STANDARDS/MANUALS/ GUIDELINES FOR SMALL HYDRO DEVELOPMENT

3.3
Electro-Mechanical–
Design of Switchyard and Selection of Equipment, Main SLD and Layout

Sponsor:

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Lead Organization:

Alternate Hydro Energy Centre
Indian Institute of Technology Roorkee

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Contact:
Dr Arun Kumar
Alternate Hydro Energy Centre,
Indian Institute of Technology Roorkee,
Roorkee - 247 667, Uttarakhand, India
Phone : Off.(+91 1332) 285821, 285167
Fax : (+91 1332) 273517, 273560
E-mail : aheciitr.ak@gmail.com, akumafah@iitr.ernet.in

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AHEC-IITR, "3.3 Electro-Mechanical– Design of Switchyard and Selection of Equipment, Main SLD and Layout", standard/manual/guideline with support from Ministry of New and Renewable Energy, Roorkee, June 2012.

PREAMBLE

There are series of standards, guidelines and manuals on electrical, electromechanical aspects of moving machines and hydro power from Bureau of Indian Standards (BIS), Rural Electrification Corporation Ltd (REC), Central Electricity Authority (CEA), Central Board of Irrigation & Power (CBIP), International Electromechanical Commission (IEC), International Electrical and Electronics Engineers (IEEE), American Society of Mechanical Engineers (ASME) and others. Most of these have been developed keeping in view the large water resources/ hydropower projects. Use of the standards/guidelines/manuals is voluntary at the moment. Small scale hydropower projects are to be developed in a cost effective manner with quality and reliability. Therefore a need to develop and make available the standards and guidelines specifically developed for small scale projects was felt.

Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee initiated an exercise of developing series of standards/guidelines/manuals specifically for small scale hydropower projects with the sponsorship of Ministry of New and Renewable Energy, Government of India in 2006. The available relevant standards / guidelines / manuals were revisited to adapt suitably for small scale hydro projects. These have been prepared by the experts in respective fields. Wide consultations were held with all stake holders covering government agencies, government and private developers, equipment manufacturers, consultants, financial institutions, regulators and others through web, mail and meetings. After taking into consideration the comments received and discussions held with the lead experts, the series of standards/guidelines/manuals are prepared and presented in this publication.

The experts have drawn some text and figures from existing standards, manuals, publications and reports. Attempts have been made to give suitable reference and credit. However, the possibility of some omission due to oversight cannot be ruled out. These can be incorporated in our subsequent editions.

This series of standards / manuals / guidelines are the first edition. We request users to send their views / comments on the contents and utilization to enable us to review for further upgradation.

Standards/ Manuals/Guidelines series for Small Hydropower Development

General	
1.1	Small hydropower definitions and glossary of terms, list and scope of different Indian and international standards/guidelines/manuals
1.2 Part I	Planning of the projects on existing dams, Barrages, Weirs
1.2 Part II	Planning of the Projects on Canal falls and Lock Structures.
1.2 Part III	Planning of the Run-of-River Projects
1.3	Project hydrology and installed capacity
1.4	Reports preparation: reconnaissance, pre-feasibility, feasibility, detailed project report, as built report
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1.8	Project Management of Small Hydroelectric Projects
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1.11	Renovation, modernization and uprating
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3.1	Selection of Turbine and Governing System
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3.6	Technical Specifications for Procurement of Generating Equipment
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3.8	Technical Specifications for Procurement and Installation of Switchyard Equipment
3.9	Technical Specifications for monitoring, control and protection
3.10	Power Evacuation and Inter connection with Grid
3.11	operation and maintenance of power plant
3.12	Erection Testing and Commissioning

PERSONS INVOLVED

1. Dr Arun Kumar, CSO & Principal Investigator ,AHEC,IIT, Roorkee
2. Dr S K Singal, SSO & Investigator,AHEC,IIT, Roorkee

Drafting Group

1. Prof. O.D.Thapar,Consultant, AHEC,IIT, Roorkee
2. Mr. S.K.Tyagi, Consultant, AHEC,IIT, Roorkee

Consultation Group

1. Dr Arun Kumar,AHEC,IIT, Roorkee
2. Mr S.N.Singh, AHEC,IIT, Roorkee
3. Dr S K Singal,AHEC,IIT, Roorkee
4. Mr. S.C.Jain, Consultant, AHEC,IIT, Roorkee
5. Mr. Mssum Ali, Consultant, AHEC,IIT, Roorkee
6. Mr. A.K.Chopra, Consultant, SHP, MNRE,GOI, New Delhi
7. Mr. Jugal Kishore, Consultant, Hardwar
8. Mr. S.V.Dinkar, Consultant, Pune
9. Mr.R.B.Saxena, Consultant ,Chandigarh
10. Mr. Surendra Singh ,PGCL, PEDA,Chandigarh
11. Mr. Pankaj Kulshreshtha, UJVNL, Dehradun
12. Mr. Himanshu Tiwari, UJVNL, Dehradun
13. Mr. A.K.Singh, UJVNL, Dehradun
14. Mr. P.K.Singhal, UPJVNL, Lucknow
15. Mr. V.K.Sharma, THDC, Rishikesh
16. Mr. U Ukhal, HPPCL, Himachal Pradesh
17. Mr. K.C.Arora, Pentaflo Hydro power Ltd
18. Mr. P.K.malohtra, Pentaflo Hydro power Ltd
19. Mr. Sanjeev Handu, Andriz Hydro power Ltd.
20. Mr. Vishnupad Saha, Andriz Hydro power Ltd.
21. Mr. Dinesh Rajput, Andriz Hydro power Ltd.
22. Mr. Pradeep Dube, Tanushree Hydropower Consultants, Noida
23. Mr. H.M.Sharma, Jyoti Ltd.,Vadodra
24. Mr. Viral B Mahida, Jyoti Ltd.,Vadodra
25. Mr. Nishant Saha, Jyoti Ltd.,Vadodra

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1.1 Introduction

Outdoor step up switchyard at hydroelectric stations are provided to step up generated voltage generally for interconnection with the grid to evacuate power. Generation voltage in SHP varies from 415 volts to 11 kV and step up voltage of small hydro up to 25 MW capacity and power evacuation voltage may not exceed 72.5 kV.

1.2 Scope

This guideline covers design, selection of main equipment, selection of main single line diagram, and detailed layout of equipment at various voltage levels.

1.3 References and Codes

Latest edition of the following shall apply.

(R1). IS: 9920 Part I to IV (2007)	– Alternating current switches for rated voltages above 1000 volts and less than 52 kV
(R2). IS: 9921Part 1 to 5 (2007)	– Alternating currents disconnectors (isolators) and earthing switches rating, design, construction, tests etc.
(R3). IS: 1893 (2008)	– Criteria for Earthquake resistance design of structures
(R4). IS: 2705 Part 1 to 4 (2207)	– Current transformer
(R5). IS: 3156 Part 1 to 4 (2007)	– Voltage transformer
(R6). IS: 3070 part 1 to 3 (1989)	– Lightning arrestors
(R7). IS: 2544 (2006)	– Porcelain insulators for system above 1000 V
(R8). IS: 5350 (2004) – Part III	– Post insulator units for systems greater than 1000 V
(R9). IS: 5621 (2004)	– Hollow Insulators for use in electrical equipment
(R10). IS: 5556 (2006)	– Serrated lock washers – specification
(R11). IS: 3716 (2006)	– Application guide for insulation co-ordination
(R12). IS: 2165 (2006)	– Phase to earth insulation co-ordination
(R13). REC	– Rural electrification Corporation (REC) specification and standards
(R14). TNEA	– Power Engineers Hand Book - 2002
(R15). CBIP	– Manual on Sub-Station Layout - 2006
(R16). UPSEB	– Construction Manual for Rural Electrification and secondary system Planning

(R17). IEC-60354 (1993)	-	Guide for loading of oil immersed transformers
(R18) IEC: 60076 (Part 1 to 5) (2011)	-	Specifications for Power Transformer
(R19) CBIP (Pub. No.295-2007)	-	Manual on transformer (oil immersed)
(R20) IEC: 62271-100 2008	-	High voltage alternating current circuit breakers
(R21) IEEE: C 37.010 (1999)	-	IEEE Application Guide for AC high voltage circuit breakers
(R22) IEEE C 37.013 (1997)	-	AC high voltage generator circuit breaker rated on symmetrical current basis
(R23) IS: 2026 (Part 1 to 4) (1997)	-	Specifications for Power Transformer
(R24) IS: 2099 (1986)	-	Bushings for alternating voltage above 1000V
(R25) IS: 3639 (1966)	-	Fittings and accessories for power transformer
(R26) IEC: 60076 (Part 1 to 5) (2000-05)	-	Specifications for Power Transformer
(R27) CBIP (Pub. No.295-2007)	-	Manual on transformer (oil immersed)
(R28) IS: 1180 (1989)	-	Outdoor Type three phase distribution transformer upto and including 100 kVA, 11 kV
(R29) IS: 13118 (1991)	-	Specification for high-voltage alternating current circuit breakers
(R30) IEC: 62271 (2002)	-	High voltage alternating current circuit breakers

ABBREVIATIONS

CBIP	:	Central Board of Irrigation and Power
IEC	:	International Electro-technical Commission
IS	:	Indian Standard
REC	:	Rural Electrification Corporation
TNEBEA	:	Tamil Nadu Electricity Board Engineer’s Association
UPSEB	:	U.P. State Electricity Board

SECTION –I

DESIGN CONSIDERATIONS FOR OUTDOOR SWITCHYARD

1.0 GENERAL

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

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

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

2.0 SEISMIC CONSIDERATION

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

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

For other regions refer IS: 1893.

3.0 BASIC INSULATION LEVEL AND INSULATION CO-ORDINATION

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".

3.1 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.

3.2 Selection of Basic Impulse Insulation Level (BIL)

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 overvoltage.

3.3 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 1 and 2 as per the Indian Standard IS: 2165. In this standard, table 1 covers the standard insulation levels highest system voltages above 1 kV and below 52 kV for voltages commonly used in India and Table 1 for highest system voltages of more than 52 kV and less than 300 kV.

Table 1: Standard Insulation Levels for (equipment in range A 1 kV < U_m < 52 kV)

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

Note: Insulation levels as per list 2 are recommended.

Table 2: Standard Phase-to-Phase Insulation Levels for 52 kV ≤ U_m < 145 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

For SHP application where temporary over voltages are high due to speed rise on load throw off equipment insulation as per list 2 of table 3.3.1 should be used.

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.

In case of generator transformer in SHP 90 % (rated voltage) lightning arrestors are recommended.

An increase of impulse level of 15% above the withstand level to earth is recommended 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.

Tamil Nadu Electricity Board EA (TNEBEA) guide for selection of lightning arrestors is given below in table 3.

Table: 3-Selection of lightening Arrestors

Lightning Arrestors Rating	Maximum Three Phase System Voltage (Grounded/Electricity Grounded System)
650 volts	650 volts
9 kV	11.25 kV
30 kV	37 kV
60 kV	73 kV

Following lightning arrestor ratings are recommended especially if the earth resistivity is high.

12 kV system – 10 kV; 36 kV – 34 kV; 72.5 kV – 66 kV

3.4 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 4 with reference to Karnataka and Tamil Nadu.

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 4: Insulation Levels of the terminal Equipments Recommended

S. No.	Description	Nominal voltage in kV		
		66	33	11
1.	Highest system voltage kV (rms)	72.5	36	12
2.	Power transformer insulation levels kV (Crest)	325	170	75
3.	Circuit breaker kV (Crest)	350	170	75
4.	Disconnecting switches between pole and earth kV (Crest)	380	170	75

3.5 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 arrestor).

Spark gaps specified for fitting to the bushings of power transformers, potential and current transformers, rated 66 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:

i) The rods are to be circular not less than 12 mm diameter
ii) The rods should overhang their supports at-least one half of the gap spacing.
iii) 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 fig.1.

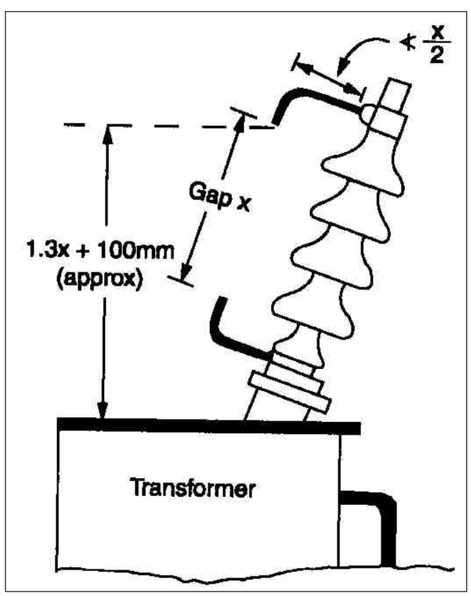


Fig. 1: Height of the rod above the ground plane
(Source: TNEBEA-Power Engineers Hand Book)

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

Spacing for standard rod-gaps is given in table 5.

Table 5: Spacing for standard rod gap (TNEBEA Practice)

	Critical Flashover voltage 1/50 micro second	**Spacing of Standard Rod Gap in cms**	
Highest system voltage kV rms U_m	kV Peak $\frac{U_m}{\sqrt{3}} \times \sqrt{2}$	Positive Polarity	Negative Polarity
72.5	59.1	7.7	6.5

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

Barometric pressure = 760 mm Hg.
Temperature = 20^0C
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 ^{0}C.

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

4.0 Electrical Clearances for Installing Equipment in the Field

Space requirements and layout of electrical equipment in switchyard depends upon various types of air clearances required to be provided for laying the equipment of different rated voltages. Following basic clearances govern the sub-station design.

(i) Earth clearance i.e. phase to ground clearance.
(ii) Phase clearance i.e. phase to phase clearance.
(iii) Safety clearance i.e. (a) Ground clearance.
(b) Section clearance.

4.1 Co-relation between insulation Level and minimum Phase to earth Clearances

Minimum clearances in air between live conductive parts and earthed structures to secure a specified impulse withstand voltage for dry conditions as per IS 3716-1978 are given in table 6.

These minimum clearances are valid for altitudes not exceeding 1000 m and do not include any addition for construction tolerances, effect of short circuits, safety of personnel etc. these clearances are suitable for general application, providing as first approximation.

Table 6: Correlations between Insulation Levels and Minimum Phase-to-Earth Air Clearances as per IS: 3716 - 1978

Rated Lightning Impulse Withstand Voltage (kV)	Minimum Phase-to-Earth Air Clearances (mm)
45	60
60	90
75	120
95	160
125	220
170	320
325	630

4.2 Working Safety Clearances

Safety clearance consists of ground clearance and section clearance. The ground clearance is the minimum clearance from any point on or about the permanent equipment where a man may be required to stand (measured from the position of feet) to the nearest part not at earth potential of an insulator supporting a line conductor and the same has been taken as 2.59 meters (i.e. 8.5 feet), which is the dimensions for a tall man with arms outstretched below the conductor.

The section clearance is the minimum clearance from any point on or about the permanent equipment where a man may be required to stand (measured from the position of feet) to the nearest unscreened live conductor in the air. The section clearance system upto 325 kV BIL may be determined by adding 2.5 meters to minimum phase to ground clearance of 0.63 which works to 3.13 meters for 72.5 kV system.

4.2.1 Height of Bus Bars above Ground within Sub-Station Promises

The minimum conductor clearance from ground is obtained by adding ground clearance, earth clearance and height of bus bar supporting clamps on the post insulator.

4.2.2 Conductor Clearance from Roadways within Sub-Station Promises

Minimum clearance between overhead conductors and roadways within sub-station premises is computed to be as "Ground clearance plus 6.25 m. This dimension provides for a truck with a man standing on its top 0.63 + 6.25 meter = 6.88 meters app.

4.3 Minimum and Safety clearances recommended in Central Board of Irrigation and Power manual

Clearances from the point of view of system reliability and safety of operating personnel recommended for substation up to 72.5 kV are given in table 7. These include the minimum clearances from live parts to earth, between two live parts of different phases and sectional clearances between live parts of different phases and sectional clearances between live parts and work section required for maintenance of an equipment. Besides, it is also necessary that sufficient clearance to ground is also available within the substation so as to ensure safety of the personnel moving about within the switchyard.

Table 7: Minimum clearances

Highest System Voltage (kV)	**Lightning impulse voltage (kVp)**	**Minimum clearances (mm)**		**Safety clearances (mm)**
		Between phase & earth	Between phase	
36	170	320	320	2800
72.5	325	630	630	3100

Notes:

i) Safety clearances are based on the insulation height of 2.44 m which is the height of lowest point on the insulator where it meets the earthed metal.

ii) The distances indicated above are not applicable to equipment which has been subjected to impulse test since mandatory clearances might hamper the design of the equipment, increase its cost.

iii) The values in table refer to an attitude not exceeding 1000 m and take into account the most unfavorable conditions which may result from the atmospheric pressure variation, temperature and moisture. A correction factor of 1.25 % per 100 m is to be applied for increasing the air clearance for altitude more than 1000 m and upto 3000 m.

iv) No safety clearance is required between the bus-bar isolator or the bus-bar insulator. However, safety clearance is necessary between the section isolator or the bus-bar itself and the circuit breaker.

v) For the purpose of computing the vertical clearance of an overhead strung conductor the maximum sag of any conductor shall be calculated on the basis of the maximum sag in still and the maximum temperature as specified.

vi) As an alternative to maintain safety clearances in some substation earthed barriers are used to ensure safety of the maintenance personnel. The use of earthed barriers is quite common at lower voltages of 36 kV and 72.5 kV. In case of paucity of space and if 2.44 m clearance is not available then localized earthed fencing with clearance can be considered by the designer.

The normally adopted spacing for the strung bus are given in table 8.

Table 8: Spacing for the strung bus

Highest System Voltage rating (kV)	Spacing between phases in mm
72.5	2200
36	1300
12	920

The spacings for the equipment in a sub-station depend upon the manufacturers practice.

The minimum clearance of live parts to ground in an outdoor sub-station is given in table 9:

Table: 9: Clearances in mm

Highest System Voltage in kV	Clearances in mm
72.5	4600
36	3700
12	3700

The bottom most portion of any insulator or bushing in service should be at an absolute minimum height of 2500 mm above ground level.

4.4 Section Clearances

A station which can not be shut down entirely for maintenance purpose must be split into sections so arranged that any one section can be isolated from its neighbour with adequate clearances as given below. Where it is impossible to obtain the required safety clearances, earthed screens may be provided.

The table 10 gives the sectional clearances for persons to enable inspection cleaning, repairs; painting and general maintenance works to be carried out in a sub-station.

Table 10: Section Clearances

Highest System Voltage in kV	Section Clearances in mm
72	3000
36	2800
12	2600

The following minimum clearances should be adopted for enclosed indoor bus bars and connections in air which are not filled with any insulating medium like compound etc. This is given in table 11.

Table 11: Minimum Clearances in air

Highest System voltage between phases or poles in kV	Minimum clearances in Air in mm	
	Between phases or poles	Phase/pole to earth
36	356	222
12	127	76

In indoor kiosks in power stations and main receiving stations, the busbar and connections should also be taped but the fact of taping should however, be taken into consideration in deciding the clearances. In addition indoor kiosks etc. should be subjected to a flashover test at works to prove that clearances are adequate so as to prevent flashovers during surge conditions.

4.5 Standard Bay Widths

Standard bay widths as per TNEBEA Practices are given in table 12.

Table 12: Standard bay widths

Voltage level in kV	Bay width in m
66	7.0
33	4.6
22	3.8
11	3.5

5.0 INSULATORS – CREEPAGE DISTANCE

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 should be so evolved that the quantity of isolators required is minimum commensurate with the expected security of supply. 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 insulators with higher creepage distance should be used.

The creepage distances for the different pollution levels are provided according to table 13.

Table 13: Creepage distance for different pollution levels

Pollution Level	Creepage distance (mm/kV of highest system voltage)	Recommended for adoption
Light	16	25 x highest system voltage i.e. 1813 mm for 72.5 kV
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.

6.0 INSULATOR TYPE

Types of insulators used are as follows:

(i) Bus Support Insulators

(a) Cap and Pin type
(b) Solidcore type
(c) Polycone type

(ii) Strain Insulators

(a) Disc insulators
(b) Long rod porcelain insulators
(c) Polymer insulators

7.0 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 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 developed which are applied within the shop and these paints have quite effective.

7.1 Design Data for Design of Switchyard Structures (Based mostly on Tamil Nadu Electricity Board Engineers Association Practice)

Design Loads

(i) Wind Pressure on Structures are given in table 7.1.1

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

Wind pressure as per table 7.1.1 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 is 226.8 kg. as per 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

(v) Uplift on adjacent spans:

Maximum slope (mean of the 3 – phase) at the point of attachment 1: 8 above horizontal.

The table 14 gives the values of wind pressure and maximum and minimum temperatures specified in different states, as per REC for design of structure.

Table 14: Wind Pressure & Temperature Data

State	Wind Pressure Zones				Max. Temp.	Min. Temp.	ICE Loading
	Kg/m^2				^0C	^0C	
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

7.2 Working Stresses - Tamil Nadu Electricity Board Engineers Association (TNEBEA) Practice

(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.

