# SUBSTATIONS

**Introduction to Substation equipment:**

The bulk power transmitted from generating stations are tapped at substations and distributed locally after step down of the transmission level voltage to suitable distribution level voltage.

**Power Transformers:**

- Used for stepping up of voltage for transmission of electrical power at generating stations and for stepping down the voltage to suitable level for distribution from main receiving stations (main step down transformer substations).
- Up to 10MVA rating, two winding, three phase oil immersed and naturally cooled (ON type) transformers are used.
- For rating above 10 MVA, forced air cooled transformers employed.
- Forced oil, water cooling and forced air cooling (air blast) transformers are employed for very high power applications.
- For adjusting the voltage, transformers are provided with on-load tap changers (which slightly alter the transformer turns ratio in order to vary the secondary voltage for a given primary voltage).
- Designed to operate at full loads during the service. The maximum efficiency is achieved at or near full load with (full load copper loss equal fixed losses or iron loss).
- Usually transformer banks (such that parallel operations is possible) and some of them may be taken out or put into service according to the changes in the load demand.
- Designed with higher leakage impedance (% impedance ranging from 6-18%) when compared to distribution transformers. The operating flux density is 1.5 to 1.77 $Wb/m^2$ and voltage regulation in the range of 6 – 10%
- The specification of the transformers consists of following:

  - KVA rating
  - Rated voltage
  - Rated frequency
  - Number of phases (single or three phase)
  - Connections (combination of Y & Δ for 3 phase transformers)

- Design of the magnetizing circuit (shell or core type)
- Intended use (power or distribution)
- Types of cooling such as:
  - Cooling medium (air, oil or water cooled)
  - Type of circulation (natural or forced)
  - Simple of mixed cooling
- Ambient temperature.
- Permissible rise in temperature during operation in $^{0}$C depending upon the class of insulation used for windings.
- Voltage regulation - in % or per unit at full load unity pf or 0.8 pf lag at 75$^{0}$C.
- Impedance or reactance in % or per unit.
- No load current (A) at rated voltage and frequency.
- Vector group.
- Efficiency in % at full, ¾ and ½ full loads at unity pf and 0.8 pf lag.

- Transformer are installed on rails of suitable length which is fixed on concrete slabs with foundation one to 1.5 meter deep.
- The specifications for power transformers as per Bureau of Indian Standard Specification IS 2026.1962.

3 phase power transformer from ABB with oil and forced air cooling

**High voltage insulators:**

- Insulators are used for providing electrical isolation between live parts/conductors with their supporting structures which are earthed or at ground potential.
- Substations employ mainly post and bushing (through) type insulators which mainly provide isolation and support the bus bars which are live.

**Post type insulators:**

- Made up of porcelain body with cast iron cap and flanged cast iron base.
- The hole in the cap is threaded so that the bus-bar can be directly bolted to it OR through bus bar clamp, the bus bar may be fixed to it.
- Available with threaded caps of one two or four numbers for fixing flanges of different shapes through bolts.
- Earthing bolts or mounting bolts are provided for fixing insulator to suitable structure / location.

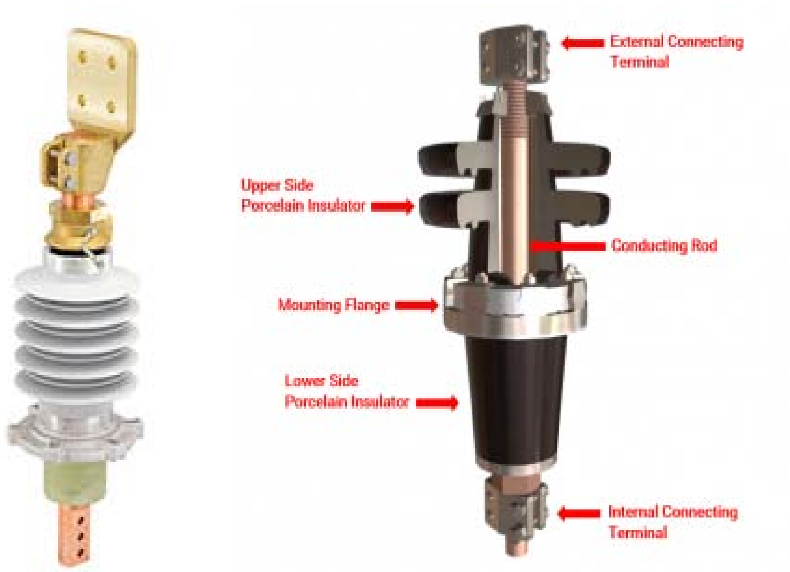
Post insulators with different types of mount for conductors/bus-bars

Post insulator with caps(threaded) for mounting clamp of different shapes

**Bushing or Through Insulator:**

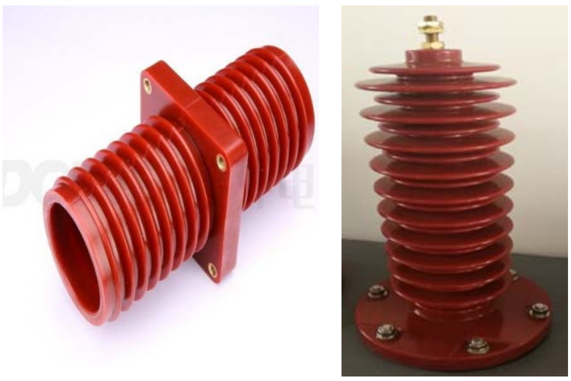
- Consists of porcelain shell body with two sections namely upper side and lower side.

- Upper and lower connecting terminals provided.
- Mounting flange for fixing the bushing insulator to suitable structure through holes provided by means of bolts. Earthing bolt is provided for some type of bushings.



Common bushing insulators used in substations (mainly for transformers)

- Bushing insulators employed for bus bars is shown in the following figure. Higher current carrying bus bar is run through the hole provided in the insulator casing. Second type shows normal bushing insulator which is similar to transformer bushing.
- Coloring scheme may be employed to bushing for identifying the R-Y-B phases of the bus-bars.


Bushing insulators for bus-bars

**Circuit Breakers:**

- Circuit breakers are mechanical devices which are designed to open or close contact members. They primarily isolate the faulty part of the system from rest of the healthy part.

- The main functions are:

1) To carry full load current continuously.
2) Open (break) / close (make) the circuit during no load condition or normal operating condition.
3) To make and break short circuit currents (during abnormal conditions) according to its designed ratings.

- Possible to operate manually/remote control under normal condition and automatically under abnormal condition (during faults).
- A trip coil in circuit breaker is activated by the protective relay (which is a device to sense abnormal condition) which in turn operates the circuit breaker to open its closed contacts.
- Suitable mechanism is employed so that minimal force is required to open the contacts of circuit breakers within fraction of seconds.
- The ratings of circuit breaker are specified as:

1) Maximum rated voltage.
2) Maximum continuous current carrying capacity.
3) Maximum interrupting capacity (the amount of short circuit current it can successfully break by opening the contacts in shortest possible time).
4) Short circuit MVA capacity.
5) Number of auto reclosures and frequency of operations.
6) Short time rating (the maximum current it can withstand upto say maximum of 4 seconds).

- Circuit breakers are available in many types based upon the mechanism of operation, medium of current interruption, speed of operation and application intended.

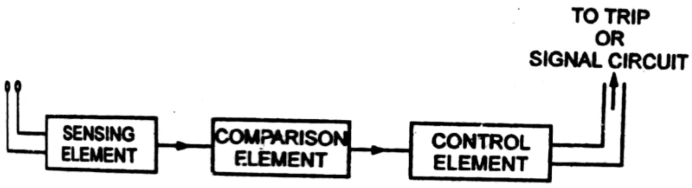
**Protective Relays:**

- Protective relays are the electrical/electronic devices which are interposed between the main circuit and the circuit breaker.
- Various types of protective relays are employed in sub stations.
- Designed to identify particular type of abnormal condition in the circuit and depending upon the severity sending signal for the circuit breaker to open the part of the circuit responsible for that abnormality.

