

SECTION – III

STEP UP SUBSTATION

Step up substation equipment at hydro generating station require special considerations which are discussed alongwith references.

It is essential that equipment actually used and the practice followed should conform to the latest Indian/IEC standards, codes of practice and guides. List of relevant standards and codes are given as Appendix -1. Specific references are given in each chapter.

CHAPTER-6

GENERATOR TRANSFORMER AND INSULATION CO-ORDINATION

6.1 General

Power transformers function is to convert electric power from one voltage level to another. In hydroelectric plants, step up transformer perform the task of delivering power produced by the generators to the transmission system. Most of these transformers are unit connected i.e. directly connected to generators with or without a generator breaker. These power transformers are generator transformers. Power transformers are liquid immersed. Power transformers are located outside preferably in the switchyard /or transformer deck in powerhouse. These guidelines are for generators/power transformers used in Hydro-stations i.e. 12 kV to 440 kV. Basic Insulation level of generator transformer is the starting point of insulation co-ordination of other switchyard equipment and is outlined.

6.1.1 Relevant national standards in this connection are as follows:

IS: 2026	-	Specifications for power transformer
IS: 3639	-	Fittings and accessories for power transformer
CBI & P	-	Manual on transformer (oil immersed)
IS: 1180	-	Outdoor Type three phase distribution transformer up to and including 100 kVA , 11 kV
IS: 3347	-	Porcelain Bushings
IS: 3716	-	Application guide for insulation co-ordination

6.2 Generator Transformers

Power transformer which step up the power produced by hydroelectric generating units (generally 0.415 to 11 kV) to a level which matches the sub transmission/transmission system voltage (typically 12 kV to 420 kV class) for range of power houses under considerations are 2 winding oil immersed transformers.

Transformers for micro hydro are normally 12 kV class, Small hydropower up to 3 to 5 MW are generally 36 kV class. Generator transformer for large and mega units may be up to 420 kV class. From 145 kV class and upwards transformers are available with two or more values of basic insulation. Choice of lower value of insulation supposes that the equipment is adequately protected against surges. Transformers in extra voltage range 420 kV and above for mega plants require very special selection criteria as rated insulation levels have to withstand switching impulses in addition to lightning impulses.

Three Phase Versus Single Phase Transformer

Three phase generator transformers are used unless transport limitations or other special reasons require use of single-phase transformer because of the following reasons.

- a) Higher efficiency than three single-phase units of equivalent capacity.
- b) Smaller space requirements and reduction in weight and dimensions.
- c) Lower installed cost.
- d) Lower probability of failure when properly protected by surge arrestors, thermal devices and oil cooling and preservation system.

6.3 Transformer Rating

The full load kVA rating of the generator transformer is kept at least equal to the maximum kVA rating of the generator or generators with which they are associated where transformers with auxiliary cooling facilities have dual kVA ratings. The maximum transformer rating should match the maximum generator rating.

6.4 Cooling

Transformer cooling system for generator transformers specified in accordance with IS: 2026 (part II) are identified according to the cooling method employed. Common letter symbols for use in this connection are as follows:

- | | | |
|------|---|--------|
| (i) | Cooling Medium | Symbol |
| a. | Mineral oil or equivalent flammable synthetic insulating liquid | O |
| b. | Water | W |
| c. | Air | A |
| (ii) | Kind of Circulation | |
| a. | Natural | N |
| b. | Forces (oil not directed) | F |
| c. | Forced (directed oil) | D |

Transformer is identified by four symbols for each cooling method for which a rating is assigned by the manufacturer.

1 st Letter	2 nd Letter	3 rd Letter	4 th Letter
Kind of cooling medium indicating the cooling that is in contact with the windings	Kind of circulation	Kind of cooling medium indicating the cooling medium that is in contact with the external cooling systems	Kind of circulation

Following cooling systems are used in hydro electric stations.

Symbol	
ONAN	Oil Immersed Natural Air Cooled
ONAF	Oil Immersed Forced Air Cooled
OFAF	Oil Immersed with forced oil circulation Forced Air Cooled
ODAF	Oil Immersed with Forced Directed oil circulation and forced Air Circulation
OFWF	Oil immersed with forced oil circulation cooled by water circulation

Transformers when located in power house should be sited so that unrestricted ambient air circulation is allowed. The maximum transformer rating with forced cooling in dual rating transformers are commonly employed. The rating of these dual rated transformers is usually as follows:

ONAN/OFAF OR ONAN/ODAF

ONAN	-	60%
OFAF	-	100%
ODAF	-	100%

OFWF transformers do not have self cool rating. Standby cooling capacity should be provided for different type of forced cooling as follows as per Central Board of Irrigation and Power Manual on Transformer.

(a)	ONAN/OFAF or ODAF	2 – 50% group 2 – 100% pump of which one will be standby, 2 – Standby fans one in each 50% group Or 3 – 50% group with independent pump and fans out of which one group to act as standby.
(b)	OFWF or ODWF	2 – 100% heat exchangers out of which one is standby.

6.5 Temperature Rise, Overload Capacity and Continuous Rating

Conservative value of temperature rise, overload capacity and continuous rating of transformer located in the switchyard is specified.

6.6 Electrical Characteristics

6.6.1 Type of Transformer and Operating Conditions

All transformers are oil immersed and may be either core or shell type and should be suitable for outdoor installation. Normally oil immersed transformer are provided with conservator vessels. Where sealed transformers are specified, there will be no conservator but adequate space is provided for expansion of oil without developing undue pressure.

Transformers designed for mixed cooling is capable of operating under the natural cooled condition up to the specified load. The forced cooling equipment comes into operation by pre-set contacts in Winding Temperature Indicator (WTI) and the transformer will operate as forced cooled unit.

Transformer are capable of remaining in operation at full load for 10 minutes after failure of blowers without the calculated winding hot-spot temperature exceeding 150⁰C. Transformer fitted with two coolers each capable of dissipating 50% of the losses at continuous maximum rating (CMR) is capable of remaining in operation for 20 minutes in the event of failure of the blower associated with one cooler without the calculated winding hot-spot temperature exceeding 150⁰C.

6.6.2 Continuous Maximum Rating and Overloads

Transformers provided with mixed cooling comply, as regards its rating temperature rise and overloads, with the appropriate requirements of IS: 2026 when operating with natural cooling and with mixed cooling.

All transformers, except where stated are capable of operation continuously, in accordance with IS: loading guide at their CMR and at any ratio. In case bi-directional flow of power is required, that is specifically stated by the purchaser.

Temperature rise test is performed at the tapping as desired by the purchaser. If nothing has been stated by the purchaser, the test is carried out at the tapping with the highest load losses.

The transformer may be operated without danger at any particular tapping at the rated kVA provided that the voltage does not vary by more than + 10% of the voltage corresponding to the tapping.

The transformer is suitable for continuous operation with a frequency variation of +3 % from normal 50 Hz. Combined voltage (V) and frequency variation (f) should not exceed the rated V/f ratio by 10%.

6.6.3 Voltage Ratio

The high voltage rating is suitable for the voltage of the transmission system to which it is connected. The low voltage rating is suitable for the generator voltage (if unit connected) or generator bus. Generator transformers are generally provided with Off-circuit taps on HV side for HV variation from +2.5 to – 7.5 % in steps of 2.5 %. On load taps if provided should have tapping range of +5% to – 10 % in steps of 1.25%.

For interconnecting 2 transmission voltage system say 66 kV and 132 kV size, auto-transformers with standard ratings as per IS are provided. For interconnecting auto-transformers, use of either regulating transformer or on-load tap changer may be made. Interconnecting transformer are generally star-star connected with tertiary delta winding for flow of 3rd harmonic current.

6.6.4 Duty Under fault Condition

Generator transformer are designed for exceptional circumstances arising due to sudden disconnection of the load and is capable of operating at approximately 25 % above normal rated voltage for a period not

exceeding one minute and 40 % above normal rated voltage for a period of 5 seconds. All transformers above 50 MVA are provided with over fluxing protection device.

6.6.5 Electrical Connections

Transformers are connected in accordance with IS vector symbol specified in ordering schedule of the requirements. Vector symbol specified for generator transformers is normally YND11.

Star/star connected transformers have delta connected stabilizing windings. Two leads from one open corner of the delta connection are brought out to separate bushings. Links are provided for joining together the two terminals so as to complete the delta connection and earthing it externally to the tank.

6.6.6 Flux density

The maximum flux density in any part of the core and yokes, of each transformer in following over voltage conditions does not exceed 1.9 tesla/19000 lines per cm² (CBI & P Manual).

- i) The above flux density is specified to meet the over fluxing of the core due to temporary over voltage of the order of 31% for 1 min., 44% for 5 sec. That may appear in abnormal conditions such as those following sudden loss of large loads/ tripping of Generator breaker.
- ii) Yoke bolt area and a flitch plate area is not counted in the net core area, if these are provided for fastening of core.
- iii) The design of limb and yoke is so coordinated that there is no cross fluxing at the joints.

The flux density at normal voltage frequency and ratio should not exceed 1.5 tesla (CBI & P Manual).

6.6.7 Current Density

The transformer is so designed that the current density of HV windings at the lowest tap does not exceed 250 A/cm². And that of LV winding should not exceed 200 A/cm².

6.6.8 Short Circuit Strength

Transformers are designed and constructed to withstand without damage the thermal and dynamic effects on external short circuits for 5 seconds under condition specified in IS: 2026 (Part-I).

The transformers are provided with separate tapping coil to limit the short circuit forces.

The position of the tapping coil is so arranged that at extreme negative tap, the percentage regulation is less than at normal tap.

Test certificates of the short circuit test, if already done on the offered design and rating is obtained. However, the thermal and dynamic ability to withstand short-circuit forces is required to be demonstrated by calculations.

Manufacturers are required to supply calculation for Thermal & Dynamic withstand capacity of the transformer as per their design along with the tenders.

6.6.9 Frequency and System Voltage

The transformers are suitable for continuous operation with a frequency variation of 3% from normal 50 cycles per second without exceeding the specified temperature rise.

6.6.10 Parallel Operation

The transformers are made capable of parallel operation with each other and with existing grid.

6.6.11 Vibration and Noise

Every care is taken to ensure that the design and manufacture of all transformers and auxiliary plant is such as to have minimum noise and vibration levels following good modern manufacturing practices.

The manufacturers are required to ensure that the noise level shall not exceed the figures as per NEMA Pub. No. TR-1.

6.7 Basic Insulation Level and Insulation Co-ordination up to 220 kV System

Insulation coordination is the correlation of the insulation of electrical equipment and system with the characteristics of protective devices such that the insulation is protected from excessive over voltages. Thus in a substation the insulation of transformer, circuit breakers, bus supports, etc. should have insulation strength in excess of the voltage levels that can be provided by protective equipment such as lightning arrestors and gaps. According to International Electro Technical Commission Technical Committee No. 28 on Insulation Coordination the same is defined as follows by IEC:

“Insulation coordination comprises the selection of the electric strength of equipment and its application in relation to the voltages which can appear on the system for which the equipment is intended and taking into account the characteristics of available protective devices, so as to reduce to an economically and operationally acceptable level the probability that the resulting voltage stresses will cause damage to equipment insulation or affect the continuity of service”.

6.7.1 Over-voltages: The selection of basic insulation level for various components of switchyard equipment and its coordination is based on the extent of different types of over voltages and dielectric stresses on insulation of the equipment. Over voltages are classified as follows (IS: 3716).

- (i) Power frequency voltages under normal operating conditions
- (ii) Temporary Over voltages
- (iii) Switching over voltages
- (iv) Atmospheric or Lightning over voltages

The terms atmospheric over voltages and switching over voltages are defined by themselves. The term temporary over voltages means over voltages essentially of power frequency or a frequency close to it. Switching over voltages are of consequence only at levels above 220 kV and not applicable to system under consideration. The protection against over voltages is essentially made by Surge diverters (lighting arrestors). Lightning impulse wave is defined as time in microsecond for the wave to reach crest (1.2 micro second) followed by the time in microsecond for the wave to reach half magnitude (50 micro second). This has been standardized in the test forms to establish insulation level on a common basis.

6.7.2 Selection of basic Impulse Insulation Level (BIL) up to 220 kV System: Equipment insulation must withstand temporary over voltages and protected against lightning by suitable lightning arrestor. The basic impulse insulation level should be selected which can be protected with a suitable lightning protective device. The best protection is provided by modern type (gapless) lightning arrestors. The spread margin between the BIL and the protective device, allowing for manufacturing tolerance, is an economic consideration that must balance the chances of insulation failure against the cost of greater insulation strength. When using lightning arrestors the economic factor may be one of greater risk to the arrestor than to the equipment insulation. The arrestor can be applied so that it will protect the insulation but may under certain extreme conditions, usually unlikely, be subjected to sustained rms temporary over voltages against which it cannot recover. Practice has been to apply arrestors so that they have an rms voltage rating above the maximum possible rms line-to-neutral power frequency voltage under any normal or expected fault condition with sufficient margin. The BIL of the equipment insulation must therefore be higher than the maximum expected surge voltage across the selected arrestors selected to withstand highest credible temporary over voltage.

6.7.3 Station Design for Lightning and Standardisation of Insulation Levels: Station design for lightning involves in general, provisions of an adequate insulation level for all equipment and protective measures to

prevent, as far as possible lightning over voltages approaching that level from appearing on station lines or on equipment. These levels are given in table 6.1 & table 6.2 as per the Indian Standard IS: 2165. In this standard, table 6.1 covers the standard insulation levels for highest system voltages of 52 kV and below and Table 6.2 for highest system voltages of more than 52 kV and less than 300 kV commonly used in India.

Table 6.1: Standard Insulation Levels for (equipment in range $1 \text{ kV} < U_m < 52 \text{ kV}$) clause (4) for preferred value

Highest Voltage for Equipment U_m	Rated Lightning Impulse Withstand Voltage (Peak)		Rated Short Duration Power Frequency Withstand Voltage (rms)
	List 1	List2	
kV	kV	kV	kV
3.6	20	40	10
7.2	40	60	20
12	60	75	28
24	85	125	50
36	145	170	70

For SHP application (up to 36 kV) where temporary over voltages are high due to speed rise on load throw off equipment insulation as per list 2 of table 6.1 are used.

