CHAPTER-8

SWITCHYARD EQUIPMENT- HV Bus Bars, Switchyard Structures, Isolating Switches, Current Transformers, Voltage Transformers, Lightning Arresters

8.1 Introduction

Outdoor step up substations at hydroelectric stations are provided to step up power at generated voltage generally for interconnection with the grid to evacuate power. Generation voltage varies from 415 volts to 11 kV (or higher) and step up voltage of small hydro up to 5 MW capacity may not exceed 36 kV. In case of large hydro stations the step up voltage may be up to 420 kV. Switchyard equipment comprises of main equipment, ancillary equipment and switchyard structures. Step up transformers and circuit breakers are discussed in Section 6 & 7. Insulators switchyard structures, isolating switches current and voltage transformers and lightning arrestors are discussed in this chapter. Auxiliary equipment for switchyards is common with powerhouse auxiliary and discussed in Section II (Chapter 4 & 5).

8.1.1 Standards and Codes

Relevant National Standards (Latest edition) are as follows:

IS: 9920 Part I to IV – Alternating current switches for rated voltages above 1000 volts and less than 52 kV
IS: 9921Part 1 to 5 – Alternating currents disconnectors (isolators) and earthing switches rating, design, construction, tests etc.
IS: 1893 – Criteria for Earthquake resistance design of structures
IS: 2705 Part 1 to 4 – Current transformer
IS: 3156 Part 1 to 4 – voltage transformer
IS: 3070 part 1 to 3 – Lightning arrestors
IS: 2544 – Porcelain insulators for system above 1000 V
IS: 5350 – Part III – post insulator units for systems greater than 1000 V
IS: 5621 – Hollow Insulators for use in electrical equipment
IS: 5556 – Serrated lock washers – specification
IS: 3716 – Application guide for insulation co-ordination
IS: 2165 – Phase to earth insulation co-ordination

8.2. General Requirements

8.2.1 General

The equipment is designed and manufactured to provide most optimum functional value and neat appearance. All major assemblies or equipment is designed to facilitate easy and quick surveillance, maintenance and optimum operation. All control sequences is simple and rational.

All live, moving and rotating parts are adequately secured in order to avoid danger to the operating staff. All electrical components are electrically earthed.

Suitable lifting eyes and forcing off bolts are provided where required or where they will be useful for erection and dismantling.

8.2.2 Seismic Consideration

Forces caused by earthquake which may occur for the seismic intensity of the zone concerned are taken into account. Stresses resulting after including these loads should not exceed permissible stresses. For Himalayan region projects it is specified as under:-

Switchyard equipment and structure be designed to safely withstand earthquake acceleration force 0.3g both in the vertical and horizontal direction in most Himalayan region.

For other regions refer IS: 1893.

8.2.3 Basic Insulation Level and Insulation Coordination

This is discussed in Para 6.7.2 for equipment up to 220 kV and Para 6.19 for EHV equipment for 420 kV.

8.2.4 Insulators

Provision of adequate insulation in a substation is of primary importance from the point of view of reliability of supply and safety of personnel. However, the station design is so evolved that the quantity of insulators required is the minimum commensurate with the security of supply.

Creepage Distance: An important consideration in determining the insulation in a sub-station, particularly if it is located near sea or a thermal power generating station or an industrial plant is the level of pollution. As a first step to combat this problem special insulator with higher creepage distance is used. In case this does not suffice, washing the insulators by using live line equipment has to be resorted to and this aspect has to be kept in mind while deciding the layout of the substation. Another method which has proved to be successful in some countries involves the application of suitable type of greases or compounds on the surface of the insulators. This, however, also requires cleaning of insulation, the frequency depending upon the degree and the type of pollution.

The creepage distances for the different pollution levels are provided according to table 8.1.

Table 8.1: Creepage distance for different pollution levels

Pollution Level	Creepage distance (mm/kV of highest system voltage)	Recommended for adoption (mm)
Light	16	25 x highest system voltage (kV) up to medium pollution level
Medium	20	
Heavy	25	
Very heavy	31	

For determining the creepage distance requirement, the highest line-to-line voltage of the system forms the basis.

8.2.4.1 Insulator Type

Types of insulators used:

A) Bus Support Insulators

i) Cap and Pin type
ii) Solidcore type
iii) Polycone type

B) Strain Insulators

i) Disc insulators
ii) Long rod porcelain insulators
iii) Polymer insulators

8.3 Switchyard Structures

The cost of structures also is a major consideration while deciding the selection of a substation. For instance, in the case of the strain/flexible bus-bar arrangement, cost of structures is much higher than in the case of rigid bus type. Similarly the form of structures also plays an important part and the choice is usually between using a few heavy structures or a large number of smaller structures. While finalizing the design, size and single line diagram of structures, safety clearance requirements should be ensured.

Steel is the most commonly used material in India for substation structures. Normally the steel structures are hot-dip galvanized so as to protect them against corrosion. However, galvanizing sometimes has not proved effective, particularly in substations located in coastal or industrial areas and in such cases painting also becomes essential. In other countries special paints have been developed which are applied within the shop and these paints have been quite effective.