- It ensures the safety of the protected equipments from any damage which might have occurred from the faulty conditions.
- All type of relays have three fundametal elements which are essential for its effective functioning:

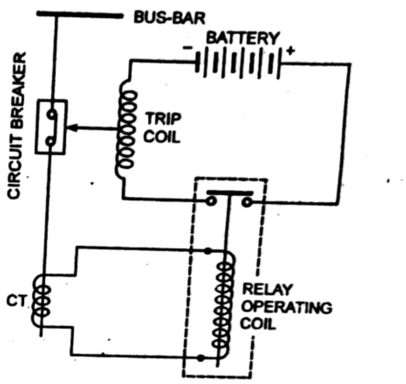
1. Measuring/Sensing element: This element responds to the changes in the actuating quantity. The actuating or sensed quantity is current in a overcurrent relay, frequency in a under frequency relay etc.
2. Comparing element: This elemement always checks the sensed quanity against a pre selected value (relay setting).
3. Actuating / control element: This element finally does the necessary action based upon the comparing element in order to operate circuit breaker depending upon the actuating quanitity is greater than the relay setting.

The above three elements are illustrated in the following figure.




Three fundamenta; functional elements of protective relays

Typical protective relaying circuit for over current protection is shown in the below figure. The connections involve three main circuits as shown below and its working is explained.




Protective relaying circuit (over current relay)

1. The primary winding of current transformer (CT) which is a sensing element and is connected in series with the main circuit which is to be protected.
2. The secondary side of CT connected to relay operating winding (comparing element).

3. The tripping coil circuit and battery (actuating element).

- Under normal operating condition of the circuit, the voltage induced in the secondary of the CT is unable to actuate the relay operating coil. This in turn keeps the trip coil of the circuit breaker de-energized. The circuit breaker contacts remain closed (which carry normal current).too
- During fault condition, primary of the CT senses large current this increases the induced voltage across the secondary and thus the current through the relay operating coil and to close the contacts.
- The trip coil of the circuit breaker gets energized to finally open the circuit breaker contacts.

**High voltage Fuses:**

- Fuses are self sacrifying protective devices which are connected in series with circuit to be protected.
- Used in small length or thin strip and is made up of material of low melting point of suitable cross section.
- For normal operating condition of the circuit, the current will be within the safe limits. During faulty conditon, the current exceeds the limit and the fuse material heats up rapidly and melts down (fuse blow out). The circuit then gets disconnected.
- It is used for protection of devices preventing the flow of excessive currents.
- The fuse obeys inverse time law of operation that is, larger the facult current through the fuse, less is the time required for fuse blow out. This is very much desired for protection purpose.

**Advantages:**

1. It is the most cheapest type of protection with minimum maintenance requiement.
2. Interrupts sufficiently higher magnitude of currents without much noise and smoke.
3. Current interrupting capability during short circuit condition.
4. Minimum time of operation can be made smaller than circuit breaker.
5. Inverse time characterstics is useful for overload protection.

**Disadvantages:**

1. Single use operation and takes time to replace or re-wiring every time after blown out.

2. Descrimination between series connected fuses is not easy and requires selection of fusing material of suitable size.
3. Cannot be employed for high voltage and high power circuits.

Fuses are used in low and medium voltage circuit of medium capacity where frequent operation is not usual. Used in protection of distributon transformers, branch circuits of distribution lines etc.

**High Voltage Disconnect Switches:**

- These are employed for connecting (making) and breaking (disconnecting) the electric circuit in a convenient way.
- Designed to operate at no loads, rated loads and slightly overloads and not to be operated during faulty conditions.
- Two contacts terminals are mounted on high voltage pin or bush insulators which are kept apart depending upon the voltage rating. A conducting strip of metal (blade) acts like a bridge between these two contacts which can be operated with a lever to close or open the two contacts.
- The terminals are in turn connected to conducting wires or cables of electric circuit.
- Two types of switches are used in practice:

1. **Air switches:** The two contacts are opened with air as the medium. These are further classified as Air-break switches and Isolators (disconnect switches).

Typical Air switch showing the moving blade and two terminals for external circuit connection

**Air-break switches:**

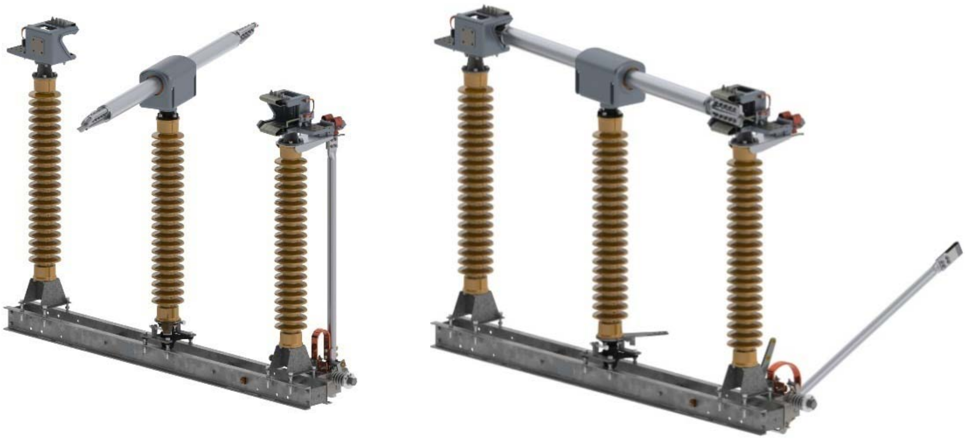
- Both the blades and the other contact pole are provided with arcing horns.

- Arcing horns are the piece of metals where arc (ionized air carrying current) is formed between them when current carrying circuit is opened.
- As the switch is opened further, these horns spread out and arc is elongated and finally it quenches (arc dies) with zero current conduction between the two contacts.
- These come with different designs and operating mechanisms. Usually mounted on poles/structure and operated by insulated rod with lever mechanism or with a crank.
- If group of these types of switches when opened simultaneously by single mechanism is called as ***Gang operation***.

Air break switch with arcing horns

**Isolators:**

- These are also called disconnect switches which are always used under no load condition to isolate some devices from live part of the circuit.
- Isolators are not operated until the circuit is interrupted by some other means (commonly circuit breaker or load switch).
- No arcing horns are provided for quenching the arc current.
- While closing a circuit, first isolator is closed then the circuit breaker or load switch is operated to make the circuit.
- It is provided with insulators for isolation of live parts with the mounting.
- Single break and double break types are available similarly it comes with vertical operation or horizontal operation of the contact blade for isolation between the two contactors.
- Below figure shows a typical isolator used in substations.



Double break horizontally operated isolator showing open and closed positions

2. **Oil switches:**

- The contacts along with the blade are placed oil-filled tank.
- Operation of the switch is performed with the handle or lever mounted outside the tank.
- When the blade moves to open, the arc formed between the blade and the contact is quenched by the oil-medium.
- Used for breaking circuits at higher voltages and operating currents.
- Available for manual or remote controlled operations.
- Mainly used for capacitor bank switching and automatic disconnect in power failure conditions.

**Load Interrupter Switches:**

- These are the switches which are designed to operate at distribution level voltages.
- Able to open or close the circuit during normal working conditions.
- The arc produced from the moving blade during opening is quenched by providing arc chutes and runner.
- An arc chute (which splits the arc into smaller arcs) is usually made up of moulded plastic with organic glass inserts.
- During opening of the blade contact (which carries normal current), arc is formed and which heats up the surrounding medium and it moves upward. The temperature increase causes the organic material inserts to release hydrogen gas.
- This hydrogen gas results in longitudinal blast which finally quenches the arc itself so that the circuit is safely opened.
- Operated manually with lever arm mechanism.

