1
Electrical Substations

1.1. General Background

Electrical Network comprises the following regions :

— Generating Stations
— Transmission Systems
— Receiving Stations
— Distribution Systems
— Load Points

In all these regions, the power flow of electrical energy takes place through *Electrical Substations. An electrical substation is an assemblage of electrical components including busbars, switchgear, power transformers, auxiliaries,* etc. The various substations located in generating stations, transmission and distribution systems and in the consumers' premises have similar layouts and similar electrical components. Basically an electrical substation consists of a number of incoming circuits and outgoing circuits connected to common busbar systems. Busbars are conducting bars to which a number of incoming or outgoing circuits are connected. Each circuit has certain electrical components such as circuit-breakers, isolators, earthing switches, current transformers, voltage transformers, etc. These components are connected in a definite sequence such that a circuit can be switched off during normal operation by manual command and also automatically during abnormal conditions such as short-circuits.

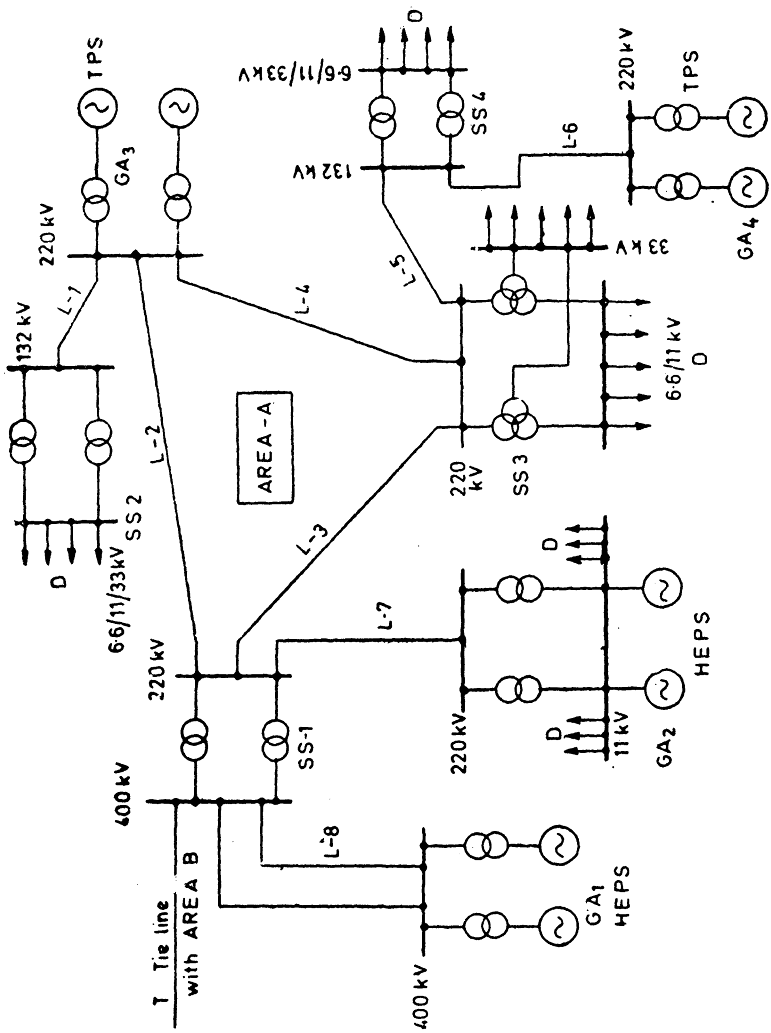
A *substation* receives electrical power from generating station *via* incoming transmission lines and delivers electrical power *via* the outgoing transmission lines. Substations are integral parts of a power system and form important links between the generating stations, transmission systems, distribution systems and the load points. (Ref. Fig. 1.1).

1.2. Functions of a Substation

An electricity supply undertaking generally aims at the following :

— Supply of required electrical power to all the consumers continuously at all times.
— Maximum possible coverage of the supply network over the given geographical area.
— Maximum security of supply.
— Shortest possible fault-duration.
— Optimum efficiency of plants and the network.

— Supply of electrical power within targeted frequency limits, (49.5 Hz and 50.5 Hz).
— Supply of electrical power within specified voltage limits.
— Supply of electrical energy to the consumers at the lowest cost.



Area A—Part of the Network under one Regional Load Control Centre.
TPS—Thermal Power Station.
HEPS—Hydro Electric Power Station.
SS—Substation.
Fig. 1.1. Single-line diagram of a Network having several substations.

As a result of these objectives, there are various tasks which are closely associated with the generation, transmission, distribution and utilization of the electrical energy. These tasks are performed by various, manual, semi-automatic and fully automatic devices located in generating stations and substations.

The tasks associated with major substations in the transmission and distribution system include the following :

— Protection of transmission system.
— Controlling the exchange of energy.
— Ensuring steady state and transient stability.
— Load shedding and prevention of loss of synchronism. Maintaining the system frequency within targeted limits.
— Voltage control ; reducing the reactive power flow by compensation of reactive power, tap-changing.
— Securing the supply by providing adequate line capacity and facility for changing the transmission paths.
— Data transmission *via* power line carrier for the purpose of network monitoring ; control and protection.
— Determining the energy transfer through transmission lines and tie-lines.
— Fault analysis and pin-pointing the cause and subsequent improvements.
— Securing supply by feeding the network at various points.
— Establishing economic load distribution and several associated functions.

These tasks are performed by the team work of load-control centre, control rooms of generating stations and control rooms of substations. *The substations perform several important tasks and are integral part of the power system.*

The locations of important substations, power stations and the transmission lines are decided while designing the power system by considering the geographical locations of load centres, and energy reserves.

A small power system is generally controlled by direct supervision of generating stations and substations through respective control rooms. A large network having several generating stations, substations and load centres is controlled from central load despatch centre. Digital or voice signals are transmitted over the transmission lines *via* the substations. The substations are linked with the load control centres *via* Power Line Carrier System (PLCC). The data collected from major substations and generating stations is transmitted to the load control centre. The instructions from the load control centre are transmitted to the control rooms of generating stations and substations for executing appropriate action. Modern power system is controlled with the help of several automatic, semi-automatic equipment. Digital computers and

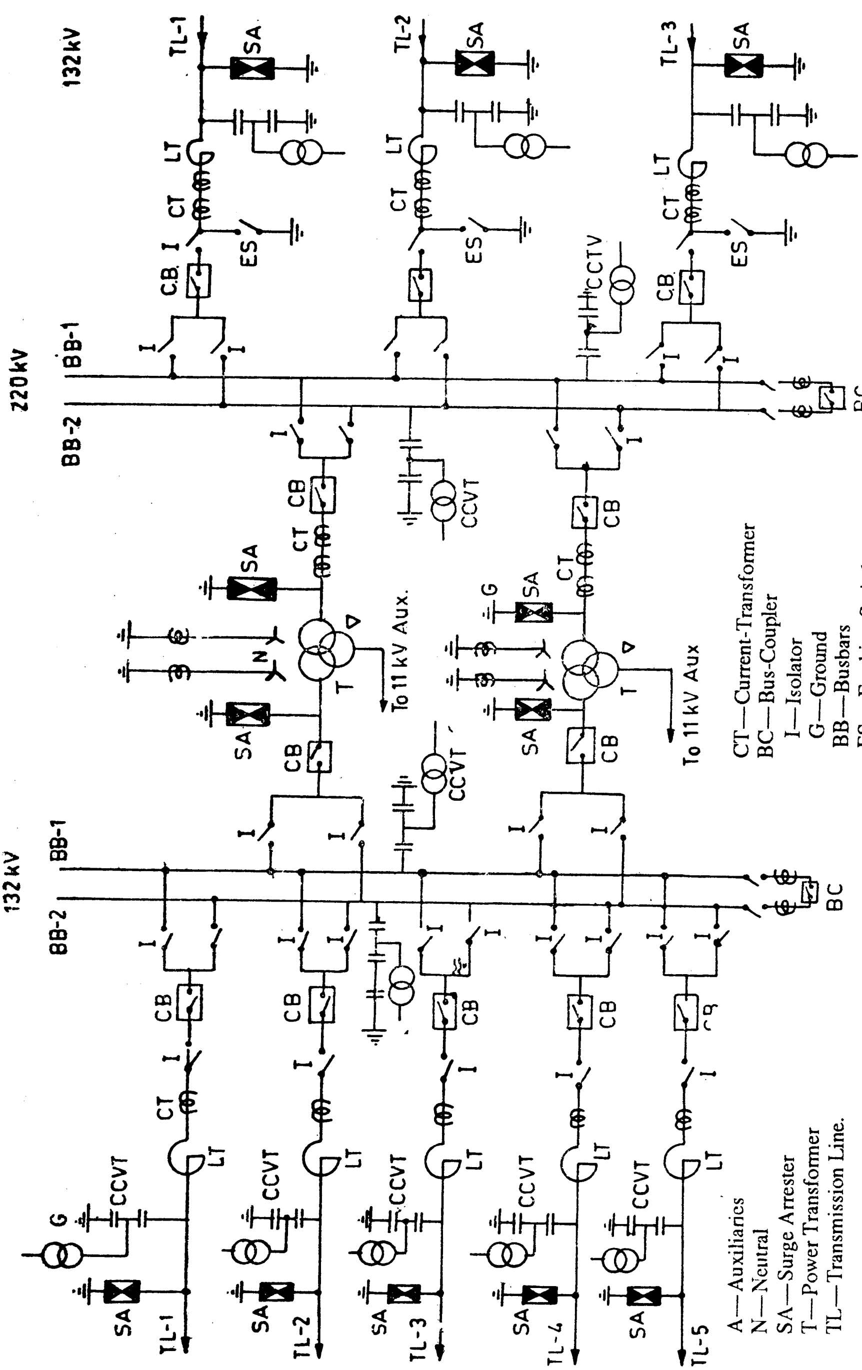


Fig. 1.2. Single-line Diagram of a 220 kV/132 kV substation with Duplicate Busbar System.

microprocessors are installed in the control rooms of large substations, generating stations and load control centres for data collection, data monitoring, automatic protection and automatic control.

