CHAPTER – 9

POWER EVACUATION, MAIN SINGLE LINE DIAGRAM, GRID INTERCONNECTION AND SWITCHYARD LAYOUT UP TO 245 kV

9.1 General

Hydro electric generating plants are generally located away from load centres. Accordingly power generated is stepped up to a suitable high voltage in step up substation at generating end and transmission lines laid for interconnection with the grid at a suitable point. The development of a hydro plant electrical single line diagram is the first task in the preliminary design of the plant. In evaluating a plant for good electrical system design, it is easy to discuss system design in terms of the plant’s single line electrical diagram. The relationship between generators, transformers, transmission lines, and sources of station service power are established, along with the electrical location of the associated power circuit breakers and their control and protection functions. Development of design for step up voltage for interconnection with grid for power evacuation, main single line diagram and substation layout up to 245 kV is discussed as follows:

a) Step up voltage and high voltage switching arrangements
b) Generating station arrangement
c) Substation layout

Design of substation at EHV/UHV level (420 kV and above) requires special considerations and is discussed in Chapter 10.

Step Up Voltage

Economic generation voltage is generally limited to following values (CBI & P Manual).

- Up to 750 kVA - 415 volts
- 751 - 2500 kVA - 3.3 volts
- 2501 – 5000 kVA - 6.6 volts
- Above 5000 kVA - 11 kV or higher

Generally terminal voltage of large hydro generators is 11 kV in India. Generators with high terminal voltages up to 20 kV are being made. Step up voltage depends upon following.

i) Length of transmission line for interconnection with the power system.
ii) Power to be transmitted.

High voltage increases cost of insulation and support structures for increased clearance for air insulation but decreases size and hence Cost of conductors and line losses. Many empirical relations have been evolved to approximately determine economic voltages for power evacuation. An important component in transmission lines is labour costs which are country specific. An empirical relation is given below.

\[
\text{Voltage in kV (line to line)} = 5.5 \sqrt{0.62L + \frac{kVA}{150}} \text{ where } kVA \text{ is total power to be transmitted; } L \text{ is length of transmission line in km.}
\]

American practice for economic line to line voltage kV (based on empirical formulation) is as follows:

\[
\text{Voltage in kV line to line} = 5.5 \sqrt{0.62L + \frac{3P}{100}}
\]
For the purpose of standardization in India, transmission lines may be classified for operating at 66 kV and above. 33 kV is sub-transmission, 11 kV and below may be classified as distribution. Higher voltage systems are used for transmitting higher amounts of power and longer lengths, and its protection and control is important for power system security and requires complex relay systems.

9.2 Grid Connection, Power Evacuation and Switching Schemes

9.2.1 Power evacuation in large hydro power stations

i) Step up voltage at the generating station may be fixed in accordance with economic studies.
ii) Interconnected transmission and switching scheme be designs in accordance with Para 9.2.4 & 9.2.5.
iii) Transmission line protection be provided as per Para 3.6. In case of fault the high voltage transmission lines must be disconnected both at receiving end as well as sending end by carrier or other communication signals.
iv) Provide for no voltage closing for receiving end breakers and synchronizing check relay closing at sending end breakers.
v) It is normal practice to provide synchronizing facility on the sending end breaker of the transmission lines.

9.2.2 Grid Connected Small Hydro Power Stations (including microhydro)

Specific provisions required for equipment and protection for interconnection of small hydro with grid at 11 kV and above is generally required for following modes of operation;

i) grid connected operation
ii) isolated operation
iii) islanding operation

9.2.3 Generating Station Arrangement

Design Considerations

i) Safety and reliability
ii) Simplicity of operation
iii) Good technical performance
iv) Readily maintainable (e.g., critical components can be removed from service without shutting down the balance of plant).
v) Flexibility to deal with contingencies.
vi) Ability to accommodate system changes

9.2.4 Unit Switching Schemes

9.2.4.1 Unit Switching Arrangements

A “unit” scheme providing outdoor switching of the generator and transformer bank as a unit on the high-voltage side only, is shown in Figure 9.1. 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 bank or transmission line in all other arrangements would mean the loss of more than a single generation 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.