8.3.1 Design Data for Design of Switchyard Structures

Design Loads

i) Wind Pressure on Structures (Refer table 8.2)

Maximum for the area on 1.5 times the projected area of one face for latticed structures and on single projected area in the case of other structures. In coastal regions the wind pressure may be assumed as 170 kg/sq.m.

ii) Wind Pressure on Conductor

…… kg/sq.m. (according to area see table 8.2) on two-thirds projected area.

iii) Maximum tension of transmission line conductors strung from terminal tower to station structures or of strung buses for lines 33 kV and above … 226.8 kg. (**Tamil Nadu Electricity Board Practice** - TNEB Practice).

iv) Maximum spans adjacent to stations:

a) Lines rated 66 kV and above …. 152.40 m
b) Lines rated 33 kV and below … 60.96 m

Table 8.2: Wind Pressure & Temperature Data

The table below gives the values of wind pressure and maximum and minimum temperatures specified in different states, as per REC for design of structure.

State	Wind Pressure Zones				Max. Temp.	Min. Temp.	ICE Loading
	Kg/m^2				^{0}C	^{0}C	
Andhra Pradesh	-	75	100	-	60	10	Nil
Assam	-	-	97.8	-	50	4.44	Nil
Bihar	-	-	97	-	60	4	Nil
Gujarat	-	75	100	-	50	10	Nil
Haryana	-	-	-	150	50	(-) 2.5	Nil
Kerala	-	75	-	-	55	10	-
Madhya Pradesh	-	75	-	-	60	4.4	Nil
Maharashtra	50	75	100	150	65	5	Nil
Karnataka	50	70	-	-	54.4	10	Nil
Orissa	-	75	100	150	60	5	Nil
Punjab	-	100	-	-	64.5	(-) 2.5	Nil
Rajasthan	-	-	100	-	50	(-) 2.5	Nil
Tamil Nadu	-	73.25	87.8	122	65.5	(-) 5	Nil
Uttar Pradesh	-	75	-	150	60	4.44	Nil
West Bengal	-	75	100	150	60	0	Nil

8.3.2 Working Stresses

a) for steel:

Bending	..	..	1265 kg/sq.cm.
Shear	..	..	1265 kg/sq.cm.

b) for concrete – 1 : 2 : 4

Bending	..	..	52.7 kg/sq.cm.
Shear	..	..	5.27 kg/sq.cm.
Bend	..	..	7.03 kg/sq.cm.

8.3.3 Factor of Safety

		Indian Electricity Rules	Adopted by (TNEB)	Recommended
a.	Fopr steel	2.0	2.5 based on maximum loading conditions (on elastic limit for tension members and crippling load for compression members).	As per TNEB Practice
b.	For R. C.	2.5	3.5 on ultimate breaking load	
c.	For hand Moulded R. C.	3.0		

Factory of safety against overturning:

a) Steel 2.5

b) R. C. 2.0

8.3.4 Slenderness Ratio (L/R)

Ratio of unsupported length (l) to radius of gyration (r) should not exceed;

a) 140 for leg members

b) 200 for other members having calculated stresses only and 250 for members having nominal stress only.

8.3.5 Minimum Thickness for Steel Members

Steel employed for structures – open hearth steel with a high yield point and an ultimate strength of not than 3867 kg/sq.cm.

The following maximum stresses in kg/cm^2 are assumed for outdoor structures, fabricated out of steel sections manufactured in India:

i.	Tension	18,000
ii.	Compression	18,000 ~ or less (based on slenderness ratio)
iii.	Shear on bolts	13,500
iv.	Bearing on bolts	27,000

8.4 Bus bars

The outdoor bus-bars are either of the rigid type or the strain type. In the rigid type, pipes are used for bus-bars and also for making connections among the various equipments wherever required. The bus-bars and the connections are supported on pedestal insulators. This leads to a low level type of switchyard wherein equipment as well as the bus-bars are spread out. Since the bus-bars are rigid. The clearances remain constant. However as the bus-bars and connections are not very high from the ground, the maintenance is easy. Due to large diameter of the pipes, the corona loss is also substantially less. It is also claimed that this system is more reliable than the strain bus. This type is however not suitable for earthquake prone area due to rigidity.

The strain type bus bars are an overhead system of wires strung between two supporting structures and supported by strain type insulators. The stringing tension may be limited to 500-900 kg. depending upon the size of the conductor used. These types of busbars are suitable for earthquake prone areas.

8.4.1 Bus bar Material – The materials in common use for bus bars and connections of the strain type are ACSR and all aluminum conductors (AAAC). The following sizes are commonly used.

	Code Name	Remarks
12 kV = 6 x 4.72 + 7 x 1.76	Dog up to 10 MVA	i) SHP voltage is generally
	ACSR	
36 kV = 6 x 4.72 + 7 x 1.76	Dog up to 10 MVA	up to 66 kV
72.5 kV = 30 x 2.79 + 7 x 2.79	ACSR Panther	ii) In case line conductor
145 kV = 30 x 4.27 + 7 x 4.27	ACSR	Zebrais of higher sizes, same be
245 kV = 54 x 3.53 + 7 x 3.53	ACSR	(Moose) adopted as bus bar material
	AAAC	
420 kV = 54 x 3.53 + 7 x 3.53	ACSR	

In the case of rigid bus arrangement, aluminum pipes of Grade 63401 WP confirming to IS: 5082 are commonly used. The sizes of pipes commonly used for various voltages are given below:

External Dia.	Internal Dia	System Voltages	Remarks
42 mm	36 mm	Up to 36 kV	Tamil Nadu Uses 50 mm IPS Aluminium Tube up to 72.5 kV
60 mm	52 mm	Up to 72.5 kV	Tamil Nadu Uses 75 mm IPS Aluminium Tube for 110 & 230 kV
80 mm	70 mm	Up to 145 kV	
114 mm	102 mm	Up to 245 kV	-
127 mm	109 mm	Up to 420 kV	-

Since aluminum oxides rapidly great care is necessary in making connections. In the case of long spans expansion joints are provided to avoid strain on the supporting insulators due to thermal expansion or contraction of pipe.
The bus bar sizes meet the electrical and mechanical requirements of the specific application for which they are chosen.

