# Module 4

# Substations

# Electrical Substations

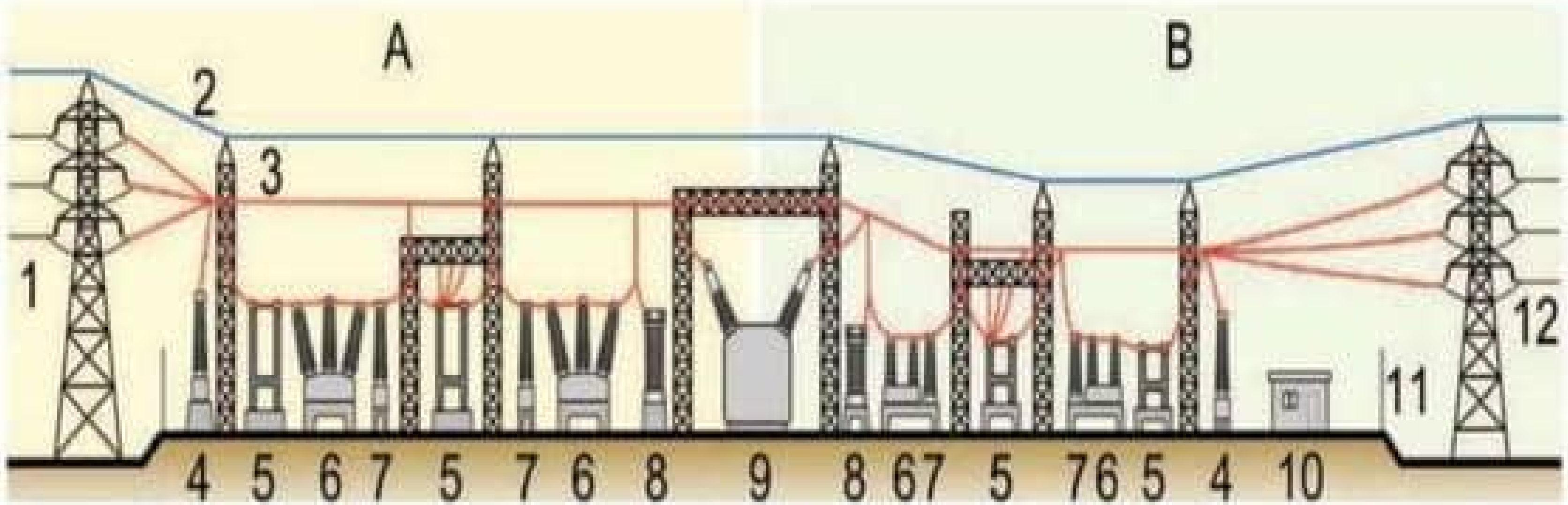
- Introduction to Substation Equipment.
- Transformers, High Voltage Fuses. High Voltage Circuit Breakers and Protective Relaying.
- High Voltage Disconnect Switches, Lightening Arresters.
- High Voltage Insulators and Conductors, Voltage Regulators, Storage Batteries, Reactors and Capacitors
- Measuring Instruments and Power line carrier Communication equipment.
- Classification of Substations- indoor and outdoor.
- Selection of site for substation, Bus-bar Arrangement Schemes and single line diagram, Inter connection of power stations.
- Introduction to gas insulated substation.
- Advantages and economics of Gas insulated Substations.

# Introduction to Substation Equipment

- A substation is the intermediate means between high voltage transmission or distribution and end user including connecting generators, transmission or distribution lines, and loads to each other, and generally stepping higher voltages down to lower voltages to meet specific customer requirements.
- For example we cannot use electricity directly form 11 KV power line or 33 KV power line. In order to use energy from these lines we would have to get power through substation from these lines. Therefore it is required to install a substation.
- Also if we want to transmit electrical energy over long distance, then it is also required to install a substation to get high voltage for transmission.

# Introduction to Substation Equipment

- A **substation** is a part of an electrical generation, transmission, and distribution system.
- Substation can be as simple as one pole mounted transformer near our homes and villages or factory and as complex as several … Power transformers, auxiliary transformers, Current Transformers(CTs), Potential Transformers(PTs), circuit breakers, isolators, bus-bars, Liner protection system (LPS), LT panel , HT panel , Power factor improvement(PFI plant) , Automatic Voltage Switches(AVS) , Industrial voltage Stabilizer(IVS) , Automatic Transfer Switch(ATS) , HT cable , LT cable, Main Distributing board , Sub Distribution board & others small & heavy electrical equipment's all in one yard.




**A: Primary power lines' side B: Secondary power lines' side**

**1. Primary power lines** **2. Ground wire**
**3. Overhead lines** **4. Transformer for measurement of electric voltage**
**5. Disconnect switch** **6. Circuit breaker**
**7. Current transformer** **8. Lightning arrester**
**9. Main transformer** **10. Control building**
**11. Security fence** **12. Secondary power lines**

# Introduction to Substation Equipment

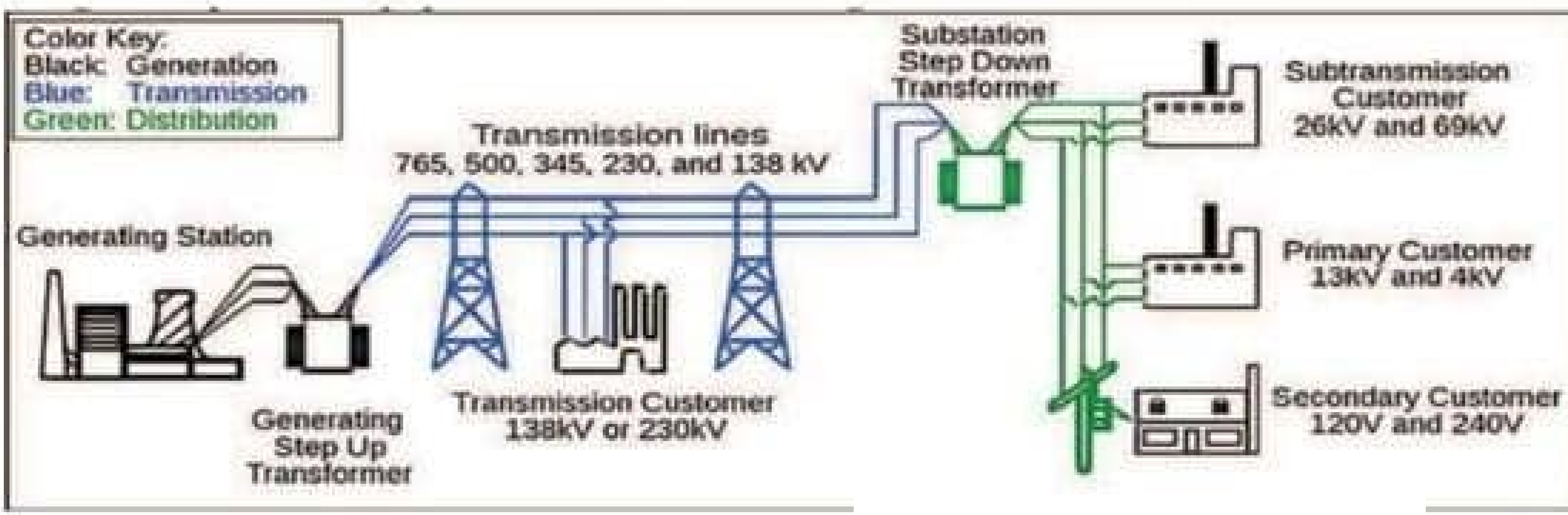
- The present-day electrical power system is a.c. i.e. electric power is generated, transmitted and distributed in the form of alternating current.
- The electric power is produced at the power stations which are located at favorable places, generally quite away from the consumers.
- It is delivered to the consumers through a large network of transmission and distribution. At many places in the line of the power system, it may be desirable and necessary to change some characteristic(e.g. voltage, frequency, p.f. etc.) of electric supply.
- This is accomplished by suitable apparatus called sub-station. For example, generation voltage (11 kV or 6·6 kV) at the power station is stepped up to high voltage(say 220 kV or 132 kV) for transmission of electric power

# Introduction to Substation Equipment

- The assembly of apparatus (e.g. transformer etc.) used for this purpose is the sub-station. Similarly, near the consumers localities, the voltage may have to be stepped down to utilization level.
- This is accomplished by a suitable apparatus called sub-station. Yet at some places in the line of the power system, it may be desirable to convert large quantities of a.c. power to d.c power e.g. for traction, electroplating, d.c motors etc.
- This job is again performed by suitable apparatus (e.g ignitron) called sub-station. Although there can be several types of sub-stations, we shall mainly confine our attention to only those sub-stations where the incoming and outgoing supplies are a.c. i.e. sub-stations which change the voltage level of the electric supply.

# 1. Transmission substation:

- A transmission substation connects two or more case is where all transmission lines have the same voltage. Transmission substations can range from simple to complex.
- Nowadays, transmission-level voltages are usually considered to be 110 kV and above. Lower voltages, such as 66 kV and 33 kV, are usually considered sub-transmission voltages, but are occasionally used on long lines with light loads. Voltages above 765 kV are considered extra high voltage and require different designs compared to equipment used at lower voltages.



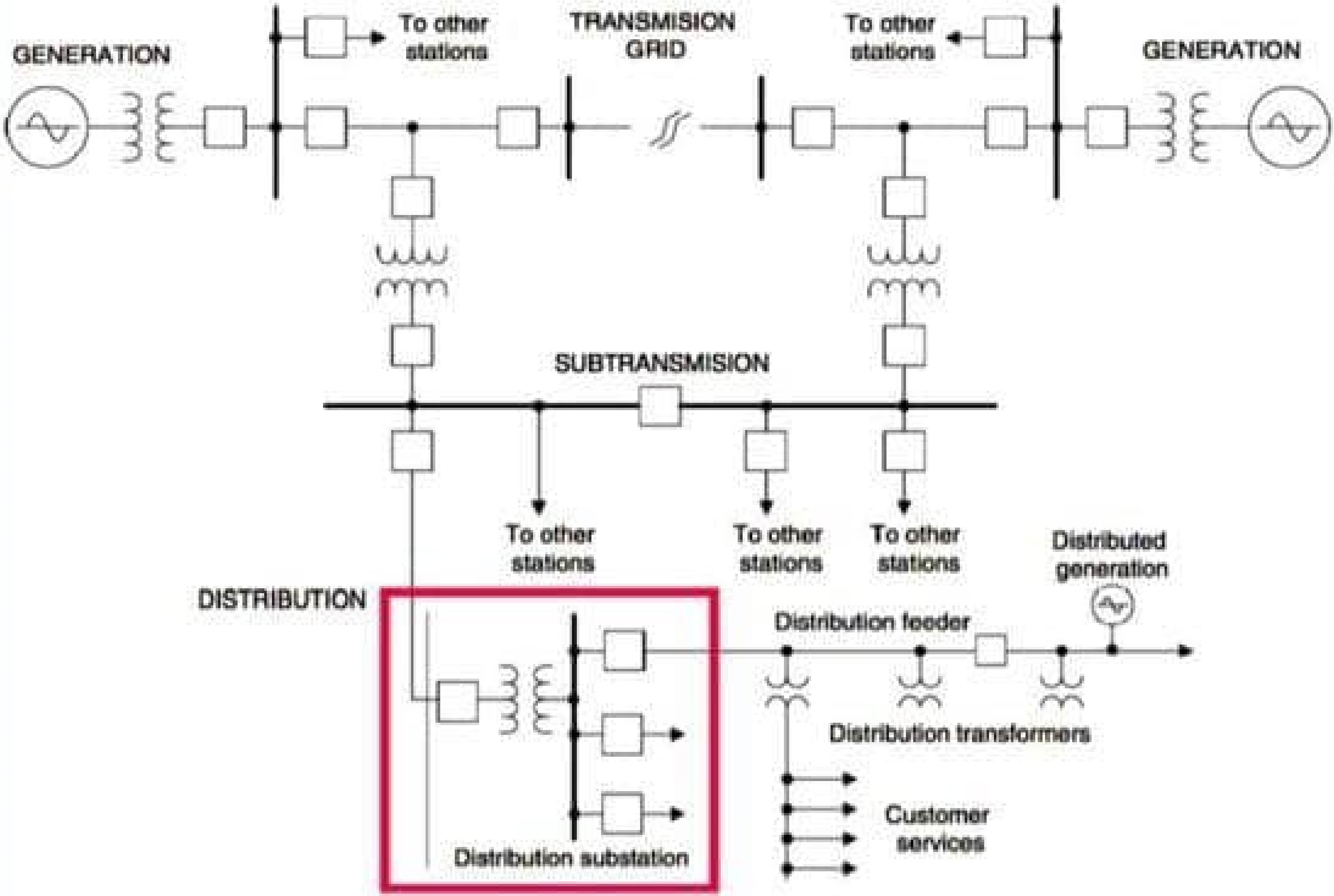
# 2. Distribution substation

- A distribution substation is a combination of switching, controlling, and voltage step-down equipment arranged to reduce sub-transmission voltage to primary distribution voltage for residential, farm, commercial, and industrial loads.

Distribution substation is generally comprised of the following major components:

a) Supply Line
b)Transformers
c) Bus-bars
d) Switchgear
e)Out-coming feeders
f)Switching apparatus
g) Switches
h)Fuses
i)Circuit breakers
j)Surge voltage protection
k)Grounding

# Distribution substation

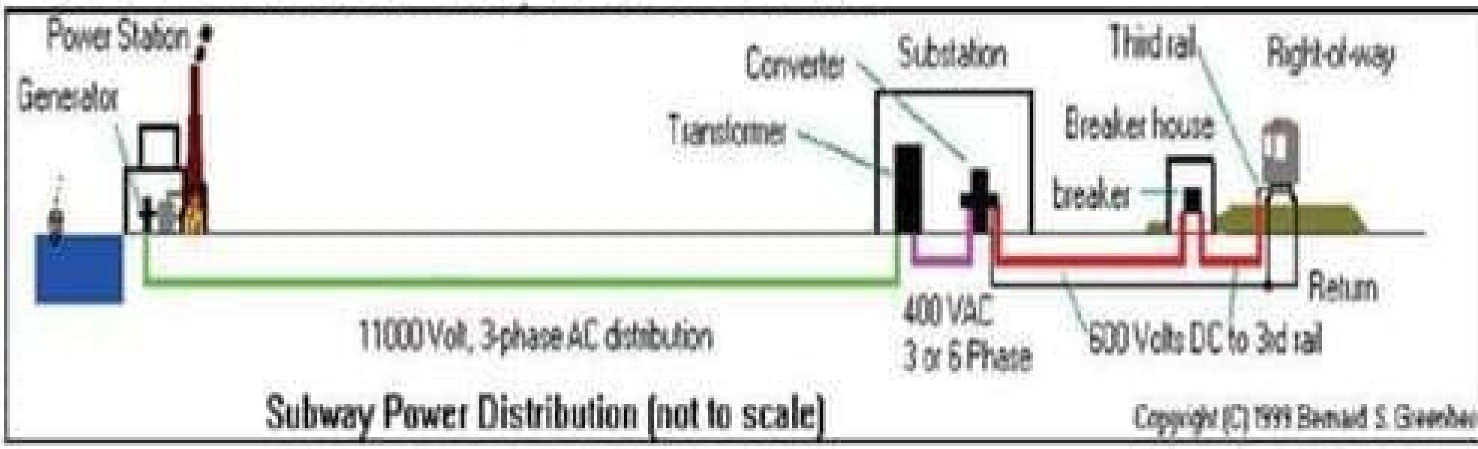


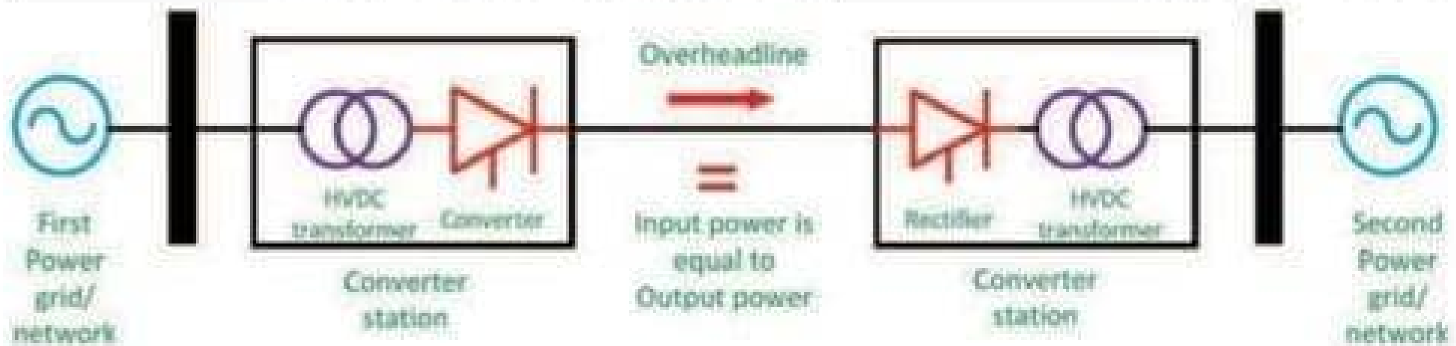
# 3.Converter substations

- A converter station converts electricity between Alternating Current (AC) and Direct Current for sending electricity.
- Converter substations may be associated with High Voltage DC (HVDC) converter plants, traction current, or interconnected non-synchronous networks.
- These stations contain power electronic devices to change the frequency of current, or else convert from alternating to direct current or the reverse.
- Direct current or HVDC (high voltage direct current) links are used for exchanges between countries exclusively on a transmission network level.

