In some circumstances, time to restore the system on the healthy pole should be added to the above. If the circuit breaker has limited voltage capability, full power cannot be restored on healthy pole unless the isolators (disconnecting switches) open and isolate the breaker. In such a case, the following time must be added.

4. Time for opening disconnector switches. The healthy pole can be energized and full power can be restored after a total time given by addition 1 to 4 above.

16.18. SHORT-CIRCUIT RATIO (SCR) OF HVDC SYSTEM

Short-circuit ratio of HVDC system is defined as the ratio of fault MVA of the AC system at the connection point of HVDC system to the rated capacity of line.

$$\text{SCR} = \frac{\text{Fault MVA of AC system}}{\text{Rated MW Capacity of DC System}}$$

SCR indicates the strength of AC system at the point of connection of HVDC substation. (Ref. Sec. 20.14)

Effective Short-circuit Ratio (ESCR)

It is defined as the ratio which includes fault MVA including contribution of AC harmonic filters. ESCR is now more commonly used. The performance of HVDC link is associated with the strength of the connected AC systems. SCR and ESCR give a measure of the strength of connected AC system. The AC systems are called strong, weak etc. as follows :

AC system	*SCR*	*ESCR*
Weak system	< 3	< 2.5
Strong system	> 6	> 5

16.19. Conclusions

1. HVDC circuit-breakers are classified into four categories :
   (*i*) Low voltage Metallic Transfer Breaker
   (*ii*) Type A Breaker which does not depend on control actions
   (*iii*) Type B1 Breaker which depends on control action but has high voltage capability.
   (*iv*) Type B2 Breaker does depend on control action and has no high voltage capability.
2. HVDC Breakers are likely to be used for a switching off parallel taps.
3. Though the HVDC C.B. have been developed, their use in HVDC systems is not envisaged.

For Further Reading :

1. Book : "EHV AC and HVDC Transmission Engineering and Practice" Khanna Publisher, Delhi (2nd Ed. 1996).
2. Ch. 47, Fig. 47.19, 20, 21, and sec 20.14.

QUESTIONS

1. With the help of sketches, explain the principle of Artificial Current Zero Circuit adopted in DC circuit breaking.
2. Draw a schematic of a two-pole two terminal HVDC System indicating main components. Explain why HVDC Circuit Breakers are not necessary.
3. Explain the configurations of a multi-terminal HVDC System without a HVDC Circuit Breaker.
4. Explain the function of Metallic. Return Transfer Breaker in a typical Bipolar Two Terminal HVDC System.
5. Discuss why HVDC Circuit Breakers are not necessary in HVDC Transmission System.

17

Electrical Substations, Equipment and Bus-bar Layouts*

17.1. INTRODUCTION

The electric power system can be divided into the following regions :

1. Generating stations 2. Transmission systems 3. Receiving stations
4. Distribution systems 5. Load points.

In all these regions need switchgear. Busbars are conducting bars to which a number of local feeders are connected. Bus-bar operate at constant voltage. Busbars are insulated from earth and from each other. Besides the bus-bars there are other equipment in the electrical schemes such as circuit-breakers, current transformers, potential transformers etc. These equipments can be installed according to various schemes depending upon requirements. The total plant consists of several equipment.

The Substations have following distinct circuits :

1. *Main Circuits.* Through which power flows from generators to transmission lines. The components *in series with the main circuit of power flow* include : Busbars, Power Transformers, Circuit Breakers, Isolators, Current Transformer CT, Line Trap Units, Series Capacitors, Series Reactors, Diode or Thyristor Rectifiers. The components *in shunt circuits connected phase to ground* include Shunt Capacitors, Shunt Reactors, Static VAR Sources, Harmonic Filters, Voltage Transformers, Surge Arresters.

1. *Bus-bar and conductor systems* are of following alternatives :
- Tubelar or Solid Aluminium or Copper Conductors supported on Porcelain or epoxy insulators.
- Isolated Phase Busducts
- Flexible ACSR stranded conductors.
- Single core or Multicore Power cables through trenches.

2. *Auxiliary Power Circuits* through which power flows to Substation Auxiliaries. The supply conductors are generally Power Cables.

3. *LV Control Circuits* Measurement, Protection, Control, Monitoring, Communication Circuits. SCADA and Computer/Microprocessors. The supply conductors are generally of Control Cables.

4. *Auxiliary Low Voltage AC and Low Voltage DC Supply Circuits.* The conductors are generally of power cables or solid busbars.

Main Circuit and Equipment are described in Sec. 17.2 to 17.28.

* Refer following books by Khanna Publishers for more details :
— Electrical Substation Engineering and Practice, S. Rao
— Power Transformers and Special Transformers, S. Rao,
— EHV AC and HVDC Transmission Engineering and Practice, S. Rao.

17.2. SUBSTATION EQUIPMENT AND OUTDOOR YARD LAYOUT

An outdoor switch-yard in a substation has several three phase equipment, three phase busbars. Their relative locations and connections are illustrated by

- Single Line Schematic diagrams,
- Single line layouts,
- Three phase layouts,

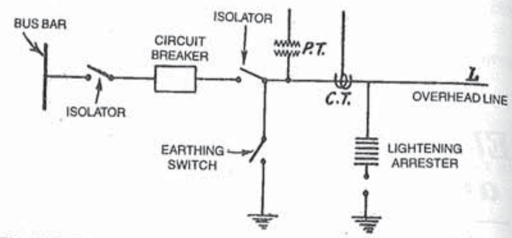
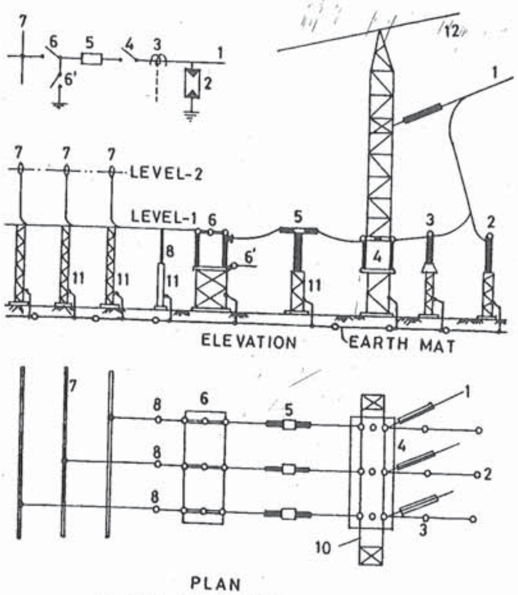


Fig. 17.1. Single Line Schematic Diagram of one bay in Switchyard.

The outdoor *busbars* are either *Rigid Aluminium Tubes* supported on Post Insulators or *Flexible ACSR Conductors* supported on Strain Insulators. The busbars are generally in *two horizontal levels* as shown in the 3-Phase Layout in Fig. 17.1 (*b*). The connections between the two levels are generally by vertical flexible ACSR (Aluminium Conductor Steel Reinforced) or AAAC (All Aluminium Alloy Conductors).

The relative locations of CB, isolators and busbars follow the general practice and particular switching requirement and maintenance and protection requirement. The reasoning should be understood and safety operation, maintenance, protection and control requirements must be satisfied.



1. Line
4. Isolator Line Side
7. Earthing Switch
10. Strain Insulator for 1
12. Shielding conductor (ACSR)

2. Surge Arrester 3.CT
5. Circuit-Breaker
8. Busbar Tubular Rigid
11. Gantry (Beam)11.Support Structure

6.Isolator (Disconnector)
9.Post-Insulator Support

Fig. 17. B Layout of a single bus

Each bay has several equipment connected in certain well defined pattern as shown in Fig. 17.1. Circuit breaker is connected between the busbar and each outgoing and incoming circuit. Isolator is provided on each side of circuit breaker. CTs are provided for measurement and protection. The protection zones should overlap and cover the circuit Breaker. Hence CTs may be necessary on each side of the Circuit Breaker. VTs are generally connected to busbars and incoming line side. Surge Arresters, (Lightning Arresters) are connected phase to ground, at the incoming feeder as the first apparatus and also at the terminal of Transformer, terminal of Capacitor Bank, terminal of Shunt Reactor, terminal of Generator, terminal of Large Motor for diverting Switching/lightning surges to ground. Power transformers are connected between of two voltage levels (Fig. 17.23, Sec. 17.11).

Shunt reactors are used with EHV lines to regulate voltage low during loads.

Fig. 17.3 illustrates the covering of circuit-breaker by the protective zones.

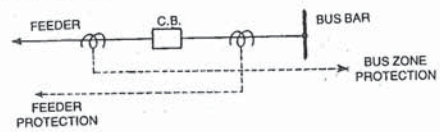


Fig. 17.3. The location of CT's should be such that CB is covered by protective zones.

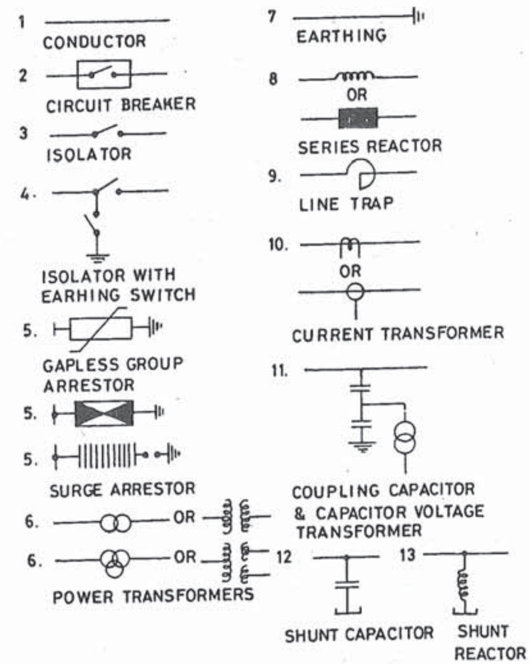


Fig. 17.4. Symbols of 3 Phase-Equipment.

Table 17.1-A. Substation Equipment and their Functions

	Equipment	*Function*
1.	Bus-bar	Incoming and outgoing circuits connected to bus-bars.
2.	Circuit-breakers	Automatic switching during normal or abnormal conditions.
3.	Isolators (Disconnectors)	Disconnection under no-load condition for safety, isolation and maintenance.
4.	Earthing Switch	To discharge the voltage on dead lines to earth.
5.	Current Transformer	To step-down currents for measurement, control, and protection.
6.	Voltage Transformer	To step-down currents for measurement, control and protection.
7.	Lightning Arrester (Surge Arrester)	To discharge lightning over voltages and switching over voltages to earth.
8.	Shunt Reactor in EHV substations	To provide reactive power compensation during low loads.
9.	Series Reactors	To reduce the short-circuit current or starting currents.
10.	Neutral-Grounding Resistor	To limit the earth fault current.
11.	Coupling capacitor	To provide connection between high voltage line and power line carrier current equipment.
12.	Line-trap	To prevent high frequency signals from entering other zones.
13.	Shunt capacitors	To provide compensations to reactive loads of lagging power factors.
14.	Power Transformer	To step-up or step-down the voltage and transfer power from one a.c. voltage to another a.c. voltage at the same frequency.
15.	Series Capacitors	Compensation of series reactance of long lines.

Main Data of a Typical 400/230 kV Outdoor AC Substation

Operating voltage	400 kV	230 kV
Rated current	2000 A	2000 A
Maximum Short-circuit current in busbars	40 kV	40 kV
Minimum phase to phase clearance	5.75 m	2.5 m
Minimum phase to phase clearance	3.65 m	2.0 m
Number of horizontal levels of tubular busbars/flexible busbars	-- 2	2
Height of tubular busbars of first level above ground	7 m	6 m
Height of tubular busbars of second level above ground	13 m	4 m
Tubular Aluminium Busbar A1 ASTM B241	4" IPS*	4" IPS

* IPS = International Pipe Standard

Table 17.1-B. Various Subsystems in Substations and their Functions

	System	*Function*
1.	Substation Earthing (Grounding) system — Earth mat — Earthing spikes — Earthing risers	To provide an earth mat for connecting neutral points, equipment body, support structures to earth. For safety of personnel and for enabling earth fault protection. To provide the path for discharging the earth currents from Neutrals, Faults, Surge arresters, overheads shielding wires etc. with safe step-potential and touch potential.
2.	Overhead earth wire shielding or Lightning Masts.	To protect the outdoor substation equipment from lightning strokes.
3.	Illumination system (lighting) — for switchyards — buildings — roads, etc.	To provide illumination for vigilance, operation and maintenance.
4.	Protection System — protection relay panels — control cables. — circuit-breakers — CTs, VTs, etc.	To provide alarm or automatic tripping of faulty part from healthy part and also to minimize damage to faulty equipment and associated system.
5.	Control cabling	For protective circuits, control circuits, metering, circuits, communication circuits is a underground power cables.
6.	Power cables.	To provide supply path to various auxiliary equipment and machines.
7.	PLCC system power line carrier current system — line trap — coupling capacitor — PLCC panels	For communication, telemetry, tele-control, power line carrier protection etc.
8.	Fire fighting system. — sensors, detection system — water spray system — fire protection control panels, alarm system — water tank and spray system	To sense the occurrence of fire by sensors and to initiate water spray, to disconnect power supply to affected region to pin-point location of fire by indication in control room.
9.	Cooling water system — Coolers — water tank	This system is required for cooling the valves in HVDC substation.
10.	DC Batteries sets and Battery chargers	Auxiliary low voltage DC supply
11.	Auxiliary standby power system — diesel-generator sets — switchgear — distribution system	For supplying starting power, standby power for auxiliaries
12.	Telephone, Telex system, Microwave system.	For internal and external communication.

17.3. ISOLATOR AND EARTHING SWITCH

17.3.1. Requirement and definitions

Isolator (disconnecting switch) operates under no load condition. It does not have any specified current breaking capacity or current making capacity. Isolator is not even used for breaking load currents.

Circuit-breaker can make and break electric circuit under normal current or short circuit conditions.

Isolators are used in addition to circuit-breakers, and are provided on each side of every circuit-breaker to provide isolation and enable maintenance.

While opening a circuit, the circuit-breaker is opened first, then isolator. While closing a circuit, the isolator is closed first, then circuit-breaker. Isolators are necessary on supply side of circuit-breakers in order to ensure isolation (disconnection) of the circuit-breaker from live parts for the purpose of maintenance. Automatic switching of isolators is preferred.

Isolators used in power-systems are generally 3-pole isolator. The 3-pole isolators have three identical poles. Each pole consists of two or three insulator posts mounted on a fabricated support. The conducting parts are supported on the insulator posts. The conducting parts consist of conducting copper or aluminium rod, fixed and moving contacts. During the opening operation the conducting rods swing apart and isolation is obtained. The simultaneous operation of three poles is obtained by mechanical interlocking of the three poles. Further, for all the three poles, there is a common operating mechanism. The operating mechanism is manual plus one of the following :

(1) Electrical motor mechanism, (2) Pneumatic mechanism.

Pneumatic mechanism was preferred in substations with Air-Blast Circuit Breakers. Now, with SF_6 circuit-Breakers, motor-mechanism is preferred. Further the isolator can be provided with earthing switches where required. The earthing switch consists of conductor bar. When the earthing switch is to be closed, these bars swing and connect the contact on line unit of isolator to earth.

To prevent the mal-operation, the isolator is provided with the following interlockings :

1. Interlocking between three poles for simultaneous operation.
2. Interlocking with circuit-breakers.

Isolator cannot be opened unless the circuit-breaker is opened. Circuit breaker cannot be closed unless the isolator is closed.

Load Break Switches

In addition to isolators and circuit-breakers, there is one more device called Load Interrupting Switch, which combines functions of the isolator and a switch. These are used for breaking load current.

Earthing Switch

Earthing switch is connected between the line conductor and earth. Normally it is open. When the line is disconnected, the earthing switch is closed so as to discharge the voltage trapped on the line. Though the line is disconnected, there is some voltage on the line to which the capacitance between line and earth is charged. This voltage is significant in high voltage system. Before starting the maintenance work these voltages are discharged to earth by closing the earthing switch.

Normally, the earthing switches are mounted on the frame of isolator.

Sequence of Operation while Opening/Closing a Circuit

While opening : (1) Open Circuit-breaker
(2) Open Isolator
(3) Close Earthing Switch (if any).

While closing : (1) Open Earthing Switch
(2) Close Isolator
(3) Close Circuit-breaker.

17.3.2. Types of Construction of isolators

— Vertical Break type (Figs. 17.3 and 17.5)
— Horizontal Break type, either centre-break or double-break (Fig. 17.4)
— Vertical Pantograph type (Fig. 17.6).

The vertical pantograph type design is preferred for rated voltages of 420 kV and above. The other types of designs are used from 12 to 420 kV.

These are outdoor air break disconnecting switches of the gang-operated horizontal break type with rating of 7 kV and above. These isolators are designed for all outdoor applications including isolation of circuit breakers, transformer banks and surge arresters and line sectionalizing. Horizontal upright mounted switches can be equipped with arcing horns for interrupting small currents such as line charging or transformer-magnetizing currents.