8.5 Isolating Switches and Earthing Switches

Isolating switches are used to isolate equipment for maintenance. Isolating switches on line side are provided earthing blade for connection to earth in off position for safety. Transfer of load from one bus to another by isolators is not recommended. The isolating switches are designed for no load operation. Inadvertent operation of the isolating switch on load will damage the switch. Although a variety of disconnect switches are available, the factor which has the maximum influence on the station layout is whether the disconnect switch is of the vertical break type or horizontal break type. Horizontal break type normally occupies more space than the vertical

Isolators for 12 kV and 36 kV normal system voltage conform to IS: 9920 (Part I to IV) and for voltage 66 kV and above as per IS: 9921.

Earthing switches is a mechanical switching device for earthing parts of a circuit, capable of withstanding for a specified time short-circuits currents, but not required to carry normal rated currents of the circuit.

Disconnecting switches may be motorized or operated manually. Generally isolating switches 72.5 kV and above are motorized. Earthing switches may be manually operated or motorised.

In case of double circuit lines the earthing switches are capable of switching inductive (electromagnetically induced) and capacitive currents (electrostatically induced) as per the values specified in IEC 62271 – 102 when parallel circuit is energized. The disconnector are capable of interrupting and making parallel circuits when transferring load between main and reserve bus bars according to IEC requirements.

8.5.1 Temperature Rise

Maximum temperature attained by any part of the isolating switch/ isolating cum-earth switches when in service at site under continuous full load conditions and exposed continuously to the direct rays of the sun and the air has to be evaluated carefully and depends upon site conditions e.g. for 2x10 MW Mukerian SHP 72.5 kV switchyard (Punjab Plains), it was specified as follows and is recommended for similar breakers.

i) Reference ambient temperature in shade = 50^0C
ii) Reference temperature under direct rays = 60^0C
of the sun for limiting temperature rise as per IS: 9921

8.5.2 Rating

Each isolating switch generally has the following particulars (table 8.3) under the site conditions for the system under design.

Table 8.3

		Large Hydro up to 245 kV	**Small Hydro**	**Micro Hydro**
1.	Highest system voltage	72.5 kV & above	36 kV	12 kV
2.	Rated frequency (cycle/second)	50 c/s	50 c/s	50 c/s
3.	Rated lightning impulse withstand voltage (without arcing horn) i) To earth and between poles (kV Peak) ii) Across the isolating distance (kV peak)	(As per insulation coordination) to be stated (+ ve & - ve wave to earth & between poles)	170 kV 195 kV	75 kV 85 kV
4.	Rated one-minute power frequency wet withstand voltage i) To earth and between poles (kV rms) ii) Across the isolating distance (kV rms) Voltage against ground and between poles	(As per insulation coordination) (against ground & between poles) To be stated	70 kV 80 kV	28 kV 32 kV
5.	Continuous rated current (Amps)	1600 A or higher	630 A	400 A
6.	Short time current ratings i) For one second not less than kA (rms) ii) For 3 seconds	20 kA or higher To be stated	16 kA To be stated	16 kA To be stated
7.	Rated peak withstand current kA (peak) in closed position	To be stated	40 kA	40 kA
8.	Transformer off-load breaking capacity A (rms)	To be stated	6.3 kA	6.3 kA
9.	Line charging capacity A (rms)	To be stated	6.3 A	2.5 A
10.	Rated DC voltage for auxiliary circuits A (rms)	To be stated		
11.	Rated supply frequency and voltage of AC operating devices	3 phase 415 volts and single phase 220 V AC		

Isolators 36 kV and 12 kV: conform to IS: 9920
Isolated 72.5 kV & above should conform to IS: 9921

The location of disconnect switches in substations affects substation layouts. Maintenance of the disconnect contacts is also a consideration in the layout. In some substations, the disconnectors are mounted at high positions either vertically or horizontally. Although such substations occupy smaller areas, the maintenance of disconnect switch contacts in such substations is more difficult as the contacts are not easily accessible.

8.5.3 Isolator Insulation

Insulation to ground, insulation between open contacts and the insulation between phases of the completely assembled isolating switch is capable of withstanding the dielectric test voltages specified as per IS: 2026.

Insulation between open contacts of a pole is at least 15% more than the insulation between the live parts of a pole to ground so that if any flashover occurs when switch is open, it is to the ground.

The post insulators consist of no. of stack units conforming to IS: 2544. The insulators selected is suitable for use in the type of normally polluted atmosphere of the area as per relevant IS and is made specifically suited to meet the particular requirements of ultimate torosional strength and cantilever loads which they are called upon to resist during service at the rated voltages. The guaranteed data and particulars of the insulators adopted for the equipment is obtained from the supplier.