1.3. Substation Layouts, Busbar Schemes

The term layout denotes the physical arrangement of various components in the substation relative to one another. Substation layout has significant influence on the operation, maintenance, cost and protection of the substation and these aspects are considered while designing the substation layout.

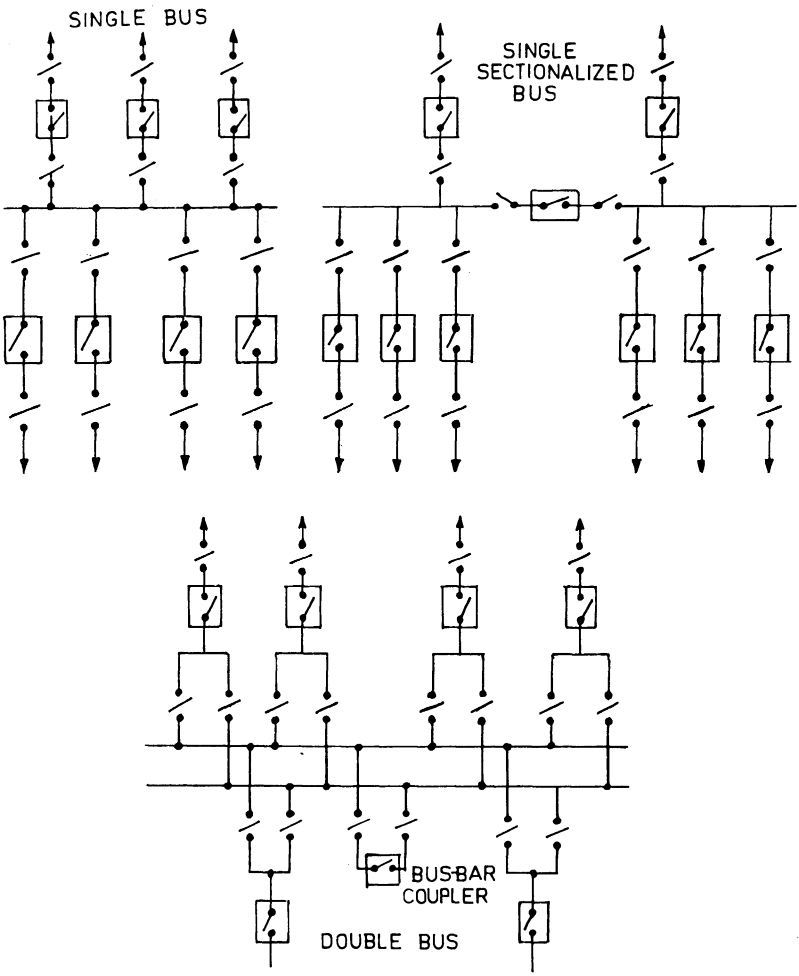


Fig. 1.3. (a) Busbar System.

The reasoning behind the connections of components in each circuit and the busbars layout should be understood. Within the frame-work of the basic requirements, the substation layout can have several alternative arrangements. The substation layouts are selected on the basis of the size, the ratings, importance, local requirements and the prevailing practice of the supply authorities.

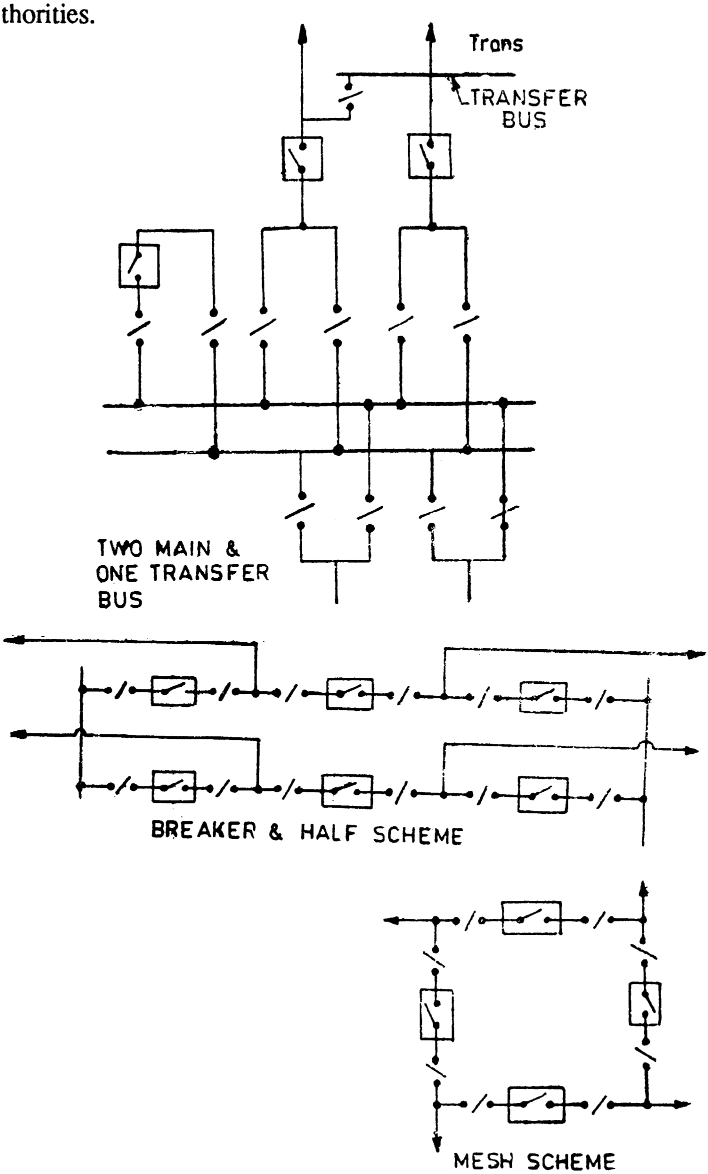


Fig. 1.3 (b) Busbars System.

Desirable Aspects. With the given number of incoming lines, outgoing lines, transformers, etc., the substation can be designed in several alternative ways. The physical arrangement of the equipment is called the layout of the substation. The layout is illustrated by means of single line diagrams. The design of a substation layout needs careful consideration of several aspects. These include the following :

1. Switching requirements for normal operation.
2. Switching requirements during abnormal operations, such as short circuits and overloads.
3. Degree of flexibility in operations, simplicity.
4. Freedom from total shutdown and permissible period of shutdown.
5. Maintenance requirements, space for approaching various equipments for maintenance, roads, for transportation of main equipment and maintenance equipment.
6. Safety of personnel.
7. Protective zones, main protection, back-up protection.
8. Bypass facilities.
9. Technical requirements such as ratings, clearances, earthing lightning protection, noise, radio interference, etc.
10. Provision for extensions, space requirement.
11. Economic considerations, availability, foreign exchange involvement, cost of the equipment.
12. Requirements of network monitoring, power line communication, data collection, data transmission etc.
13. Compatibility with ambient conditions.
14. Environmental aspects, audible noise, RI, TI etc.
15. Long service life, Quality, Reliability, Aesthetics.

Busbar Schemes. The choice of busbar schemes for a.c. yards depend upon several factors mentioned above. The important busbar schemes include the following :

1. Single busbar
2. Double busbar with one breaker per circuit.
3. Double busbar with two breakers per circuit.
4. Main and transfer bus
5. Ring bus
6. Breaker and a half ($1\frac{1}{2}$ breaker) arrangement
7. Mesh arrangement etc.

The various schemes are generally compared to emphasize their advantage and limitations. The basis of comparison is generally the degree of reliability and economic justification. The degree of reliability is evaluated by determining continuity of service under anticipated operating conditions and possible faults. The summary of comparison of various schemes is given in Table 1.1.

TABLE 1.1. Busbar Schemes

Scheme	*Application*	*Remarks*
Single Bus	Low voltage and medium voltage substations. Not preferred for important large substations	Cheapest. Total shutdown in case of a fault. Use of bus-sections.
Duplicate bus	High voltage substations	Costlier than single bus. One bus can serve as a reserve. During maintenance or fault, the reserve bus is used.
Two main and one transfer bus	Important EHV substations	Additional flexibility for operation.
Breaker and a half	Important 400 kV substations	Uses three breakers for two circuits. High flexibility of operations. Higher cost.
Mesh	Used for large substations having many incoming and outgoing circuits	Costlier. Gives good operational flexibility.

Essential Features

A typical substation has the following essential features :

— Outdoor switchyard having any one of the above busbar schemes
— Low voltage switchgear, medium voltage switchgear and control room building
— Office building
— Roads and rail track for transporting equipment
— Incoming line towers and outgoing line towers/cables
— Store
— Maintenance workshop
— Auxiliary power supply scheme ; Protection system
— Battery room and low voltage d.c. supply system.
— Fire fighting system
— Cooling water system ; Drinking water system, etc.
— Station earthing system
— Lightning protection system, overhead shielding.
— Drainage system.
— Substation lighting system etc.
— Fence and gates, Security system etc.

All these requirements are considered while designing a substation layout.