Gang-operated earthing switches can be mounted on one side of the break jaw end of the main switches.

The grounding switches can be closed easily through a lever mechanism by use of the handle, but only when the main isolator is open, due to the provision of a mechanical interlock.

Horizontal Break Centre Rotating Double Break Isolator

This type of construction, has three insulator stacks per pole. The two on each side are fixed and one at the centre is rotating type. The central insulator stack can swing about its vertical axis through about 90°. The fixed contacts are provided on the top of each of the insulator stacks on the side. The contact bar is fixed horizontally on the central insulator stack. In closed position, the contact shaft connects the two fixed contacts. While opening, the central stack rotates through 90°, and the contact shaft swings horizontally giving a double break.

The isolators are mounted on a galvanised rolled steel frame. The three poles are interlocked by means of steel shaft. A common operating mechanism is provided for all the three poles. Fig. 17.5.2 shows one pole of a triple pole isolator in closed position.

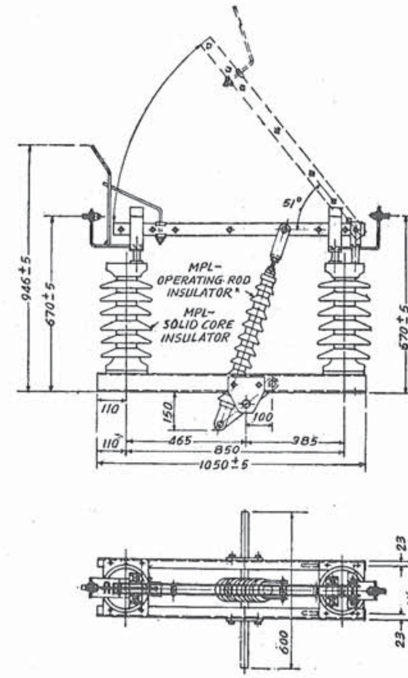


Fig. 17.5.1. Verticallv Break 25 kV Isolator
(*Courtesy* : Hi-Velm Indu·tries Pvt. Ltd., India.)

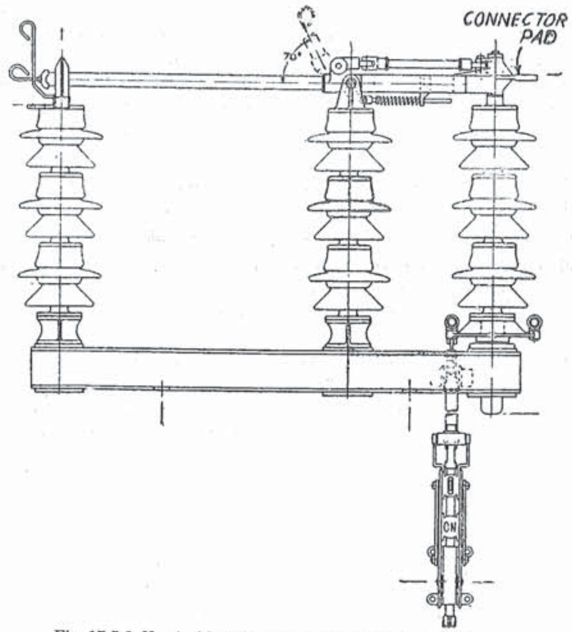


Fig. 17.5.2. Vertical Break Isolator (not described here)
(The insulator stack on right side swings about its vertical axis,
The contact pipe swings in vertical plane.)

17.3.3. Pantograph Isolator

Fig. 17.5.3 illustrates the construction of a typical pantograph isolator. While closing, the linkages of Pantograph are brought nearer by rotating the insulator column. In closed position the upper two arms of the pantograph close on the overhead station busbar giving a grip. The current is carried by the upper busbar to the lower busbar through the conducting arms of the pantograph. While opening, the rotating insulator column is rotated about its axis. Thereby the pantograph blades collapse in vertical plane and vertical isolation is obtained between the line terminal and pantograph upper terminal.

Pantograph isolators cover less floor area. Each pole can be located at a suitable point and the three poles need not be in one line, can be located in a line at desired angle with the bus-axis.

17.3.4. Ratings of Isolators and Tests

The definition regarding Normal Current Rating, Short time current rating, Rated voltage, Rated Insulation level for isolators are similar to the corresponding terms applicable to high voltage a.c. circuit-breakers (Refer Sec. 3.19). Isolators do not have breaking or making capacity.

The terms Type tests and Routine tests defined in Chapter 10 are applicable to Isolators also. The following *type tests* are conducted on Isolators :

— Temperature Rise tests (Refer Sec.10.12.2)
— Power frequency voltage withstand tests (Refer Sec. 12.10)
— Impulse voltage withstand tests (Refer Sec. 12.8)
— Mechanical Endurance tests (Refer sec. 10.2)

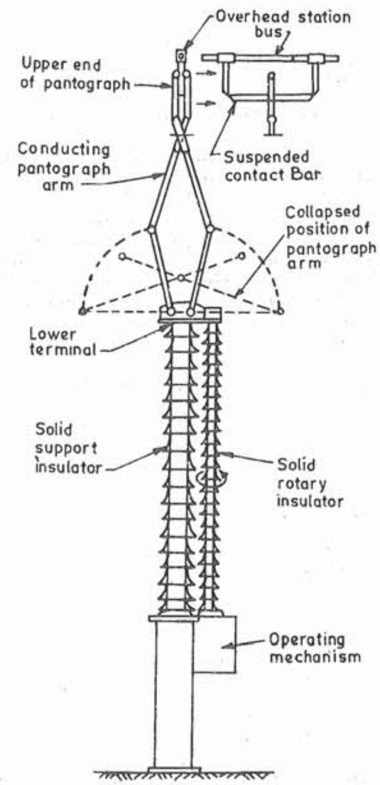


Fig. 17.5.3. Pantograph insulator for UHV sub-station.

— Millivolt drop tests (Refer Sec. 10.2.4)
— Short Time Current test (Refer Sec. 11.6)

Type tests are conducted on one or first few isolators to confirm the design and rating. Following routine tests are conducted on Isolators. These are conducted on each Isolator manufactured by the company before dispatch to site.

— Power Frequency Voltage Withstand Test
— Mechanical Operation Tests
— Measurement of Resistance.

17.4. BUS-BAR ARRANGEMENTS IN SWITCHYARDS

There are several ways in which the switching equipment can be connected in the electrical layout of generating station, receiving station or a switchgear in a distribution system. The selection of the scheme is in general affected by following aspects :

1. Degree of flexibility of operations desired.
2. Importance of load and local conditions. Freedom from total shut down and its period desired.
3. Economic consideration, availability and cost.

4. Technical considerations.
5. Maintenance, safety of personnel
6. Simplicity.
7. Provision of extension.
8. Protective Zones.

With these basic requirements there are several combinations, some of which are briefly described below.

For a small and medium sized station where shut-down can be permitted at times, simple, single bus-bar system can be favoured. For major plant such a large generating station or receiving station, bus-bar system is carefully designed and a costly system is always justified. Technical considerations are more important than economic considerations. In major plants, shut down results in disconnection of supply to a large area. Hence, to avoid shut-down, the major plants should have elaborate bus-bar system, with duplicate buses, sectionalization, alternative supply arrangements etc. The technical considerations include function of each equipment, its location, sequence of operation, relative location, interlocking, facility of periodic maintenance with alternative supply etc. Economy is most important. The extra-high voltage equipment such a isolator, circuit-breakers etc. are generally costly. Hence unnecessary equipment should not be provided.

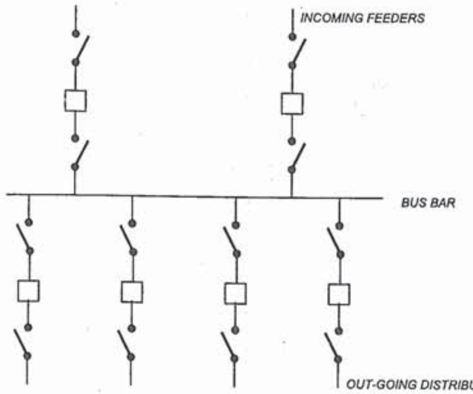
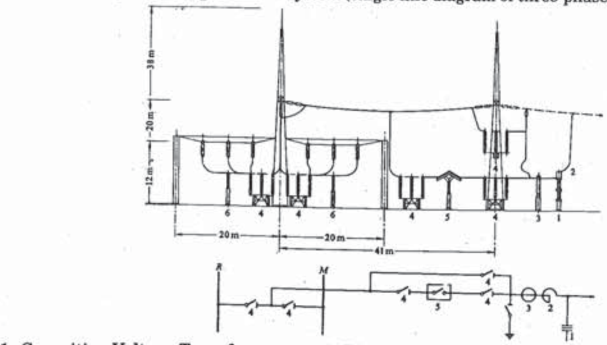


Fig. 17.6. Single bus-bar system (single line diagram of three-phase system).



1. Capacitive Voltage Transformer **2. Line Trap** **3. Current Transformer**
4. Isolators **5. Circuit-breaker** **6. Post insulator**
***M*–Main buses ; *R*–Reserve buses**

Fig. 17.7. Section through a feeder bay in a 220 kV Switchyard.

(*a*) **Single bus-bar arrangement.** This simple arrangement consists of a single (three-phase) bus-bar to which the various feeders are connected. In case of a fault or maintenance of a bus-bar the entire bus-bar has to be de-energized and the total shutdown results.

Hence this type of arrangement provides least flexibility and immunity from total shut-down. However, this scheme is the most economical and simple. It is used for switch-boards, small and medium sized sub-stations, small power stations.

(*b*) **Duplicate bus-bar arrangement.** The duplicate bus-bar system provides additional flexibility, continuity of supply and permits periodic maintenance without total shut-down. In the event of fault on one bus the other can be used.

Fig. 17.8 (*a*) shows the duplicate bus-bar arrangement in a generating station. Each generator has only one circuit-breaker and between the circuit-breaker and each busbar there is one isolator. There are two buses called *main* bus and reserve bus. The coupler can be closed so as to connect the two buses. While transferring the power to the reserve bus, the following steps may be taken :

1. Close tie circuit-breaker, *i.e.* bus coupler. The two buses are now at same potential.
2. Close isolators on reserve bus.
3. Open isolators on main bus.

The power is now transferred to the reserve bus and main bus is disconnected. In more important stations, two circuit-breakers are used per generator, one for each bus.

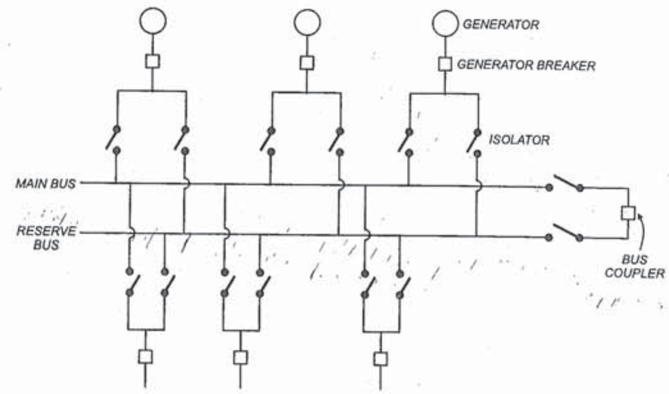


Fig. 17.8 (*a*) Duplicate bus-bar system (Single line diagram of 3-phase System)

For 400 kV Switchyards two Main Buses plus one transfer bus scheme is preferred. The transfer bus is used for transferring power from Main Bus I to Main Bus II.

(*c*) **Sectionalization of bus** (Fig. 17.9). Sectionalizing the buses has added advantages. One section can be completely shut down for maintenance and repairs while the other continues to supply. Secondly by adding a current limiting reactor between the sections, the fault MVA can be reduced, thereby circuit-breaker of lesser capacity may be permitted.

(*d*) **Ring bus** [Fig. 17.8(*b*)] Ring bus provides greater flexibility. The supply can be taken from any adjacent section. The effect of fault in one section is localised to that section alone. The other section continues to operate.

(*e*) **One-and a half breaker arrangement.** One-and-a-half breaker arrangement needs three circuit-breakers for two circuits. Any circuit-breaker can be switched-off for the purpose of maintenance, without the provision of bypass. (Fig. 17.10)

The number of circuit-breaker per circuits $1\frac{1}{2}$, hence the name.

Refer Fig. 17.10 having two bus-bar sets I and II. In $1\frac{1}{2}$ breaker arrangement, circuit I and circuit II can take supply either from bus-bar I or bus-bar II. Thus this arrangement gives high security against loss of supply. Such arrangement is particularly suitable for the switchyards in large generating stations in which very high power is to be handled by individual circuits. (Say 500

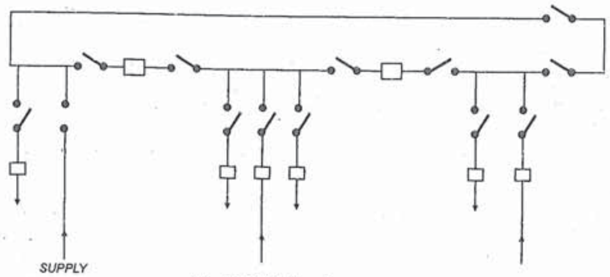


Fig. 17.8 (*b*) Ring bus.

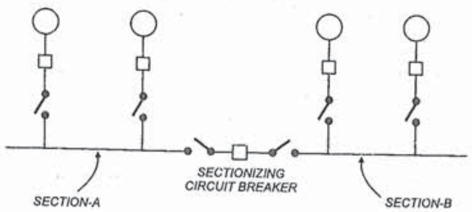


Fig. 17.9. Sectionalization of bus.

MW) $1\frac{1}{2}$ Breaker arrangement uses $\frac{1}{2}$ circuit-breaker per circuit. The higher cost is justified because of higher security and by passing facility obtained.

The $1\frac{1}{2}$ circuit-breaker arrangement has been used in important 400 kV, 750 kV sub-stations.

(*f*) **Mesh arrangment.** Another method of economic use of circuit-breakers in a sub-station is mesh-arrangement (Fig. 17.11). In mesh arrangement, the circuit-breakers are installed in the

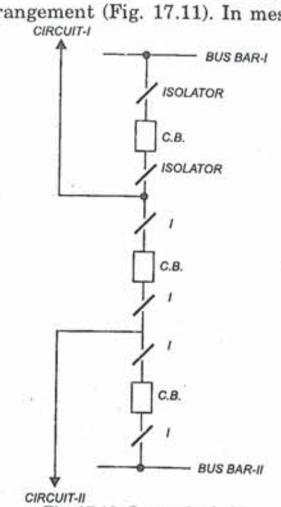


Fig. 17.10. One-and-a-half circuit-breaker arrangement.

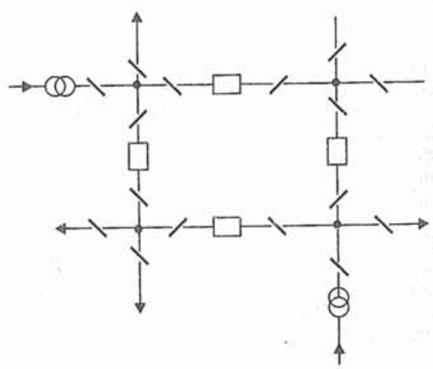


Fig. 17.11. Mesh Arrangement (Only four circuit-breakers control eight circuits.)

mesh formed by the buses. The circuits are tapped from the node points of the mesh. In the figure shown, four circuit-breakers are utilized to control eight circuits. In the event of a fault on any circuit, two circuit-breakers have to open, resulting in opening of the mesh.

17.4.1. Bus-bar System Recommended for Large Important sub-stations

— Duplicate bus-bar arrangement with additional transfer bus

— $1\frac{1}{2}$ circuit-breaker arrangement

— Mesh arrangement

Single bus-bar system is not preferred.

Duplicate bus-bar system is suitable for highly interconnected power network in which flexibility is important. It gives no security against bus-bar faults.

$1\frac{1}{2}$ circuit-breaker arrangement is preferred in important large stations where power handled per circuit is large.

Interconnected Mesh gives maximum security against bus-bar faults are requires minimum outage against busbar faults. It uses fewer circuit-breakers than $1\frac{1}{2}$ arrangement. It lacks switching flexibility. It is preferred in sub-stations having large number of circuits.

17.4.2. Maintenance Zoning

The sub-station layout should be designed with due considerations to maintenance zoning, *i.e.* grouping of various equipments such that they can be isolated and physically separated from neighbouring live parts for maintenance.

In simple *single bus-bar feeder circuit* the following three maintenance zones are required :

— circuit-breakers maintenance zone

— bus-bar zone including bus-bar isolator

— feeder zone including the feeder isolator and feeder-side equipment.