Table 6.2 Standard Phase-to-Phase Insulation Levels for $52 \text{ kV} \leq U_m < 245 \text{ kV}$ (IS: 2165)

Highest Voltage for Equipment U_m (rms)	Base for P.U. Values $U_m \sqrt{2/3}$ (peak)	Rated Lightning Impulse Withstand (peak)	Rated Short Duration Power-Frequency Withstand Voltage (rms)
kV	kV	kV	kV
72.5	59	325	140
123	100	450 550	185 230
145	118	(450)* 550 650	(230)* 230 275
245	200	650* 750* 850 950 1050	360* 360* 360 395 460

Generator transformer/step up transformer in SHP are liable to be subjected to high temporary over voltages due to load rejection, as well as line capacitance which may remain connected on interconnecting tie line in case of receiving end breaker opening. Basic insulation level on power frequency over voltages of 1.3 per unit for transformers is worked out in table 6.3 for a typical 145 kV transformer. In case of special circumstances if the power frequency voltage is higher than higher rated voltage surge diverter be used. This was done for Sobla Small hydro power house 6 MW interconnected with the grid at 33 kV. In case of generator transformer 90 – 95 % lightning arrestors are used.

An increase of impulse level of 15% above the withstand level to earth is used for disconnecting switches between the terminals of each pole in the open condition. A corresponding increase of distance may be applied for distances between phases for bus bars and connections, or between connections which may be located on opposite sides of an open disconnecting switch.

Table 6.3

1.	Basic Data		
	Highest voltage for equipment U_m	k V rms	145
	Corresponding line to (ground) neutral voltage $\left(\frac{U_m}{\sqrt{3}}\right)$	k V rms	83.72
	Corresponding Temporary over voltage (derived from system studies) This voltage is high in step up sub stations due to load rejection i.e. 1.3 per unit	k V rms	108.8
	Minimum safety factor For lightning overvoltages		1.25
2.	Representative Characteristics of Surge Diverter (obtain from manufacturer)		
	Rated Voltage (nearest available above 125 x 108.8)	kV _{rms}	140
	Maximum lightning impulse spark over voltage	kV	415
	Maximum front-of-wave impulse spark over voltage	kV	470
	Maximum residual impulse spark over voltage	kV	405
3	Protection Levels		
	To lightning impulse	kV	415
4	Insulation level (phase to earth)		
	Lightning Impulse		
	Minimum lightning impulse voltage	kV	415
	Rated lightning impulse voltage as per IS:	kV	550
	Ratio of the rated lightning impulse voltage to the lightning impulse protective level	kV	1.32

6.7.4 Existing Insulation Practice of Substation Equipments

The substation equipments namely the power transformers circuit breakers and disconnecting switches are considered for detailing the existing practice.

Existing Practice

The commonly adopted insulation levels at present for the above mentioned equipments are given in table 6.4 with reference to Karnataka and Tamil Nadu (66 kV, 110 kV and 220 kV) and Northern India (132 kV Bhakra System). Transformers are the starting point for insulation co-ordination and are as such directly protected by lightning arrester.

A commonly adopted practice is to locate lightning arrester as near to the transformer as possible. In large substations additional arresters could be required at suitable locations to protect circuit breakers, isolators and other equipments. Since each of these equipments cannot be provided with arrester individually, it is the normal practice to adopt higher insulation to provide the equipment with as good protection as is economically justified. Insulation level for circuit breaker and other equipments connected to the bus bar together with the bus bars themselves are designed for insulation class about 10% higher than the insulation level for the transformers (one class higher). Insulation level across the open poles of the isolating switches is kept about 10 to 15 % higher than that provided between the poles and the earth, so that in the event of a surge at an open isolating switch, the flashover should pass to earth and not across open poles.

Table 6.4: Insulation Levels of the terminal Equipments Recommended

S. No.	Description	Nominal voltage in kV					
		220	132	110	66	33	11
1.	Highest system voltage kV (rms)	245	145	123	72.5	35	12
2.	Power transformer insulation levels kV (Crest)	900	550	450	325	170	75
3.	Circuit breaker kV (Crest)	1050	650	550	350	170	75
4.	Disconnecting switches between pole and earth kV (Crest)	1050	650	550	380	170	75

6.7.5 Protection with Spark Gaps

The spark gap is among the cheapest protective devices used for diverting the surges from line to earth. After the break down of the spark gap the circuit breaker always operates to interrupt the fault of power frequency current in the circuit. Thus the operation of the gap generally results in the circuit outage and interruption of supply of the power system. It is therefore used as a back up to surge arrestor (lightning arrester).

Spark gaps specified for fitting to the bushings of power transformers, potential and current transformers, rated 72.5 kV and above.

The spark gaps are to conform to the following specification, to prevent any damage to the bushing due to the flashover gazing the petticoats of the bushing:

- The rods are to be circular not less than 12 mm diameter
- The rods should overhang their supports at-least one half of the gap spacing.
- The rods should be mounted so as to give a height of 1.3 times the gap spacing plus 100 mm (4 inches) above the ground plane as shown in Figure 6.1.

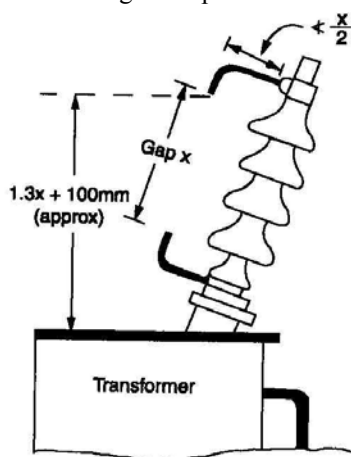


Figure 6.1

The gap setting furnished below is adopted for all stations whether lightning arresters are provided or not.

Table 6.5

Highest system voltage kV rms U_m	Critical Flashover voltage 1/50 micro second kV Peak $\frac{U_m}{\sqrt{3}} \times \sqrt{2}$	Spacing of Standard Rod Gap	
		Positive Polarity (mm)	Negative Polarity (mm)
72.5	59.1	7.7	6.5
123	100.4	12.4	10
145	118.3	15.4	13
245	200	28.0	23

Spacing for standard rod-gaps is given in table 6.5 (TNEB Practice).

Note: - The spacing given above is for the standard atmospheric conditions viz:

Barometric pressure	= 760 mm Hg.
Temperature	= 20°C
Humidity	= 11 grams of water vapour per cubic meter.

For non-standard atmospheric conditions the spacing to give the critical flash over voltage should be modified by dividing the above spacing by 'd' where:

$$d = 0.386 \times \frac{P}{(273 + t)}$$

P = barometric pressure in mm Hg.

and t = temperature in °C.

When the humidity differs the standard spacing should be increased by 1% for each gram per cubic meter below the standard value and decreased by 1 % each gram per cubic meter above the standard.

6.8 Impedance

Impedance of the transformers has a material effect on system stability, short circuit currents, and transmission line regulation, and it is usually desirable to keep the impedance at the lower limit of normal impedance design values.

Typical values of impedance voltage for transformers with two separate windings (at rated current, given as a % of the rated voltage of the winding to which the voltage is applied) as per IS 2026 part I – 1977 and for generator transformers (145 kV class and above) as per CBI & P Manuals on Transformers are given in table 6.7.

Table 6.7

Rated Power (kVA)	Impedance Voltage (%) as per IS 2026	Impedance Voltage (%) as per CBI & P manual
Up to 630	4.0	-
631 to 1250	5.0	-
1251 to 3150	6.25	-
3151 to 6300	7.15	-
6301 to 12500	8.35	-
12501 to 25000	10.0	-
25001 to 200000	12.5	12.5
250000	By agreement	14.0-14.5

Transformers with lower or higher values of impedance are normally furnished with increase in cost. The value of transformer impedance should be determined giving consideration to impacts on selection of interrupting capacities of station breakers and on the ability of the generators to aid in regulating transmission line voltage. Transformer impedances should be selected based on system and plant fault study. Impedances shown are subject to a tolerance of plus or minus 10% as per IS: 2026.

Transformer Efficiency: Transformer losses represent a considerable economic loss over the life of the power plant. A study be made to select minimum allowable efficiencies for purpose of bidding. Capitalization for transformer losses should be carried out in accordance with CBI & P manual on transformer. A typical study for capitalization of additional transformer loss with 10% impedance instead of 12.5% is enclosed as Annexure - 6.1.

6.9 Terminal Bushings

Generator transformer connections for large generator transformers are mostly by bus ducts which is isolated phase for Mega units and segregated phase bus ducts for medium/large units. For small hydro power stations power cables may be used. Accordingly terminal for the generator transformers should be as follows:

LV Side: LV bushings should be mounted on turrets suitable for connection to bus bar in bus ducts. For SHP cable boxes may be provided, if cables are used

HV Side: 72.5 kV to 420 kV bushings are oil impregnated paper (OIP) type condenser bushings in accordance with IS 2099 and IEC 137. Dimensions interchange capability current, insulation level and creepage distance for various classes of the bushings should be in accordance with CBI & P Manual on transformers Section P.

Solid Porcelain/Oil Communicating and other type bushings up to 36 kV voltage class in accordance with IS: 3347. The dimensional parameters of the bushings up to and including 36 kV voltage class should be in accordance with IS: 3347.

The rated current, voltage, Basic Insulation Levels should be in accordance with IS 2099.

6.10 Transformer Efficiency

Standard losses are given in CBI & P manual on the basis of optimized design of manufacturer. Table 6.8 gives these losses for 11 kV to 66 kV class transformers. Capitalization for transformer losses should be carried out in accordance with CBI & P manual on transformer Section L (example at Annexure-6.1).

Table 6.8: STANDARD LOSSES AT 75°C

Sl. No.	Three-phase power rating	No-load loss (kW)	Load loss (kW)
(a)	11 kV Transformers (kVA)		
	200	570 (W)	3300 (W)
	315	800 (W)	4600 (W)
	630	1200 (W)	7500 (W)
	1000	1800 (W)	11000 (W)
	1600	2400 (W)	15500 (W)
(a)	33 kV Transformers (MVA)		
	1.00	1.8	8
	1.60	2.1	14
	3.15	3.2	22
	4.00	4.0	24
	5.00	4.6	27
	6.30	5.4	33
	8.00	6.1	44
	10.00	7.2	53
(b)	66 kV Transformers (MVA)		
	6.3	6.0	40
	8.0	7.1	48
	10.0	8.4	57
	12.5	9.7	70
	20.0	13.0	102

6.11 Tanks

The main tank body excluding tap-changing compartments, radiators and coolers are capable of withstanding vacuum given in table 6.9 (CBI & P Manual).

Table 6.9

Highest system voltage kV	MVA rating	Vacuum pressure kN/m ² gauge	(mm of Hg)
Up to 72 kV	Up to 1.6	34.7	250
	Above 1.6 & up to 20 MVA	68.0	500
	Above 20 MVA	100.64	760
Above 72 kV	For all MVA ratings	100.64	760

6.12 Pressure Relief Device

The pressure relief device should be provided of sufficient sizes for rapid release of any pressure that may be generated within the tank, and which might result in damage to the equipment. The device should operate at a static pressure of less than the hydraulic test pressure for transformer tank. Means should be provided to prevent the ingress of rain water.

Unless otherwise approved the relief device should be mounted on the main tank, and, if on the cover, should be fitted with skirt projecting 25 mm inside the tank and of such a design to prevent gas accumulation.

6.13 Anti Earthquake Clamping Device

To prevent transformer movement during earthquake, a clamping device should be provided for fixing the transformer to the foundations. Necessary bolts should be embedded in the concrete. The arrangement should be such that the transformer can be fixed to or unfastened from these bolts as desired. The fixing of transformer to the foundation should be designed to withstand seismic events to the extent that a static coefficient of 0.3g (or as applicable) applied in the direction of least resistance to that of loading will not cause the transformer or clamping device as well as bolts to be over stressed.

6.14 Dielectric Tests

(a) 220/132 kV winding

- i) Lighting impulse on all the line terminals (routine test)
- ii) Induced over-voltage with partial discharge indication (routine test)

(b) 33 kV winding

- i) Separate source AC on the all line terminal (routine test)
- ii) Lightning impulse on all the line terminals (routine test)

6.15 Oil Conservator System and Accessories

Following Oil conservator systems are preferred for generator step-up transformer.

- (i) Inert gas pressure system. Positive nitrogen gas pressure is maintained in the space between the top of the oil and the tank cover from a cylinder through a pressure reducing valve.
- (ii) Air-cell, constant-pressure, reservoir tank system. A system of one or more oil reservoirs, each containing an air cell arranged to prevent direct contact between the oil and the air – see guide specification for details.

For other accessories e.g. Surge arrester, oil flow alarm, fans and pumps, on-line dissolved gas monitoring system, Temperature detectors, Lifting devices, on line monitoring system see guide specifications.

6.16 Oil Containment and Fire Protection System

If any oil filled transformers are used in the power plant, provisions should be made to contain any oil leakage or spillage resulting from a ruptured tank or a broken drain valve. Physical separation by the use of fire wall/barriers is also provided in power plants. Fire protection of power transformers may be provided as discussed 5.6.4 and in accordance with CBI & P Manual on Transformer in Section 'O'.

6.17 Transformers for Small Hydro

Standard rating for power transformer and recommended cooling of voltage class commonly used (up to 33 kV) are given in table 6.10 (A) & table 6.10 (B)

Table 6.10 (A) 11 kV Class Transformers

Three phase power rating kVA	Voltage ratio kV (Nominal)	Cooling
200	11/0.433	ONAN
315	11/0.433	ONAN
630	11/0.433	ONAN
1000	11/0.433	ONAN
1600	11/0.433	ONAN

Table 6.10 (B) 33 kV Class Transformers

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

6.18 Generator Transformers for Large Hydro up to 245 kV

A typical specification for 72.5 kV transformer with forced air cooling issued for 12 MVA transformer is at Annexure 6.2 as guide specification for large transformers up to 245 kV.

245 kV class transformers are made suitable for connection to systems having a short circuit level of 40 kA.

6.19 Equipment Insulation and Coordination of EHV System

Transmission at EHV at 420 kV and even above may be required for providing heavy transmission ties between bulk loads and remote hydro generating stations for interconnection with grids. During initial period of development of an extra high voltage system, over voltages are usually most critical because of reduced short circuit level and greater risk of opening remote/receiving end circuit breakers with load dropping and ferranti voltage rises. The insulation level chosen for a system has a considerable influence on costs and reliability of high voltage equipment.

Standard insulation level for equipment in this range C as per IS: 2165 associated with standard values of highest voltage used in India (420 kV and 765 kV) are given in table 6.11. The discussions are limited to 420 kV EHV system which is so far maximum for hydro power plant ties.