# Converter substations

- Several different levels of project costs have been incurred for a HVDC system with a power transfer capacity around 200kV & 600 MW. Different types of converter station used for DC end.



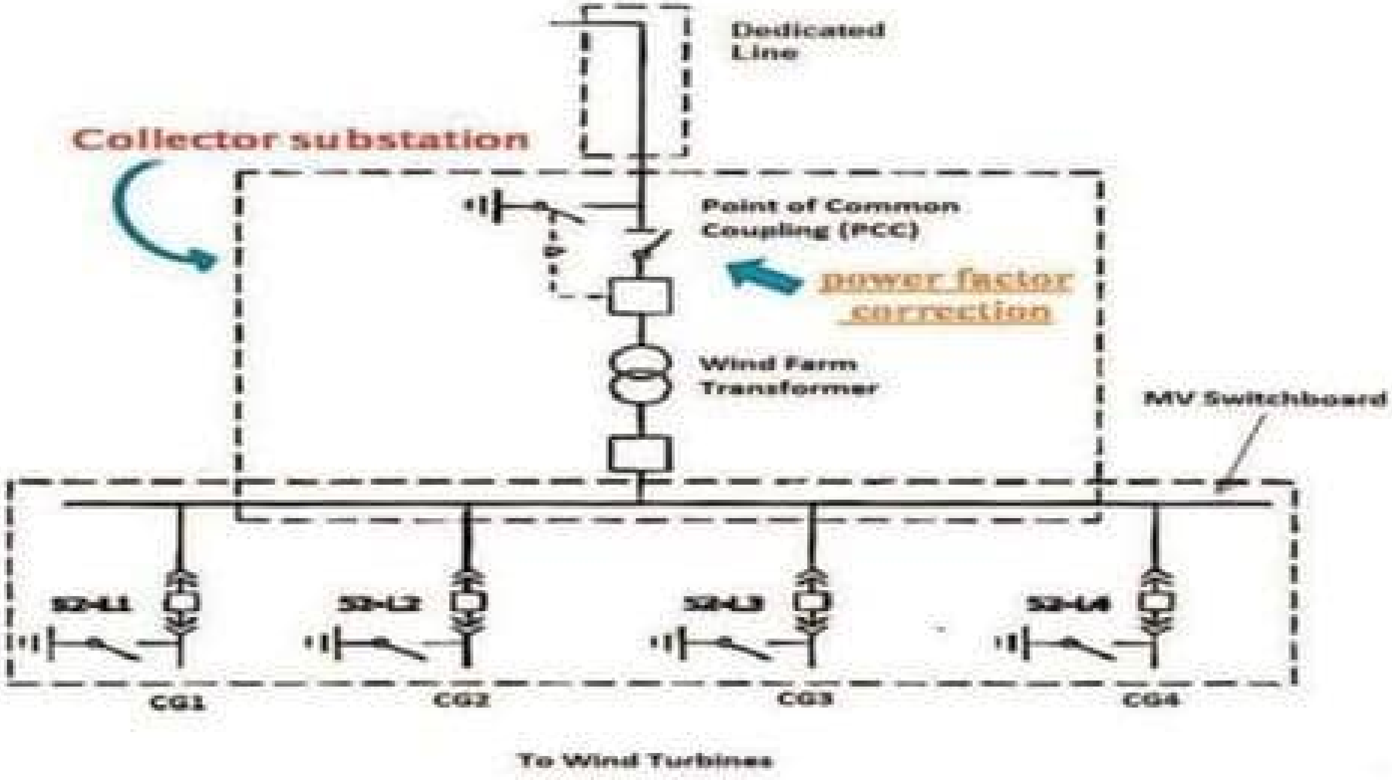

HVDC Substation Layout

# 4. Collector substation

- To build a wind farm, a solar farm or hydroelectric plants need a collector substation to tie all the generators and connect them to the power grid.
- Usually for economy of construction the collector system operates around 35 kV, and the collector substation steps up voltage to a transmission voltage for the grid.
- The collector substation can also provide power factor correction if it is needed, metering, and control of the wind farm.
- In some special cases a collector substation can also contain an HVDC converter station. Collector substations also exist where multiple thermal or hydroelectric power plants of comparable output power are in proximity.

# Collector substation

- The collector system is comprised of many components. Transformer, high voltage conductors (underground or overhead), sensor (current, voltage, thermal and magnetic), Lightning protection, grounding system, circuit breakers and switches, monitoring system etc.,



# Classification of substation

**1. Classification based on voltage levels**

**A.C. Substation :** HV (between 33 KV and 66 kV),
**EHV** (132 kV and 400 kV),
**UHV** (above 400 kV),
**MV/** distribution substation/public substation (2kV to 33kV),
**LV/**private substation (220V and 440V),
**HVDC** Substation.

**2. Classification based on construction features**

**Outdoor substation:** It is under open sky (rated voltage beyond 66kV).
**Indoor substation:** This is inside a building (rated voltage beyond 11kV).
**Mining Substation:** Needs special design consideration because of extra precaution for safety needed in the operation of electric supply.
**Mobile Substation:** Temporary requirement.
**Pole Substation:** This is an outdoor substation with equipment installed overhead on H- pole or 4-pole structure

# Classification of substation

**3. Classification based on configuration:**

**AIS** : Air insulated outdoor substation (up to 800 kV)

**GIS** : SF6 Gas Insulated Substation (GIS)

**Composite:** This types of substations having combination of the above two

**4. Classification based on application:**

**Step Up Substation:** Associated with generating station as the generating voltage is low.

**Primary Grid Substation:** Created at suitable load Centre along primary transmission lines.(Step down 66kV from 220 kV)

**Secondary Substation:** Along secondary transmission line (step down to 11 kV).

**Distribution Substation :** Created where the transmission line voltage is step down to supply voltage. Bulk supply and industrial substation Similar to distribution sub-station but created separately for each consumer. 11kV delivered to distribution substation

# Substation Transformer

- Transformers are an essential part of any electrical power system. They come in various sizes and voltage ratings.
- AC transformers are one of the keys to allowing widespread distribution of electric power as we see it today.
- Transformers efficiently convert electricity to higher voltage for long distance transmission and back down to low voltages suitable for customer usage.
- The distribution power transformers perform the necessary voltage transition from transmission (or sub-transmission) voltage level to a level suitable for power distribution. One example of such transition would be a change from 66 kV to 11 kV.

# Substation Transformer

# Current Transformer

- A current transformer is a gadget utilized for the transformation of higher value currents into lower values. It is utilized in an analogous manner to that of AC instruments, control apparatus, and meters. These are having lower current ratings and are used for maintenance and installation of current relays for protection purpose in substations.

# Potential Transformer:

- The potential transformers are similar in characteristics as current transformers but are utilized for converting high voltages to lower voltages for protection of relay system and for lower rating metering of voltage measurements.

# Insulators

- The insulators are the materials which do not permit flow of electrons through it. Insulators are resisting electric property. There are numerous types of insulators such as shackle, strain type, suspension type, and stray type etc. Insulators are used in substations for avoiding contact with humans or short circuit.

# Isolators

- The isolators in substations are mechanical switches which are deployed for isolation of circuits when there is an interruption of current. These are also known with the name of disconnected switches operation under no-load conditions and are not fortified with arc-quenching devices. These switches have no specific current breaking value neither these have current making value. These are mechanically operated switches.

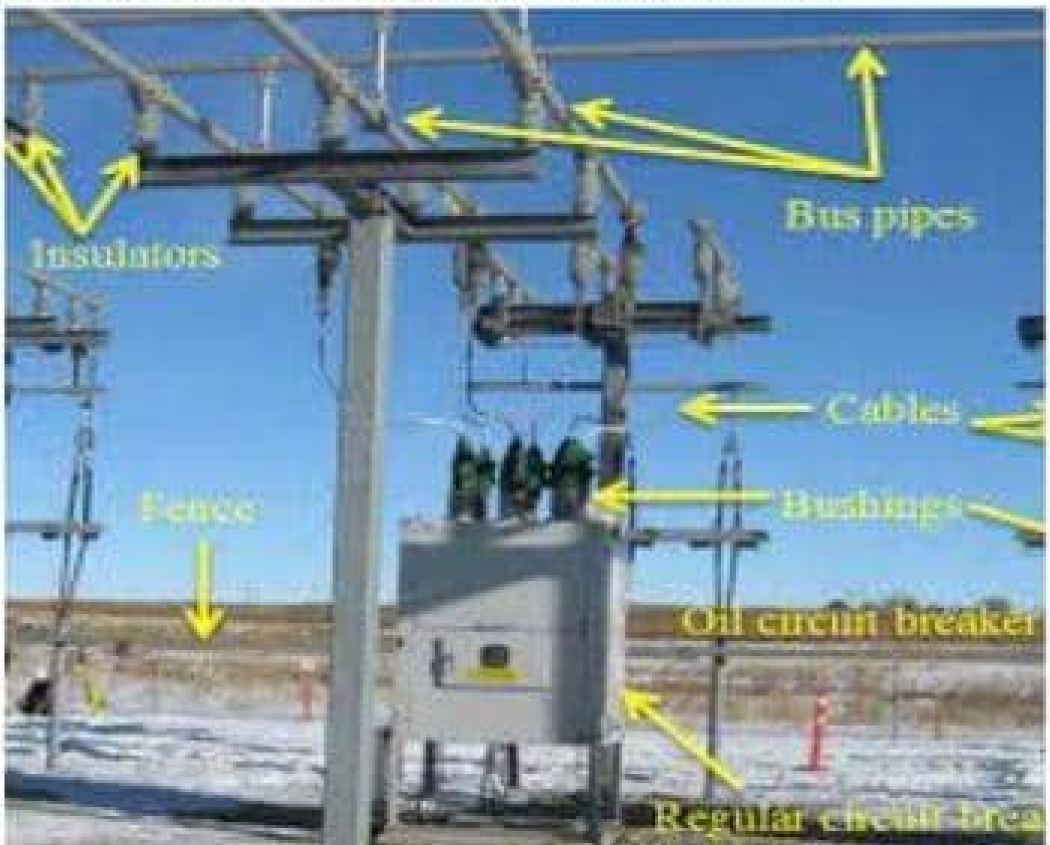
# Circuit Breakers

- Circuit breakers which control high voltages and protect other substation equipment are also located at power substations.
- Many outdoor substations use oil-filled circuit breakers. This type of circuit breaker has contacts immersed in an insulating oil contained in a metal enclosure.
- It should be pointed out that large arcs are present whenever a high-voltage circuit is interrupted.
- This problem is not encountered to any great extent in low-voltage protective equipment.

# Circuit Breakers

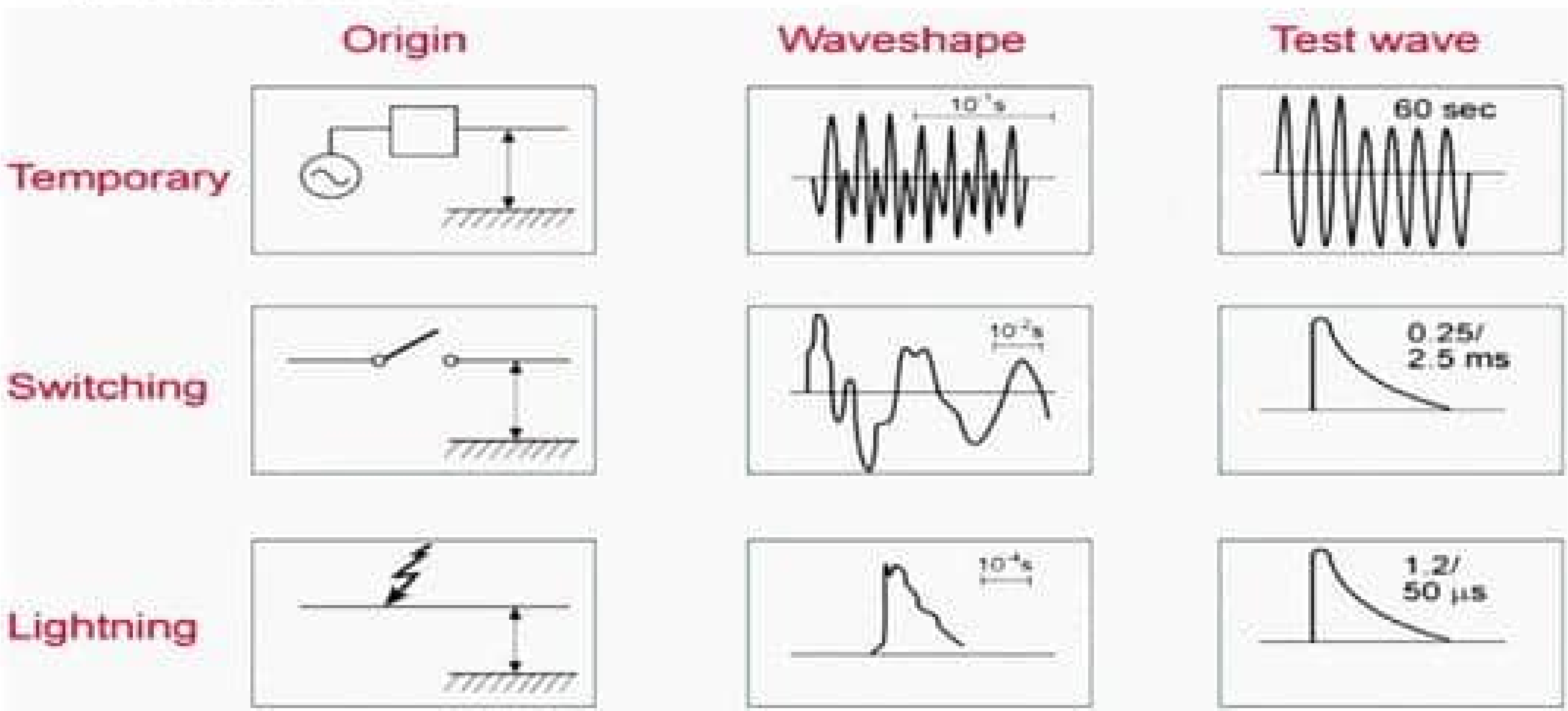
# Substation Bus

- The electrical and physical connection of substation buses are typically governed by safety, reliability, economy, maintainability and ease of operations.
- Bus is actually the electrical structure to which all power lines and transformers are connected.



# Surge Arresters

- The electrical installations are exposed to overvoltage stresses caused by various sources. By nature, the overvoltage caused by the sources have different characteristics in terms of magnitude, frequency, duration and rate of rise.



# Surge Arresters

- The surge arrester should withstand the continuous and temporary power frequency over voltages experienced in the system during normal operation, system faults and switching operations.
- The surge arresters also have to be able to limit the surge over voltages below the specified withstand level of the equipment in the installation.