In case of small generator feeding a large power system generator sharing a transformer (Figure 9.2) may be provided.
Figure 9.1 Unit Generator Transformer Connection (Typical)

Figure 9.2 Generators with Generator Breakers and Sharing a Transformer
9.2.5 Switching Schemes for Outdoor Step-up Sub Station

9.2.5.1 General Consideration for the Selection of Switching Scheme

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

(a) Inter-connected transmission system
(b) Voltage level
(c) Site Limitation
(d) General and special Considerations

Inter-Connected Transmission System

The scheme should fit in the planning criteria used to design the connected transmission system. A system should be stable if a permanent fault occurs on a line. It is, therefore, important to avoid system un-stability caused by outage of line, transformer or generator due to sub-station faults. Sustained generation outage by such faults should not exceed available spinning reserve. This could exceed the reserve to the extent by which important load may be connected to be dropped automatically by under frequency actuated relays.

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.

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 even at 420 kV level have been made.

General Miscellaneous Considerations

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

Expansion of sub-station should be easily possible.
In seismic prone areas height of structures should be as low as possible.
The outgoing transmission lines should not cross each other.

9.2.6 Switching Schemes for Large Step up Sub-Station

9.2.6.1 Double bus single breaker scheme

This scheme is quite common on large and medium station up to 245 kV in India being economical and maintenance of breaker is possible by utilizing bus coupler. The scheme is shown in figure 9.3. Transfer bus has also been used in this scheme. Reference be made to CBI & P Manual on substation layout.
Disadvantages

1. 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.
2. Utilizing bus coupler during breaker maintenance will necessitate transfer of tripping circuits through auxiliary contacts.
3. 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. Bhakra Left Bank powerhouse (5 x 90 MW) was provided this arrangement.

9.2.6.2 Single Bus Schemes

Single bus at generator voltage

A single bus scheme at generator voltage as shown in figure 9.2 is commonly used for step up substations in small hydro power range (Agnoor SHP – Figure 9.7 an example).

Single bus with a transfer bus

Single bus scheme with transfer bus is shown in figure 9.4.

1. All units are connected on a single bus and entire generation will be lost in case of bus faults.
2. 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.

3. This is generally provided on generating stations having installed capacity which is relatively small for the grid. Gangwal and Kotta power houses (3 x 24 MW) were provided with this arrangement.

![Figure 9.4 Single bus With a Transfer Bus](image)

**9.2.6.3 Single Sectionalized Bus**

Single sectionalized bus (Figure 9.5) is very commonly employed being economical; generation outages can be controlled by sectionalizing. Simple arrangements does not require isolating switch operation to select bus and adopted even on large power houses i.e. 5 x 120 MW at Bhakra Right Bank and Dehar Power plant 220 kV portion (2 x 165 MW) and used in many station where parallel outgoing feeders are provided. Bhakra Right Bank power house single line diagram is shown in Figure 9.6 and Dehar power plant (245 kV portion) in figure 10.8 (Chapter 10).
Double bus double breaker scheme, one and half breaker scheme are used for EHV substation and discussed in chapter 10. Ring bus scheme although Reliable and economical as only one element is lost in case of any fault, but protection is complicated and hence not used in India. It is used in British grid system for sub-station and not generating stations.
9.3 Switchyard Layout

9.3.1 General

There is no standardization regarding the physical arrangement of the various components relating to one another in the layout of switchyard equipment. For the same type of bus bar system different layouts have been used in different countries and in India. Variations in layout are inevitable in view of varying climatic and other conditions in various parts of the country. Typical layouts for various types of bus-bar systems are discussed with reference to those adopted or recommended for step up substations in hydroelectric projects in the country.

One of the primary requirements of a good substation layout is that it should be as economical as possible. It should ensure the desired degree of flexibility and reliability, ease of operation and maintenance and meet all requirements from the point of view of safety of the operation and maintenance personnel. Minimum clearances and requirements of inspection and maintenance is also important in designing substation.