**Table 6.11
Standard Insulation Levels for $U_m > 300$ kV (IS: 2165)**

Highest voltage for equipment U_m (RMS) (kV)	Base for PU values $U_m \frac{\sqrt{2}}{\sqrt{3}}$ (Peak) (kV)	Rated switching impulse withstand voltage (Peak)		Ratio between rated lightning and switching impulse withstand voltage	Rated lightning impulse withstand voltage (Peak)
		p. u.	kV		
420	343	2.76	950	1.11	1050
			1.24	1175	
		3.06	1050	1.12	1175
				1.24	1300
765	625	2.08	1300	1.36	1425
				1.10	1425
				1.19	1550
				1.38	1800

		2.28	1425	1.09 1.26 1.47	1550 1800 2100
		2.48	1550	1.16 1.26 1.55	1800 1950 2400

Fixation of safe and economic insulation level for the EHV equipment in the initial stage of development of EHV system requires special consideration and is outlined with special reference to 1000 MW Dehar hydro power plant of Beas Project 420 kV EHV lines were provided for interconnection with grid. This power plant located on Beas Sutlej Link is characterized by its remote location with respect to load centres.

6.19.1 Over-Voltages in EHV Overhead Lines

Over voltages in the systems may be caused by the following:

a) External Causes

These are mainly due to atmospheric conditions:

- i) Direct lightning stroke.
- ii) Statically induced charges on the conductors due to the proximity of charged clouds.
- iii) Dynamically induced current due to a lightning discharge which strikes the ground near a line. Such a discharge is called a "Side" as distinct from a "direct" stroke.
- iv) Electrostatic charges imparted to a transmission line whose altitude above sea level varies considerably along the route.
- v) Electrostatic charges imparted to the line due to the friction of dust or fine snow blown past the conductors.

b) Internal Causes

Under this heading may be classed the various pressure rises due to switching operations, e.g. switching-in of a non-loaded line; sudden changes in the load; the circuit interruption due to circuit breaker opening under conditions of fault or severe overload; bus paralleling; arcing grounds, etc. It is also convenient to class under this heading resonance effects which may be set up by the inherent capacitance and inductance of lines and apparatus.

Accordingly in extra high voltage systems over voltages may be discussed as under:

- i) Atmospheric overvoltage
- ii) Temporary over voltages
- iii) Switching over voltages

- **Atmospheric Over-Voltage**

Lightning is not a very important source of over voltages for EHV and UHV systems.

It is only the lightning strokes hitting the line directly which constitute a risk for an EHV system. Further according to paper by Mr. N. Hylten Cavallius, Induced atmospheric over voltage, i.e. over voltages caused by a stroke close to the line, are of importance only for lines with a system voltage of say 100 kV or below. Strokes between clouds are of no importance.

Accordingly to another paper by D.M.C. Gill is of Hydro Qubec, for EHV system above 300 kV, the switching over voltage starts to become the determining factor for external insulation. Above 1000 kV crest, the external insulation begins to break down under switching rather than under a lightning surge of the same value. Therefore, for the consideration of external insulation level the atmospheric over voltages is of secondary importance.

- **Temporary Over voltages**

In initial stage of development of an EHV system long single lines are liable to interconnect distant load centres to isolated sources of generators. Sudden load throw-off at receiving end is liable to cause the generator or group of generators at the sending end to enter almost instantaneously under excited conditions and very high dynamic power frequency over voltages may occur at the two ends of the interconnected line and may be critical for fixing external insulation of EHV equipment. The over-voltages are of course due to sudden replacement at machine terminals of normal load by high capacity load demanding leading MVARs. When the EHV system develops into an interconnected network, power frequency over voltage tends to reduce.

Detailed studies are required to be carried out for this purpose, and remedial measures taken as considered necessary. The measures available to keep the dynamic over voltage within safe limit are the use of shunt reactors, use of protective devices and limiting operating conditions.

Information regarding temporary over voltage, choice of surge diverter rating and BIL adopted up to 420 kV system within Scandinavian countries is given in study' committee report appointed by CIGRE.

- **Switching Over Voltage**

The switching over voltage may be caused by de-energisation, energisation and re energisation of line, switching of faulted line, switching of unloaded transformers. Most severe transient over voltages are caused by closing or re-closing of a line particularly energisation of line with trapped charge under no load conditions. Dangerous switching surge also sometimes occur by the interruption of a line reactor. Switching operation creating overvoltages are shown in figure 6.2. In 420 kV system switching overvoltage factors fall approximately in the following ranges.

Closing of a line	2.0 to 2.9. p.u.
Re-closing of line	3.2 p.u.

The rise times of switching surges are generally between 1000 to 5000 microseconds. In initial development stage of an EHV system higher values are liable to occur as switching follows load rejection.

Switching over voltage may be controlled by having opening and closing resistors in circuit breakers. As the system develops and gets interconnected, over voltage arising from switching operation is usually the predominant stress in the insulation design of A.C. EHV system. Determination of these transients over voltage by analog and digital simulation methods has been detailed in a CIGRE paper. Figure 6.3 shows means that can be adopted to limit switching over voltages.

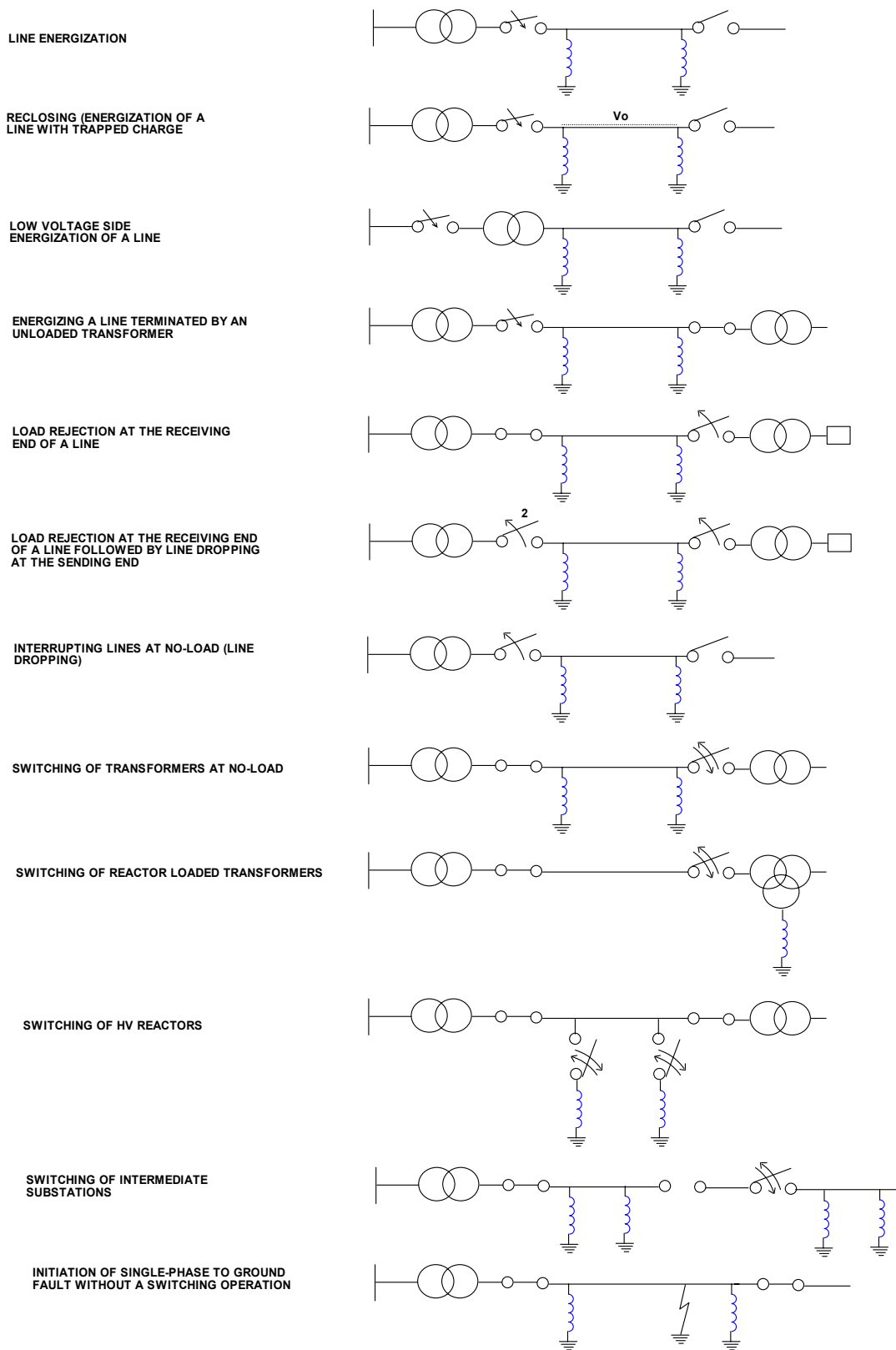


Figure 6.2: Switching Operations Creating/Over voltages
 (Source: Invitation Lecture Notes by N. Hylten Cavalius – Director EHVDUHV System Hydro Quebec- On his visit to Dehar Project)

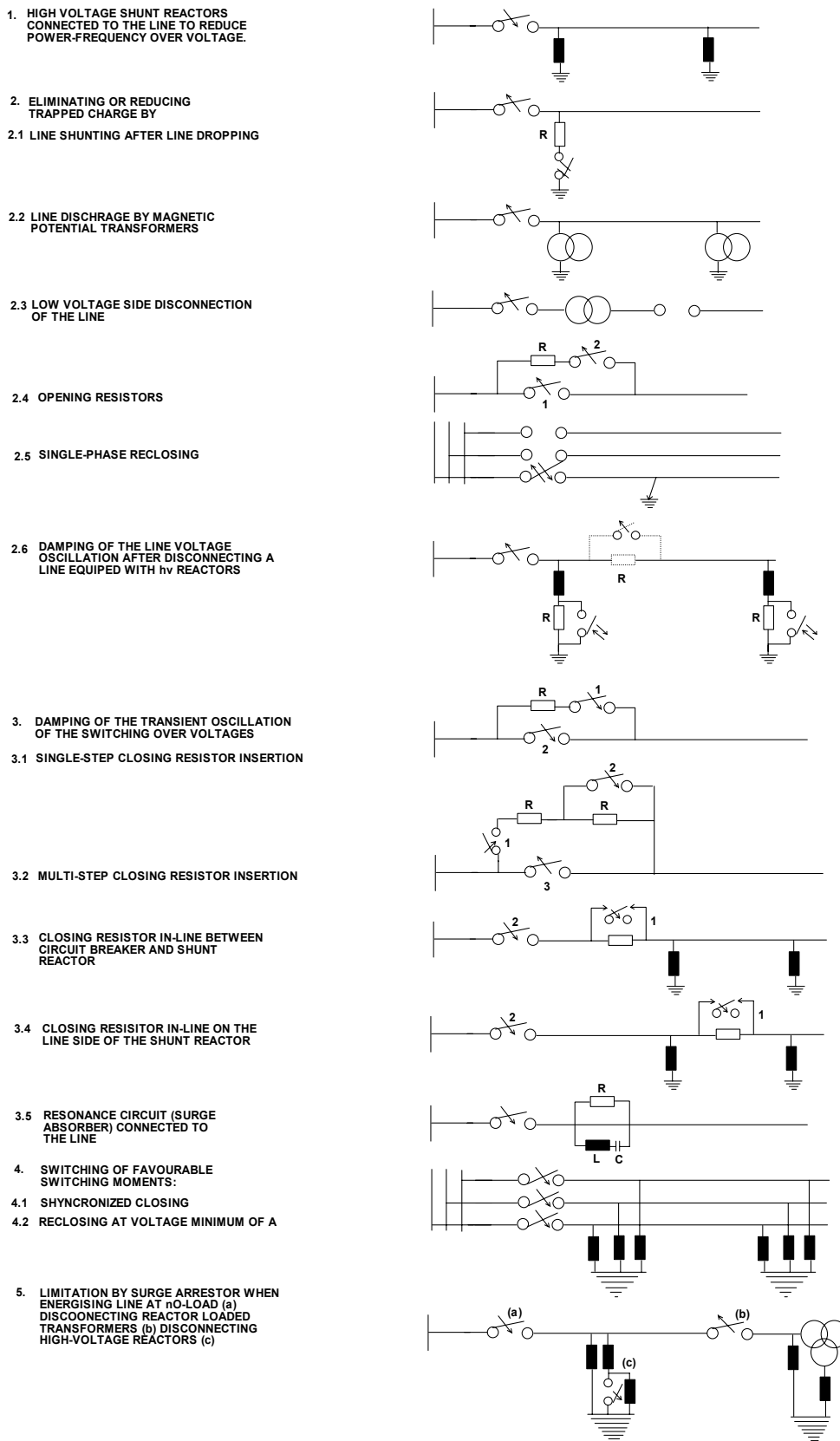


Figure 6.3: Means to Limit Switching Over voltages
 (Source: Invitation Lecture Notes by N. Hylten Cavalius – Director EHVDUHV System Hydro Quebec- On his visit to Dehar Project)

6.19.2 Dehar EHV System over Voltages

Description

Figure 6.4 shows a single line diagram for Dehar 420 kV EHV system. The power plant had four units of 165 MW each in the first stage. Two more units of similar capacity were proposed to be added in second stage. Two of the units supply a 245 kV system through 245 kV step up unit transformers. The other units supply 420 kV system through 420 kV step up unit transformers. A single circuit 420 kV line 280 km long to Panipat was proposed for interconnecting the power plant to the grid in the first stage. A second 420 kV line was proposed to be added a/long-with two second stage units.