In *duplicate bus-bar arrangement* there are usually seven zones :

— circuit-breaker zones

— two bus-bar-isolator zones

— two bus-bar zones

— a circuit-breaker, isolator zone and circuit-connection zone

— a feeder zone including feeder isolator, bypassing isolator.

line side equipment.

17.5. USE A LOAD BREAK SWITCHES

In distribution systems, voltage upto 33 kV are used. The fault levels may not be high enough to justify the use of circuit-breakers economically.

In such cases, the load break switches are used in conjunction with H.R.C. fuses and circuit-breakers. Load break switches are capable of making breaking currents under *normal conditions.* They can carry the specified current of specified values for specified time. They are capable of making but not breaking, short circuit currents. Switch Isolators or Switch Dis-connectors combine the functions of switch and isolators. Load-break switches serve the following requirements :

— breaking rated currents.

— making rated currents.

— making specified S.C. currents.

— carrying specified short-circuit currents.

— interrupt small inductive, capacitive currents.

While selecting the schemes with load break switches, circuit-breakers or H.R.C. fuses should be provided at strategic locations so as to interrupt fault currents, since load break switches cannot do so. Fig. 17.12 illustrates typical uses of load break switches.

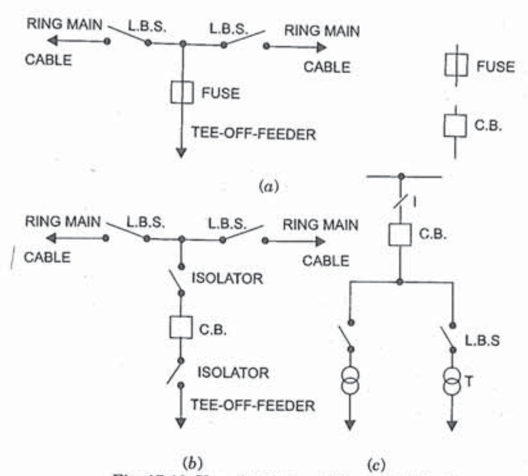


Fig. 17.12. Use of LBS (Load Break Switches) supplemented by CB or HRC Fuses.

17.6. SWITCHGEAR IN GENERATING STATIONS

The switchgear in generating stations can be classified as

— main switchgear — auxiliary switchgear

Main switchgear comprise circuit-breakers, isolators, busbars CT's, PT's etc. in the main circuit of generator associated transformers and transmission line. It is generally of EHV and outdoor type.

Auxiliary switchgear is generally indoor type and controls the various auxiliaries of the generator, turbine, boiler and the station auxiliaries. Auxiliary switchgear is at two or three voltage level such as 11 kV, 6.6 kV, or 3.3 kV, 415 Volts.

The ratings and requirements of main switchgear and auxiliary switchgear are quite different. Upto unit capacity of 200 MW, the auxiliary switchgear is generally at two voltage levels such as 6.6 kV and 415 V. For unit capacity of 500 MW. Three voltage levels are necessary, 11 kV, 6.6 kV, 400 V.

17.6.1. Main Switchgear Schemes

(*a*) Classical Method of Generator Connections

Generator voltage is less than 27 kV because of design considerations. The classical system consisted of connecting a number of generators to a common bus-bar through generator circuit-breakers. This system is used in many small medium sized stations and pumped storage schemes. With increase in the size of generator units, load and fault currents also increase and the classical system becomes technically unacceptable, and *unit system* is preferred.

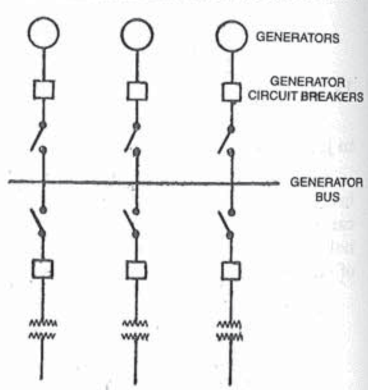
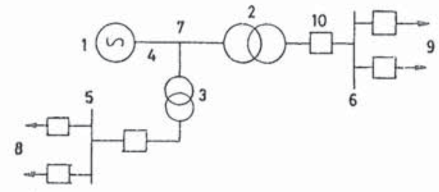


Fig. 17.13. Classical (old) system of generator connection, for small units.

17.6.2. Unit System of Generator Connections : (Scheme without Generator-Circuit-Breaker)

The standard ratings of generator-transformer units in Thermal and Nuclear Power Plants in India are : 200 MW, 236 MW (nuclear), 500 MW. Identical units are installed and are connected in parallel on HV side of main step-up transformer (generator transformer). *There is no circuit-breaker between the generator, generator-transformer and unit-auxiliary transformer.* Each unit has the following, (Ref. Fig. 17.14).



1. Main Generator
2. Main Unit transformer
3. Unit auxiliary transformer
4. Busduct between 1-2-3
5. Auxiliary Bus
6. HV Bus
7. T-off between 1, 2 and 3
8. Unit auxiliaries (motors etc.)
9. Transmission lines
10. Main C.B. Fig. 17.1.

Fig. 17.14. Unit system of generator connection.

Several identical units are connected to feed power to the EHV bus as shown in Fig. 17.19.

Each *Unit* has its own Boiler (Steam Generator). The various boiler auxiliaries, generator auxiliaries together are called *unit-auxiliaries.* The auxiliaries of the generator units are supplied power at 11 kV, 6.6 kV, 3.3 kV, 400 V AC. The power for the auxiliaries supplied by the same generator *via* the *unit-auxiliary transformer.*

The Auxiliary Switchgear in the power plant is an indoor metal clad drawout-type switchgear at 11 kV, 6.6 kV, 3.3 kV, 400 V AC.

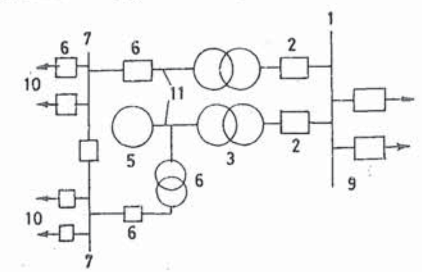
The main switchgear on HV side of the Main Unit Transformer is either 132 kV, 220 kV or 400 kV outdoor switchgear or a SF Gas Insulated Switchgear called GIS (Gas Insulated Substation).

In the conventional unit generator connection system (Figs. 17.14, 17.15 and 17.19, we do not need any circuit-breaker between the generator and main step-up transformer. The connection is direct by mean of Isolated Phase Busduct (Sec. 17.8).

The unit is started by taking auxiliary power from the main HV bus and the generator is brought to rated speed then rated voltage and then synchronized with the main HV Bus by closing the main circuit breaker.

Station Transformer

The *common station auxiliaries* like lighting, feed water pumps, air conditioning and cooling systems, battery-charging system, oil-filtration plants etc. are supplied power through the step-down station transformer (Fig. 17.15). The Starting power for unit auxiliaries is usually taken from the HV Bus *via* the station transformer. In some power plants, a quick staring gas turbine generator is provided for starting power and peaking power.

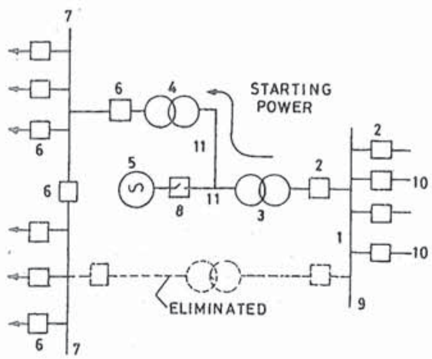


1. EHV bus
2. Circuit breaker
3. Main transformer
4. Auxiliary transformer of unit
5. Generator
6. Auxiliary C.B.
7. Auxiliary bus
8. Station service transformer
9. EHV yard
10. Auxiliary system
11. Isolated phase bus duct
12. Isolated phase bus-duct.

Fig. 17.15. Single line diagram-Unit system of generator-transformer connections in thermal power stations.

17.6.3. Unit Scheme Employing Generator Circuit Breaker

This concept was developed by European Companies during 1970s for unit ratings of 500 MW and above to minimise the installation cost. Fig. 17.16 is the schematic. The Gen. C.B. is connected between the Generator and the T-Off for Unit Auxiliary Transformer. The rating of Generator Breaker depends on MW rating and percentage impedance of the generator. The Generator-Breaker is either Air Blast Circuit Breaker or Puffer-type SF Circuit breaker. The three poles are enclosed in stainless steel or aluminium enclosures, and the enclosures are coupled axially with the bus duct.



1. EHV bus
2. Circuit breaker (EHV)
3. Main transformer.
4. Auxiliary transformer.
5. Generator.
6. Auxiliary transformer.
7. Auxiliary bus.
8. Generator circuit-breaker.
9. EHV-outdoor switchyard.
10. Transmission lines.

Note. Station Service Transformer (10) is eliminated.

Fig. 17.16. Scheme with Generator Circuit-Breaker.

With the generator breaker, while starting the unit, the generator breaker is kept open and the starting power for unit auxiliaries is taken from the HV bus *via* Main Unit Transformer.

The auxiliaries are started and the turbine is brought to rated speed. Then the excitation is increased till rated voltage of generator is reached. The generator is synchronised with the LV side of Main Unit Transformer by closing the Generator-Breaker. The input to turbine is increased and generator shares more load.

When generator breaker is switched off, the auxiliaries continue to get power from the main transformer. The Station Transformer is eliminated and this results in major reduction in capital cost.

Station Service Transformer is eliminated. Starting power for Auxiliaries is drawn from main HV bus.

Generator Circuit Breaker Scheme is not yet preferred in India as starting power is not easily available from other power stations *via* transmission lines.

17.6.4. Main Switchgear in Generating Stations

The power flow from the generator to the transmission system is *via* the main switchgear at 132 kV/220 kV/400 kV. The switchgear is either with outdoor SF_6 C.B. or with indoor SF_6 Gas Insulated Switchgear (GIS). Before 1980s the Air Blast Breakers and Minimum Oil Breakers were popular. They are not preferred any more and are found only in older installations (1985).

17.6.5. Single and Multiple Generator Transformer Unit

In single generator-transformer unit, transformer of almost same rating is provided with each generator. Three winding transformers are used where two values of high voltages are required (Fig. 17.17).

In multiple generator-transformer unit, two or three generators are connected to a generator

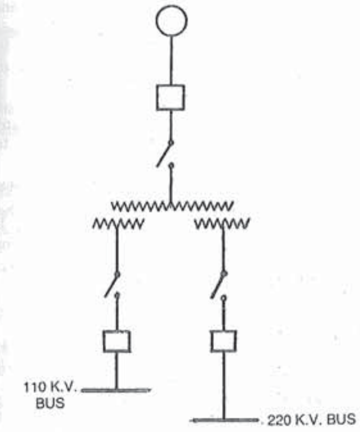


Fig. 17.17. Use of three winding transformer, single generator transformer unit.

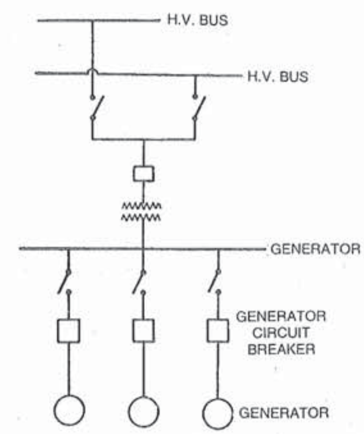


Fig. 17.18. Multiple generator transformer unit.

bus. Transformer is connected between the generator bus and high voltage bus (Fig. 17.18). Such scheme can be adopted in small hydro-electric power station, having unit size upto 15 MW and total transformer capacity upto 60 MW.

However, this scheme is not very common in modern thermal stations due to high capacity of modern turbo-generator (500 MW and above).

17.7. AUXILIARY SWITCHGEAR IN POWER STATIONS

The auxiliaries in thermal power station include boiler auxiliaries, condenser auxiliaries, generator and turbine auxiliaries, station auxiliaries, etc. The auxiliary motors are of rating, ranging from fractional horse-power to several thousand horse-power. The total power required by auxiliaries is of the order of 6 to 8 per cent of the station output. The purpose of auxiliary switchgear is to facilitate switching, control and protect of various auxiliaries. In 200 MW unit capacity class generating stations, the auxiliary system is generally at two voltage levels such as 6.6 kV and 0.415 kV.

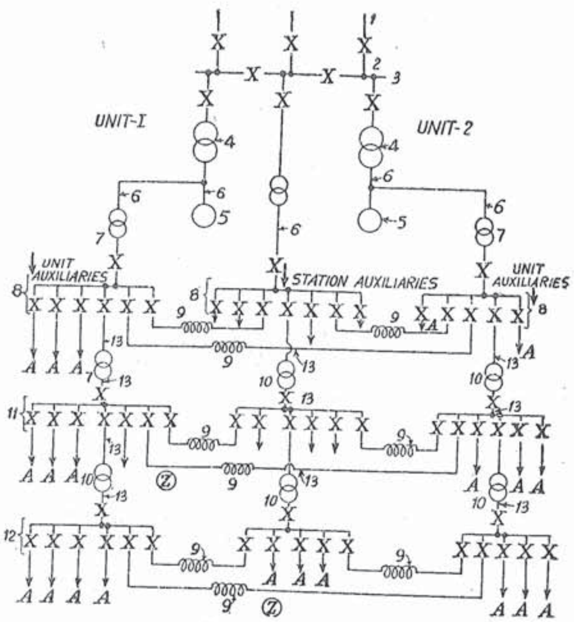
However, with 500 MW unit class power stations, three voltage levels, such as 11 kV, 6.6 kV, or 3.3 kV and 415 V are necessary, so that the auxiliary switchgear of enough breaking capacity can be installed. The auxiliaries concerned with the unit are called "Unit Auxiliaries", and are supplied by generator *via* the unit-auxiliary transformer, (Fig. 17.15).

The auxiliary of the station common to all the units are called Station Auxiliaries (Fig. 17.19).

To determine the rating of circuit-breakers in auxiliary system, the following aspects should be considered :

— Fault level at H.V. bus.
— Contribution to fault current from H.V. bus *via* the starting transformer.
— Contribution to fault current *via* the station service transformer. (Fig. 17.15)
— Contribution to fault current by the large auxiliary motors.

Typical rating of circuit-breakers in auxiliary system are as follows :



1 — EHV transmission line.
2 — EHV switchgear generally outdoor.
3 — EHV bus, generally outdoor, sectionalised.
4 — Main transformer of generator transformer unit (outdoor) Rating almost equal to that of 5.
5 — Turbo generator (indoor).
6 — Isolated phase buses, continuous type (Fig. 17.21).
7 — Unit auxiliary transformer (rating about 6 to 8%, that of 5).
8 — Auxiliary switchgear (say 12 kV).
9 — Current limiting reactors, switched during emergency or starting.
10 — Auxiliary transformers.
11 — Auxiliary switchgear (say 7.2 kV).
12 — Auxiliary switchgear (415 V).
13 — Metal enclosed conductor, Fig. 17.20.
A = To auxiliary equipment
X = Switchgear
Z = These interconnections are generally omitted.

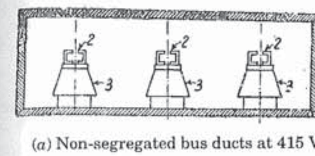
Fig. 17.19. Auxiliary switchgear for a thermal power stations.

Table 17.1

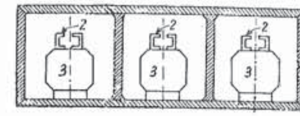
Rated voltage kV	*Breaking capacity MVA*	*Normal current ratings A*
12	1000 750 500 350	400, 800, 1200, 1600, 2000, 3000, 3500
7.2	500 350 250	400, 600, 800 1200, 1600, 2000, 2400
3.6	250 150	400, 600, 800, 1600 2000, 2400
0.415	31 26 15	400, 500, 800, 1200 2400

The auxiliary switchgear is indoor type. Similar units are installed side-by-side. The following type of circuit-breakers are used in drawout type metal enclosed indoor auxiliary switchgear (Refer Sec. 15.4).

— Air-break circuit-breaker, with magnetic arc elongation (for LV).
— Vacuum circuit-breakers with RC surge suppressors. (Refer Sec. 15.5)
— SF_6 circuit-breaker (Refer Sec. 15.27).



(*a*) Non-segregated bus ducts at 415 V.



(*b*)

1. Metal Enclosures Fabricated, Aluminium/Steel
2. Conductors, Aluminium Channels (or Flats)
3. Insulators (Porcelain or Resin Cast)

Fig. 17.20. Segregated enclosures of conductor used for auxiliary system at 6.6 kV or 11 kV.