# Surge Arresters

Lightning arresters with grounded bottom terminal (144kV)

# Insulators and Conductors

- All power transmission lines must be isolated to avoid safety hazards. Large strings of insulators are used at substations and at other points along the power distribution system to isolate the current carrying conductors from their steel supports or any other ground mounted equipment.
- Insulators may be made of porcelain, rubber or a thermoplastic material.

# Types of Aluminum Conductors


- AAC: All Aluminum Conductor
- AAAC: All Aluminum Alloy Conductor
- ACSR: Aluminum Conductor Steel Reinforced
- ACSS: Aluminum Conductor  Steel Supported
- ACCR: Aluminum Conductor Steel Reinforced
- ACCC: Aluminum Conductor Composite Core

# Protective relays

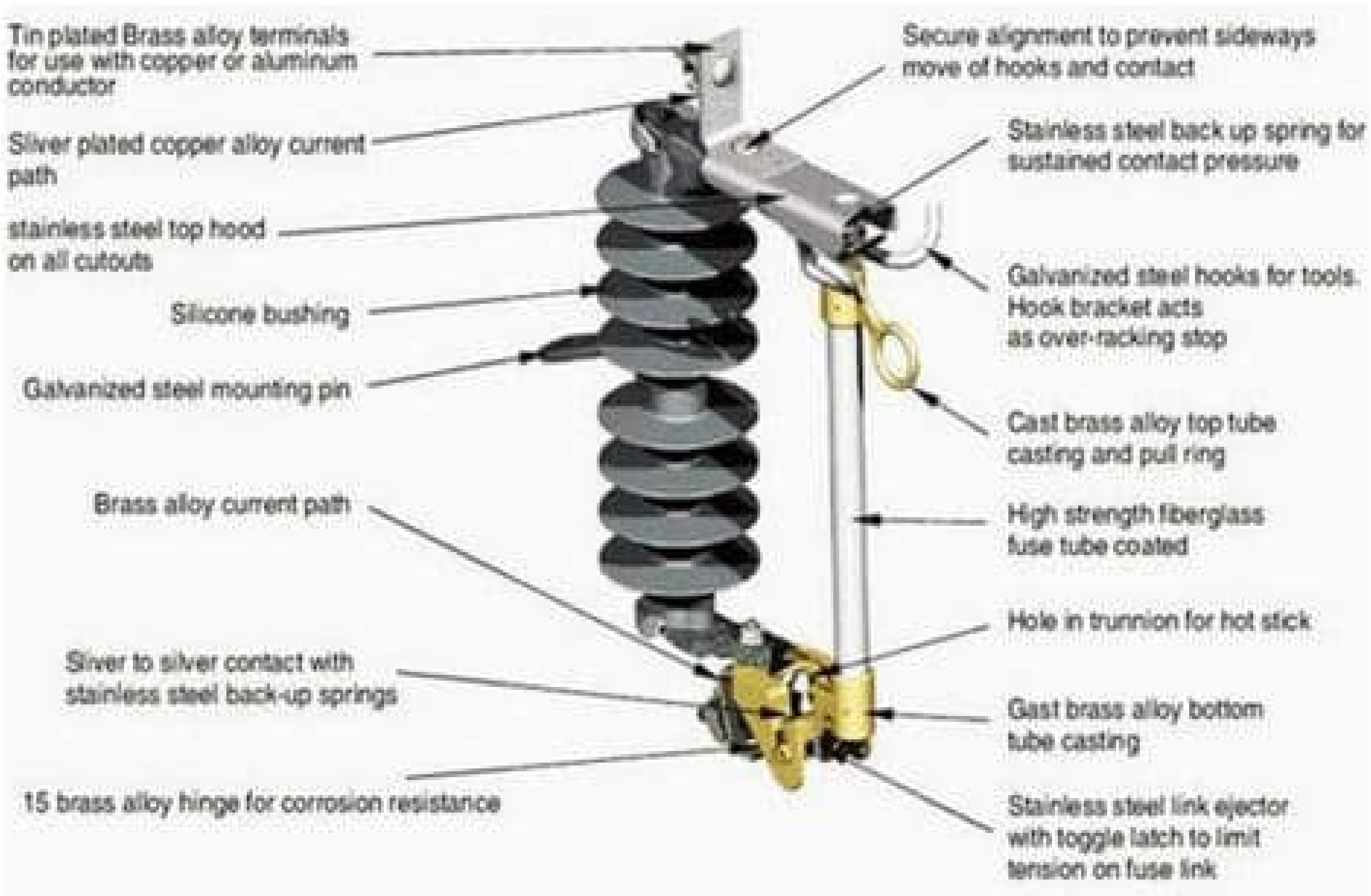
- Protective relays provide an accurate and sensitive method of protecting electrical distribution equipment from short circuits and other abnormal conditions.
- Overcurrent relays are used to cause the rapid opening of electrical power lines when the current exceeds a predetermined value.
- The response time of the relays is very important in protecting the equipment from damage.
- Some common types of faults which may be protected by relays are line-to-ground short circuits, line-to-line short circuits, double line-to-ground short circuits, and three-phase line short circuits. Each of these conditions is caused by faulty circuit conditions which draw abnormally high current (fault current) from the power lines.

# Protective relays

# Fuses

- Since electrical power lines are frequently short-circuited, various protective equipment is used to prevent damage to both the power lines / equipment and personnel.
- This protective equipment must be designed to handle high voltages and currents.
- High-voltage fuses (those used for over 600 volts) are made in several ways.
- An expulsion-type fuse has an element which will melt and vaporize when it is overloaded, causing the power line connected in series with it to open.
- Liquid fuses have a liquid-filled metal enclosure, which contains the fuse element. The liquid acts as an suppressing medium.
- When the fuse element melts due to an excessive current in a power line, the element is immersed m the liquid to extinguish the arc.

# Fuses



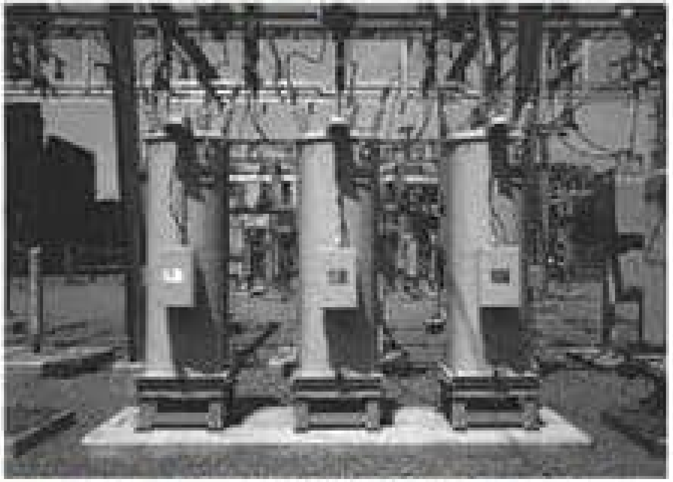

Expulsion-type fuse

# Types of Fuses

# Voltage Regulators

- Voltage regulators can be found both at the substation and out on distribution lines to help maintain a constant voltage level along the entire feeder.
- When the load on the line is low, the voltage drop is not very large and the customers near the end of the line have adequate voltage.
- When the load on the line is high, the voltage drop is also higher and customers near the end of the line may experience low voltage.
- Voltage regulators automatically adjust to these low and high load situations to assure all customers have proper voltage to run their electrical equipment.

# Voltage Regulators



Siemens JFR single-phase voltage regulators

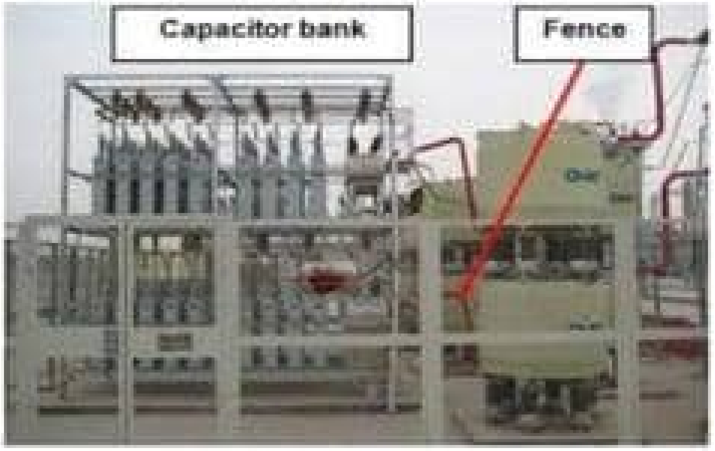
# Reactor

- A reactor is a coil which has large number of turns and whose ohmic resistance value is much greater. Reactors are used to limit the short circuit currents which can cause damage to the equipments of the power system. The additional reactance added in series with the system for protection, are called reactors.

# Reactors at Substation

# Capacitor at Substation

- Large capacitor bank are connected in "SERIES " in a substation to improve the voltage power supply at the load end in a balanced transmission line
- In electric power distribution, capacitor banks are used for power-factor correction. These banks are needed to counteract inductive loading from devices like electric motors and transmission lines, thus making the load appear to be mostly resistive.



# Selection of site for substation

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

**1. Type of Substation:**

The category of substation is important for its location. For example a step-up substation, which is generally a point where power from various sources (generating machines or generating stations) is pooled and stepped up for long distance transmission, should be located as close to the generating stations as possible to minimize the transmission losses. A step-down substation should be located nearer to the load center to reduce transmission losses, cost of distribution system and better reliability of supply.

# Selection of site for substation

**2. Availability of Suitable and Sufficient Land:**

The land proposed for a substation should be normally level and open from all sides. It should not be water logged particularly in rainy season. The site selected for a substation should be such that approach of transmission lines and their take off can be easily possible without any obstruction.

According to the latest practice the land required for various types of substations is given below:

| | *Type of Substation* | *Area Required* |
|---|---|---|
| (*a*) | 400 kV substation | 50 acres |
| (*b*) | 220 kV substation | 25 acres |
| (*c*) | 132 kV substation | 10 acres |

# Selection of site for substation

**3. Communication Facility:**

- Suitable communication facility is desirable at a proposed substation both during and after its construction. It is better, therefore, to select the site along-side on existing road to facilitate an easier and cheaper transportation.

**4. Atmospheric Pollution:**

- Atmosphere around factories, which may produce metal corroding gases, air fumes, conductive dust etc., and nearer to sea coasts, where air may be more humid and may be salt laden, is detrimental to the proper running of power system and therefore substations should not be located near factories or sea coast.

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

- The site should be such where staff can be provided essential amenities like school, hospital, drinking water, housing etc.

**6. Drainage Facility:**

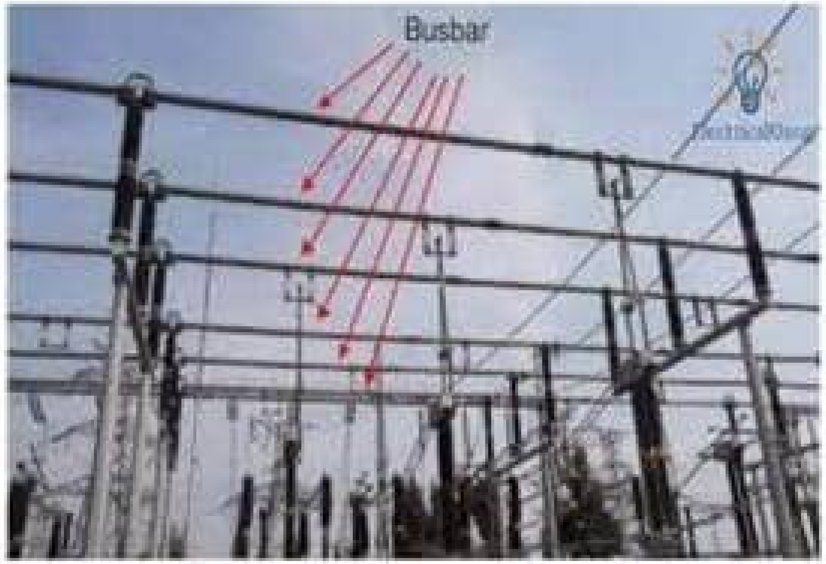
- The site selected for the proposed substation should have proper drainage arrangement or possibility of making effective drainage arrangement to avoid pollution of air and growth of micro-organisms detrimental to equipment and health.

# Bus-bar Arrangement Schemes

- An electrical bus bar is defined as a conductor or a group of conductor used for collecting electric power from the incoming feeders and distributes them to the outgoing feeders. In other words, it is a type of electrical junction in which all the incoming and outgoing electrical current meets. Thus, the electrical bus bar collects the electric power at one location.
- The bus bar system consists the isolator and the circuit breaker. On the occurrence of a fault, the circuit breaker is tripped off and the faulty section of the busbar is easily disconnected from the circuit.
- The electrical bus bar is available in rectangular, cross-sectional, round and many other shapes. The rectangular bus bar is mostly used in the power system. The copper and aluminium are used for the manufacturing of the electrical bus bar.

- The various types of busbar arrangement are used in the power system. The selection of the bus bar is depended on the different factor likes reliability, flexibility, cost etc. The following are the electrical considerations governing the selection of any one particular arrangement.

# Electrical Busbar



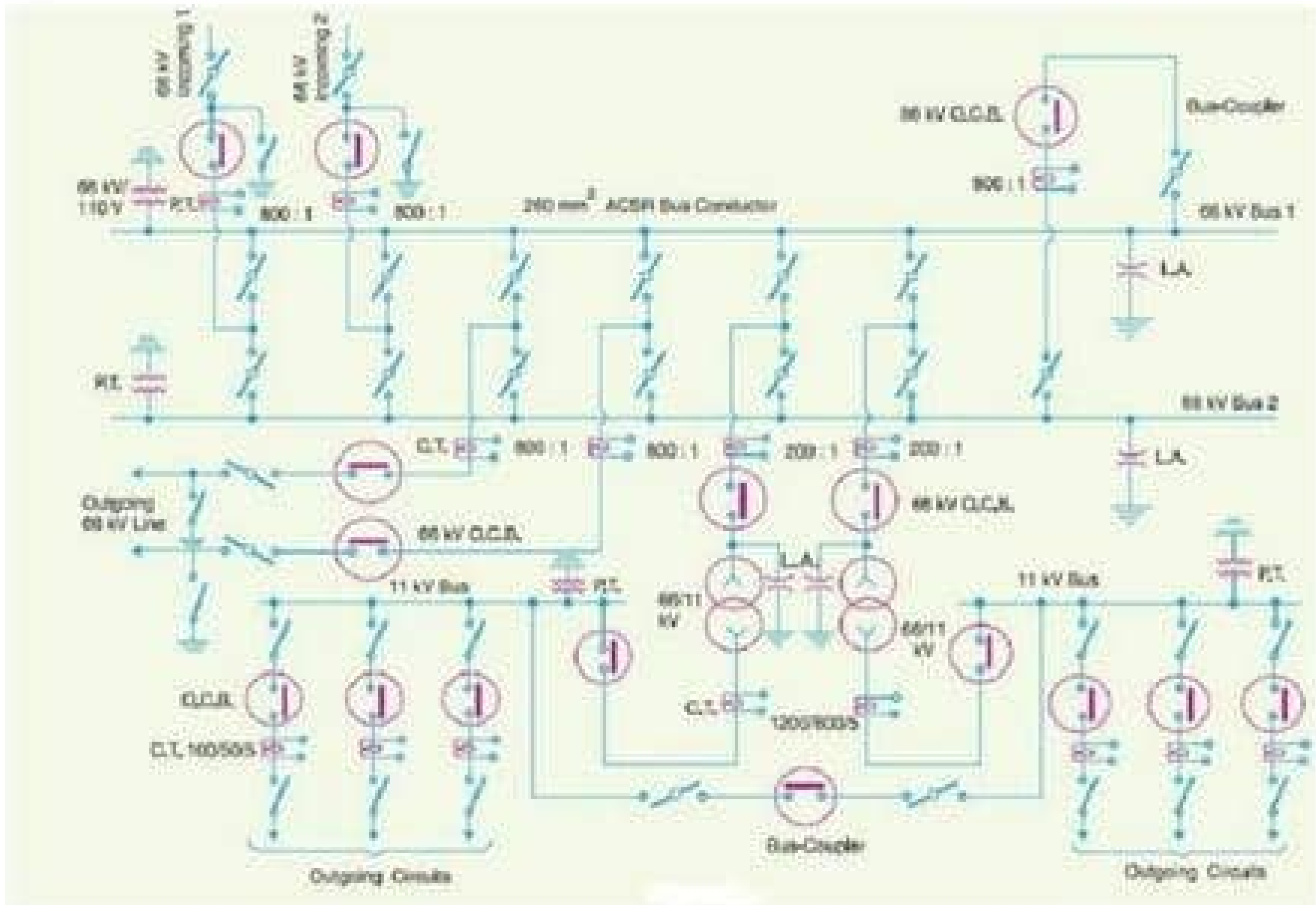

# Single line Diagram of Substations

- Definition: Single line diagram is the representation of a Substation or power system using the simple symbol for each component. ... It is not necessary to show all the components of the system on a single line diagram.