7.3 Factor of Safety

Factor of safety are given in table 15

Table 15: Factor of Safety

		Indian Electricity Rules	Adopted by (TNEBEA)	Recommended
a.	For 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

7.4 Slenderness Ratio (L/R) (TNEBEA Practice)

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.

7.5 Minimum Thickness for Steel Members

(a) Galavanised members:

(i) Main member of a lattice beam or stanchion - 6.4 mm
(ii) Bracings - 4.75 mm

(b) Painted Members:
All Members - 6.4 mm

7.6 Circuit Breakers - Mounting and supporting structure

The circuit breakers should be self supporting type. However, if necessary for the purpose of minimum ground clearance the circuit breakers should be mounted on raised steel structures which should be included in the scope of supply of circuit breaker. Information and data for design of foundations from the supplier of the circuit breaker be obtained.

8.0 GIS SUBSTATIONS

Advancement in the use of SF6 as an insulating and interrupting medium have resulted in the development of gas insulated substations. Environment and/or space limitations may require the consideration of GIS (gas insulated substation) equipment. This equipment utilizes SF6 as an insulating and interrupting medium and permits very compact installations. GIS substation are preferable to air insulated system ((AIS) because of following reasons:

i. Compact design reduces space requirements
ii. Higher reliability
iii. Life cycle costs and safety are better because GIS is maintenance free
iv. Location advantage especially in areas (town) where space costs are high
v. Environmental advantage as rain, dust, snow, ice, salt etc. do not affect the hermetically sealed metal clad GIS

Three-phase or single-phase bus configurations are normally available up to 72.5 kV class, and all equipment (disconnect/isolating switches, grounding switches, circuit breakers, current, and potential transformers, etc.) are enclosed within an atmosphere of

SF6 insulating gas. The superior insulating properties of SF6 allow very compact installations.

GIS installations are also used in contaminated environments and as a means of deterring animal intrusions. Although initial costs are higher than conventional substations, a smaller substation can offset the increased initial costs by reducing the land area necessary for the substation.

8.1 GIS Compact Switchgear

Compact sub-station with gas insulated switchgear may be considered in following cases.

(i) Installations in areas with high risk of pollution and corrosion from industrial plants or by marine and desert climates.
(ii) Applications involving use of metal clad switchgear with components of conventional design to minimize area requirement.
(iii) Underground substations
(iv) Where space is not easily available for outdoor installation
(iv) Installations in difficult site conditions (e.g. seismically active areas, high altitude areas etc.).

8.2 Metal Clad GIS Switchgear

SF6 – insulated metal enclosed high voltage switchgear up to 72.5 kV are now available and may be used where site/space limitation require then use. The data of a typical GIS substation is given in table 16. Feeder control and protection are inbuilt.

Table 16: Data for typical GIS substation

Rated voltage (kV)	Upto 145
Rated power frequency withstand voltage (kV)	Upto 275
Rated lightning impulse withstand voltage (kV)	Upto 650
Rated normal current bus bar (A)	Upto 3150
Rated normal current feeder (A)	Upto 2500
Rated breaking current (kA)	Upto 40
Rated short-time withstand current (kA)	Upto 40
Rated peak withstand current (kA)	Upto 108
Inspection (years)	> 25
Bay width (mm)	800

8.3 Compact Air Insulated Substation (CAIS)

A compact air insulated station is mounted on common base frame with integrated current transformer and with SF6 insulated dead tank interrupter assembly. Compact air insulated sub-station (CAIS) factory assembled with dead tank SF_6 design is being offered for such-station at 66 kV. Technical particulars of a typical substation are given in table 17 space saving up to 60% is claimed for H type (single sectionalized bus) substation with two incoming generator transformers and two outgoing feeders configuration.

Table 17: Technical particulars of a typical substation

Rated voltage	kV	72.5	123	145
Rated frequency	Hz	50		
Rated power-frequency withstand voltage	kV	140	230	275
Rated lightning impulse withstand voltage	kV	325	550	650
Rated normal current	A	2500		
Rated short-circuit breaking current	kA	40		
Rated short-circuit making current	kA	100		
Rated duration of short circuit	s	3		
Circuit Breaker Specific Technical Characteristics				
Opening Time	ms	38	38	38
Break time	ms	50	60	60
Closing time	ms	85	106	106

9.0 Power Line Carrier Equipment

The carrier equipment required for communication, relaying and telemetering is connected to line through high frequency cable, coupling capacitor and wave trap. The coupling capacitors are installed on the line side of the wave trap and are normally base mounted. The wave traps for voltage levels upto 72.5 kV can be mounted on the gantry structure on which the line is terminated at the substation or mounted on top of the capacitor voltage transformer.

10.0 Substation Auxiliary Facilities

Auxiliary facilities for step up substation in SHP are designed in conjunction with power house auxiliaries and are discussed in a separate guideline.

11.0 Inspection and Maintenance

Adequate facilities must be provided in the substation for inspection and maintenance of various equipment and at the same time to ensure safety of personnel and maintain proper and other clearances.

During maintenance, it is essential that the equipment is isolated and earthed. One of the essential requirements of earthing is that earthing must be actually visible from the point of working in the substation. Where this is not possible, provision of temporary earthing is made near the equipment. Besides the permanent illumination, provision should also be made for portable lights for which purpose power outlets should be provided in marshalling boxes or equipment cubicles.

12.0 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 bus bras are suitable for earthquake prone areas.

12.1 Bus bar Material

The materials in common use for bus bars and connections of the strain type are ACSR and all aluminum conductor. The different sizes commonly used are given in table 18.

Table 18 : Sizes of Conductors

Conductor Size	Code	Remark
12 kV = 6 x 4.72 + 7 x 1.76	ACSR DOG up to10MVA	In case line conductor is of higher size the same may be used for bubar
36 kV = 6 x 4.72 + 7 x 1.76	ACSR DOG up to10MVA	
72.5 kV = 30 x 2.79 +7 x 2.79 145 kV = 30 x 4.27 + 7 x 4.27	ACSR PANTHER ACSR ZEBRA	
245 kV = 54 x 3.53 + 7 x 3.53	ACSR MOOSE	

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 in table 19.

Table 19 : Sizes of pipes for various voltages

External Dia.	Internal Dia	System Voltages	Remarks
42 mm	36 mm	Up to 36 kV	Tamil Nadu Uses 50 mm IPS Aluminium Tube upto 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		Up to 145 kV	

Since aluminum oxidises rapidly great care is necessary in making connections. In the case of long spans expansion joints should be provided to avoid strain on the supporting insulators due to thermal expansion or contraction of pipe.

The bus bar sizes should meet the electrical and mechanical requirements of the specific application for which they are chosen.

13.0 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 luminaries 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.

14.0 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 should be so evolved that the quantity of insulators required is the minimum commensurate with the security of supply. An important consideration in determining the insulation in a substation, 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 insulators with higher leakage distance should be 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 other 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.

15.0 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 fiber optic cable

VHF equipment is normally recommended for 33 kV systems. Fibre optic cable is recommended when offsite control is provided.

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.

Economic study for Microwave transmission for the purpose is required.

16.0 AUXILIARIES

Besides the main equipment a number of auxiliary facilities and system as enumerated below have to be provided. These are discussed alongwith auxiliaries for the powerhouse. In step-up substations most of the facilities are provided in the powerhouse.

(i) Earthing and Grounding – Steel grounding system is provided for earthmat and interconnection
(ii) Oil Handling System – portable oil purification system is provided
(iii) Illumination and lighting system – illumination system is discussed with auxiliaries system
(iv) Compressed air system – is required for cleaning etc. and provided in the powerhouse
(v) Fire protection system – All substations should be equipped with fire lighting systems conforming to the requirements given in latest IS: 1646 and Fire protection manual Part –I issued by Tariff Advisory Committee of Insurance Companies.
(vi) AC Auxiliary power system – is provided in the power house
(vii) DC system is provided in the powerhouse
(viii) Cables – discussed in powerhouse electrical auxiliaries

17.0 REPAIR/INSPECTION FACILITIES FOR TRANSFORMER

Large substations sometimes require the facilities of repair bay along with a crane of adequate capacity for handling the heaviest equipment, which is usually the transformer. In hydropower station powerhouse crane is generally used for this purpose. Repair/service bay of powerhouse is used for repair of transformer.

Provision of a rail track should be made for movement of transformer from switchyard to the repair bay. Points for jacking, winching should be provided at the transformer foundations and 90^0 turn on the rail track for changing the direction of the wheels.

18.0 PALE FENCING

Pale fencing around switchyard consists of 75 mm wide and 2500 mm high pales fixed on two members 45 x 45 x 6 mm angle horizontal runners. Vertical supports may be of 50 x 50 x 6 mm angle. Two meter gates of approximately 4000 mm width (2000 mm wide each leaf) is normally required for entry/exist of transformers etc.

SECTION-II

SELECTION OF SWITCHYARD EQUIPMENT

1.0 SELECTION OF GENERATOR TRANSFORMER

1.1 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 SHP for outdoor switching i.e. 11 kV to 220 kV.

1.2 Generator Transformers

Power transformer which step up the power produced by hydroelectric generating units (0.415 to 11 kV) to a level which matches the sub transmission/transmission system voltage (typically 12 kV to 66 kV class) for range of power houses under considerations are 2 winding oil immersed transformers.

Three Phase Versus Single Phase Transformer

Three phase generator transformers should be 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.

1.3 Transformer Rating

The full load kVA rating of the generator transformer should be 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.

1.4 Standard Rating

Standard rating for power transformer of voltage class commonly used are given in table 20, 21 and 22 as per CBIP manual on Transformer and recommended for use as generator transformer with specific provision as specified in these guidelines.

Table 20 : 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 21 : 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

Table 22 : 66 kV Class Transformers

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

1.5 Cooling

Transformer cooling system for generator transformers specified in table 23, 24 and 25 are in accordance with IS: 2026 (part II) and are identified according to the cooling method employed. Letter symbols used in the table are as follows:

Table 23 : Letter symbols

Description	Symbol
(i) Cooling Medium	
a. Mineral oil or equivalent flammable synthetic insulating liquid	O
b. Air	A
(ii) Kind of Circulation	
a. Natural	N
b. Forced (oil not directed)	F

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

Table 24 : Transformer Identified by Different Symbols for Cooling Method

1st Letter	2nd Letter	3rd Letter	4th 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 hydroelectric stations upto 25 MVA capacity

Table 25 : Cooling System for Hydroelectric Stations

Symbol	Description
ONAN	Oil Immersed Natural Air Cooled
ONAF	Oil Immersed Forced Air Cooled
OFAF	Oil Immersed with forced oil circulation Forced Air Cooled

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

ONAN/OFAF

ONAN - 60%
OFAF - 100%

The rating under ONAF condition although not guaranteed should be about 80%.

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 and is given in table 26.

Table 26 : Cooling Equipment

ONAN/OFAF	2 – 50% group 2 – 100% pumps of which one will be standby, 2 – Standby fans one in each 50% group Or 3 – 50% group with independent pumps and fans out of which one group to act as standby.

1.6 Temperature Rise, Overload Capacity and Continuous Rating

Conservative value of temperature rise, overload capacity and continuous rating of transformer located in the switchyard should be specified. For the purpose of standardization of maximum temperature rise of oil and windings, the following ambient temperatures are recommended by CBIP.

Cooling medium : Air
Maximum ambient temperature : 50^0C
Maximum daily average ambient temperature : 40^0C
Maximum yearly weighted average temperature : 32^0C

With the above ambient temperature condition the temperature rises for power transformers as per CBIP is for oil temperature 50 degree centigrade and winding temperature 55 degree centigrade.

However more conservative temperature rise are specified for generator, transformers. Reference ambient temperatures and climatic conditions and temperature rise specified for generators transformer at Mukerian stage II in Punjab given in Annexure 1.

1.7 Transformer Studies

It is recommended that following studies be carried out for transformers 72.5 kV and above from economic considerations.

(i) Type of cooling
(ii) Insulation level
(iii) Departure from normal design impedance

1.8 Electrical Characteristics

1.8.1 Type of Transformer and Operating Conditions

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

Transformers designed for mixed cooling should be capable of operating under the natural cooled condition up to the specified load. The forced cooling equipment should come into operation by pre-set contacts in WTI and the transformer will operate as forced cooled unit.

Transformer should be capable of remaining in operation at full load for 10 minutes after failure of blowers without the calculated winding hot-spot temperature exceeding 150^0 C. Transformer fitted with two coolers each capable of dissipating 50% of the losses at continuous maximum rating (CMR) should be capable of remaining in operation for 20 minutes in the event of failure of the blower associated with one cooler without the calculated winding hot-spot temperature exceeding 150^0C.

1.8.2 Continuous Maximum Rating and Overloads

Transformers provided with mixed cooling should 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 should be 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 should be specifically stated by the purchaser.

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

The transformer may be operated without danger on 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 should be suitable for continuous operation with a frequency variation of +3 % from normal 50 Hz. Combined voltage and frequency variation should not exceed the rated V/f ratio by 10%.

1.8.3 Voltage Ratio

The high voltage rating should be suitable for the voltage of the transmission system to which it will be connected. The low voltage rating should be 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 should be 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 3^{rd} harmonic current.

1.8.4 Duty Under fault Condition

Generator transformer should be designed for exceptional circumstances arising due to sudden disconnection of the load and should be 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 5 MVA should be provided with over fluxing protection device.

1.8.5 Electrical Connections

Transformers shall be connected in accordance with IS vector symbol specified in ordering schedule of the requirements. Vector symbol specified for generator transformers is normally $Y_n d_{11}$.

Auto connected and star/star connected transformers shall have delta connected stabilizing windings if specified in the order. Two leads from one open corner of the delta connection shall be brought out to separate bushings. Links shall be provided for joining together the two terminals so as to complete the delta connection and earthing it external to the tank.

1.8.6 Flux density

The maximum flux density in any part of the core and yokes, of each transformer at normal voltage and frequency should be such that the flux density in following over voltage conditions does not exceeds 1.9 tesla/19000 lines per cm^2.

i) 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.

ii) Yoke bolt area and flitch plate areas shall not be counted in the net core area, if these are provided for fastening of core.

iii) The design of limb and yoke shall be so coordinated that there is no cross fluxing at the joints.

1.8.7 Short Circuit Strength

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.

The bidders shall submit test certificates of the short circuit test, if already done on the offered design and rating. 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.

1.8.8 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.

1.8.9 Parallel Operation

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

1.8.10 Vibration and Noise

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

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

1.8.11 Basic Insulation Levels (BIL)

Transformers are the starting point for insulation co-ordination and are as such directly protected by lightning arrestor.

1.9 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. Detailed study should be made if reduced short circuit level or line regulation considerations are materials and specific feasible impedance values are required.

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 as per CBIP Manuals on Transformers are given in table 27.

Table 27 : Typical values of impedance for transformers

Rated Power (kVA)	Impedance Voltage (%) as per IS 2026	Impedance Voltage (%) as per CBIP manual	
		Three phase power rating	Impedance voltage (%)
		11 kV Trans. (kVA) Up to 1600 kVA	5
Up to 630	4.0	33 kV Trans. (MVA)	
631 to 1250	5.0	1.00	5
1251 to 3150	6.25	1.60	6.25
3151 to 6300	7.15	3.15	6.25
6301 to 12500	8.35	4.00	7.15
12501 to 25000	10.0	5.00	7.15
Above 25001	12.5	6.30	7.15
		8.00	8.35
		10.00	8.35
		66 kV Trans. (MVA)	
		6.3	8.35
		8.0	8.35
		10.0	8.35
		12.5	8.35
		20.0	10.00
		16	10
		25	10
		31.5	12.5

Transformers with lower or higher values of impedance are normally furnished with difference 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.

1.10 Transformer Efficiency

Transformer losses represent a considerable economic loss over the life of the power plant. Standard losses as per CBIP manual on the basis of optimized design of manufacturer is given in table 1.10.1 for 11 kV to 66 kV class transformers. Based on these losses Capitalization for transformer losses should be carried out in accordance with CBIP manual on transformer. These are given in table 28.

Table 28 : Standard Losses at 75^{0}C

S. No.	Three-phase power rating	No-load loss (kW)	Load loss (kW)
(a)	11 kV Transformers (kVA)		
	200	0.57	3.3
	315	0.80	4.6
	630	1.2	7.5
	1000	1.8	11.0
	1600	2.4	15.5
(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

1.11 Terminal Bushings

Connections for the generator transformers are mostly by power cables for small hydro stations up to 10 MVA rating from generator terminals to power transformer in switchyard. Bus ducts which could be isolated phase for large units or segregated phase bus ducts for smaller units 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

Solid Porcelain/Oil Communicating and other type bushings up to 36 kV voltage class in accordance with IS:603347-2008. 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.

66 kV to 220 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 CBIP Manual on transformers Section P.

The electrical characteristics of bushing insulator shall be in accordance with IS: 2099 as amended from time to time. All type and routine tests shall be carried out in accordance with IS: 2099. The test voltage for various tests as stipulated in IS: 2099 – 1986 are given in table 29.

Table 29 : The test voltages for various tests

Nominal system voltage	Rated voltage of the bushing	One minute wet and dry power frequency voltage withstand test	Lightning impulse withstand test 12/50 micro sec. kV peak
kV	kV	kV	kV
11	12	28	75
33	36	70	170

1.12 Tanks

The main tank body excluding tap-changing compartments, radiators and coolers shall be capable of withstanding vacuum given in table 30.

Table 30 : Capability of withstanding vacuum

Highest system voltage kV	MVA rating	Vacuum gauge pressure kN/m^2	(mm of Hg)
Up to 72 kV	Up to 16 above 1.6 & up to 20	34.7 68.0	250 500
Above 72 kV	For all MVA ratings	100.64	760

1.13 Pressure Relief Device

The pressure relief device shall 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 shall operate at a static pressure of less than the hydraulic test pressure for transformer tank. Means shall be provided to prevent the ingress of rain water.

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

1.14 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 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.

1.15 Fittings and Accessories

Rating and diagram plate

- (i) 2 Nos. earthing terminals
- (ii) Cover lifting lugs.
- (iii) Skids and pulling eyes on both directions.
- (iv) Oil-filling valve with flange
- (v) Jacking pads.
- (vi) Pocket on tank cover for thermometer.
- (vii) Air release devices.
- (viii) Conservator with oil filling hole, cap and drain plug-size 19 mm nominal pipe (3/4 in. BSP/M 20).
  - (a) Plain oil level gauge for all transformers up to and including 1.6 MVA.
  - (b) Magnetic type oil gauge for transformers above 1.6 MVA, with low oil level alarm contact.
- (ix) Silica gel breather with oil seal.
- (ix) Pressure relief device.
- (xi) Valves:
  - (a) Drain valve with plug or blanking flanges. The same can be used for filtering purpose.
  - (b) A sampling device or sampling facility on drain valve.
  - (c) 1 No. filter valve on upper side of transformer tank.
- (xii) Buchholz relay with alarm and trip contacts with one shut-off valve on conservator side.
  - (a) Size of Buchholz relay up to 10 MVA-50 mm
  - (b) 10 MVA and above-80 mm

(xiv) Oil temperature indicator with one electrical contact shall be provided with anti-vibration mounting.

(xv) Winding temperature indicator with two electrical contacts for alarm and trip purposes. Switching of fans shall be done by winding temperature indicator for all transformers having ONAF rating. The winding temperature indicator shall be provided with anti-vibration mounting.

(xvi) Tank mounted weather-proof marshalling box for housing control equipment and terminal connectors. Wiring up to marshalling box with PVC SWA PVC copper cables 660/1100 volts grade.

(xvii) Rollers-4 Nos. Details of rollers with gauge are given in table in 31.

Table 31 : Details of rollers with gauge

S. No.	Rating	Type	Gauge	
			Shorter axis	**Longer axis**
1.	Up to 5 MVA	Flat, uni-directional	As per manufacturer's practice, however, not to exceed 1000 mm	
2.	6.3 MVA	Flanged, bi-directional	1435 mm	1435 mm
3.	10 MVA and above	Flanged, bi-directional	1676 mm	1676

(xviii) Inspection cover.

(xix) Cooling accessories

ONAN/ONAF cooling

(i) Radiators with shut-off valves and air release plugs.
(ii) Fans.
(iii) Filter valves.
(iv) Drain and sampling device.
(v) Air release device.

1.16 Dielectric Tests

(i) 220/132 kV winding

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

(ii) 33 kV winding

(a) Separate source AC on the all line terminal (routine test)
(b) Lightning impulse on all the line terminals (routine test)

1.17 Accessories

Normal accessories are arcing horns, oil flow alarm, fans and pumps, dissolved gas monitoring system, temperature detectors, lifting devices.

Provision of following oil preservation system 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.

1.18 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 in the use of fire wall/barriers is also provided in power plants. Specifications for fire protection of power transformers may be provided in accordance with CBIP Manual on Transformer.

1.19 Factory and Field Testing

Transformer specifications must contain complete and exhaustive section for quality control, Inspection, factory and field test. Provision for witness testing of factory test and method for type test should be specified in detail. Various routine, type and special tests are detailed in IS 2026 part I.