The site is selected and the site map is drawn indicating the levels of the ground. The *locations* of various parts such as switchyard, switchgear building, office buildings, roads/rail tracks, fencing etc. are decided. Several alternatives are considered before finalising the layout. After finalising the substation layout, preliminary layout drawings are prepared by considering approximate dimensions of component areas. The layout drawings are finalised later after getting the overall dimensional drawings of various components and the buildings.

Substation layout and busbar schemes have important influence on the cost, operation, maintenance of the substation. The layout should satisfy the various functional requirements and should be simple to operate and maintain.

1.4. Voltage Levels in AC Substations and HVDC Substations

A substation receives power *via* the incoming transmission lines and delivers power *via* the outgoing lines. The substation may have step-up transformers or step-down transformers. Generally the switchyards at sending-end of lines have step-up transformers and switchyards at receiving-end have step-down transformers. *The rated voltage level refers to nominal voltage of 3 phase a.c. system and is expressed as r.m.s. value between phases.* An A.C. substation has generally 2 or 3 main voltage levels. The *long distance transmission* is generally at extra high voltages such as 132 kV, 220

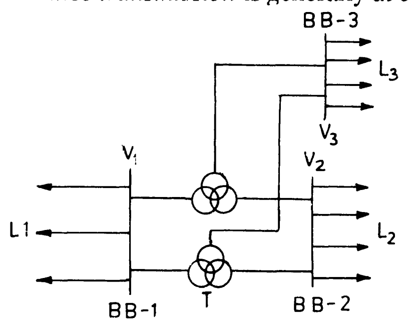


Fig. 1.4 A. Voltage levels in EHV AC substation.

L—Lines
BB—Busbars
T—Transformers

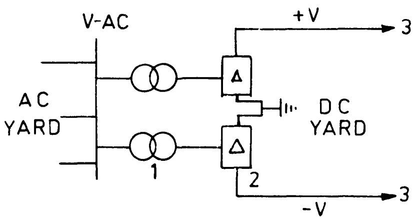


Fig. 1.4 B. Voltage levels in HVDC Substation.

1. Converter transformers
2. Converter valves
3. Transmission line poles

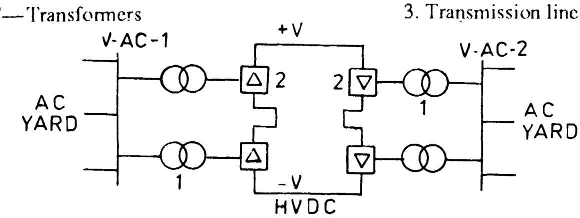


Fig. 1.4 C. Voltage levels in Back-to-back substation

1. Converter transformer 2. Valves.

kV, 400 kV a.c. The *distribution* is at medium high voltages such as 33 kV, 11 kV, 6.6 kV and 3.3 kV a.c.

In a generating substation, the generator is directly connected to step-up transformer and the secondary of the step-up transformer is connected to outdoor EHV switch-yard. The switch-yard in a generating station comprises generator transformer, unit auxiliary transformer and several out-going lines. In addition to the main EHV switch-yard, a generating station has indoor auxiliary switch-gear at two or three voltages such as 11 kV, 3.3 kV, 400 volts.

The *factory substations* receive power at distribution voltage such as 3.3 kV and step it down to 440 volts a.c. Larger factories receive power at 132 kV and have internal distribution at 3.3 kV, 440 volts a.c.

The choice of incoming and outgoing voltages of substations is decided by the rated voltages and rated power of corresponding lines. Long distance and high power transmission lines are at higher voltages. The nominal voltages are selected from the standard values of rated voltages specified in Indian Standard or relevant national standard. The standard also specifies the following reference values for each voltage level.

— Nominal voltage e.g. 220 kV, 400 kV
— Highest system voltage, e.g. 245 kV, 420 kV
— Lowest system voltage, e.g. 200 kV, 185 kV.

TABLE 1.2. Reference Values of Nominal Voltages in A.C. and HVDC Substations

	A.C. Substations		
765 kV, 400 kV,	220 kV,	132 kV,	110 kV,
66 kV,	33 kV,	22 kV,	11 kV,
6.6 kV,	3.3 kV,	400 V a.c r.m.s phase to phase	
	*H.V.D.C. Substations**		
	± 400 kV, ± 500 kV, ± 600 kV		
	Station Auxiliaries		
Auxiliary A.C. Supply :	11 kv, 6.6 kV, 3.3 kV,		
	400 V, 3 ph., phase to phase		
	230 V a.c. single phase		
Auxiliary L.V.D.C :	220 V, 110 V, 48 V D.C.		

* Choice of voltage depends on length and power of HVDC transmission link.

Forms of Substations

For voltage upto 11 kV, the sub-stations are either in the form of indoor metal clad draw-out type Switchgear or Outdoor Kiosk. In indoor metal clad Switchgear, the required number of factory assembled units are taken to site

* Coice of voltage depends on lenght and power of HVDC transmission link.

and placed in a row. Recently SF_6 Gas Insulated Switchgear has been introduced for medium high voltage such as 3.3 kV, 6.6 kV, 11 kV, 33 kV.

For voltages of 33 kV and above, outdoor substations are generally preferred. In outdoor substations, the various equipments are installed below the open sky. The outdoor substations are used for voltages in the range of 33 kV to 760 kV a.c.

The indoor and outdoor substations have similar components. However, configurations, assembly and dimensions of indoor sub-stations are quite different from those of outdoor substation.

SF_6 Gas Insulated Substations (*GIS*) are preferred for the following :

— EHV, HV, MV substations.

— Substations in urban areas, industrial areas, mountainous regions where land is costly and civil works are complex.

— Heavily polluted areas such as sea-shores, industrial areas, thermal power stations etc. where open terminal substations experience frequent flashovers.

— Maintenance free substations.

Besides the main voltage levels, each substation has *auxiliary a.c. and d.c. distribution systems* for feeding the various auxiliary systems, protection systems and control systems. The reference values of auxiliary voltages are mentioned in Table 1.2.

High voltage D.C. Transmission systems (*HVDC*) have following parts at each end of the HVDC Transmission line.

— EHV A.C yard which is at 400 kV A.C. or 220 kV A.C.

— HVDC yard which is at ± 400 kV D.C. or ± 500 kV D.C., etc.

— Valve hall, Converter Transformers and A.C. Filters.

— Electrode line, earth electrode.

Bipolar HVDC system has two poles, one of a positive and other negative. Polarity with respect to earth.

The nominal voltage ± 500 kV refers to voltage of the two d.c. poles with respect to earth. The midpoint of converters is earthed through earth electrodes. One HVDC substation is required at each end of the long HVDC transmission line. In case of *Back-to-Back HVDC Substation*, the long distance HVDC transmission line is eliminated and such substation has the following parts :

— A.C. Switchyard of one grid.

— A.C. Switchyard of other grid.

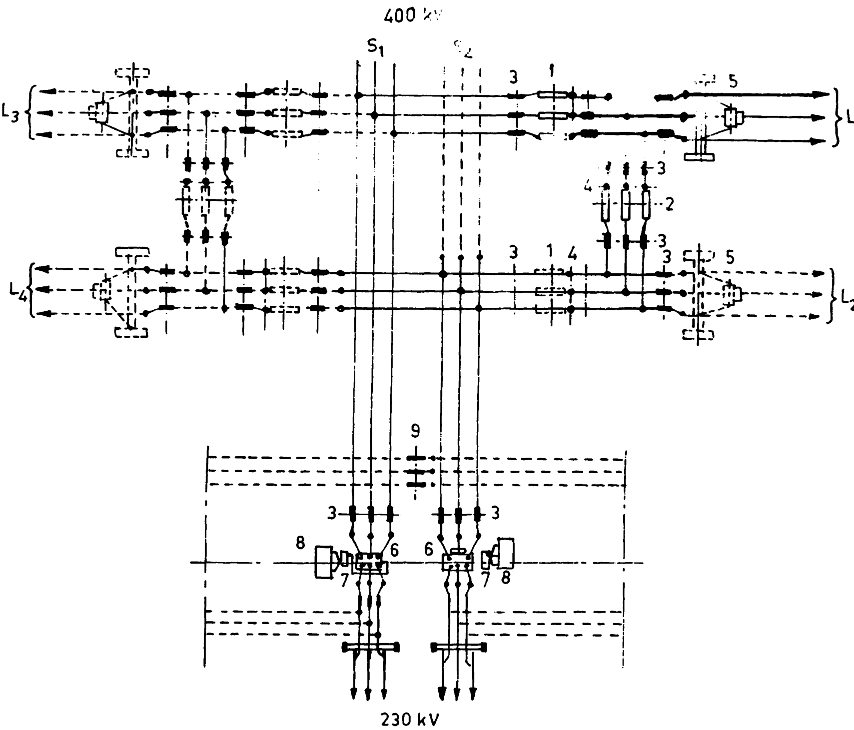
— Back-to-back converter transformers and valves.

Such substations are used for asynchronous links between two a.c. systems for interconnection. The frequency fluctuations on one a.c. side are not reflected on the other a.c. side and the power can be transferred in either directions by adjusting the characteristics of the converter valves. Power can be exchanged rapidly and accurately.

1.5. Types of Substations

The substations can be classified in several ways including the following:

(1) Classification based on voltage levels, *e.g.* :
A.C. Substation : EHV, HV, MV, LV ; HVDC substation



1. Line Circuit-breaker
2. Bus coupler
3. Isolator
4. Current transformer
5. Line shunt reactor
6. Power transformer
7. 230 kV switchgear
8. —Shunt reactor connected to transformer tertiary
9. Busbar tie isolator

S_1 — Busbars I
S_2 — Busbar II
L to L — 400 kV lines
—Supplied in first stage
....-Future extension

Fig. 1.5 Layout of a 400 kV substation.

