from Auto to Manual mode**

  In case of following faults, the operation of the excitation system is changed from Auto to Manual mode.
  - Over voltage
  - Under voltage
  - Over excitation
  - Under excitation
  - Diode failure
  - PT fuse failure

- **Rotor current limiter**

  The rotor current limiter restricts the rotor current to be within stipulated value.

- **Protection Module**

  Protection module contains
  - Over voltage
  - Under voltage
  - Over excitation
  - Under excitation
  - Diode failure
  - PT fuse failure

- **Metering** – Following instruments should be provided on excitation panel to meter.
  - Generator voltage
  - Excitation voltage
  - Excitation current
  - Power factor
  - Null balance
• **Single / parallel mode selection**

• **Local / Remote – voltage Raise / lower control for Auto & Manual**

In Auto/Manual Mode, the voltage of generator can be controlled from 85% to 110% of Vnominal using the motorized Pot (MOP) by operating push buttons.

• An interlock is to be provided through variac limit switch to ensure that manual mode will not switch ‘on’ when motorized variac is not in minimum position initially.

4.0 **Main components of excitation system**

- AVR (Auto Mode)
- Manual Mode
- DC field flashing system
- Single / parallel mode selection
- Local / Remote voltage Raise/Lower control for auto & manual
- Auto over fluxing control
- Droop CT for parallel operation
- Rotor current limiter
- Follow up control (auto track unit) to match auto and manual output.
- Change over from auto to manual (Bumpless)
- Change over from manual to auto through null balance
- Auto VAR/P.F. controller
- Minimum – maximum excited MVAR limiter
- Pot with dial and counter for VAR/P.F. setting

• **Protection**

  Under excitation
  Over excitation
  Over voltage
  Rotating diode failure
  PT fuse failure of sensing transformer

• **Short circuit maintenance CT and control circuit**

• **Analogue metering**

  Generator voltage
  Power factor
  Excitation voltage
  Excitation current
  Null balance

  • Micro controller based annunciator
  • Panel lamp and space heater
  • IP-54 Protection class enclosure
  • 240 V, 1 Φ, excitation T/F.
  • 3 phase VT 100 VA
5.0 Type of excitation system

The two types of excitation systems are widely used.

- Brushless excitation system – for alternator capacity up to 4000 KW.
- Static excitation system – For capacity above 4000 KW.

5.01 Brushless excitation system

It dispenses with slip rings and brushes. A small AC alternator (called exciter) is mounted on rotor shaft to generate the AC excitation current. The stator of AC alternator (exciter) has single phase winding which is fed by DC current proportional to main generator output after rectification through AVR. The rotor of AC alternator (exciter) has three phase winding. The output of rotor of AC alternator is rectified by rotating rectifier and is fed to the rotor of main generator.

Block diagram of brushless excitation system is shown in Fig. 1.

5.02 Static excitation system

The excitation power is taken from the generator output or from the station auxiliary supply. This is rectified through a stationary thyristor bridge. The AVR senses the deviation in generator terminal voltage and signals advancing or retarding of firing pulses of the thyristor and in turn of the excitation current of the generator. The rectified excitation current is applied to the generator rotor field through the normal slip ring.

Block diagram of static excitation system is shown in Fig. 2.
FIG. 1: BLOCK DIAGRAM OF BRUSHLESS EXCITATION SYSTEM
SECTION – 10

SELECTION OF HYDRO POWER GENERATION EQUIPMENT
(IN A GLANCE)

1.0 The hydro power generation equipment requirement in short have been given in Table-1 for the following capacity of hydro unit, for the guidance in a glance.