1.20 Erection, Maintenance Testing and Commissioning

Erection, Maintenance, Test and Commissioning is to be done in accordance with provisions made in CBIP manual.

1.21 Typical Transformer Rating and Characteristics

Transformer rating and characteristics for a 11/66 kV transformer for SHP (2 x 10 MW) is enclosed as Annexure-3.

2.0 SELECTION OF CIRCUIT BREAKER

2.1 Introduction

Circuit breaker is a mechanical switching device capable of making, carrying and breaking current under normal circuit condition as well as under specified abnormal circuit condition such as short circuit etc. Circuit breakers are generally classified according to interrupting medium used to cool and elongate electrical arc permitting interruption. Selection of outdoor circuit breakers for switchyards 12 kV and above upto 245 kV (highest system voltage) as regards types, rating, performance requirements and tests for AC high voltage circuit breakers that are installed in SHP outdoor switchyard after the step up transformer on outgoing transmission line feeders. Special requirement for rating of AC high voltage generator circuit breakers between the generator and transformer terminals are also discussed.

2.2 Classification

Following types of circuit breakers formerly used in high voltage outdoor substations are no longer in use and are being phased out.

(i) Bulk oil circuit breakers (Dead Tank Design) :
In these circuit breakers oil contents is used for arc extinction and also for insulating live parts from the tank which is dead and generally earthed (ground).

(ii) Minimum oil breakers (Live Tank Design) :
In these circuit breakers oil is primarily used for arc extinction and not necessarily for insulating live parts from earth (ground). The tanks of these circuit breakers are insulated from earth ground. The circuit breakers are phase separated. These circuit breakers were widely used up to 72 kV level and are being phased out from existing installation.

(iii) Air blast circuit breaker:
Circuit breaking in these circuit breakers occurs in a blast of air under pressure. These circuit breakers were widely used upto 765 kV system. These circuit breakers are being phased out.

2.3 Type of Circuit Breaker

Following types of circuit breakers are in use now-a-days for max. voltage class used for small hydro station upto 25 MW.

(i) SF-6 – Sulphur Hexa Flouride Breakers 36 kV to 220 kV class
(ii) Vacuum circuit breakers up to 36 kV class
(iii) Air circuit breaker up to 415V (Generator circuit breaker)

2.3.1 Sulphur Hexafluoride as an Arc Quenching Agent

Pure sulphar hexafluoride gas is inert and thermally stable. It possesses very good arc quenching as well as insulating properties which make it ideally suitable for use in a circuit breaker. Sulphar hexafluoride remains in a gaseous state upto a temperature of 9^0C at 15 kg/cm^2 pressure its density is about five times of air and the free heat convection is 1.6 times as much as that of air. Apart from being a gas, it is non-inflammable, non-poisonous and odourless. When arcing takes place through the gas, some by-products are produced due to breakdown of the gas. These by-products are a hazard to the health of the maintenance personnel therefore should be properly taken care of.

At a pressure of three atmospheres the dielectric strength of sulphur hexafluoride is about 2.4 times that of air and compares very well with that of oil. Even when gas is exposed to electric arcs for fairly long periods, it has been found that decomposition effects are small and the dielectric strength is not materially affected. On the other hand the metallic fluorides at the temperatures of the arc are good insulators and the arc is therefore, not at all harmful to the breaker.

Gas circuit breaker generally employ SF-6 (sulphur hexafluoride) as an interrupting medium and sometimes as an insulating medium. In "single puffer" mechanisms, the interrupter is designed to compress the gas during the opening stroke and use the compressed gas as a transfer mechanism to cool the arc and to elongate the arc through a grid (arc chutes), allowing extinguisher of the arc when the current passes through zero. In other designs, the arc heats the SF6 gas and the resulting pressure is used for elongating and interrupting the arc. Some older low-pressure SF6 breakers employed a pump to provide the high pressure SF6 gas for arc interruption.

Gas circuit breakers typically operate at pressures between six and seven atmospheres. The dielectric strength of SF6 gas reduce significantly at lower pressures, normally as a result of lower ambient temperatures. Monitoring of the density of the SF6 gas is critical and some designs will block operation of the circuit breaker in the event of low gas density.

Circuit breakers are available as live-tank or dead-tank designs. Dead –tank designs put the interrupter in a grounded metal enclosure. Interrupter maintenance is at ground level and seismic withstand is improved versus the live-tank designs. Bushings are used for line and load connections which permit installation of bushing current transformers for relaying. The dead-tank breaker does require additional insulating gas to provide the insulation between the interrupter and the grounded tank enclosure.

Live-tank circuit breakers consist of an interrupter that is mounted on insulators and is at line potential. This approach allows a modular design as interrupters can be connected in series to operate at higher voltage levels. Operation of the contacts is usually through an insulated operating rod or rotation of a porcelain insulator assembly by an operator at ground level. This design minimizes the quantity of gas used for interrupting the arc as no additional quantity is required for insulation of a dead-tank enclosure. The design also readily adapts to the addition of pre-insertion resistors or grading capacitors when they are required. Seismic capability requires special consideration due to the high center of gravity of the interrupting chamber assembly.

Interrupting times are usually quoted in cycles and are defined as the maximum possible delay between energizing the trip circuit at rated control voltage and the interruption of the main contacts in all poles. This applies to all currents from 25 to 100% of the rated short circuit current.

Breaker ratings need to be checked for some specific application. Applications requiring reclosing operation should be reviewed to be sure that the duty cycle of the circuit breaker is not being exceeded. Some applications for out –of- phase switching or back-to-back switching of capacitor banks also require review and may require specific duty circuit breakers to insure proper operation of the circuit breaker during fault interruption.

2.3.2 Vacuum Circuit Breaker

Vacuum circuit breakers use an interrupter that is a smaller cylinder enclosing the moving contacts under a high vacuum. When the contacts part, is a formed from contact erosion. The arc products are immediately forced to and deposited on a metallic shield surrounding the contacts. Without anything to sustain the arc, it is quickly extinguished.

Vacuum circuit breakers are widely employed up to 36 kV class. The small size of the breaker allows significant savings in space and material compared to earlier designs employing air magnetic technology. When used in outdoor circuit breaker designs, the vacuum cylinder is housed in a metal cabinet or oil filled tank for dead tank construction.

2.3.3 Advantages and Disadvantages

2.3.3.1 Advantages

Advantages of SF6 breakers over the conventional breakers is given below:

i) due to outstanding arc quenching property of SF6, the arcing time is very small. This reduces contact erosion.
ii) using SF6 gas at low pressure and low velocity; the current chopping can be minimized.
iii) during arcing of SF6 breaker, no carbon dioxide is formed and hence no reduction of dielectric strength.
iv) SF6 breaker is silent in operation and moisture ingression into the gas cycle is almost nil.
v) SF6 breaker performance is not affected due to variation in atmospheric conditions.
vi) SF6 breaker is compact in size and electrical clearances are drastically reduced.

2.3.3.2 Disadvantages

The only disadvantage of using SF6 to some extent is suffocation. In case of leakage in the breaker tank, this gas, being heavier than air settles in the surroundings and may lead to suffocation of the operating personnel. However, it is non-poisonous.

2.3.4 Protection Classes for Switchgear Installation

The protection classes are identified by a compound symbol made up of the two code letters' EP, which always remain the same two digits denoting the degree of protection and, if] required, the supplementary code letter B. The supplementary code letter must be stated if in the case of switchgear and distribution equipment the protection class is attained only through taking certain measures when the apparatus is installed. The term protection denotes the complete compound symbol (code letters, code digits and the supplementary code letter if applicable).

2.3.5 Evaluation of SF6 and Vacuum Switching Technologies

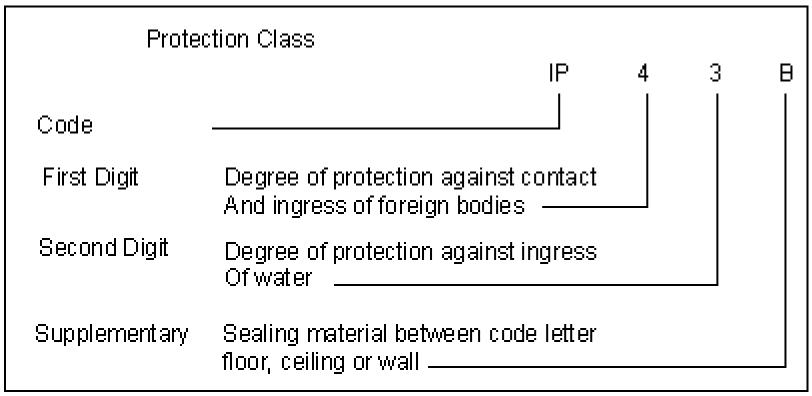
It is given in table 32.

Table 32 : Evaluation of SF6 and Vacuum Switching Technologies

S. No.	Criteria	SF 6 circuit breaker	Vacuum circuit breaker
I. SWITCHING DUTIES			
1.	Summated breaking current capacity	To 50 times rated short circuit breaking current To 10,000 times continuous rated current.	To 100 times rated short circuit breaking current To 20,000 times continuous rated current.
2.	Critical switching i. Motor, Reactors small inductive current.	Very well suited Over voltage generally under *2.5* p.u. Normally no action necessary to limit over voltages.	Well suited. Under certain circumstances steps may be necessary to limit over voltages because of possibility of virtual current chopping. Use of surge arresters recommended
	ii. Capacitors	Well suited. Restrike free. In special cases reactors may be necessary to limit in rush current - Low over voltage.	Suited. Generally Restrike free. In special cases reactors may be necessary to limit in rush current-Reignition and restrikes possible in certain cases due to statistical scatter of breakdown voltage in vaccum.
	iii. Over head and cable feeders.	Very well suited-Restrike free.	Very well suited Restrike free.
	iv. Switching of arc furnaces.	Only suitable in applicable with comparatively low number of operations per day.	Suitable also for applications with very high number of operations (over 100 co-per day.

S. No.	Criteria	SF 6 circuit breaker	Vacuum circuit breaker
3.	Suitability of single and multi shot auto reclose cycles.	Very well suited	Very well suited.
II. MAINTAINABILITY			
1.	Number of operations between servicing, referred to operating mechanism.	500 to 20,000 C-O Operations	10,000 to 20,000 C-O operation
2.	Service life of interrupters	5000 to 20,000 Cooperations (Between over hauls)	20,000 to 30,000 Co-operations or (manufacturers guidelines)
3.	Service interval	Lubrication of operating mechanism after 5 to 10 years (if limiting number of operations not reached)	Lubrication of operating mechanism after 10 years (if limiting number of operations not reached.
4.	Expenditure on overhaul of interrupters.	Overhaul involves complete dismantling of interrupter. Labour costs high, material costs low.	Tester used to check vacuum level. If necessary replace interrupter. Low labour costs. High material costs.
5.	Supervision of Circuit breaker condition.	Supervision of SF6 gas pressure possible (Pressure guage with contacts for remote signalling.)	Checking the insulation and quench media not easily possible-But generally supervision of vacuum level not necessary (sealed for life)
6.	Refilling of arc quenching media	Possible	Not possible
III. RELIABILITY			
1.	Failure rate	Lowest (7-13 per 1000 CB-Yrs)	Lowest (7-13 per 1000 CB-Yrs)
2.	Mechanical life	Good	Excellent
3.	Fire Hazard	Zero	Zero
4.	Interrupting capacity in case of leakage.	Switching of rated current still possible.	Not possible

S. No.	Criteria	SF 6 circuit breaker	Vacuum circuit breaker
IV. COST			
1.	Cost of production	Sightly higher than VCB	-
2.	Maintenance cost	Lowest negligible cost for minimum 10 years.	Lowest negligible cost for minimum 10 years.



If in addition to the code letters IP only one code digit for the degree of protection is used, the missing digits *a* to be replaced by a dash as given in table 33.

For example: IP - 4 Class Protection: (Splash proof)

2.4 Rated Characteristics

The main characteristics of a power circuit breaker including its operating devices and auxiliary equipment used to determine the rating are as follows :-

(i) Rated voltage
(ii) Rated insulation level
(iii) Rated frequency
(iv) Rated normal current
(iv) Rated short-time withstand current
(v) Rated short-circuit breaking current
(vi) Rated short-circuit making current
(vii) Rated operating sequence (duty cycle)
(viii) Rated transient recovery voltage (TRV) for terminal fault
(ix) Total breaking time (maximum)

(x) Rated characteristics for short-time faults, for three pole circuit breakers designed for direct connection to overhead transmission lines and rated at 52 kV and above and at more than 12.5 kA rated short breaking current

In addition, the following characteristics are necessity for specific application.

(i) Rated line charging breaking current
(ii) Rated inductive breaking current
(iii) Rated capacitor breaking current
(iv) Rated out of phase breaking current

Table 33 : Degree of protection used

Degree of protection against Contact and foreign bodies:		**Degree of protection against water**	
First Digit	**Description**	**Second Digit**	**Description**
0	No Protection	0	No Protection
1	Protection against large foreign bodies	1	Protection against vertically galling water droplet
2	Protection against medium sized foreign bodies	2	Protection against obliquely falling water droplet
3	Protection against small foreign bodies	3	Protection against sprayed water (spray proof)
4	Protection against granular foreign bodies	4	Protection against splashing (splash proof)
5	Protection against dust deposit	5	Protection against water jet (Hot proof)
6	Protection against ingress of dust	6	Protection against inundation
		7	Protection against immersion in water
		8	Protection against indefinite immersion in water

2.5 Standard Ratings of Circuit Breakers

2.5.1 Rated Voltage

Voltage rating of the power circuit breaker is in terms of three phase line to line voltage of the system. The rated voltage of the circuit breaker should be of standard rating chosen so as to be at least equal to the highest voltage of the system at the point where the circuit breaker is to be installed. The operating voltage and the power frequency recovery voltage should not exceed the rated maximum values because this maximum is upper limit for continuous operation.

It is however considered that operation at altitude above 1000 meters should be given special considerations and certification from manufacturer be obtained because of possible influence of altitude on interrupting capacity.

In case of generator circuit breakers the rated maximum should be equal to the maximum operating voltage of the generator, which is usually equal to 1.05 times rated voltage. The rated voltage is expressed in kV (rms) and refer to phase to phase voltage and is given in table 34.

Table 34 : Rating of circuit breaker

Nominal system voltage kV rms	Rated voltage of circuit breaker kV rms
11	12
22	24
33	36
66	72.5

2.5.2 Rated Insulation Level

Insulation level of power circuit breakers should be selected from standard insulation level listed in IS: 13118. Refer table 2.1 (section-4) for voltage up to 36 kV and table 2.2 (section-4) for voltages up to 245 kV and for insulation co-ordination refer (Para 2.3.4. of section-4) of IS: 13118.

The surge protection of the system should be coordinated with the impulse strength of the breaker, both across the open contacts and to ground. Attention should also be given to increase in surge voltage because of reflections which occur at breakers when their contacts are open, especially where cables are involved.

Surge arrestors are generally installed on the bus or on transformers and not on each circuit breaker, the surge voltage at the breaker can exceed that at the arrestors. The amount of the excess depends upon the steepness of the wave front and the distance from the circuit breaker to the surge arrestors. When the circuit breaker is in the open position, either intentionally left open or during operation, an incoming surge voltage may be doubled by reflection at the open contacts. Selection of too low an insulation level for circuit breakers, if not individually protected by arrestors, may result in line-to-ground, or open gap insulation failure of the circuit breaker. Use of individual line entrance surge arrestors may be required if the lightning trip-out rate of the line exceeds 1 per year (refer IEEE std. 37.010-1999).

2.5.3 Rated Frequency

Standard power circuit breakers are rated at 50 cycles. Service at other frequencies requires special consideration.

2.5.4 Rated Normal Current

Rated normal current of a circuit breaker is the rms value of the current which the circuit breaker shall be able to carry continuously at rated frequency. With the rise in temperature of its different parts not exceeding specified values. Values of rated normal currents should be selected from standard value of normal currents as per IS: 13118 which are 400A; 630A; 800A; 1250A; 1600A; 2000A; 2500A; 3500A; 4000A; 5000A; 6300A (if required higher values can be selected). These ratings are based on operation of the circuit breaker or switchgear assembly where the ambient temperature (measured outside the enclosure) does not exceed 40^0C and the altitude does not exceed 1000 m. Standard equipment may be operated at higher altitude by reducing the continuous current rating in accordance with table 35 (based on American Practice- IEEE 37010 and 370131).

Table 35 : Rated current at higher altitude

Altitude in meters (approx.)	Insulation level	Rated continuous current
1000	1.00	1.00
1500	0.95	Refer to manufacturer
3000	0.80	Refer to manufacturer

The rated continuous current is based on the maximum permissible total temperature limitations of the various parts of the circuit breaker when it is carrying rated current at an ambient temperature of 40^0C.

When the ambient temperature is greater than 40^0C, the current must be reduced to less than rated continuous current to keep temperatures within allowable limits.

2.5.5 Rated short-time withstand current

Rated short-time withstand current is equal to the rated short circuit breaking current. The rated peak withstand current is equal to rated short circuit making current. Rated duration of short circuit should be as per IS 13118.

2.5.6 Rated Short Circuit Breaking Current

The rated short circuit breaking current is the highest short circuit current which the circuit breaker will be capable of breaking in a circuit having power frequency recovery voltage corresponding to rated voltage and transient recovery voltage equal to the rated value of the circuit breaker as specified in IS. For three pole circuit breakers the AC component relates to three phase short circuit including short line fault.

Rated short circuit breaking current is characterized by two values and is given at Fig. 22.

(i) rms value of AC component and is termed rated short circuit current
(ii) Percentage DC component

rms value of AC component of the rated short-circuit breaking current should be selected from standard values given in IS 13118. Percentage DC component is dependant upon the time from initiation of short circuit current and standard values are given in IS 13118.

The standard values practice of breaking current or being 6.3 kA, 8 kA, 10 kA,12.5 kA kA,16 kA, 20 kA, 25 kA, 31.5 kA, 40 kA, 50 kA, 63 kA, 80 kA, 100 kA. The earlier practice was to express the rated breaking capacity in MVA.

MVA : $\sqrt{3}\,kV \times kA$
MVA : breaking capacity of circuit breaker
kV : rated voltage
kA ; rated breaking current

2.5.7 Rated Short Circuit Making Current

The circuit breakers some times, close on to a existing fault. In such cases, the current increases to the maximum values as the peak of first current loop. The circuit breaker must be able to close without hesitation as contacts touch. The circuit breaker must be able to withstand the high mechanical forces during such closure.

As per IS: 13118 rated short circuit making current should be at least 2.5 times the rms value of the A. C. component of its rated short circuit breaking current.

2.5.8 Transient Recovery Voltage and Restriking Voltage and First Pole to clear Factor

The instantaneous value of the recovery voltage at the Instant of arc extinction is called the active recovery voltage figure as shown in fig 24.

2.5.9 Rated Transient Recovery Voltage (TRV) for terminal faults

The rated transient recovery voltage (TRV) for terminal faults relating to the rated short-circuit breaking current is the reference voltage. This constitutes the limit of the prospective transient recovery voltage of circuits, which the circuit breaker will be capable of breaking in the event of a short circuit at its terminals.

Wave form of transient recovery voltage varies according to the arrangement of actual circuit.

Standard value of rated TRV for 3 pole circuit breaker as per in IS: 13118 for the circuit breakers used in the outdoor substations under consideration are given below table 36.

2.5.10 First Pole to Clear Factors

The ratio of transient voltage that appears across the contacts at the instant of arc extinction to service frequency recovery voltage is called the restriking voltage first pole to clear factor.

In three-phase circuits the restriking voltage refers to the voltage across the first pole to clear because this voltage is generally higher than that appears across each of the other two.

Table 36: Standard values of TRV

Rated voltage	First pole to clear factor	Time	TRV Peak value	Rate of rise	Remarks
(kV)		(μs)	(kV)	(kV/μs)	
3.3	1.5	40	6.2	0.15	
7.2	1.5	52	12.3	0.24	
12	1.5	60	20.6	0.34	
36	1.5	108	62	0.57	
72.5	1.5	166	124	0.75	
145	1.3	77	215	2.0	
145	1.5	89	249	2.0	
245	1.3	130	364	2.0	

2.5.11 Recovery voltage

The active recovery voltage depends upon the following factors.

i) the power factor
ii) the armature reaction
iii) the circuit conditions

Effect of power factor on recovery voltage:- With low p.f., for example when the ratio of reactance to resistance of the circuit is high, the active recovery voltage will be high; whereas with high p.f. i.e. when the resistance is high as compared to the reactance, the active recovery voltage would be correspondingly lower. This is illustrated in fig. 2 on left side the p.f. is zero and at the instant of arc extinction A the active recovery voltage is at peak value equaling to AB while in fig on right side the p.f. is 0.5 and the active recovery voltage at the instant of arc extinction is CD which is less than AB.

In general the active recovery voltage equals the maximum value of the system voltage multiplied by sin θ where θ is the power factor angle.