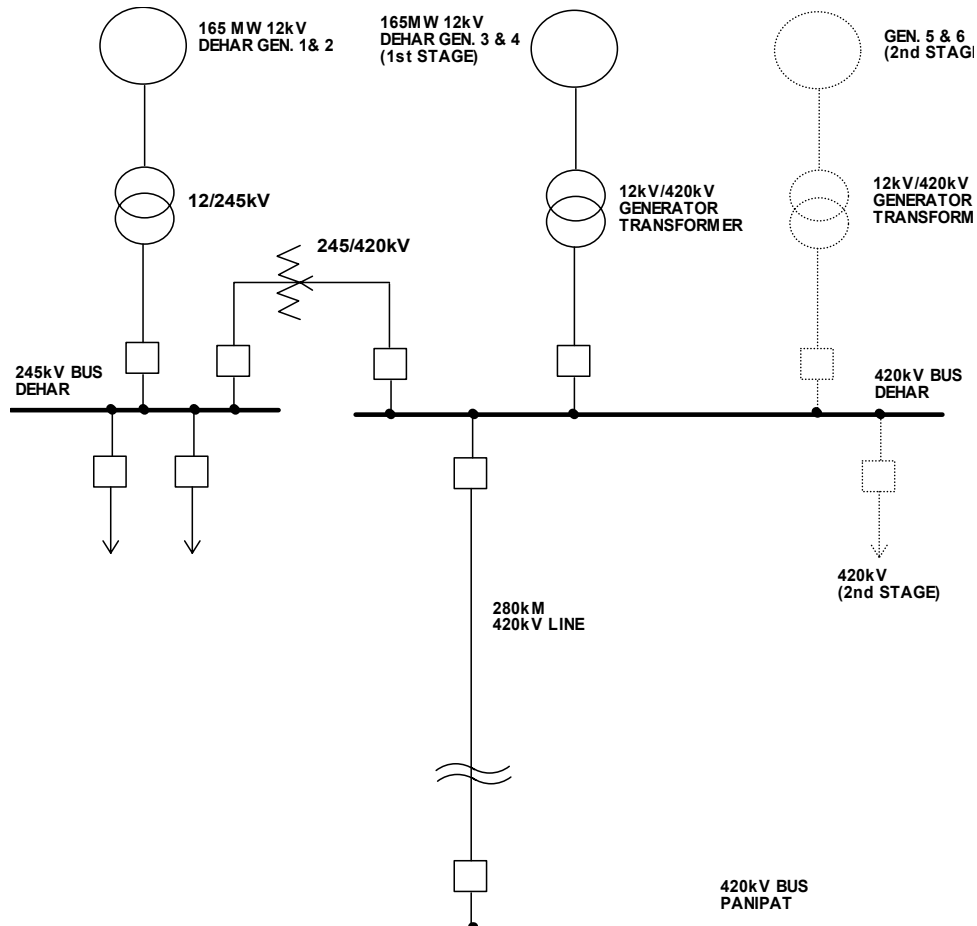


Figure 6.4: Dehar EHV System (1st Stage)
(As Designed)

Temporary over Voltages Due to Load Rejection

A study of dynamic over voltages of Dehar EHV system for a worst case of load rejection was carried out with the help of M/s English Electric Co. U. K. the simplified network studied is shown in figure 6.4 and consisted of 2 nos. Dehar generators (generators 3 & 4) each supplying the normal maximum load (taken as 150 MW at 0.995 terminal power factor per machine) through its step-up 12/420 kV transformer and 420 kV line to Panipat in the first stage. Both the cases of one machine in service and that of two machines running were examined by different methods. Two future units (5 & 6) and a second 420 kV line was to be added later on in second stage. First stage when 2 units are working and one 420 kV line is in operation was considered the worst case. The 420 kV bus at Dehar was interlinked to 245 kV generator bus for units 1 & 2 by an interlinking transformers.

In the preliminary study (Method i) it was assumed that the generators could be represented by constant voltage behind transient reactance. The study indicated the values of voltage which will prevail during the transient period following initial sub-transient period after loss of load at the remote end of the line. The power frequency over voltage at 12 kV machine terminals, sending end of line and receiving end of line are summarized in table 6.12.

Table -6.12

				Voltage Magnitudes (p.u.)	
Conditions Method (i)		M/c Terminals		Sending: End of line	Receiving end of line
One Machine	(On Load)	1.050		1.045	1.008
	(Load Off)	1.523	,	1.878	1.964
Two Machines	(On Load)	1.050		1.045	1.022
	(Load Off)	1.246		1.76	1.44
Method (ii) (2 Machines Only)					
Steady State (On load)		1.050		1.073	1.022
Time t = 0 (Just after load shed)		1.249		1.410	1.468
	t = 0.05 sec	1.216		1.372	1.429
	t = 0.10 sec	1.190		1.413	1.398
	t = 0.20 sec	1.150		1.297	1.35.1
	t = 0.30 sec	1.115		1.259	1.311
	t = 0.45 sec	1.068		1.205	1.255
	t = 0.60 sec	1.052		1.188	1.236
	t = 1.00 sec	1.052		1.188	1.236
	t = 2.50 sec	1.052		1.188	1.236
Method (iii) (One Machine Only)					
Steady State	(On load)	1.050		1.073	1.022
	(Load Off)	1.802		2.652	2.865

In the second method English Electric digital computer programme suitable for transient stability studies was used. The ensuing transient power frequency voltages over a specified time period were obtained. In this programme the integral variables in the machine differential equations are voltages representing average values of flux linkages within the machine. They are rms values and as such do not indicate the power frequency oscillation of the currents and voltage associated with the, machines or networks. This is normal for transient stability calculations in which the oscillation frequencies of primary interest are these characteristics of the comparatively slow rotor mechanical oscillations, of the order of 1 Hz. Thus, values of over voltage obtained with this method, while more accurate than those of method (1), indicate average values but not the high peak values which may prevail for a few cycles of power frequency following the load throw-off. Results obtained are given in table 6.12. Method (iii) shows maximum over voltage values occurring during a run covering first five cycles of load rejection. Values in the table are expressed as equivalent rms. values. These are for the case of one machine in operation and over voltages of about 2.8 p.u. expected at the receiving end of line. Values of this order persist for at least the short period of 5 cycles over which the calculation was carried out. It may be noted that although the calculations by method (iii) were carried out with constant machine excitation (equal to the normal load values) and without representation of the prime mover, the almost instantaneous AVR action would have negligible effect in limiting the over voltages obtained due to the short time period considered (open circuit field time constant of the machines is of the order of 8.8 seconds).

These preliminary studies indicated necessity of reduction in these over voltages with the use of reactors. It was tentatively assumed that, the temporary over voltage could be brought down to a value of 1.5 and use of conservative value for switchyard equipment basic insulation level.

Inclusion of transformer saturations effects showed no improvement in over voltage values.

Temporary Over Voltages Due to Other Causes

- **Un-Symmetrical Short Circuits**

Additional voltage rise can occur on sound phases of a system when a single phase is earthed. The voltage rise on the sound phase will depend on the impedance to the zero sequence currents which flow in the network. It is expected that in the solidly earthed 420 kV system over voltages due to single phase to earth short circuit shall not be more severe than the case already considered though study may be carried out and over voltage brought to safe limits by proper remedial measures if found necessary.

- **Resonant Harmonic Over Voltage**

The magnitude of the harmonic voltages in the network will depend on the impedance of the network external to the transformer. Extreme over voltages can only appear at receiving end transformer terminals if the system is capacitive at the frequency considered and equal in value to the magnetizing reactance of transformer and a series resonant exists. The value will, however, be limited by the damping resistance of the transformer and the network. The critical configuration can be prevented from occurring by use of suitable reactors.

Switching Over Voltage

Detailed studies for switching over voltages for Dehar EHV system were not carried out. It was, however, considered that worst case of switching over voltage will occur due to switching operation following a worst case of load rejection. Preliminary calculations indicated switching over voltage of 1.71 to 3.47 per unit at receiving end of line without reactor depending upon load phase angle. Detailed studies were to be carried out to fix exact size of shunt reactor compensation and measures be taken so as to limit the switching over voltage and use conservative values of basic insulation levels.

6.19.3 Lightning Arrestor

Protective Characteristics

Outages of switchyard equipment and bus bars due to over voltage are not desirable. Surge diverters are used to provide surge protection to transformer; these have to be properly coordinated with lightning and switching surges arising within the switchyard. For proper selection of the lightning arrestors the following two factors are important:

- a) The protection of the arrestor from the system.
- b) The protection afforded to the system by the arrestors.

The main cause of the failure of an arrestor is usually due to its inability to seal off the power frequency current once it has sparked over due to a lightning or switching surge on the system. To avoid such a contingency it had been hitherto considered desirable to select lightning arrestor characteristics so that the arrestor is able to seal off for the maximum dynamic over voltages, which may occur on the system. In cases where the dynamic over voltages are extremely high and it becomes doubtful whether the arrestors would seal off or not, the lightning arrestors are so selected as not to spark over on such switching surges which correspond to the above mentioned dynamic over voltages. This will necessitate selection of higher B.I.L.

However, there has been development in lightning arrestors design. These modern lightning arrestors are based on current limiting spark gap design and are allowed to spark over under switching surge conditions. These are designed to handle energy discharge of the EHV transmission line and are capable of resealing against transient voltage in excess of name plate rating. Characteristics of some different makes of lightning arrestors as extracted from available manufacturers data at that time are given in table 6.13. Lower B.I.L.s may result by the adoption of these lightning arrestors.

IEC recommends that the rating of surge diverters is chosen as the available rating immediately above the determining temporary over voltage in the system. Temporary over voltage includes voltage rise during faults, 'over voltages' due to inrush current, sudden loss of load and other causes. The determining over-voltages is influenced by other causes e.g. by the earth fault factor, system configuration, operating practice etc. the IEC Standards further recommend that the system should be studied individually to determine maximum credible temporary over voltage. It is, therefore, very important that the power frequency over voltage must be determined, which is likely to be quite severe in initial stage of development of an EHV system and for remotely located hydro generating station with long EHV lines.

Table- 6.13
Extract of data for arrestors of some different Makes

Sl No.		M/s Asea-Sweden		Hindustan Brown Boveri	Canadian Ohio Brass Co. Ltd.		M/s General Electric USA	
		XAL 360	XAL 390	HM 390	MPR 372	MPR 396	Alu gand 372	Alu gand. 384
1.	Type	XAL 360	XAL 390	HM 390	MPR 372	MPR 396	Alu gand 372	Alu gand. 384
2 (a)	Rated Voltage kV (rms)	360	390	390	372	396	372	384
(b)	Rated discharge current kA	10	10	10	-	-	-	-
3	Power frequency Spark over voltage kV (rms)	490	530	663	502	535	528	545
4	Max. Switching Surge spark over voltage kV (crest)	815	885	-	830	885	832	858
5.	Max. 100% impulse spark over voltage with 1.2/50µs wave	860	935	975	765	815	897	927
6.	Max. front of wave spark over voltage kV	960	1040	1170	1010	1075	1053	1076
7.	Max. residual voltage with 8/20 current wave I = 10 kA, kV (crest)	810	880	975	826	880	832	858

For Dehar Power Plant Switchyard equipment, as already explained above, suitable measures were to be taken to limit the maximum temporary over voltage to 1.5. Accordingly the surge diverter rated voltage should be the available rating immediately above $\frac{(420 \times 1.5)}{\sqrt{3}}$ kV i.e. 364 kV rms. The lightning arrestors

of different makes as available in the market at that time close to this figure have rated voltages of 360, 372, 384 and 390 kW. Arrestors of 390 kV rating would have a minimum power frequency flash over voltage of about 530 kV r.m.s. or 750 kV crest. It is, therefore, not likely to flash over due to a switching

transient of about or up to $\frac{(750)}{\frac{420}{\sqrt{3}} \times \sqrt{2}}$ i.e. 2.2.

6.19.4 Transformer Insulation Level

An adequate transformer insulation level is required to be so fixed that it can be safely protected by the lightning arrestors. The arrestor switching surge spark over voltage and the switching surge strength of the transformer have to be so coordinated that sufficient protective margin is available to ensure definite protection.

IEC Committee indicates a minimum safety factor of 15% for switching over voltages and 25% for lightning over voltages. It is, however, recommended that appropriate safety factor be adopted as the system expands and experience gained. B.I.L. of transformers protected against both switching and lightning by typical type of lightning arrester rated 390 kV mounted at their terminals has been worked out in Table 6.14 below, with a safety margin of 15% and 25% against switching over voltage respectively.

Higher BIL of 1425 kV for power transformers for Dehar EHV system was adopted, because of the following considerations.

1. High temporary over voltages
2. The initial development of 420 kV system in the region demands higher margins of safety and adoption of safe, economical and conservative values of BIL.
3. The cost difference between 1300 kV and 1425 kV BIL Transformers was low being of the order of 5% at that time.

Table – 6.14

1.	Basic Data		Example 1	Example 2
	Highest voltage for equipment Urn Corresponding line to ground voltage	k V _{rms}	420	420
	$\frac{U_m}{\sqrt{3}}$	k V rms	243	243
	Peak – Base for p.u. value $\frac{\sqrt{2}}{\sqrt{3}}$	k V	343	343
	Determining Temporary over voltage (derived from system studies)	k V rms	(364 (1.5)	364 (1.5)
	Minimum safety factor	kVp	515 (1.5)	515 (1.5)
	For switching over voltages		1.15	1.25
	For lightning overvoltages		1.25	1.25
2.	Representative Characteristics of Surge Diverter (ASEA)			
	Rated Voltage	kV _{rms}	390	390
	Maximum switching impulse spark over voltage	kV	885	885
	Maximum lightning impulse spark over voltage	kV	935	935
	Maximum front-of-wave impulse spark over voltage	kV	1040	1040
	Maximum residual impulse spark over voltage	kV	880	880
3	Protection Levels			
	To switching impulse	kV	885	885
	*To lightning impulse	kV	935	935
4	Insulation level (phase to earth)			
	Switching Impulse			
	Minimum switching impulse voltage	kV	1020	1110
	Rated switching impulse voltage (as per draft IEC)	kV	1050	1175 (see note -1)
	Ratio of the rated switching impulse voltage to the switching impulse protective level	kV	1.185	1.33
	Lightning Impulse			
	Minimum lightning impulse voltage	kV	1170	1170
	Rated lightning impulse voltage	kV	1300	1425
	Ratio of the rated lightning impulse voltage to the lightning impulse protective level	kV	1.39	1.52
	Ratio between rated lightning and switching impulse withstand voltage	kV	1300 1425	1.24 1.30

* Highest value among; maximum lightning impulse spark over voltage, maximum discharge voltage at rated discharge current and maximum front of wave spark over voltage divided by - 1.15

Note -1: IS: standard 2165 & IEC standard recommend maximum 1050 kV for 3.05

p.u. switching impulse withstand for this voltage.

The lightning arrester provided the same degree of protection to the bushings as the internal insulation of the transformer. However, it is a normal practice to provide one or two steps higher insulation for bushings to take care of contamination etc.