- Hydro turbine generator set up to 10 kW
- Hydro turbine generator set above 10 kW and up to 50 kW
- Hydro turbine generator set above 50 kW and up to 100 kW
- Hydro turbine generator set above 100 kW and up to 500 kW
- Hydro turbine generator set above 500 kW and up to 1000 kW
- Hydro turbine generator set above 1000 kW and up to 5000 kW

2.0 Single Line Diagram–

The single line diagram mentioning rating of equipments of following capacity of micro and mini hydro schemes are enclosed as Annexure 1, 2, 3 and 4.
1. Single line diagram of 2×25 KW hydro scheme with one transformer for each unit – Annexure-1.
2. Single line diagram of 2×100 KW hydro scheme with one transformer for each unit.
3. Single line diagram of 2×50 KW hydro scheme with one transformer for two units.
4. Single line diagram of 2×500 KW hydro scheme with one transformer.

Basis of single line diagram

- Fault level of 11 KV system has been taken as 16 KA.
- The rating of cables have been decided considering rated current and fault level.
- The station and auxiliaries supplies have been taken through 415V/ 415V isolating transformer to avoid station bus fault reflecting directly on generator and thus ensuring safety of generator from electrical and mechanical stresses.
- In remote hill areas there are no roads for transporting equipments to power house site, one transformer for each unit has therefore been provided. It will also ensure availability of supply in case one transformer goes out of order or in break down.
- Provision of manual and auto synchronization with the grid and one machine with other machine have been considered for units of capacity 25 KW and above. The governor and AVR therefore should have provision for speed and voltage droop characteristics respectively.
### Table 1 – Selection of hydro Power Generation Equipment in a glance