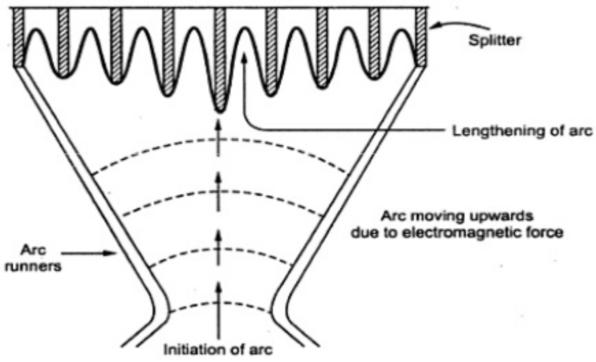



Figure showing the arc runner and the splitters for quenching purpose

**Lightning Arresters:**

- Power system equipments are sensitive to high voltage surges and gets damaged.
- High voltage surges are to be diverted or prevented from entering into the power system equipments.
- Lightning arresters are the devices which are connected between the line and earth. Incoming high voltage surges will be diverted to ground and normal voltage will be isolated from ground.
- The over voltages surges are the result of lightning strikes, disturbance caused due to switching and other factors which causes the insulators to flashover / puncture and it results in cascading damages.
- The working of lightning arresters is by absorbing most of the transient energy in order to prevent dangerous reflections and preventing the normal frequency current at the first current zero after the discharge of the transient.
- The breakdown voltage of arresters is almost independent of the steepness of the wave front.
- Compared with the breakdown time of the insulation of the apparatus, the arresters are designed to discharge transient voltages at a faster rate, which is desirable for safety purpose.

Protection against lightning can be done in three ways, which are mentioned as follows:

1) Ground wires: Transmission towers and its insulators are protected against direct strokes by running a conductor (guard wire/ shielding wire) over the tip of the towers or poles and are earthed at regular intervals (at every tower/pole is most suited).

2) Lightning arresters: Substations, inter connectors and power houses are protected against direct strokes by earthing screen which comprises of network of copper conductors earthed at regular points.

Both grounding wires and earthing screen will not provide protection against high voltage wave surges. In such case, Surge diverter (commonly known as lightning arrester) is the most common device which is used to protect against high voltage waves reaching the terminal equipments.

3) Gaps type arresters: These are the special shape of electrodes which are separated in normal air medium. Rod gaps is the most primitive, low cost surge arrester which is employed as second line of defence against surges. Similarly, horn gap arrester is employed due simplicity and economy in low to medium voltage lines.

**Reactors:**

- Coil with large inductive reactance compared to the its ohmic resistance of the winding.
- Used in systems or circuit in order to limit the short circuit current to a safer limit so as to protect the system. It effectively localizes the fault so healthy part of the system is not affected by the fault.
- The efficiency of the system is not affected since the ohmic resistance of the reactor is very small.
- Some type of reactors is shunted to long lines for reducing the Ferranti effect.
- Two types of reactors are in practical use:

i. **Open type:**

- Cast-in-concrete air-cored.
- Constructed from circular coils or bars of stranded copper which are embedded in number of specially shaped concrete slabs.
- This whole arrangement is placed on a concrete base and mounted on porcelain footstep insulators.
- Very simple in construction and robust.
- Large space required and difficulty of cooling large coils by employing fans
- Not suitable for outdoor applications.
- Applications in systems up to 33 kV only.

ii. **Oil immersed reactors:**

- Oil-immersed gapped iron-cored & Oil-immersed magnetically-shielded coreless.
- Uses insulation and cooling arrangement similar to ordinary transformers with the windings are placed in tanks.
- Air cored construction requires the necessity of laminated iron shield/copper shields around the conductors so as to prevent the magnetic flux entering the tank walls causing losses and heating.
- In iron cored reactors, air gaps are deliberately introduced in the core to obtain magnetising current of desired value and also prevent core saturation during fault current limiting.
- Used in systems for voltages above 33 kV.

**Storage Batteries:**

- Storage batteries required for storing electrical energy in the form of DC.
- Protective relays and plant control requires DC obtained from secondary or storage batteries.
- Storage batteries types are lead acid and alkaline batteries and lead acid commonly employed in practice due to higher voltage per cell and cost.
- These are charged from DC generators run by synchronous motors which run on AC derived from the station.
- Modern trend is to use solid converters for directly charging batteries from AC supply.

**Capacitors:**

- These are the reactive power sources which supply reactive power into the system for obtaining better power factor when connected in parallel.
- Draws leading current when connected to AC source and designed with lesser losses.
- Capacitors of identical type and rating are connected in parallel called banks. Several banks of capacitors are connected to the system or taken out as per the requirement for power factor correction.
- In order to improve power transfer capability of a line series capacitor will be employed.

- Used for AC coupling / Capacitive coupling where power line carrier signal of several kHz is to be injected into the high voltage power line which is operating at 50 Hz and similarly decoupling at the other side.

**Voltage Regulators:**

- The terminal voltage of the alternators can be adjusted during loading conditions in order to cope with internal voltage drops associated with its impedance and power factor.
- The excitation of the alternator is adjusted within the specified limits to regulate its terminal voltage by some percentage.
- The regulator performs the following functions:

  - Adjusting the system voltage within prescribed limits.
  - To adjust the reactors powers from the generators when operated in parallel.
  - To avoid over voltages in the system due to sudden removal/loss of large loads connected.
  - In order to prevent loss of synchronization during fault clearance the synchronizing power can be maximized by increasing excitation.

- The amount of excitation required depends upon the loading condition and power factor. Voltage regulators with precise characteristics is used in modern day alternators.
- Electromagnetic type voltage regulators devised earlier are replaced by electronic voltage regulators due to faster response and sensitivity.

**Measuring Instruments:**

- Modern power stations employ lesser number of operating staff and this requires complete instrumentation and automatic controls for effectively controlling the plants and to achieve economy.
- Instruments are of following types:

  - Indicating
  - Recording
  - Integrating

- Instruments are very essential to monitor and adjust the parameters of the system as per the requirement.
- Continuous information of several parameters is essential for achieving best performance possible and data for obtaining performance parameters on regular intervals.
- The cost and pricing of energy and related economics will be based on the readings obtained from the instruments.
- The state estimation of the system is obtained from these instruments and based on this, the health of the system is evaluated.
- Instruments indicate the health of equipments and based on that maintenance and corrective measures are carried out.
- All of these are properly placed in groups in central room (instrument room/control room) with proper air conditioning.

Instrumentation/control room of a typical substation/power station

The entire set of instruments installed in the power stations/substations are mainly classfied into two categopries:

1. **Mechanical Instruments:** Instruments used for measurement of mechanical quantities, such as pressure, temperature, flow, speed etc. which includes pressure sensors, temperature indicators, flow meters, fuel gauges, gas analyzers, RPM meters etc. These may be mechanically operated or electronically operated.
2. **Electrical Instruments:**These are used for measuring electrical parameters such as current, voltage, power, energy and power factor. The types are ammeters, voltmeters,

watt meters, kWh meters, KVARh meters, synchroscope, frequency meters, ground detectors etc.

**Carrier Communication equipments:**

- The power lines can also be utelized for information exchange with power line carrier equipment. Power-line communication (PLC) carries data on the power conductors working at high voltages such as 110 kV, 220 kV, 400 kV
- The frequency of comunication signal will be the order of 25 to 500 kHz.
- Power-line carrier communication (PLCC) is mainly used for communication, relaying & protection, monitoring and supervisory control.
- Housed in a separate room known as carrier room and connected to the HV line through proper coupling and isolation equipments.