**The key diagram of typical 66/11 kV Substation**

(i) There are two 66kV incoming lines marked incoming 1' and incoming 2' connected to the bus bars. Such an arrangement of two incoming lines is called a double circuit. Each incoming line is capable of supplying the rated substation load. Both these lines can be loaded simultaneously to share the substation load or any one line can be called upon to meet the entire load. The double circuit arrangement increases the reliability of the system. In case there is a breakdown of one coming line, the continuity of supply can be maintained.

# Key diagram of 66/11kv substation



# The key diagram pf typical 66/11 kV Substation

(ii)The substation has duplicate bus bar system one main bus bar and the other space busbar. The incoming lines can be connected to either bus bar with the help of a bus coupler which consists of a circuit breaker and isolators. The advantage of double bus bar system is that if repair is to be carried on one bus bar, the supply need not be interrupted as the entire load can be transferred to the other bus.

(iii) There is an arrangement in the sub station by which the same 66kV double circuit supply is passing through the sub-station. The outgoing 66kV double circuit line can be made to act as incoming line.

(iv) There is also an arrangement to step down the incoming 66kV by two units of 3 phase transformers each one transformer acts as a standby unit. If need arises both the transformers can be called upon to share the substation load. The 11kV outgoing lines feed to the distribution substations located near consumers localities

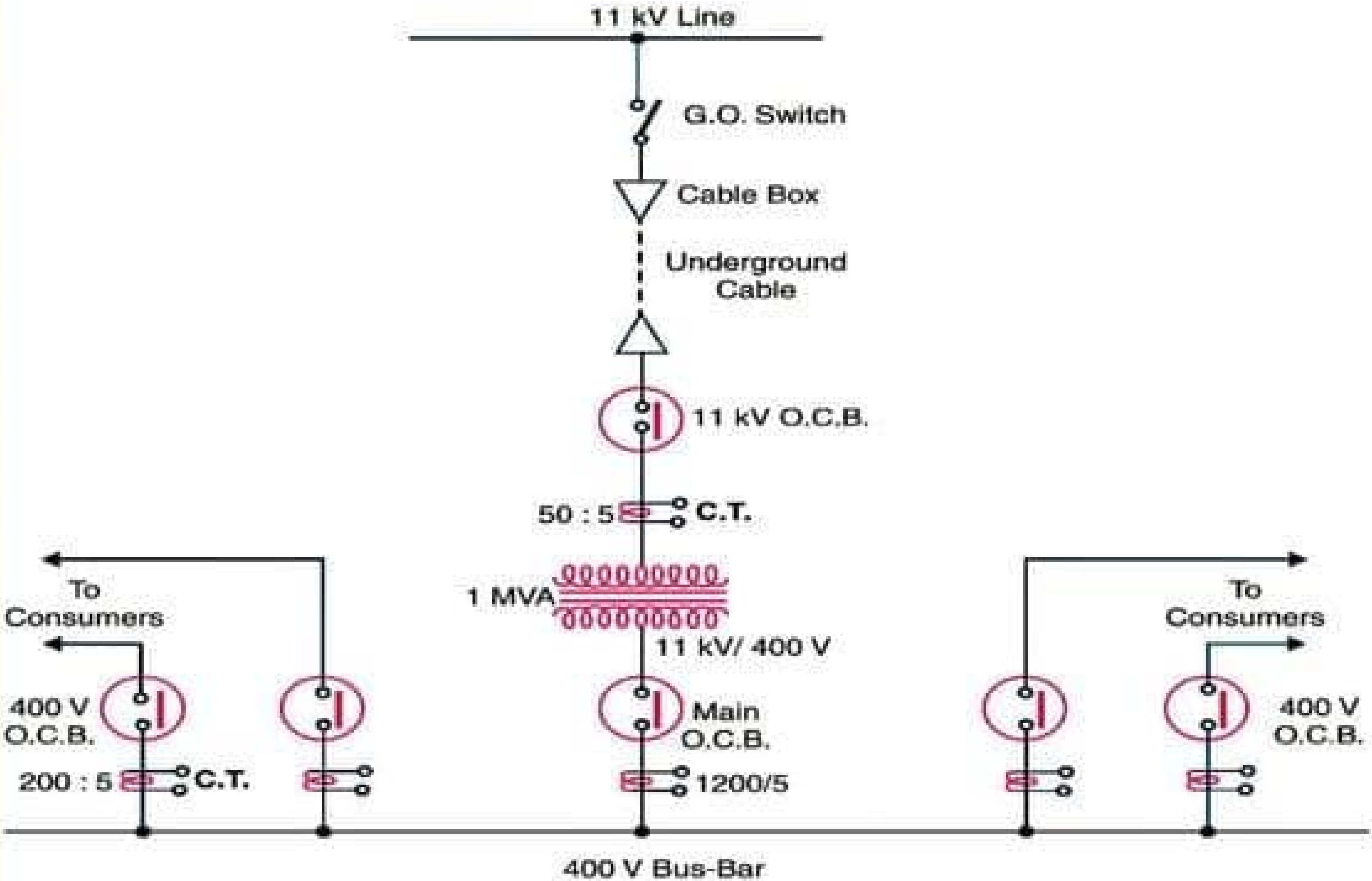
## The key diagram of typical 66/11 kV Substation

(v) Both incoming and outgoing lines are connected through circuit breakers having isolators on their either end. Whenever repair is to be carried over the line towers, the line is first switched off and then earthed.

(vi) The lighting arresters are connected near the transformer terminals to protect the from lighting strokes

(vii) There are other auxiliary components in the substation such as capacitor bank for power factor improvement, earth connections, local supply connections, dc supply connections, etc.,

# The key diagram of 11kV/400V Substation



## The key diagram of 11kV/400V Substation

The typical 11kV/400V indoor substation possess

(i) The three phase, three wire 11kV line is tapped and bought to the gang operating switch installed near the substation. The gang operated switch consists of isolators connected in each phase of the 3 phase line.

(ii) From the G.O. switch the 11kV line is brought to the indoor substation as underground cable. It is fed to the transformer (11kV/400V) via the 11kV OCB. The transformer steps down the voltage to 400V, 3-phase, 4-wire..

(iii) The secondary of transformer supplies to the bus bars via the main OCB. From the busbar , 400V, 3-pahse,

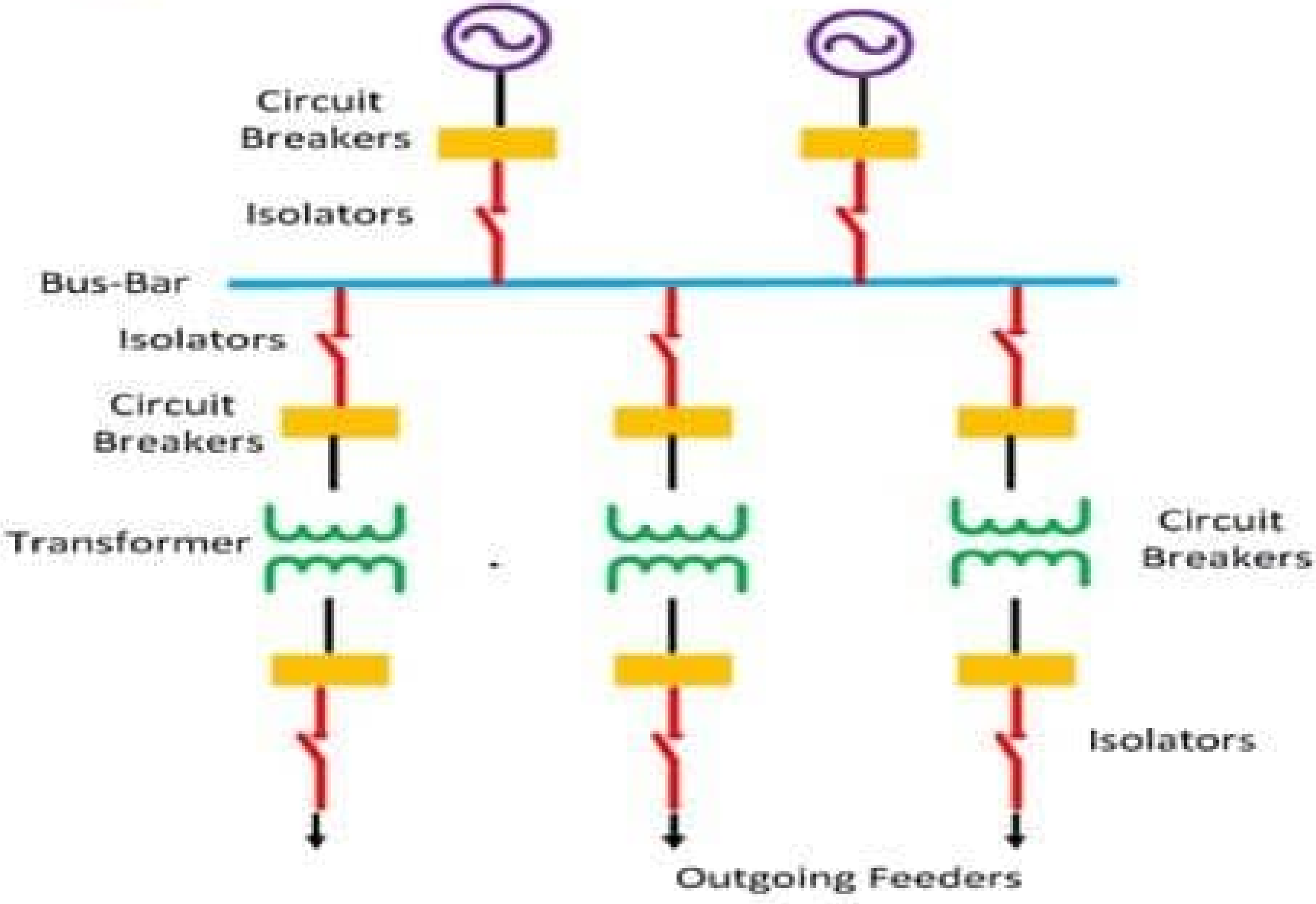
(iv) 4-wire supply is given to the various consumers via 400V. OCB. The voltage between any phase and neutral is 230V. The phase residential load is connected between any one phase and neutral.

# Bus-bar arrangement in Sub-stations

The different type of electrical busbar arrangement in Sub-station is as follows

- Single Bus-Bar Arrangement
- Single Bus-Bar Arrangement with Bus Sectionalized
- Main and Transfer Bus Arrangement
- Double Bus Double Breaker Arrangement
- Sectionalized Double Bus Bar Arrangement.
- One and a Half Breaker Arrangement
- Ring Main Arrangement
- Mesh Arrangement

# Single Bus-Bar Arrangement




Single Bus-Bar Arrangement

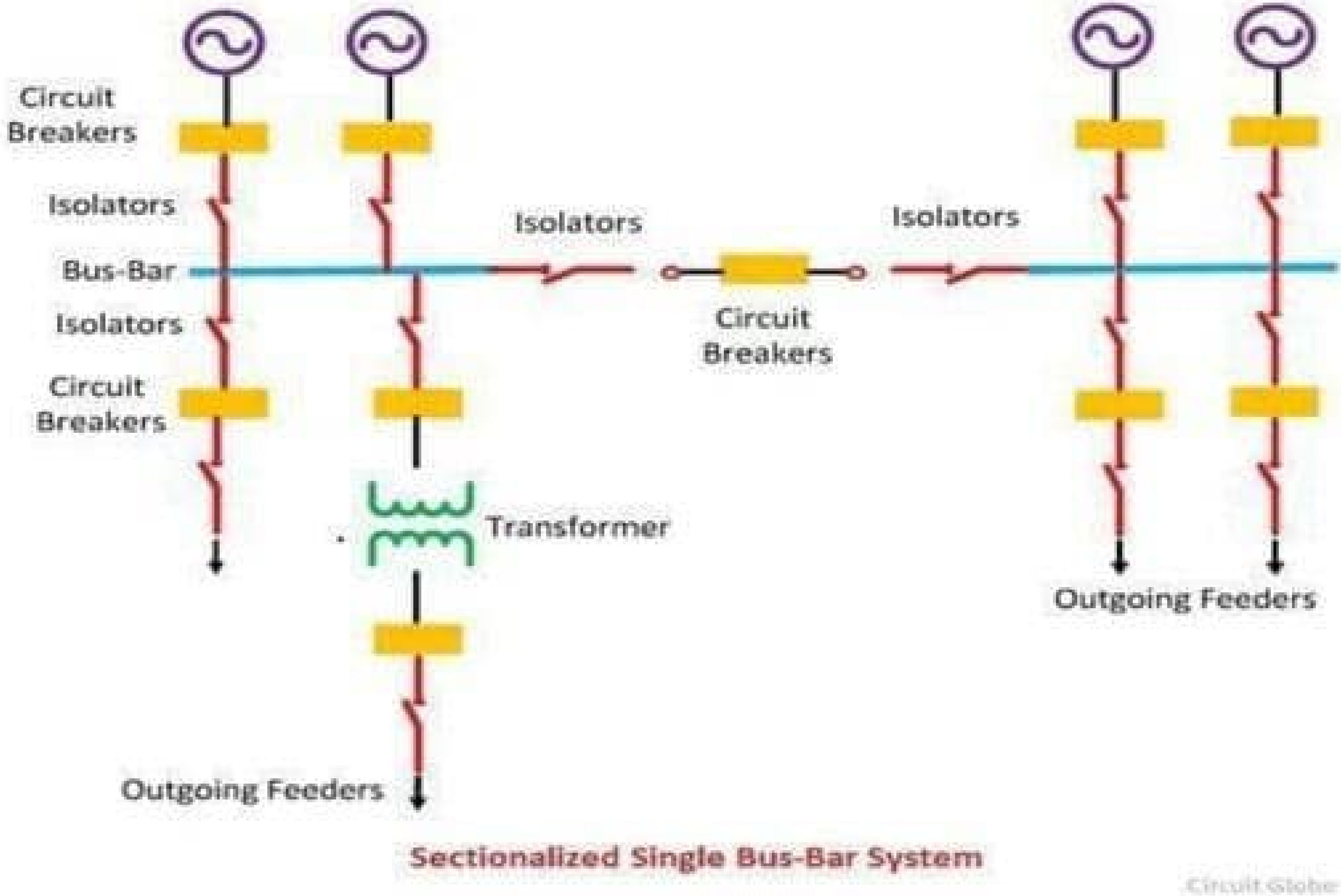
# Single Bus-Bar Arrangement

- The arrangement of such type of system is very simple and easy. The system has only one bus bar along with the switch. All the substation equipment like the transformer, generator, the feeder is connected to this bus bar only.

The advantages of single bus bar arrangements are

- It has low initial cost.
- It requires less maintenance
- It is simple in operation

# Single Bus-Bar Arrangement with Bus Sectionalized



## Single Bus-Bar Arrangement with Bus Sectionalized

- In this type of busbar arrangement, the circuit breaker and isolating switches are used. The isolator disconnects the faulty section of the busbar, hence protects the system from complete shutdown.