17.8. ISOLATED PHASE BUS SYSTEMS (Fig. 17.21)

The conductors between generator, unit transformer, unit-auxiliary transformer are enclosed in hollow, tubelar aluminium enclosures. The enclosures are continuous* and are connected in star and earthed at each end. The conductors are supported on epoxy insulators within the enclosures. Such a system is called Isolated Phases Bus System, and is used in all thermal power stations having generator rating of 60 MVA and above. The eddy currents induced in the enclosures flow longitudinally in the enclosures. Thereby they produce associated magnetic-field outside and within the enclosures. This field interacts with the field of the main conductors. As a result, in case of isolated phase bus system, the magnetic-field is substantially reduced, outside the enclosures. Thereby the electrodynamic forces between main conductors during external short circuits are substantially reduced. (To about 5% of their value without enclosures.) Therefore, the insulator design is simplified. Heat is produced in the enclosures as well as in the conductors. Upto normal current ratings of 20 kA, air natural cooling may suffice. Between 20 kA and about 40 kA normal current rating forced air cooling is preferred. Above 40 kA conductors are water cooled. Maximum permissible temperature of conductors and enclosures is of the order 85°C. The design is such that the enclosure current is almost equal to conductor current. Aluminium conductors are of octagonal or double-channel or tublar cross-section. Enclosures are also aluminium [Refer Fig. 17.21 (*b*)].

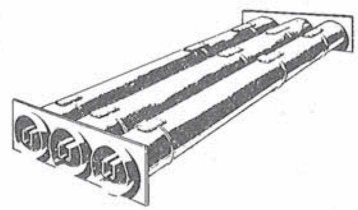
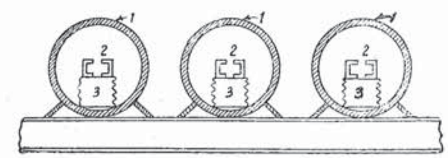


Fig. 17.21. (*a*) A view of isolated phase bus duct (continuous type enclosures)



1. Enclosures, Tubular Fabricated, Welded, Continuous Construction of Aluminium Earthed and Star Connected at both ends, Insulated from Generators and Transformers.
2. Aluminium Conductors
3. Insulators Support, Porcelain or Synthetic Resin Cast.

Fig. 17.21. (*b*) Isolated phase bus system for conductors between generators and main transformers.

* For normal currents above 4 kA, continuous type enclosure is preferred [Fig. 17.21 (*b*)]. For currents less than 4 kA discontinuous enclosures may be used.

In continuous type of design of bus-ducts, the sections of each enclosure are welded to get continuous run. In discontinuous type design, the next section is insulated from the previous one, see Note as below.

The advantages of Isolated Phase Bus System include :

— Reduced electrodynamic forces between conductors during short-circuit conditions, hence simplified insulator design.
— Almost, total absence of faults in bus section.
— Safety of personnel.
— Reduced maintenance.
— Magnetic shielding, no induced current in neighbouring metallic frame works, reinforcements, etc.

Generator circuit-breakers, discussed earlier, are also enclosed in continuous metal enclosures. Thereby the advantages mentioned above are inherited by the generator circuit-breakers too.

The conductors of auxiliary system are enclosed in segregated or non-segregated metal enclosures [item 13, Figs. 17.19 and 17.20]. Such enclosures are compact and minimise the phase to phase faults.

They are dust-proof, vermin proof water-proof, and ensure maintenance free and fault free service. The enclosures of segregated bus ducts are made of fabricated, rolled steel sections, to which steel sheets are welded or screwed. The construction is generally made of standard section of about 2 metres length connected lengthwise. The thickness of sheets should be above 2 mm.

17.9. CONTINUOUS HOUSING TYPE ISOLATED-PHASE BUSES

The high-capacity and high-safety, continuous housing-type isolated bus employed in power stations and substations represents one of the most reliable current buses.

As shown in Fig. 17.22, each phase conductor is separately enclosed in a metal housing, and the housing units are connected electrically. Housings of three phases are short-circuited on both ends to enable current to circulate sufficiently. Since the circulating current is approximately as much as 95% of the conductor current, it greatly reduces the external magnetic field produced by the conductor current. Accordingly, the larger the conductor current is, the greater effect is demonstrated.

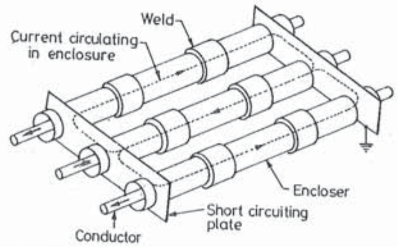


Fig. 17.22. Fundamental Principle of continuous Housing Type Isolated-phase Bus

ADVANTAGES

1. **Nonexistence of Phase-to-phase Faults.** Each phase conductor is enclosed by an individual metal housing separated from adjacent conductor housings by an air space. This design prevents phase-to-phase faults from occuring.

2. **Large Momentary Current Strength.** Since the metal enclosure has an electromagnetic shielding effect, the electromagnetic force on phase conductors is reduced to approximately 1% in an AC magnetic field, and to 3% in an AC magnetic field caused by short-circuit current with a

maximum DC component, compared with electromagnetic force on a phase conductor without enclosure.

Furthermore, the bus conductors are a channel type, with a large section modulus, for this reason, and due to the high mechanical strength of insulators supporting the bus conductors, the buses have ample momentary current strength.

4. **Free from Electromagnetic Inductive Overheating and Inductive Interference.** The external leakage magnetic flux is very slight, rendering practically negligible inductive overheating on the peripheral steel structures and pipings and inductive interference on adjacent control wiring.

5. **High Current Carrying Efficiency.** Bus bar conductors are the channel type which displays very little skin effect and has a large cooling surface. The conductor surface and the interior of the enclosure are painted for efficient heat dissipation. As a result, temperature rise is small and current carrying efficiency is quite high.

6. **High Airtightness.** Standard connections between the housing units are welded, presenting a completely enclosed construction having a high airtight characteristic.

7. **High Dielectric Strength.** The bus conductors are supported on corrugated insulators with high dielectric strength to prevent insulation deterioration.

8. **Reduced Maintenance.** Construction itself is simple, and all standard joints are welded. Moreover, the metal housing prevents infiltration of dirt and dust. Actually, maintenance and inspection are practically unnecessary.

9. **Simpler Installation.** Each unit is shipped to the site in a completely assembled state, after having been fully built, factory-tested and packed, permitting the buses to be easily installed at the site and requiring little incidental construction work. Overall construction costs are thus reduced.

CONSTRUCTION

1. **Conductor Support.** The support used for each bus conductor is of high-strength construction which ably withstands large electromagnetic forces. To allow for free expansion and contraction of the conductor caused by temperature changes, one of the conductors in each unit is fixed, while the other is loosely supported in the axial line.

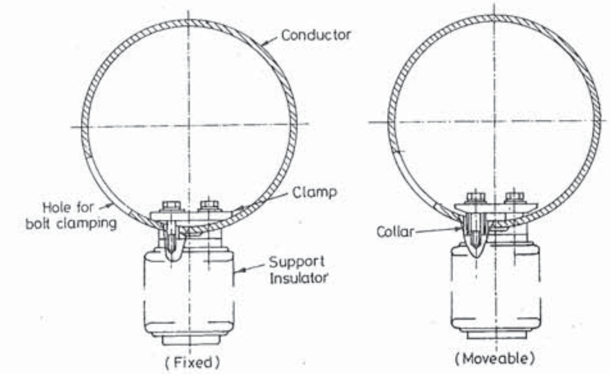


Fig. 17.23 Conductor Support (Rated current: 6,000 A and above)

2. Inspection Cover. A watertight inspection cover is provided on the enclosure for assembly and inspection. This inspection cover is a clamp-on type (shown in Fig. 17.25) for easy removal.

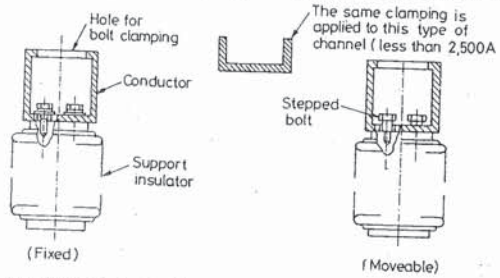


Fig. 17.24 Conductor Support (Rated current: Less than 6,000 A)

3. Connectors. An expansion connector composed of aluminium sheet layers is used as a connector between the conductors. One side is welded at the factory, and the other side is welded after installation to ensure completely welded construction. The enclosure is connected at the installation site after connection of the conductor, eliminating bothersome maintenance and inspection after operation.

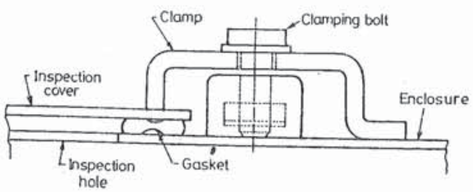


Fig. 17.25 Hinged part of inspection cover.

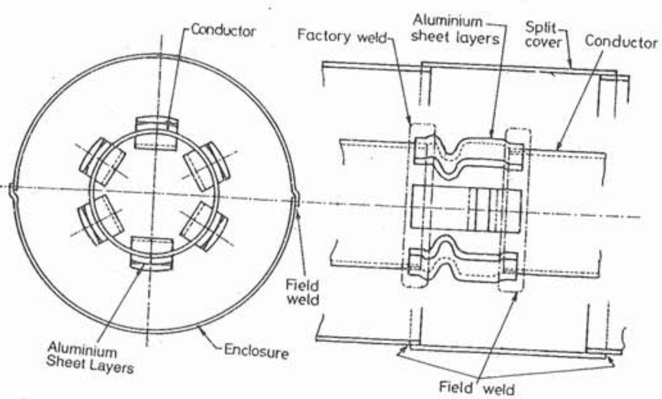


Fig. 17.26.

4. Wall-penetrated Portion. As shown in Fig. 17.28, the flanges of the enclosed buses are attached to the frame embedded in the building wall. A seal-off bushing is used (see Fig. 17.29) to close off air circulation.

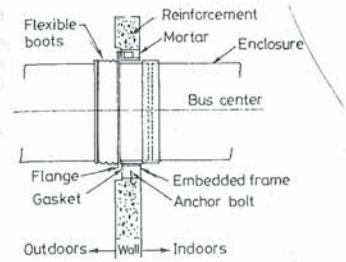


Fig. 17.27. Wall-Penetrated Portion

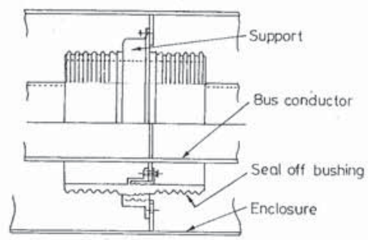


Fig. 17.28 Construction of Seal-off Bushing

5. Flexible Connectors. For protection against vibrations and possible foundation sinking the connections with generators and heavy transformers - as well as those in the wall-penetrated portion - are of special flexible construction. Flexible copper braids with adequate slack are used in the bus conductor connections to prevent undue stress from affecting the conductors and the terminals of machines.

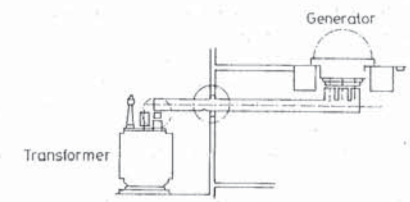


Fig. 17.29. Example of Installation of an Isolated-phase Bus

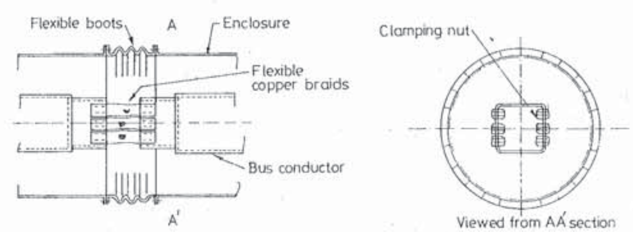


Fig. 17.30. Construction of Flexible Connector

BUS TRUNKING SYSTEMS

Busbar Trunking System is the modern factory built Electrical Distribution System designed not only as an alternative to cables but have many advantages over conventional cable distribution system is fast becoming Industry/building standard for future. Decentralized distribution is the main highlight of this distribution system *i.e.* each equipment/appaliance used in the installation is protected immediately by a protective device & can be maintained individually without disturbing other distribution networks thus reducing downtime. This system also eliminates separate requirement of distribution & panel boards. Loads can be fed from Plug-in Boxes unlike cables where each floor/machine is to be fed separately from the main switchboard. Furthermore, this system can be installed quickly with minimum technical expertise.

COMPACT LOW IMPEDANCE SANDWICH BUS TRACKING - TECHNICAL FEATURES

Insulated Sandwich Bus Trunking is prefabricated, pre tested system in standard length and shapes available in Copper and Aluminium in ratings from 500A to 5000A suitable for system voltages up to 1000V. These can be used as rising mains and for horizontal power distribution. It consists of three phases and neutral conductor with option of pre decided specifically located Plug-in points. The basic construction and assembly features of these systems make them different from other systems. Busbars are insulated from each other by electrical insulating materials throughout it's length except at joint and Plug-in points, and are tightly packed in enclosures (bolted at regular intervals).

STANDARDS AND SPECIFICATIONS

- Equipment is designed for low voltage power distribution as per IEC 60439 (1 & 2) and IS 8623 (1 & 2)
- System is designed for rated operational and insulation voltage - 1000VAc, rated impulse withstand voltage-12kV and rated frequency of 50 Hz.
- SBC: Copper bustrunking available from 800A to 5000A (3ϕ, 4W) and SBA: Aluminium bustrunking is available from 500A to 3600A (3ϕ, 4W).
- Bustrunking enclosure is made of CRCA/G.I. sheet of 1.6 mm (16 SWG) with anti corrosive coating and finally epoxy polyster powder coating of flint grey shade (RAL-7032).
- Busbars in SBC type are made of 99.9% pure ETP grade Copper, whereas busbars in SBA type are made of 99.5% pure, 19501 grade aluminium. Busbars are with full round edges for easy insertion/withdrawal of Plug-in boxes and joint blocks.
- Earthing: Internal earth of G.I/Copper of cross-section equal to 50% of phase (option-1) and External earth of Cu/Al of desired section can be provided, duly riveted/bolted along with bustrunking enclosure (Option-2).
- As a standard practice, degree of protection is IP-54 for Plug-in type and IP-55 for feeder type bustrunking.
- Individual busbars are covered with multi layers of F-class flexible insulation material to achieve excellent mechanical and electrical strength even at high temperatures and humid condition. Continuous insulation has low water absorption and no possibility of pin holes and insulation cracking.
- System is designed for ambient temperatures of 40°C with temperature rise of 55°C on bustrunking as per standards.
- Three plug-in outlets on front side of 3 mtr section can be provided as standard, (5nos. max on special request).

ADVANTAGES

- Close proximity of busbars doesn't allow mutual inductance between phases yielding low reactance, low impedance, low voltage drop and low power loss.
- Specially designed housing bolted at every 250 mm act as a heat sink to yield improved thermal characteristic, high mechanical and short circuit strength.
- Due to compactness system can be installed in lesser space.
- System is maintenance free and adds elegance to the surrounding.
- Due to elimination of air there is no rise of chimney effect, so no fire barriers are required.
- Automatic polarity is maintained during installation.
- System can be mounted edgewise OR flatwise, horizontally or vertically in any direction with all kinds of bends and tees etc.
- Flexible and safe distribution system leads to easy and fast installation. System is completely re-usable.

- Any section of bustrunking can be removed without disturbing adjacent sections.
- Joint assembly can be removed/installed at any time to isolate/join two sections of bustrunking in installed condition.
- Disc spring washer are used in Uniblock joint to uniformly distribute pressure. The disc spring washers accomodates the thermal expansion of the busbars and housing at joint area.
- Plug-in boxes with MCCB/SFU's/Fuse holders or load break switches can be provided with door interlocking and interlocking with bustrunking to ensure "Plug-in" and "Plug-out" possible only in 'OFF' condition.
- Extra safe cable connection in plug-in boxes without additional cable support.
- Plug-in boxes can be easily mounted, ensuring 100% automatic polarity.
- 4 Pole isolator is provided in Plug-in boxes upto 125A for extra safe connection on live bustrunking. All plug-in boxes are compatible with all ratings of bustrunking.
- Safe, easy and quick plug-in/plug-out is possible on live bustrunking. Earth contact of Plug-in boxes with bustrunking makes before phase and neutral and is last to break when removed.
- Each Plug-in box has three gland plates to connect cables from any three direction after providing cable glands.

OTHER COMPONENTS

1. **Reducer.** These are required to connect two dissimilar rating/type of bustrunking. Reducer may be designed with switching or isolating device.

2. **Sectional Isolator Unit.** These are required to isolate the bustrunking run in between, for various reasons. Section Isolator Unit can be fitted with Load Break Switches/SFU's/MCCB's.

3. **End Cover.** These are provided to close the open end of Rising main/bustrunking at the end and it provides necessary IP level.

4. **Vertical Support.** One set of Vertical Support is generally provided per floor per rising main along with rigid or spring hanger (as applicable) when the floor height is more than 3.5 mtrs to avoid horizontal swing in bustrunking sections.