6.19.5 Insulation Level of other Switchyard Equipment

Lightning arrestors will limit surge voltages to locations remote from the arrestors, the zone of protection depending upon rate or rise of the incoming surge, arrester discharge characteristics, number of connected lines in the sub-station and insulation level of the equipment in the sub-station and insulation level of the equipment in the sub-station. It is a commonly accepted practice to apply arresters as near the transformer as possible. In large sub-stations, additional arrestors could be required at suitable locations to protect circuit breakers, isolators and other equipment. Since each of these equipment cannot be provided with an arrester. Individually it is the normal practice to adopt higher insulation to provide the equipment with as good protection as is economically justified. Insulation level for circuit breaker and other apparatus connected to the bus-bars together with the bus bars themselves are designed for insulation class about 10% higher than BIL for transformers (One class higher).

Insulation level across the open poles of the isolating switches is kept about 10 to 15 % higher than that provided between the poles and the earth, so that in the event of a surge at an open isolating switch, the flashover should pass to earth and not across open poles or between poles.

6.19.6 Conclusions

- i) Safe, economic and conservative values are required to be adopted in initial stages of development of an EHV system based upon studies after determination of over voltages.
- ii) BIL of 1425 kV for the power transformers directly protected by the lightning arrestors was recommended as it was marginally costlier than the lower value of 1300 kV.

6.19.7 Present practice (CBI & P) for 420 kV class generator transformer

- a) Rated lightning impulse withstand voltage – 1425 kV (peak)
- b) Rated switching impulse withstand voltage – 1050 kV (peak)
- c) Rated discharge at $1.5 \frac{U_m}{\sqrt{3}}$ single phase winding – pico coulomb 500

6.20 420 kV Class Generator Transformer

A three phase rating (depends upon the size of the unit) generally about 200 MVA and above. For Dehar generators the unit size was 175 MVA.

Percentage impedance voltage is about 14.5% and the cooling is OFWF.

Air core reactance of HV winding not less than 20% and knee point voltage not less than 1.1 per unit.

Short circuit level - Transformers are made suitable for connection to system having short circuit level 40/63 kA (rms) 1 second (CBI & P).

Terminal Bushing

- b) **LV Terminals:** Oil-sealed/oil communicating condenser bushings mounted on turrets suitable for connection to bus bars in isolated phase ducts having spacing of about 1250 mm for 250 MVA three phase units.
- c) **HV Terminal End:** 420 kV oil field condenser bushings. No arcing horns are provided.
- d) **Neutral:** 17.5 kV porcelain bushings

6.21 Factory and Field Testing for Large Transformers

Following tests are generally performed in accordance with IEC: 60067 on the transformer.

6.21.1 Routine Test

- a) Measurement of winding resistance
- b) Measurement of voltage ratio, polarity and check of voltage vector relationship
- c) Measurement of no-load loss and excitation current
- d) Measurement of short-circuit impedance and load loss
- e) Tests on on-load tap-changers, where appropriate
- f) Dielectric tests
- i) Switching impulse withstand voltage test, transformer winding $U_m > 170$ kV ii) Lightning impulse withstand voltage test, transformer winding $U_m > 72.5$ kV
- iii) Separate source withstand voltage test
- iv) Induced AC over voltage

6.21.2 Type Tests

- a) Lightning impulse voltage withstand test, transformer winding $U_m < 72.5$ kV
- b) Temperature rise test

6.21.3 Special Tests

- a) Lightning impulse test on neutral terminal
- b) Long-duration induced AC voltage test (ACLD) transformer winding $72.5 < U_m < 170$ kV
- c) Short circuit withstand test
- d) Measurement of zero sequence impedance on three phase transformer
- e) Measurement of acoustic sound level
- f) Measurement of the harmonic of the no-load current
- g) Measurement of the power taken by the fan and oil pump motors
- h) Test with lightning impulse chopped on the tail.
- i) Determination of capacitances and dissipation factor between winding-to-earth and between windings
- j) Determination of transient voltage characteristics

6.21.4 Additional tests

- a) Magnetic circuit (isolation) test
- b) Determination of capacitances and dissipation for condenser bushings > 72.5 kV
- c) Magnetic balance test on three phase transformers
- d) Dissolved gas analysis (DGA) of oil filled in the transformer before and after temperature rise test above 72.5 kV.
- e) Frequency response analysis (FRA) test > 170 kV (recommended)
- f) Measurement of magnetization current at low voltage
- g) Functional tests on auxiliary equipment
- h) Tests on oil filled in transformer
- i) Oil pressure test on completely assembled transformer
- j) Dew point measurement before dispatching

The dielectric tests may be routine, type or special tests depending upon the voltage rating, specific customer requirements and referred standards.

6.21.5 Recommended field tests

- a) Dew point measurement for large transformer filled with dry air or nitrogen filled
- b) Winding resistance measurement
- c) Verification of vector group and polarity
- d) Measurement of voltage ratio test
- e) Measurement of magnetizing current
- i) Magnetic balance test on three phase transformer
- g) Magnetic circuit (isolation test)
- h) Measurement of short circuit impedance at low voltage
- i) Insulation resistance measurement
- j) Measurement of capacitance and dissipation factor on transformer above 72.5 kV class
- k) Dissolved gas analysis (DGA) on transformers above 50 MVA
- l) Tests on oil filled in transformer as per IS: 1866

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**Example Calculation for Rationalization of capitalization Formula for Transformer Losses
(Based on CBI & P Manual on Transformers)**

Capitalization of transformer losses depends upon the rate of interest, rate of electrical energy per kWh, life of transformer and average annual loss factor. The annual loss factor takes into account the loading of the transformer during the year in computing the rate of capitalization of iron losses, copper losses and auxiliary losses. Following assumptions are recommended. These calculations are carried out to compare cost of transformer while purchasing.

- (i) Rate of interest (r):
- (ii) Rate of electrical energy (EC): It is the cost of energy per kWh at the bus to which the transformer to be connected.
- (iii) Life of the transformer (n): It is taken 25 years.
- (iv) Life transformer is in service for a period of 350 days in a year (allowing 15 days for maintenance, breakdown, etc.).
- (v) The cooling pumps remain in service for 40% of the time, the transformer is in service.
- (vi) Annual loss factor: The annual loss factor may be worked out on the basis of the formula given below.

$$LS = 0.3LF + 0.7 (LF)^2$$

Where:

LS is the annual loss factor
LF is the annual load factor

Assuming annual load factor as 60%, annual loss factor works out to 0.432.

Capitalization Formula Suggested

Capitalised Cost of Transformer = Initial cost + Capitalised cost of annual iron losses +
Capitalised cost of annual copper losses + Capitalised
cost of annual auxiliary losses

$$\text{Capitalised cost of losses per kW} = 8400 \times EC \times \frac{(1+r)^n - 1}{r(1+r)^n}$$

$$\text{Capitalised cost of copper losses per kW} = 8400 \times EC \times \frac{(1+r)^n - 1}{r(1+r)^n} \times LS$$

$$\text{Capitalised cost of iron losses per kW} = 0.4 \times 8400 \times EC \times \frac{(1+r)^n - 1}{r(1+r)^n}$$

Substituting the values, the capitalized cost of transformer.

Actual value of losses can be worked out by considering appropriate value of r, EC, LF, etc.

Generator Transformer

Difference of loss = 2.381 kW

Load factor (LF) = 80% = 0.8

Rate of interest (r) = 10% = 0.1

Rate of electrical energy (EC) = 2.5 Rs

Life of transformer (n) = 25 year

$$\text{Annual Loss Factor (LS)} = 0.3(\text{LF}) + 0.7(\text{LF})^2$$

$$\begin{aligned}\text{LS} &= 0.3 \times 0.8 + 0.7 \times (0.8)^2 \\ &= 0.688\end{aligned}$$

Capitalised Cost of Additional Copper loss per kW

$$\begin{aligned}&= 8400 \times \text{EC} \times \frac{(1+r)^n - 1}{r(1+r)^n} \times \text{LS} \\ &= 8400 \times 2.5 \times \frac{(1+0.1)^{25} - 1}{0.1(1+0.1)^{25}} \times 0.688 \\ &= \text{Rs. } 131043\end{aligned}$$

Capitalised cost of additional transformer losses

$$\begin{aligned}&= 131043 \times 2.381 \\ &= \text{Rs. } 312013\end{aligned}$$

Typical Technical Specification: Large Generator Transformers (Para 6.1.18)

1.1 Transformer Rating and Characteristics

The rating and electrical characteristics of the transformers shall be as under:

S. No.	Particulars	Type (Outdoor)
1.	Continuous kVA ratings	---- MVA ONAN/ONAF
2.	Type	Oil immersed
3.	Frequency	50 C/s
4.	Type of cooling	Oil natural air/Oil natural Air forced; water cooling
5.	No. of phases	Three
6.	Rating voltage on H.V. side	72.5 kV r.m.s. (or higher 245 kV)
7.	Rated voltage on L.V. side	11 kV r.m.s.
8.	Vector symbol	YND11
9.	Connections a) H.V. Winding b) L.V. winding	Star with neutral earthed Delta
10.	Off load taps on H.V. side (for H.V. Variation)	+ 2.5 to -7.5 % (in steps of 2.5%)
11.	H.V. and L.V. bushings suitability	L.V. suitable for cable box/bus duct H.V. condenser bushings with plain sheds

1.2 DESIGN AND CONSTRUCTION

The transformers shall be 3-phase oil immersed type, With core type of constructions, type of cooling as per ‘SCHEDULE OF Requirement ‘ with Tank mounted radiators, and shall be suitable for outdoor service as step up transformer, adequate Ceramic ball/spacers shall be provided in the core/winding for circulation of oil so as to ensure proper cooling. All apparatus shall be designed to ensure satisfactory operation under such sudden variation of load and voltage as may be met with under working conditions on the system including those due to short circuits. To minimize the eddy current losses in the windings, CTC shall be used wherever required similarly for minimizing the stray losses magnetic shield in yoke, magnetic shunt in tank walls, bushing turrets, clamps, flitch plates etc. shall be provided wherever required.

Manufacturer shall indicate the design value of eddy current loss, stray losses as a % age of load losses in the design.

All materials used in the manufacture of the transformer shall be of the best quality of their respective kind obtainable in the market and shall conform to standards as per clause above. The design of transformer and properties of the material used should be such so as to reduce to minimum the risk of development of acidity in the oil.

Corresponding parts, liable for replacement shall be interchangeable.

All outdoor apparatus, including bushing insulators with their mountings shall be designed so as to avoid pockets in which water can collect.

1.3 Service Conditions

A. Reference Ambient Temperatures

The reference ambient temperatures for which the transformers are to be designed are as under:-

i)	Maximum ambient temperature	--- degree C
ii)	Maximum daily average ambient temp :	--- degree C
iii)	Maximum yearly weighted average ambient temp :	--- degree C
iv)	Minimum ambient air temperature : ;(Cooling medium shall be Air)	Minus --degree C
B.	CLIMATIC CONDITIONS :	
i)	Maximum relative humidity	--- %
ii)	Yearly average number of thunder stroms _____ varies from 30 to 50..	
iii)	Average no. of rainy days per annum	--- days
iv)	Fog : The atmosphere is subject to fog for two month in winter.	
v)	Number of months during which tropical monsoon conditions prevail	--- months
vi)	Dust stroms occur at frequent intervals	
vii)	Average annual rainfall	--- cms
viii)	Maximum wind pressure	--- kg/sq.m.

C. ALTITUDE

Altitude above M.S. level not exceeding 1000 mtrs.

1.4 Temperature Rise, Over Load Capacity & Continuous Rating

a) With the above service conditions, each transformer shall be capable of operating continuously on any tap at normal rating without exceeding following temperature rises, over maximum ambient temperature of 50 deg. C.

- i) 30 deg. C in oil by thermometer
- ii) 45 deg. C in winding by resistance
- iii) The temp. of hot spot in the winding not to exceed 90 deg. C when calculated over max. annual weighted average temp. of 40 deg. C & 105 deg. C at worst ambient of 50 deg. C.

b) The limits of temperature rise mentioned above and over load capacity as per IEC-354 (1993) will have to be satisfied by the manufacturer by carrying out the heat run test at the lowest negative tap. This test shall be carried out by feeding the following losses : -
(Total max. losses at 75 deg. C at highest current tap) x 1.1

c) The safe overload capacity of the transformer and the duration of overload for each type of cooling (ONAN/ONAF) under maximum temperature conditions without any damage to the winding or harmful effects on the insulation shall be clearly stated in the tender, which must be as per IEC-354 (1993) – Guide for loading of oil immersed transformers, suitable for climatic conditions given above.

d) The transformer may be operated without exceeding temperature rises, winding gradients and hot spot at any particular tapping at the rated MVA provided that the voltage does not vary by more than $\pm 10\%$ of the voltage corresponding to that tapping. Transformer shall be able to withstand for 30 minutes after achieving steady state at full load rating without injurious heating to winding/insulation etc. under auxiliary failure condition.

1.5 Guarantees, Bid Evaluation and Penalty

i) The no load loss in kW at rated frequency and the total losses in kW at rated output, rated voltage and rated frequency shall be guaranteed under penalty for each transformer. The no load loss at

rated frequency should not be more than 15 kW and total losses on rated load should not be more than 81 kW.

- ii) Price adjustment for Bid Evaluation shall be calculated as follows:

Price Adjustment due to losses calculated at 70% average load factor shall be Rs. 1.85 lac/ kW loss (calculated for the system) over the minimum losses offered by any Bidder

- iii) Penalty on losses higher than the guaranteed figure shall be at a rate of Rs. 1.85 lacs/kW (or as calculated).

1.6 Tapping

The tapping range shall be as given in Para 1.2. The transformers should be provided with OFF circuit tap changers' having local manual control.