**Advantage of single Bus-bar Arrangement with Bus Sectionalization**

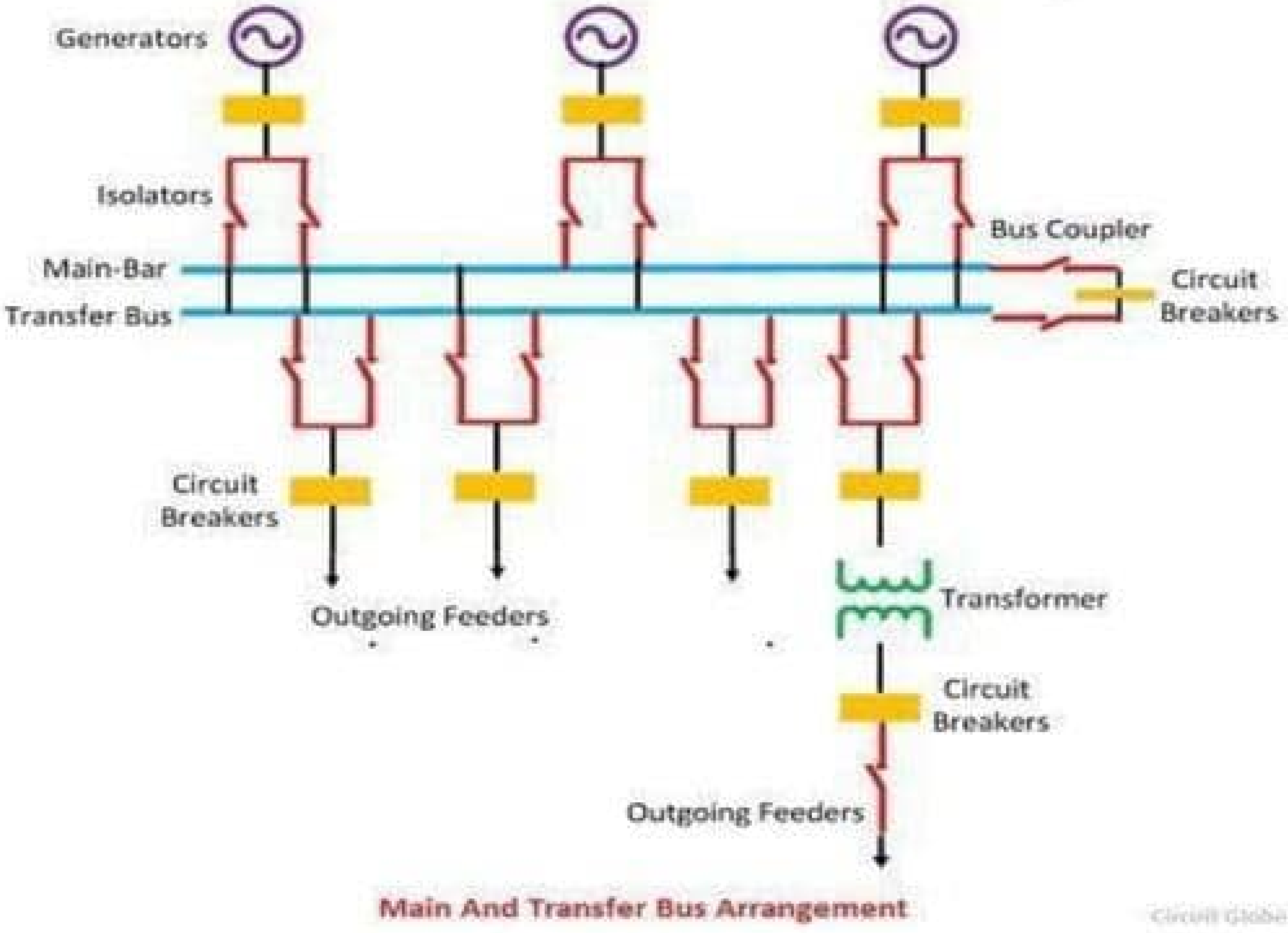
The following are the advantages of sectionalized bus bar.

- The faulty section is removed without affecting the continuity of the supply.
- The maintenance of the individual section can be done without disturbing the system supply.
- The system has a current limiting reactor which decreases the occurrence of the fault.

**Disadvantages of Single Bus-Bar Arrangement with Sectionalization**

- The system uses the additional circuit breaker and isolator which increases the cost of the system.

# Main and Transfer Bus Arrangement



# Main and Transfer Bus Arrangement

- Such type of arrangement uses two type of busbar namely, main busbar and the auxiliary bus bar. The busbar arrangement uses bus coupler which connects the isolating switches and circuit breaker to the busbar. The bus coupler is also used for transferring the load from one bus to another in case of overloading. The following are the steps of transferring the load from one bus to another.

- The potential of both the bus bar kept same by closing the bus coupler.
- The bus bar on which the load is transferred is kept close.
- Open the main bus bar.

# Main and Transfer Bus Arrangement

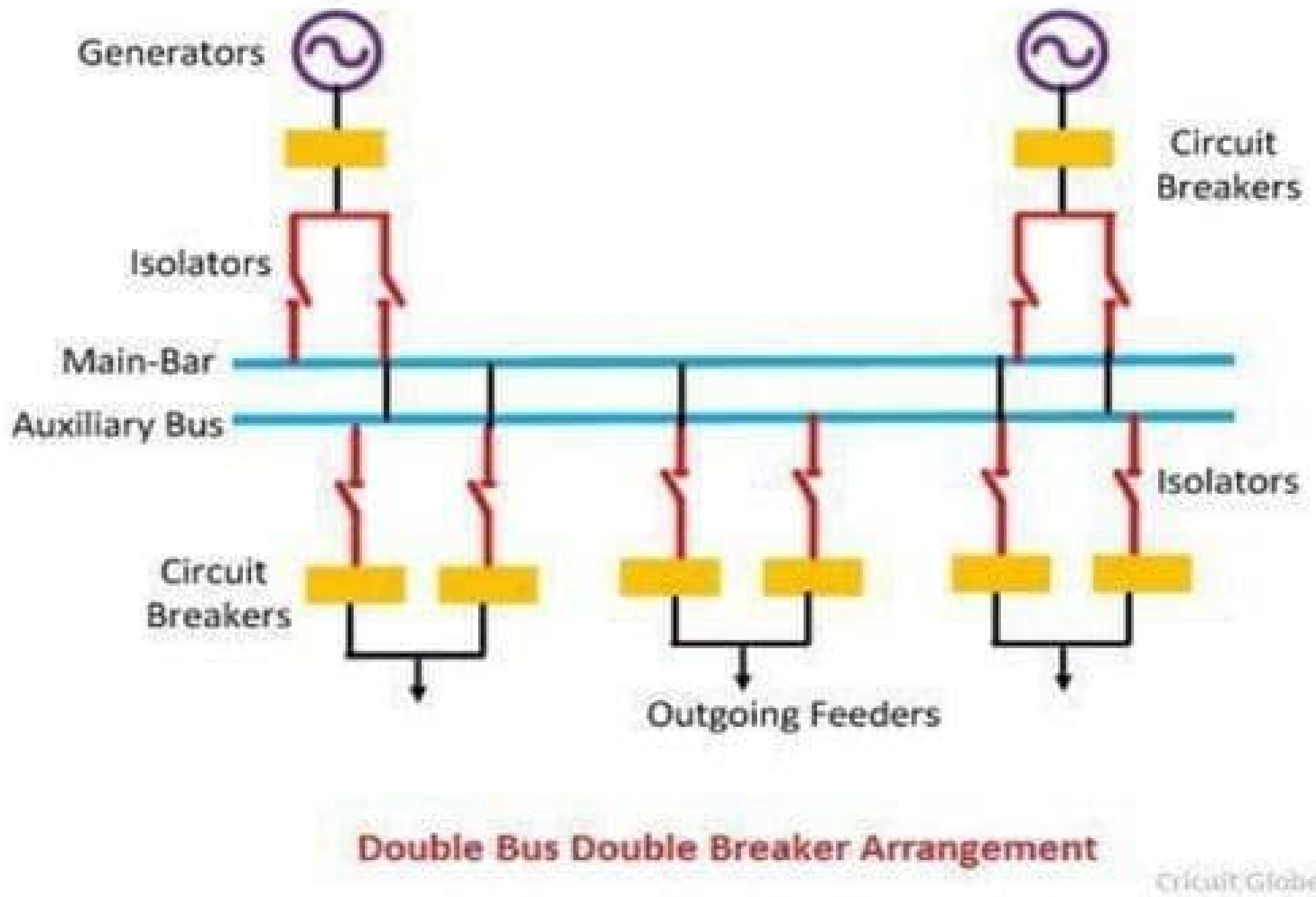
**Advantages of Main and Transfer Bus Arrangement**

- The continuity of the supply remains same even in the fault. When the fault occurs on any of the buses the entire load is shifted to the another bus.
- The repair and maintenance can easily be done on the busbar without disturbing their continuity.
- The maintenance cost of the arrangement is less.
- The potential of the bus is used for the operation of the relay.
- The load can easily be shifted on any of the buses.

**Disadvantages of Main and Transfer Bus Arrangement**

- In such type of arrangements, two bus bars are used which increases the cost of the system.
- The fault on any of the bus would cause the complete shutdown on the whole substation.

# Double Bus Double Breaker Arrangement



# Double Bus Double Breaker Arrangement

- This type of arrangement requires two bus bar and two circuit breakers. It does not require any additional equipment like bus coupler and switch.

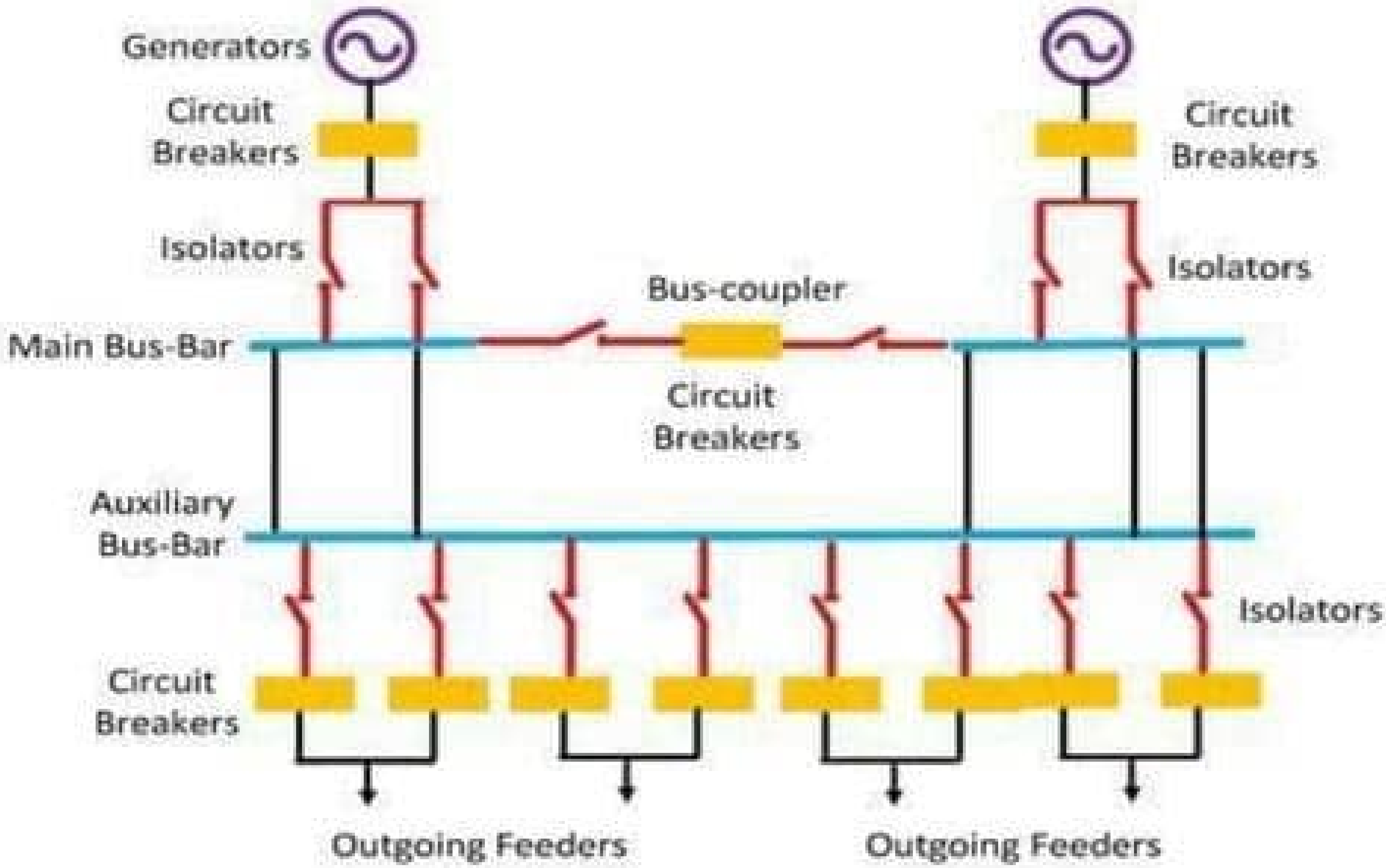
**Advantages of Double Bus Double Breaker**

- This type of arrangement provides the maximum reliability and flexibility in the supply. Because the fault and maintenance would not disturb their continuity.
- The continuity of the supply remains same because the load is transferrable from one bus to another on the occurrence of the fault.

**Disadvantages of double bus Double breaker**

- In such type of arrangement two buses and two circuit breakers are used which increases the cost of the system.
- Their maintenance cost is very high.

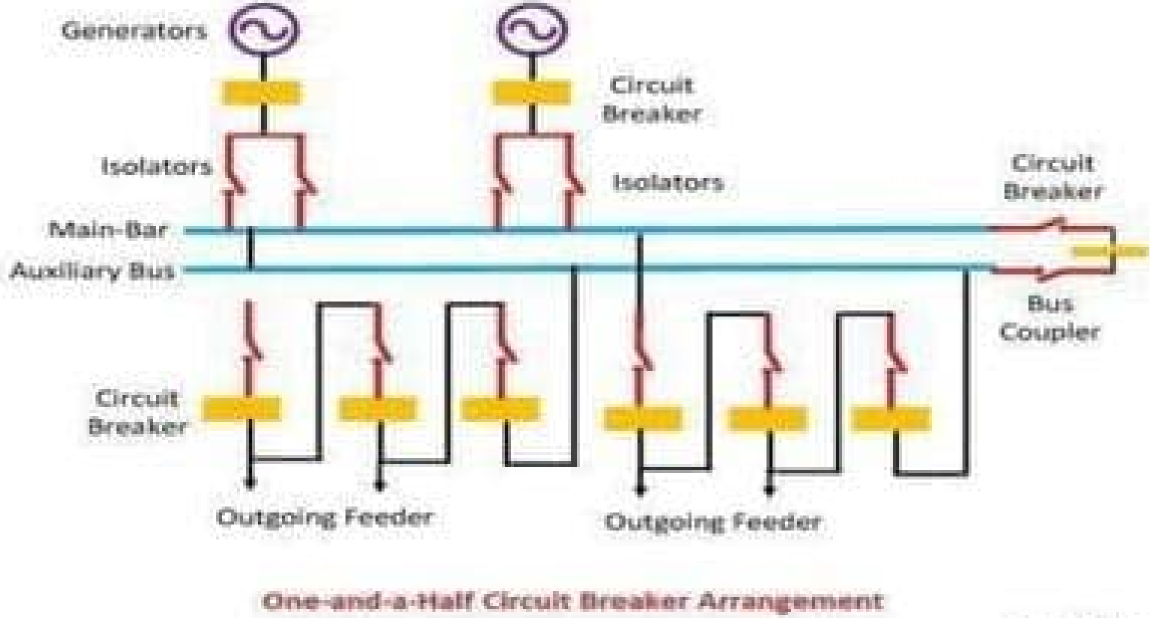
# Sectionalized Double Bus Bar Arrangement.




Sectionalized Double Bus Arrangement

# Sectionalized Double Bus Bar Arrangement

- In this type of bus arrangement, the sectionalized main bus bar is used along with the auxiliary bus bar. Any section of the busbar removes from the circuit for maintenance and it is connected to any of the auxiliary bus bars. But such type of arrangement increases the cost of the system. Sectionalization of the auxiliary bus bar is not required because it would increase the cost of the system.