5. **Wall/Floor Flange.** These are plates designed to cover the cut-out made for passing bustrunking through walls or floor. WALL/FLOOR flanges are required to be fitted to the both sides of wall or floor. When using the flange together with floor support in case of rising mains. These are placed between the floor and base channel.

6. **End Feed Box (Direct).** To feed bustrunking through cables, Direct End Feed Unit (EFU) is available with sufficient space for direct connection through lugs and bolts. MCCB, SFU, Isolators and Fuse Holders etc. can be fitted in End Feed Unit as per specific requirement. 375 mm length of bustrunking is integrally fitted (measured and charged with bustrunking) along with End Feed Unit as standard practice so that joint between End Feed Unit and bustrunking is exactly same as of two normal bustrunking lengths. Undrilled cable gland plate is provided for multiple cable feeding option. End Feed unit can be made LHS or RHS type as per site requirement.

7. **Flanged End Box (Adaptor Box).** Flanged End Box is used to accomodate Flange End and connect it to Panel or Transformer through flexible connections. It differs from End Feed Unit since it does not have any integral bustrunking length.

Flanged End Box may be provided with necessary busbar arrangement for phase matching of bustrunking with equipment and usually contains openings/window for busbar accessibility.

8. **Expansion Unit.** It is usually recommended to be installed after at every uninterrupted run of 50 mtrs to accomodate for composite expansion of complete bustrunking run. Expansion duct

is set by fixing bolts to prevent duct expansion during transit and installation. After complete installation, the fixing bolts are removed to allow thermal expansion of bustrunking at full load.

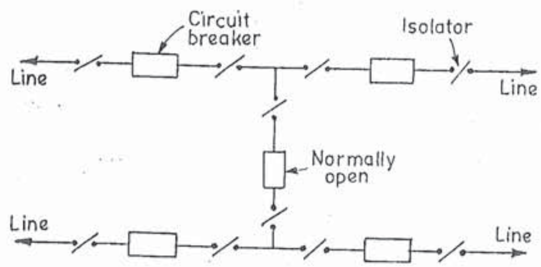
9. **Fixed Tap-off Provision (500-800A).** It is specially designed Tap-Off Point along with Tap-Off Box arrangement provided on main bustrunking as per the requirement ready to use MCCB/SFU etc.

TYPICAL APPLICATIONS

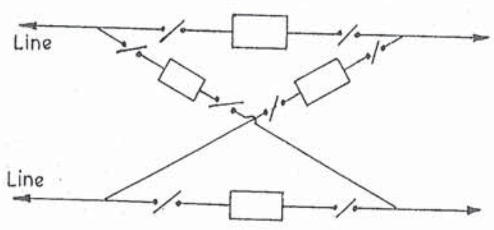
— Typical applications mainly includes Rising Mains, Horizontal Power Distribution, Transmission of power from Transformer to Switchgear, Generator to Switchgear & Switchgear to Switchgear as shown below :

17.10. SWITCHING SUB-STATIONS

There are several sub-stations between generating stations and final load points. They generally comprise step-down transformers and switchgear. In case no transformer is involved, the sub-station is called switching station (Fig. 17.22).



(a) With five breakers.

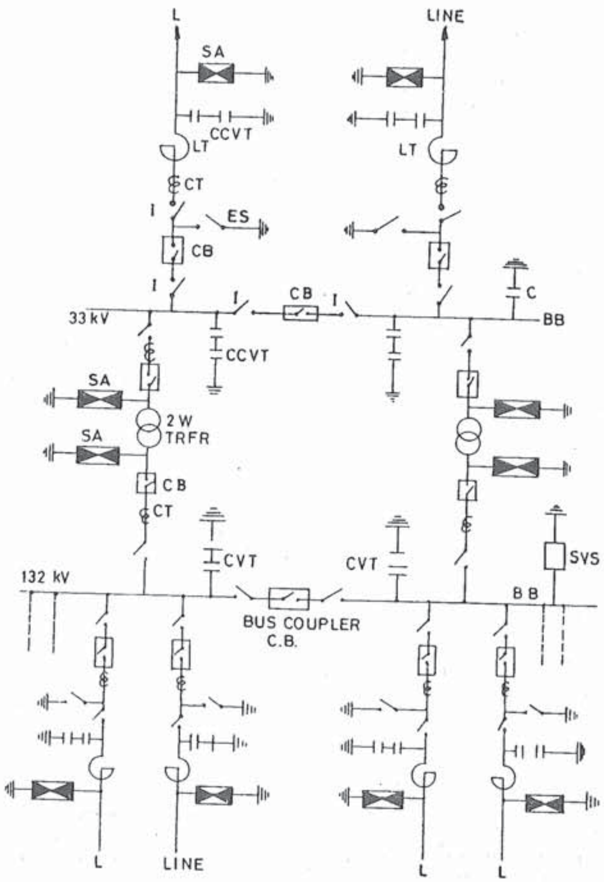


(b) With four breakers.

Fig. 17.22. Intermediate switching station with two incoming lines and two outgoing lines.

17.11. LAYOUT THE SWITCHYARD EQUIPMENT

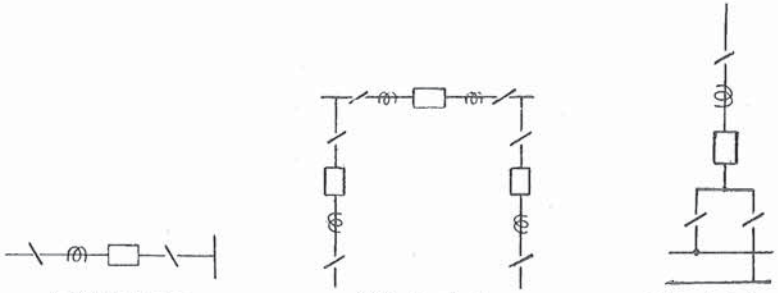
Fig. 17.23 gives the layout of switchyard equipment of a receiving station having two incoming lines and four outgoing lines. In this figure CT's and PT's are not shown. There can be several possible arrangements. The figure shows a single bus-bar arrangement [Refer Fig. 17.7 (b) for a typical side view].



L — Line
BB — Busbar
LT — Line trap
ES — Earthing switch
SA — Surge arrester
CCVT — Coupling Capacitor and Voltage Transformer.
3W — Three-Winding Transformer CVT — Capacitor Voltage Transformer
CB — Circuit-breaker
I — Isolator
CT — Current transformer
VT — Voltage transformer

Fig. 17.23. Single line diagram of a substation with single-busbar scheme.

17.12. LOCATION OF CURRENT TRANSFORMERS



(a) Single bus-bar arrangement. (b) Sectionalised single bus. (c) Duplicate bus.

Fig. 17.24. Location of CT's.

17.13. TYPICAL SUBSTATION IN DISTRIBUTION SYSTEM

In 11 kV distribution system, the cost of elaborate protection may not be justified for protecting transformers upto about 500 kVA. The sub-stations are generally unattended. In such cases H.V. Fuses such as drop-out fuses is the only protection provided on h.v. side. Hence the scheme for such sub-stations is very simple (Fig. 17.25). The fuses should be coordinated.

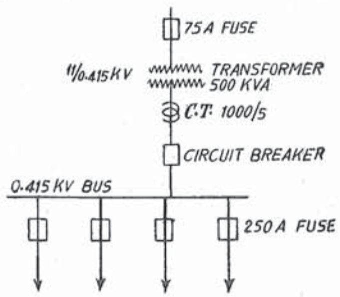


Fig. 17.25

17.14. SWITCHGEAR FOR A MEDIUM SIZE INDUSTRIAL WORKS

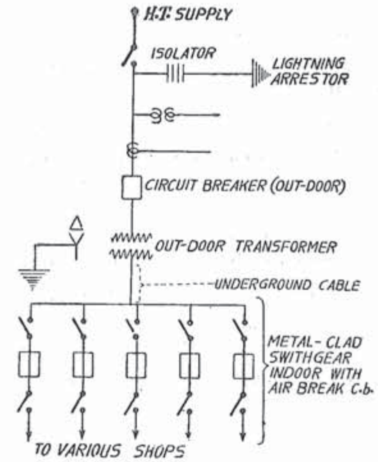
The switchgear in the sub-station of local points, such as industrial works, railway track-side sub-station, cinema houses, large buildings, foundries, etc. come in a variety of forms. Their requirements vary depending upon fault levels, kVA rating, voltage rating and other local requirements. In general the sub-station comprise the following :

— incoming line section — transformer section
— secondary switching section.

Incoming line section may comprise outdoor circuit-breaker or drop-out fuse, or it may comprise metal-clad switchgear. Draw-out type switchgear may be used for indoor installation. The secondary switching section can have one of the following forms :

— Draw out type switchgear with air circuit-breakers or vacuum or SF_6 C.B.
— Stationary moulded case or miniature circuit-breakers.
— Motor control centres.

Fig. 17.26 illustrates two typical schemes. Recently, SF_6 GIS has been introduced for 11 kV and 33 kV substations.



(a)

Fig. 17.26. Typical switchgear arrangement for medium size factory, incoming sub-station.

17.15. BUS-BARS

The 'Buses' concerned with switchgear do not have any wheels, not do they transport people. However, they all called buses, perhaps due to their commonness with omnibuses that they do have conductors and do transport electric current. Earlier, the conductors to which several local feeders or sources are connected were called Buses. Now the conductors carrying heavy currents are also called Buses. The standard definitions are given below :

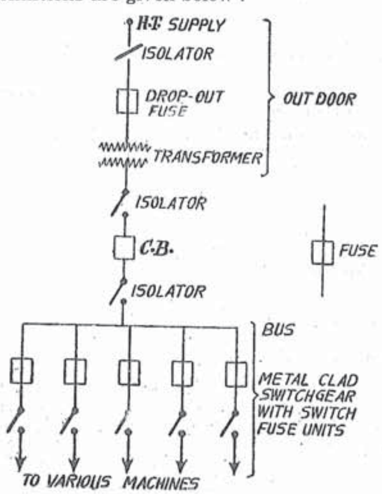


Fig. 17.27. Typical switchgear arrangements for medium size factory, incoming sub-station.

17.16. SOME TERMS AND DEFINITIONS

(a) *Bus-bars.* Conductors to which a number of circuits are connected.

(b) *Bus-bar connection.* The conductors that form the electrical connection between the bus-bars and individual piece of apparatus.

(c) *Open bus-bars.* The bus-bar which does not have protective cover.

(d) *Enclosed bus-bar.* The bus-bar that is contained in a duct or a cover of any material. The bus-bar enclosed in metal enclosures are called metal enclosed bus-bars. The enclosures are either of aluminium or sheet-steel.

(e) *Outdoor bus-bars.* An open or metal enclosed bus-bars designed for installation under open sky. Outdoor busbars are supported on glazzed porcelain insulators.

(f) *Indoor bus-bars.* The bus-bars designed for indoor use.

(g) *Compound immersed bus-bars.* Enclosed bus-bars immersed in liquid or semi-solid insulating materials.

(h) *Oil immersed bus-bars.* (i) *Solid-insulated bus-bars*

(j) *Compressed gas insulated bus-bars.* Bus-bars enclosed in enclosures filled with gas at a pressure above atmospheric pressure.

(k) **Ratings**

(i) *Rated current (Normal Current Rating).* The rms value of current which the bus-bars can carry continuously with temperature rise within specified limits. The standard values are the following.

200, 400, 600, 800, 1200, 1600, 2000, 2400, 3000 Amperes.

(ii) *Rated voltages.* The rms values of voltage, between lines for which the bus-bars are intended. Standard values are the following (in kV):

0.415, 0.6, **3.3, 6.6, 11,** 15, **22, 33,** 110, **132, 220, 400,** 500, 765 kVrms.

Note : The preferred voltages are printed in bold print.

(iii) *Rated frequency.* usually 50 Hz. (60 Hz. in USA).

(iv) *Rated short-time current.* This corresponds to the shortime current rating of circuit-breakers/switches/isolators. It is defined as the rms value of the circuit which the bus-bar can carry, with temperature rise within specified limits; for a specified duration.

The specified limits are :

Ambient temp. average	: 35°C
Ambient temp. peak (1 hr.)	: 40°C
Temp. rise permitted	: 40°C
Short time current duration	: 1 sec. or 3 sec.

17.17. MATERIALS FOR BUS-BARS

Copper and aluminium are used for bus-bars. Copper being scarce and costly, aluminium is being increasingly used for bus-bars. The material used for bus-bars should have low resistivity, higher softening temperature, good mechanical properties and low cost. During 1960's the need for substituting the copper with aluminium became very urgent, particularly in countries like India who import copper. Now aluminium is being increasingly used for various switchgear applications.

Table 17.2. Properties of Pure Aluminium and Copper*

	Property	*Units*	*Copper*	*Aluminium*
1.	Electrical resistivity at 20°C	$\frac{\text{ohm. mm}^2}{\text{m}}$	0.017241	0.02828
2.	Temp. Coefficient of resistivity	$°C^{-1}$	0.00411	0.00403
3.	App. softening temperature	°C	200	180
4.	Thermal conductivity	$\frac{\text{Cal}}{\text{cm. sec. C°}}$	0.923	0.503
5.	Melting point	°C	1083	657
6.	Density at 20°C	g/cm^3	8.94	2.703

Copper. The electrical and mechanical properties of copper are influenced by impurities and manufacturing process. The impurities increase the resistivity but are sometimes necessary to get desired properties. In many cases, where extreme mechanical properties are not desired, 'high conductivity electrolytic tough pitch copper' is used. 'Tough pitch' indicates that the oxygen contents are controlled within close limits. The conductivity of tough pitch copper with oxygen content of about 0.02 to 0.04 per cent is about 100 per cent I.A.C.S. (International Annealed Copper Standard). Electrolytic copper should have minimum 99.9 per cent copper by weight.

Copper is used in the form of rods, strips, various sections like angle, channel etc., the latter being preferred for high values of currents.

Copper starts becoming soft at 200°C. Hence the permissible maximum temperature short-circuit condition is 200°C. Copper oxides quickly at temperatures above 85°C. Hence, for normal currents, the maximum temperature permissible is 85°C.

At present, the trend is toward using copper where space required is minimum and quantity is not large. For large requirement of quantity, aluminium being preferred, as its use is economically justified.

Aluminium. Aluminium is used for bus-bars of indoor and outdoor switchgear.** Aluminium is also used for enclosures and conductors of Isolated Phase Bus Systems in generating stations. Aluminium is now being used for primary tubes of current transformers, current carrying blades of isolators, conductors in SF_6 switchgear, etc. Aluminium castings (5 to 12% silicon) are used in assembly bus-bar. Aluminium castings are used in the framework of circuit-breakers where weight should be minimum. Aluminium is used in form of strips (thickness above 2.5 mm), rectangular bars (width above 10 mm), round bars (diameter above 10 mm), for bus-bars applications. For heavy currents, channels and angle sections are used. While using aluminium for bus-bars, the difficulties arise due to the following aspects :

1. Higher resistivity, hence associated problems of temperature rise.
2. Lower tensile strength than copper.
3. Lower thermal conductivity than copper.
4. Higher coefficient of linear expansion than copper.
5. Higher joint resistance and associated problems about jointing.
6. Special welding techniques are necessary.

The following procedure is satisfactory for making bolted or clamped joints in bus-bar and connections of switchgear (between aluminium and aluminium) :

1. Clear the bus-bar joint surface with rough emery.
2. Apply an oxide inhibiting grease on the prepared joint surface immediately. The grease*** is applied to prevent the exposure of prepared surface to air and moisture.

* Properties vary with alloying and manufacturing process. The figures given in the table are for reference alone.

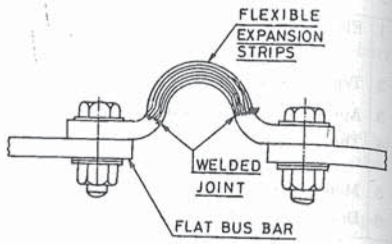
** Aluminium for bus-bars : EIE – M, IS 5082, E91E – WP, IS 5082.

*** Esso Multipurpose Grease H Caltex 2. Indian Oil Multipurpose Grease.

3. Make joint as early as possible, (within about 2 hours) by bolting or clamping.

Aluminium to copper joints present a problem that the resistance of joint increases with time, due to bimetallic corrosion. While making such joints copper bus-bar areas are tin-plated or silver plated. The aluminium bas-bar areas are prepared as described above. Then the joint is made.

Another method is to use bimetal strips with aluminium on one side and copper on the other. These plates are used for making A1-Cu joint. Such joints are used in Europe for outdoor constructions. The joints resistance after four days should be less than about 20 micro-ohms for busbars of indoor switchgear. The pressure between contacts should be adequate.



(Thin-aluminium strips welded to the bus-section.)
Fig. 17.28. Flexible joints.

The desired length of bus-bars is obtained by connecting required number of sections of standard length [2 to 6 metres]. The joints between neighbouring bus-bars sections are made either by welding or bolting or clamping.