1.7 Core

- i) The transformer should be so designed that the working flux density does not exceed 1.5 Tesla at normal voltage, frequency and ratio and 1.9 Tesla under over voltage condition due to temporary over voltages.
- ii) Tenders with higher flux density than specified shall not be considered.
The core shall be built up with thin laminations of high grade, non-ageing, low loss, high permeability, cold rolled super grain oriented silicon steel, superior grade CRGO steels of maximum 0.27 mm or low lamination thickness specially suitable for transformer cores.
- iii) After being sheared, the laminations shall be treated to remove all burrs. They shall be coated with a baked enamel insulation coating. The insulation shall be inert to the action of hot transformer oil and shall be perfectly adhesive. Paper and varnish insulation shall not be accepted. Laminations shall be checked for burrs during stage inspection.
- iv) The core shall be rigidly clamped and/or 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 and the clamping structure shall be so constructed that the eddy currents will be minimum.
- v) Construction of the core shall be such that number of steps in the limb and yoke shall be matching and dimensionally identical to minimise the effect of cross fluxing and better mechanical strength.
- vi) The core shall be provided with lugs suitable for lifting the complete core and coil assembly of transformer. The core and coils shall be so fixed in the tank that its shifting will not occur when the transformer is moved or when a short circuit occurs.
- vii) The design of magnetic circuit shall be such as to avoid static discharges, development of short circuit paths within itself or to the earthing clamping structure and the production of flux components at right angles to the plane of the lamination which may cause local heating.
- viii) Every care shall be exercised in the selection treatment and handling of core steel to ensure that the lamination are flat and that finally assembled core is free from distortions.
- ix) The supporting frame work of the core shall be so designed as to avoid the presence of pockets which would prevent complete emptying of the tank through the drain valve or cause trapping of air during filling.
- x) Oil ducts, where necessary should be formed across the plane of the lamination and be given a suitable slope to assist oil circulation. The overall design of core and winding should be such that free flow of oil is not obstructed.
- xi) The frame work and clamping arrangement shall be earthed by connecting to the tank body through a copper strip, yoke bolt area should be compensated if bolts are used for fastening of the core. Also flitch plate area will not be counted in core area.
- xii) The insulation of core to bolts and core to clamp plates shall be able to withstand a voltage of 2 kV (RMS) for one (1) minute.
- xiii) Core and winding shall be capable of withstanding shocks during transport, installation, service and adequate provision shall be made to prevent movement of core and winding relative to tank during these conditions.

- xiv) All steel sections used for supporting the core shall be thoroughly sand blasted after cutting, drilling and welding.
- xv) Maximum flux density allowable continuously, as well as for time intervals of 1 minute and 5 secs. and the limit of flux density at which core material used by them saturates shall be intimated.
- xvi) The name of the core material must be mentioned in the tender. Magnetization curves of the core material/design calculations shall be furnished to satisfy that flux density is as desired.
- xvii) Built-up core for verification of flux density shall be inspected/tested. The core material shall be subjected to various tests as per relevant IEC/IS to ensure quality. Core may also be inspected during horizontal assembly, built up assembly.

NOTES:

- iv) The above flux density has been specified to meet with the over fluxing of the core due to temporary over voltage of the order of 31% for 1 min., 44% for 5 sec. That may appear in abnormal conditions such as those following sudden loss of large loads/ tripping of Generator breaker.
- v) Yoke bolt area and flitch plate areas shall not be counted in the net core area, if these are provided for fastening of core.
- vi) The design of limb and yoke shall be so coordinated that there is no cross fluxing at the joints.

1.8 Winding

- i) The conductor used for the winding shall consist of solid drawn high conductivity electrolytic grade copper free from scale and burrs and suited to the requirement.
- ii) In case of copper strip, the corners shall be rounded off to eliminate risk of injury to internal insulation during winding & other operations. No strip Conductor wound on edge should have width, exceeding six times its thickness.
- iii) All permanent current carrying joints in the windings and leads shall be welded or brazed. Preference shall be given to a winding with a continuous conductor. The windings shall be pre-shrunk during manufacture so that it is extremely unlikely that any further shrinkage takes place in service. Provision shall be made so that in the event such a shrinkage does occur it will be possible to take up this shrinkage by means of adjustable clamping screws and end rings. The voltage between adjacent coils shall be kept as low as consistent with given design.
- iv) The windings shall be so designed that all coil assemblies of identical voltage ratings shall be interchangeable and field repairs to the windings can be made readily without special equipment.
- v) The coils shall be supported between adjacent sections by insulation used in the assembly of the windings and shall be arranged to ensure free circulation of the oil and to reduce hot spots in the windings.
- vi) All threaded connections shall be provided with locking facilities. All leads from the windings to the terminal board and bushings shall be rigidly supported to prevent injury from vibration. Guide tubes shall be used wherever practicable.
- vii) The winding shall be designed to reduce to a minimum the out of balance forces in the transformer at all voltage ratios.
- viii) The windings shall be clamped securely in place so that they will not be displaced or deformed during short circuits. The assembled core and winding shall be dried and suitably impregnated before removal from the treating tanks.
- ix) The insulation of the coils shall be treated suitably to develop full electrical strength of the windings and for this hot oil vacuum impregnation process shall be used for improving the electrical and thermal properties of insulating paper.
- x) All materials used in the insulation and assembly of the windings shall be insoluble, non-catalytic and chemically inactive in the hot transformer oil and shall not soften or otherwise be adversely affected under the operating conditions.
- xi) The conductors shall preferably be CTC, transposed at sufficient intervals in order to minimise eddy current and equalize the distribution of current and temperature along the winding.
- xii) Windings shall preferably be made in dust proof condition.
- xiii) Tappings shall be so arranged as to preserve the magnetic balance of transformer at all voltage ratios. Tapping winding shall be provided separately from the main HV winding.

- xiv) Coil assembly and insulating spacers shall be so arranged as to ensure free circulation of oil and to reduce the hot spot of the winding.
- xv) The insulation of transformer windings and connections shall be free from insulating compound which are liable to soften, ooze out, shrink or collapse and be non-catalytic and chemically inert in transformer oil during service.

1.8.1 Reinforced Insulation

At each end of HV winding an electrostatic shield and/or cap & ring shall be provided so as to increase the ratio of the electrostatic capacity between turns as compared with the electrostatic capacity of the high voltage winding to earth and to the low voltage winding. HV winding shall preferably be interleaved.

1.8.2 Current Density

The transformer shall be so designed that the current density of HV windings at the lowest tap should not exceed 250 A/cm². And that of LV winding should not exceed 200 A/cm².

1.9 Insulation Levels

The insulating material to be used, shall be of class “A” as specified in the latest edition of IS: 12371.

The dielectric strength of winding insulation and of the bushings shall conform to values given in IS: 2026/1981 part-III amended up to date except for the changes made in this specification.

The following impulse test and power frequency test voltage must be offered.

The provision of note under clause 5.4 IS: 2026 (Part-III) – 1981 should be kept in view while offering this parameter. The star connected windings of the transformers shall have graded insulation.

All windings for system voltage lower than 66 KV shall have uniform insulation.

Rated System Voltage (kV)	Highest system voltage (kV)	1.2/50 μ Sec. positive impulse with stand voltage of line end (kV peak)	One minute p.f. withstand voltage	
			Line end(kV)	Neutral end(KV)
11 (core higher) (66 kV to 220 kV; 72.5 kV to 245 kV as per table 1.1)	12	95	38	-

Short circuit strength and provision of separate tapping coil for regulation:

Transformers shall be designed and constructed to withstand without damage the thermal and dynamic effects on external short circuits for 5 seconds under condition specified in IS: 2026 (Part-I)- 1977.

The transformers shall be provided with separate tapping coil to limit the short circuit forces.

The position of the tapping coil shall be so arranged that at extreme negative tap, the percentage regulation is less than at normal tap.

Test certificates of the short circuit test, if already done on the offered design and rating should be submitted. However, the thermal and dynamic ability to withstand short-circuit forces shall be demonstrated by calculations.

Manufacturers shall supply calculation for Thermal & Dynamic withstand capacity of the transformer as per their design along with the tenders.

1.10 Frequency and System Voltage

The transformers shall be suitable for continuous operation with a frequency variation of 3% from normal 50 cycles per second without exceeding the specified temperature rise.

1.11 Parallel Operation

The transformer shall be capable of parallel operation with each other and with existing grid.

1.12 Important Technical Particulars

Important technical particulars of the transformers to be guaranteed by the tenderers shall be submitted with tender.

1.13 Tolerances

Various tolerances on technical parameter shall be as under :-

I. Impedance :

Maximum tolerance allowed on impedances at all taps shall be as per IS: 2026 (Latest edition).

II. Losses

No positive tolerance shall be allowed on guaranteed No load losses, Load Losses and Auxiliary Losses individually at rated voltage, current, principal tap & 75°C temp.

III. Temperature Rise Test

No positive tolerance shall be allowed on Temp. Rise of oil, windings, Windings temp. Gradients & Hot Spot Temp. than the Guaranteed Values.

IV. Weights

No negative tolerance shall be allowed on Weight of Copper, Weight of CRGO & Weight of Oil etc.

V Transformer shall be tested for over-load conditions as specified in latest edition of IEC-354/1993 , which shall be read with IEC-76/1993.

VI. Capitalization of Losses

Capitalisation of losses shall be done as per following formula:

(No load Losses +.5xTotal; Load Losses) x Rate of Capitalisation Say @Rs.1.85lac/kw. (or as calculated for system)

Total load losses = Load Losses+ Auxiliary Losses

1.14 Cooling (To be suitably modified for other types of Cooling)

--- MVA transformers shall be provided with ONAN/ONAF (or as required) type of cooling. The ONAN cooling of the transformers shall be by natural circulation of air while the circulation of oil shall be effected by natural convection, the maximum oil flow being assumed by a method whereby the return flow of cooled. Oil is made to enter the tank on a level with the bottom of hot columns of oil thus avoiding centre heads of cold oil at the bottom of the tank. Out flow shall be arranged to coincide as nearby as possible with the hot oil level at the top of the tank so that the total available difference will be fully employed in circulation of the oil round the shortest possible paths.

The windings of the transformer shall be designed to deliver continuously rated MVA with ONAN/ONAF cooling as applicable. Each transformer shall be provided with two completely independent groups of 2 x 60 % capacity tank mounted radiators. Each group of coolers for ONAF type cooling shall essentially consist of one set of cooler fans. In addition, each group of radiators shall be provided with one stand by cooler fan.

The stand by cooler fan shall be switched 'ON' automatically in case of failure of any one of the cooler fan in that group of coolers. The provision shall be made to make any one out of total fans as stand by.

The transformer shall be capable of delivering the rated output continuously with two groups of coolers/radiators mentioned above in service without exceeding the specified temperature rise. All the fans in the two groups of coolers shall be arranged to start automatically when the winding temperature exceeds a preset adjustable temperature to be specified by the supplier.

The supply controls and piping of each group of radiators shall be completely independent of those of other group so that either group of radiators can be taken out of service for maintenance with the transformer and the other group of radiators in services.

Radiators shall be designed to withstand the pressure conditions specified for the tank and shall be designed so as to be accessible for cleaning and painting to prevent accumulation of water on the outer surfaces.

The connection pipe between the tank and the cooler units shall be connected by machined steel flanges welded to the cooler units and the tank and provided with gaskets to ensure no leakage what-so-ever. At each cooler unit connection, there shall be provision on the tank, an indicating shut-off valve which can be fastened in either open or closed positions. Separate oil tight blank flange shall be provided for each tank connection for use when the cooler unit is detached.

In addition to above, each cooler shall also be provided with the following:-

- i) A drain valve 25mm at lowest point.
- ii) A thermometer pocket fitted with a captive a crewed cap on the inlet and outlet oil branches.
- iii) A filter valve at the top and bottom.
- iv) Air release plug 15mm.
- v) Fans shall be mounted on independent, below the radiators for effected cooling.
- vi) Inlet/outlet pipe for T/F tank for radiator shall be tapped from opposite side of the tank for better circulation.
- vii) Pipes with circular bends/elbows shall only be used.

A suitable expansion piece shall be provided in each oil pipe connection between the transformer and the tank mounted oil coolers/if required.

Provision shall be made in each cooler/radiators bank header for installing 2 no. Radiators on each side, if required.

The power supply available for the cooling system shall be 415 volts, 3 phase-4 wire & all the mechanism should be designed accordingly.

1.15 Air Blast Type of Cooling (or as required)

- i) The transformers shall be equipped with a cooling air blast type of cooling for the transformers.
- ii) Each cooler/ Radiator unit shall be designed for detaching from the transformer without disturbing the oil in the transformer tank. Coolers shall be designed to withstand pressure conditions specified for the tank.

- iii) Coolers/Radiators shall be designed so as to be accessible for cleaning & painting and to prevent accumulation of water on the outer surfaces to completely drain oil into the tank and to ensure against formation of gas pockets when the tank is being filled.
- iv) Coolers units shall be connected to the tank through machined steel flanges welded to the cooler units and to the tank and provided with gaskets. The flanges shall be provided with grooves to avoid slippage of gaskets during tightening. At each cooler unit connection, there shall be provision on the tank for an indicating shut off valve which can be fastened in either open or closed position, a separate oil tight blank flange shall be provided for each cooler unit. It shall have a lifting eye, a 19mm dia oil drain plug at the bottom and 19mm dia air vent plug at the top.
- v) Fans or blowers for air blast cooling shall be so mounted as to ensure that no damage to the coolers can arise from vibration of the fans. Galvanised wire mesh screens shall be fitted to prevent accidental contact with the blades. The mesh being not greater than 25mm.
- vi) The radiators shall be equally distributed on either side of transformers.
- vii) The maximum dimensions of the transformer shall be intimated in the bid. The rail gauge of 1676 mm shall be in the center line of these limits of dimensions.

1.16 Air Blowers

Air blowers (any standard make only) shall be mounted on separate brackets (i.e. not on radiators) and shall be suitable for continuous outdoor operation and shall start direct on line. Stand by cooling fans equivalent to 15% of cooling capacity with minimum of 1 fan with each unit shall be supplied.

Suitable painted wire-mesh guards with mesh not greater than 25mm shall be provided to prevent accidental contact with the blades.

1.17 Cooler Control

Cooler units shall be suitable for operations with a 415 volts, 3- phase, 50 cycles power supply. Control equipment for fan motors shall be mounted in a Marshalling Box adjacent to the transformer and shall include necessary three pole electrically operated contactor and with control gear of suitable design both for starting and stopping the motor manually and also automatically from the contacts of the winding temperature indicating device. Additional terminals for remote control of motors shall be provided. Over load and single phase protection shall be provided but no volt release shall not be fitted. A single phase preventer should be installed on the main supply to cooler circuit so that in case of single phasing all the three phases are put off, thus, preventing single phasing. A single metal clad main isolating switch with H.R.C. fuses shall be provided for the main supply.

The switching in or out of cooling equipment shall be controlled by temperature indicators and there shall be provision for automatic switching in or out at pre-determined temperature level which should be capable of adjustment and setting at will. The cooler control scheme shall be so designed that.

- a) It shall be possible to run all fans, including stand by fans, on manual.
- b) There should be provision to change over any fan to stand by.