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Equipment</th>
<th>Description</th>
<th>Installed Capacity in kW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upto 10 kW</td>
</tr>
<tr>
<td>1.</td>
<td>Turbine</td>
<td>• Types</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cross flow</td>
<td>Cross flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pelton</td>
<td>Pelton</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Turgo impulse</td>
<td>Turgo impulse</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Axial flow</td>
<td>Axial flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Francis</td>
<td>Francis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pump as turbine</td>
<td>Pump as turbine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Any other suitable turbine</td>
<td>Any other suitable turbine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Any other suitable turbine</td>
<td>Any other suitable turbine</td>
</tr>
<tr>
<td>2.</td>
<td>Generator</td>
<td>• Type</td>
<td>Synchronous/ Induction single phase / 3 phase</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Voltage</td>
<td>240 V/415V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Runaway speed</td>
<td>Suitable to withstand 30 minute runaway speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Insulation stator /rotor</td>
<td>Class F/H</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Temperature rise</td>
<td>Class B temperature rise (80°C above maximum ambient temperature 40°C and altitude (1000 m))</td>
</tr>
<tr>
<td>3.</td>
<td>Overall efficiency of T-G set</td>
<td>• Minimum required weighted average efficiency</td>
<td>45%</td>
</tr>
<tr>
<td>4.</td>
<td>Governor</td>
<td>• Controller/governo r Microprocessor based</td>
<td>Electronic load controller or Induction generator controller</td>
</tr>
<tr>
<td>S. No.</td>
<td>Equipment</td>
<td>Description</td>
<td>Installed Capacity in kW</td>
</tr>
<tr>
<td>-------</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Upto 10 kW</td>
<td>Above 10 kW and upto 50 kW</td>
</tr>
<tr>
<td>5.</td>
<td>Excitation system</td>
<td>Ballast load of ELC</td>
<td>Air heater</td>
</tr>
<tr>
<td>6.</td>
<td>Switchgear</td>
<td>MCB</td>
<td>MCCB with shunt trip or Air Break power contactor with thermal over load relays</td>
</tr>
<tr>
<td>7.</td>
<td>Synchronization panel</td>
<td>Manual &amp; Auto</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Protection</td>
<td>Generator</td>
<td>Over current protection inbuilt in MCB/MCCB</td>
</tr>
<tr>
<td>S. No.</td>
<td>Equipment</td>
<td>Description</td>
<td>Installed Capacity in kW</td>
</tr>
<tr>
<td>-------</td>
<td>-----------</td>
<td>-------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td></td>
<td>Monitoring</td>
<td>Voltage, Current, frequency, kWh, kW, kVAR, PF</td>
<td>Voltage, current, frequency, kWh, kW, kVAR, PF</td>
</tr>
<tr>
<td></td>
<td>• Voltage, current, frequency, kWh, kW</td>
<td>• Voltage, current, frequency, kWh, kW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Stator Temp.</td>
<td>• Stator Temp.</td>
<td>• Stator Temp.</td>
</tr>
<tr>
<td></td>
<td>• Bearing temp.</td>
<td>• Bearing temp.</td>
<td>• Bearing temp.</td>
</tr>
<tr>
<td></td>
<td>• Oil level in bearing sump.</td>
<td>• Oil level in bearing sump.</td>
<td>• Oil level in bearing sump.</td>
</tr>
<tr>
<td></td>
<td>Turbine</td>
<td>• Turbine speed</td>
<td>• Turbine speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bearing Temp.</td>
<td>• Bearing Temp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Oil pressure in OPU</td>
<td>• Oil pressure in OPU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cooling water pressure</td>
<td>• Cooling water pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Oil level in OPU</td>
<td>• Oil level in OPU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Penstock pressure</td>
<td>• Penstock pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Vibration of shaft</td>
<td>• Vibration of shaft</td>
</tr>
<tr>
<td>8.</td>
<td>D.C.Battery</td>
<td>• Lead Acid</td>
<td>24V 50 AH open type single cell construction, high discharge type, complete with sall wood stand with float and boost charger and D.C. distribution board.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Nickel-cadmium (Ni-cd batteries are preferred on account of long life and zero-maintenance)</td>
<td>24 V 100 AH open type single cell construction, high discharge type, complete with sall wood stand with float and boost charger and D.C. distribution board.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24 V 200 AH open type single cell construction, high discharge type, complete with sall wood stand with float and boost charger and D.C. distribution board.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24V- 200 AH open type single cell construction, high discharge type, complete with sall wood stand with float and boost charger and D.C. distribution board.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>48V- 200 AH open type single cell construction, high discharge type, complete with sall wood stand with float and boost charger and D.C. distribution board.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>110 V 300 AH open type single cell construction, high discharge type, complete with sall wood stand with float and boost charger and D.C. distribution board.</td>
</tr>
<tr>
<td></td>
<td>9. Cable</td>
<td>• PVC</td>
<td>16 sqmm for 10 kw 1100 volt Aluminium conductor PVC/XLPE insulated armoured FRLS Cable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• XLPE (XLPE Cable is preferred)</td>
<td>35 sqmm for 25 kw 1100 volt Aluminium conductor PVC/XLPE insulated armoured FRLS Cable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Generator- power cable single core</td>
<td>400 sqmm for 100 kW 1100 volt Aluminium conductor PVC/XLPE insulated armoured FRLS Cable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>For 500 kW 3 Run of 1100 V 400 sqmm copper cable per phase. PVC/XLPE insulated armoured FRLS Cable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>For 1000 kW 3.3 kV 300 sqmm al. conductor PVC/XLPE insulated armoured FRLS Cable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>For 2500 kW 2 Run of 3.3 kV 400 sqmm copper cable per phase PVC/XLPE insulated armoured FRLS Cable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Control cable multicore 1100V, copper conductor, PVC insulated FRLS</td>
<td>2.5 sq mm for panel wiring</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 sq mm for CT/PTS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.5 sq mm for panel wiring</td>
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<td></td>
<td></td>
<td></td>
<td>4 sq mm for CT/PTS</td>
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<td>2.5 sq mm for panel wiring</td>
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<td>4 sq mm for CT/PTS</td>
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<td></td>
<td>2.5 sq mm for panel wiring</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 sq mm for CT/PTS</td>
</tr>
</tbody>
</table>
NOTE:
(i). Ampere-meter should never be used with full load current flowing through it instead use always current transformer and standard 5A amp. Meters.
(ii). The operators of remotely placed hydel schemes are mostly not very experienced, strict use of automatic synchronizing is certainly the best solution.
(iii). Speed monitoring system – It should be provided with at least two independent sub systems for emergency over speed tripping.
First stage – Electro mechanical sensor with speed indicator and over speed relay.
Second stage – Mechanical over speed switch
(iv). Emergency – Solenoids – An emergency solenoid is to be provided for automatic emergency shutdown of turbine and or inlet valve.
(v). Micro hydro power station of capacity above 10 kW should have following provisions
    • Parallel operation in local grids/ main grid when ever available.
    • Parallel operation between units at the station
    • Governor / load controller should have adequate provision for adjusting the kW speed droop for facilitating the parallel operation of the unit.
    • AVR should have adequate provision for adjusting the KVAR voltage droop for facilitating the parallel operation of the unit.
(vi). The cables are generally laid on racks in trenches covered with chequered plates / concrete slabs which amounts to a duct. The cable rating should be adopted applicable to ducts. The cable ratings should be multiplied by the rating factors for variation in temperature of air and ground and group rating factors for cable. The total rating factors may be taken as 0.60.
(vii). Weighted average efficiency of turbine generator set is given by the following equation.
\[ \eta_{Tav} = K_1 T_{n100} \times T_{G100} + K_2 T_{n50} \times T_{G50} \]
Where in
- \( K_1 \) = A factor based on percentage of period in a year 100% rated discharge is available.
- \( K_2 \) = A factor based on percentage of period in a year 50% rated discharge is available
- \( T_{n100}, T_{G100} \) = Efficiency of turbine and generator unit respectively at 100% rated output at rated head.
- \( T_{n50}, T_{G50} \) = Efficiency of turbine and generator unit respectively at 50% rated output at rated head.
For small hydro unit \( K_1 = .5 \) and \( K_2 = .5 \) may be adopted.