Expansion joints should be provided when the length of bus-bars become significant. Flexible joints are necessary when the bus-bars terminate in switchgear or transformer terminals.

17.18. BUS-BAR DESIGN

(a) TYPES OF CONSTRUCTIONS

— Indoor or Outdoor
— Open or Enclosed
— Rigid Tubular
— Flexible ACSR
— Non-segregated metal enclosed bus ducts.
— Segregated metal enclosed bus ducts.
— Isolated phased bus ducts of continuous type or discontinuous types.

Enclosed bus-bars. The bus-bars are rigid conductors of aluminium or copper supported on support insulators. The assembly is supported on fabricated rolled steel sections and is enclosed by sheet steel or aluminium sheets.

Non-segregated Bus Ducts. The conductors of the three-phases are in a common metal enclosures with metal insulator barriers between them (Fig. 17.20).

Isolated Phase Bus Systems. The conductors of each phase is enclosed in a separated metal enclosures (Fig. 17.21 *a*, *b*).

Isolated Phase Bus System of Discontinuous Type. The Isolated Phase Bus System in which the enclosures are made up of units of standard length are jointed to get desired total length. The neighbouring enclosures are insulated from each other and are electrically discontinuous.

Isolated Phase Bus System or Continuous Type. The enclosures are electrically continuous throughout their length. The three enclosures are connected in star and earthed at each end. The enclosures are insulated from the terminal apparatus.

(b) TEST ON BUS-BARS

1. *Temperature Rise Test (Heat Run).* Rated current is passed and final steady temperature rise is noted. [Refer Sec. 10.22]

Temperature rise permitted : 35°C/40°C
Ambient Temperature : 40°C Maximum
: 35°C Average.

2. *Rated short time current test.* This test is described in chapter 'Short-Circuit Testing of Circuit-Breakers'. [Ref. Sec. 11.6.]

3. *Rated Momentary Current Test.* This test verifies whether the busbars withstand the rated peak value of the first major cycle on short circuit. [Refer : Making Current, Sec. 3.19.5]

4. *High Voltage Test.* Power frequency voltage test; Impulse voltage withstand test, if necessary. [Refer Sec. 12.6]

(c) DESIGN CONSIDERATIONS

(*i*) *Materials.* Copper was used for electrical busbars and is now almost totally replaced by aluminium. Aluminium is now used for busbars in generating stations, sub-stations, transmission and distribution systems, indoor and outdoor switchgear. The aluminium used for bus-bars should have high conductivity, good mechanical properties, high softening temperature, etc. IS : 5082–1992. Wrought Aluminium and Aluminium Alloys for Electrical Purposes : Bars, Rods, Tubes and Sections specifies the requirements of aluminium for busbars.

(*ii*) **Forms.** The structural forms of bus-bars are generally selected on the basis of mechanical considerations of strength, supporting arrangement. When the spacing between bus-bars is small mechanical forces become significant. Typical bus-bar shapes include :

— Single flat rectangular sections
— Angles, channels
— Hollow tubelar sections
— Multiple rectangular sections
— Double channels
— Hollow rectangular sections.

(*iii*) **Current carrying capacity.** The various aluminium companies give regular tables of cross-sections and their current carrying capacities based on ambient temperature (40°C or 50°C) and temperature rise (35°C average, 40°C maximum). for various conditions and arrangements. The current carrying capacity varies with arrangement, cross-section, proximity, type of enclosure, ambient temperature, etc.

For preliminary calculations, Table 17.3 gives reference values.

Table 17.3
Approximate Current Ratings of Aluminium Bus-bars

Shape of Busbar : Rectangular, solid
Arrangement : With larger surface vertical
Material : E91E-WP as per I.S. 5082-1969
Ambient Temp. : 35°C over ambient.
Condition : Still unconfined air without enclosures.

	50 Hz, A.C. Current Rating, Amperes			
(mm)	*Single Bar (per phase)*	*Two Bars (Per Phase)*	*Three Bars (Per Phase)*	*Four Bars (Per Phase)*
25 × 6	350	700	950	1000
50 × 6	675	1300	1700	1925
75 × 6	950	1750	2300	2600
100 × 6	1225	2150	2800	3200
125 × 6	1500	2500	3200	3700
50 × 10	825	1500	1950	2250
75 × 10	1180	2050	2650	3000
100 × 10	1500	2475	3150	3550
125 × 10	1850	2925	3600	4200
150 × 10	2100	3350	4000	4600
200 × 10	2750	4100	4900	5700
75 × 12	1350	2250	2800	3200
100 × 12	1750	2700	3350	3900
125 × 12	2100	3100	3900	4500
150 × 12	2400	2500	4450	5100
200 × 12	3050	4500	5300	6100
250 × 12	4 000	5010	6000	6800

Joints should be with oxide-inhibiting grease.

Derating Factors		*Derating Factor*
(*a*) Temp. rise of 40°C,	ambient 35°C	: 0.88
(*b*) Temp. rise of 35°C,	ambient 30°C	: 0.76
(*c*) Enclosure :	Outdoor,	: 85 to 0.95
	Indoor, Well-ventilated	: 0.6 to 0.8
	Indoor, poorly ventilated	: 0.5 to 0.6
(*d*) Rating factor for non-metallic back matt paint		: 1.2

A current density of 750 A/in^2 or 116 A/cm^2 can be considered as very safe choice in selecting cross-section for unenclosed bus-bars of copper.*

Table 17.4. A Appropriate cross-sections for various current ratings Single Bare Conductors in open air*

Continuous A.C. Currents ratings Amp. (r.m.s.)	*Cross-sectional Area*	
	Copper mm^2	*Aluminium mm^2*
100	20	25
150	34	40
200	41	56
225	47	63
250	53	71
300	68	122
350	79	145
400	94	145
450	115	165
500	125	187

(*iv*) **Temperature Rise During Short Circuit Conditions.** At temperatures about 160°C, aluminium becomes soft and loses its mechanical strength. This sets a limits on permissible temperature rise during short-circuit conditions. The calculations of temperature rise are complicated. Tables and graphs are generally available for difference bus-bars for the purpose of calculations of temperature rise. For preliminary calculations, the following expression can be used :

$$T = \left(\frac{I}{A}\right)^2 (1 + \alpha\theta) \cdot 10^{-2}$$

T = Temperature rise/sec. during short circuit condition (C)

C = 0.54 for copper 1.17 for aluminium

I = R.M.S. value of short circuit current

A = Cross–sectional area, mm^2

α = Temperature coefficient of resistivity at 20°C

0.00393 for copper

0.00403 for aluminium alloy (EIE-M)

0.00364 for aluminium alloy E91E-WP

* The figures are only for single rectangular conductors for more conductors in parallel, the current does not increase proportionately. For actual selection refer tables supplied by manufacturers. Refer : DIN 43670. The recommended current density for copper busbars is 165 A/cm^2 and for aluminium conductor is 118 A/cm^2 [VDE 4014/16].

θ = Temperature at the instant of short circuit, *i.e.*, ambient plus permissible temperature rise.

(*v*) **Oscillations.** The periodic variations in force results in oscillations in conductors and insulators. The nature of such oscillations at the time of short-circuit depend on characteristic frequency of the conductor system and operating frequency of circuit. Prolonged oscillations can cause of failure of structural parts by mechanical fatigue.

(*vi*) **Bending Load on Insulators.** As the conductors are supported on insulators. Insulators experience bending forces, due to the forces on conductors. The force is given by equation below. The cantilever strength of insulators should be more than F.

(*vii*) **Insulation Requirements of Busbars.** Insulation is required between phases and between phase and earth. Therefore, bus-bars are supported on insulators and necessary clearances are maintained between phases, and between phase and earth. For indoor metal clad switchgear upto 11kV, now, synthetic resin-bonded or cast parts are used for insulator supports. Formerly, porcelain, varnished papers, resin-bonded parts, densified resin bonded wood parts were more popular. The insulator supports for outdoor busbars are invariably, of glazed porcelain. Electrical clearances, line to ground (earth) and line to line, must be maintained. These clearances are more for outdoor busbar systems. Outdoor stations have a lattice steel structure for supporting buses, isolators, jumpers, etc. Outdoor buses are generally copper/aluminium bars, rods, pipes or thin walled tubing. Thin walled tubing is favoured because of higher stiffness. The clearances are more, to avoid faults due to birds. Simple ACSR standed conductor pieces are kept inside the tubes to prevent vibrations of tubular bus.

Table 17.5
Reference Values of Minimum Creepage Distances for Porcelain Insulators for Outdoor use

Highest system Voltage r.m.s	*Creepage Distance*	
	*Moderately polluted Atmosphere**	*Heavily Polluted Atmosphere***
kV	mm	mm
3.7	75	130
7.2	130	230
12	230	320
24	430	560
36	580	840
72	1100	1700
132	1850	2800
145	2250	3400
245	3800	5600
420	6480	9660

(*viii*) **Spacing of Support Insulators.** The spacing of support insulators is determined on the basis of the force on a span length of busbar under short circuit conditions.

$$F = 2.04\, i_s^2 \times \frac{L}{r}\, 10^{-2} \text{ kgf}$$

i_s = peak momentary short circuit current (assymetrical), kA

L = span between insulator supports, cm

r = spacing between neighbouring conductors in three phase bus system, cm.

Distance r is determined by clearance considerations and by shapes of conductors selected. By increasing L, the value of F is increased necessitating insulators of high cantilever strength. The cantilever strength of insulators is first noted from the catalogue of insulators; on the basis of which the span L is calculated.

(*ix*) **Clearances between Phases and between Phase and Earth.** The minimum clearances are specified in standards Table 17.6 give reference values of clearances for various conditions.

(*x*) **Creepage distance.** The shortest distance along the contour along the external surface of insulators, from earth to the conductor [Refer Table 17.5]. The porcelain insulators are exclusively used for outdoor bus supports. They may be pin type, post-type or suspension type. For voltages upto 36 kV, pin-type of single post type insulator are used. Above this level, multiple post-type insulators (stack) are used for supporting air-insulated bus-bars above ground support, or the bus-bars are supported on suspension string insulators. Insulator surface is contaminated by soot, dust, salt layer near sea-shores, deposits of chemicals in industrial areas, etc. The insulators should be washed regularly as often as thrice in a year. In sea-shore areas, the station buses are over insulated, *e.g.* 24 kV insulators may be used for 12 kV buses.

(*xi*) **Ground Clearance.** Distance between the highest earthed part of the equipment and the ground. This should be minimum 2.75 metres (Ref. Fig. 12.1 sec 12.1). This is for safety of personnel moving in the sub-station.

Table 17.6. Indoor Bus-bars : Open or Enclosed Clearances for Voltages upto 33 kV

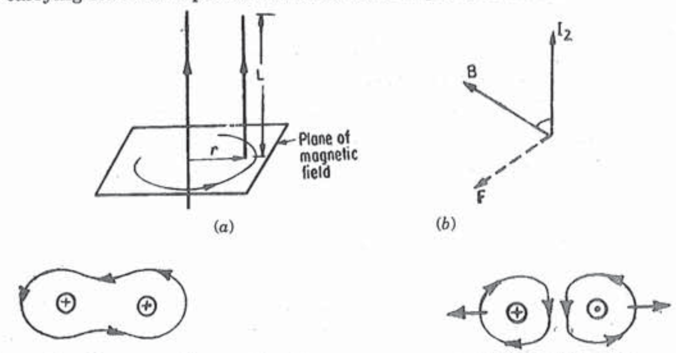
Rated Voltage, rms kV	*Minimum Clearance to Earth*		*Maximum Clearance between Phases*	
	Open mm	*Enclosed mm*	*Open mm*	*Enclosed mm*
0.415	19	16	26	19
0.5	26	19	12	19
3.3	51	51	51	51
11	77	77	127	127
15	102	102	165	156
22	240	140	242	242
33	223	223	356	356

Table 17.7. Clearances for Open Outdoor Bus-bars

Rated Voltage, rms kV (rms)	*Minimum Clearance to Earth*	*Maximum Clearance between Phases*
	mm	*mm*
6.6	140	178
11	178	229
15	216	267
22	279	330
23	381	431
66	685	786
110	1068	1219
132	1270	1473
220	2082	2361

17.19. ELECTRODYNAMIC FORCES ON BUS-BARS DURING SHORT-CIRCUITS

Current carrying conductors placed near each other experience electro-mechanical force.



(c) Force of attraction when current in same direction. (b) Force of repulsion.

Fig. 17.29.

The dynamic force occurs at the peak of first major loop, on short circuit. This force is given by the expression :

$$F = 2.04\, i_s^2 \frac{L}{r} \times 10^{-2} \text{ kgf}$$

where F = force between conductors

i_s = peak value of current, kA

L = length of conductors, cm

r = separation between conductors, cm

[1 newton = 0.101972 kgf].

From this force, required cantilever strength of the support insulator or span is determined.

Perpendicular conductors tend to straighten-out due to electromagnetic forces.

Bus-bar Design

The early sub-station were generally with *flexible bus* design. A flexible bus consists of flexible ACSR (Aluminium cable steel reinforced) or All-aluminium alloy stranded conductors supported by strain insulators from each end. The flexible bus is held at higher level above the various sub-station equipment. The connections between the flexible bus and the terminals of sub-station equipment are by flexible conductors held in vertical or inclined plane.

Rigid bus-bars are easy to maintain. They are at lower height. Connections to sub-station equipment are easy. Aluminium tubes are preferred for rigid bus.

A sub-station usually has a combination of Rigid Bus-bar and Flexible Bus-bars. ACSR conductors are preferred for flexible bus.

Configuration of Clamps and Connectors. Typical configurations of clamps and connectors used in sub-stations include the following:

1. *Tee-Connector* for connecting ACSR flexible conductor to ACSR tap conductor.
2. *Tee-Connector* for connecting with ACSR conductor to aluminium tubular bus.
3. *Parallel-Groove Connectors* for connecting two ACSR flexible conductors in parallel.
4. *Fixed type bus Post Clamps* for supporting tubular bus on post insulators.

5. *Sliding type Bus Post Clamp* for supporting tubular conductors on post insulators.

6. *Expansive type flexible Bus Post Clamp* for supporting and joining two busbars lengths on to a post insulator.

7. *Connector* between ACSR conductor and equipment terminal.

8. Connector between tubular bus section and equipment terminal

9. Spacers double-ACRS conductors and quadruple ACSR conductors.

10. Hardware for string insulator assembly.

Reference Data for Clamps and Connectors and Hardware Fittings

Conductor tension	1000 kg conductor
Wind load	560 kg
Forces due to short-circuit	1600 kg

Bus-bar Design

The bus-bars are designed to carry certain normal current continuously. The cross-section of conductors is designed on the basis of rated normal current and permissible temperature rise. The value of cross-section so obtained is verified for temperature rise under short time short-circuit current.

The bus-bar conductors are supported on *post insulators* or *strain insulators.* The insulators experience electrodynamic forces during short circuit currents. These forces are maximum at the instant of peak of first major current loop. These forces produce bending moment on separate insulators. The spacing of support insulators is decided on the basis of bending moment per metre.

The factors to be considered for bus-bar design are as follows :

1. Material
2. Cross-section of conductors.
3. Temperature rise during continuous normal current.
4. Temperature rise during short circuit current of 1 second or 3 seconds
5. Design of insulator-creepage distance and clearance.
6. Distance between phase conductors.
7. Force on insulators during peak short circuit current.
8. Span of insulator supports.
9. Enclosure design.

Example. *Design cross-section of an enclosed aluminium conductor for normal current rating of 1000 A, rms, 50 Hz and ambient temperature 30°C permissible temperature rise 35°C.*

Ans.

Derating Factor for Ambient Temp.	$= 0.76$
Derating Factor for Enclosure	$= 0.5$
Operating Factor for Matt-black paint	$= 1.2$
Total Derating factor	$= 0.76 \times 0.5 \times 1.2$
	$= 0.46$

Current rating 1000 A continuous aluminium conductor is selected cross-section to correspond to $\frac{1000}{0.46} = 2175$ A.

From the table :

Use one 150×10 mm Flat (2100 A)
Or one 125×12 mm Flat (2100 A)

Selection of support insulator. The insulators are selected by considering mechanical bending load occurring at that instant of peak short circuit current. During short circuit in the system, short circuit current flows through the bus-bars. The insulator supporting the busbars experience a bending force. The insulators should have enough cantilever strength to withstand the dynamic force occurring during short circuit.