(2) Classification-Outdoor or Indoor.
Outdoor substation is under open sky. Indoor substation is inside a building.

(3) Classification based on configuration, *e.g.* :
— Conventional air insulated outdoor substation or
— SF_6 Gas Insulated Substation (GIS)
— Composite substations having combination of the above two.

(4) Classification based on application.
— Swichyard in Generating Station
— Switching substation (without power transformers)
— Sending-end substation
— Receiving substation
— Distribution substation
— Factory substation.
— Compensating substation. †
— Load substation, *e.g.* arc-furnace substation.

Table 1.3 gives the Main Data about a typical 400/230 kV A.C. Substation. Table 1.4 gives the Main Data about a typical HVDC Substation.

TABLE 1.3. 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 kA
Minimum phase to phase clearance	5.75 m	2.5 m
Minimum phase to earth clearance	3.65 m	2.0 m
Number of horizontal levels of tubular bus-bars/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
Distance between the two busbar system S_1, S_2	17 m	4 m
Tubular Aluminium Busbar Al ASTM B241	4" IPS*	4" IPS

Rated frequency 50 Hz

1.6. Essential Features of a Substation

An *A.C. Substation* has following parts :

— A.C. Switchyard
— Control Building
— Low-voltage and Medium voltage A.C. System for Auxiliaries.

* IPS—International Pipe Standards.
† At interval of opp. 300 km along EHV-AC Line.

— D.C. Battery System and D.C.L.V. Distribution System
— Mechanical, Electrical and other auxiliaries
— Civil works

TABLE 1.4. Main data of a Bipolar HVDC Substation*

Operating voltage of A.C. yard	400 kV A.C.
Operating voltage of D.C. yard	± 500 kV D.C
Rated Power of D.C., Bipolar mode	1500 MW
Number of Converter Transformers : each 300 MVA ; Winding, 1 Ph.	6
Number of quadruple valves	6
Minimum clearance, phase to phase on 400 kV A.C. side	5.75 m
Minimum clearance phase to ground on 400 kV A.C. side	3.65 m
Minimum phase to phase clearance on 500 kV D.C. side	12 m
Minimum phase to ground clearance on 500 kV D.C. side	7 m
Size of Busbars in D.C. yard	10" IPS
Size of Busbars in A.C. yard	4" IPS
Type of HVDC Transmission	Bipolar
Transmission line voltage	± 500 kV
Transmission line length	1000 km
Power Rating of Transmission line	1500 MW
Total MVAr or AC Filters	2000 MVAr
Number of PLCC Repeater Stations	2

An *HVDC Substation* has following main parts :

— A.C. Switchyard
— Converter Transformers
— A.C. Filter banks
— Valve Halls
— D.C. Switchyard, Smoothing Reactors, DC Filters
— Mechanical, Electrical and other auxiliary systems.

One such substation at each of the 1000 km, 1500 MW HVDC transmission line. IPS— International Pipe Standard.

Each substation is designed separately on the basis of functional requirements ; ratings, local conditions etc. For the same requirement, several alternative designs are possible. However, the principles and basic technical requirements of all the substations are similar and the substation is designed on the basis of these requirements and the earlier experience.

Substation parts and equipment :	
Outdoor Switchyard	— Incoming Lines — Outgoing Lines — Busbar — Transformers — Insulators —Substation Equipment such as Circuit-breakers, Isolators, Earthing Switches, Surge Arresters, CTs, VTs, Neutral Grounding Equipment —Station Earthing system comprising ground mat, risers, earthing strips, earthing spikes —Overhead earthwire shielding against lightning strokes, or, lightning masts. —Galvanised steel structures for towers, gantries, equipment supports. —PLCC Equipment including line trap, tuning unit, coupling capacitor, etc. — Power cables —Control cables for protection and control — Roads, Railway track, cable trenches — Station lighting system
Main Office Building	— Administrative building — Conference room etc.
11 kV Switchgear, LV Switchgear and Control-panel Building	— 11 kV Indoor Switchgear —6.6 kV/3.3 kV Indoor Switchgear and Load control centres — Low voltage a.c. Switchgear — Control Panels, Protection Panels.
Battery room and D.C. distribution system	—D.C. Battery system and charging equipment — D.C. Distribution system
Mechanical, Electrical and other Auxiliaries	— Fire fighting system — Lighting system — Oil purification system

Substation parts and equipment :	
	— Cooling water system — Telephone system — Workshop ; Stores etc.
Protection system	— CTs, VTs — Protective Cables — Protective Relays — Circuit breakers
SCADA, supervisory	— Computer/Microprocessors
Control and Data	— Data collection system — Data processing system
Aquisition system	— Man-machine interface — Expert system, etc.

1.7. Substation Equipment

A sub-station is an assemblage of electrical apparatus. *Transformers* are necessary in a substation for stepping-up and stepping-down of a.c. voltage. Besides the transformers, the substation has several other electrical equipments including *bus-bars, circuit-breakers, isolators, surge-arresters, CTs., VTs., Shunt Reactors, Shunt Capacitors etc.* A typical layout of a substation circuit is illustrated in Fig. 1.2.

In every electrical substation there are generally various indoor and outdoor switchgear, equipment. Each equipment has a certain functional requirement (Ref. Table 1.5). The equipment are either indoor or outdoor, depending upon the voltage rating and local conditions. Generally indoor equipment is preferred for voltages upto 33 kV. For voltages of 33 kV and above, outdoor switchgear is generally preferred. However, in heavily polluted areas indoor equipment may be preferred even for higher voltages.

Recently indoor metal-clad SF_6 insulated switchgear has been introduced for medium high voltages such as 3.3 kV, 6.6 kV, 11 kV, 33 kV.

An outdoor equipment is installed under the open sky. The indoor switchgear is generally in the form of metal enclosed factory assembled units called metal-clad switchgear.

Circuit-breakers are the switching and current interrupting devices. Basically a circuit-breaker comprises a set of fixed and movable contacts. The contacts can be separated by means of an operating mechanism. The separation of current carrying contacts produces an arc. The arc is extinguished by a suitable medium such as dielectric oil, vacuum, SF_6 gas. The circuit-breakers are necessary at every switching point in the substation.

Isolators are disconnecting switches which can be used for disconnecting a circuit under no current condition. They are generally installed along with the circuit breakers. An *isolator* can be opened after the circuit breaker. After opening the isolator, the *earthing switch* can be closed to discharge the trapped electrical charges to the ground. The *current transformers* and *voltage transformers* are used for transforming the current and *voltage* to a lower value for the purpose of measurement, protection and control. *Surge arresters* divert the over-voltages to earth and protect the sub-station equipment from over-voltage surges.

Busbars are either flexible or rigid. Flexible busbars are made of ACSR conductors and are supported on strain insulators. Rigid busbars are made up of aluminium tubes and are supported on post insulators.

Galvanised Steel Structures are made of bolted/welded structures of angles/channels/pipes. These are used for towers, gantries, equipment support structures etc. Galvanised structures provide rigid support to the various equipment and insulators. The design should be safe and economical.

Compensating substations are installed at an interval of 300 km along EHV-AC lines for feeding reactive power (VAr) to line.

Following Compensation Equipment is necessary for voltage control.

— *Series Capacitors* are sometimes installed in series with long EHV A.C. Transmission lines to compensate line reactance.

— *Shunt Capacitors* are installed near load points in distribution sub-stations, receiving sub-stations for improvement of power factor. Shunt capacitors are switched on during high inductive loads. They are switched off during low loads. Shunt capacitors are also included in static VAr sources (SVS).

— *Shunt Reactors* are necessary with long EHV transmission lines to compensate the reactive power of the line capacitance during low loads.

— *Static VAr Sources (SVS).* These are thyristor controlled shunt capacitors and shunt reactors which give rapid, stepless control of rective power (VAr). These are connected in receiving stations and distribution systems.

Power Line Carrier Current Equipment (PLCC) is necessary for transmitting/receiving high frequency signals over the power line (transmission line) for the following:

— Voice communication

— Data transmission

— Protection signalling

— Control signalling

The functions of various sub-stations equipment and associated systems are summarised in Table 1.5 and 1.6.

TABLE 1.5. Functions of Substation Equipment

Equipment	*Function*
1. Bus-bar	Incoming and outgoing circuits connected to bus-bars.
2. Curcuit-breakers	Automatic switching during normal or abnormal conditions.
3. Isolators (Diconnectors)	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*	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 long lines.

*Used only for EHV-AC lines.

TABLE 1.6. Functions of Associated Systems in Substations

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 switchyard — 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, telemetery, telecontrol, 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.

Contd...

System	*Function*
— piping — valves	
10. Auxiliary standby power system — diesel-generator sets — switchgear — distribution system	For supplying starting power, standby power for auxiliaries
11. Telephone, Telex system, Microwave system.	For internal and external communication.

1.8. Substation Earthing System : (Grounding System)

The grounding system in a substation is very important. The functions of a grounding system include:

— To ensure safety to personnel in substations against electrical shocks.

— To provide the ground connection for connecting the neutrals of star connected transformer windings to earth (neutral earthing).

— To discharge the over-voltages from overhead ground wires or the lightning masts to earth. To provide ground path for surge arresters.

— To provide a path for discharging the charge between phase and ground by means of earthing switches.

— To provide earth connections to structures and other non-current carrying metallic objects in the sub-station (equipment earthing).

The substation grounding system comprises of a grid (mat) formed by a horizontal buried conductors. In addition to such a grid below ground level, earthing spikes (electrodes) are driven into the ground and are connected electrically to the earth grid, equipment bodies, structures, neutrals etc. are connected to the station earthing system by earthing strips.