9.3.2 Selection of Site

Site limitation is one of the important considerations in deciding the type of layout of a substation. It should be free from all obstructions from the point of view of convenience of terminating high voltage transmission lines.

9.3.3 Switchyard Equipment

The substation layout is influenced to a great extent by the dimensions of the various equipments and their accessories within the substation. Characteristics of the various equipments and selection criteria is discussed in chapter 6 to 8. Factors affecting the substation layouts are as follows:

9.3.3.1 Generator Transformer

Step up transformers in large hydro electric stations are generally located on transformer deck in the powerhouse so as to reduce cost of generator transformer connection by bus duct or in some cases (underground power house) by power cables. Bus bars and switching equipment is provided as near to a flat terrace as possible. Power house crane is used to handle transformer. In small hydro station step up transformers are generally located in the switchyard and connected to generator by suitable power cables. The bay width is determined by transformer dimensions. Arrangement for removal of transformer in case of repair/maintenance without disturbing other equipment is required and also affects layout. Interlinking transformer for interconnecting generator HV buses at two voltages, if required are installed in switchyard. In order to reduce the chances of spread of fire, transformers are provided with a soaking pit of adequate capacity or chill drains to contain the oil. Besides, separation walls are provided in between the transformers and also between the transformer and roads within the substation.

9.3.3.2 Circuit Breakers

In the case of outdoor type installation, the circuit breakers have fixed locations and the station layout is such that adequate section clearances are always available from the live parts.

9.3.3.3 Isolators

The location of disconnect switches in substations affects substation layouts. Maintenance of the disconnect contacts is a consideration in the layout. In some substations, the disconnects 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.
9.3.3.4 Instrument 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.

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.

9.3.3.5 Reactive Compensation Equipment

The substation layout should be such as can accommodate the required compensation equipments.

9.4 Electrical and Safety Clearances

9.4.1 Electrical Clearances for Installing Equipment in the Field (up to 245 kV)

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.

9.4.1.1 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 9.1.

Table 9.1: Correlations between Insulation Levels and Minimum Phase-to- Earth Air Clearances as per IS: 3716 - 1978

<table>
<thead>
<tr>
<th>Rated Lightning Impulse Withstand Voltage (kV)</th>
<th>Minimum Phase-to-Earth Air Clearances (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>75</td>
<td>120</td>
</tr>
<tr>
<td>95</td>
<td>160</td>
</tr>
<tr>
<td>125</td>
<td>220</td>
</tr>
<tr>
<td>170</td>
<td>320</td>
</tr>
<tr>
<td>325</td>
<td>630</td>
</tr>
<tr>
<td>380</td>
<td>750</td>
</tr>
<tr>
<td>450</td>
<td>900</td>
</tr>
<tr>
<td>550</td>
<td>1100</td>
</tr>
<tr>
<td>650</td>
<td>1300</td>
</tr>
<tr>
<td>750</td>
<td>1500</td>
</tr>
<tr>
<td>850</td>
<td>1600</td>
</tr>
</tbody>
</table>
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.

9.4.1.2 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 for system up to 132 kV 650 kV BIL may be determined by adding 2.5 meters to minimum phase to ground clearance of 1.3 which works to 3.8 meters for 132 kV system.

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). In consideration to it, minimum height of bus bar for 132 kV may be about 365 mm which may be raised to about 450 mm to correspond to the terminal height of the 132 kV circuit breakers.

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 625 mm. This dimension provides for a truck with a man standing on its top 130 + 625 meter = 755 meters app.