The porcelain should be homogeneous and free from all cavities and flaws.

Design of the insulators ensures ample insulation, mechanical strength and rigidity for satisfactory operation under site conditions. The design also ensures that the losses caused by capacitive currents or conduction through dielectric are minimum and that the leakage due to moist and dirty insulator surface is least.

8.5.4 Arcing Horn & Arcing Contacts

A set of adjustable arcing horns is mounted on each insulator stack of the isolating switch.

Besides above adjustable arcing horns which are required for the purposes of insulation co-ordination, the isolators may be provided make before and break after arcing contacts if considered necessary by the manufacturers.

A graph showing impulse and power frequency spark over voltages for various gap settings of the arcing horns is obtained from supplier.

8.5.5 Load Break Switches

Load break switches for sectionalizing if required may be used as per following specifications.

i) 12 kV REC Specification 43; IS: 9920 Part I to IV
ii) 36 kV REC Specification 54; IS: 9920 Part I to IV
iii) 72.5 kV & above IS: 9921

8.5.6 Terminal Connectors

Each isolator connected with outgoing lines is provided with appropriate number of bimetallic, solderless clamp type of connectors suitable for the transmission line conductor. Each terminal clamp is made suitable for both vertical & horizontal connection of station bus bars and jumpers. Each isolator is also to be provided with appropriate number of grounding terminals and clamps for receiving grounding connections. The maximum length of the jumper that may be safely connected or any special instructions considered necessary to avoid undue loads on the post insulators is avoided.

8.5.7 Interlocks

"For the purpose of making the operation of the isolator dependent upon the position of the associated circuit breaker or other equipment as may be required at site, a suitable electrical interlock is provided on each isolator. The interlocks should of robust design of some reputed make and contained in a weather proof and dust tight housing.

Besides the electrical interlocks, the earthing switches are provided with mechanically operated interlock so as to ensure that: -

(a) It should be possible to close the earthing switch only when the isolating switch is in the fully open position.

(b) It should be possible to close the isolating switch only when the earthing switch is in the fully open position.

(c) The earth switch should not open automatically while attempting to close the isolator.

The operation of the earth switches is also interlocked with the CVTs/CTs supplies from the transmission line i.e. it should be possible to close the earth switch only when the line is dead from the feeding end, and there is no supply from the secondaries of the line CVTs/CTs.

(d) The operation of earth/isolating switch should not take place when the corresponding isolator/earth switch is in operating mode.

In addition to the above, the line and the bus isolators are made to fulfill the following requirements:-

(i) The circuit breaker of corresponding bay is open.

(ii) The bus isolator of the bus coupler bay should close only when the bus coupler circuit breaker is open.

(iii) The line isolator should close only when the corresponding circuit breaker and the earthing switch of the corresponding line are open.

(iv) Electromagnetic type interlocking is also provided to avoid wrong local operation of the isolator (manual or motor) when the corresponding circuit breaker is in closed position. Operation of isolator may be categorized manual or motorized with remote facility according to facilities provided in the system.

Isolators and earth switches are so designed that the above noted requirements can be conveniently met.

8.5.8 Supporting Structures

All isolators and earthing switches are mounted rigidly in an upright position on their own galvanised steel supporting structure and not on the bus-bar structures.

8.5.9 Tests

Each isolator and earth switch is to strictly comply with the requirements of all the type tests and subjected to all routine tests stipulated in the latest edition of relevant Indian standard (IS: 9920 and 9921).

Copies of the type tests already performed on similar type of isolators are obtained and scrutinized for adequacy.

8.6 Current Transformers

Current transformers may be either of the bushing type or wound type. The bushing types are normally accommodated within the transformer bushings and the wound types are invariably separately mounted. The location of the current transformer with respect to associated circuit breaker has an important bearing upon the protection scheme as well as layout of, substation. Current transformer class and ratio is determined by electrical protection, metering consideration.

Outdoor Type: The outdoor CTs are either oil filled type or of resin cast type (up to 36 kV) which should be enclosed in a sealed housing to avoid direct exposure to sun and other atmospheric effects.

Current ratings, design, Temperature rise and testing etc. is in accordance with IS: 2705 (Part I to IV). Unless otherwise specified in these specification.

12 kV current transformers should conform to Rural Electrification Corporation (REC) specification 59/1993.

8.6.1 Type and Rating

The current transformer is of outdoor type, single phase, oil immersed, self cooled and suitable for operation in 3 phase solidly grounded system.

Each current transformers should have the following (table 8.4) particulars under the site conditions for the system under design (typical 245 kV system).

8.6.2 Details of Current Transformer

Details of current transformer i.e. current, number, ratio, no. of cores and protection/metering class based on metering and relaying scheme are specified.