# Sectionalized Double Bus Bar Arrangement

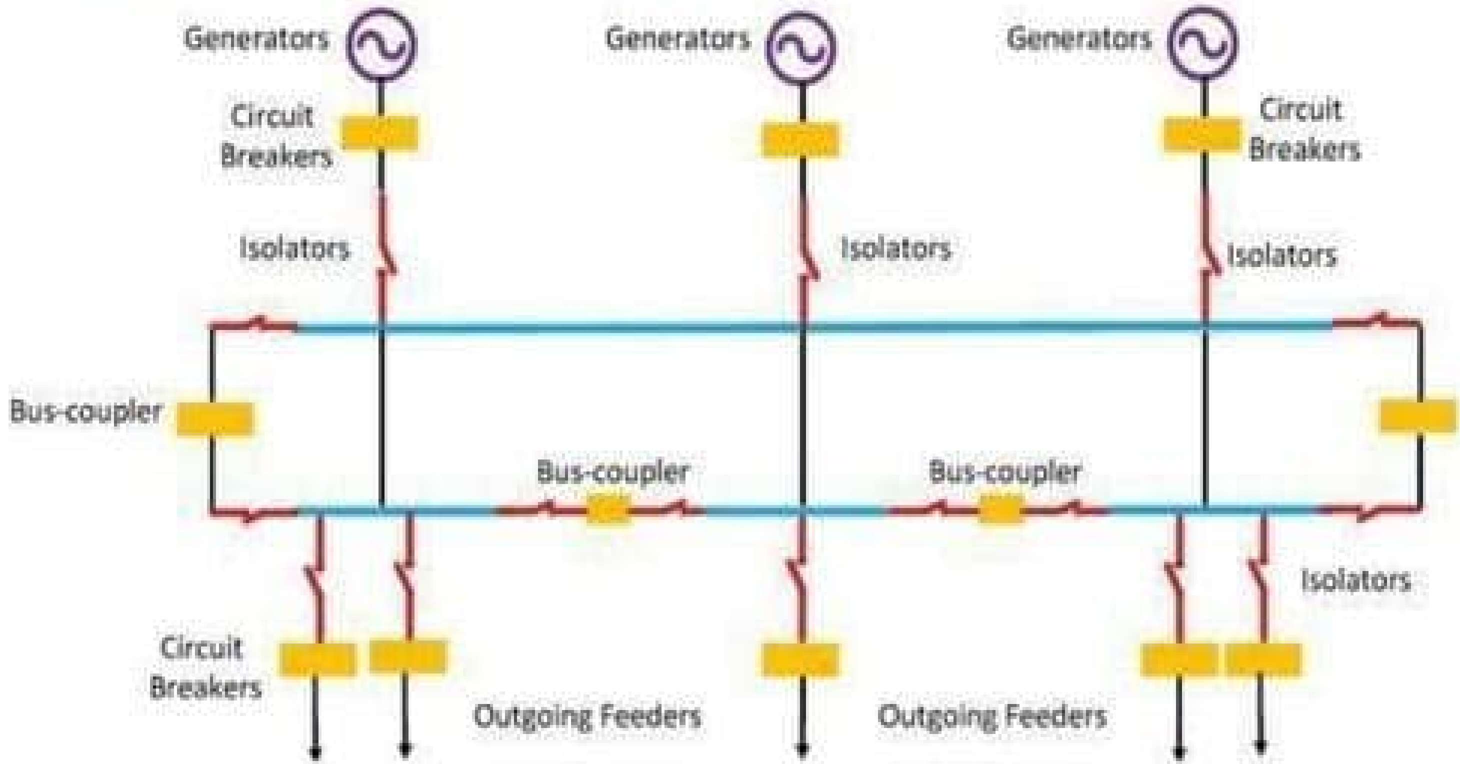
**Advantages of One and a Half Breaker Arrangement**

- It protects the arrangement against the loss of supply.
- The potential of the bus bar is used for operating the relay.
- In such type of arrangement, the additional circuits are easily added to the system.

**Disadvantages of One and a Half Breaker Arrangement**

- The circuit becomes complicated because of the relaying system.
- Their maintenance cost is very high.

# Ring Main Arrangement




Ring Main Arrangement

- In such type of arrangement, the end of the bus bar is connected back to the starting point of the bus to form a ring.

# Ring Main Arrangement

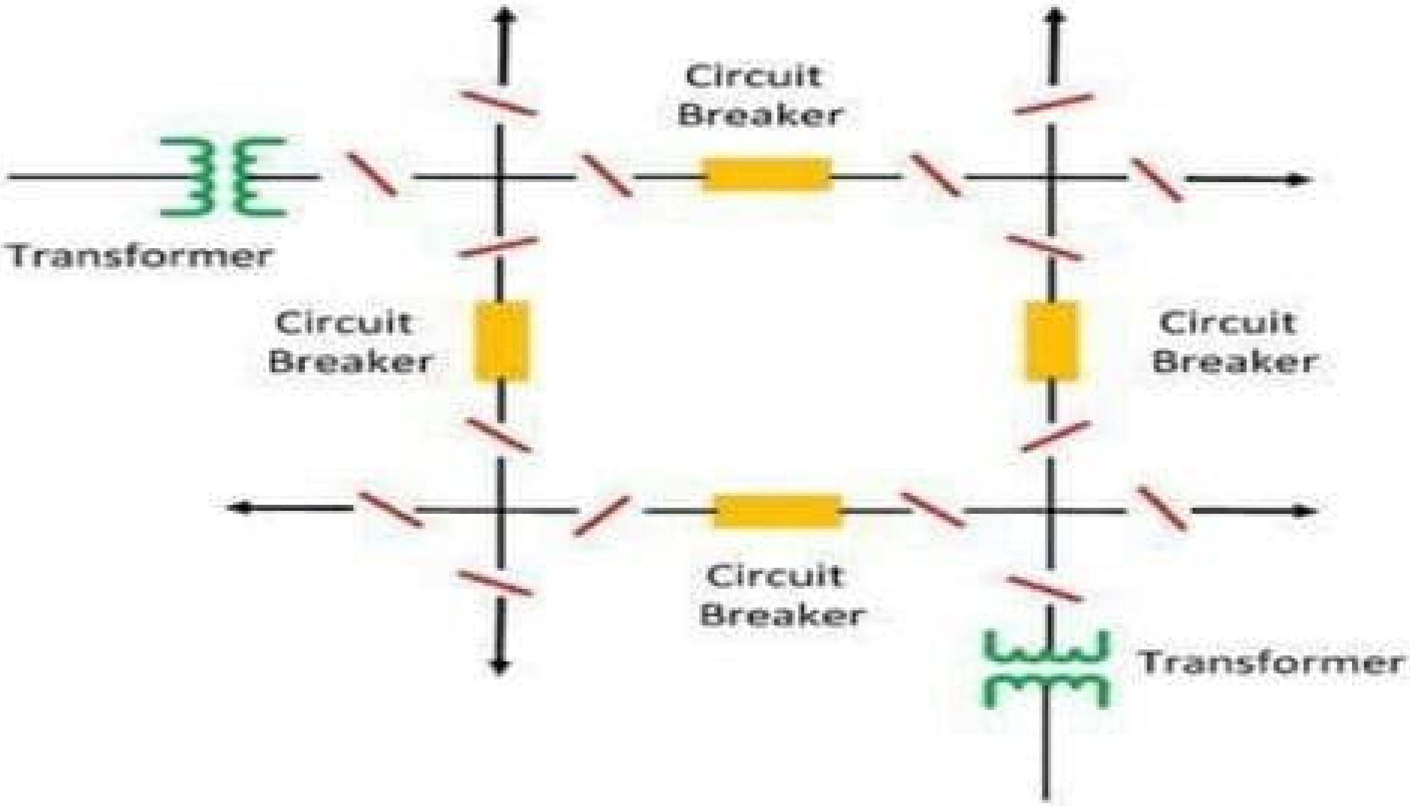
**Advantages of Ring Main Arrangement**

- Such type of arrangement will provide two paths for the supply. Thus the fault will not affect their working.
- The fault is localized for the particular section. Hence the complete circuit is not affected by the fault.
- In this arrangement, a circuit breaker can be maintained without interrupting the supply.

**Disadvantages of Ring Main Arrangement**

- Difficulties occur in the addition of the new circuit.
- Overloading occurs on the system if any of the circuit breakers is opened.

# Mesh Arrangement




Mesh Arrangement

Circuit Globe

# Mesh Arrangement

- In such type of arrangement, the circuit breakers are installed in the mesh formed by the buses.
- The circuit is tapped from the node point of the mesh. Such type of bus arrangement is controlled by four circuit breakers.
- When a fault occurs on any section, two circuit breakers have to open, resulting in the opening of the mesh.
- Such type of arrangement provides security against bus-bar fault but lacks switching facility. It is preferred for substations having a large number of circuits.

# Interconnection of Power Stations

# Interconnection of Power Stations

- The connection of several generating stations in a network of particular transmission voltage level is commonly known as electrical grid system.
- By interconnecting different power generating stations we can solve various difficulties arise in power system. The structure, or "network topology" of a grid can vary depending on the load and generation characteristics, constraints of budget and the requirements for system reliability.
- Although, forming a grid by interconnecting different generating stations located at different places is significantly expensive since the protections and operations of the entire system become more complicated.

# Interconnection of Power Stations

There are some advantages of interconnected Power Stations

- The interconnected grid increases the reliability of power system significantly. In case of failure of any generating station, the network (grid) will share the load of that generating plant. Which increases reliability of the System.
- The arrangement can exchange the peak load of a plant. In case of individual operation of a generating station, if the peak load increases beyond the capacity of the generating station, we have to impose partial load shedding on the system.
- When we connect the generating station to a grid system the grid carries the extra load of the station. There is no need for partial load shedding or no need for enhancement of the capacity of that particular generating station.

# Interconnection of Power Stations

- The grid system can improve the diversity factor of each generating station connected to the grid.
- The diversity factor gets improved because the maximum demand of the grid shared by the generating station is much lesser than the maximum demand imposed on the generating station if it runs individually.
- **Diversity factor** is the ratio of the sum of the individual maximum demands of the various subdivisions of a system (or part of a system) to the maximum demand of the whole system (or part of the system) under consideration. **Diversity** is usually more than one.

# Interconnection of Power Stations

- Interconnection between hydroelectric power station and thermal power station makes their operation economical.
- When water is available in sufficient quantity during rainy season, the hydroelectric power station is employed as a base load station and thermal power station is employed as peak load station because the running cost of hydroelectric plant is low.
- When water is not available in sufficient quantity, such as in summer season, the thermal power station takes base load and hydroelectric power station takes peak load.
- Economy is also obtained by sharing the total demand among the interconnected power stations in such a way that the more efficient power stations run continuously throughout the year at high load factor.

$$Load\ factor = \frac{average\ load}{peak\ load}$$

# Interconnection of Power Stations

**Disadvantages of interconnection of power stations are**

**(1)Synchronizing Problem:**

- The generators of all the interconnected generating stations must operate the same at frequency and in a synchronized manner.
- During the heavy load condition some generators go out of step due to this synchronization breakup.
- And finally complete system goes out of step is also called black out condition.

**(2)Expensive Tie Lines:**

- In the interconnected power system to control the system reactive power, tie lines are used.
- Expense of tie lines for construction of interconnecting transmission line between generating stations.

# Interconnection of Power Stations

**(3)Expensive Circuit Breaker:**

- An interconnected system use circuit breaker to isolate the faulty part from the healthy part during the fault condition.
- For high voltage power system, higher rating circuit breaker is used.
- During the large flow of current on transmission line under faulty condition with a consequent increase in capacity of circuit breakers therefore expensive circuit breaker are required with interconnected power system.
- Hence cost of circuit breakers increase.

**(4) Metering and Instrumentation:**

- Adequate metering and instrumentation is needed at different levels.
- It is necessary to install sequential recorders, disturbance recorder, time of day meters etc.

# Gas Insulated Substation

- For maintaining proper voltage levels at transmission and distribution level and for providing greater stability a number of electrical transformation and switching setups have to be created in between generating station and consumer ends. These transformation and switching setups are generally known as electrical substations.
- Based on nature of dielectric medium a substation is of two types as following :

  1. AIS (Air insulation sub-station )
  2. GIS ( Gas insulation sub-station )

# AIR INSULATED SUBSTATION

# GAS INSULATED SUBSTATION

# Need for GIS

- Non availability of sufficient space. It is very much required to establish a substation at load center. Establishing a substation at load center is quite economical and profitable in following ways
  (i). Reduction in length of feeders
  (ii). Improvement of the quality of voltage regulation due to short length feeders
- Difficult climatic and seismic conditions at site, like high altitude and atmospheric pollution
- Aesthetically “superior” to air insulated substations
- The higher the voltage, the more favorable gas insulated technology becomes
- Overcomes or decreases the magnitude of limitations of AIS site selection

# Gas Insulated Substation

- Compact, multi-component assembly.
- Enclosed in a ground metallic housing.
- Sulphur Hexafluoride (SF6) gas – the primary insulating medium.
- (SF6) gas- superior dielectric properties used at moderate pressure for phase to phase and phase to ground insulation
- Preferred for voltage ratings of 72.5 kV, 145 kV, 300 kV and 420 kV and above.
- Various equipments like Circuit Breakers, Bus- Bars, Isolators, Load Break Switches, Current Transformers, Voltage Transformers, Earthling Switches, etc. housed in metal enclosed modules filled with SF6 gas

# Properties of SF6

- Non-toxic, very stable chemically.
- Man-made.
- Lifetime – Very long (1000years).
- Insulating properties 3-times that of air.
- Colorless & heavier than air.
- Almost water insoluble.
- Non inflammable.

# Gas Insulated Substations

# Components of Gas Insulted Substation

**GIS Assembly:**

1. Bus bar
2. Circuit Breaker
3. Disconnector (line or bus)
4. Earthing switch (line or bus)
5. Current transformer (feeder / bus)
6. Voltage transformer (feeder/ bus)
7. Feeder Disconnector
8. Feeder Earthing switch
9. Lightning / Surge Arrester
10. Cable termination
11. Control Panel.

# Gas Insulated Substation

**Advantages :**

- Occupies very less space compared to ordinary substations ( AIS).
- Hence, most preferred where area for substation is small (eg: Cities)
- Most reliable compared to Air Insulated Substations.
- Number of outages due to the fault is less
- Maintenance Free.
- Can be assembled at workshop and modules can be commissioned in the plant easily.

# Gas Insulated Substation

**Disadvantages**

- High cost compared to conventional substation(AIS).
- Excessive damage in case of internal fault.
- Diagnosis of internal fault and rectifying takes very long time (high outage time).
- SF6 gas pressure must be monitored in each compartment.
- Reduction in the pressure of the SF6 gas in any module results in flash over and faults.
- SF6 causes ozone depletion and global warming

# GROUNDING (OR) EARTHING

## Introduction

(i) Connecting frame of electrical equipment ie, non current carrying part to be connected to earth (soil).

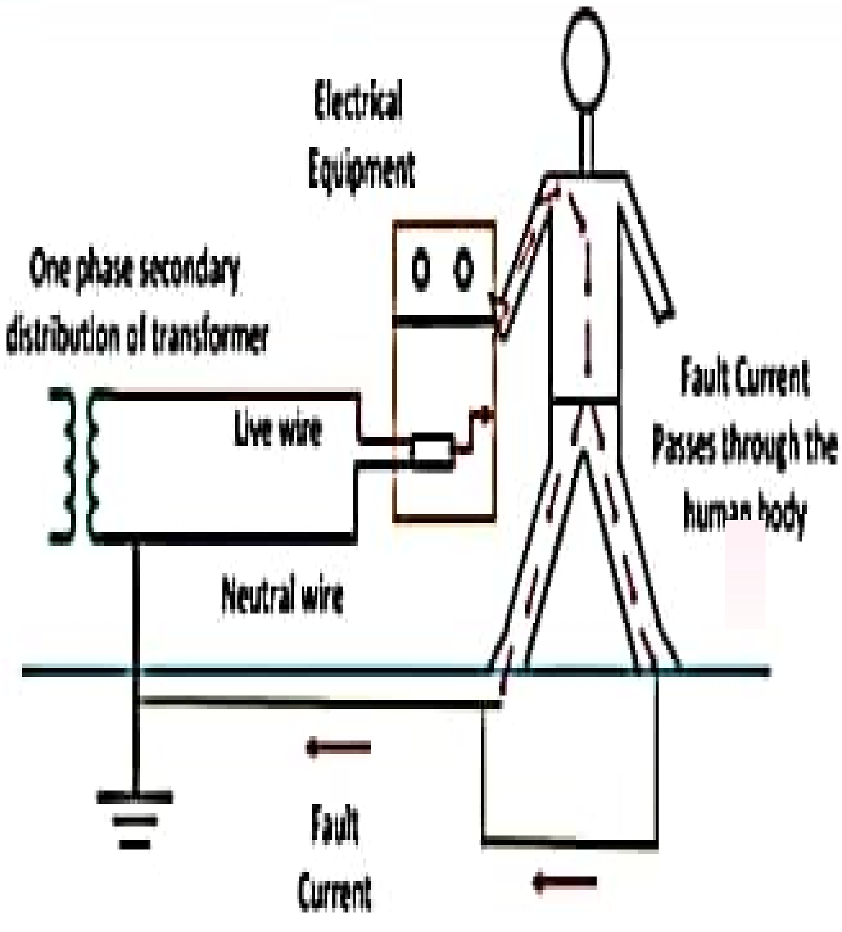
(ii) Some electrical part of the system ie, neutral point of star connected system, one conductor of secondary of transformer to be connected to earth (soil).