**Bus-Bars:**

- The main conductor (also called bus) which carries electic current and to which many connections are made in order to tap the current.
- With bus-bars it is possible to connect switches and other equipments in various arrangments as per the convinience.
- This arragment is such that it is possible to attend any particular equipment or part of the system without interruption to incoming & outgoing feeders.
- For ease of operation two buses are provided to which incoming and outgoing feeders with the primary equipments connected.
- The first bus is called the main bus and the second called the auxillery bus (or transfer bus).
- Main bus will be associated with eloborate system of measurring instruments, relays etc. in most of the cases.
- In order to transfer feeders and other equipments to any one of the bus, selector or transfer swtiches are employed.
- Bus bars are the copper or aluminium conductors which can be of any suitabe shape (round hallow tubes, solid bars of square or round cross section, rectagular x-section bars etc.
- Aluminium is preferred over copper due to lower cost, corrosion resistance and ease of farmability. In order to improve connectivity, silver coated aluminium material is used.

- Length of standard bus-bar varies from 5 to 6 mts. According to maximum current to be carried, differnet sizes of bus-bars are employed and the most commin size are available in 40×4 $mm^2$, 40×5 $mm^2$, 50×5 $mm^2$, 50×6 $mm^2$, 60×8 $mm^2$, 80×8 $mm^2$ & 100×10 $mm^2$.

**Classification of Sub-Stations:**

- Substations are installed at locations in order to provide electrical energy to local loads in that area.
- Energy received from the generating station is received though high voltage transmission lines, the high voltage is reduced to a level suited for local distribution and fed locally.
- Some substations simply acts like switching stations where transmission lines from different sources are connected together.
- Converting substations rectify AC to DC or vice vesa (invert DC to AC) OR conversion of power frequency to a lower value or vice versa.
- Some protective elements are installed to isolate equipments during facult condition.
- From substations the following operations are regularly performed:

  1. Regulation of outgoing feeders voltages.
  2. Power factor correction.
  3. Instrumentation for monitoring and assessing the condition of the system.

- Street lighting equipments and on/off control of street lights can also be performed.

Classfication of substations are based on several factors such as:

1. Nature of duty performed
2. Types of service offered
3. Operating voltage
4. Its importance
5. Design

Based on nature of duty performed, substations are classfied into three categories:

**1) Step-Up or Primary Substations:**

- Associated with generating stations.

- The power generated at voltage ranging from 3.3 to 33kV.
- This is stepped up to the transmission level voltage in order to transmit the power over a long distance to the load centres economically.

2) **Primary Grid Substations:**

- Located at main load centres along the primary tranmission lines.
- The primary transmission voltage is stepped down to different secondary voltages meant for secondary substations.
- The secondary transmission lines connect these stations to secondary substations (step down substation) which are situated at the load centres.
- These secondary voltages are the sub-transmission voltages/primary distribution voltages.

3) **Step down or Distribution Substations:**

- These are located near load centres.
- The sub-transmission voltages are further stepped down to secondary distribution voltages (440/220V).
- Consumers are connected to these stations through distribution network and service lines.

Based on service rendered, substations are classfied into three categories:

1) **Transformer Substations:**

- Transformers are installed in these substations for the purpose of transfer of electrical power from one voltage level to other voltage level as per the requirement.

2) **Switching Substations:**

- Not for meeting the load demand.
- Only used for switching of power lines without inlvolving voltage transformation.
- Various transmission lines from odther parts are connected together in some fashion.

3) **Converting Substations:**

- Used for conversion of AC to DC or vice-versa.
- Conversion of power frequency to lower value or vice versa.

Based on operating voltages, substations are classfied into three categories:

1) **High Voltage (HV) Substations:**

- The operating voltages lie in the range of 11 to 66 kV

2) **Extra High Voltage (EHV) Substations:**

- The operating voltages lie in the range of 132 to 400 kV

3) **Ultra High Voltage (UHV) Substations:**

- Operating voltages levels above 400 kV

Based on importance, substations are classfied into two categories:

1) **Grid Substations:**

- Stations used to transfer bulk power from one point to another point on the grid.
- Any disturbance occuring in these stations can affect the grid and have more importance.

2) **Town Substations:**

- Employed for step down of supply voltage to either 33/11 kV for distrubution to the town, which is further stepped down to secondary distribution voltages at 440/220V.
- Problems assocaited with these stations can affect power supply to the respective town and not to other parts of the grid.

Substations are classfied into two categories based on the design:

1) **Indoor type Substations:**

- All the necessary equipments of the substation are installed within confined building.
- Commonly employed upto voltage rating of 11 kV.
- Depending upon the surrounding conditions such as pollutants, fumes, gases causing corrosion and conductive dust particles, can be built for voltages upto 66 kV.

2) **Outdoor Substations:**

- Further classified into two categories-

i. **Pole Mounted Substations:**

- Employed for the purpose of power distrubution to localities.
- Single stout pole/ H-pole and 4-pole structures with corresponding mountable platforms for transfomer housing is employed.
- The capacity of transfomer from 25KVA to 250KVA are employed depending on the load requirement.

ii. **Foundation Mounted Substations:**

- Transformer capacity more than 250KVA are heavy and cannot be supported on poles.
- Proper concrete structures are employed to support transformers and are fenced for protection and trespassing.
- Mainly employed for voltage rating of 33 kV and above.

**Indoor Substations:**

Indoor substations come in variety of types depending upon the construction and high voltage switch boards. The main features of such substations are:

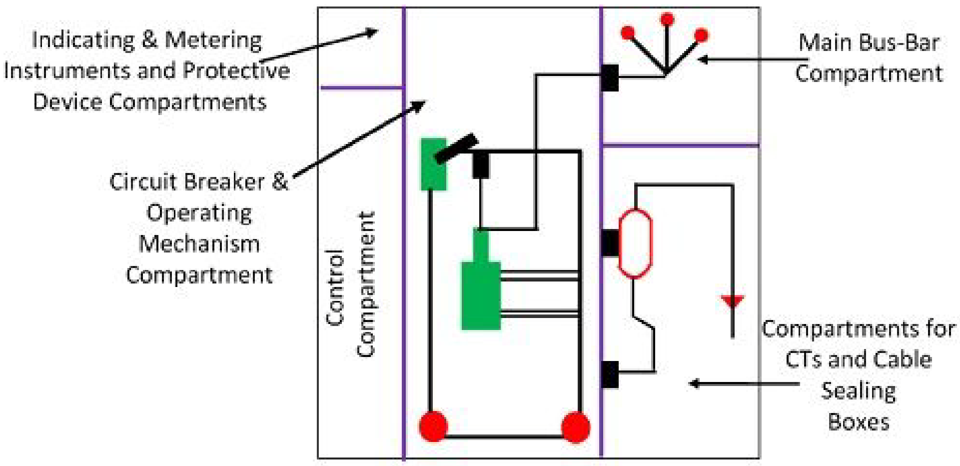
- The high voltage supply to the primary of the transformer is supplied through interposed circuit breaker.
- Different feeders emerge through the bus bars.
- Each feeder panel consists of isolator switch and circuit breaker along with the necessary measuring instruments.
- The oil filled transformers with conservator tanks will commonly have Buchholz’s relay.
- Reverse power relays are employed for the protection of feeders.
- Storage batteries are the auxiliaries which are used for-

  i) Operation of protective gears and for the relay power supplies.
  ii) Emergency lighting in case of complete power supply failure.

- Fire fighting equipments are the other auxiliary equipments consist of fire extinguishers, water buckets and sand.

The different compartments of the stations are as follows and the following diagram represents the typical arrangement of those

- Control compartment
- Instrumentation and protective device compartment
- Circuit breaker with operating mechanism compartment
- Main bus-bar compartment
- Current transformer and cable sealing box compartment




Typical arrangement of compartments in indoor substation

- Commonly all the substations consist of number of open and enclosed chambers or compartments. All the main equipments in the installation are arranged in these compartments which are also called as cells.
- The circuit breaker and its operating mechanism are mounted on the truck, which can be withdrawn from the cubicle and the isolating device is of the plug-in-type.
- Enclosed chamber space where equipment is mounted with main bus-bar is called as a cubicle.