If the switchyards have a soil of low resistivity, earth resistance of the earthing system would be low. If the soil resistivity is high, the mesh rods are laid at closer spacing. More electrodes are iserted in the ground.

The fence, equipment body, tanks, support, structures, towers, structural steel works, water pipes etc. should be earthed.

The value of earth resistance of the ground system determines the voltage rise of the various earthed points during the earth fault. If earth fault current is I, earth resistance is R, the voltage rise under short circuit condition would be $V = IR$. The permissible potential rise and the maximum possible earth

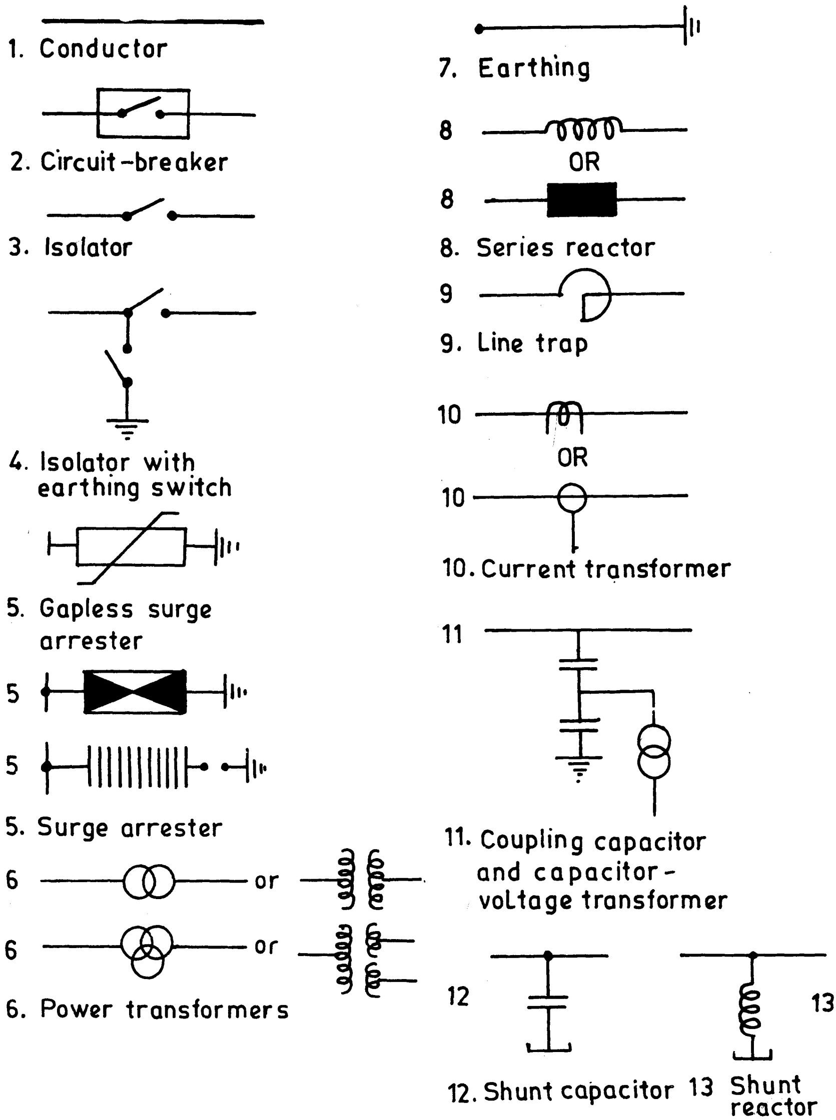


Fig. 1.6. Symbols.

fault current set a limit on the maximum value of earth resistance. To achieve earth resistance within specified limits, enough number of earth spikes and sufficient surface area of earth grid and closer ground-mesh rods are necessary

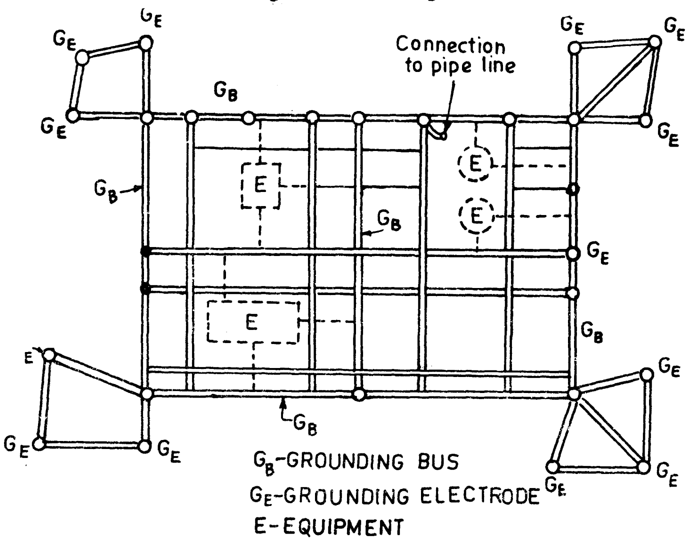


Fig. 1.7. Substation Earthing System.

The 'touch-potential' and the 'step-potential' in the switchyard under any earth fault condition should be within safe limits. Earth-mesh design is based on these limits.

1.9. Insulation Co-ordination and Surge Arresters

A substation has two or more nominal voltage levels. Each voltage level has specified substation equipment including busbars CT_S, VT_S, Isolators, circuit breakers, transformers. These equipment have their respective *insulation levels* Insulation level of an equipment denotes its specified rated vol-

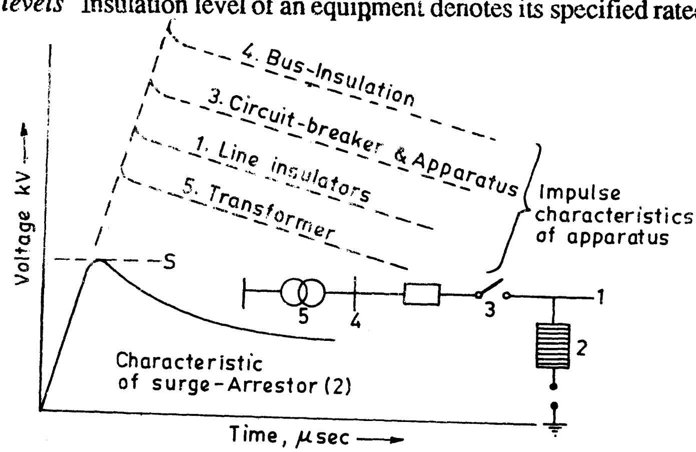


Fig. 1.8. Insulation coordination.

tage, power frequency withstand voltage and impulse withstand voltage, which together characteristics an insulation of the equipment the rated insulation level of the equipment is confirmed by conducting type tests on respective equipment.

'Basic Insulation Level' (BIL) is a term which includes the following characteristics of a substain equipment :

— Power frequency voltage withstand level.
— Lightning impulse voltage withstand level.
— Switching impulse voltage withstand level (applicable to transformer windings rated 220 kV and above).

These withstand levels together characterise the insulation level of a substation equipment. However for practical purposes, BIL refers to Basic Impulse Level.

It is not economical and convenient to design the equipment to withstand the full surge voltages occurring in the power system. The use of following means results in economic solution to insulation co-ordination problem :

— Use of over-head ground wires to prevent direct lightning stroke on conductors.
— Use of rod-gaps. (This practice is now not preferred)
— Use of surge-arresters on incoming lines and near transformer terminals, generator terminals.
— Use of surge absorbers (RC combination or non-linear resistors) between phase and ground near large rotating machines and near vacuum switchgear to reduce peaks of switching transients. (Refer Table 1.7).

Insulation co-ordination is correlation of insulation of equipment and circuit with the characteristic of protective devices such that the insulation is protected from over voltage surges.

The surge arrester should have protective level less than the withstand level of the equipment. In other words, the protective device must have a lower breakdown voltage than insulation to be protected.

The insulation level of an equipment or machine is expressed in terms of crest value of the specified impulse wave called impulse withstand level and r.m.s. value of one minute power frequency voltage which the apparatus can withstand during the tests made under specified conditions. The r.m.s. value of this voltage is called power frequency voltage withstand level. The term 'surge' refers to voltage waves occuring in the actual system and 'impulse' refers to voltage waves applied for testing.

The development of Metal-Oxide Arresters (MOA) also called Zinc-Oxide Arresters (ZnO Arresters) has resulted in better insulation co-ordination in EHV AC and HVDC substations. The zinc-oxide arresters are gapless, and have superior voltage-current characteristic and high energy discharge capacity. Such arresters permits use of lower insulation levels of associated substation equipment.

As the lightning strokes strike a line, the overvoltage surges travel from transmission lines ; circuit breakers, busbars towards the transformer. The protective device bypasses the over voltages and protects the equipment insulation. Various protective devices are provided in the substation to protect the equipment insulation.

Over-voltage surges are also caused during switching operations. The magnitude and wave shape of the switching over-voltages depends upon the values of equivalent inductance, capacitance and resistance in the system, the magnitude of the current to be interrupted and other local conditions. Over-voltage surges are produced during opening of a circuit-breaker. The amplitude of such over-voltages can be reduced by incorporating opening resistors across the circuit-breaker interrupters. Over-voltage surges are also produced during the closing operation of circuit-breaker especially while closing on unloaded transmission lines. Such surges can be minimised by incorporating pre-closing resistors across the interrupters of the circuit breakers. SF_6 circuit-breakers used in EHV substations give lesser switching over voltage surges.