Loading capacity of the transformers shall be made to avoid hunting of fans and specified.

1.18 Insulating Oil

- i) Sufficient insulating oil of NAPHTHENIC TYPE (Made from NAPHTHENIC CRUDE) conforming to BS: 148/IEC: 296 class-I/IV shall be supplied for first filling of each transformer.
- ii) 10% extra oil of the total quantity of oil shall also be supplied.
- iii) In case the transformer is to be supplied gas filled. Particular attention shall be paid to deliver the oil at site free form moisture and of uniform quality throughout in non-returnable epoxy coated steel drums.
- vii) The quantity of oil for first filling of each transformer shall be stated in tender along with trade mark of the oil to be supplied.

viii) Use of inhibitors in oil shall not be resorted to.

1.19 Suppression of Harmonics

The transformer shall be designed with particular attention to suppression of harmonic voltage especially the 3rd and 5th. Percentage of harmonics at normal voltage and at maximum system voltage shall be stated.

1.20 Tank

The transformer tank and cover shall be oil tight and shall be fabricated from good commercial grade low carbon steel of adequate thickness. The weld procedure and performance shall be in line with ASME-BPV-9 /IS:2062. The tank and the cover shall be of welded construction. All seams shall be welded and where practicable they shall be double welded. The tank shall be designed and constructed for vacuum filling of oil and shall be capable of withstanding without leakage or distortion continuous internal gas pressure of 0.7 atmosphere with oil at operating level. The tank cover shall be bolted with the lower position of the tank and the transformer design shall be such that it shall be possible to move the complete transformer unit by skidding in any direction without injury when using plates or rails.

Where the design of the tank is such that the bottom plate will be in direct contact with the surface of the foundations, the minimum bottom plate thickness shall be 20mm to 25mm.

Man holes/inspection covers with welded flange and bolted covers shall be provided on the tank cover. The inspection covers shall be of sufficient size to afford easy access to the lower ends of bushings, terminals etc.

All bolted connections to the tank and connections between sections of the tank shall be provided with suitable flanges, with properly spaced bolts and suitable oil tight gasket which shall give satisfactory service under operating conditions.

The thickness of M.S plate for bottom, sides and top of the tank shall be adequate as per CBIP recommendations.

The transformer tank along with radiators and other accessories shall be tested for vacuum and pressure test as per CBIP recommendations.

Special attention shall be given to the methods of marking the hot oil tight joints between the tank and cover as well as between the cover and the bushings and all other outlets to ensure that the joints can be remade satisfactorily and with ease with the help of semi-skilled labour. Where compressible gaskets are used, means shall be provided to prevent over compression.

Suitable guides shall be provided for positioning the various parts during assembly or dismantlement. Adequate space shall be provided between the cores and windings and the bottom of the tank for collection of any sediment.

Lifting eyes or lugs shall be provided on all parts of the transformer requiring independent handling during assembly or dismantlement. In addition the transformer tank shall be provide with lifting lugs and bosses properly secured to the sides of the tank for lifting the transformer by using hydraulic or screw jacks.

The design of the tank, the lifting luge and bosses shall be such that the complete transformer assembly filled with oil can be lifted with the use of these lugs without any damage or distortion.

All bolts and nuts used in connection with tank and fittings shall be galvanized/Zinc plated & passivated.

The tank shall be provided with suitable lugs for the purpose of grounding with a mild steel flat.

The main body including tap changing compartments and radiators and coolers shall be capable of withstanding full vaccum of 760mm of mercury when empty of oil.

In addition, the design of tank, its shape, proportions, weight of material and construction shall be such as to best facilitate oil circulation and to ensure against transmission or magnification of noise or vibration which might be injurious or objectionable.

As far as possible, the transformer tank and its accessories shall be designed without pockets wherein gasses may collect where pockets cannot be avoided. Pipes shall be provided to vent the gas into the main explosion pipe. The vent pipes shall have a minimum inside diameter of 15mm except for short branch pipes which may have 6mm minimum inside diameter.

The tank cover shall be provided with three pockets for mercury in glass thermometers and four pockets for the bulbs of oil and winding temperature indicators. Minimum depth of the thermometer pockets shall be 10" from top oil level. Protection shall be provided where necessary, for each capillary tube. The thermometer pockets shall be fitted with a captive screwed top to prevent ingress of water. The pockets shall be located in the position of maximum oil temperature at CMR and it shall be possible to remove the instrument bulbs without lowering the oil in the transformer tank.

Each transformer tank shall be fitted with the following valves/plugs with standard screw connections for external piping.

1. One filter cum oil drain valve with plug or blanking flange (size 80mm/ 100mm/ dia.) and so placed as to completely drain the oil of the transformer.
2. One no. top filter valve. Size 50mm near the top of the tank diagonally opposites to filter cum drain valve.
3. Three robust sampling valves with spouts suitable for taking sampling of top, middle and bottom oil. The top and middle sampling valves shall be brought down by internal pipe connections. Suitable name plates shall be affixed to the sampling valves. The sampling device shall not be fitted on the filter valve.
4. At least two nos. 15 mm/ dia air release plugs on top of cover, suitably located.
5. One pressure relief valve/device to operate at a pressure below the test pressure for the tank.
6. Suitable no. of jacking bolts shall be provided on tank cover and inspection covers.

1.21 Conservator Tank

- i. An oil conservator tank preferably air cell type complete with sump, filling hole and drain valve shall be mounted above the radiators and located so as not to obstruct taking of bare connections from the transformer terminals.
- ii. The capacity of the conservator tank shall be adequate to meet the requirements of expansion of the total cold oil volume in the transformer and cooling equipment from minimum ambient temperature of minus 5 deg.c. to 115 deg.c.
- iii. The minimum indicated oil level shall be, with the feed pipe from main tank cover, under not less than 15mm depth of oil and the indicated range of oil level shall be from minimum to maximum.
- iv. One magnetic type oil level gauge with alarm contacts shall be mounted at a convenient height to be read from ground level. Prismatic oil level gauge shall also be provided.
- v. Oil level at 30 deg.c. shall be marked on the gauge
- vi. The conservator tank shall have one oil filling hole with cap at the top and drain valve of appropriate size at the bottom. A shut off valve shall be provided at the conservator to cut off supply to the transformer.
- vii. The conservator tank will be designed in such a way that the same can withstand strong wind pressure by adding adequate stiffeners, if necessary.
- viii. Each conservator shall be fitted with a double compartment breather with oil seal in which silica gel is the dehydration agent and designed so that :-
 - a) The passage of air is through the silicagel.
 - b) The external atmosphere is not continuously in contact with the silicagal
 - c) The moisture absorption is indicated by a change in colour of the tinned crystals and can be daily observed from distance.

- d) All breathers shall be mounted at approximately 1400 mm above ground level.
- e) The breather should be made of superior quality see-through material and should consist of two compartments placed in parallel.
- f) In addition to M.O.G. prismatic type oil gauge shall also be provided.
- g) The conservator shall be of air cell type if possible having provision for rubberized air cell so that air does not come in contact with oil in the conservator otherwise heaters may be provided with conventional air breathing system.

1.22 Anti Earthquake Clamping Device

To prevent transformer movement during earthquake, a clamping device shall be provided for fixing the transformer to the foundations. The contractor shall supply necessary bolts for embedding in the concrete. The arrangement shall be such that the transformer can be fixed to or unfastened from these bolts as desired. The fixing of transformer to the foundation shall be designed to withstand seismic events to the extents that a static coefficient of 0.3g (or as applicable) applied in the direction of least resistance to that of loading will not cause the transformer or clamping device as well as bolts to be over stressed.

1.23 Earthing Terminals

Two earthing pads suitable for connecting 50x 8mm mild steel flat shall be provided at positions close to the two diagonally opposite bottom corner of tank. These grounding terminals shall be suitable for bolted connection. Two earthing terminals shall also be provided each on cooler, marshalling box and any other equipment mounted separately.

1.24 Under Carriage

The transformer shall be supported on a strong structural steel base equipped with forged steel or cast steel, single flanged, bi-directional wheels suitable for moving the transformer completely filled with oil. Jacking pads shall be provided to make it possible to change the direction of wheel through 90 degree when the transformer is lifted on jacks and permit movement of the transformer both in the longitudinal and transverse direction. Track gauge in both longitudinal and transverse direction shall be 16776 mm i.e the same as that of Indian Broad gauge Railways. Means shall be provided for locking the swivel movement in position parallel to and at right angles to longitudinal axis of the tank.

Pulling eyes and skids shall be provided to facilitate moving of the transformer and they shall be suitably braced in the vertical direction so that bending does not occur when the pull has a vertical component.

1.25 Bushing Insulators and Terminals

- 1 Transformer shall be fitted with fitted with bushing insulators as follows : (see note)
 - a) HV Bushings: --- kV class, 800A, OIP condenser bushing.
 - b) LV Bushings: --- KV class 2000 A bushing.
 - c) HVN Bushings: --- KV class 2000A, LV bushing

Note:- Bushing should be suitable for 25 times rated current for 5 seconds.

- ii) Bushings of -- kV shall be filled with transformer oil and there shall be no communication with the oil in the transformer. An oil gauge, preferably of prismatic type shall be provided to indicate that correct level is maintained.
- iii) Short time current withstand capability of bushing shall be 31.5KA for 3 seconds (72.5kV)
- iv) The electrical characteristics of bushings shall be in accordance with IS: 3347 and IS: 2029.
- v) These bushings shall be suitable for single ACSR Zebra conductor (or as required). All bushings shall be equipped with suitable terminals of approved type and size and all external current carrying surfaces shall be adequately silver plated. All ends as well as all tappings on the windings shall be brought to terminals. Bushings which pass through the cover shall be removable without disturbing the transformer cover.

- vi) The bushings shall have high factor of safety against leakage to ground and shall be so located as to provide adequate electrical clearances between bushings of various voltages and between bushings and grounded parts.
- vii) Bushings of identical voltage shall be interchangeable. The insulating class of the high voltage neutral bushings shall be properly co-ordinated with the insulation class of neutral of the high voltage winding.
- viii) Clamps and fittings made of sheet or marble room shall be galvanised.
- ix) Each bushing shall be so coordinated with the transformer insulation that all flash-overs will occur outside the tank. All bushings shall have puncture strength greater than dry flash over value. Any stress shield shall be considered as integral part of bushing assembly. Only condenser type bushing shall be accepted.
- x) Oil circulation shall be capable to take care of expansion bushing oil up to 115 °C.

1.26 Centre of Gravity

The center of gravity of the assembled transformer shall be low and as near the vertical center line as possible. The transformer shall be stable with or without oil., if the center of gravity is eccentric relative to track either with or without oil, its location shall be shown on the outline drawings.

1.27 Joints, Gasket and Valves

- i. All gasket used for making oil tight joints shall be of proven material such as granulated cork bonded with synthetic rubber. The material used should not deteriorate under the action of hot oil.
- ii. All valves up to and including 100mm shall be of gun metal or of cast steel. Larger valves may be of gun metal or may have cast iron bodies with gun metal fittings. They shall be of full way type with internal screw and shall open when turned counter clockwise when facing the hand wheel. Means shall be provided for padlocking the valves in the open and closed position, every valve shall be provided with flanges having machined faces. The drilling of valves flanges shall comply with the requirement of IS: 2026/IS: 3639.
- iii LEADER/BOMBAY Metal/AVDCO/KPETSON make valves shall be preferred.

1.28 Cleaning and Painting

While in service, the equipment will be subjected to extremely severe exposure to atmosphere, pressure, high humidity and long periods of high ambient temperature. All corrodible parts and surfaces shall be of such material and shall be provided with such protective finish that no part of the installed equipment is injuriously affected by atmospheric conditions.

The whole of the exposed portion except bright parts shall be thoroughly cleaned by sand blasting and painted with two primary coats of approved rust resisting paint in dark admiralty grey colour (shade 632 of 15.5). In side surface shall be clean, smooth, free from void and of best construction. The nature of coatings, provided inside, shall be specified and it shall be ensured that it does not react with transformer oil or deteriorates its electrical/chemical properties.

Some paint suitable for primary and secondary coats shall also be supplied to cover the damage to paint work which may be experienced during transportation.

1.29 Marshalling Box

A sheet steel of minimum 3mm thickness, vermin proof, well ventilated and weather proof marshalling box of a suitable construction shall be provided for the transformer ancillary apparatus, wiring up to marshalling box shall be with PVC/SWA, PVG copper cable 660/1100 volts grade IS certified/marked.

The marshalling box shall accommodation the following equipment:-

- a) Temperature indicators
- b) Control & protection equipment for the cooling plants

c) Terminal board and gland plants for incoming and outgoing cables.

All the above equipment except (a) shall be mounted on panel and back of panel wiring shall be used for inter-connection. The temperature indicator shall be so mounted that the dials are not more than 1600 mm from the ground level and the door(s) of the compartment(s) shall be provided with glass window of adequate size to prevent internal condensation., an approved type of metal clad heater with thermostat shall be provided, controlled by water tight single pole iron clad rotary switch mounted on outside of the box. The ventilation louvers, suitably padded with felt, shall also be provided.

All incoming cables shall enter the kiosk from the bottom and the gland plate shall not be less than 450 mm from the base of the box. The gland plate and associated compartments shall be sealed in suitable manner to prevent the ingress of moisture from the cable trench.

1.30 Control Connection, Instrument Wiring, Terminal Boards & Fuses

All wiring connections, terminal boards, fuses and lines shall be suitable for tropical atmosphere. Any wiring liable to be in contact with oil shall have oil resisting insulation. There shall be no possibility of oil entering connection boxes used for cables and wiring when 415 volts connections are taken through junction boxes of marshalling boxes, they shall be adequately screened and 415 volts danger notice must be affixed to the outside of junction boxes or marshalling boxes. All wiring shall be in accordance with relevant ISS. All wiring shall be with stranded copper of 1100 volts grade and size not less than 4.00Sq. mm for CT leads and not less than 2.5 Sq.mm for other connections. All wiring cables shall be ISI-marked/certified.

All wires on panels and all multicore cables shall have ferrules which bear the same number at both ends. The same ferrule number shall not be used on wires in different circuits, on the same panels. Ferrules shall be of white insulating material and shall be provided with glossy finish to prevent adhesion of dirt. They shall be clearly and durably marked in black and shall not be affected by dampness or oil. Wiring shall, in general be accommodated on sides of the box and wires for each circuit shall be separately grouped.