Following are the three categories of indoor substations:

**1. Substations of the Integrally built type:**

- All the apparatus is installed on site.
- The cell structures are constructed using bricks or concrete.

**2. Substations of the composite built-up type:**

- The assemblies and the parts are pre-fabricated in factory or workshops and assembled on site within the substation location.
- The compartments will be of metal cabinets or enclosures in which the main equipment of each cell is housed. This includes minimum oil circuit breaker, load interrupter switch and voltage transformers are mounted.

**3. Unit type Factory Fabricated and metal Clad Switch Boards:**

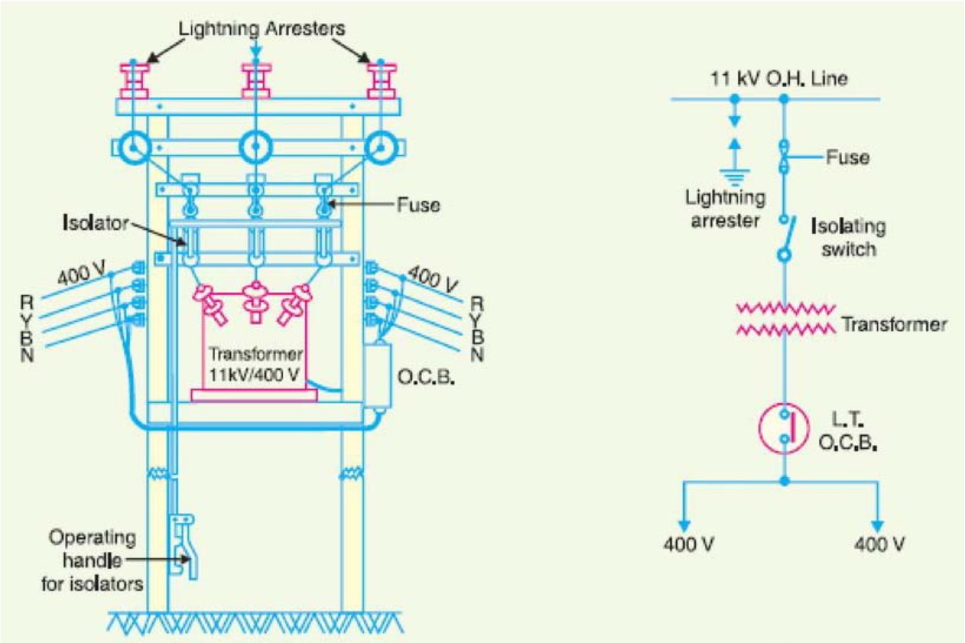
- Fully pre-assembled units built in factory/workshop are shipped to the site.
- After mounting all the necessary units/modules, only connections to incoming and outgoing power circuits are to be done at the site.
- The cubicles will be in the form of fully enclosed metal clad cabinets.
- With the partitioning of cubicle space into compartments, the access to the particular apparatus will be easy and safe.
- The circuit breaker along with its operating mechanism is mounted on the truck. This entire unit can be withdrawn from the cubicle.
- In withdrawable-truck unit-type cubicles, plug-in-type isolating device are employed.
- If the truck is rolled out from the cubicle, the contacts of these devices connecting to live parts are automatically closed by metal shutters serving to isolate the live parts for safety purpose. When the truck is rolled back into the cubicle, the shutters open automatically.
- If the circuit breaker is closed, it is not possible withdraw it from the cubicles by interlocks are provided which prevent the truck from being rolled in or out.

Example for unit type metal clad switch board


Metal clad withdrawable-truck unit-type cubicle

**Outdoor Substations:**

**1. Pole Mounted substation:**



Pole mounted substation for distribution at 440V 3-phase from 11kV mains

- Employed for mounting distribution transformers of capacity up to 250 kVA.
- Cheapest, simple and compact sized substations.
- All the equipment is of outdoor type and mounted on the supporting structure of HT distribution line.
- Triple Pole Mechanically Operated (TPMO) switch of suitable capacity with fuse is used for switching of the HT transmission line to the incoming equipment.
- HT fuse unit is installed for protection at HT side.

- Lightning arresters are installed over the HT line to protect the transformer from the surges.
- Substation is earthed at two or more places.
- Mainly erected in very thickly populated locations to save space with low maintenance cost.
- A large number of such substations in a town achieves total distribution solution at lower capital cost.
- But owing to increase in number of transformers, total kVA and no load losses of the transformers increase which results in higher cost per kVA.

## 2. Foundation Mounted Substations:

Foundation mounted outdoor substation

- Built entirely in the open and all the equipments are assembled into one unit usually enclosed by a fence from the safety point of view.
- Substations for primary and secondary transmission and for secondary distribution, (above 250 kVA) are foundation mounted outdoor type.
- For the ratings designed, equipments required are heavy which necessities good access for proper transport to the site.
- Exposed bus-bars and other associated equipment makes the clearances and spacing in between are governed by the operating voltage and considerations from intrusion by external elements.
- The installation is done in such a manner to provide facility of easy inspection, cleaning and maintenance.

- Earlier, the switchgear used was the circuit breakers of suitable type on both the sides. With the increased reliability of the modern transformers and in order to achieve economy, circuit breaker on the incoming side is dispensed. The isolating switches thus serve the purpose.

Outdoor substations with higher voltage rating 132 & 330kV are represented in the following snapshots.

Outdoor view of a 132kV substation

Switch yard of a 330kV substation

**Advantages and Disadvantages of Outdoor Substations over Indoor Substations:**

Following are the main advantages of the outdoor substations compared to indoor substations:

1) All the equipment is within view and therefore fault location is easier. Repairing work is easy
2) The extension of the installation is easier, if required.
3) The time required in erection of such substations is lesser.
4) The smaller amount of building materials (steel-concrete) is required.
5) The construction work required is comparatively smaller and cost of the switchgear installation is low.
6) There is practically no danger of a fault which appears at one point being carried over to another point in the installation because the apparatus of the adjoining connections can be spaced liberally, without any appreciable increase in costs.

Outdoor substations are widely employed in spite of some of its drawbacks. The disadvantages of outdoor installations in comparison of indoor installations are:

1) The various switching operations with the isolators, as well as supervision and maintenance of the apparatus are to be performed in the open air during all kinds of weather.
2) More space is required for the substation and requires lengthy control cables.
3) Adequate measures are to be taken for protection against lightning surges.
4) The influence of rapid fluctuation in ambient temperature and dust and dirt deposits upon the outdoor substation equipment makes it necessary to install apparatus specially designed for outdoor service and therefore costlier.

**Selection and location of site for a Substation:**

The following factors are considered while making site selection for a substation:

**1. Type of Substations:**

- The location of substation mainly based on the category.
- Step-up substation where power from various sources (generating machines or generating stations) is pooled and stepped up for long distance transmission should be located as close as possible to the generating stations for minimizing the transmission losses.
- Step-down substation should be located nearer to the load centre to reduce distribution losses, cost of distribution system and better reliability of supply.

2. **Availability of suitable and sufficient land:**

- The land proposed for a substation should be normally level and open from all sides.
- During any point of time that too in rainy season there should not be water logging.
- The site selected should be such that approach of transmission lines and their take off can be easily possible without any obstruction.
- Land nearer to airport, shooting practice grounds etc., should be avoided.
- As per the present trends, the land required for various types of substations is given in the below table.

| Substation Type | Area Required in Acres |
|---|---|
| 400kV | 50 |
| 220kV | 25 |
| 132kV | 10 |

3. **Communication Facility:**

- Suitable communication facility is desirable at a proposed substation both during and after its construction.
- Selection of the site along-side on existing roadways is preferred to facilitate easier and cheaper transportation.

4. **Atmospheric Pollution:**

- Locations near factories which may produce metal corroding gases, air fumes, conductive dust etc. to be avoided.
- Coastal areas with humid and salty conditions are not preferred for the installation of substations.