The surge-arresters offer low resistance to over-voltages and divert the over-voltage surges to earth. Surge arresters are installed in sub-stations as a first apparatus on incoming lines and also near the terminals of large transformers.

TABLE 1.7. Protective Devices against Lightning Surges

Device	*Where applied*	*Remarks*
Rod gaps	Across insulator string, bushing insulators.	—Defficult to co-ordinate —Create dead short circuit —Cheap
Horn gaps		
Overhead Ground Wires (earthed)	—Above overhead lines —Above the sub-station area	Provide effective protection against direct strokes on line conductors, towers, substation equipment.
Vertical Masts in substations	—In substations	—Instead of providing overhead shielding wires

Contd...

Device	*Where applied*	*Remarks*
Lightning Masts Rods (earthed)	—Above tall buildings	Protect buildings against direct strokes. Angle of Protection $\alpha = 30°$ to $45°$
Lightning Arresters (Surge Arresters)	—On incoming lines in each substations —Near terminals of Transformers and Generators	—Diverts over-voltages to earth without causing short-circuit
	—Near motor and generators terminals	—Used at every voltage level in every substation and for each line
Surge absorbers (R-C or Z_nO type)	—Near large HV rotating machines	Resistance Capacitance Combination absorbs the over-voltage surge and reduces steepness of wave

1.10. Protective Systems in Substations

A fault in its electrical equipment is defined as a defect in its electrical circuit due to which the flow of current is diverted from the intended path. Faults are caused by breaking of conductors or failure of insulation. Fault impedance is generally low, and fault currents are generally high. During the faults, the voltages of the three phases become unbalanced and the supply to the neighbouring circuits is affected. Fault currents being excessive, they can damages not only the faulty equipment, but also the installation through which the fault current is fed. For example, if a fault occurs in a motor, the motor winding is likely to get damaged. Further, if the motor is not disconnected quickly enough the excessive fault currents can cause damage to the starting equipment, supply connections, etc.

Fault in certain important equipment can affect the stability of the power system. For example, a fault in the bus-zone of a substation can cause tripping of all the feeders and can affect the stability of the interconnected system.

Table 1.8 gives fault statistics for a 220 kV system.

Besides the faults, there are several abnormal operating conditions. These include,

—Under voltage, Over-voltage
—Under frequency
—Reversal of direction of power flow
—Poor power factor
—Voltage swings and current swings
—Temperature rise,
—Over-currents

Some of these abnormal conditions are not serious enough to cause tripping. The protection system is arranged to sound an alarm. For serious faults such as short-circuits, the protection system are arranged to trip the circuit-breakers and isolate the faulty section quickly and automatically.

The protective relays are connected in the secondary circuits of current transformers and/or potential transformers. The relays sense the abnormal conditions and close the trip circuit of associated circuit-breaker. The circuit-breaker open its contacts. As arc is drawn between the contacts as they separate. The arc is extinguished by suitable medium and technique.

The *relays* distinguish between normal and abnormal condition. Whenever an abnormal condition develops, the relay closes its contacts. There by the trip circuit of the circuit breaker is closed. Current from the battery-supply flows in the trip-coil of the circuit-breaker and the circuit-breaker opens and the faulty part is disconnected from the supply. The entire process, 'occurrence of fault-operation of relay opening of circuit breaker—removal of faulty part from the system', —is automatic and fast. Circuit breakers are switching devices which can interrupt normal currents and fault currents. Besides relays and circuit breakers, there are several other important components in the protective relaying scheme, these include : protective current transformers and voltage transformers, protective relays, time-delay relays, auxiliary relays, secondary circuits, trip circuits, auxiliaries and accessories, etc. Each component is important. Protective relaying is a team work of these components.

TABLE 1.8. S'atistic of faults in substations

Equipment	*Causes of fault*	*% of Total Faults*
1. Overhead lines and Switch-yards	1. Lightning strokes 2. Storms, earthquakes icing 3. Birds, trees, kites, aero-planes, snakes, etc. 4. Flashovers due to pollution.	30—40
2. Underground cables	1. Damage during digging 2. Insulation failure 3. Failure of joints 4. Overheating	8—10
3. Alternators (Generator)	1. Stator faults 2. Rotor faults 3. Abnormal conditions 4. Faults in associated equipment 5. Faults in protective system	6—8

Contd...

Equipment	*Causes of fault*	*% of Total Faults*
4. Transformers	1. Insulation failure 2. Faults in tap-changer 3. Faults in bushing 4. Faults in protection circuit 5. Inadequate protection 6. Overloading, Over-voltage	10—12
5. CT, VT	1. Over-voltages 2. Insulation failure 3. Breaking of conductors 4. Faults in secondary circuits	5—10
6. Switchgear	1. Mechanical failure 2. Insulation failure 3. Leakage of oil or gas 4. Inadequate Maintenance	5—10
7. Control Cables, Control Circuit, relays	1. Earth faults 2. Open circuits 3. Contact failure 4. Wrong operations 5. Non-operation	5—10

The function of protective relaying include the following :

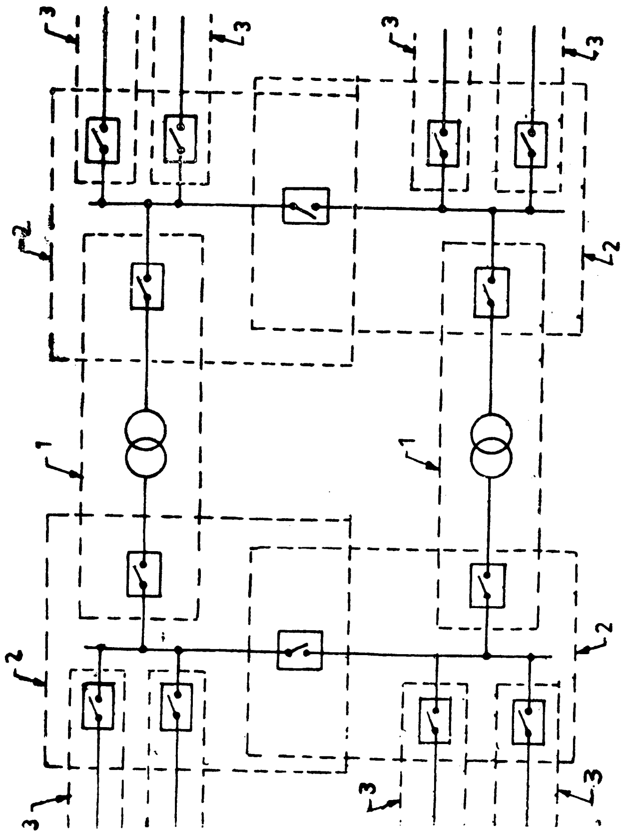
— To sound an alarm or to close the trip circuit of circuit breaker so as to disconnect a component during an abnormal condition in the component, which include over-load, under voltage temperature rise, unbalanced load, reverse power, underfrequency, short circuits, etc.

— To disconnect the abnormally operating part so as to prevent the subsequent faults, *e.g.* over-load protection of a machine protects the machine and prevents insulation failure.

— To disconnect the faulty part quickly so as to minimize the damage to the faulty part.

— To localise the effect of fault by disconnecting the faulty part, from the healthy part, causing least disturbance to the healthy system.

— Recently the functions of supervisory control and data aquisition (SCADA) have been added to the combined protection, control and automation system.



1. Transformer p.z.
2. Busbar Section p.z.
3. Transmission Line p.z.

Fig. 1.9. Protective Zones in a substation.

The substation is covered by several protective zones. Each protective zone covers one or two components of the substation. The neighboring protective zone overlap so that no part of the substation is left unprotected. Each protective system comprises protective transformers, protective relays, all-or-nothing relays, auxiliaries, trip-circuit, trip coil, etc. During the abnormal condition, the protective relaying senses the condition and closes the trip circuit of the circuit-breaker. Thereby the circuit-breaker opens and the faulty part of the system is disconnected from the remaining system.

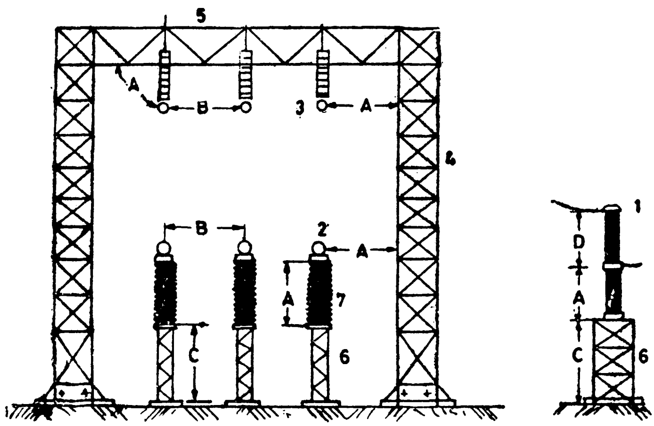
The protective zones are provided for transformers, bus-bars, transmission lines, etc. The protective relaying requirement of the various elements

TABLE 1.9. Primary and Back-up Protective Systems of a 400/230 kV AC System

Protected Part	*Primary (Main) Protective System*	*Secondary (Back-up) Protection System*
1. 400 kV lines	— Distance relay with auto-reclosing system — Over current with time delay for short-circuit and earth faults — Over voltage protection	— Distance relay with autoreclosing system — Over current time delay relays for short-circuits and earth faults — Over voltage protection
2. 230 kV Feeders	— Carrier current differential protection	— Circuit-breaker backup protection
3. 400 kV/230 kV/ 20 kV, 120 MVA Power Transformer	— Buchholz Relay — Differential Protection — Winding temperature and oil temperature protection	— Differential Protection — Circuit, breaker backup — Over-current and earth fault protection
4. 400 kV line shunt Reactor 50 Mvar	— Differential protection	— Over-current time delay protection
5. 400 kV Busbars	— Differential protection	— Circuit breaker backup protection
6. 20 kV Shunt Reactors 20 Mvar	— Instantaneous over current protection	— Over-current time protection — Negative sequence current protection — Busbar differential — Earth fault protection

differ. Various types protective of systems have been developed to satisfy these requirements. For example, the over-current protection responds to increased currents. The differential protection responds to the vector difference between two or more similar electrical quantities.