Table 8.4

		Large Hydro	**Small Hydro**	**Micro Hydro**
i)	Nominal system voltage	66 kV & above	33 kV	11 kV
ii)	Highest system voltage	72.5 kV & above	36 kV	12 kV
iii)	Frequency	50 Hz	50 Hz	50 Hz
iv)	Insulation level (kV Peak) (based on system insulation coordination) Impulse withstand test voltage with 1.2/50 micro-second, + ve and – ve wave to earth and between poles	To be stated	170 kV	75 kV
v)	One minute power frequency (wet) withstand voltage against ground and between poles.	- kV (rms) to be stated	70 kV (rms)	28 kV (rms)
vi)	Short time current rating (based on system studies)	- kA To be stated	31.5 kA	12.5 kA
vii)	Rated dynamic current peak (based on system studies)	- kA To be stated	2.5 time of short time current rating vi	
viii)	Total minimum creepage of CTs bushings (based on environment)	As per Para 8.2.4		

a) Temperature rise of CTs up to 36 kV Class

The maximum temperature rise of windings does not exceed the following (table 8.5):

Table 8.5

	Indoor Type	**Outdoor Type**
Maximum ambient temp.	45^0C	60^0C
Permissible temp. rise for Class E insulation Class B insulation Class F insulation	 70^0C 80^0C 105^0C	 50^0C 60^0C 85^0C

Temperature Rise

b) 72.5 kV and above

The maximum temperature attained by any part of the equipment in service at site under continuous overload capacity conditions and exposed continuously to the direct rays of sun should not exceed the permissible limit fixed by the applicable standard, when corrected for the difference between the ambient temperature at site and the ambient temperature specified by the standard.

8.6.2 General Requirements of Current Transformer

a) 72.5 kV & Above

Current transformers should be of robust design, tested quality and reliable in operation. Only pure high grade paper, wound evenly under controlled conditions and impregnated with mineral oil under high vacuum is required to be used for the main insulation. The assembly of each CT is dried, filled with appropriate quality of insulating oil under high vacuum and hermetically sealed with or without inert gas to eliminate undesirable effect of moisture and oxygen on the internal insulation. No breathers and/or drying chemicals are allowed in the design and construction of CTs.

The shape of the external metal parts is required to ensure that rain water runs off and it does not accumulate. All external surfaces are required to be resistant to atmospheric corrosion either by the selection of suitable materials or by proper treatment such as hot dip galvanization, zinc coating and suitable enamel painted over rust inhibitive coat of zinc chrome primer etc. Likewise, the internal metal surfaces coming in contact with oil should be given proper treatment unless the material used itself is oil resistant. Bolts, nuts and washers to be used as fastners should be heavily hot dip galvanised throughout. The galvanising should conform to IS: 2629-1966. All CTs should have an oil level gauge marked with the maximum and minimum levels. Although no oil samples may be required to be taken for analysis or any filter connections made for reconditioning of oil at site but a filling plug at the top and a drain at the bottom of the lower tank should be provided on each CT for use during initial assembly or any subsequent repair.

The current transformers should be with dead/live tank design. The current transformers should be of single phase oil immersed, self cooled and suitable for services indicated, complete in all respects conforming to the latest edition of relevant standard specification. The cores should be of high grade, non-ageing silicon laminated steel of low hysteresis loss and high permeability to ensure high accuracy at both normal and fault currents. The CTs should be hermetically sealed with or without inert gas to eliminate breathing and prevent air and moisture from entering into the tank. To take care of volumetric variation of oil due to temperature changes, stainless steel bellows/Nitrogen is provided. In case Nitrogen is used the supplier is required to ensure that gas is filled at suitable pressure to take care of the expansion & compression of nitrogen gas. The equipment should be provided with oil level gauge and pressure relieving device capable of releasing abnormal internal pressures. The secondary terminals should be brought out in a compartment on one side of the equipment for easy access. The secondary taps should be adequately reinforced to withstand normal handling without damage. Equipment is provided with power factor terminals for testing loss angle (Tan delta). The equipment is provided with drain valve, sampling plug to check deterioration of oil characteristics and replacement of oil at site. Means adopted for sealing the CTs hermetically and to absorb the variation in volume of oil due to temperature variation by way of provision of stainless steel volume adjustable bellows or other means is required to be specifically approved. Rubber or PVC/synthetic bellows for the purpose are not accepted. The secondary terminals of CTs are provided with short circuiting arrangement.

b) 36 kV and 12 kV Class CTs (For Small and Micro Hydro)

Windings: Change in the CT ratio is obtained by providing tapings in the secondary winding. The primary bar and secondary windings are of copper.

Core: The core of the CT is invariably of torroidal type. The magnetic circuit is of high grade, non-ageing electrical silicon laminated steel of low hysterias loss and high permeability to ensure high accuracy at both normal and over currents.

8.6.4 Terminal Connectors 72.5 kV and Above

All current transformers are provided with appropriate number of solder less clamp type primary connectors suitable for ACSR conductor and should be suitable for horizontal as well as vertical takeoff with single conductor as per actual requirement.

8.6.5 Type of Mounting

a) 72.5 kV and Above

The current transformers are required to be suitable for mounting on steel structures. The necessary flanged, bolts etc. for the base of CTs are galvanized.

b) 36 kV and 12 kV Class Outdoor Type

The CTs are supported on a suitable post insulator to be mounted on a pedestal/steel structure. Mounting flanges, bolts, etc. are hot dip galvanized and supplied along with the CT. Suitable mounting holes are provided at the base for clamping to the structures.

The CTs are provided with bolted type terminals to receive ACRS conductors up to 15 mm dia (without requiring use of lugs) both in vertical and horizontal directions. The terminals are such as to avoid bimetallic actions.

8.6.6 Tests

Each current transformer are required to comply with type and routine test including short time current test as stipulated in relevant Indian Standard specification.