Effect of armature reaction on recovery voltage: The recovery voltage is less than the normal system voltage because of demagnetizing effect of armature reaction. The fault currents flowing in the generator winding are of lagging power factor. They have a demagnetizing armature reaction. Hence they reduce the terminal voltage.

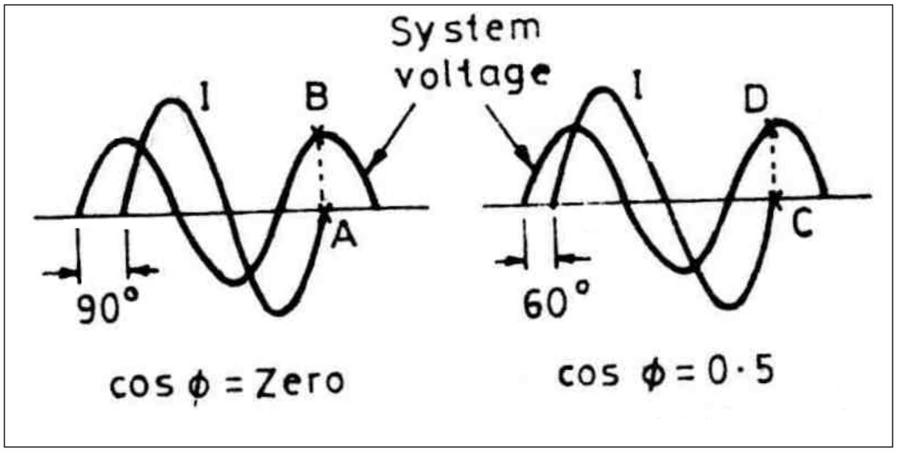


Fig. 2 : Effect of p.f. on recovery voltage (Source IS: 13118)

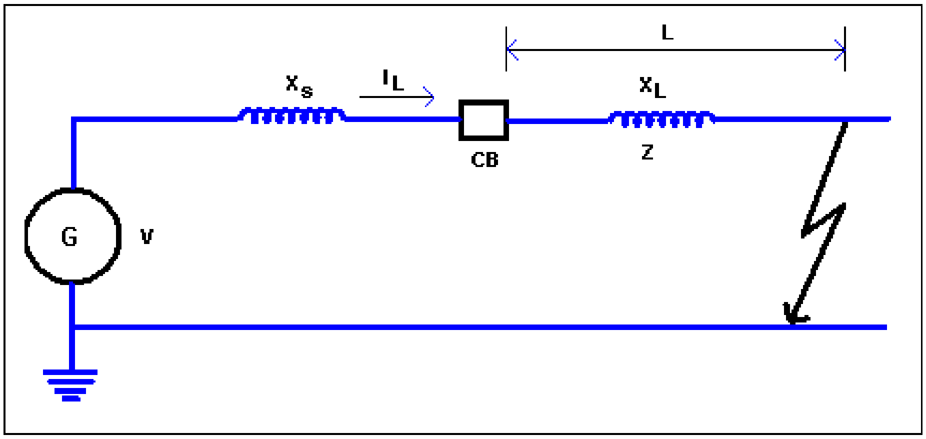
Effect of circuit conditions on recovery voltage: Another factor that influences the recovery voltage is the circuit conditions e.g. three phase faults that are insulated from earth, either at neutral or at fault, produce recovery voltages in the first phase to clear which are normally more severe than those produced by single phase or three phase faults on systems with earthed neutrals. This is explained below.

Consider an unearthed three phase fault, on a three-phase system with the neutral earthed, being cleared by a circuit-breaker. When the breaker opens, it draws out an arc in each phase. Assume that the arc in R phase is the first to be cleared (fig. 2). At the instant of this extinction the Y and B phases are still acting and have the same instantaneous phase voltage – 0.5v, where v is the phase to neutral value of the system. Now the resistance of the arcs in the Y and B phases at this instant are negligible, which means that the fault itself is momentarily at the potential – 0.5V. Since the fault is common to all three phases the momentary value of the recovery voltage component in phase R must be V + 0.5V i.e., 1.5V (fig. 2). This means that the recovery voltage component in the first phase to clear on a 3-phase unearthed fault is 1.5 times that on an earth fault assuming an earthed neutral.

2.5.12 Rated Characteristics for Short-Line faults

Rated characteristics for short line faults are required for three generator pole circuit breakers designed for direct connection to overhead transmission lines and having a rated voltage of 52 kV and above and a rated short-circuit breaking current exceeding 12.5 kA. These characteristics relate to the breaking of a single phase earth fault in a system with earthed neutral.

The short line fault circuit is taken as composed of a supply circuit on the source side of the circuit breaker and a short line on its load side (fig. 3) with the following rated characteristics.



G = source of power
V = voltage, phase-to-neutral value: V/√3
I_L = short-line fault current
CB = circuit breaker

X_s = reactance on source side
X_L = reactance on line side
Z = surge impedance of the line
L = length of line to fault

Fig. 3 : Short-line fault circuit

2.5.13 Rated Supply Circuit characteristics

Voltage equal to the phase-to-earth voltage V/√3 corresponding to the rated voltage V of the circuit breaker.
Short circuit current, in case of terminal fault, equal to the rated short circuit breaking current of the circuit breaker.

Prospective transient recovery voltage, in case of terminal fault, given by the standard values in IS: 13118.

2.5.14 Rated line Characteristics

Standard values of rated surge impedance rated peak factor and time should be taken from IS: 13118.

2.5.15 Rated out –of-phase breaking current

Rated out –of-phase breaking current is required to be specified for generator breaker and as per IS 13118. This provision will provide with following.

a. The power frequency recovery voltage should be 2.0/√3 times the rated voltage for earthed neutral systems and 2.5/√3 times the rated voltage for other systems.
b. The rated out-of-phase breaking current should be 25% of the rated short-circuit breaking current.
c. Transient recovery voltage as pre IS: 13118.

2.5.16 Rated Line Charging Breaking Current

Rated Line Charging Breaking Current is required to be specified for feeder circuit breakers. Standard value of line charging capacity of circuit breakers for the commonly used voltages are given in table 37.

Table 37 : Standard values of charging capacity of circuit breaker

Rated voltage (kV)	Rated line-charging breaking current (A)
12	2.5
36	40
72.5	40
145	50
245	125

This implies for overhead line length equal to 1.2 times the rated voltage of the circuit breaker in kilovolts. In case line length is longer than it may be necessary to specify a higher value of line charging capacity.

2.5.17 Rated time quantities and operating sequence

Rated values to be assigned to the following time quantities (fig. 4) will depend upon rated supply voltage reclosing operations etc.

(i) Opening time;
(ii) Break time;
(iii) Closing time;
(iv) Open-close time;
(v) Reclosing time;
(vi) Close-open time;

Rated operating sequence is defined as follows:-

o – t – co - t´ - co

Where
o - opening operation
co - closing operation followed immediately by an opening operation (without internal time delay)
t,t´ - time interval between successive operation/ t& t″ are in minutes or seconds

Power circuit breakers are rated for interrupting ability on the basis of a standard operating duty.

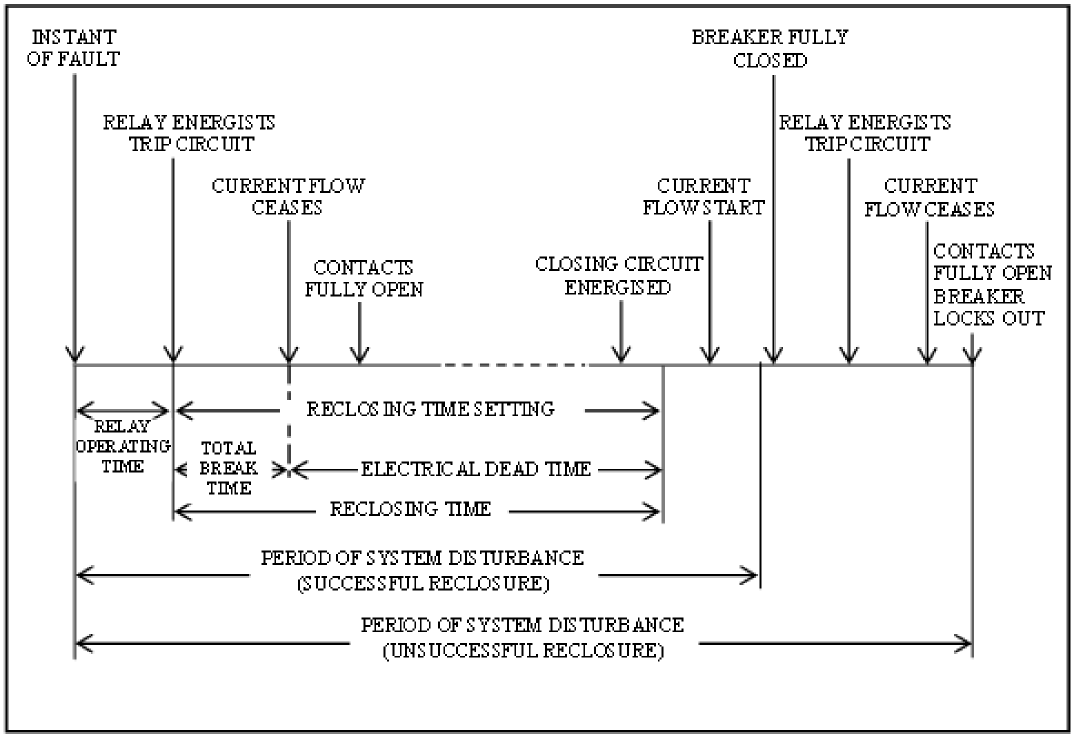


Fig.4 : Reclosing – Close Open Reclose Time

The rated interrupting time of a circuit breaker is the maximum permissible interval between the energization of the trip circuit at rated control voltage and rated mechanism pressure and the interruption of the current in the main circuit in all poles. It is used to classify breakers of different speed.

For line-to-ground faults, the interrupting time is estimated to exceed the rated interrupting time by 0.1 cycle. For asymmetrical faults, it is estimated that the interrupting time may exceed rated time by an additional 0.2 cycle. Hence, for grounded asymmetrical faults, the last phase to clear is estimated to be 0.3 cycle slower than the rated interrupting time. Additionally, rated interrupting time may be exceeded during extreme cold weather or when the breaker has been closed for an extended period of time. Also, the breaker may be slower at the lower limits of control voltage and/or mechanism stored energy. These interrupting times are in the range of several milliseconds have system stability implications.

The rated interrupting time may be exceeded for close-open operations. The increase in interrupting time on close-open operation may be important from the standpoint of possible system instability. For low values of current, these considerations are less important.

2.6 CO-ORDINATION OF RATED VALUES

Co-ordination of rated voltages, short circuit breaking current and rated normal current for guidance as per IS 13118 for rated voltage 33 kV and above as commonly used are as follows (Table 38).

Table 38 : Coordination of rated voltage, short circuit breaking current

Rated voltage (kV)	Rated short-circuit breaking current (kA)	Rated normal current (A)							
3.6	10	400							
	16		630		1250				
	25				1250	1600		2500	
	40				1250	1600		2500	4000
7.2	8	400							
	12.5	400	630		1250				
	16		630		1250	1600			
	25		630		1250	1600		2500	
	60				1250	1600		2500	4000
12	8	400							
	12.5	400	630		1250				
	16		630		1250	1600			
	25		630		1250	1600		2500	
	40				1250	1600		2500	
	50				1250	1600		2500	
17.5	8	400	630		1250				
	12.5		630		1250				
	16		630		1250				
	25				1250				
	40				1250	1600		2500	
24	8		630						
	12.5		630		1250				
	16		630		1250	1600			
	25				1250	1600		2500	
	40					1600		2500	4000
36	8		630						
	12.5		630		1250				
	16		630		1250	1600			
	25				1250	1600		2500	
	40					1600		2500	4000
52	8			800					
	12.5				1250				
	20				1250	1600	2000		

Rated voltage (kV)	**Rated short-circuit breaking current (kA)**	**Rated normal current (A)**							
72.5	12.5			800	1250				
	16			800	1250				
	20				1250	1600	2000		
	31.5				1250	1600	2000		
145	12.5	800	1250						
	20		1250	1600	2000				
	25		1250	1600	2000				
	31.5		1250	1600	2000	3150			
	40			1600	2000	3150			
	50				2000	3150			
245	20		1250	1600	2000				
	31.5		1250	1600	2000				
	40			1600	2000	3150			
	50				2000	3150			

2.7 Tests

2.7.1 Type Test

Following type tests as applicable in accordance with IS 13118 and IEC-60056-1987 are recommended to determine adequacy of the circuit breaker.

(i) Dielectric tests (1.2/50 micro second lightning impulse withstand) and 1 minute power frequency voltage with stand (dry & wet) test
(ii) Radio interface voltage (r.i.v.) tests
(iii) Temperature rise tests
(iv) Measurement of the resistance of the main circuit
(v) Short-time withstand current and peak withstand current tests
(vi) Mechanical and environmental tests
(vii) Miscellaneous provisions for making and breaking tests
(viii) Short circuit making and breaking tests
(ix) Basic short circuit test duties
(x) Critical current tests
(xi) Single phase short making and breaking tests
(xii) Capacitive current switching tests
(xiii) Magnetizing and small inductive current switching tests

2.7.2 Routine tests

(i) Power frequency voltage withstand dry tests on the main circuit
(ii) Voltage withstand tests on control and auxiliary circuits
(iii) Measurement of the resistance of the main circuit
(iv) Mechanical operating tests
(v) Design and visual checks

2.8 Fault Calculation

In order to determine interrupting duty of circuit breakers it is necessity to determine fault current at each circuit breaker location. Determination of maximum short circuit current is the most important requirement of circuit breaker application. Rigorous determination of short circuit current as a function of time involves complex calculations. Growth in interconnecting power system as systems expand will increase short circuit duty. Accordingly some approximation and degree of judgment should be used.
Different published methods of determining short circuit currents are available. Reference may be made to the following for details and selection.

IEEE application guide for AC high voltage circuit breakers rated on a symmetrical current basis IEEE std. C37010-1999.

First step in carrying out short circuit studies is to determine system impedances with reference to the point of fault and current distribution for different kind of faults. For present day large interconnected system this becomes time consuming laborious study.

AC or DC network analyzer for calculation of fault current was previously frequently used for short circuit studies. In the analyzer all the essential elements of the power system were represented in a miniature replica and fault currents determined from calculation readings. In this method constant voltage behind sub transient/synchronous reactance were used as required. Accordingly real time studies to determine DC component of fault current in addition to AC component to determine the critical current value existing at the time of primary arcing contact parting cannot be calculated. Further network analyzers is a fixed place study. Now-a-day computer studies are carried out for such application.

2.8.1 Staged Short Circuit Tests

Staged fault short circuit tests adequately controlled on actual systems have been carried out mostly on new equipments and systems to determine circuit breaker capability. These are accurate, costly and not always possible as selection of circuit breaker precedes power system installation.

2.8.2 Circuit Breaker Rating for Short Circuit Duty

Steps involved in fixing circuit breaker short circuit rating are as follows:

(i) Determine normal current duty of the circuit breaker and select higher available rated current from standard values as per IEC/IS 13118 clause 4.4.

(ii) Short Circuit studies be carried for following types of faults which are considered worst according to IEEE std. C37010-1999.

   (a) Three phase ungrounded faults
   (b) Phase to ground fault

More severe of the short circuit faults be taken for selecting the short circuit rating.

(iii) Determine short circuit currents for the required accuracy by a suitable method. For line to ground faults, the required symmetrical interrupting capability is 15% higher.

(iv) Circuit breaker having the rms value of the ac component of the short circuit higher then short circuit duty as calculated from table X A of IS 13118 (table 2.6.1 for commonly used voltages) be selected.

(v) A circuit breaker having adequate symmetrical interrupting capability will normally have adequate capability to meet normal asymmetrical requirement. Maximum symmetrical interrupting capacity of new circuit breaker is as follows:

$$\text{Rated short current x } \left(\frac{Rated \max imum\ voltage}{operating\ voltage} \right)$$

For higher X/R ratio or other special conditions refer the detail methods given in IEEE std.C37010-1999.

2.8.3 Simplified Methods for calculation short circuit current

Simplified methods calculating fault current to fix short circuit rating of circuit breakers have been recommended by standardizing agencies over years as given below.

Simplified conservative methods of calculation were recommended by protective devices committee of AIEEE for general use of the industry. It was recommended that rigorous methods be used when specifically required. The method is based upon determination of an initial value of rms symmetrical current (ac component) to which multiplying factor are applied for application purposes as given in table 39.

Table 39 : Multiplying factor

		General	Generator current breakers/short circuit more than 500,000 kVA
A.	8 cycle breaker	1.0	1.1
	5 cycle breaker	1.1	1.2
	3 cycle breakers	1.2	1.3
	2 cycle breakers	1.4	1.5
B.	Mechanical stresses and mandatory duty	1.6	

Accordingly the steps involved for determining short circuit rating of circuit breakers are as follows as per the AIEE simplified method:

(i) Determine highest value of rms symmetrical current for any type of fault equal E/X_1 phase fault or $3E/2X_1+X_0$ for ground fault whichever is greater.

(ii) Multiply this current by appropriate factors from table 2.8.1.

(iii) The resulting interrupting and momentary current should be used to select the available normal rated circuit breaker.

2.8.4 E/X Simplified method as per IEEE std. C37010-1999

The AIEEE simplified method was further referred in IEEE std. 37010-1999. This simplified method is now recommended. For short circuit duty of circuit breakers unless complex more accurate studies are warranted.

In these studies generating station and transmission lines interconnected with the system are represented in detail and the system is represented by equivalent system.

For small hydro say 5 MW unit size connected to regional grids, the grid size can be assumed to be infinite size and calculation carried out accordingly.

Calculation based on simplified method of calculating short circuit current recommended by IEEE std. 37010-1999 be made.

Steps involved in applying method are as follows:

(i) Calculate E/X_1 for 3 phase faults where X_1 = positive sequence

Positive sequence X_1 is assumed equal to negative sequence X_2 and obtained from design date or test.

(ii) Calculate ground fault current $3E/2\ X_1 + X_0$

X_0 = zero sequence reactance obtained from design date or test
E = phase to neutral voltage

(iii) If phase fault current does not exceed 80% of 100% symmetrical circuit breaker interrupting capacity or 70% ground fault current then the circuit breaker selection is adequate.

More exact procedure of calculation with adjustment for AC and DC decrements should be used if the criteria is not fulfilled. In this method multiplying factors to initial value of symmetrical short circuit current are given in the factor of curves for 2 cycle to 8 cycle.

2.8.5 Characteristics specified for 72.5 kV and 36 kV class circuit breaker are given in table 40.

Table 40 : Characteristics specified for 72.5 kV and 36 kV class circuit breakers

S. No.	Description	72.5 kV	36 kV
	Type and circuit breaker	SF_6	SF_6
i.	Number of poles	3	3
ii.	Class	Outdoor	Outdoor
iii.	Rated frequency	50 c/s	50 c/s
iv.	Rated voltage of breaker	72.5 kV	36 kV
v.	Rated insulation level : a). 1.2/ 50 micro sec. Lightning impulse withstand voltage for complete C.B. i. to earth (with C.B. closed) ii. across terminals of open circuit breaker a. one minute dry and wet power frequency withstand voltage i. to earth (breaker closed) ii. across terminals of open circuit breaker	 325 kVp 325 kVp 140 kV rms 140 kV rms	 170 kVp
vi.	Rated normal current at site conditions	1600 A	630 A
vii.	Rated line charging breaking current	Not less than 10A. corresponding switching over voltage values on line side & supply side to be intimated by the tenderer	100 A
viii.	Rated short circuit breaking current (Fig. A.1 in Annexure 2.1) a) rms value of AC component (rated short circuit current) b) percentage D.C. component	 31. 5 KA at 72. 5 KV As per IEC-62271 (Latest edition)	 12.5 kA at 36 kV (750 MVA) as per IS: 13118
ix.	First pole to clear factor	1.5	
x.	Rated transient recovery voltage for terminal faults (Fig.A.2&3 in annexure 2.2 &2.3) a) corresponding to rated short circuit breaking current (Symmetrical & Asymmetrical) b) Corresponding to currents below the rated & short circuit current	As per IEC –62271 (latest edition) -do-	
xi.	Breaking capacity under short line fault conditions with rated supply side and line side characteristics	-do-	
xii.	Rated short circuit making current	78. 75 KA peak	2.5 times the

S. No.	Description	72.5 kV	36 kV
		at 72. 5 kV	rms value of Ac component
xiii.	Rated operating sequence	Break dead Time-Make-Break (Minimum dead time should not be more than 15 cycles at 50 c/s inclusive of the time for auto reading relay. Unit of adjustment of dead time shall be 15 to 35 cycles.	
xiv.	Total break time for any current upto rated breaking current	Not more than 60 ms	
xv.	Min. short time current rating and its duration	31.5 kA for 3 sec.	
xvi	Minimum total creepage distance phase to earth	1700 mm	
xvii.	Difference in the instant of closing/opening of contacts of all the 3 pole a) Opening b) Closing	 Not more than 3.33 ms. Not more than 5 ms.	
xviii	Small inductive current interrupting capacity	Any value upto 10A with out switching over voltage exceeding 2.0 p.u.	
xix.	Whether breaker suitable for single pole operation or gang operation of three poles	Gang operation of three poles through mechanical linkages	
xx.	Number of trip coils	Two Nos. per breaker	

3.0 SELECTION OF OTHER SWITCHYARD EQUIPMENT

(Isolators, Current Transformers, Voltage Transformers and Lightning Arrestors)

3.1 Isolators

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-circuit currents, but not required to carry normal rated currents of the circuit.