Efficiency of gear box (if provided)

The efficiency of the turbine will be multiplied by the average efficiency of gear box to obtain over all weighted average efficiency.
SECTION – 11

(TYPICAL CALCULATION FOR FAULT LEVELS)

1.0 Typical calculation for 3 phase short circuit fault level
Calculation the three phase short circuit fault level at 415 V and 11 kV bus in the following single line diagram. The system fault level at 11 kV is 500 MVA.

\[ X_1 = 6.25\% \]
\[ X_2 = 6.25\% \]
\[ X_0 = 6.25\% \]

500kVA, 415V GENERATOR AT 0.8PF

Sub transient positive sequence reactance of generator \( x_1'' = 15.7\% \)

Calculations:

Let base KVA = 500 KVA

T/F impedance at 500 KVA base \( x_1 = x_2 = x_0 = \frac{6.25 \times 500}{1500} = 2.08\% \)

Fault impedance at 500 KVA base \( = \frac{1 \times 500 \times 100}{500 \times 1000} = .1\% \)

- Fault level at 415 V bus at (A)

Positive sequence net work:
Fault level at 415 V bus = \frac{\text{Base KVA}}{\text{Per unit reactance}}

= \frac{500 \text{ KVA}}{0.017}
= 290411 \text{ KVA}

Fault current at 415 V bus = \frac{\text{fault KVA}}{\sqrt{3} \times V}

= \frac{29411 \times 1000}{\sqrt{3} \times 415V}
= 40.96 \text{ KA}

- Fault level at 11 KV bus

Positive sequence Network

Fault level at 11 KV bus = \frac{\text{Base MVA}}{\text{per unit reactance}}

= \frac{500 \text{ KVA}}{0.00099}
= 505035 \text{ KVA}

Fault current at 11 KV bus = \frac{\text{Fault KVA}}{\sqrt{3} \times \text{Voltage}}

= \frac{505035}{\sqrt{3} \times 11}
= 26.538 \text{ KA}
2.0 Typical calculation for earth fault current on single phase to earth fault

Calculate the earth fault current on single phase to earth fault in the above system of 1.0 at 415V and 11 KV bus. Single phase to earth fault level fed by 11 KV system is 500 MVA.