8.6.7 External Insulation (72.5 kV & Above)

The external insulation comprises of a hollow porcelain, which also serves as a housing for the main insulation or other internal parts of the CTs. Insulators are of high grade and homogeneous porcelain made by the wet process. The porcelain should have hard glazing and should comply with the requirements of IS 5621 in all respects. The skirt forms are carefully selected to achieve the necessary flashover distance and total / protected creepage distances as required.

8.6.8 Fittings and Accessories (72.5 kV & Above)

1. Primary terminals
2. High frequency current surge divertors
3. Terminal connectors for connections from line to the CT primary
4. Oil level gauge
5. Pressure relief device
6. Expansion chamber or other suitable type of device for absorbing variations in the volume of oil due to change of temperature.
7. Weather proof secondary terminal box fitted with door and complete with terminals and shorting links.
8. Lifting lugs
9. Fixing lugs with bolts, nuts and washers for holding down the CTs on the supporting steel structures.
10. Rating and diagram plates
11. First filling of oil
12. Oil filling plug and drain valve
13. Earthing terminals

8.7. Potential Transformer and Coupling Voltage Transformer

a) 72.5 kV & Above (up to 245 kV)

The voltage transformer may be either of the electro-magnetic type or the capacitor type. The electro-magnetic type VTs are costlier than the capacitor type and are commonly used where higher accuracy is required as in the case of revenue metering. For other applications capacitor type is preferred particularly at high voltages due to lower cost and it serves the purpose of a coupling capacitor also for the carrier equipment. For ground fault relaying an additional core or a winding is required in the Voltage transformers which can be connected in open delta. The voltage transformers are connected on the feeder side of the circuit breaker. However, another set of voltage transformer is normally required on the bus-bars for purpose of synchronization. Potential transformer class and ratio is determined by electrical protection, metering consideration.

b) 36 kV and 11 kV Class

The voltage transformers are of outdoor, 3 phase either oil filled or resin cast type, which are enclosed in a weather-proof housing to avoid direct exposure to sun and other atmospheric influences. The incoming and outgoing terminals are brought out through suitable porcelain bushings. The voltage transformers are suitable for operation in a solidly grounded system.

8.7.1 Type and Rating of Potential Transformer (PT)

Potential transformer, design, Temperature rise and testing etc. is required to be in accordance with IEC: 186, IS: 3156 (Part I & II).

The PTs are single phase oil immersed self cooled type suitable for outdoor installation of kV class required. The core is of high grade non ageing electrical silicon laminated steel of high permeability. The PTs are sealed hermetically sealed to eliminate breathing and prevent air and moisture entering the tank. Oil level and pressure releasing device etc. are provided.

Each potential transformers have the following (table 8.6) particulars under the site conditions for the system under design.

Table 8.6

		Large Hydro	**Small Hydro**	**Micro Hydro**
1.	Rated voltage	72.5 kV & above	36 kV	12 kV
2.	Rated frequency	50 Hz	50 Hz	50 Hz
3.	Accuracy class of winding	1.0	1.0	1.0
4.	Voltage ratio	66 kV/√3/110V/√3	33 kV/√3/110V/√3	11 kV/√3/110V/√3
5.	Grade of oil	As per IS: 335		
6.	Maximum phase angle error with 25% and 110% of rated burden at 0.8 p.f. lagging at any voltage between 80% and 120%	40 min.	40 min.	40 min.
7.	Temperature rise at 1-1 times rated voltage with rated burden (OC)	As per IS: 3156	As per IS: 3156	As per IS: 3156
8.	Rated voltage factor & time	Continuous 1.2 30 sec. – 1.5	Continuous 1.2 30 sec. – 1.5	Continuous 1.2 30 sec. – 1.5
9.	1 minute power frequency (wet/dry) withstand test voltage	- kV r.m.s. To be stated	75 kV r.m.s.	28 kV r.m.s.
10.	1.2/50 micro seconds impulse wave withstand test voltage	- kV (Peak) To be stated	170 kV (Peak)	75 kV (Peak)
11.	One minute power frequency withstand test voltage on secondary	- kV To be stated	2 kV	2 kV
12.	3 second short time current relay	As per IS: 3156	As per IS: 3156	12.5 kA
13.	Dynamic Rating	As per IS: 3156	As per IS: 3156	2.5 times
14.	Minimum creepage distance of bushings (based on environment)	As per Para 2.4		

8.7.2 Temperature Rise

a) 72.5 kV & Above

The maximum temperature of the windings, cores etc. is not allowed to exceed 45°C over ambient, while max. temperature of oil at top does not exceed 35°C over ambient. The PTs are required to be suitable for mounting on steel structures. All nuts, bolts, flanges and base are hot dip galvanized. The terminal connectors are such as to give intimate contact between conductor & terminal and offer protection against and effects of electrolytic and atmospheric corrosion and should also have sufficient mechanical strength. The connectors should conform IS 5556: 1970. The junction boxes are required to be suitable for terminating all the connections of the PTs secondaries with other equipments of the power station 400V grade terminal connectors of 15 Amp (continuous) current rating are provided.

b) 36 kV and 12 kV Class

When tested in accordance with IS: 3156, the temperature rise of the windings should not exceed the following limits (table 8.7):

Table 8.7

Class E insulation	50^0C
Class B insulation	60^0C
Class F insulation	85^0C

Note: Maximum ambient temperature is taken as 65^0C

8.7.3 12 kV Voltage Transformer

The dimensions and electrical characteristics of the 12 kV bushings are required to be in accordance with IS: 2099-1986 or its latest version.