Example. *The bus-bars are having phase-to-phase spacing of 24 cm. Their short circuit current rating is 25 kA$_{rms}$. Determine the minimum force on conductors during short circuit conditions.*

$$i_s = I_{rms}\sqrt{2} \times 1.8$$
$$= 2.55\, I_{rms} \quad \text{(Factor 1.8 is for assymetry).}$$
$$I_{sc} = 25 \text{ kA}_{rms}$$
$$i_s = \text{peak short circuit current}$$
$$= 2.55 \times 25 \text{ kA}$$
$$i_s^2 = (2.55)^2 \times 25^2$$
$$= 6.5 \times 6.25 = 4050 \text{ kA}$$
$$F = 2.04 \times i_s^2 \times \frac{L}{r}\, 10^{-5} \text{ kgf}$$
$$= 2.04 \times i_s^2\, \frac{1}{0.24} \times 10^{-4}$$
$$= \frac{2.04 \times 40.50}{0.24} = \quad 346 \text{ kgf per metre.}$$

Force on bus-bars per metre length = 346 kgf.

Cantilever load on insulator is given by $F \times H$ kg-metre

where F = Force, kgf per span length
H = Height of insulator, metre

Assume insulator height = 0.13 metre

Cantilever strength of insulator $= S_k$

Let S_k = 500 kg–metre from catalogue of insulators

$F \times H$ = cantilever load per metre run

$F \times H \times L$ = cantilever load per span length of insulator

$$F \times H \times L = \frac{S_k}{\text{Factor of safety}}$$

where F = Force on bus-bars per metre run
H = Height of insulator, metre
L = Span of insulators
S_k = Cantilever strength of insulator, kg–m

Factor of safety = 4

Substituting in given example,

$$346 \times 0.13 \times L = \frac{500}{4}$$

$$\text{Span of insulator } = \frac{500}{4} \times 346 \times 0.13 = 2.9 \text{ metres}$$

Let the span of insulators = 2.5 m.

17.20. IMPORTANT TECHNO-ECONOMIC CONSIDERATION FOR CONSTRUCTION OF SUB-STATIONS/SWITCHYARDS

A large number of Sub-stations/Switchyards, to meet the requirements of increasing demand for transmission and distribution networks, are being constructed involving huge amount of expenditure. In this era of competition, the aspect of exercising maximum possible economy while making no compromise on the operational requirements, safety & reliability aspects and the technical parameters should be known. Some of such techno-economic issues have been briefly described below :

17.20.1. Activities in Construction of Sub-station

Planning of sub-station starts with a system study. If there is a pocket of low voltage or a new load center is due to develop in the area or is already developed, the construction of sub-station is justified. The size of the sub-station to be constructed is based on power requirements as well as other environmental factors. The location of sub-station with regard to system improvement, vicinity to the load to be catered and configuration of incoming and outgoing line has to be properly envisaged.

Acquisition of land is yet another activity which demands good amount of exercise, as total cost depends much upon the selection of site. The amount of civil work within the sub-station and length of transmission network for the connection to the new sub-station depends upon the location of land. The location of land has also to be viewed from the angle of accessibility.

The design and layout is the next activity. Depending upon the nature of piece of land available, the layout can be made for different levels of voltage in the sub-station, incoming lines and outgoing lines. This exercise needs to be done on scale and also has to be in line with the statutory electrical requirement in vogue.

The civil design will depend upon the soil strata available at the site selected. There may be other parameters, which include local factors like high wind velocity, high temperature or low temperature etc. The structural design of gantry and equipment support will be the next item on agenda. This particular activity will include design and fabrication of structures. This has to be in line with the latest standard practice in the field as well as the experience gained from the past construction and the actual site requirement for accommodating equipments in the available space.

The selection of parameters of electrical equipments such as transformer, breaker, CT, PT, LA, PI, Isolator, earthing system has have to be meticulously done in accordance with the system requirement, protection and operational needs.

The procurement of equipments, which are specified, is one of the major activities as it involves drafting of specifications, tenderization, scrutiny of tenders, awarding of contract, execution of contract and receipt of materials. This activity is capital-intensive and has to be carefully planned out.

The actual civil work starts immediately after the land acquisition. The cutting and filling work is the first and foremost work to be done which is followed by protection wall, fencing, gates, watch and ward tower etc. The work of cable trench, control room, switchyard structure foundation follows the land leveling work and other important civil work. The roads, staff quarters, water supply and drainage system is also a part of the civil work.

The erection of gantry structures and equipment support structures is yet another important work. This is followed by equipment erection in the open switchyard and in the control room.

The commissioning of bays and commissioning of the sub-station is yet another activity. However, the receipt of transformer, its storage and erection of the same on the plinth is an independent job. The testing and commissioning of the transformer is a part of commissioning activities.

The final stage of the sub-station activity is the grooming of the sub-station by providing horticulture, painting, landscaping, sing boards etc.

Statutory clearance for the design and construction of sub-station has to be obtained from time to time.

17.20.2. Cost Effectiveness

Each one of the activities enumerated above has to be properly weighed for cost effectiveness. The cost effectiveness does not man avoiding expenses on need-based items of work or equipments. The reliability and availability of the sub-station has to be properly evaluated before arriving on cost effectiveness in construction. Cost effectiveness surely means avoiding wasteful expenses on material, labour, storage, transport and capital interest by proper Planning & Resource Management.

The cost effectiveness will vary from site to site. For example, the cost of land in and around metropolitan towns will be extremely high, whereas the load center will be close to each other. Besides, in this region, density of load will also be heavy and therefore the design of sub-station in electrical, mechanical and civil terms will be together a different proposition compared to the sub-stations to be constructed in rural sector.

The cost effectiveness in procurement may depend upon the market situation prevailing with a particular reference to the supply and demand during the process of tenderization. The cost may also depend upon the techno-commercial terms and conditions provided in the specifications.

The cost effectiveness of civil work will be very much an important factor. The labour and civil construction inputs (cement, wood, sanitary work, piping, sand, gravel, steel etc.) will be a decisive factor in the cost effectiveness of civil works.

Electrical erection testing and commissioning activities will generally depend upon the voltage rating of the equipment and cost of labour prevailing in the region.

17.20.3. Ways and Means of Economizing

(*a*) **Land acquisition.** The cost of land will depend upon the vicinity or remoteness of the proposed sub-station with reference to metropolitan, big towns or cities. Since the system study indicates the construction of sub-station in a particular location, the choice of type of switchgear has to be based on the land cost.

When the sub-station is to be constructed in the metropolitan or in the densely populated urban area, the cost of land matters much. To create a new load center is of prime importance and connection of the same to the existing/new transmission network is a next important activity. Besides acquiring such land in densely populated area has a very high cost benefit ratio due to high density of load around the sub-station and low cost of maintenance of lines (as new sub-station is meant to cater very heavy load in a radius of few of Kms.)

Creating a sub-station and the load center away from metropolitan and densely populated urban area is a matter of choice. Here, the cost of land is of prime importance along with the amount of cutting and filling to be done in the soil as well as nature of soil. In this category, there may be various techno-economic considerations as follows.

The land may be cheaper, but may need cutting, filling and leveling, but soil quality may be good.

The land may be levelled one, but susceptible to water logging, accessability may be difficult.

The land may be absolutely good in every sense such as levelled one, no likelihood of inundation, good quality of soil etc., but this piece of land may be much away from the thoroughfares and towns/cities. This proposition will prove costly from the angle of manning the sub-station, taking equipments to site, carrying out construction activities and later on maintaining sub-station. However, this may prove to be better for making the lines in and out.

The land may be very cheap, but may involve hill cutting. This will be a costly proposition.

In the densely populated areas under civil authorities, there may be a compulsion to locate a S/S in the heart of the town. The cost of land and the EHV cabling has to be weighed against the revenue return, system improvement and the customer satisfaction.

(*b*) **Layout drawings.** Making a lay out is the next important job. Optimization of lay-out will lead to better utilization of the available space at least cost. The number of bays to be accommodated on H.V. side and L.V. side will depend upon the maximum rated capacity of the S/S in MVA. Since the power transfer capability of each transmission line is almost fixed it is possible to calculate the number of H.V. and L.V. base at the S/S plannings stage only. However following points are vital while optimizing the layout.

Type and configuration of the equipments to be used for each voltage class.

Available land piece and shape.

The switching scheme. Whether it is single bus, two bus or three bus system. In case of two bus whether it is a main and auxiliary or main I and main II, whether sectionalization is required.

The affordable placement of transformer. Whether incoming lines and transformers are in the same horizontal axis or the transformers are placed between two voltage levels. If the transformers are placed between two voltage levels whether they are placed adjacent to each other or away from each other.

The position of incoming and out going lines of different voltage class is the factor, which will affect the lay-out. The positions of lines will depend upon the environment of the S/S. To be precise whether the S/S is situated in urban, sub-urban, rural area or industrial belt.

The control room sizing will depend upon the number of panels to be housed, which in turn will depend upon the number of voltage levels and nature of the S/S.

(*c*) **The earth mat design.** The earth mat design is one of the important area which needs optimization. The following needs to be taken care of.

(*i*) The resistivity of the earth is one of the important parameter of the earth mat design. It should be ascertained whether it is possible to get lower resistivity by penetration in to the lower levels of the soil or whether it is possible to improve (reduce) the soil resistivity by artificial means. For economic design of earth mat precise values of earth resistivity and short circuit current should be available, Tentative figures, usually lead to higher costs.

(*ii*) The short time current rating, fault level, touch and step potentials, are the other parameters affecting the design. It should be found out how and where the most realistic parameters can be applied/worked out.

(*iii*) The cost of the earth mat also depends upon depth of burial of the earth mat and depth to which the electrodes require driving.

(*iv*) If it is possible to artificially increase the conductivity of the earth fault current through earth mat and the electrode (use of bentonite etc.) to that extent the optimization can be achieved.

(*v*) The size of earth mat material and electrode material can be optimized by making trial and error on the spacings. The step potential can be reduced by spreading metal or gravel in the switching area.

(*d*) **Civil Engineering works.** Civil engineering works are the main and time consuming activity in the construction of S/S. Besides it is one of the most variable item of activity in terms of cost. The civil works include construction of boundary walls, water supply arrangement (making a bore, sump, overhead tank, piping etc.), drainage system (affluent, storm water etc.), cable trenches, structure foundations, control room building, stores, office building, staff quarters, recreation facilities, roads, culverts, fire protection, service room, A/C plant housing, generator room (where required) etc. There are many parameters as discussed below, which if taken care can help in cost reduction :-

(*i*) The boundary wall construction using locally available material such as stone, fly-ash bricks etc. can lead to economy and good strength. In case of black cotton and other poor

types of soil if short piling is resorted to instead of deep excavation and stepped brick masonry, economy with high reliability can be achieved.

(*ii*) The water supply can be economically arranged by selecting proper location for the well, sump and the tank. The depth of the bore can be fixed by critically evaluating the water resource by means by hydrological tests.

(*iii*) The optimization and cost effectiveness of the drainage system can be achieved by choosing optimum location of the septic tanks and disposal of waste-water etc.

(*iv*) The cost of construction of the cable trenches can be minimized by preparing the cable schedules well in advance. The cable trenches can be categorized depending upon the maximum number of cables to be routed. The type of civil work (P.C.C., R.C.C., stone/brick masonry etc.) can be decided according to the type of soil/rock encountered at the site. The depth of the cable trench can be a decisive factor for selecting the structure of the cable trench.

(*v*) The foundations for gantry columns, equipment support structures, transformers and breakers can be economically constructed by critical evaluation of the forces acting on the equipments and structures (which are ultimately transferred to the foundation). Wherever possible, use of individual leg type footings for columns can bring in good economy. The under cut type of footings in the normal soil and soft rock/fissured rock can bring substantial economy with high reliability.

(*vi*) The architecture and design of control room building should be done very precisely for affording maximum flexibility as well as ease in control room operations at least cost. The space requirement considering the number of panels to be housed (including future expansions), office, store, conference room, toilet/bath, cable trench and cable entries, battery room, carrier room, computer room etc. should be assessed well in advance. The location of the control room should be so selected as to allow for future expantion. Wherever office building and store rooms are to be built away from the control room their locations and design should be done with an ascent on maximum floor space at minimum resource/cost. In seismic zone, extra care should be taken to provide framed structures approved by the concerned authorities.

(*vii*) Number and type of quarters to be constructed should be strictly in accordance to the staff set-up of the S/S. The location of the staff quarters should be such as to afford construction of minimum length of roads and convenient accessibility to the civic roads. The designs of quarters should be in accordance with the status wise space requirement with an ascent on good ventilation. If the S.S situated in seismic zone extra care should be taken to provide framed structures for staff quarters as per statutory requirements.

(*viii*) The other miscellaneous civil works such as recreation facilities, gardens etc. can be provided using minimum space and state of art horticulture and recreation equipments.

(*e*) **Switchyard structures.** The structural designs of gantry and equipment support structures should be based on realistic load requirements. The switching scheme should be as simple as possible. The statutory clearances should be kept to the requirement. The following points need be kept in view while optimizing the structure designs.

(*i*) The climatic conditions should not be considered excessive to what warrants as per the local situation and or meteorological data, since the wind pressure, rainfall, temperature, altitude, H.F.L. etc. governs the structural design.

(*ii*) The structures in the switchyard should be divided into various categories like beams, columns, equipment support etc. in accordance with the configuration. The division can also be in respect of their position in the switchyard. This includes structures in the line bays, bus bays, transformer bays etc. Again, the division can be made depending upon whether the structure is in the end position or the middle position. The structures with fly over and T configuration shall be designed with the loads in various directions and levels. With this type of exercise it will be possible to design structures in most economical manner.

(*iii*) The equipment support structures can be designed keeping in view the exact equipment dimensions, specified ground clearance and sectional clearance. The short circuit forces wherever required (Breaker, CT, PT, LA) should be accounted while finalizing these designs.

(*iv*) Cost of foundations for structures can be reduced considering the most probable loads on structures. The design of structures separately for each position in switchyard.

(*v*) The 220kV/400kV switchyard also have equipments like fire protection system, Air-conditioning plants, D.G. sets etc. The power transformers need protection from fire. There are alternative systems such as Fire Tender, mulsifyre system, Nitrogen bubble etc. The mulsifyre system needs many accessories and regular maintenance. Fire tender and nitrogen bubble are also effective systems. The transformer fire protection can also be arranged through fire tender using special foam meant to extinguish the fire. D.G. sets to be procured should be equivalent to the bare minimum emergency power required for s/s and control room, such as battery chargers, control room lighting, air-conditioning and fire protection gadgets.

(*vi*) In some of the 400 and 220kV sub-stations, air-conditioning system is provided for maintaining the temperature in the relay room. However it is observed that in some cases even control room and offices have been made air-conditioned by using central air-conditioning plant. This puts lot of financial strain on the sub-station in terms of construction and maintenance. It becomes mandatory to have a compressor room and cooling tower. Lot of water also is required to be arranged and water to be used needs to be of good quality. Besides, in case of any fault in the cooling plant the relay room is badly affected and in turn the operations are badly affected. If the relay rooms are designed in a compact manner, a special air cooling system which can maintain a temperature of the room from 22 to 24 degrees can save the situation. Even window air-conditioners can remedy the situation.

17.20.4. Construction activities

The economics of the s/s also depends upon the pre-planning of the construction activities. Time bound construction programme with all pre-defined and approved drawings goes a long way in cost cutting and reducing gestation period. Any delay in construction means loss of material, escalation in prices, loss of interest on the capital invested as well as continued overloading of the existing s/s.

The transformer which cannot be erected for want of plinth requires watch and ward and monitoring. Similarly other expensive equipments like Breakers, CTs/PTs/Isolators have metallic parts and are susceptible to theft. Planning of material procurement as per the PERT & CPM drawn at the project clearance stage and reviewed from time to time. This may help in reducing the cost incurred on storage, watch and interest on capital. There are large number of variables in the construction of EHV sub-stations and if they are tackled individually and handled in totality, substantial cost saving is possible.

The cost saving can be without jeopardizing safety norms in any way. However judicious and critical review of each one of the input of construction including procurement policies, construction management and quality control can bring about sizable saving which each one of the utility in this country needs to evaluate.

Proper planning and optimization measures would definitely result in appreciable cost saving.

It is reported that high intensity raids forms 80 to 100% of all the weather related failures.

17.20.5. Maintenance of over-head transmission lines

Major breakdowns of transmission lines can be prevented or the damages can be minimized by well defined routine preventive maintenance inspection and timely repair. Inspection should not be confined to the transmission line proper but should also cover the neighbourhoods. The scope of inspection should cover all the elements of transmission line system to ensure safety as well as to enhance the reliability of power supply. Maintenance operations comprise the detection and removal of faults or abnormal conditions on the lines. Faults are detected by simple patrolling performed by single patrolmen, or by detailed inspections carried out by a crew of several men. Scope of inspection and different techniques presently being adopted in maintenance of transmission lines are briefly given below :-

A. Patrolling

The objective of routine inspections is not merely repair work, but to ensure prevention of outages, safeguarding against accidents, and detection of dangerous conditions along the line, such as inundation, soft soil, proximity of trees and building sites, conductor vibration, supporting structures exposed to lightning, etc.

Patrolling is done on foot, horse-back, by motorcycle, automobile and in mountainous terrain also by helicopters. The advantage of using a helicopter lies in the fact that a helicopter can fly low and slowly, giving the patrolman sufficient time to inspect the line from above, and that up to 300 km of lines can be inspected in a single day.