9.4.1.3 Minimum and Safety clearances recommended by Central Board of Irrigation and Power manual

Clearances from the point of view of system reliability and safety of operating personnel recommended for sub station up to 245 kv are given in table 9.2. 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>
<thead>
<tr>
<th>Highest System Voltage (kV)</th>
<th>Lightning impulse voltage (kVp)</th>
<th>Minimum clearances</th>
<th>Safety clearances (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Between phase &amp; earth (mm)</td>
<td>Between phase (mm)</td>
</tr>
<tr>
<td>36</td>
<td>170</td>
<td>320</td>
<td>320</td>
</tr>
<tr>
<td>72.5</td>
<td>325</td>
<td>630</td>
<td>630</td>
</tr>
<tr>
<td>123</td>
<td>450</td>
<td>900</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td>550</td>
<td>1100</td>
<td>1100</td>
</tr>
<tr>
<td>145</td>
<td>550</td>
<td>1100</td>
<td>1100</td>
</tr>
<tr>
<td></td>
<td>650</td>
<td>1300</td>
<td>1300</td>
</tr>
<tr>
<td>245</td>
<td>950</td>
<td>1900</td>
<td>1900</td>
</tr>
<tr>
<td></td>
<td>1050</td>
<td>2100</td>
<td>2100</td>
</tr>
</tbody>
</table>
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 up to 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 should 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 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.

Following are the normally adopted spacing for the strung bus:

<table>
<thead>
<tr>
<th>Highest System Voltage rating kV</th>
<th>Spacing between phases in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>245 kV</td>
<td>4500</td>
</tr>
<tr>
<td>145 kV</td>
<td>3600</td>
</tr>
<tr>
<td>72.5 kV</td>
<td>2200</td>
</tr>
<tr>
<td>36 kV</td>
<td>1300</td>
</tr>
<tr>
<td>12 kV</td>
<td>1300 or 920</td>
</tr>
</tbody>
</table>

The spacings between phase to phase for the equipment in a sub-station depends upon the manufacturers practice which are tested as per standards.

The minimum clearance of live parts to ground in an outdoor sub-station is as follows (Tamil Nadu Practice):

<table>
<thead>
<tr>
<th>Highest System Voltage</th>
<th>Clearances in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>245 kV</td>
<td>5500</td>
</tr>
<tr>
<td>145 kV</td>
<td>4600</td>
</tr>
<tr>
<td>72.5 kV</td>
<td>4600</td>
</tr>
<tr>
<td>36 kV</td>
<td>3700</td>
</tr>
<tr>
<td>12 kV</td>
<td>3700</td>
</tr>
</tbody>
</table>

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

**9.4.1.4 Section Clearances**

A station which cannot 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 following table 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>
<thead>
<tr>
<th>Highest System Voltage</th>
<th>Section Clearances</th>
</tr>
</thead>
<tbody>
<tr>
<td>145 kV</td>
<td>3500 mm</td>
</tr>
<tr>
<td>72 kV</td>
<td>3000 mm</td>
</tr>
<tr>
<td>36 kV</td>
<td>2800 mm</td>
</tr>
<tr>
<td>12 kV</td>
<td>2600 mm</td>
</tr>
</tbody>
</table>

The following minimum clearances should be adopted for enclosed indoor busbars and connections in air which are not filled with any insulating medium like compound etc.

<table>
<thead>
<tr>
<th>Highest System voltage between phases or poles</th>
<th>Minimum clearances in Air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Between phases or poles</td>
</tr>
<tr>
<td>36 kV</td>
<td>356 mm</td>
</tr>
<tr>
<td>12 kV</td>
<td>127 mm</td>
</tr>
</tbody>
</table>

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.

9.4.1.5 Standard Bay Widths (in meters) as per TNEB Practices

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Bay Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>66 kV</td>
<td>7</td>
</tr>
<tr>
<td>33 kV</td>
<td>4.6</td>
</tr>
<tr>
<td>22 kV</td>
<td>3.8</td>
</tr>
<tr>
<td>11 kV</td>
<td>3.5</td>
</tr>
</tbody>
</table>

9.5 GIS Sub Station

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 substations 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 145 kV class, and single phase bus to 500 kV and higher, and all equipment (disconnect/isolating switches, grounding switches, circuit breakers, metering 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 may offset the increased initial costs by reducing the land area necessary for the substation.