Disconnecting switches may be motorized or operated manually it is recommended that 36 kV and above should be motorized. Earthing switches may be manually operated.

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

3.1.1 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 2 x 10 MW 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

3.1.2 Rating

Each isolating switch should have the particulars as given in table 41 under the site conditions for the system under design.

Table 41 : Rating of isolating switch

1.	Highest system voltage	72.5 kV	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)	325 kV (+ ve & - ve wave to earth & between poles)	170 kV 195 kV	75 kV 85 kV
4.	Rated one-minute power frequency wet withstand voltage	140 kV	70 kV	28 kV

	i) To earth and between poles (kV rms) ii) Across the isolating distance (kV rms) Voltage against ground and between poles	(against ground & between poles)	80 kV	32 kV
5.	Continuous rated current (Amps)	1600 A	630 A	400 A
6.	Short time current ratings i) For one second not less than kA (rms) ii) For 3 second	20 kA 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		

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.

3.1.3 Isolator Insulation

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

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

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

Design of the insulators should ensure ample insulation, mechanical strength and rigidity for satisfactory operation under site conditions. The design should also ensure 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.

3.1.4 Arcing Horn & Arcing Contacts

A set adjustable arcing horns should be 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 be obtained from supplier.

3.1.5 Load Break Switches

Load break switches for sectionalizing or for selection of bus 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

3.1.6 Terminal Connectors

Each isolator connected with outgoing lines should be provided with appropriate number of bimetallic, solderless clamp type of connectors suitable for the transmission line conductor. Each terminal clamp should be suitable for both vertical & horizontal connection of station bus bars and jumpers. Each isolator should also 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 should be avoided.

3.1.7 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 should be provided on each isolator. The interlocks should be of robust design of some reputed make and contained in a weather proof and dust tight housing.

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

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

(iii) The earth switch should not open automatically while attempting to close the isolator. The operation of the earth switches should also be interlocked with the CVTs 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.

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

In addition to the above, the line and the bus isolators should 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 should also be 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 for 36 kV and above.

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

3.1.8 Supporting Structures

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

3.1.9 Tests

Each isolator and earth switch should strictly comply with the requirements of all the type tests and should be subjected to all routine tests stipulated in the latest edition of relevant Indian standard.

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

3.2 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 shall be either oil filled type or of resin cast type which shall be enclosed in a sealed housing to avoid direct exposure to sun and other atmospheric effects.

Indoor Type: The CTs shall be of resin-cast type suitable for indoor installation.

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

12 kV current transformers should conform to REC specification 59/1993 and IS: 2705

3.2.1 Type and Rating

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

Each current transformer should have the particulars as given in table 42 under the site conditions for the system under design (typical values up to 72.5 kV systems are given).

Table 42 : Particulars of current transformer

(i)	Nominal system voltage	66 kV	33 kV	11 kV
(ii)	Highest system voltage	72.5 kV	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	325 kV	170 kV	75 kV
(v)	One minute power frequency (wet) withstand voltage against ground and between poles.	140 kV (rms)	70 kV (rms)	28 kV (rms)
(vi)	Short time current rating (based on system studies)	31.5 kA	31.5 kA	12.5 kA
(vii)	Rated dynamic current peak (based on system studies)	78.75 kA	2.5 time of short time current rating vi	
(viii)	Total minimum creepage of CTs bushings (based on environment)	As per Para 2.5 of section 1		

3.2.2 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 be specified.

3.2.2.1 Temperature Rise

(i) 36 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.

(ii) Temperature rise of 11 kV Class CTs

The maximum temperature rise of windings shall not exceed the figures as shown in table 43.

Table 43 : The maximum temperatures

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

Note: The supplier shall furnish evidence to the satisfaction of the purchaser about the class of insulation used.

3.2.3 General Requirements

(i) 36 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 should be used for the main insulation. The assembly of each CT should be 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 should be used in the design and construction of CTs.

The shape of the external metal parts should ensure that rain water runs off and it does not accumulate. All external surfaces should be resistant to atmospheric corrosion either by the selection of suitable materials or by proper treatment such as hot dip galvanisation, 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 nor 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 should be provided. In case Nitrogen is used the supplier should 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 should be provided with power factor terminals for testing loss angle (Tan delta). The equipment should also be 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 should be clearly brought out in the tender. Rubber or PVC/synthetic bellows for the purpose should not be accepted. The secondary terminal of CTs should be provided with short circuiting arrangement.

(ii) 11 kV Class

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

Core: The core of the CT shall invariably be of torroidal type. The magnetic circuit shall be 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.

3.2.4 Terminal Connectors 36 kV and above

All current transformers should be provided with appropriate number of solderless 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.

3.2.5 Type of Mounting

a) 12 kV & Above

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

b) 11 kV Outdoor Type

The CT should be suitably mounted on a pedestal/steel poles. Mounting flanges, bolts, etc. shall be hot dip galvanized and shall be supplied along with the CT. Suitable mounting holes shall be provided at the base for clamping to the structures.

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

3.2.6 Tests

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

3.2.7 External Insulation (12 kV & Above)

The external insulation should comprise of hollow porcelain, which will also serve as housing for the main insulation or other internal parts of the CTs. Insulators should be 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 should be carefully selected to achieve the necessary flashover distance and total / protected creepage distances as required.

3.2.8 Fittings and Accessories (12 kV & Above)

(i) Primary terminals
(ii) High frequency current surge diverters
(iii) Terminal connectors for connections from line to the CT primary
(iv) Oil level gauge
(v) Pressure relief device
(vi) Expansion chamber or other suitable type of device for absorbing variations in the volume of oil due to change of temperature.

(vii) Weather proof secondary terminal box fitted with door and complete with terminals and shorting links.

(viii) Lifting lugs

(ix) Fixing lugs with bolts, nuts and washers for holding down the CTs on the supporting steel structures.

(x) Rating and diagram plates

(xi) First filling of oil

(xii) Oil filling plug and drain valve

(xiii) Earthing terminals

3.3 Potential Transformer and Coupling Voltage Transformer

(i) 36 kV & Above

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.

(ii) 12 kV

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

3.3.1 Type and Rating of Potential Transformer

Potential transformer, design, Temperature rise and testing etc. should be in accordance with IEC: 60186 (1998), IS: 3156 (Part I & II) & IS: 5556 (connectors).

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

Each potential transformer should have the particulars as given in table 44 under the site conditions for the system under design (typical values for system up to 72.5 kV are given).

Table 44 : Particulars of potential transformer

1.	Rated voltage	72.5 kV	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	140 kV r.m.s.	70 kV r.m.s.	28 kV r.m.s.
10.	1.2/50 micro seconds impulse wave withstand test voltage	325 kV (Peak)	170 kV (Peak)	75 kV (Peak)
11.	One minute power frequency withstand test voltage on secondary	2 kV	2 kV	2 kV
12.	3 second short time current rating	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 section 4		

3.3.2 Temperature Rise

(i) 36 kV & Above

The maximum temperature of the windings, cores etc. should not exceed 45°C over ambient, while max. temperature of oil at top should not exceed 35°C over ambient. The PTs should be suitable for mounting on steel structures. All nuts, bolts, flanges and base should be hot dip galvanized. The terminal connectors should be 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 should 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 should be provided.

(ii) 12 kV

When tested in accordance with IS: 3156, the temperature rise of the windings should not exceed the limits as given in table 45.

Table 45 : Temperature rise of windings

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

Note: Maximum ambient temperature shall be taken as 45^0C

3.3.3 12 kV Voltage Transformer

The tank shall be given three coats of rust preventing paint. The other iron parts shall be hot dip galvanized. The tank shall be provided with lifting lugs either welded on the sides or top cover plate of the tank.

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

The tank shall be provided with two separate earthing terminals.

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

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

Indoor Type: The voltage transformer shall be of resin-cast type suitable for indoor installation and shall be normally mounted on one of the 12 kV incoming circuit breakers.

3.3.4 Coupling Voltage Transformer (72.5 kV & Above)

These transformers should be 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 should be of suitable ratio (say 72.5 kV/√3/110V/√3 for 72.5 kV line) suitable for outdoor installation on steel structures. The equipment should be supplied with terminal connectors suitable for vertical takeoff from line conductor and hot dip galvanized base fasteners. Other details should be in accordance with the specifications for potential transformers. The secondary terminals should be provided duly marked for above requirements.

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

3.4 Lightning Arrestors

Lightning arrestors are the basis of insulation co-ordination in the system and are installed at outdoor transformer terminals 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.

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

IEC: 60099-4 (2009) - Specification part – 4 for surge arrestor without gap for AC system

IS: 3070 - Specification for lightning arrestors

Typical parameters for systems up to72.5 kV are given in table 46.

Table 46 : Typical parameters systems up to72.5 kV

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	25 kA	18 kA
5.	Anticipated levels of temporary over voltage and its duration(based on system studies) a > Voltage (p. u.) b > Duration (seconds)	1.5/1.2	1.5/1.2	1.5/1.2
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

3.4.1 General Technical Requirements

(i) The Surge Arrestors should conform to the technical requirements given in table 47.

(ii) The energy handling capability of the Arrestor offered, supported by calculations should be obtained with offer.

(iii) The Lightning Arrestor should be fitted with pressure relief devices and arc diverting ports and should be tested as per the requirements of IEC specification for minimum prospective symmetrical fault current.

(iv) The grading ring on each complete Arrestor for proper stress distribution should be provided if required for attaining all the relevant technical parameters.

(v) **Terminal Arrangement:** The tope metal cap and the base of the lightning arrestors shall be galvanized. The line terminal shall 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 shall be provided with two separate terminals distinctly marked for connection to earth.

(vi) **Sealing:** The arrestors shall be hermetically sealed to avoid ingress of moisture. Suitable rubber gaskets with effective sealing system should be used. Manufacturers should device a suitable routine production testing to verify the efficiency of sealing.

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

(viii) **Pressure Relief Device:** The arrestors for 33 kV and 66 kV systems should have a suitable pressure relief system in order to avoid damage to its porcelain housing.

Table 47 : Technical Requirements for Metal Oxide (Gapless) Lightning Arrestors

1.	System voltage	72.5 kV	36 kV	12 kV
2.	Rated Arrestor Voltage kV rms (See Section - 4 also)	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	10 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	No Applicable
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	No applicable	
14.	a. Terminal Connector suitable for ACSR conductor size b. Take off	Single suitable ACSR Vertical/Horizontal	See note 1 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 Para 2.5 of section 1		

SECTION – III

GUIDE FOR SELECTION OF MAIN SINGLE LINE DIAGRAM

1.0 GENERAL

Major considerations for the selection of an economical and suitable main single line diagram and switching scheme for a sub-station are given below:

(i) Voltage level
(ii) Site Limitation
(iii) General and special Considerations

1.1 Voltage Level

(i) Power carrying capability of transmission lines increases roughly as the square of the voltage. Accordingly disconnection of higher voltage class equipment from bus bars get increasingly less desirable with increase in voltage levels.
(ii) High structures are not desirable in earthquake prone areas. Therefore in order to obtain lower structures and facilitate maintenance it is important to design such sub-stations preferably with not more than two levels of bus bars.

1.2 Site Considerations

Practical site consideration at a particular location e.g. lack of adequate flat area for layout of equipment in the sub-station may also influence the choice in such locations. Pollution caused by location near to sea or some other contaminated atmosphere may also affect layouts. At some locations completely in door sub-stations may be required.

1.3 General Miscellaneous Considerations

Other considerations in the selection of a suitable arrangement and layout are given below:

(i) Repair or maintenance of the equipment should be possible without interruption of power supply.
(ii) Expansion of sub-station should be easily possible.
(iii) In seismic prone areas height of structures should be as low as possible.
(iv) The outgoing transmission lines should not cross each other.

2.0 SWITCHING SCHEMES FOR DIFFERENT TYPES OF SWITCHYARDS

Main single line diagrams for different schemes which may be considered for designing a sub-station for SHP up to 25 MW are as follows:

2.1 Unit Switching Schemes

A "unit" scheme providing outdoor switching of the generator and transformer bank as a unit on the high-voltage side only, is shown in fig. 5. The unit scheme is well suited to power systems where loss of large blocks of generation is difficult to tolerate. The loss of a transformer or transmission line in all other arrangements may mean the loss of more than a single generating unit. Small power systems may not be able to compensate for the loss of multiple units, as could occur using other arrangements. The "unit" scheme makes maintenance outages simpler to arrange.

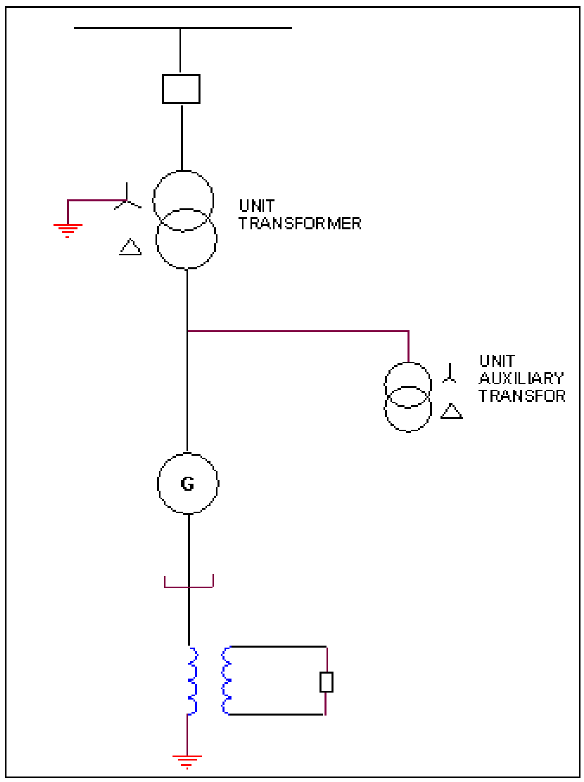


Fig. 5 : Unit Generator Transformer Connection

2.2 Several generators sharing one transformer

In case of small power stations feeding large power system several generators may share single transformer (fig. 6).

3.0 BUS SCHEMES

3.1 Single Bus Scheme

Single bus scheme is the most commonly used scheme in SHP. Variations include single bus single breaker scheme – single sectionalized bus scheme and single bus with transfer bus. The schemes are shown in figures 7, 8 and 9.

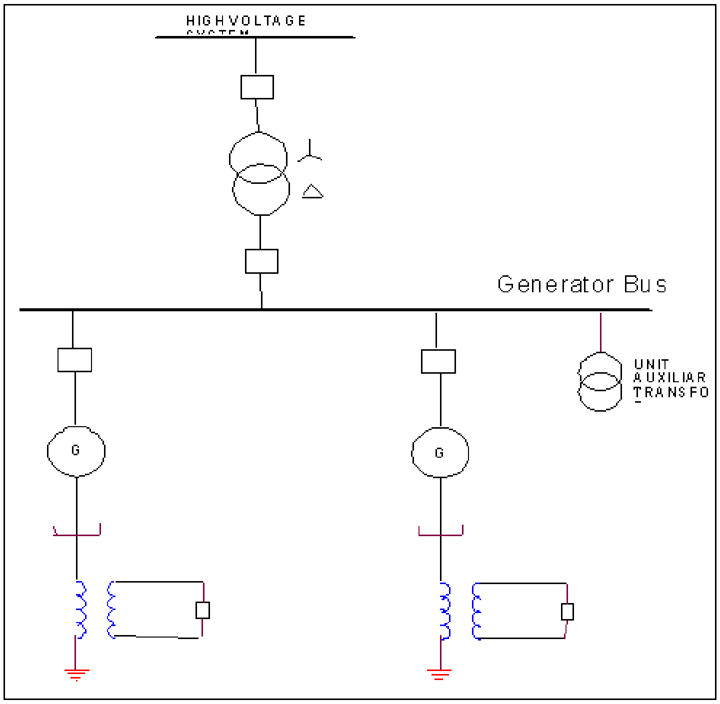


Fig. 6 : Generators with Generator Breakers and Sharing a Transformer

Single bus scheme with or without a transfer bus

- All units are connected on a single bus and entire generation will be lost in case of bus faults.
- This is generally provided on small generating station.
- Single bus with a Transfer bus scheme is useful for feeder breaker maintenance, but involves transfer of tripping circuits through auxiliary switches. Generator breakers are maintained along with unit maintenance outage period. Not recommended for SHP.
- Single sectionalized bus is very commonly employed being economical; generation outages can be controlled by sectionalizing. Simple arrangements does not require isolating switches to select bus and adopted even on large power. Recommended for SHP.

3.2 Double Bus Single Breaker Scheme

This scheme is common on large and medium station up to 220 kV in India and continent being economical and maintenance of breaker is possible by utilizing bus coupler and is also employed in SHPs in large number of units and high voltage feeders.

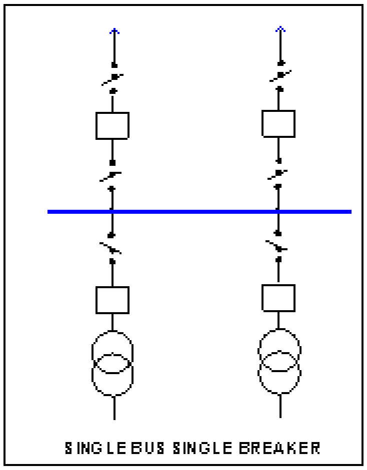


Fig. 7 : Single Bus Scheme

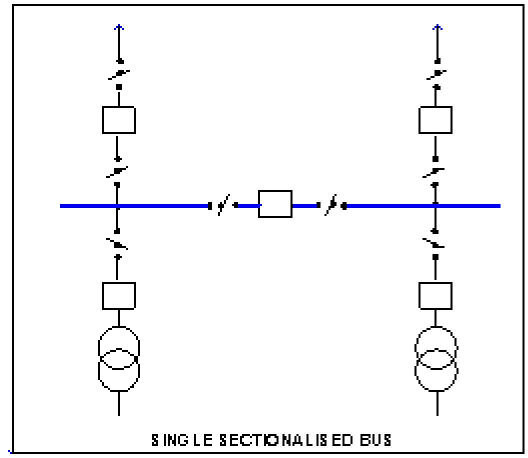


Fig. 8 : Single sectionalized bus

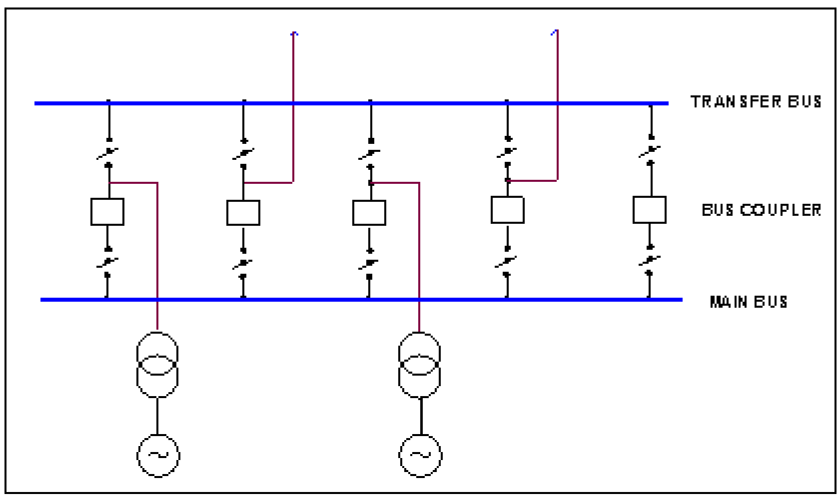


Fig. 9 : Single bus With a Transfer Bus

Disadvantages of Double Bus Single Breaker Scheme

(i) Selection of bus is by isolating switches which is a weak link. Inadvertent operation on load in spite of interlocking arrangements may damage the switch.

(ii) Utilizing bus coupler during breaker maintenance will necessitate transfer of tripping circuits through auxiliary contacts.

(iii) Discretion of operator to select the bus is not desirable. If machines are on one bus then entire power generation will be lost in case of bus fault which is not desirable for large generating station.

A typical single line diagram is shown in figure 10.