Extra-high-voltage lines are routine-patrolled at least once a month, high-voltage lines at least once in two months, and low-voltage lines at least once every year. Crossings and especially exposed sections of lines in densely populated industrial districts are patrolled more frequently. Once a year a night patrol should be carried out on extra-high-voltage lines to check up on corona formation in general and on joints in particular.

In addition to such regular patrols, there are also special patrols of the countryside before harvest time and after every major climatic disturbance, such as after heavy ice loadings, floods, cloud-bursts, gales, violent thunderstorms, line outages, etc. It is reported that high intensity winds form 80-100% of all the weather related failures.

During routine patrolling all the observations made, faults identified and the corrective actions (rectification carried out) taken subsequently is recorded in detail, since documented records are valuable data for effective future maintenance.

B. Scope of Routine Inspection

As far as maintenance of transmission line is concerned, it is an established rule that inspection should not be confined to the transmission line proper, but should also cover the surroundings. Attention has to be paid in particular, to soil around the supporting structures. Grass, bushes and other plants around poles and towers are removed. The supporting structures like pole or tower proper is inspected to detect any decay of wood or corrosion of steel or concrete and possible damage to the structure. The verticality of the supports is also checked. A detailed examination is carried out on the connection of the grounding wire with the grounding electrode, the grounding wire proper, bracings and anchor guys of the supporting structures. The pretension in the guys are monitored and adjusted if required. Crossarms are inspected to make certain that they are not loose or bent, insulator-pins are examined for bending, insulator strings are checked for their vertical position and possible damage. The overload ground wire attachment and sags of the conductors and overhead ground wire are also checked.

1. **Inspection of surroundings.** The neighbourhood of an overhead transmission line is checked to make sure that the original use of the grounds has not undergone changes due to construction of earth-work, setting up of a dump pile, or due to floods, building of a play-ground, wire-fence, etc. Utmost attention should be paid to forest stands or isolated trees below the line or alongside it, road-and river crossings, railway crossings and power or communication-line crossing and populated areas with protruding aerials & TV antennas.

2. **Emergency patrol.** In case of an outage, an emergency patrol is sent out with the object of speedy detection of the fault and instant reporting. For this purpose, the patrolman is usually equipped with a transceiver communication set.

The location of a fault on high-or extra-high-voltage lines due to short-circuit or broken conductor can be detected, within 0.5 km, by measurement from transformer substations. D.C. impulses are sent into the affected phase conductors of a disconnected line at a rate of e.g., 150 c.p.s. The emission and reflection of the impulses from the fault is observed on a cathode-ray oscilloscope, the distance of the fault is determined from the reproduced image.

In hilly terrains, materials required for repairs/replacement, such as insulators, conductors, clamps, etc. shall be stored in convenient, well-protected shelters, distributed along the line.

C. General Inspection

General inspections include examination of the soil near foundations, decay of wooden supporting structures at the ground-line, possible, corrosion of steel supporting structures at the ground-line and the state of the surface finish etc. In addition general inspections include climbing the supporting structures and checking the crossbeams, crossarms and braces, connection of overhead ground wires to the grounding wires, individual pin-insulator-ties (at least with the aid of a mirror attached to the end of a pole); During inspection attachment of conductors to clamps, conductor joints, dead-ending clamps, etc., are also checked.

Trimming of trees and bushes along the line and below it is also considered a part of the maintenance. The crew appointed to this work is equipped with proper tools and trained. Spreading of undergrowth also needs to be prevented.

1. **Inspection of Insulator Strings of EHV Lines.** In the case of an extra-high-voltage line, inspection also includes the testing of insulator strings. This is done by checking the voltage distribution between insulator caps of a live line. Many methods have been developed to inspect the insulator strings.

The highest voltage drop occurs across the insulator adjacent to the conductor. The magnitude of the voltage drop decreases gradually down to the third or second insulator unit, counted from the cross-arm. Irregular voltage distribution along the string indicates the presence of a faulty insulator. The voltage drop between insulator caps is generally measured with an electrostatic voltmeter (e.g., the Ferranti Line tester) attached to a long insulated pole.

The patrolman is often equipped with a high-frequency defectoscope, enabling him to detect defective high-voltage insulators by listening and measurement. The voltage-distribution is judged from the sound of the discharge at the double prongs, interconnected via. a well-insulated condenser, and fixed at the end on an insulated stick, the so-called buzz-stick.

As during such a test an insulator having the lowest voltage drop does not buzz, such an insulator is called a silent insulator. A faulty insulator is thus detected from the location of the silent insulator in string. For better results, these measurements should be performed when the relative humidity is not excessive generally below 70%.

During shut down, defective insulators are detected by measuring insulation resistance of insulators using light weight and portable meggars. In addition, live line measurement of the voltage and the electric field across the insulators is carried out to identify the punctured insulators. Ultrasonic Fault Detector to detect faulty insulators, insulators strings and other electrical equipments up to 800 kV under charged condition are now being employed. Various methods to find out the level of severity of pollution present on the insulators in a string are now being used. The measurement is done by using instruments like conductivity meter, leakage current monitor etc.

2. **Inspection of Conductors and Clamps.** During inspections of long spans, at least once in a year, bolt-clamps on suspension insulator strings are loosened and a check is made to ascertain that the conductors have not damaged due to vibration and that no strands have broken. At the same time, conductors near dead-ending clamps are examined to ensure that they are not corroded or otherwise damaged.

Location of defects are all clamps and joints in which two different metals are in contact, particularly branching-off clamps. The same applies also to low-voltage lines. Joints and branching-off clamps are tested under load at least once every two years with the aid of a paraffin stick to make certain that these do not get heated under load, or by means of a voltmeter connected, via a well-insulated condenser, to the prongs of a long insulated stick to the end of which the active parts of the apparatus are attached.

Until recently the only way to measure sag was to climb a tower and take a sighting with a theodolite to the next tower. Today handheld laser range-finders offer a very efficient way to directly measure sags and ground clearances.

3. **Special Inspections.** Special inspections are carried out to examine the surface finish of steel-towers or checking the corrosion of structures below the ground-line. The latter is generally followed by coating the endangered sections with asphalt & checking the ground resistance of individual groundings, and of the line as a whole. Power utilities in U.K. have begun using polarization resistance measurements to assess the corrosion risk to overhead tower foundations.

The schedule of the various inspections, for a transmission time is given in Table 17.8,

Table 17.8 - Typical Schedule

Sl. No.	*Type of inspection*	*Inspection schedule (in years)*			
		EHV	*HV*	*LV*	*Crossings*
—	—	—	—	—	—
1.	General Inspection	1	2	4	1
2.	Surface finish of steel structures	3	3	3	3
3.	Corrosion of steel structure below GL	5	5	5	5
4.	Test on strain Insulators	1	—	—	1
5.	Test on suspension Insulators	2	—	—	—
6.	Insulation resistance measurement*	—	1	1	1
7.	Ground resistance measurement*	2	5	4	1
8.	Overall grounding resistance of over head ground wire system*	1	1	1	1

Note : Inspection marked with an asterisk must be carried out before a new or repaired transmission line is placed into operation.

17.20.6. Maintenance & Repair

In addition to the above listed inspection, the maintenance and repair jobs e.g. re-connection of broken conductors, readjustment of conductor and overhead ground wire sags, replacement of insulators, repair of joints, clamps and grounding wires, tensioning of anchor-guys, addition of dampers in locations where vibration occurred, reduction of grounding resistance, etc. are also performed. After the repair of every fault, the repair job must be thoroughly checked and, whenever necessary, an insufficiently performed repair job must be properly completed, as a repair is often made in haste, or carried out only as a temporary repair job.

1. **Major Repairs of the Line.** Major repairs of the line consist of replacement of conductors, increasing the spacing between conductors on towers, addition of overhead ground wires, relocating or adding individual towers, re-locating entire sections of transmission lines, increasing the size of the conductors or raising the voltage. In the case of over-dimensioned structures, the line capacity is increased by adding an additional conductor to each existing one, *i.e.*, creating two-conductor bundles.

2. **Training for Personnel.** Maintenance and repair require experienced and well-trained crews, excellent technical equipment, fast, sufficiently spacious but light-weight vehicles especially

equipped for the purpose with dirigible spotlights, a portable spotlight powered by a portable storage battery, and a transceiver communication set. Maintenance and repairs are speeded up when good telephone communication and mechanical ladders or insulated work baskets are available.

3. **Live-Line Maintenance.** In Russia, U.S.A., Canada and Sweden, live-line maintenance has been successfully practiced for a number of years. Live-line maintenance tools make it possible to perform repairs on high- and extra-high-voltage lines without interruption to service. Live-line tools are fastened to the ends of insulated poles, sticks or rods, of late made generally of plastic tubing reinforced with glass-fibres.

The main types of live-line work on high-voltage lines are : replacement of fuses; connection and disconnection of pole- or tower-mounted transformers, condensers or switches; replacement of insulators, crossarms, braces, footings, poles and towers; addition of new lines; replacement of wood poles or their mounting on footings. In Russia, such operations are performed on live lines upto 110 kV operating voltage. In other countries, live-line work on extra-high-voltage lines is limited to replacing insulator strings and mounting vibration dampers. In Sweden, such work is carried out even on 400 kV lines. All such work are generally performed only in dry weather.

Live low-voltage lines are repaired with the aid of rubber gloves and special protective work suits. In all types of hot line work, the workers' heads should be protected by helmets made of insulating material.

QUESTIONS

1. Draw a scheme of receiving station incorporating the single bus-bar and associated equipment.
2. Design a bus-bar system for an 11 kV indoor, enclosed switchgear, normal current 800 A. Short time current 20 kA for 1 second. Permissible temperature rise 50°C. Material : Aluminium bars, Ambient temperature 35°C.
3. Describe the main switchgear arrangement in a generating station.
4. Explain with the help of neat sketches the following :
   (*a*) Non-segregated bus-ducts (*b*) Segregated bus-ducts.
5. Explain the principle and construction of isolated phase bus-system.
6. Calculate maximum force between two parallel bus-bars per span length for following conditions :
   (*a*) Peak instantaneous current : 50 kA, in both conductors.
   (*b*) Spacing between bus-bars : 20 cm.
   (*c*) Span between support insulators : 75 cm.
7. Calculate with the help of tables given in this chapter, the cross-section required for the bus-bar.
   Given : 1. enclosed bus ; indoor, well ventilated room.
   2. rated normal current 1900 A, r.m.s.
   3. rated short-time current 30 k A, 1 sec. Obtain the cross-section on basis of 1 and 2 above and then check the temperature rise (ambient 35°C) for 3.
8. Give detailed of auxiliary system in a thermal power station with reference to auxiliary switchgears.
9. State the various equipment and auxiliaries in a substation.
10. Write detail note on the use of aluminium in switchgear.
11. Which tests are necessary on station bus-bars ?
12. Define : (*a*) Creepage (*b*) Clearance.
   How can the porcelain insulators be cleaned ?
13. Explain the use of isolator and earthing switch.
14. Distinguish between the functions of isolator, circuit breaker earthing switch.
15. Describe construction of any triple pole isolator.
16. Why interlockings are necessary between isolator, circuit breaker and earthing switch?

17. State the sequency of operation of circuit-breaker, isolator and earthing switch.
   (*a*) While opening (*b*) While closing.
18. In a 110 kV/32 kV sub-station the following equipment is to be connected. Draw a diagram of electrical scheme.
   Items : (1) Two overhead 110 kV lines, (2) 110 kV circuit-breakers, 4 No. (3) 110 kV/33 kV. Transformers, 2 No. (4) 33 kV circuit-breakers, 6 No. (5) Lightning arresters 110 kV, 2 No. (6) Lightning arresters 33 kV, 4 No. (or 6 No.) (7) 33 kV overhead lines, 4.
   Show isolators and earthing switches where necessary. Mark zones of protection.
19. What is the bus Trunking System.
20. What are the advantages of the bus-bar Trunking system.
21. What is the importance of Patrolling in maintenance of a HV Transmission line.
22. What is Live-Line Maintenance of Transmission lines.

18-A

Transient Overvoltage Surges, Surge Arresters and Insulation Co-ordination

Introduction — Principle of Insulation Co-ordination — Lightning Surges and Surge Arresters — Switching Surge — Insulation Co-ordination.

18.1. INTRODUCTION

Each electrical equipment should have long service life of more than 25 years. The conductors are supported on insulators/embedded in insulation system. The internal and external insulation of every electrical equipment is exposed to continuous normal voltages and occasional abnormal over voltages. The equipment insulation should be designed such that the equipment *withstands* the highest power frequency system voltage, occasional temporary power-frequency overvoltages, occasional lightning/switching surges reaching the equipment (after the interception by surge arresters). The terms related with rated insulation levels are defined in the relevant IS/IEC Standard Specifications. Each equipment has assigned Rated Insulation Level, the capability is proved by Type tests/Routine tests for that equipment. (*e.g.* Table 16.1).

The insulation system is protected against abnormal p.f. overvoltages, lightning surges and switching surges.

— The *insulation requirements* are determined by considering the following :

— *Highest power frequency System voltage* (continuous)

— *Temporary Power-Frequency Overvoltages* (a few mill-seconds to seconds) caused by load throw-off, faults, resonance etc.

— *Transient Overvoltages Surges* (few hundred microseconds). caused by Lightning, Switching, Restrikes, Travelling waves etc. The Surge Arresters intercept the surges and protect the installation.

— *Withstand Levels of the equipment.* The BIL is specified and other withstand levels are then selected from relevant tables in standard specifications.

Basic Impulse Insulation Level (BIL) is reference level expressed in peak (crest) voltage value with standard 1.2/50 μs lightning impulse wave. Apparatus should be capable of withstanding test waves above BIL.

— *Protective levels of Surge arresters* and available *Protective Margin* against Lightning/Switching Surges.

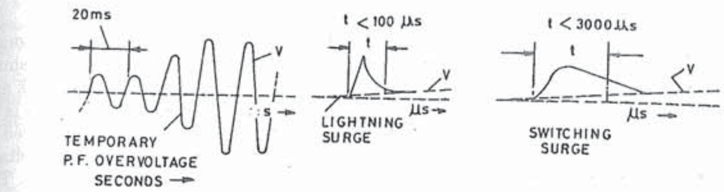
$$\text{Protective Margin} = \begin{bmatrix}\text{Withstand Level}\\ \text{of Equipment}\end{bmatrix} - \begin{bmatrix}\text{Protective Level by}\\ \text{Surge Arrester}\end{bmatrix}$$

— Co-ordination with other equipment connected to same voltage level.

— Co-ordination between various voltage levels in the Network.

— System Neutral Earthing.

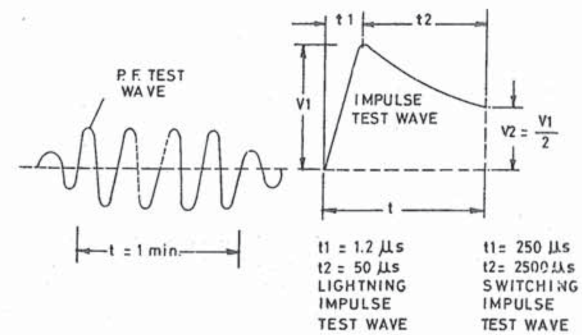
Fig. 18. A-1 illustrates the range of waveforms and durations of Power-frequency Overvoltage, Lightning Surges and Switching Surges. The time durations, rate of rise, peak values of these over-



Temporary P.F. Overvoltage Lightning Surges

Fig. 18 A-1. Three Representative Wave forms* of P.F. Overvoltages and Surges occurring in Network.

voltages of actual overvoltages in the system differ widely. Hence stresses on insulation are also quite different. Power frequency overvoltages are of low overvoltage factor but longer duration. Lightning and Switching Surges are of higher over voltage factor and of lesser duration. The standard test waveforms have been obtained from field studies from several locations, over several years and are used as representatives for laboratory tests of equipment for proving the withstand *capabilities.*



P.F. Overvoltage Impulse Voltage Wave

Fig. 18 A-2. Standard Test Waveforms for Laboratory Tests.
(Word "Impulse" used for "test wave," "Surge" for "wave" in network)

Table 18.1. Example of Rated Insulation Characteristics of an Outdoor Busbar

Nominal voltage*	132 kV rms, 50Hz
Highest system voltage**	145 kV rms, 50 Hz
1 Min. 50 Hz Withstand***	300 kV rms
Lightning Impulse Voltage Withstand	450 kV peak
Switching Impulse Voltage Withstand+	380 kV peak
Lightning Surge Protective Level	390 kV p
Lightning Surge Protective Margin by S.A.	60 kV

* Rated voltage
** Design voltage for continuous withstand
*** Test voltage for 1 min. power frequency voltage withstand test
+ Switching overvoltage factor K, not specified for 132 kV busbars