Protective Zones. The sub-station is covered by several protective zones. The neighbouring protective zones overlap. The boundaries of a protective zone are determined by locations of its CT's. During a fault in a particular protective zone, generally only that zone should get disconnected from the rest of the sub-station. The other healthy parts should remain in service. Each zone has certain protective scheme and each protective scheme has several protective systems.



A Phase to ground clearance B Phase to phase clearance
C Ground clearance (Earth clearance) D Clearance between terminals of C.B.

1. Circuit-breaker
2. Tubular rigid bus
3. ACSR flexible bus
4. Column (Tower)-Galvanised steel
5. Beam (Gantry)-Galvanised steel.
6. Support structure-Galvanised steel.

Fig. 1.10 (*a*) Clearance

Primary and Back-up Protection. In case the primary (main) protection fails, the back-up protection acts and protects the substation equipment. Operation of backup protection results in disconnection of larger part of the substation.

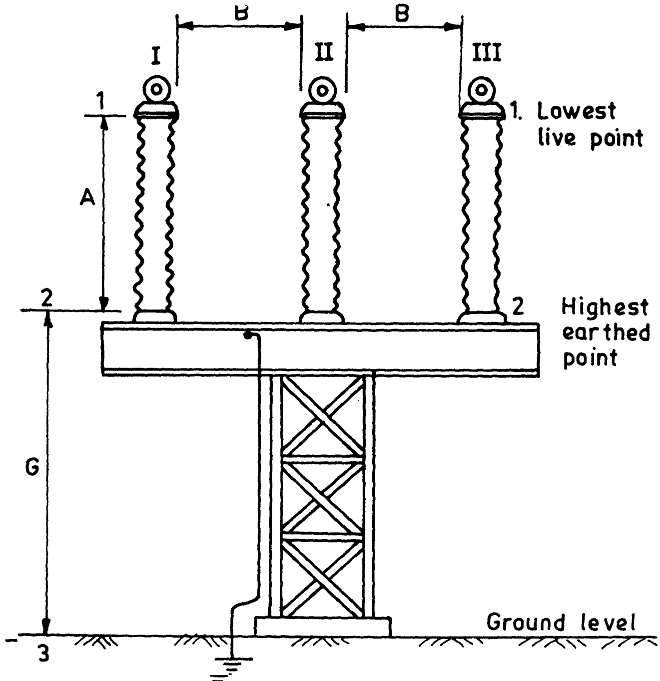
Table 1.9 gives data about Primary protection and Back-up protection in a 400/230 kV AC substation.

The fault-clearing process is fast and automatic. One cycle in 50 Hz system takes 0.02 second. Typical fault-clearing times in the grid-substations are mentioned in Table 1.10. Rapid fault clearing is essential in large grid-substations.

1.11 Clearances (Insulation Distance) and Creepage Distance (Leakage Distance)

The term *Clearance* means the shortest distance between two conducting parts along a stretched string.

Certain minimum clearance is necessary between two phase and between each phase and ground to avoid flashover during lightning or switching over voltage transients.



A-Phase to ground clearance B-Phase to phase clearance
C-Ground clearance
Fig. 1.10 (*b*). Clearances.

TABLE 1.10. Reference Values of fault-clearing times in Grid Substations (*Time in cycles, 1 Cycle = 1/50 sec*)

Function	*HV Systems*	*EHV Systems*
1.1. Main (Primary) Relay	1—2	0.5—1.5
1.2. Main Protection Circuit breaker	1.5—2.5	1—2—2.5
1. Main Protection Fault Clearning time (1+2)	2.5—4.5	1.5—2.5—4
2. Margin, backup Protection, backup breaker	7—12	5.5—6.5
Backup Protection Fault clearing Time (1+2)	9.5—16.5	7—9—10.5

The minimum requirement of phase to phase clearance, phase to ground clearance and section clearance are specified in relevant standards. The values are referred to the impulse withstand levels of the insulators.

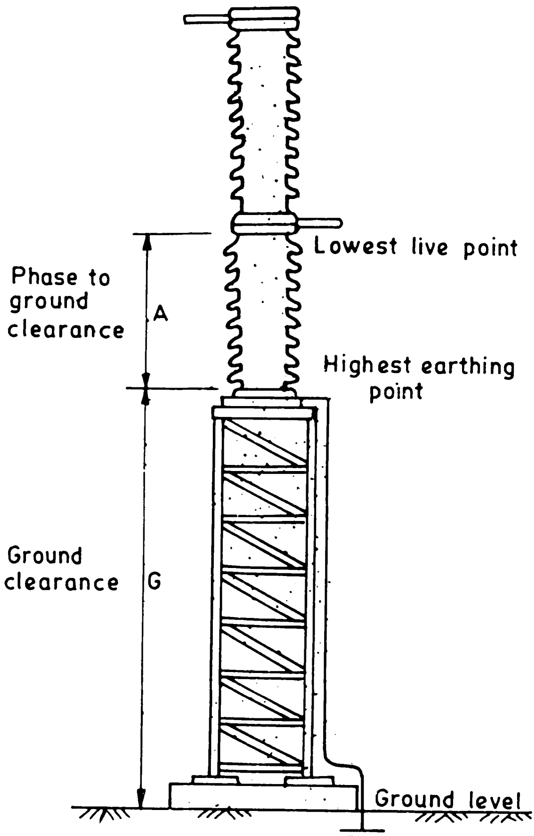


Fig. 1.10 (c). Phase to ground clearance and Ground clearance.

'Creepage' distance or leakage distance is the shortest distance along the surface of insulator across two conducting parts separated by solid insulator. During continuous service voltage, the dust and moisture particles get attached to the surface of the solid insulator forming leakage path for the surface current. When such a leakage path extends from live part to the earth, the flashover occurs and the insulation fails due to surface tracking.

The minimum required creepage distances are recommended for insulators of different voltage class. These values are specified in terms of mm per kV ; where kV refers to the rated phase to phase service voltage of the insulator separate values for equipment to be installed indoor ; outdoor-clean atmosphere, outdoor-moderately polluted atmosphere, outdoor-heavily polluted atmosphere.

The values of minimum creepage distances for a.c. equipment varies between 16 mm/kV for clean atmosphere to 24 mm/kV for heavily polluted atmosphere. The values of clearances for HVDC insulators are higher as the continuous application of D.C. voltage accelerates the tracking process. Clearances of the order of 35 to 50 mm/kV are used for insulators in HVDC substation.

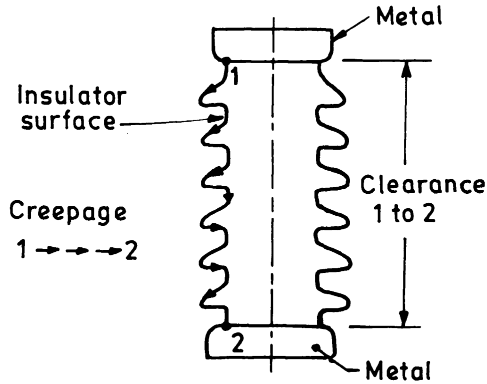


Fig. 1.11. Creepage (Leakage Distance).

TABLE 1.11. Creepage Distances for AC Equipment

Clean Areas	16 mm/kV*
Moderately Polluted Areas	20 mm/kV
Industrial Areas	22 mm/kV
Heavy polluted/coastal Areas	25 mm/kV

* kV refers to highest service voltage, r.m.s phase-to-phase, *e.g.* 36 kV, 72.5 kV, 145 kV.

Definitions Regarding Clearances and Creepages

1. **Creepage Distance.** Shortest distance between two conducting parts along the surface of the insulating material.
2. **Clearance.** Shortest distance between two conducting parts along a stretched string.
3. **Clearance between open contacts.** Gap between open contacts.
4. **Clearance to Earth.** Clearance between conductor and nearest earthed part.
5. **Clearace between phases.** Shortest distance between conducting parts of adjacent phases.
6. **Ground Clearance.** Distance between ground and the highest earthed point on equipment.

   It is the distance between the upper most point of the earthed structure (supporting the insulator) and the ground.
7. **Section Clearance.** The minimum distance between a live conductor and the limits of work section.

8. **Work Section.** A space in which a person may work safely with a condition that some part of his body always remains within that space. Work section is also called **maintenance zone.**
9. **Isolating Distance.** The distance between the nearest conducting parts of an isolator when open.
10. **Outdoor Equipment.** The equipment which can be installed under open sky.
11. **Indoor Equipment.** The equipment which is suitable for installing in the building.

1.12. Power Line Carrier Communication (PLCC)

The communication and that data transmission from one substation to another substation is carried out by means of power line carrier communication system. PLCC utilises high frequency channel in the frequency range between 50 and 500 kHz. The high frequency data is transmitted through the power line conductors. PLCC is also used for protection. In case of very long lines, microwave communication is preferred.

The PLCC equipment comprises the following :

— Line trap unit
— Coupling capacitor
— Tuning unit
— Transmitter, receiver and other electronic equipment.