5. **Availability of Essential Amenities to the Staff:**

- Preferred location is such that essential amenities like school, hospital, drinking water, housing etc. can be provided to the staff.

6. **Drainage Facility:**

- The site selected for the proposed substation should have proper drainage facilities or effective drainage arrangement can be provided in order to avoid pollution of air and growth of micro-organisms detrimental to equipment and health.

**Main Electrical Connections in Substations:**

- The electric power is received and distributed through substations by means of the main bus-bars.
- All necessary equipments are connected to these bus bars according to some scheme.

In practice there are two fundamental types of power station and substation circuit arrangements:

(1) The main connections of primary (or power) circuits.
(2) The secondary (or control) circuit arrangements.

**Primary Circuit Main Connections:**

- Circuit main connections are represented by either single line or three-line schematic or elementary diagrams.
- Single line schematic shows all three-phases of each circuit as a single line.
- Three-line schematic shows each phase of every circuit as a separate line (three-phase circuit are represented as three lines corresponding to each phase).

**Single line diagram:**

- Represents the electrical circuit arrangement of any electrical power installation in its basic form.
- Aids the designer in selecting the electrical equipment for any given installation such as protective relay, control and signalling-alarm system schemes and their elementary and wiring diagrams.
- In the day-to-day operation of installations, single line diagram in the form of operative diagrams play an important role in the performance of all circuit switching operations.
- Indicates all the main elements of any given installation such as generators, bus-bars, power transformers, circuit breakers, isolators, series and shunt capacitors, fuses, CTs and PTs, line trap units, diode or thyristor rectifiers, static VAR sources, harmonic filters, surge arresters etc.

**I. The components in series with the main circuit of power flow are:**

➢ Bus-bars

- Power transformers
- Circuit breakers
- Isolators& Fuses
- Current Transformers
- Line trap units
- Series capacitors and reactors
- Solid state rectifiers etc.

**II. The components in shunt circuits connected between phase and ground:**

- Shunt capacitors
- Shunt reactors
- Static VAR compensators
- Harmonic filters
- Potential Transformers
- Lightning or surge arresters etc.

**III. Interconnecting high voltage power lines with the main bus-bars in the substations:**

- Isolators (or disconnecting switches)
- Circuit breakers
- Instrument transformers etc.

**IV. Lightning/surge arresters are connected phase to ground at the incoming line as the first apparatus and to terminals of the following:**

- Transformer
- Capacitor bank & Shunt reactor
- Generators and Large motors

**V. Connections are of divided into three kinds:**

1. **Incoming**: Power feeder connections into the substations from the main power lines.
2. **Tie**: Lines interconnecting two substations and each of which are fed through its own incoming feeder connections.
3. **Outgoing**: Feeder connections for feeding other subsequent substations.

In addition to above type of connections, the specific connections of some of the equipments/instruments based on general practice, particular switching requirement, maintenance and protection purpose are as follows.

- PTs are generally connected to bus-bars and on incoming line side for control and metering purpose.
- Circuit breaker is connected between the bus-bar and each incoming and outgoing circuit.
- Isolator is provided on each side of the circuit breaker.
- CTs are provided for measurement and protection. In order to overlap protection zones and to cover the circuit breaker, they must be included on both sides of the circuit breaker.

**The main connection scheme is drawn keeping in view the following factors:**

1. General bus-bar arrangement.
2. Operating voltage.
3. Number of incoming and outgoing lines.
4. Number of transformers.
5. Safety to equipment and operating personnel.
6. Future extension requirement.

- The main connection diagram drawn for a substation shows the arrangements of all the circuits with its main bus-bars.
- Electrical connections of a substation are usually represented by a single line diagram and it implied that all the phases are connected identically.

**Bus-bar arrangement Schemes:**

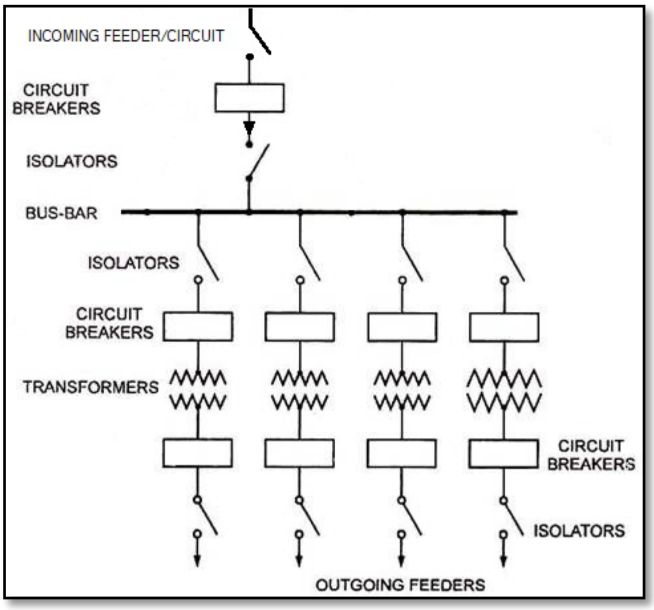
- Substation bus-bars are the most significant part which is required to handle large amount of electrical energy within a confined space.
- Designed to handle all the loads and to withstand the severe possible electro-mechanical forces.
- Different types of electrical bus system arrangement schemes are used in practice and selection of a particular scheme depends upon the system voltage, the location, significance of substation in power system, flexibility needed in system and the cost

involved. The selection of a given type of bus-bar scheme depends upon the following factors:

- Simplicity of system.
- Easy maintenance of different equipments.
- Minimizing the outage during maintenance.
- Future provision of extension with growth of demand.
- Optimizing the arrangement scheme so as to get maximum returns from the system.
- Available area and location of connecting lines.

Following are the commonly employed bus bar arrangement schemes

**Single Bus System:**



Single Bus-Bar arrangement

- Simplest arrangement consisting of a single bus-bar with all the incoming lines, transformers and feeders are connected to this bus.
- Each incoming and outgoing feeder is controlled by a circuit breaker and respective isolators for isolation of all these from the bus-bar during maintenance.
- Scheme is employed in small, medium sized substations with voltage levels up to 33kV, small power and DC stations.

**Advantages:**

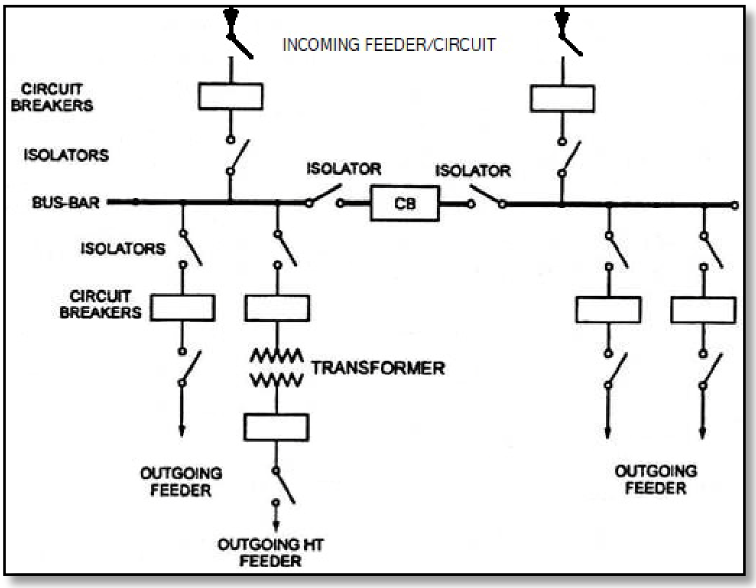
- Very simple design & operation

- Low initial cost

**Disadvantage:**

- Difficulty of maintenance and repair.
- No flexibility due to only one bus available.
- Total power interruption in outgoing lines due to failure of single bus.
- Future expansion of bus requires total interruption of supply to outgoing feeders

**Single Bus System with Bus Sectionalizer:**




Sectionalized single bus bar system

- The bus-bar is divided into two sections by a circuit breaker and isolators and both incoming and outgoing circuits are distributed evenly on the sections.
- A fault on one part does will not affect the other and prevents a complete shutdown.
- Normally the number of sections of a bus-bar are 2 to 3 in a substation and mainly limited by the short-circuit current to be handled.
- In a sectionalized bus-bar arrangement only one additional circuit breaker is required which does not cost much in comparison to the total cost of the bus-bar system.