9.5.1 Gas Insulated Switchgear (GIS)

Compact sub-station with gas insulated switchgear is installed in areas with high risk of pollution and corrosion from industrial plants or by marine and desert climates. Applications involving use of insulated switchgear may be considered in following cases.
i) Metal clad switchgear with components of conventional design to minimize area requirement.

ii) Underground substations

iii) Outdoor installation where space is not easily available

iv) Installations in difficult site conditions (e.g. seismically active areas, high altitude areas etc.).

9.5.2 Details of GIS Substation as per CBI &P Manual on Substation Layout - 2006

i) Most GIS designs were developed initially for double bus, single breaker arrangement. This has been widely used and provides good reliability, simplicity in operation, easy protective relaying and excellent economy.

ii) It is found economical to adopt 3-phase enclosure up to 145 kV system voltage. For system voltages above 145 kV, single-phase enclosure designs are preferred. Functionally, the performance does not differ between 3-phase enclosure and single-phase enclosure of GIS but, it could depend on users choices.

iii) The GIS components like circuit breakers, load break switches, earthing switches, isolators, voltage transformers, current transformers, surge arresters and connectors are functionally separate modules of a standardized modular system.

iv) The enclosure of GIS could be made of aluminium alloy or stainless steel. The selection of material largely depends on temperature rise considerations and permissible limits depending on emissivity (solar radiation) and/or temperature rise of conductor).

v) SF₆ is five times as dense as air. It is used in GIS on pressures from 3.5 - 7 bars absolute. The pressure is so selected that gas will not condense into liquid at the lowest temperature, the equipment could experience. This gas is about 100 times better than air in terms of interrupting arcs.

vi) Cone or disc shaped insulators moulded from high quality resin support to active parts in side the enclosures and serve as barriers between adjacent gas-filled compartments.

vii) Silver-plated plus contacts provide connections between individual components and bolted flanges between the enclosures.

viii) The operating mechanism for circuit breaker could be electro-hydraulically (hydraulic spring drive) operated or spring-spring operated for least maintenance.

ix) The load break switches and high speed earthing switches are operated by motor charged spring mechanism and the safety earthing switches and disconnects are operated by motor operated mechanism.

x) Manual operation of safety earthing switches is also possible as an alternative to motor operation.

xi) Connectors enable straight line, 90 deg, 120 deg to 180 deg, four way and T-connections between the various elements.

xii) The modules include compensating units to permit lateral mounting, axial compensation, parallel compensation, tolerance compensation, vibration compensation etc. The lateral mounting units enable sections of switchgear to be removed and re-inserted without interfering with adjacent parts. Axial compensators take-up the changes in bus bar length due to temperature variation. Parallel compensators are intended for accommodating large linear expansions and angle tolerances. Tolerance compensators are intended to take up manufacturing and assembly tolerances. Vibration compensators absorb vibrations caused by transformers connected directly to SF₆ switchgear by oil/SF₆ bushings.

xiii) Approximate space requirements for double bus lay out with vertical breaker scheme can be estimated approximately by assuming the width (3.0 m x 8.5 m x 8.0 m) leaving 1.5 m along the depth, for panels, 2.0 m for movement on either side along the length of bus bar for 400 kV system

xiv) Depending on the bus bar arrangement, the various elements are assembled to constitute various bays in the desired sequence.

xv) Underground 420 kV Gas insulated switchgear (GIS) and gas insulated bus ducts (GIB) at Tehri Hydro-electric Project refer Para 14.2.4 Vol. I.

9.5.2.1 Supporting Structures

Depending on the design of installation, the GIS can be self supporting or erected on steel supporting structures of simple design anchored to the substation floor.
9.5.2.2 Grounding

The three enclosures of single phase GIS are required to be bonded to each other at the ends of GIS to ensure to flow circulating currents. These circulated enclosures currents cancel the magnetic field that would otherwise exist outside the enclosure out to conductor current. 3-phase enclosures GIS does not have circulating currents but does have eddy currents in the enclosure and should also be multi point grounded. Although multi point grounding leads to some losses in the enclosure due to circulating current multi point grounding results in many parallel path for the current from an internal path to flow to the switchyard ground grid. The recommendations of manufacturers and multi point grounding concept normally ensures touch and step potentials within safe levels prescribed by IEEE 80.