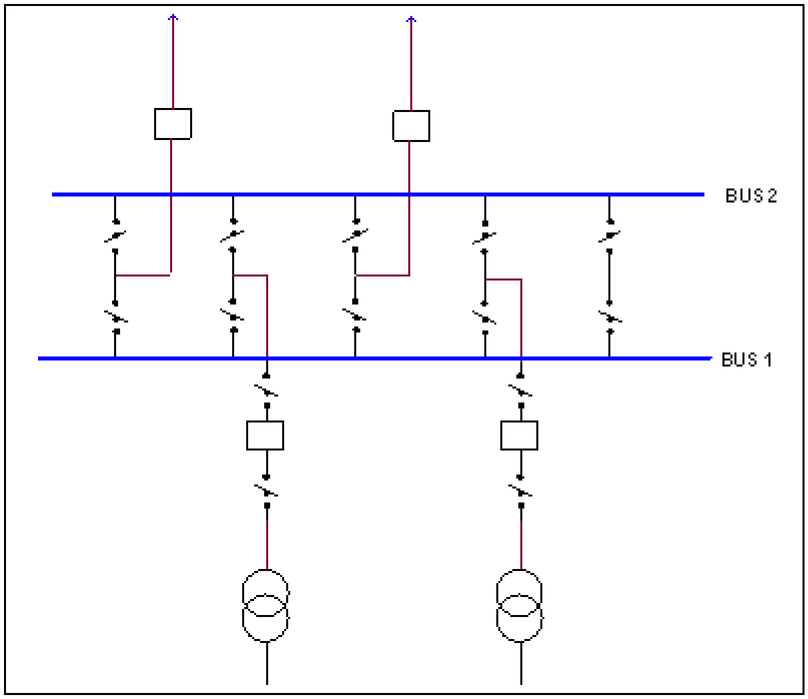


Fig. 10 : Double Bus Single Breaker Scheme

SECTION-IV

SWITCHYARD LAYOUT

1.0 GENERAL

Low level layout of the switchyard of step up station should be provided. Layout of switchyard may be generally designed in accordance with Central Board of irrigation and power manual on Sub-Station layout for 36 kV and above. Rural electrification standard be adopted for 12 kV substations.

1.1 Transformer Layout

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 where feasible drainage arrangements are provided to drain the oil away from the transformers in case of fire. Besides, separation wall are provided in between the transformers and also between the transformer and roads within the substation.

1.2 Typical layouts of switchyards

These are attached as follows:

Fig. 11:	12 kV outdoor switchyard with Lattice type structure recommended for hilly areas – 2 x 500 kVA SHP
Fig.12:	12 kV outdoor switchyard with pole structure – REC standard layout
Fig.13 & 14:	12 kV outdoor switchyard with Steel Channels Structures (2 sheets)
Fig.15 & 16:	36 kV outdoor switchyard – single bus scheme with SF6 Breaker (2 sheets)
Fig.17:	36 kV outdoor switchyard – single bus two breaker scheme with vacuum circuit breakers
Fig.18&19:	36 kV outdoor switchyard – single sectionalized bus (H- Type) 2 x 3.5 MW Project with SF6 circuit breakers (2 sheets)
Fig.20&21:	72.5 kV outdoor switchyard – single sectionalized bus –proposed for Typical 2 x 10 MW – 2 sheets.

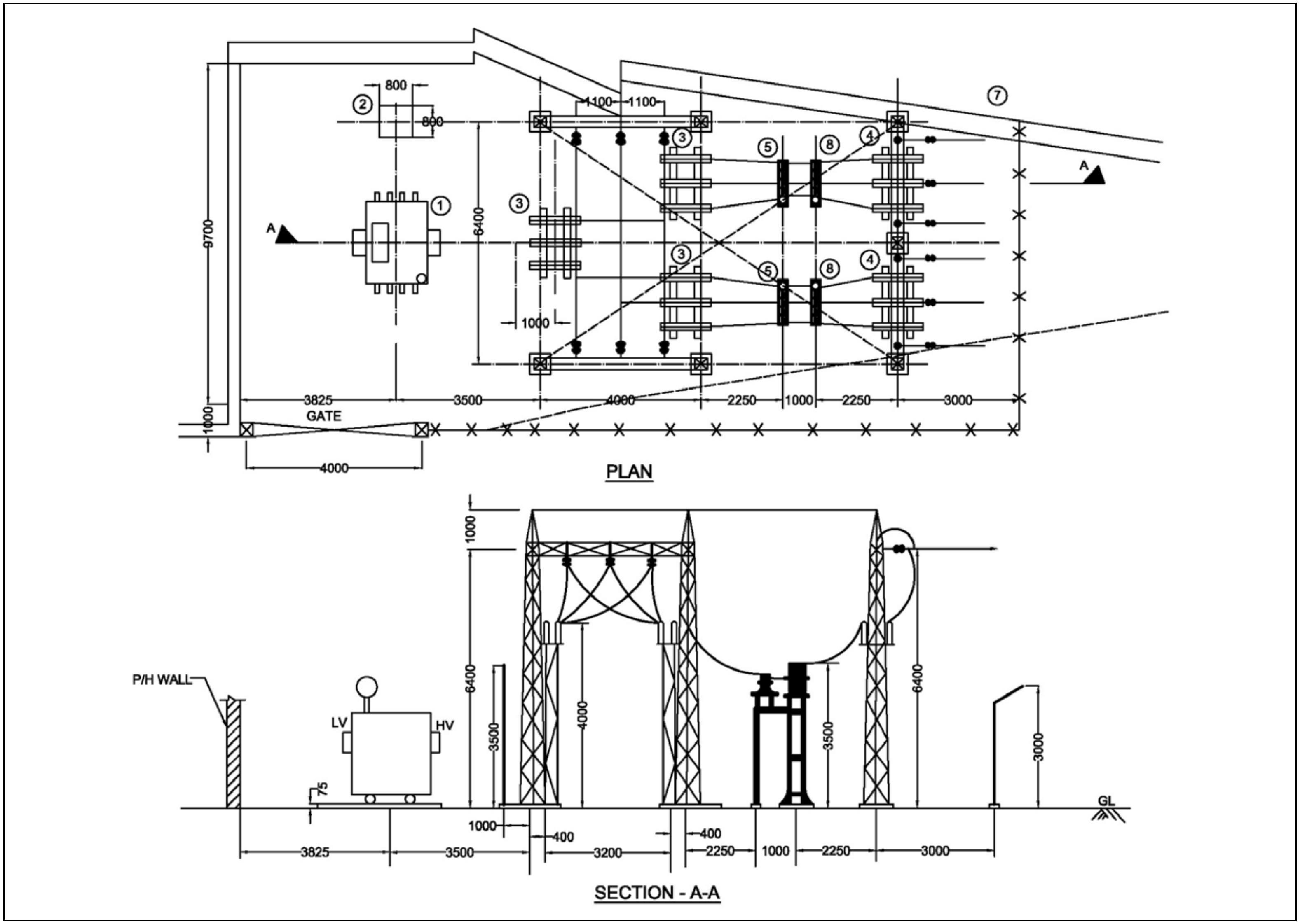
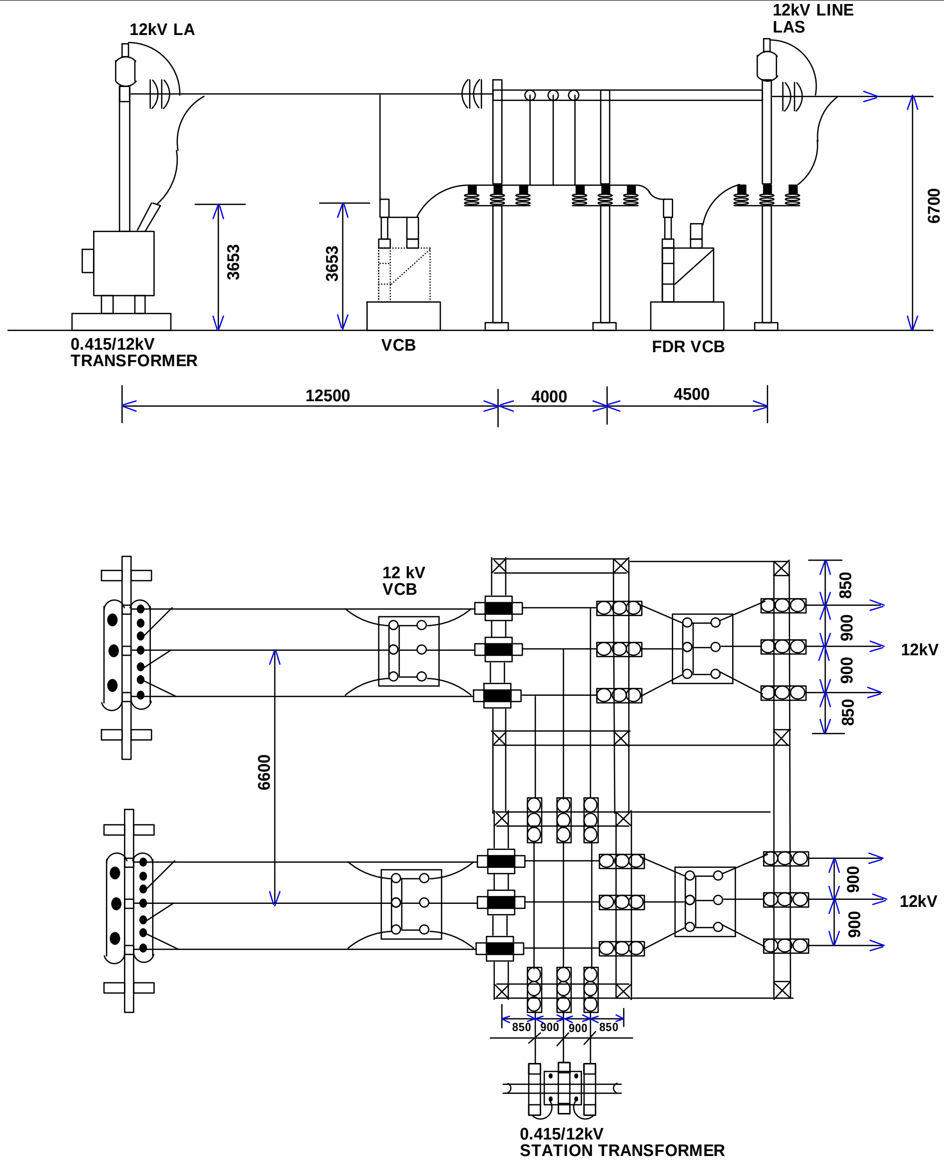


Fig. 11 : Layout of 12 kV typical Substation



NOTES

1. THE LAYOUT AS SHOWN ENVISAGES THE USE OF 12kV VACUUM CIRCUIT BREAKERS (REC SPEC. 22/1983). WHICH SHALL NOT REQUIRE ISOLATING SWITCHES AS THEIR INTEGRAL PART AS PARTICULARLY NO MAINTENANCE IS NEEDED ON THESE BREAKERS AND IT WILL ALSO ECONOMISE IN THE COST.
2. CONDUCTORS USED FOR 12kV JUMPERS AND BUSBARS SHALL NOT BE LESS THAN 50 SQ.MM. (C.E.) ACSR.
3. THE SUPPORTS SHALL BE SUITABLY CONCRETED.

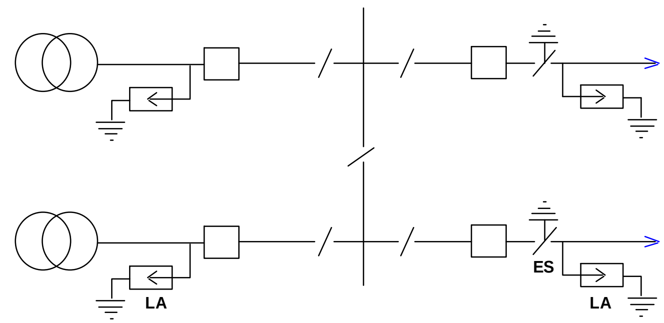


Fig. 12 : 12 kV Outdoor Switchyard with Pole Structure

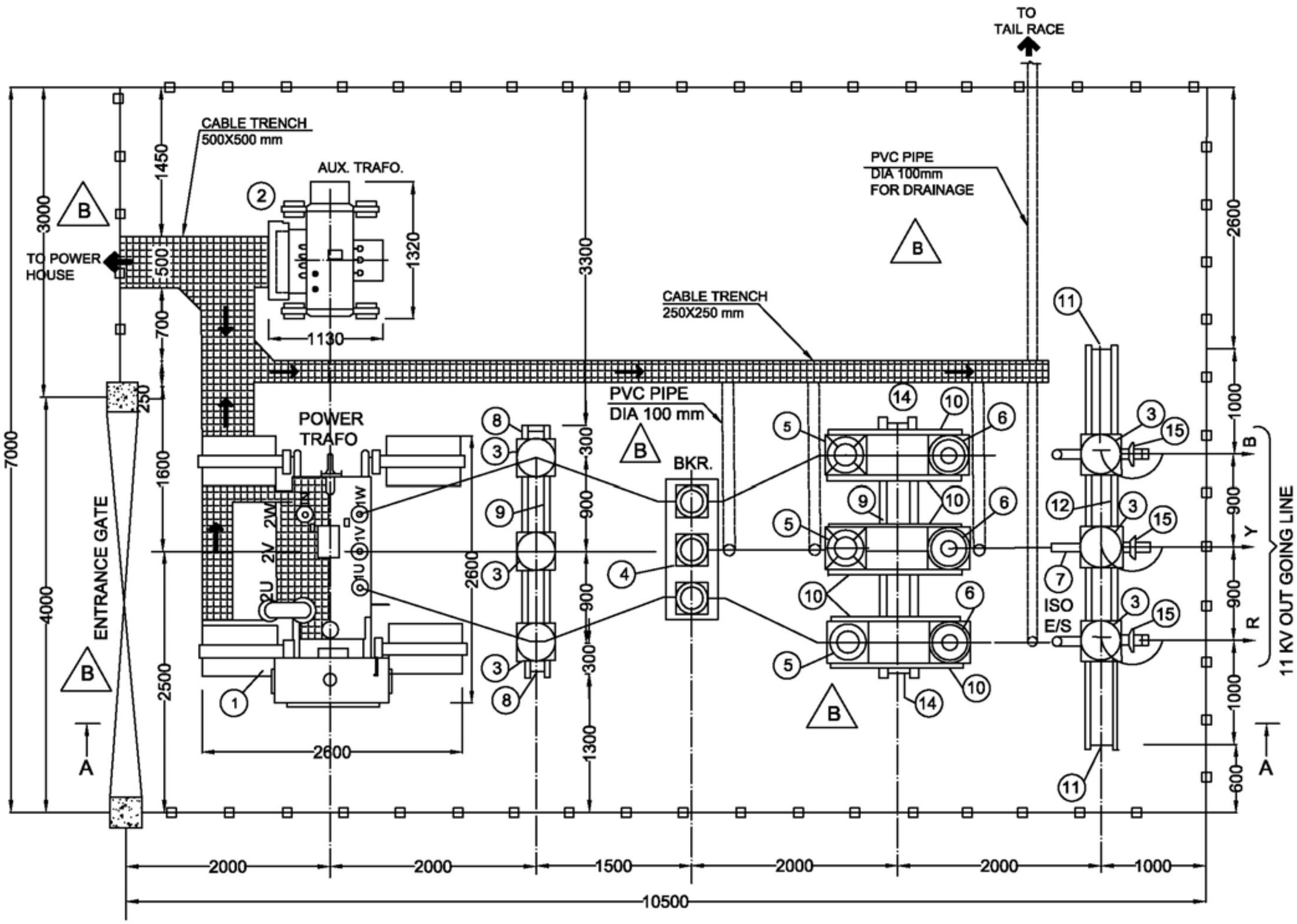


Fig. 13 : PLAN – Layout of 12 kV Switchyard of atypical (2 x 500 kW) (sheet 1 of 2)
(Support ISMC – Rolled Steel Channels)

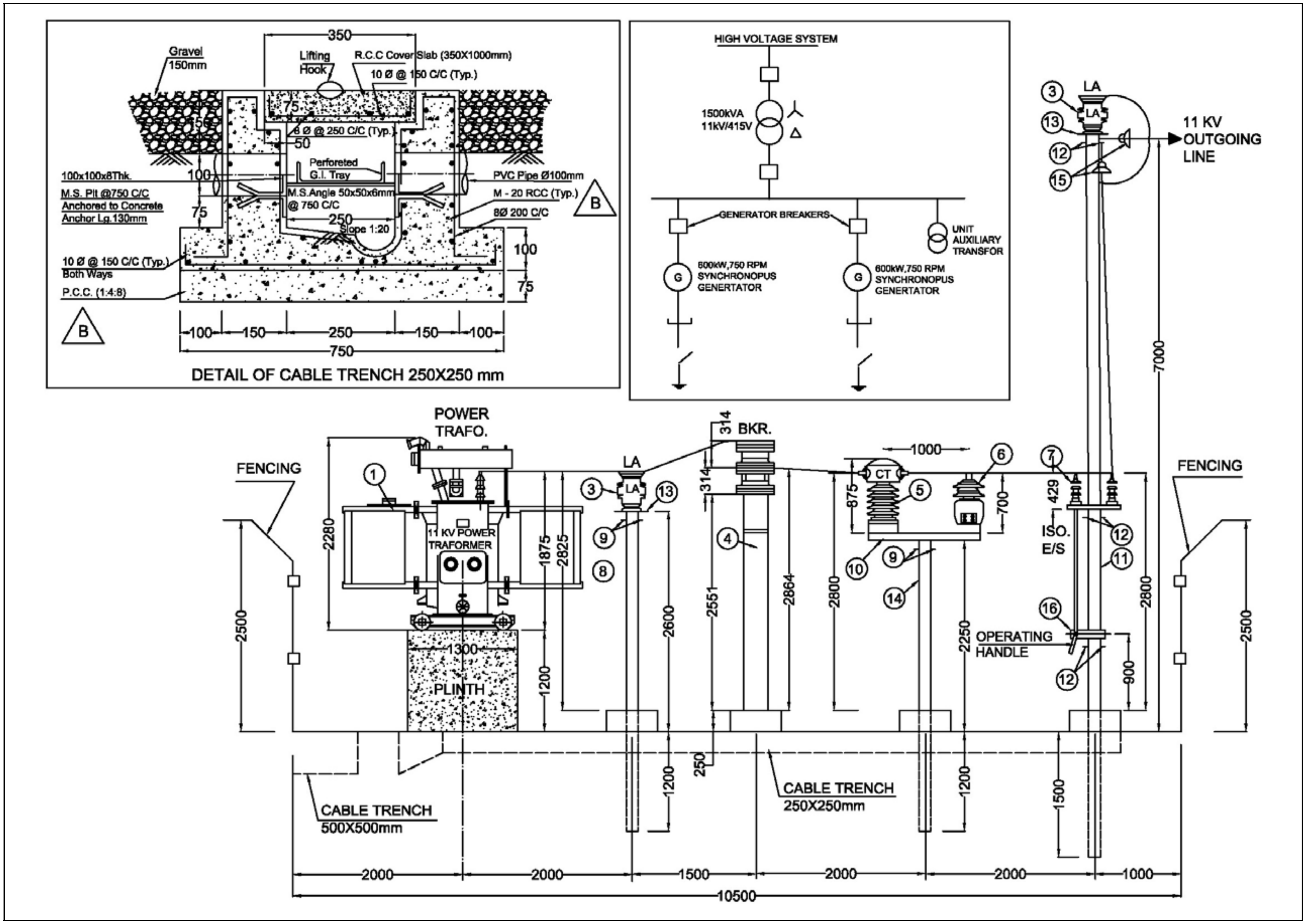


Fig.14 : SECTION A-A – Layout of 12 kV Switchyard of atypical SHP (2 x 500 kW) (sheet 2 of 2)