Back of panel wiring shall be arranged so that access to the connecting stems of relays and other apparatus is not impeded. All the cables and capillary types of oil & WTI etc are to be wired properly on cable trays with the help of suitable cleats up to the marshalling box. The cable trays shall be kept minimum 100mm away from the tank body to avoid excessive heating of cables/wires.

Wires shall not be joined or tied between terminal points. Wherever possible, all circuits in which the voltage exceeds 125 volts, shall be kept physically separated from the remaining wiring.

The function of each circuit shall be marked on the associated terminal boards.

Where apparatus is mounted on panels, all metal cases shall be separately earthed by means of copper wire.

No live metal part shall be exposed at the back of terminals boards.

All fuses shall be of cartridge type of fuses and links shall be labeled.

All wiring diagrams for control panels shall preferably be drawn as viewed from the back. The overall design of wiring shall be such that various wires and ends of the same wire can be traced easily and there is convenience to access the terminations and ferrule number shall be readable with convenience.

1.31 Drying Out and Erection

The transformer shall be dried out by an appropriate method at the manufacturer's works and so arranged for transportation and storage that it may be put into service without further drying out at site. For any subsequent drying which may be necessary at site the manufacturer shall give details of the method recommended for using the same.

The transformer shall be designed to withstand pressure and vacuum tests as specified by CBIP specification for power and distribution transformers:-

- i) Vacuum as per CBIP manual to be applied to tank and cooling equipment when empty of oil.
- ii) Pressure of 1 Kg/Cm² mercury applied to tank and cooling equipment when empty of oil.
- iv) Pressure of 0.5 Kg/Cm² to be applied at conservator on fully assembled transformer when full of oil.

Clear instructions shall be given in the maintenance manual regarding special precautionary measures e.g. striking up of tap changer barrier or tank cover which must be taken before applying the specified vacuum treatments. The maximum vacuum which the complete transformer filled with oil, can safely withstand without any special precautionary measures being taken shall also be stated in the maintenance manual. The bushings shall be capable of withstanding vacuum operation when drying the transformer.

1.32 Drawings

One set of following dimensional drawings of the equipment offered, along with illustrated and descriptive literature shall be submitted.

The successful bidders after the award of the contract shall supply four copies of the following drawings within 30 days after the receipt of purchase order, which will describe the equipment in detail for approval by the Purchaser.

- i) Detailed outline General Arrangement drawing showing plan, front elevation, side elevation with all fittings and accessories etc. The following information must be specifically included on this drawing.
 - a) Make of transformer oil.
 - b) The no. of cooling fans, input to each cooling fan & its sweep.
 - c) Electrical clearances, minimum as well as actual.
 - d) The no. of radiator elements width, thickness of sheet & height of each radiator.
 - e) A small sketch showing untanking details.
 - f) Thickness of transformer tank bottom, side & top plates.
 - g) Type, shade, shade no. and thickness of transformer paints.
 - h) Roller, rail gauge sketch.
- i) Weight of oil, Bare copper windings, core, untanking mass, transportation mass and dimensions etc.
- ii) Detailed drawing of bushing, showing plan elevation, terminal details, mounting details, make and type number, incorporating electrical characteristics, description of various parts, total creepage/protected creepage distance, weight of oil, total weight of bushing, dimensions, short time rating etc.
- iii) Transportation sketch showing dimensions and weights of the heaviest package and the shipping arrangements of the transformer.
- iv) Rating and diagram plate.

NOTE: Bushing CT's for Winding Temperature Indicator (WTI's) are to be provided on HV side.

- v) Detailed structural drawings for the transformer tank, under carriage, conservator, radiators, supporting structures for cooling fans etc.
- ix) Dimensional drawings of multi bolt bimetallic connectors for line ends and flexible connectors for the neutral ends.
- x) Cooling equipment drawings :

General Assembly of fan control cubicle & marshalling box. The plan view showing foundation details must be specifically included if this cubicle box is separately mounted.
- viii) Schematic diagram of cooler control scheme along with detailed write up explaining the sequence of operations and functions of each equipment.

Wiring diagram/cabling details of fan control cubicle showing connections with WTI etc.

ix) Core Drawings:

- a) Core dimensional drawing showing frame size (Elevational plan) , limb Yoke sections along with step details and calculations for flux density and make of CRGO.
- b) Calculations for no load current, no load losses and characteristics of core Material shall also be finished.
- c) Make of CRGO and Sub-supplier name for cutting of CRGO shall be given in the drawing

x. Winding drawing:

- a) HV, LV and Regulating winding conductor cross-sections along with calculations for current density.
- b) Make of copper used and insulating paper/press board used shall be given in the drawing.
- c) Name of the vendor for processing of copper shall be given.

xi. Thermosyphon drawings:

Thermosyphon arrangement drawing, showing tray details, internal tray arrangement and removal of tray assembly etc. showing dimensions, qty. of oil and sorbant used.

xii. Roller stopper arrangement drawing

1.33 Additional Drawings

The following drawings shall be supplied for reference and record in addition to the above drawings enlisted in Para 1.32.

- i) Schematic diagram showing flow of oil in the cooling system as well as each limb of the core and winding and cross sectional views showing duct sizes, cooling pipes shall be furnished.
- ii) Large scale drawing of high and low voltage windings of transformer showing the nature and arrangement of insulation and terminal end connections.
- iii) Drawing showing sectional view of the HV and LV windings when viewed from top.
- iv) Detailed drawings of conservator and pressure relief device (explosive vent) mounted on position.
- v) Fan mounting details
- vi) Valves & plug schedule plate indicating the location of various valves on the transformer mentioning the functioning of each.
- vii) Foundation plan of the transformer including auxiliary equipment.
- xii) Any other drawing considered necessary by the Purchaser.
- ix) A schedule showing the requirement of set of spare gaskets.

1.34 Routine Testing:

All routine tests shall be carried out on each transformer as per IS- 2026/ IEC-60076 & IEC- 354.

(a) Type testing:

Following type tests and Transformer withstand capacity beyond name plate as per IEC-354 shall be carried out as per IEC-76/IEC- 354 & IS- 2026 on the transformers:-

- i) Temp. Rise Test with 2x50% coolers only.
- ii) Impulse Voltage withstand test on all the three phases with chopped impulse.

(b) Special Tests

- i) Dissolved Gas Analysis (DGA) Test before and after temp. rise test.

- ii) Noise Level Test.
- iii) Measurement of Tan Delta & Capacitance of Transformer winding and bushing At 10 kV
- iv) Magnetic balance test.
- v) Magnetising current at low voltage, excitation loss at 90% and 110% of rated voltage voltage measured by average voltmeter method. The excitation losses shall also be measured after impulse tests are completed.
- vi) Oil leakage test as per CBIP Manual

NOTE :

- a) The insulation resistance values of the transformer windings will be recorded at the time of carrying out routine tests, for 20 seconds, one minute, two minutes & ten minutes with the help of 5000 V motorized meggar. (Preferably EVERSLED/AVO & VIGNOLE MAKE). The polarization index values (ratio of 120 /20 sec. & ratio of 10 minutes/ 1 minute values) will be accordingly calculated and recorded in the test certificates and it should not be less than 1.5 & 2.0 respectively.
- b) Capacitance and Tan delta values for each transformer will be taken and recorded in the Test certificates at 10KV.
- e) Pressure/Vacuum test as per CBIP. However, vacuum test shall be carried out at full vacuum
- f) Lightning impulse test as per IS: 2026/ 1981 (Part-III)/ IEC-60076 amended up to date with chopped impulse on all the limbs of HV. &LV windings.
- g) The tenderer should clearly indicate the testing facilities available with them and tests which are to be arranged outside.

Losses shall be measured with- 3 Watt meter method only. Resistance shall be taken with Double-Kelvin Bridge. Losses shall be measured directly from CTs and PTs and through the panel. Ratios of the measuring instruments shall be such that the multiplying factor is the minimum.

All tests shall be carried out in the presence of the Purchaser before dispatching the material.

1.35 Testing Of Transformer Oil

The transformers are to be supplied oil filled if the total weight does not effect shipping. Sufficient quantity of oil (including 10% extra) of Napthene Base oil shall be put up for inspection 3 weeks before offering the transformers for inspection for carrying out necessary tests as per procedure prescribed in the relevant IS:335/BS/IEC. The testing should be carried out in the presence of Purchaser's representative at the works of oil supplier. A composit sample of oil may also be got further tested from nearest Central Power Research Institute (CPRI) lab for Tan Delta , Resistivity and water contents etc. on receipt of oil whether, being separately supplied filled in the transformer at purchaser's site.

1.36 Foundations and Fixings

All plant and equipment shall be provided with a complete set of foundation bolts, washers, nuts, plates and other fixtures as may be required and these shall be supplied by the supplier.

1.37 Off Circuit Tap Changer

Each transformer shall be provided with an off circuit tap changing switch suitable for varying its effective ratio of transformation whilst the transformer is de-energized and without producing phase displacement. The off circuit switch handle will be provided with a locking arrangement along with tap position indicator, thus enabling the switch to be locked in position. A warning plate indicating that switch shall be operated only when the transformer is de-energised shall be fitted.

1.38 Thermosyphon Filter Arrangement

Thermosyphon filter arrangement shall be provided on the transformer for preserving the quality of transformer oil. The filter assembly shall be mounted on the transformer/ground supported and connected with pipes and shut off valves. Suitable instruction required to be followed for commissioning, dismantlement and maintenance of the filter arrangement, regeneration and storage of the absorbent etc. must be included in the instructions manual. A detailed drawing, showing internal arrangement shall also be required to be submitted.

The absorbent capacity required in the Thermosyphon Filter shall be 0.7% (Min) of total oil by weight.

1.39 Fittings and Accessories

Each transformer shall be complete with the following fittings and accessories:

1. One 150 mm (6") dial type indicating thermometer (OTI) of robust pattern mounted on the side of the transformer at a convenient height to read the temperature in the hottest part of oil and fitted with alarm and trip contacts.
2. 2 Nos. 150mm dial type winding hot spot temperature indicators (WTI) placed in HV/LV winding, as described below:-

It shall be indicating type responsive to the combination of top oil temperature and winding current calibrated to follow the hottest spot temperature of transformer winding. The device shall have a additional pointer to register the highest temperature reached. Each winding temperature indicator should have four sets of contacts. The contacts of one of the WTI shall be used for trip and alarm purpose, wiring of which will go to the main control and relay panel of the transformer (external control cables from the Marchalling box to the C&R panel) are covered in separate section.

The third set of contacts of WTI shall be used in the cooler control circuit. In other words, it will act as a winding temperature control for ONAF cooling of transformers for automatic control of fans depending upon the temperature. Fourth set of contacts shall be spare.

The contacts of each WTI should be adjustable to close between 60° deg.C to 120 deg.C and shall reopen when the temperature has fallen by any desired amount between 10 deg.C to 25 deg.C. However, supplier should mention in their manuals the actual adjustable settings of these contacts.

Cooler control contacts of all the WTIs shall be wired in parallel.

3. One pressure relief valve/device (PRV) of minimum 6 inch (150mm) size for main tank with provision for alarm and trip contacts.
4. One explosion vent on transformer tank cover.
5. Inspection covers with jacking bolts in the top cover plate of the tank.
6. One filter cum oil drain valve with plug or blanking flange size 80mm.
7. One filter valve at top of transformer tank size 50mm.
8. Three oil sampling valves.
9. Set of lifting lugs/jacking lugs/pads and eye bolts on all parts for ease of handling.
10. One double float gas/oil surge detecting (Buchholz) relay in the pipe connecting the conservator with tank, complete with alarm tripping contacts to detect accumulation of gas and sudden of oil pressure, complete with two shut off valves on conservator side as well as tank side and a coupling to permit easy removal without lowering flanges/oil level in the main tank. The size of shut off valve shall be 80mm.

11. Two grounding terminals on breadth side of tank
12. One ONAN/ONAF cooling equipment comprising of suitable, 2x60% tank mounted radiators with shut valves, fans for ONAF cooling of transformers, air release and drain plugs. The fans shall be arranged in two groups for ONAF cooling of transformers) 2 Nos. metal encased alcohol thermometers for each cooler for fixing on incoming & outgoing headers of coolers.
13. Skids and pulling eyes on both sides.
14. One Marshalling box housing dial type thermometers for winding and oil temperature indicators with automatic control equipment for controlling fan motors, heater, complete wiring and local/auto selector switch and supply isolating switches with H.R.C. fuses/MCB's and Ammeter for indicating current of auxiliary equipment.
15. Two thermometer pockets for mercury in glass thermometer of minimum 10" depth from top level.
16. A set of universal type bi-metallic multi-bolt double grooved conductor clamps for HV side capable of receiving single ACSR conductor (Zebra) for primary bushing of 72.5 KV side of transformer.
17. Suitable bi-metallic flexible connectors for neutral terminals
18. I set of terminal bushings each for HV & LV winding
19. I set of Neutral bushing (s)
 - a) 1 No. filling valve
 - b) Oil valve between cooler and main tank.
 - c) Two nos. header valves on diagonally opposite corners (50mm) of each cooler.
20. Suitable size bi-directions wheels for 1676 mm rail gauge in both directions-4 Nos. along with locking and bolting devices.
21. The following plates in English shall be fixed to the transformer tank at about 1750mm above ground level :-
 - a) Rating plate bearing date as specified in IS: 2026/1977, it must contain insulation levels of various windings, impedance at normal & extreme taps short circuit duration, WTI ratio besides other information.
 - b) Terminal marking plate showing the internal connections & voltage vector relationship of various windings in accordance with IS: 2026: 1977 (Latest Edition).
 - c) Diagram plate showing the location and function of all valves and air release cocks or plugs.
24. Oil conservator (for main tank) complete with magnetic type oil level gauge, prismatic oil level gauge, filling hole and cap drain valve size 19mm, shut off valve, inter connecting pipes etc. Magnetic and a level gauge shall be provided with low oil level alarm contacts with a dial showing minimum, maximum and normal oil level. The gauge shall be readable from the transformer base level. Silicagel breather with oil seal, shall be fitted as already prescribed. Breather should be made of see through material and should consist of two compartments placed in parallel with 2x100% capacity. One drain pipe up to floor level with one valve may be provided.
25. One no. thermosyphon filter arrangement with spare Alumna for one time replacements.
26. One no. spare pocket on tank cover for thermometer.
27. Any other item which is not included above but is essential for the satisfactory operation of the equipment.