The GIS should be extendable to meet the requirement of addition of bays in future. The side on which the extension is to be made should be provided with suitable extension bellows/flanges with blanking plates. The building that is to house the GIS should have space provision for future extension.

9.5.2.3 GIS Terminations

GIS terminations could be any of the following:

- SF₆ to air bushings
- SF₆ to cable termination
- SF₆ to oil bushings for direct connection to transformer
- SF₆ bus duct

All termination modules are commonly used to connect the GIS with transformer. Overhead lines could be connected to GIS either though cables or through SF₆ to air bushings. Type of terminations has also bearing on the size of substations. If cable or SF₆ bus ducts are used, substation can be kept quite compact. SF₆ to air bushings, on the other hand, requires minimum clearance in air and thus requires more space and in addition, they are subject to environmental conditions. Especially in cities/industrial areas where space is both restricted and expensive and the surrounding environment has impact on type of termination, preference should be for cable termination or SF₆ bus duct. Selection of cable termination will have to be judiciously done keeping in view the specific requirement.

9.5.3 Metal Clad GIS Switchgear

SF₆ – insulated metal enclosed high voltage switchgear up to 145 kV are now available and may be used where space may be a limitation. The data of siemens GIS substation as per Siemens Power Engineers Guide is given in table 9.3 Feeder control and protection are inbult.

| Table 9.3 |
|---------------------------------|------------------|
| Rated voltage (kV)              | Up to 145        |
| Rated power frequency withstand voltage (kV) | Up to 275 |
| Rated lightning impulse withstand voltage (kV) | Up to 650 |
| Rated normal current bus bar (A) | Up to 3150       |
| Rated normal current feeder (A)  | Up to 2500       |
| Rated breaking current (kA)      | Up to 40         |
| Rated short-time withstand current (kA) | Up to 40 |
| Rated peak withstand current (kA) | Up to 108        |
| Inspection (years)              | > 25             |
| Bay width (mm)                  | 800              |

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9.6 Switchyard Layout

9.6.1 Switchyard Layout for Small hydro and large hydro up to 245 kV

Low level layout of the equipment in switchyard of step up station is recommended in earthquake prone areas. Layout of switchyard is generally designed in accordance with Central Board of irrigation and power manual on Sub-Station layout for 36 kV and above. Rural electrification standard are adopted for 12 kV substations. Step up transformers in large hydro stations are generally installed on transformer deck in powerhouse (Para 9.2.1). Typical layouts of substations are attached as follows:

**Small Hydro Switchyard**

9.7 12 kV outdoor switchyard with Lattice type structure recommended for hilly areas –
2 x 500 kVA Agnoor SHP
9.8 12 kV outdoor switchyard with pole structure – REC standard layout (2 sheets)
9.9 & 9.10 12 kV outdoor switchyard with Steel Channels Structures (2 sheets) – Jainagra - SHP
9.11 & 9.12 36 kV outdoor switchyard – single bus scheme with SF6 Breaker (2 sheets)
9.13 36 kV outdoor switchyard – single bus two breaker scheme with vacuum circuit breakers –
Halaipani Project
9.14 & 9.15 36 kV outdoor switchyard – single sectionalized bus (H- Type) 2 x 3.5 MW Sikasra Projects
with SF6 circuit breakers (2 sheets)

**Large Hydro Switchyard**

9.16 & 9.17 72.5 kV outdoor switchyard – single sectionalized bus – proposed 2 x 10 MW Mukerian
project stage –II – 2 sheets.
9.18 & 9.19 145 kV Typical Outdoor Switchyard main bus with transfer bus – 2 sheets (Ganguwal Hydro
Stations).
9.20 & 9.21 245 kV Typical Outdoor switchyard for single sectionalized bus – 2 sheets (Bhakra Right
Bank and Dehar 220 kV Portion) – Transformers on the transformer deck in powerhouse

**References**

2. Project Details etc. mentioned in the Draft.
Works- Guidelines for Selection of Switchyard SHP Station*, Alternate Hydro Energy Centre
4. Rural Electrification corporation (REC Standard)
The layout as shown envisages the use of 11 kV vacuum circuit breakers (REC SPEC. 22/1983), which shall not require isolating switches as their integral part. Particularly no maintenance is needed on these breakers and it will also economise in the cost.