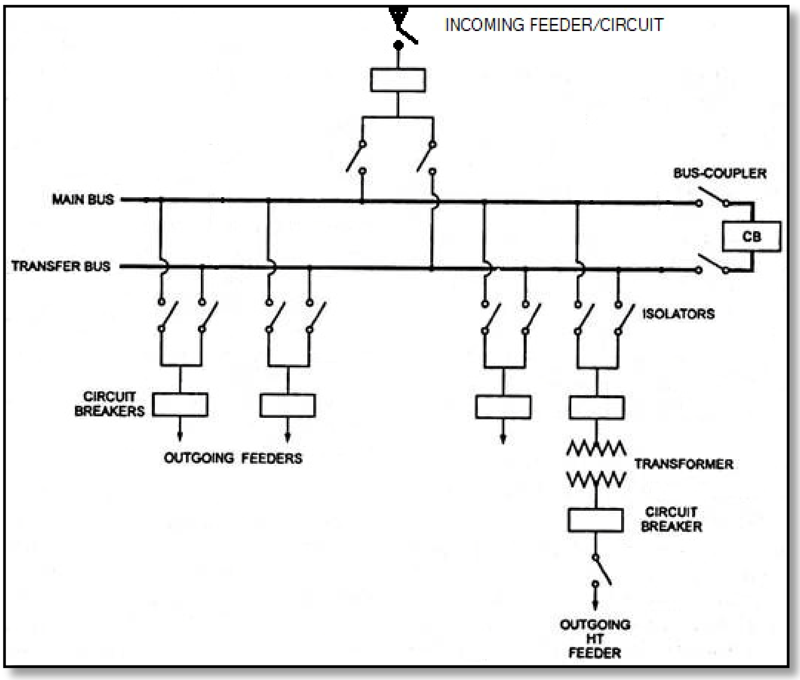
**Advantages:**

- If one section of the bus bar system is under maintenance then a part of the load on the substation can be fed by the other section of the bus bar which involves the switching the sectional circuit breaker or bus coupler breaker.

**Disadvantage:**

- Similar to single bus system the outgoing circuit will be interrupted during maintenance of equipment connected to it.

**Main and Transfer Bus arrangement:**




Schematic of Main and Transfer bus arrangement

- Provides additional flexibility, continuity of supply and allows periodic maintenance without total shutdown.
- Suitable for highly interconnected power network in which flexibility is the main feature.
- This arrangement consists of two bus-bars and one is the main bus-bar and second one is the transfer bus-bar (used as an auxiliary bus-bar).
- Each incoming and outgoing circuit may be connected to either bus-bar with the help of bus coupler/tie-circuit breaker which consists of a circuit breaker and isolators.
- In order to this arrangement change-over from one bus-bar to the other can be carried out under load conditions through the bus coupler.

**Merits:**

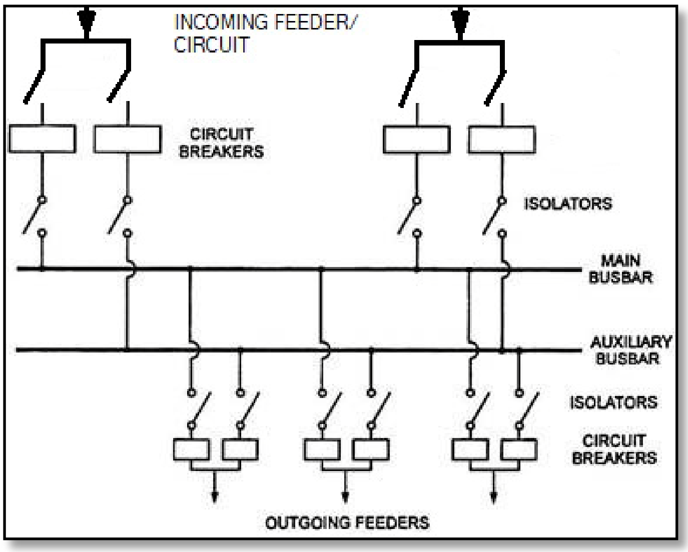
- Some amount of flexibility is provided with two operating buses.

- Any one of the bus can be isolated for maintenance without interrupting the supply as the entire load can be transferred to the auxiliary bus. Similarly during fault on one bus the entire load can be on the other bus.
- Ease of circuit changeover from one bus to other bus by the use of bus-tie circuit breaker with isolators.

**De-merits:**

- Two extra isolators are required per circuit
- Needs one extra breaker and isolators which increases the cost of the system
- While one bus is out of service for maintenance and line fault on any circuit will cause total supply interruption.

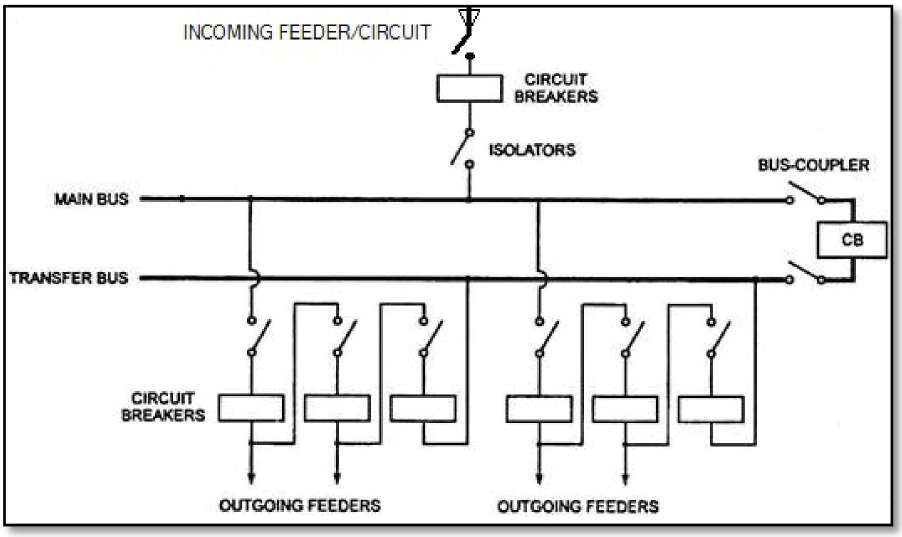
**Double Bus Double Breaker bus system:**




Schematic of Double Breaker Bus arrangement scheme

- In this system two circuit breakers are employed for each circuit.
- No bus coupler is required and permits switch-over from one bus to the other without interruption.
- High installation and maintenance cost.
- Maximum flexibility during faults and also during the time of maintenance hence the scheme is more reliable.