- Case (i) & case (ii) are called as earthing (or) grounding.
- This connection to the earth may be through a conductor or some other circuit element such as circuit breaker, resistor, reactor etc.

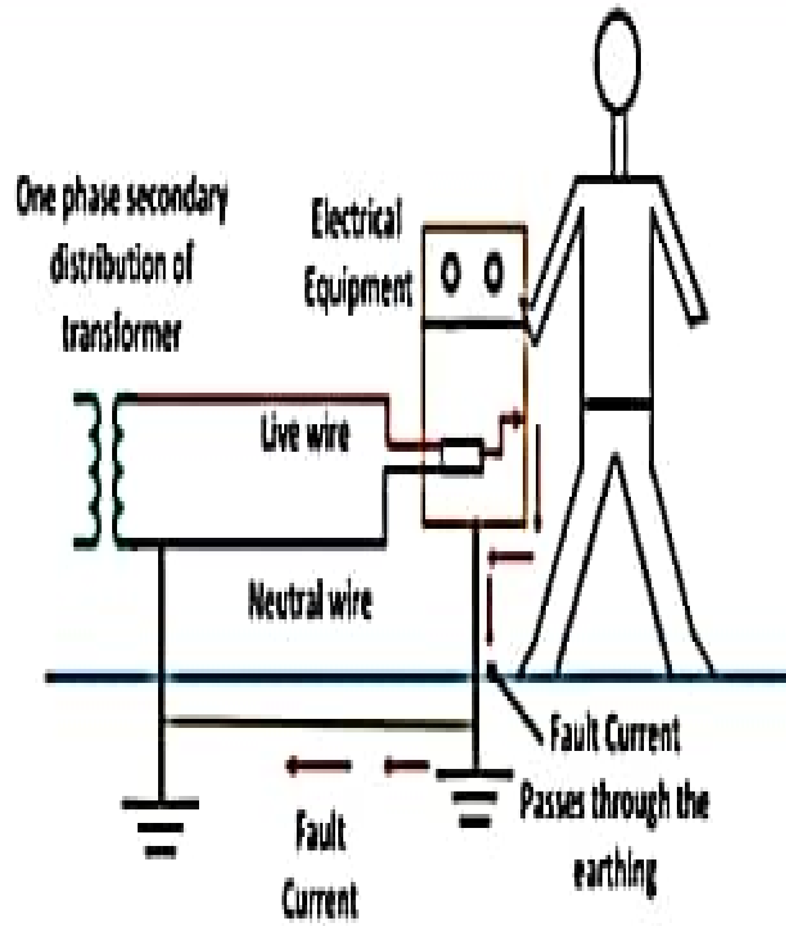
# IMPORTANCE OF GROUNDING

**The grounding is essential because of the following reasons:**

- The grounding protects the personnel from the short circuit current.
- The grounding provides the easiest path to the flow of short circuit current even after the failure of the insulation.
- The grounding protects the apparatus and personnel from the high voltage surges and lightning discharge.




Electrical System Without Earthing




Electrical System With Earthing

# GROUNDING (OR) EARTHING

## Introduction (contd.)

- Grounding is the method by which we can avoid ourselves from electrical hazards major part of the grounding process is earth, the earth is a good conductor, so we provide a conductive path for the fault current to earth by using low resistance wires

### Advantages of Earthing or Grounding

- ✓ It provide protection to the power system
- ✓ Earthing of electrical equipment ensure the safety of persons handling the equipment.

### Classification of Earthing or Grounding

- ✓ Equipment Grounding
- ✓ System Grounding

# (i) EQUIPMENT GROUNDING

- The process of connecting non-current carrying metal parts (metallic enclosure) of electrical equipments connected to earth such a way that in case of insulation failure, the enclosure effectively at earth potential is called equipment grounding.

- It connects the non-current carrying conductive materials such as cable trays, junction boxes and motor frames to earth ground.

- 3 Categories
  - ✓ Ungrounded Enclosure
  - ✓ Enclosure connected to Neutral Wire
  - ✓ Ground Wire connected to Enclosure

## Advantages of Grounded System

- It will be a stable neutral point.
- The life of the insulation will increase.
- Will get general safety to personnel and the equipment due to the operation of the fuses.
- Overvoltage due to sudden lightning will be discharged to the earth.
- Earth fault relaying will relatively simple.

## Advantages of Ungrounded System

- System Voltage Increase
- Protection Complicacy
- Arcing Ground

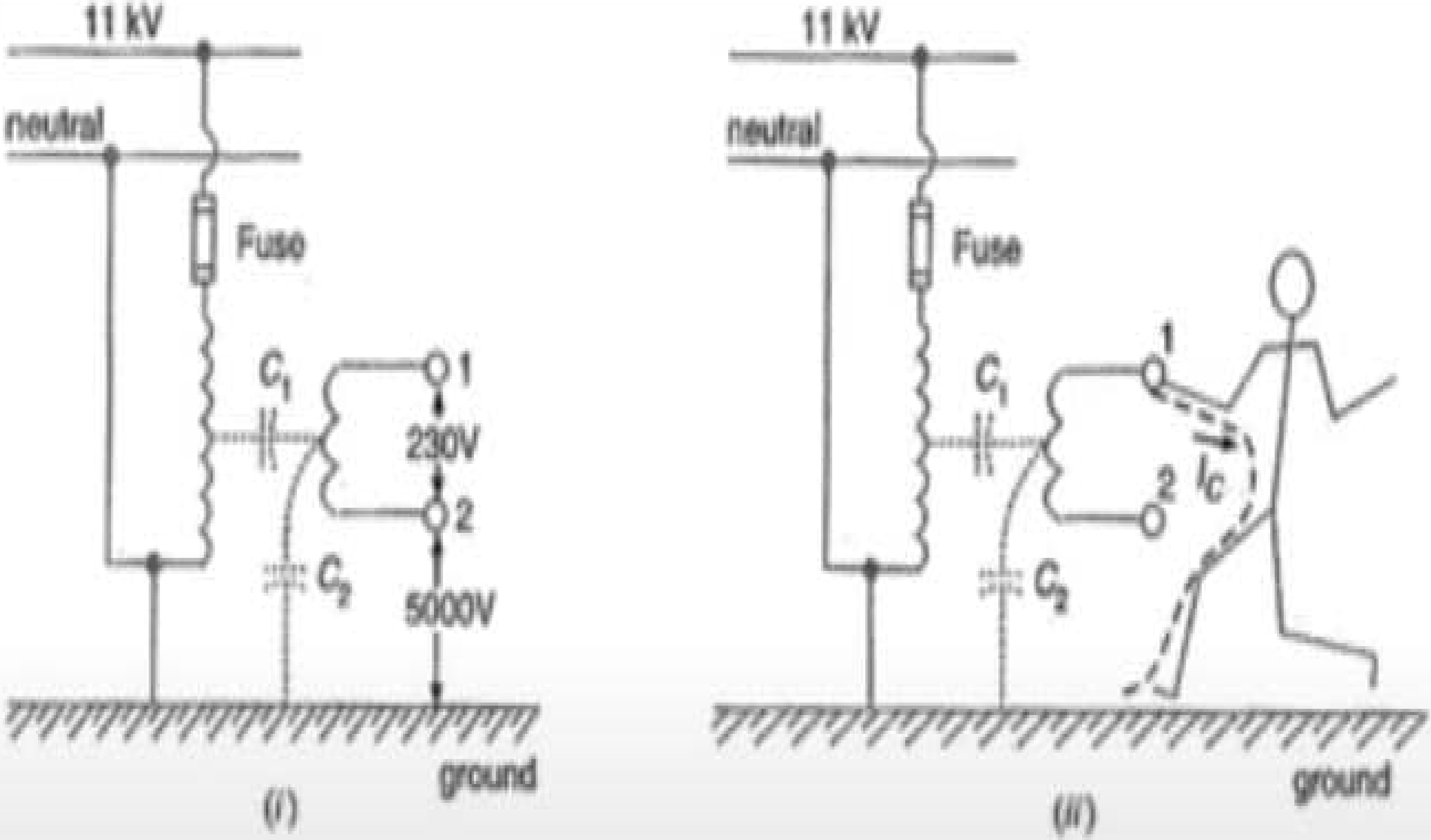
# (ii) SYSTEM GROUNDING

- The process of connecting some electrical part of power system (neutral point of a star connected system, one conductor of the secondary transformer etc) to earth (soil) is called system grounding.

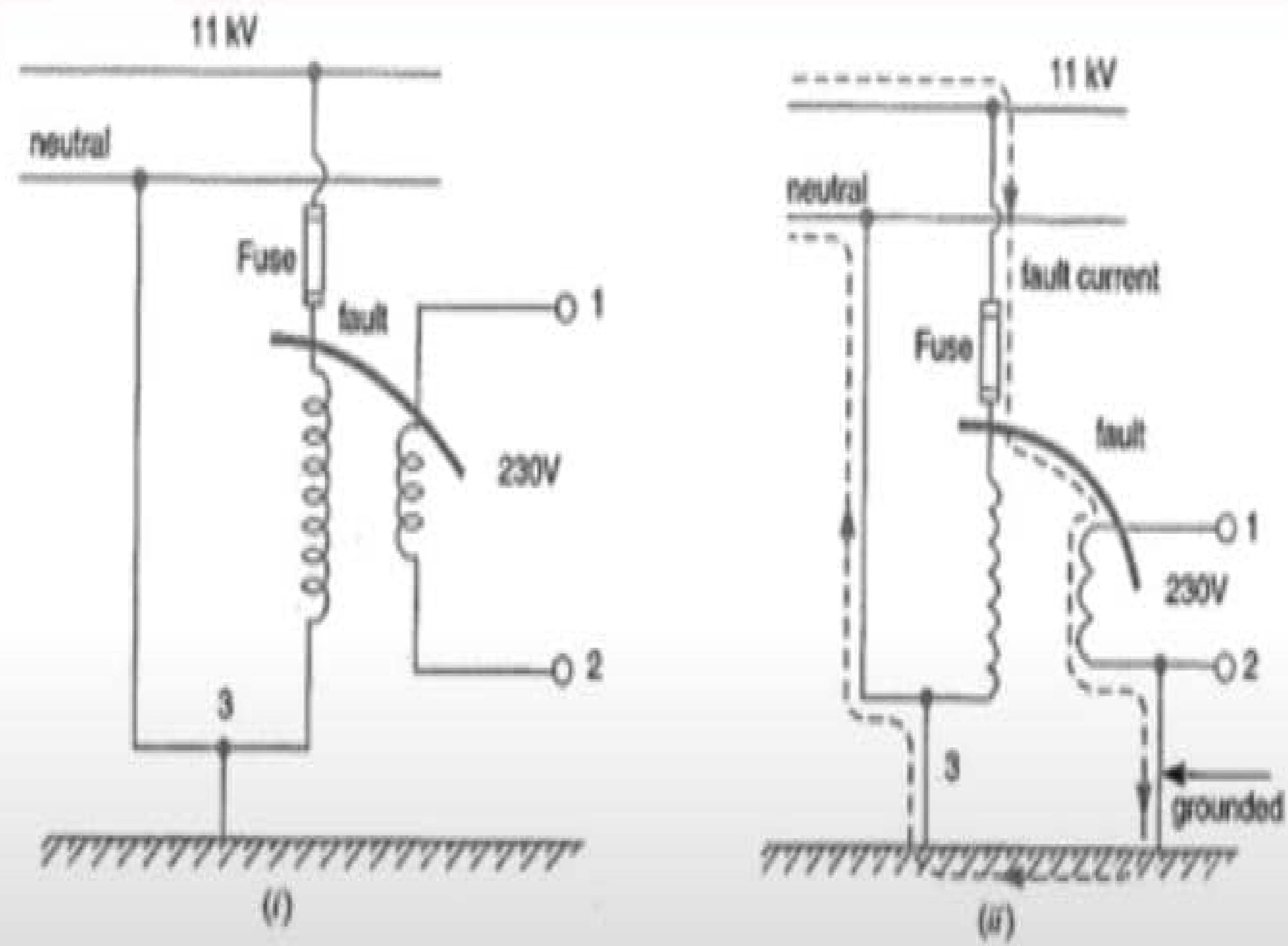
- In this the neutral point of the current carrying conductor such as the neutral point of a circuit or a transformer will be connected to earth ground

- Ensure reliability and safety of power system network.

# Importance of System Grounding



# Importance of System Grounding (contd.)

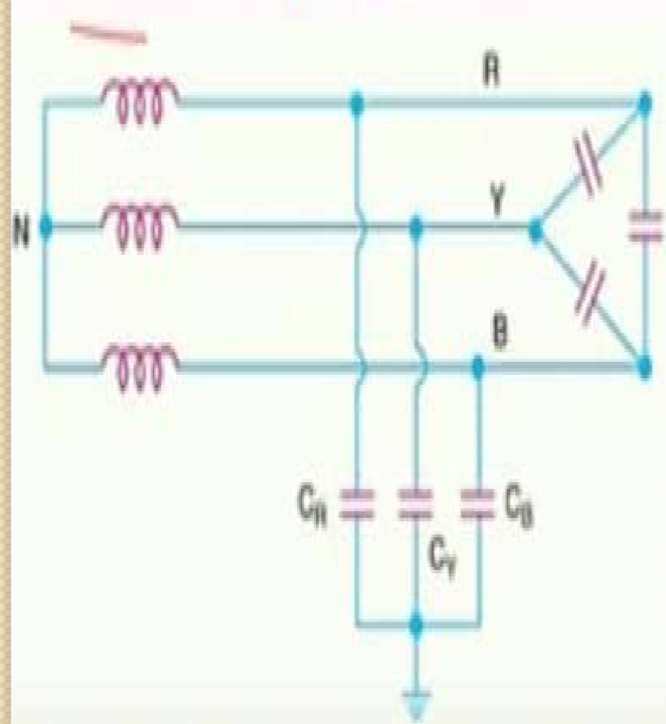


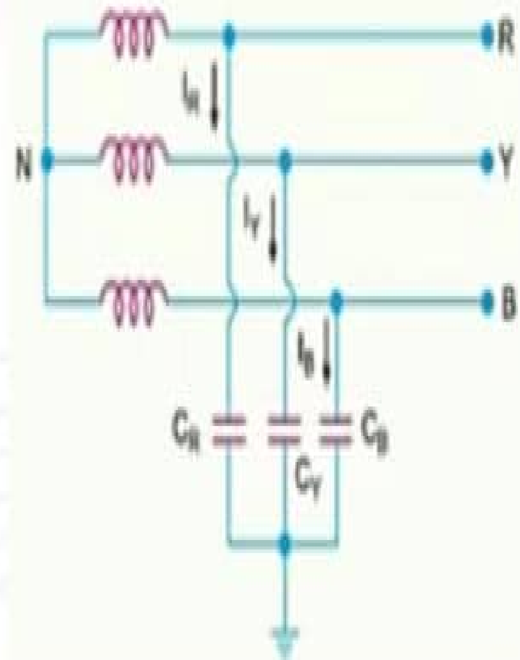
# UNGROUNDED SYSTEM

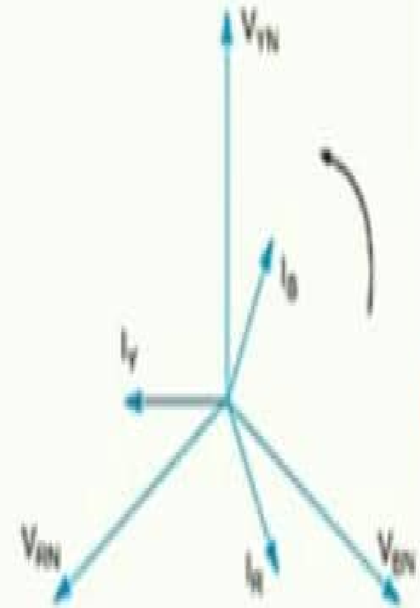
- **Definition:** The system without neutral grounding is known as the ungrounded system.
- **The main feature of the ungrounded system** is its ability to remove the earth faults without interruption.
- In ungrounded system, neutral is not connected to the ground.
- The line conductors have capacitances between one another and ground.