Calculations:

- Earth fault/ current at 415 V bus

\[
\text{Line to earth fault KVA supplied at 415 V bus} = \frac{3 \times \text{Base MVA}}{X_1 + X_2 + X_0}
\]
Earth fault current at 11 KV bus

\[
\text{Earth fault current} = \frac{3 \times 500 \text{ KVA}}{0.0189 + 0.00896 + 0.0152} = 34835.11 \text{ KVA}
\]

\[
\text{Earth fault current} = \frac{34835.11}{\sqrt{3} \times 0.415} = 48.520 \text{ KA}
\]
Note: Since transformer is $\Delta$ only zero sequence reactance of transformer and fault MVA at 11 KV will come into picture.

\[
\text{Phase to ground fault MVA} = \frac{3 \times \text{Base MVA}}{X_1 + X_2 + X_0} = \frac{3 \times 500 \text{ KVA}}{.0009 + 0.00973 + .000954} = 530597.80 \text{ KVA}
\]

\[
\text{Phase to ground fault current} = \frac{530597.80 \text{ KVA}}{\sqrt{3} \times 11 \text{ KV}} = 27.882 \text{ KA}
\]

3.0 Typical calculation for determine size of cables

Calculate the size of 415 V and 11 KV XLPE single core cables in the above system of Example 1.0. The cables are to be laid in cable trench covered with chequered plates. Maximum ambient temperature 50°C.

- **Calculation**
  
  (a) Cable size connecting generator terminal and 415V bus.

  - Rated current of generator = \( \frac{500 \text{ KVA}}{\sqrt{3} \times 415} = 696.42 \text{ A} \)
  
  - 3 Phase short circuit current the cable has to carry = 40.96 \text{ A}
  
  - Line to earth fault current the cable has to carry = 48.520 \text{ KA}
  
  - The cable has to carry 696.42 A and line to earth fault 48.520 KA for one second.
  
  - Rating factor of XLPE cable at 50°C = .76.
  
  - Assume that there are two circuits of three single core cables in trefoil touching formation and there are two racks in the trench.
  
  Rating factors for the above conditions = .78
  
  - Rating of 630 sq.mm 1100 V copper conductor single core XLPE insulated cable in duct = 610 \text{ A} with short circuit rating of 59 \text{ KA} for one second.
  
  - Effective rating to above cable considering rating factor = \( 610 \times .76 \times .78 = 361 \text{ A} \)

  - No of cable runs = \( \frac{696.42}{361} = 1.924 \) (Say 2)

**Specification of cable to be selected:**

2 run \( \times 630 \text{ sqmm} \) 1100 V copper conductor single core XLPE insulated armoured cable.

(b) Cable connecting 11KV side of transformer to 11 KV breaker

- Rated current of T/F on 11 KV side = \( \frac{1500 \text{ KVA}}{\sqrt{3} \times 11} \)
• The cable has to carry 78.82 A and phase to earth fault current of 27.88 KA.
• The size of cable selected is 300 sqmm 11 KV Aluminium conductor multicore XLPE insulated armoured cable.
• The continuous rating of above cable in duct = 330 A
• The effective rating of cable after applying rating factor of ambient temperature and group-laying. Assume that are two cables per rack and cables are touching

\[ = 330 \times 0.76 \times 0.79 \]

= 198.13 A

• The short circuit withstand capacity of 300 sq mm cable for one second = 28.2 KA

**Specification of 11 KV cable**

300 sqmm 11 KV Aluminium conductor 3 core XLPE insulated armoured cable.

**4.0 Typical calculation for determining size of 11 KV circuit breaker**

**Basic Data:**

• Continuous current the breaker has to carry = 78.82 A
• The maximum fault current for one second the breaker will break = 27.88 KA.

**Calculation**

From the table 1 of circuit breaker – chapter, the rating of breaker should be as below to meet above requirement.

• Rated normal current = 1250 A.
• Short circuit breaking current = 40 KA
• Type of breaker – vacuum circuit breaker
• Rated voltage of breaker = 12 KV.