**One-and-a-Half Breaker arrangement:**



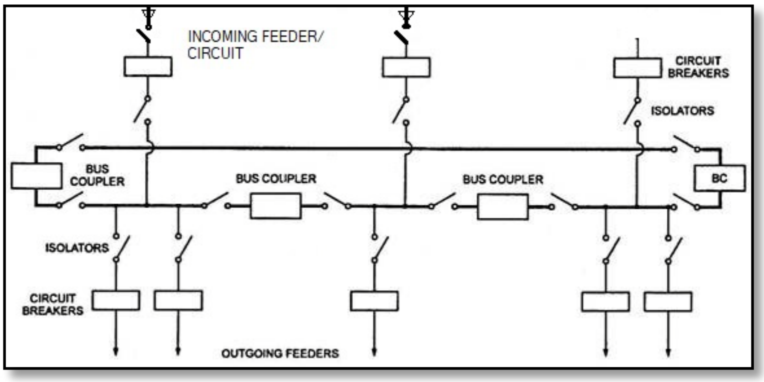

One-and-a-Half circuit Breaker arrangement

- This is an improvement over double bus double breaker arrangement and it affects saving in the number of circuit breakers.
- Needs three circuit breakers for two circuits with the number of circuit breakers per circuit works out to be 1½ and hence the name.
- Preferred in large stations where power handled per circuit is large.
- Provides high security against fault in a bus or in a breaker with no interruption of the supply.
- Possibility of addition of circuits to the system is another advantage.
- Main drawback of this arrangement is complications in relaying system because at the time of fault two breakers are to be opened.
- The other drawback is that for maintenance of circuit breakers without load shedding requires the opening of two breakers while the other circuit in the line-up will be operating with one breaker from one bus only.
- At the time of fault in that bus supply to the other circuit is also interrupted.
- The maintenance cost is higher.

**Ring Main Arrangement:**

- This is an extension of the sectionalized bus-bar arrangement where the ends of the bus bars are connected at both the ends as a loop (to form a ring circuit).
- Provides greater flexibility as each feeder is supplied by two paths such that the failure of a section does not cause any interruption of the supply.

- The effect of fault in one section is localised to that section alone and the rest of the sections continue to operate.



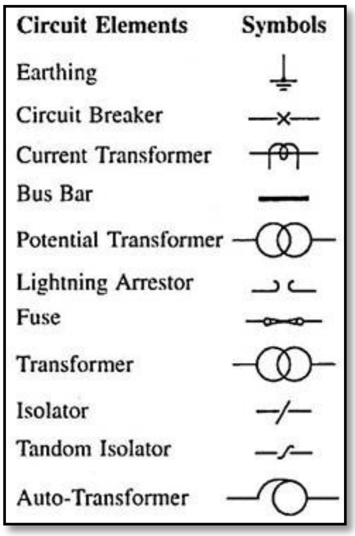

Schematic of Ring main arrangement

- Circuit breakers can be maintained without interrupting the supply.
- The cost is not considerable as the numbers of breakers used are nearly the same as that of a single bus-bar system.
- The main draw backs are:

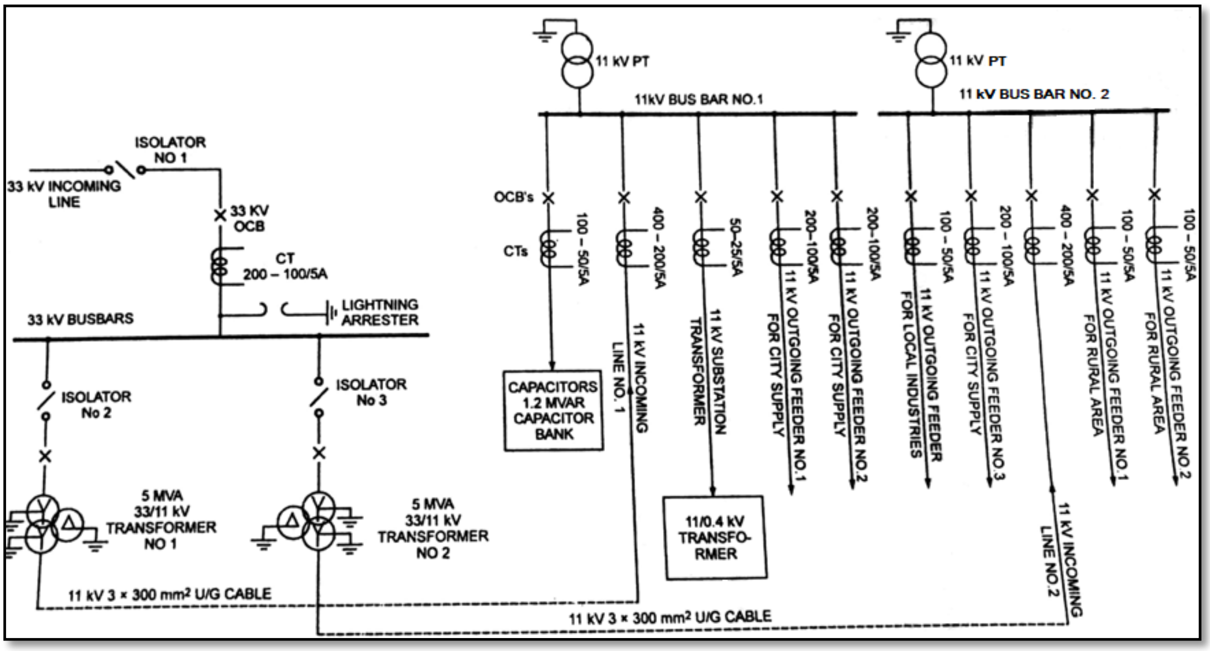
  - Addition of new circuit in the ring will pose difficulty.
  - Possibility of overloading of the circuits on opening of any section of the breaker.

**Graphical symbols of various elements of substation:**

All the main elements of substation installation are represented by standard graphical symbols. The representation of these on the single line diagram is as given below.



Typical Single line diagram of a 33kV substation is represented in the following figure. The connection of various elements is according the points mentioned above.




Single line diagram of a 33KV substation with two bus bar arrangement

**Gas Insulated Stations (GIS):**

- Conventional substations are open types which are exposed to atmosphere and prone to pollution and contamination.
- Corresponding to the dielectric & insulation strength of the air medium, sufficient clearance among various components and ground is required.
- The area required for installation of substation limits their use in growing needs of the society and up gradation whenever space is the constraint.
- Earth quake and related events causes considerable damages.
- Less reliable.
- Electro Magnetic Compatibility issues and corona noise.

To achieve compactness with lesser floor area, GIS are increasingly gaining popularity in recent times. It overcomes majority of the drawbacks associated with conventional substations and are given below.

- Highly reliable and compact.
- Free of contamination and pollution effects.

- Less influence on the environment during construction.
- Free of interference noise and lesser issues with EMC.
- Up gradation to higher voltage level is possible without much difficulty.
- Useful in metro cities where getting sufficient land for substation is difficult.
- Least affected by earth quake etc.

Gas filled substation inside a building of metallic structure

**Features:**

- GIS is a high voltage substation in which the major structures are contained in a sealed environment with gas as the insulating medium.
- Compared to normal air the Sulphur Hexafluoride gas ($SF_6$) has superior dielectric and insulation strength.
- Equipments such as circuit breakers, bus-bars, isolators, load break switches, CT& PT, and earthing switches are housed in metal enclosed modules which are filled with $SF_6$ gas at moderate pressure.
- Originated in Japan as a need to develop technology in order to realize substations as compact as possible.
- The clearance required for phase to phase and phase to ground for all equipment is much lower than that required in an air insulated substation.
- The total space required for a GIS is 10% of that needed for a conventional substation of similar rating.
- Because of sealed environment, GIS is less sensitive to pollution, least affected by salty environment, sand or snow.

- Initial cost of installing a GIS is higher than that of air insulated substation but the operation and maintenance costs are significantly less.
- $SF_6$ is highly electronegative in nature which has strong tendency to absorb free electrons. This makes it an excellent arc quenching medium.
- $SF_6$ does not age or deplete and no need to top-up gas levels during the lifetime of equipments. Thus the need for maintenance on any component within the switchgear is negligible.
- For voltage ratings of 66kV and higher these are employed.

**Disadvantages:**

- $SF_6$ is a greenhouse gas and more potent than $CO_2$. Proper sealing is required so that extremely negligible quantity is lost into atmosphere.
- It is heavier than air and odourless.
- During arcing phenomenon in this gas, some of toxic by-products are formed which causes skin irritation.
- Insulation coordination problem in systems connected to overhead lines through underground cables. This requires fitting of high impulse voltage rating surge arresters at the line to cable junction.