The tank is provided with two separate earthing terminals. The tank is required to be given three coats of rust preventing paint. The other iron parts are required to be hot dip galvanized. The tank is required to be provided with lifting lugs either welded on the sides or top cover plate of the tank.

The unit has rating and diagram plate and have suitable base channels to facilitate mounting of the equipment on the structure.

Terminals: The voltage transformers is provided with bolted type terminals on the 12 kV side to receive ACSR conductors up to 8 mm dia (without requiring use of lugs) both in vertical and horizontal directions. The terminals oare such as to avoid bimetallic action.

8.7.4 Coupling Voltage Transformer (72.5 kV & Above)

These transformers are suitable for use on transmission line to pass through the carrier frequencies for communication and low voltage for protection and metering. The single phase CVTs are of suitable ratio (say 245 kV/√3/110V/√3 for 245 kV line) suitable for outdoor installation on steel structures. The equipment is supplied with terminal connectors suitable for vertical takeoff from line conductor and hot dip galvanized base fasteners. Other details are in accordance with the specifications for potential transformers. The secondary terminals are provided duly marked for above requirements.

The wave traps are hung underneath feeder bay structure. The carrier frequencies and wave trap capacity are decided in accordance with the other ends of the transmission lines terminating at substation.

8.8 Power Transformers Layout

Selection of power transformer is discussed in chapter 6. Layout of transformer is discussed as it is the largest piece of equipment in a substation and it is, therefore, important from the point of view of handling and station layout. In small hydro stations transformer are installed in the switchyard and the bay width is determined by transformer dimensions. Handling of transformer is normally done by the powerhouse crane and for large transformer rails are laid from powerhouse to the site of installation in switchyard. For this purpose bi-directional rollers are provided on the transformers. Arrangement for removal of transformer in case of repair/maintenance without disturbing other equipment is required and also affects layout. In order to reduce the chances of spread of fire, transformers are provided with a soaking pit of adequate capacity to contain the total quantity of oil. Sometimes drainage arrangements are provided to drain the oil away from the transformers in case of fire. Separation wall are provided in between the transformers and also between the transformer and roads within the substation.

8.9 Lightning Arrestors

Lightning arrestors are the basis of insulation co-ordination (Para 6.7 of chapter 6) in the system and are installed as near to outdoor transformer terminals as possible for direct protection against lightning impulse overvoltage spark over (1.2/50 micro second wave) and are capable of withstanding dissipation of energy associated with lightning impulse only. This implies that temporary over voltages (at or near power frequency) which are of the order of mili-second must be withstood to avoid damage. Taking into consideration high temporary over voltages expected on load throw off 90- 95 % lightning arrestors should be provided in step up substation.

Metal oxide (gapless) lightning arrestor confirming to following standards are now being specified.

IEC: 99-4 - Specification part – 4 for surge arrestor without gap for AC system
IS: 3070 - Specification for lightning arrestors
Parameters for the system (typical values for 66 kV system for large hydro) are given in (table 8.8) below.

Table 8.8

		Large Hydro	Small Hydro	
1.	Nominal system voltage (kV rms)	- (66 kV)	33 kV	11 kV
2.	Highest system voltage (kV rms)	- (72.5 kV)	36 kV	12 kV
3.	1.2/50 microsecond impulse voltage withstand level a) Transformer (kVp) b) Other equipment and lines (kVp)	 - (325) - (325)	 170 170	 75
4.	Minimum prospective symmetrical fault current for 1 second at Arrestor location (kA rms) (based on system studies)	- (31.5 kA)	To be stated	
5.	Anticipated levels of temporary over voltage and its duration(based on system studies) a > Voltage (p. u.) b > Duration (seconds)	a. 1.5 b. 1.2	a. 1.5 b. 1.2	a. 1.5 b. 1.2
6.	System frequency(Hz)	50 ± 2.5 c/s	50 ± 2.5 c/s	50 ± 2.5 c/s
7.	Neutral Grounding	Effectively earthed	Effectively earthed	Effectively earthed
8.	Number of Phases	Three	Three	Three

8.9.1 General Technical Requirements

1 The Surge Arrestors conform to the technical requirements given in table 8.9.
2 The energy handling capability of the Arrestor offered, supported by calculations is obtained with offer.
3 The Lightning Arrestor are fitted with pressure relief devices and arc diverting ports and tested as per the requirements of IEC specification for minimum prospective symmetrical fault current.
4 The grading ring on each complete Arrestor for proper stress distribution is provided if required for attaining all the relevant technical parameters.

Note 1

Terminal Arrangement: The tope metal cap and the base of the lightning arrestors is galvanized. The line terminal have a built-in-clamping device which can be adjusted for both horizontal and vertical takeoff to suit ACSR (conductor size to be specified by the purchaser). The base of the lightning arrestors is provided with two separate terminals distinctly marked for connection to earth.

Sealing: The arrestors are hermetically sealed to avoid ingress of moisture. Suitable rubber gaskets with effective sealing system are used. Manufacturers are required to devise a suitable routine production testing to verify the efficiency of sealing.