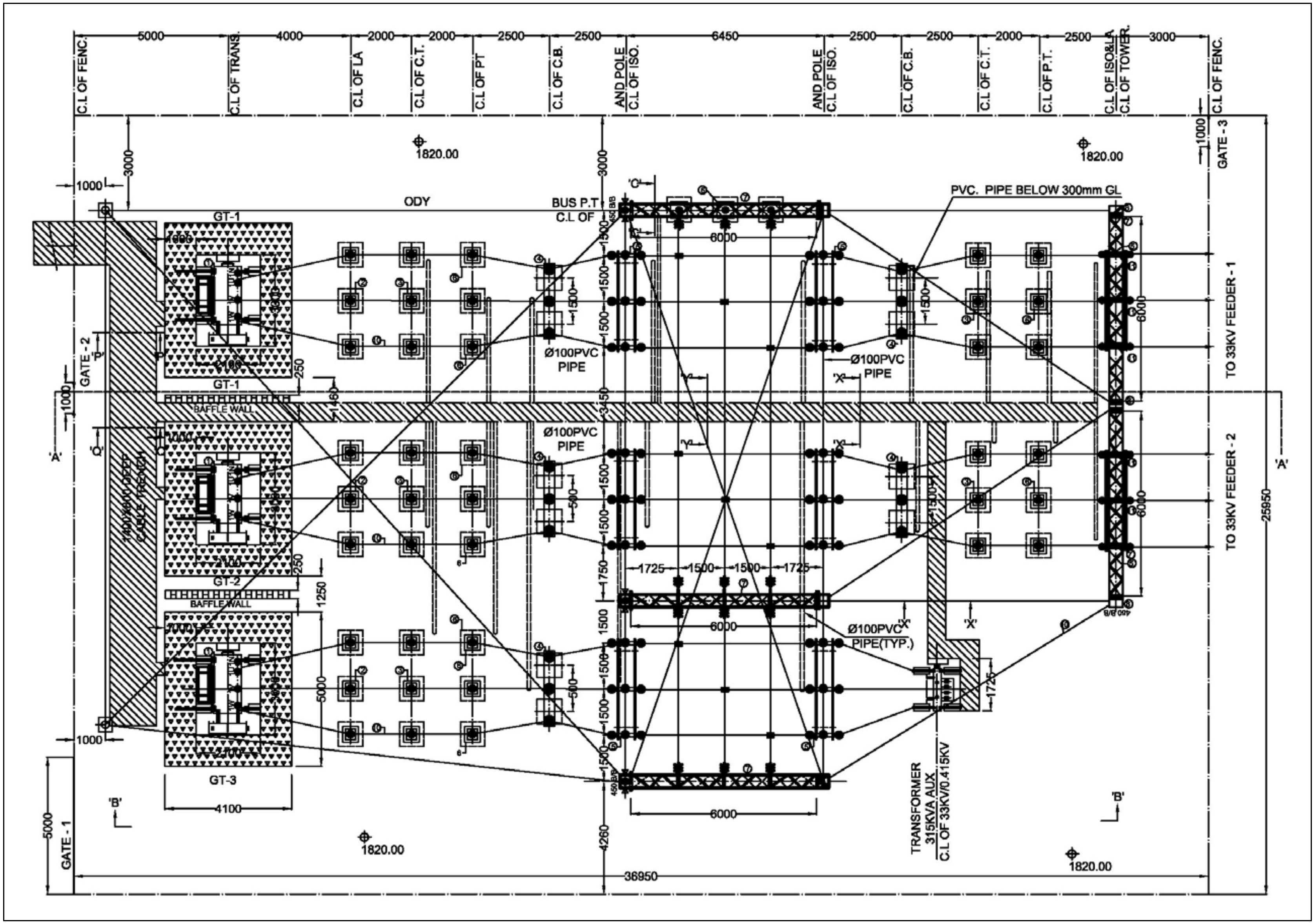


Fig. 15 (a) : 33 kV Switchyard Layout (Plan) – Single Bus Scheme with SF6 Circuit Breaker

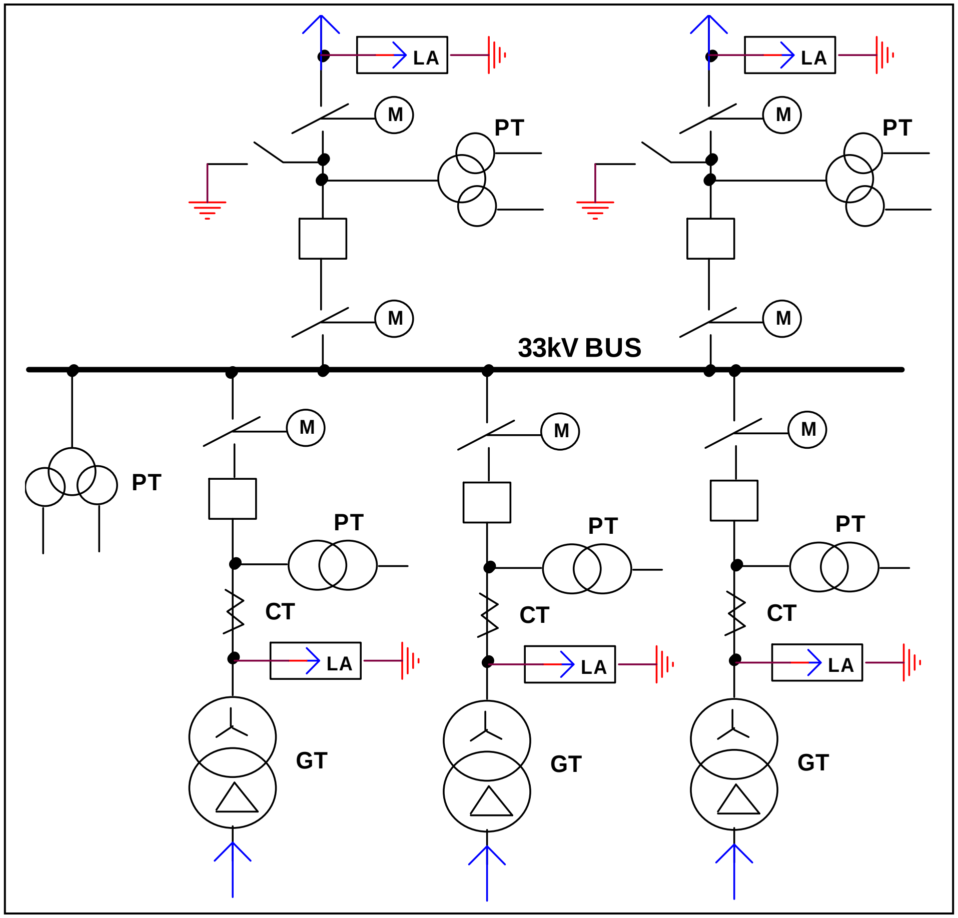


Fig. 15(b) : 33 kV Switchyard Layout (Plan) – Single Bus Scheme with SF6 Circuit Breaker

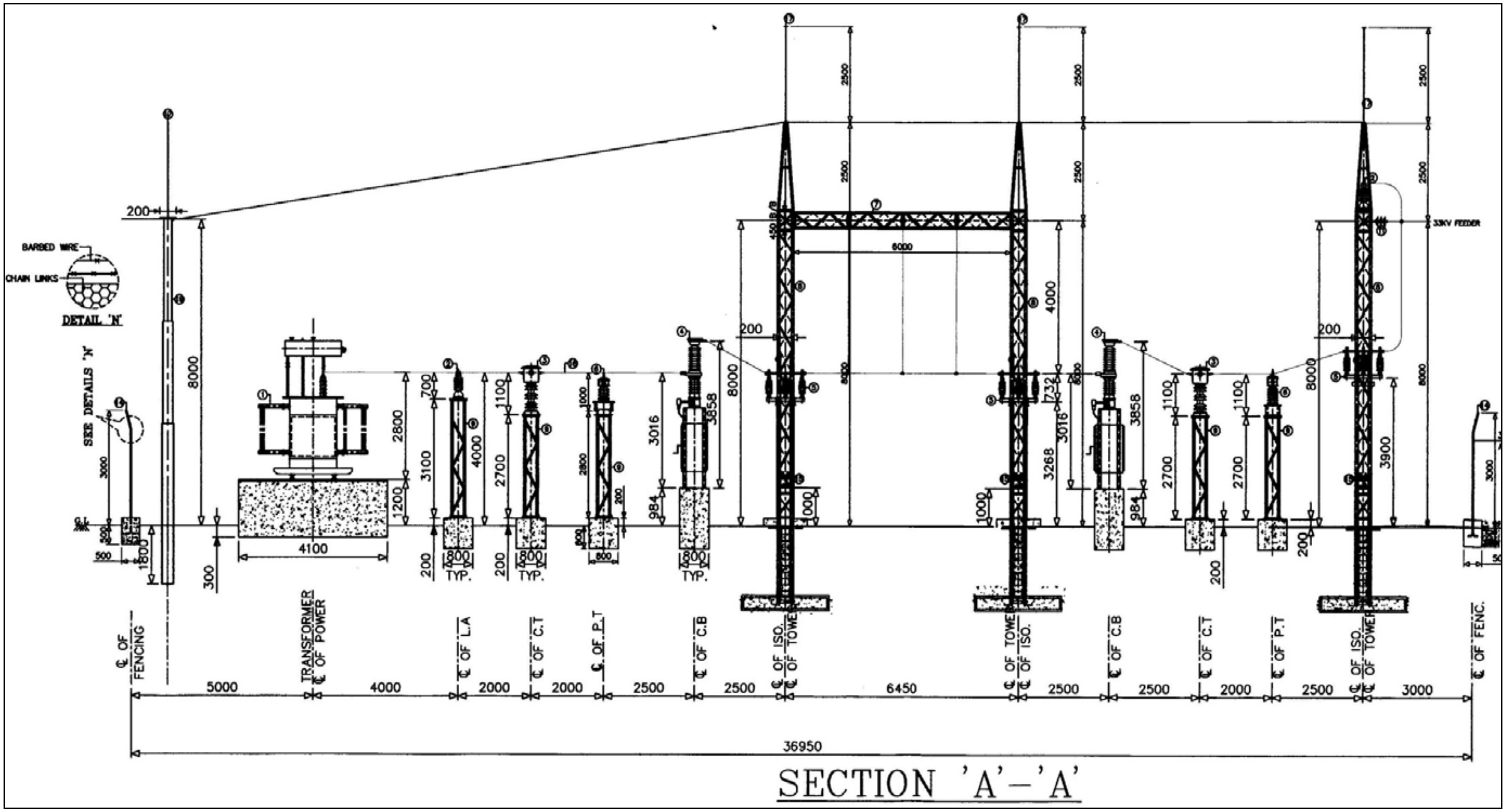
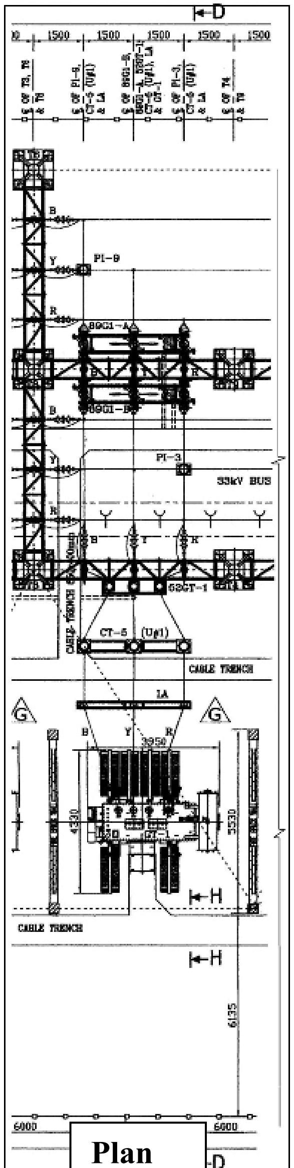
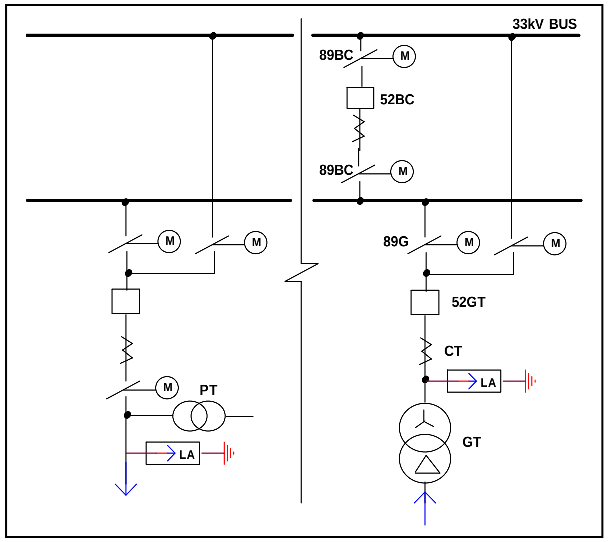
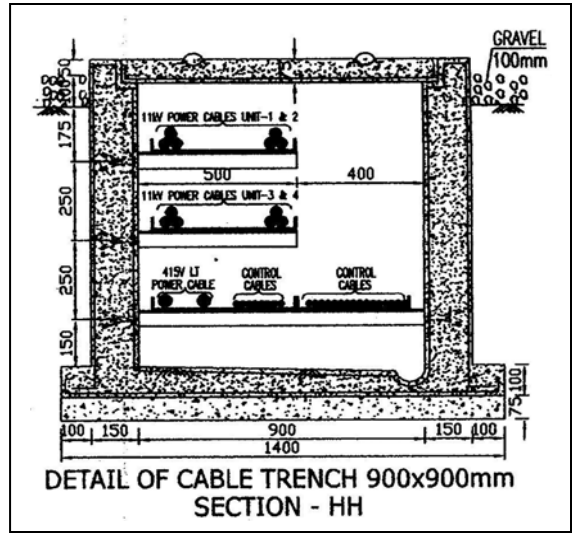


Fig. 16 : 33 kV Switchyard Layout – Single Bus Scheme with SF6 Circuit Breaker







LEGEND

GT – Generator Transformer
LA – Lightning Arrestor
CT - Current Transformer
52GT – Circuit Breaker (VCB)
PI – Post Insulator
89G – Isolator with Motor

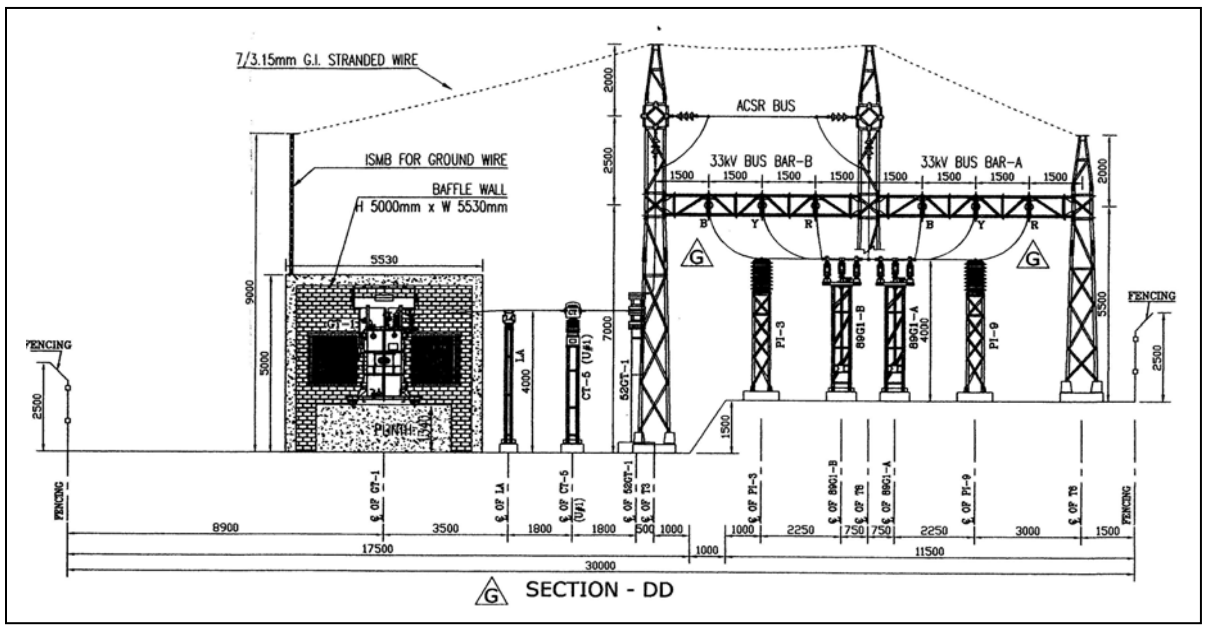


Fig. 17 : 33 kV Switchyard Layout - Single Breaker Two Bus Scheme -Typical Transformer Bay (4 x 4 MW) with Vacuum Circuit