PLCC is used for voice communication, telemetery, telecontrol, network monitoring, Supervisory Control and Data Aquisition (SCADA). Identical PLCC equipment is installed in the substations at each end of the transmission line.

1.13. Substation Structures

The substation structures constitute one of the major aspect in the cost of the substation. The structures are used for the following :

— Support structures for post insulators
— Support structures for equipment like circuit-breaker, CTs, VTs, Surge Arresters, Isolators, etc.
— Towers and Gantries
— Lightning masts
— Supporting water tanks and other auxiliaries.

Galvanised steel structures made up by bolted or welded joints are preferred in India. Aluminium alloy structures are preferred in USA. The structures are built-up by assembling angles/channels. Taper shapes are preferred in some European countries, whereas uniform cross-section throughout the height is used in some countries.

1.14. Busbar Design, Clamps and Connectors

The busbars in a substation are either rigid type or flexible type.

Rigid busbars are made up of aluminium alloy tubes of 50 to 250 mm diameter. They are supported on post insulators.

Long lengths are obtained by either welding or by clamping adjacent sub-lengths.

Flexible busbars are made up of ACSR conductors. They are supported at both ends by strain insulators. Clamps and connectors are used for the following :

- — Connecting the equipment terminal to the rigid busbars or flexible busbars.
- — Supporting rigid busbars
- — Supporting flexible busbars
- — Extending the length of busbar
- — Taking tee-off from a rigid bus or flexible bus.

For each of the above applications separate well designed clamps are necessary. Clamps are made up of aluminium alloy.

They should be capable of withstanding mechanical stresses, thermal stresses and should be corona-free.

The design of conductor system is based on the following aspects :

1. Cross section required for carrying rated full load current without exceeding the specified temperature for given maximum ambient temperature.
2. Cross-section for specified temperature limits under short-time short circuit condition.
3. Mechanical load due to wind, ice, short-circuit forces, gravity etc.
4. Design of support insulator system :
   - — Bending load *vis-a-vis* cantilever strength
   - — Distance between consecutive insulator supports (span) based on maximum dynamic force and the available cantilever strength.
   - — Requirements of creepage distance, protective creepage, clearance etc.
5. **Materials.** Aluminium alloys of various grades, shapes and lengths are now available. Special sections are developed for large special requirements.
6. **Critical stress and Corona Inception Level.** The diameter and contours of conducting system should be designed such that the surface is smooth and sharp corners are avoided. The diameter

should be large enough to avoid corona at specified test voltage. Special voltage grading rings are provided to reduce surface stress at connections, joints corners etc.

1.15. Special Requirement of EHV AC Substations and HVDC Substations

The envrionmentalists and government rules and regulations have brought forward the following major requirements which should be considered while designing a substations and associated equipment.

1. Audible Noise. Audible noise is produced by transformers, reactors, auxiliaries, conductor system etc. The noise levels at various locations within the substation and at the fence, should be below specified limits (Range 40 to 70 dBA).

2. Radio Interference and TV Interference. The operation of substation and power transfer through transmission lines should not give Radio Interference (RI) and Television Interference (TI) in the neighboring areas. These interferences are caused by corona and also by harmonics.

1.16. Voltage Control Equipment and Reactive Power Compensation Equipment in Substation

The voltage of substation basis should be held within targeted limits (+10%). The voltage is influenced by the flow of reactive power. The following methods are used for voltage control :

— Use of tap changing transformers.
— Switching in shunt capacitor during heavy loads of lagging power factor.
— Use of shunt reactor during low-loads on long transmission lines.
— Use of Static VAr Sources (SVS) or Synchronous Compensators.

By appropriate use of the above means, the voltages at the sending substation and the receiving substation can be maintained within targeted limits.

Voltage profile of long EHV lines varies along the line and with changing load Intermediate compensating substations are installed at an interval of 250 to 300 km.

The voltage control is not possible from remote load-despatch centre. Voltage control depends upon the corrective action in each substation. The strategy for voltage control is planned by system analysis group and directives are given to each substation control-room operator to take appropriate actions.

1.17. Project Planning

The substations are built by the supply company through their project division or separate contractors.

The entire substation project is planned and executed on turnkey basis.

The major steps in executing a substation project include the following :

— Award of contract
— Preparation of quality plans
— Design of civil works, layouts
— Design of equipment
— Opening of site office and preparation of site
— Civil works : excavation, foundation, super structures, finishing
— Receipt of equipment, structures at site, storing
— Laying control cables and power cables
— Laying of earth mat, earth spikes and earth risers
— Installation of overhead shielding wire
— Installation of steel structures
— Installation of equipment
— Transportation of power transformers
— Installation on plinth, drying out and precommissioning
— Quality checks of equipment
— Connection of control cables
— Precommissioning checks, subsystem tests
— Final commissioning and observation
— Handing over to the customers operating staff

The entire project execution is closely monitored at every stage. The project evaluation and review techniques (PERT) are used. The project is monitored with the help of digital computer software.

1.18. Testing and Commissioning at Site

After installation and the preliminary adjustments of the equipment, the site tests are performed. The tests can be classified in groups :

1. Test on equipment.

— Commissioning of auxiliaries
— Checks of mechanical and electrical functions of the main substation equipment.

2. Circuit testing of control cabling and control equipment and protection systems.

— Testing of control and protection equipment with regards to functioning and sequential operations. These tests verify the characteristics of control equipment and protection equipment against the desired characteristics.

3. Pre-commissioning Tests.

— These include tests on all the equipment in accordance with the relevant approved commissioning procedures. These tests are conducted to ensure that the equipment is operationally ready for energising and final commissioning.

4. Subsystem energization tests.

— After successful precommissioning tests the various subsystems (groups of equipment forming a subsystem) are energised and started according to the approved commissioning procedure.

5. System Commissioning Tests.

— After successful sub-system energizing tests, and sub-system tests, the final system commissioning tests are performed. These include the following :

  (*a*) Tests to confirm insulation, voltage, current, power capabilities of high voltage equipment and proper functioning with associated control and protection.

  (*b*) Trial operation under close supervision.

6. Acceptance Tests.

After satisfactory system tests, the acceptance tests are conducted. These include :

(*a*) Tests at and upto nominal continuous ratings.
(*b*) Tests at other load such as minimum load and maximum emergency load.
(*c*) Tests of control functioning.
(*d*) Tests on protection equipment.

The various acceptance tests are conducted with the normal operating mode of the connected network.

The requirement of tests varies with the size, rating and importance of the substation. The tests schedule is drawn in advance and agreed jointly by the owner and the contractor.

1.19. Operation and Control

Large substations are connected between the generating stations and load centres. The supervision, control, protection and operation of large substations is very important in the network control. Modern power systems are large interconnected networks. The major sub-stations are in constant communication with the regional load control centres. The data regarding current, voltage, frequency, power, through the incoming lines and outgoing lines of the substations is continuously scanned. Required data is telemetered to load control centres *via* the PLCC channels. From this data the load control centre knows the loading of various transmission lines. The load control centre determines the appropriate loading of various lines. The load control centre directs the control rooms of various substations and generating station to take appropriate action so as to maintain load-frequency control and exchange desired power between the regions.

The major tasks performed by a large substation control room include :

— SCADA (Supervisory Control and Data Acquisition). The data regarding load on the lines, load on transformers. Busbar voltages etc. is priodically obtained. This may be transmitted to load control centre.

— Protection of transmission lines. During the fault on the transmission lines, the circuit breakers on each end of the transmission line are tripped by the line protection in the respective sub-station. Autoreclosing is generally tried for improving transient stability.

— Voltage control of substation buses is carried out by local load control room by means of tap-changing, compensation of reactive power.

— During heavy loads and under-frequency condition, the substation control room instructs the distribution substation to shed the unimportant loads.

— The various tasks are supervision of loading of various lines, voltages of buses, loading of transformers, planning of routine operation, maintenance of records etc., are performed from the control room of substations.

— Issue of Work Permits, switching off the circuit for maintenance, earthing, safety precautions etc. are ensured from Control Room.

Some of these functions are carried out by on-line SCADA system in the substation control room. Recently, the various functions are being carried out by microprocessors. The softwares have been developed. The 'on-line' functioning determines appropriate action on the basis of the actual values.

1.20. Protection, Monitoring and Control by Microprocessors and Computers

Major substations have power-line communication channels (PLCC) with the load control centres. Data regarding bus voltages, line currents, kW loads etc. are periodically scanned and transmitted from the substation control room to the load despatch centre. The regional load despatch centre gives instructions to substation control room to take appropriate operating action regarding tap-changing of transformers ; loading the transformers, and lines etc. The protection and control functions are carried out by automatic semi-automatic means. The rapid development of computer and micro-processor based SCADA systems have revolutioned the methods of substation control and Network control.

Traditionally the protective functions and control functions were by independant systems. Recently Combined Microprocessor based protection, control and Monitoring systems have been introduced, for substations.

1.21. Scope of the Subject

Several Power Engineers work in electrical substations. The work related with substations covers a wide range of activities such as

- project planning
- design of substations layouts, civil works, structures electrical systems auxiliaries etc.
- specifications of substations and associated subsystems and equipment.
- purchase of equipment
- quality plans and field quality checks
- transportation, receipt at site, storage
- installation, testing, commissioning
- operation and maintenance.

Large EHV substations and HVDC substations form an important part of electrical network. A large amount of power is transferred through substations. There is increasing demand for reduction in noise level, Radio and Television Interference ; increased reliability security and continuity of power. Entirely new types of substations such as HVDC substations ; SF_6 gas insulated substations (GIS) have been recently developed. This book covers the basic principles and practical aspects about various activities pertaining to the modern electrical substations.