Conductors used for 11 kV jumpers and busbars shall not be less than 50 SQ.MM. (C.E.) ACSR.

The supports shall not be cabled but may be suitably concreted.
Figure 9.9: PLAN – Layout of 12 kV Switchyard Jainagra SHP (2 x 500 kW) (sheet 1 of 2) (Support ISM & C – Rolled Steel Channels (AHEC Project))

Figure 9.10: SECTION A-A – Layout of 12 kV Switchyard Jainagra SHP (2 x 500 kW) (sheet 2 of 2) (AHEC Project)
Figure 9.11: 33 kV Switchyard Layout (Plan) – Single Bus Scheme with SF6 Circuit Breaker (Sheet 1 of 2) (AHEC Project)

Figure 9.12: 33 kV Switchyard Layout – Single Bus Scheme with SF6 Circuit Breaker (Sheet 2 of 2) (AHEC Project)
LEGEND

GT – Generator Transformer
LA – Lightning Arrestor
CT - Current Transformer
52GT – Circuit Breaker (VCB)
PI – Post Insulator
Figure 9.13: 33 kV Switchyard Layout - Single Breaker Two Bus Scheme - Typical Transformer Bay (4 x 4 MW Halaipani Project) with Vacuum Circuit Breaker (AHEC Project)

Figure 9.14: Sikasar Project (2 x 3.5 MW) Sheet 1 of 2 – 33 kV Outdoor Switchyard Layout – Plan (AHEC Project)
Figure 9.15: Sikasar Project (2 x 3.5 MW) Sheet 2 of 2 – 33 kV Outdoor Switchyard Layout – Sections 
(AHEC Project)

Figure 9.16 Layout of 72.5 kV Switchyard (Plan) (Sheet 1 of 2) - Mukerain Stage-II (2 x 10MW) – Proposed 
(AHEC Project – Specification drawing)
Figure 9.17 Layout of 72.5 kV Switchyard (sections) (Sheet 2 of 2) – Mukerian Stage II (2 x 10 MW) - Proposed
(AHEC Project – Specification drawing)

Figure 9.18: 145 kV Typical Outdoor Switchyard main bus with transfer bus – (sheet 1 of 2) (Ganguwal Hydro Stations) (CBIP Mukerian on Sub-station)
1. ALL DIMENSIONS ARE IN MM.

2. EQUIPMENT SPACING IN THE DRAWINGS ARE BASED ON OLD PRACTICE OF MOUNTING THE EQUIPMENT (e.g. LA, MOCB, CT etc.) DIRECTLY ON FOUNDATION WITH SCREEN AROUND IT. IN DRAWING EQUIPMENTS ARE MOUNTED ON STRUCTURE AND SCREEN IS THEREFORE, INTER EQUIPMENT SPACING CAN FURTHER BE OPTIMISED BY USER.

Figure 9.19: 145 kV Typical Outdoor Switchyard main bus with transfer bus – (sheet 2 of 2) (Ganguwal Hydro Stations) (CBIP Manual on Sub-station)

Figure 9.20: 245 kV Typical Outdoor switchyard for single sectionalized bus – (sheet 1 of 2) (Bhakra Right Bank 5 units and Dehar 220 kV Portion 2 units) – Transformers on the transformer deck in powerhouse (As Designed)
Figure 9.21: 245 kV Typical Outdoor switchyard for single sectionalized bus – (sheet 2 of 2) (Bhakra Right Bank and Dehar 220 kV Portion) – Transformers on the transformer deck in powerhouse (As Designed)