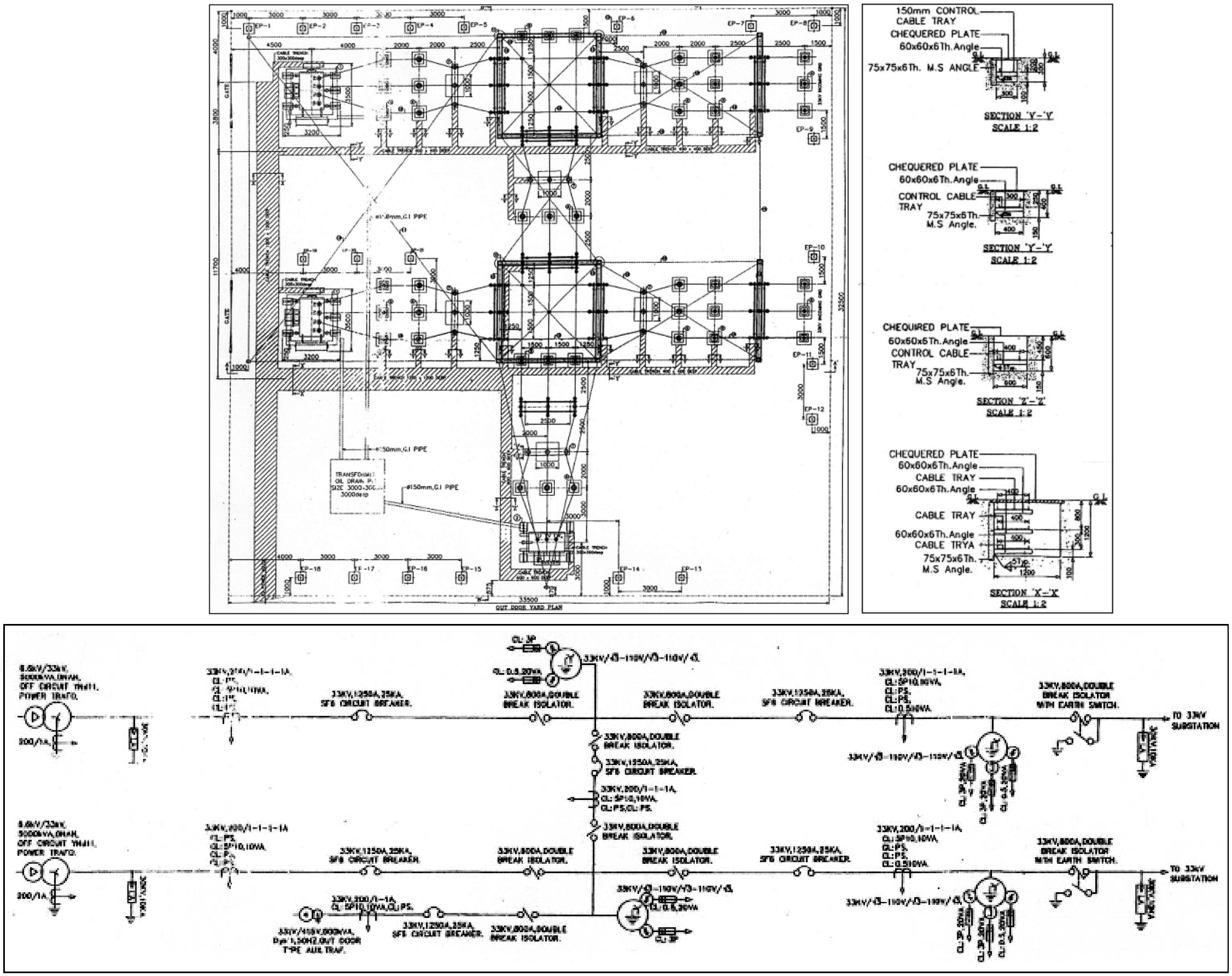


Fig. 18 : 33 kV Outdoor Switchyard Layout – Plan of a 2x3.5 MW shp station

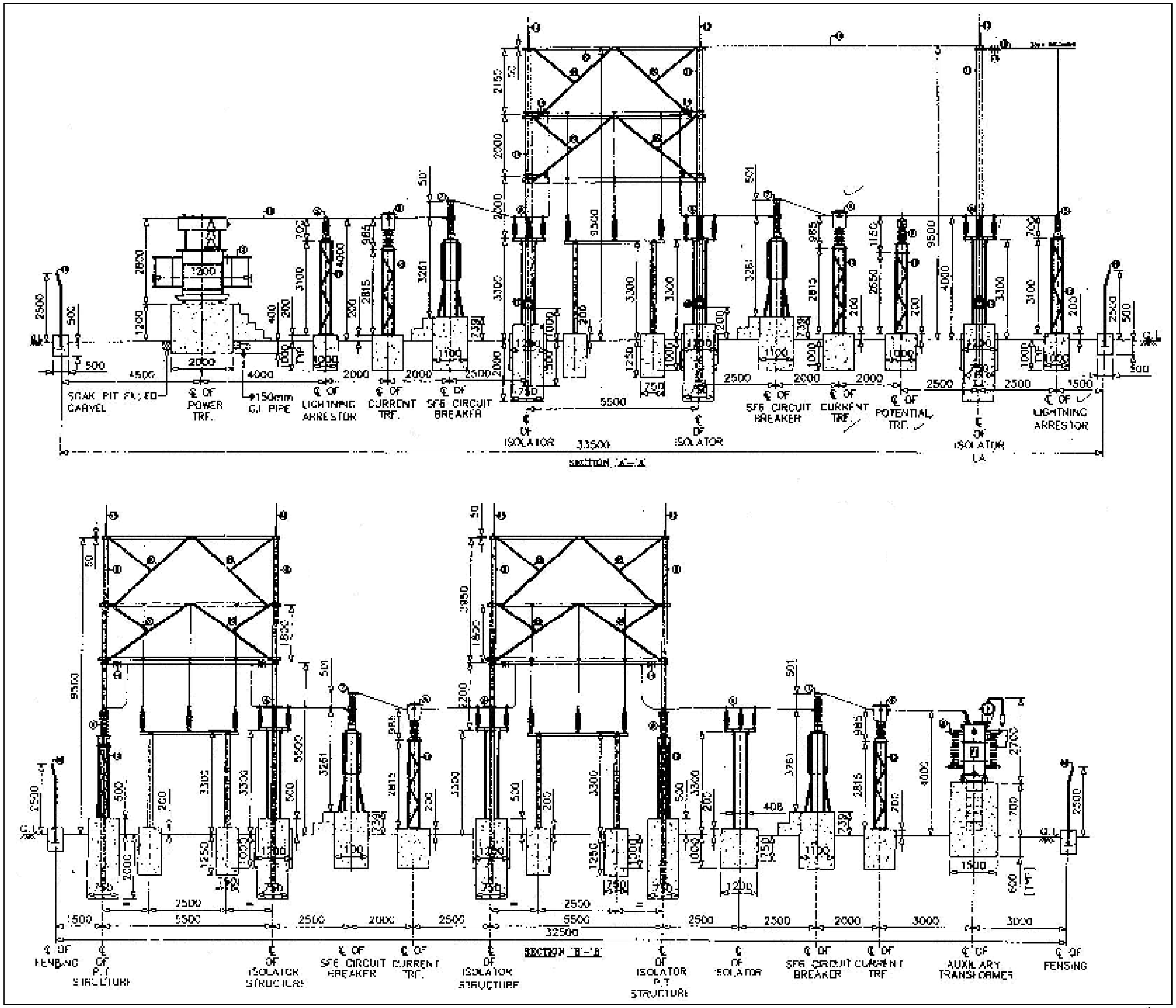


Fig. 19 : 33 kV Outdoor Switchyard Layout – Sections of a 2x3.5 MW plant

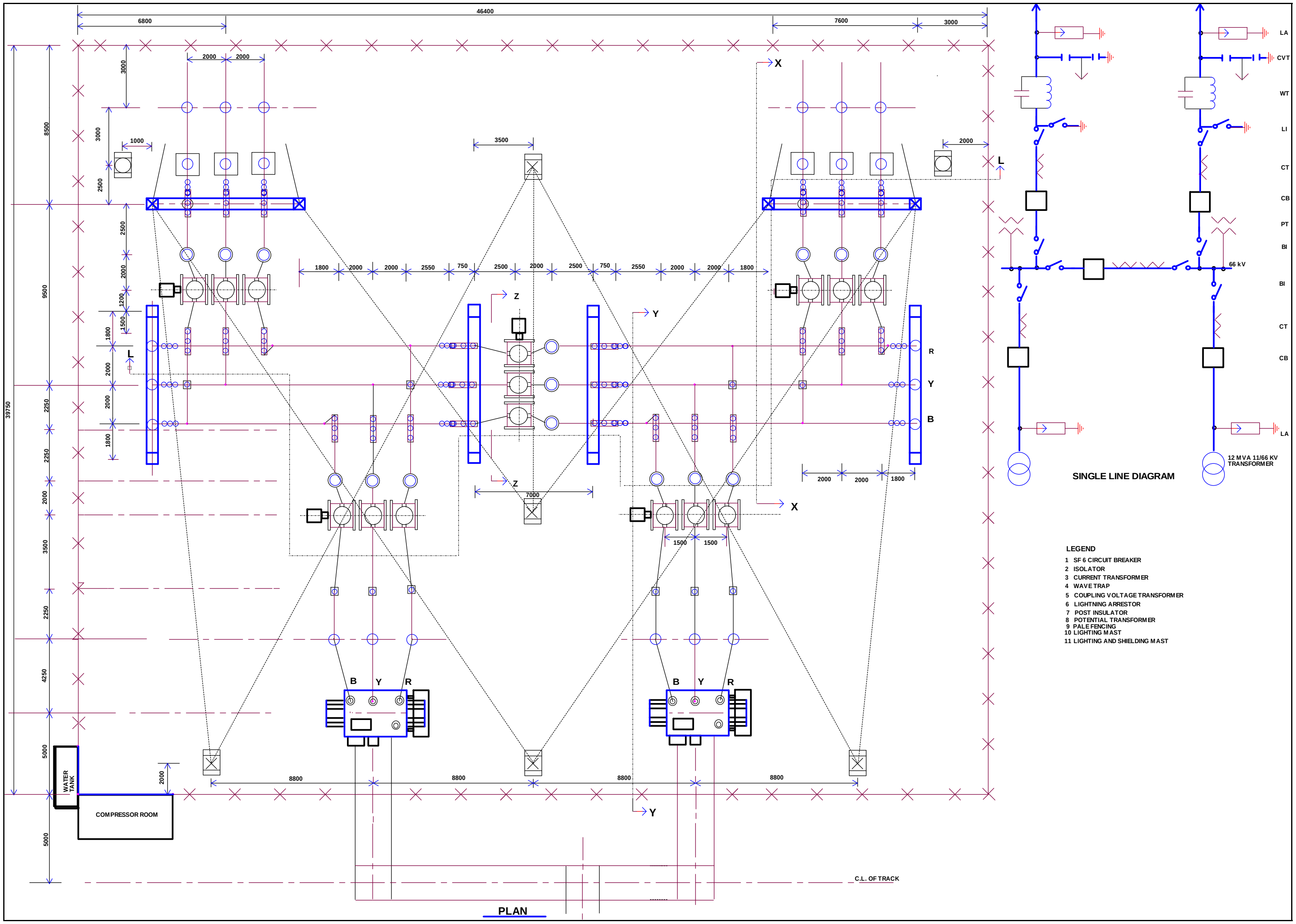


Fig. 20 : Layout of 72.5 kV Switchyard (Plan) of a typical 2 x 10MW shp station

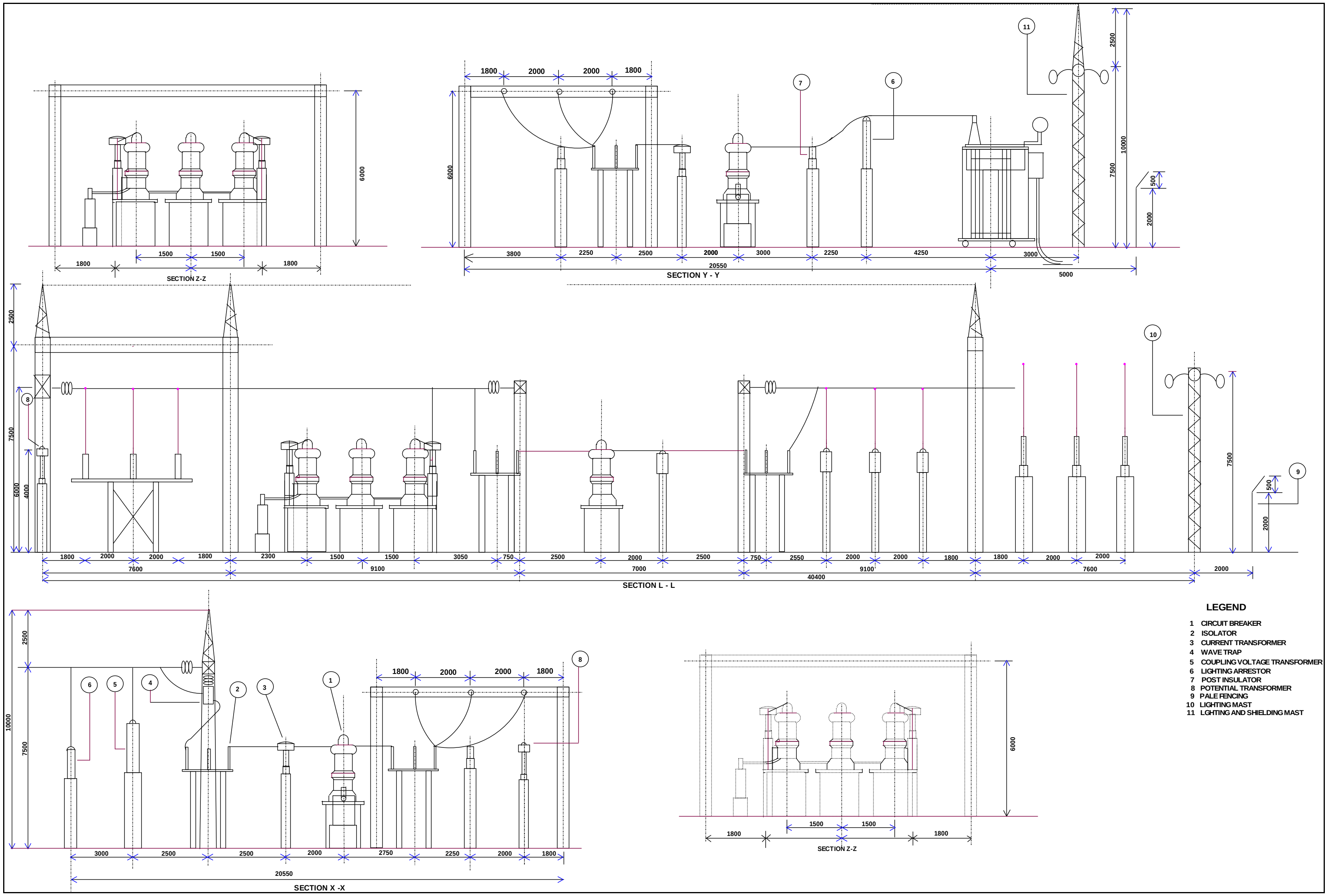


Fig. 21 : Layout of 72.5 kV Switchyard (sections) of a typical 2 x 10MW SHP station

ANNEXURE- 1

Ambient temperature & temperature rise for Generator transformer 11/66 kV class rated 10/12.5 MVA

1.0 REFERENCE AMBIENT TEMPERATURES

The reference ambient temperatures for which the transformers are to be designed are given in table 48.

Table 48 : The reference ambient temperatures

i)	Maximum ambient temperature	50 degree C
ii)	Maximum daily average ambient temp:	40 degree C
iii)	Maximum yearly weighted average ambient temp:	40 degree C
iv)	Minimum ambient air temperature : (Cooling medium shall be Air)	Minus 5 degree C
B.	CLIMATIC CONDITIONS:	
i)	Maximum relative humidity	100%
ii)	Yearly average number of thunder storms ________ varies from 30 to 50.	
iii)	Average no. of rainy days per annum	60 days
iv)	Fog: The atmosphere is subject to fog for two month in winter.	
v)	Number of months during which tropical monsoon conditions prevail	3 months
vi)	Dust storms occur at frequent intervals	
vii)	Average annual rainfall	60 cms
viii)	Maximum wind pressure	150 kg/sq.m.

2.0 ALTITUDE

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

3.0 TEMPERATURE RISE, OVER LOAD CAPACITY & CONTINUOUS RATING

(i) 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.

(a) 30 deg. C in oil by thermometer
(b) 45 deg. C in winding by resistance

(c) 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.

(ii) The limits of temperature rise mentioned above and over load capacity as per IEC-60354 (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

(iii) 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-60354 (1993) – Guide for loading of oil immersed transformers, suitable for climatic conditions.

(iv) 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 ±10% of the voltage corresponding to that tappings. 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.

ANNEXURE-2

RATIONALIZATION OF CAPITALIZATION FORMULA FOR TRANSFORMER LOSSES

The rated capitalization of transformer losses depends upon the rate of interest, rate of electrical energy per kWh, life of transformer and average annual loss f actor. 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.

(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 f actor works out to 0.432.

1.0 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.

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

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

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 can be worked out by the purchaser by considering appropriate value of r, E_L, L_F, and L_C.

2.0 EXAMPLE FOR CALCULATION OF CAPITALIZED COST OF GENERATOR TRANSFORMER

Difference of loss = 2.381 kW

Load factor = 80% = 0.8

Rate of interest (r) = 10% = 0.1

Rate of electrical energy (EC) = 2.5 Rs

Life of transformer (n) = 35 year

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

$LS = 0.3x0.8+0.7x(0.8)^2$
$= 0.688$

Capitalised Cost of Additional Copper loss per kW

$$= 8400 \times EC \times \frac{(1+r)^n - 1}{r(1+r)^n} \times LS$$

$$= 8400 \times 2.5 \times \frac{(1+0.1)^{35} - 1}{0.1(1+0.1)^{35}} \times 0.688$$

= Rs. 139338.81

Capitalised cost of additional transformer losses

= 139338.81 x 2.381
= Rs. 331766

ANNEXURE - 3

A. Typical Transformer Rating and Characteristics

The rating and electrical characteristics of the transformers shall be as given in table 49.

Table 49 : Rating of transformers

S.No.	Particulars	10/12.5 MVA (Outdoor type)
1.	Continuous kVA ratings	10/12.5 MVA ONAN/ONAF
2.	Type	Oil immersd
3.	Frequency	50 C/s
4.	Type of cooling	ONAF
5.	No. of phases	Three
6.	Rating voltage on H.V. side	72.5 kV r.m.s.
7.	Rated voltage on L.V. side	11 kV r.m.s.
8.	Vector symbol	Ynd_{11}
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. H.V. condenser bushings with plain sheds

B. Insulation Levels

1. Insulating material to be used, shall be of class"A" as specified in the latest edition of IS: 12371
2. The dielectric strength of winding insulation and of the bushings shall conform to values given in IS: 2026/1981 part-III amended upto date except for the changes made in this specification.
3. The impulse test and power frequency test voltage must be offered as given in table 50.

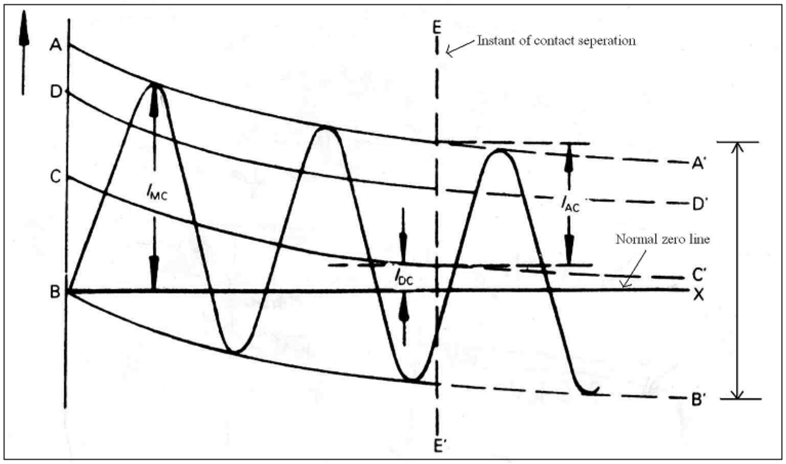
Table 50 : Impulse and Power frequency test

Rated System Voltage	Highest System Voltage	1.2/50 μ Sec. positive impulse with stand voltage	One minute power frequency withstand voltage	
(kV)	(kV)	of line end (kV peak)	Line end (kV)	Neutral end (kV)
11	12	95	28	-
33	36	170	70	-
66	72.5	325	140	38
132	145	550	230	-

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.

ANNEXURE-4

ANNEXTURES FOR SELECTION OF CIRCUIT BREAKERS



Current wave

AA, BB′	=	envelop of current wave
BX	=	normal zero line
CC′	=	displacement of current wave zero line at any instant
DD′	=	r.m.s. value of the ac component of current at any instant, measured from CC′
EE′	=	instant of contact separation (initiation of the arc)
I_{AC}	=	peak value of ac component of current at instant EE′
$I_{AC}/\sqrt{2}$	=	r.m.s. value of ac component of current at instant EE′
I_{Dc}	=	d.c. component of current at instant EE′
$\frac{I_{DC} x100}{I_{AC}}$	=	percentage value of the d.c. component

Fig. 22 : Short-circuit making and breaking currents, and percentage of d. c. Component (Source: IS- 13118)

ANNEXURE-5

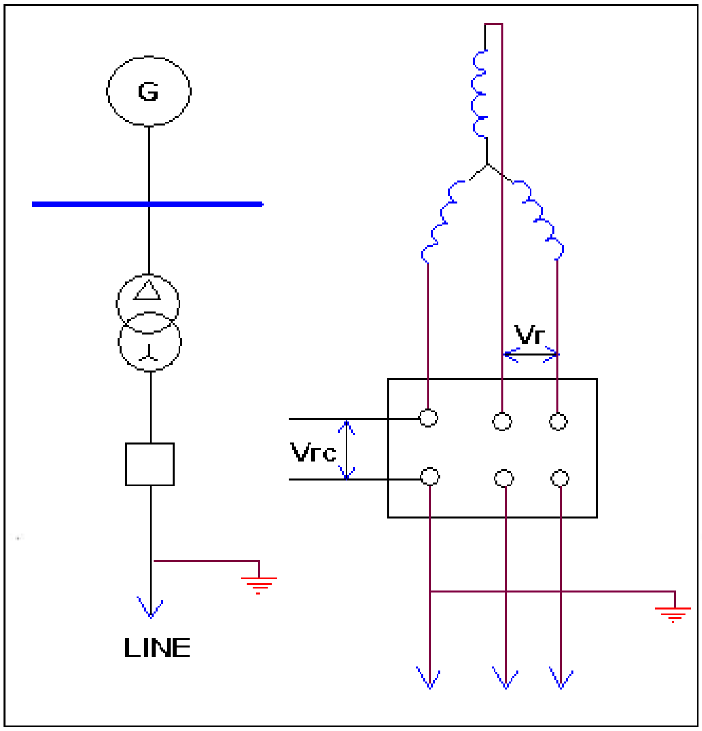


Fig. 23 : Recovery voltage across poles

Note:

Vr is recovery voltage stated in terms of voltage between phases at service frequency
Vrc is recovery voltage component existing across the breaks of each pole.

ANNEXURE-6

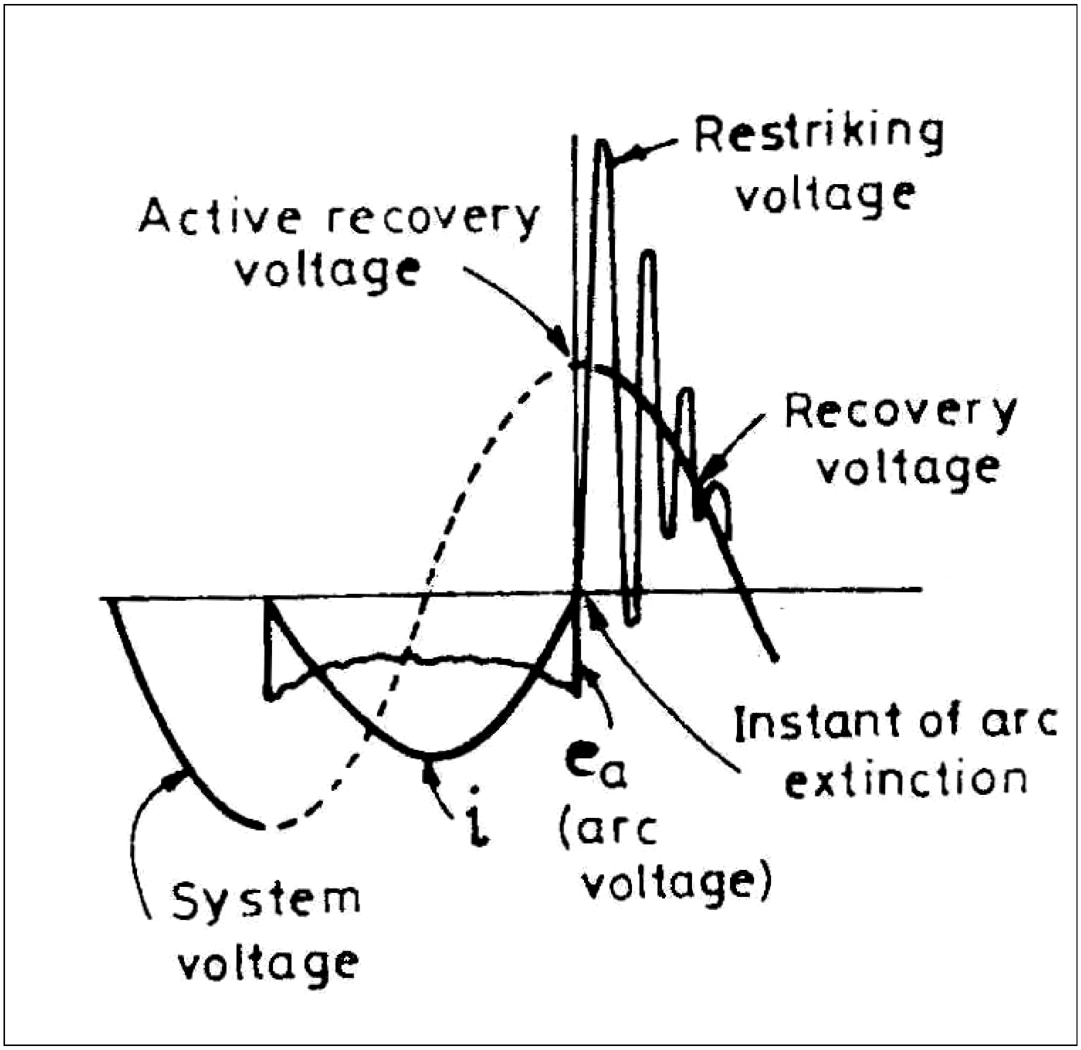


Fig. 24 : Arc extinction (Source: IS- 13118).