Table 8.9 Technical Requirements For Metal Oxide (Gapless) Lightning Arrestors (with special reference to 66 kV for large system)

		Large Hydro	Small Hydro	
1.	System voltage	66 kV	33 kV	11 kV
2.	Rated Arrestor Voltage kV rms	60	30	9
3.	Max. continuous operating voltage (kV rms)	49		
4.	Installation	Outdoor	Outdoor	Outdoor
5.	Class	Station Class	Station Class	Station Class
6.	Type of construction for 10 kA rated arrestor	Single Column, Single-phase	Single Column, Single-phase	Single Column, Single-phase
7.	Nominal discharge current corresponding to 8/20 micro sec wave shape (kA rms)	10 kA	10 kA	5 kA
8.	Type of mounting	Pedestal	Pedestal	Pedestal
9.	Connection	Phase To Earth	Phase To Earth	Phase To Earth
10.	Max. Switching Surge kV(P) Protective level voltage at 1000 amp.	140	70	NA
11.	Maximum steep current impulse residual voltage at nominal discharge current kV (Peak)	186	93	38
12.	Maximum residual voltage at nominal discharge current kV	170	85	32
13.	Minimum prospective symmetrical fault current for pressure relief test(kA rms)	31.5		
14.	a. Terminal Connector suitable for ACSR conductor size b. Take off	Single suitable ACSR Vertical/Horizontal	Vertical/Horizontal	Vertical/Horizontal
15.	Whether insulating base and discharge counter with milli- ammeter are required	Yes	Yes	Yes
16.	Minimum creepage distance of Arrestor housing(mm)	As per table 8.2.1		

Disconnective Device: The arrestors for 11 kV systems may be provided with a suitable disconnecting device. This is connected in series with the ground lead and should not affect the sealing system of the arrestors. The disconnecting device conform to the requirements specified in IS: 3070 (Part – 2) – 1985.

Pressure Relief Device: The arrestors for 33 kV (oil filled) and large system arrestors should have a suitable pressure relief system in order to avoid damage to its porcelain housing.

8.9.2 Lightning Protection

A substation has to be shielded against direct lightning strokes by provision of overhead earth wires or spikes. This equipment is essential irrespective of the isoceraunic level of the area due to .serious consequences and damage to costly equipment in case substation is hit by a direct stroke. The choice between these two methods depends upon several factors economy being the most important consideration. Both the methods have been used sometimes even in the same station. Generally, the spikes method involves taller structures than the alternative of using earth wires. Another method' comprises the use of separate lightning masts which are provided at location determined on the basis of substation area and height of bus-bars. - Besides providing lightning protection, these masts serve as supports for luminaires required for switchyard illumination. Spikes and the earth-wire have to be suitably placed so as to provide coverage to the entire substation equipment. Generally an angle of shield of about 45° for the area between ground wires and, 30° for other areas is considered adequate for the design of lightning protection system.

8.10 Equipment for Communication, Relaying and Tele Metering and Off-site Control

Following types of equipments may be used for the purpose.

i) Carrier Equipment
ii) Microwave
iii) VHF wireless
iv) Dedicated fibre optic cable

Carrier equipment is most commonly used system in the country. The carrier equipment required for communication, relaying and Tele metering is connected to line through coupling capacitor and wave trap. The wave trap installed at the line entrance. The coupling capacitors are installed on the line side of the wave trap and are normally base mounted. The wave traps for voltage levels up to 145 kV can be mounted on the gantry structure on which the line is terminals at the substation or mounted on top of the capacitor voltage transformer. Wave traps for voltage levels of 245 kV and above generally require separate insulator stacks mounted on structure of appropriate height.

VHF equipment for communication only may be recommended for 33 kV systems. Fibre optic cable is recommended when offsite control is provided.

Economic study for Microwave transmission for the purpose is required.

8.11 Reactive Compensation Equipment

Reactive compensation is seldom required in hydroelectric substation up to 220 kV except in small hydro using induction generator. Capacitor bank is required for reactive power requirement. This could be at generator voltage or high voltage and is provided step up substation.

Reactive compensation for 400 kV substations may be of switched or non-switched type as indicated by system studies of the system in which the substations are located.

The non-switched type compensation usually comprises shunt reactors permanently connected to transmission line or to bus bars at the substations as per the requirements. Next to the transformer shunt reactors constitute large pieces of equipment. These also can be in the form of single phase units or three phase units. Often another reactor called neutral grounding reactor which is connected between the neutral busing of the shunt reactor and earth is provided to facilitate single-pole auto-reclosing. Since these equipments also contain oil, the provisions which are necessary' for transformers have to be made for shunt reactors also.

The switched compensation can comprise switched reactors, switched capacitors or thyristor controlled reactors and thyristor switched capacitors known as State Var Compensators (SVC). These are selected according to the system requirements. Depending on the quantum of compensation required, it may be connected through the tertiaries of transformers if the compensation to be provided is small and' may be provided separately on 400 kV bus-bars of substation if the compensation to be provided' is large. Sometimes switched type line reactors may have to be provided if necessitated by the system requirements

References

1. Rural electrification Corporation (REC) specification and standards
2. Power Engineers Hand Book - Tamil Nadu Engineer’s Association
3. Central Board of Irrigation and Power - Manual on Sub-Station Layout