# Ungrounded 3- Phase System

# Under Normal Condition




Under Normal Condition, $C_R = C_y = C_B = C$

$I_R = I_y = I_B = V_{ph}/X_c$

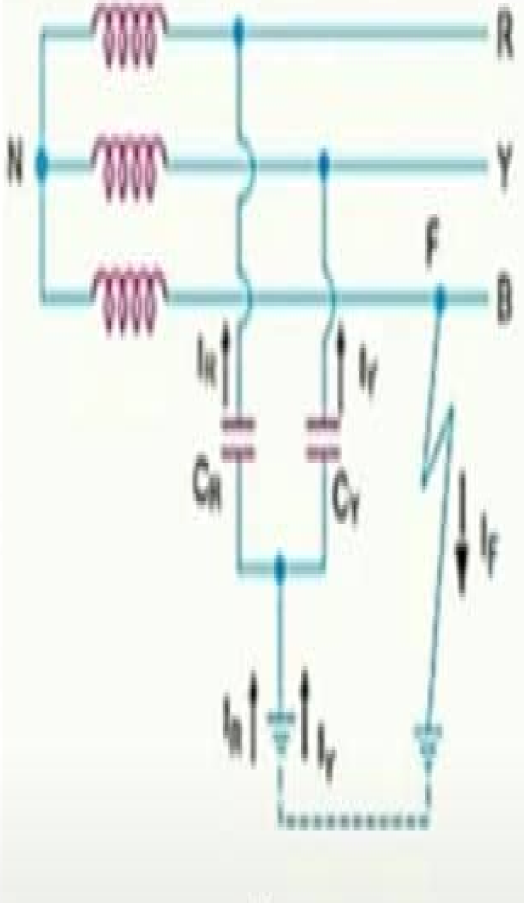
Vph = Phase Voltage i.e. Line to Neutral Voltage

Xc = Capacitive Reactance of the Line to Ground

# Ungrounded System with Fault on One Phase

The fault current $I_f$ has two components $I_R$ and $I_Y$, which flow through capacitance $C_R$ and $C_Y$ under the potential difference of $V_{BR}$ and $V_{BY}$ respectively.

The current $I_R$ and $I_Y$ leads from their respective voltage by 90º and their phasor sum is equal to fault current $I_f$.




(i)


(ii)

Capacitive Fault Current in line B, $I_F = I_R + I_Y$ --- Phasor Sum

$$I_R = \frac{V_{BR}}{X_{C_R}} = \frac{\sqrt{3}V_{ph}}{X_C}$$

$$I_Y = \frac{V_{BY}}{X_{C_Y}} = \frac{\sqrt{3}V_{ph}}{X_C}$$

$$I_R = I_Y = \frac{\sqrt{3}V_{ph}}{X_C} = \sqrt{3} \times \text{Per phase capacitive current under normal condition}$$

$$\therefore I_F = \sqrt{3}I_R = \sqrt{3} \times \frac{\sqrt{3}V_{ph}}{X_C} = \frac{3V_{ph}}{X_C}$$

$$= 3 \times \text{Per phase capacitive current under normal condition}$$

From the figures shown above the following points are concluded:

- The potential of the faulty phase becomes equal to ground potential. However, the voltages of the two remaining healthy phases rise from their normal phase voltages to full line value. This may result in insulation breakdown.
- The capacitive current in the two healthy phases increase to √3 times the normal value.
- The capacitive fault current ($I_f$) becomes 3 times the normal per phase capacitive current.
- This system cannot provide adequate protection against earth faults. It is because the capacitive fault current is small in magnitude and cannot operate protective devices.

From the figures shown above the following points are concluded: (contd.)

- The capacitive fault current $I_F$ flows into earth. Experience shows that $I_F$ in excess of 4A is sufficient to maintain an arc in the ionized path of the fault. If this current is once maintained, it may exist even after the earth fault is cleared. This phenomenon of persistent arc is called arcing ground.

- Due to arcing ground, the system capacity is charged and discharged in a cyclic order. This set up high-frequency oscillations on the whole system and the phase voltage of healthy conductors may rise to 5 to 6 times its normal value. The overvoltages in healthy conductors may damage the insulation in the line.

Due to above disadvantages, ungrounded neutral system is not used these days. The modern high voltage 3-phase systems employ grounded neutral owing to a number of advantages.

# METHODS OF NEUTRAL GROUNDING

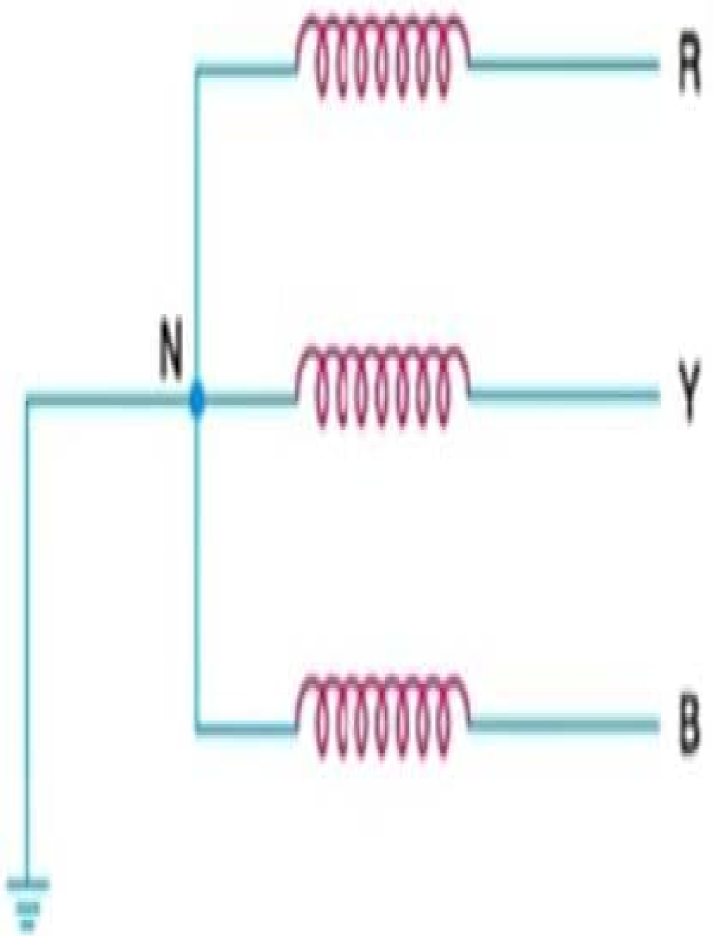
- ✓ Solid Grounding (or) Effective Grounding
- ✓ Resistance Grounding
- ✓ Reactance Grounding
- ✓ Resonant Grounding (or) Arc Suppression Coil Grounding

# Solid Grounding (or) Effective Grounding

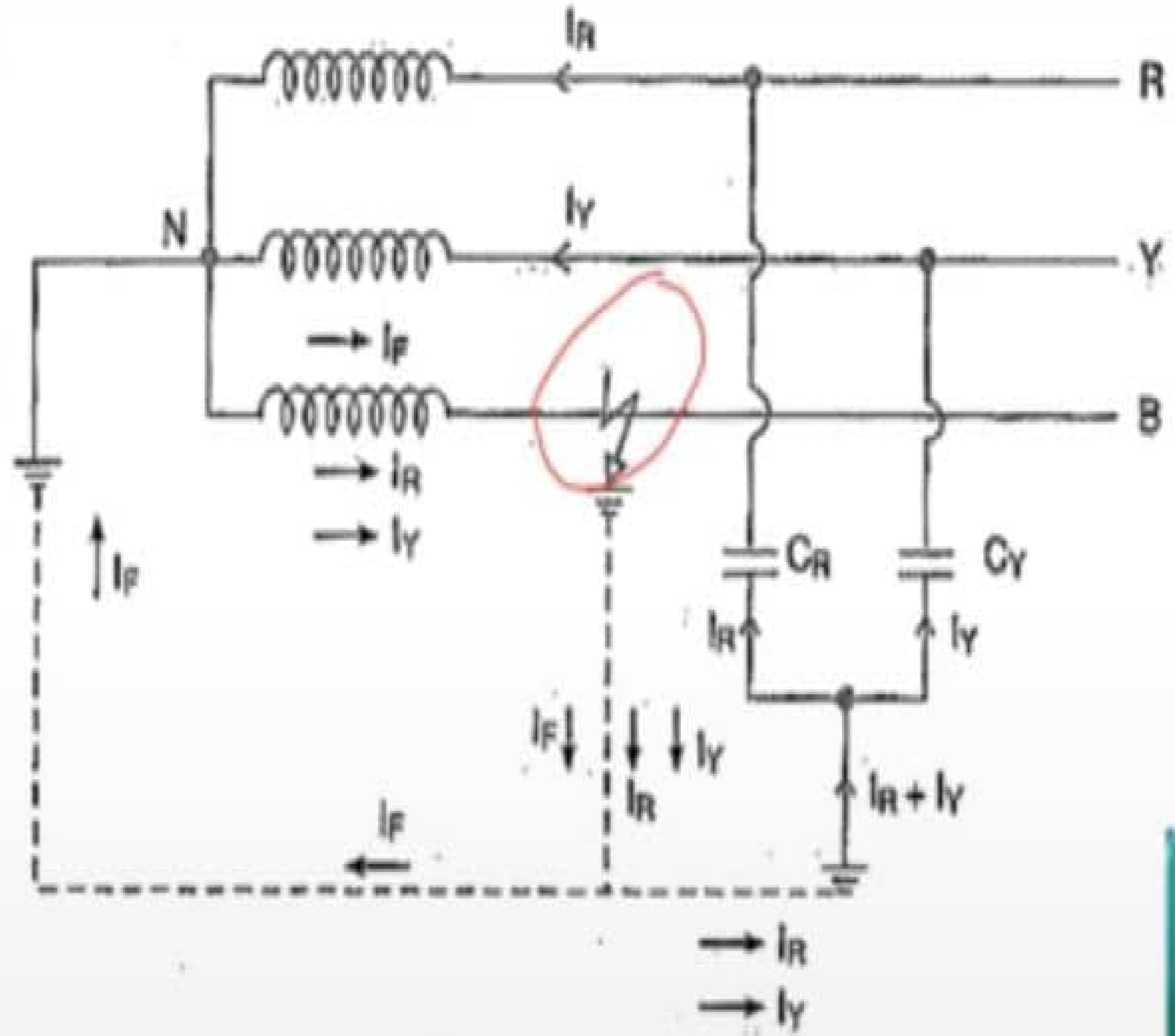
- When a neutral point of a 3-phase system is directly connected to earth (soil) through a wire of negligible resistance & reactance is called solid grounding (or) effective grounding.

- Since the neutral point is directly connected to the earth through a wire, the neutral point is held at earth potential under all conditions.

- Therefore, under fault conditions, the voltage of any of conductor to earth will not exceed the normal phase voltage of the system.



# Solid Grounding (or) Effective Grounding



# Solid Grounding (or) Effective Grounding

- When earth fault occurs on any phase, the resultant capacitive current $I_C$ is in phase opposition to the fault current $I_F$.

- The two currents completely cancel each other. Therefore, no arcing ground or over-voltage conditions can occur.

- Consider a line to ground fault in line B as shown in Fig.

- The capacitive currents flowing in the healthy phases R and Y are $I_R$ and $I_Y$ respectively.

- The resultant capacitive current $I_C$ is the phasor sum of $I_R$ and $I_Y$.

# Solid Grounding (or) Effective Grounding

- In addition to these capacitive currents, the power source also supplies the fault current $I_F$.

- This fault current will go from fault point to earth, then to neutral point N and back to the fault point through the faulty phase.

- The path of $I_C$ is capacitive and that of $I_F$ is inductive. The two currents are in phase opposition and completely cancel each other.

- Therefore, no arcing ground phenomenon or over-voltage conditions can occur.

# Solid Grounding (or) Effective Grounding

- When there is an earth fault on any phase of the system, the phase to earth voltage of the faulty phase becomes zero. However, the phase to earth voltages of the remaining two healthy phases remain at normal phase voltage because the potential of the neutral is fixed at earth potential. This permits to insulate the equipment for phase voltage. Therefore, there is a saving in the cost of equipment.

- It becomes easier to protect the system from earth faults which frequently occur on the When there is an earth fault on any phase of the system, a large fault current flows between the fault point and the grounded neutral. This permits the easy operation of earth-fault relay.

## Advantages

- The neutral is effectively held at earth potential
- No arcing ground phenomenon or over-voltage conditions can occur
- There is a saving in the cost of equipment
- It becomes easier to protect the system from earth faults

## Disadvantages

- Since most of the faults on an overhead system are phase to earth faults, the system has to bear a large number of severe shocks. This causes the system to become unstable
- This results in heavy earth fault currents which may cause the burning of circuit breaker contacts.
- The increased earth fault current results in greater interference in the neighbouring communication lines.

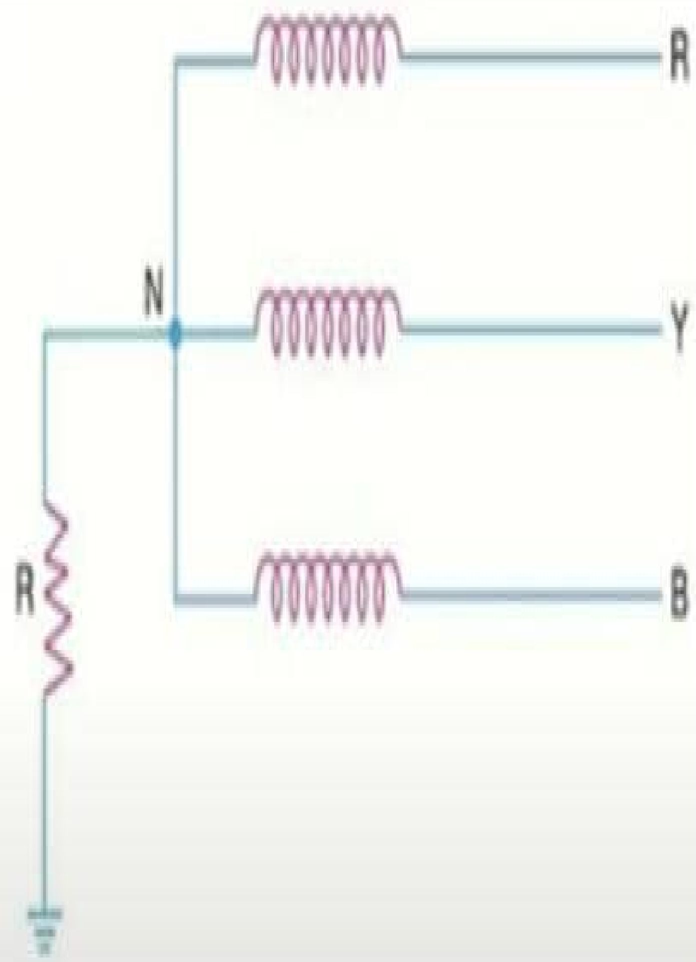
# Applications

- Solid grounding is usually employed where the circuit impedance is sufficiently high so as to keep the earth fault current within safe limits.

- This system of grounding is used for voltages up to 33 KV with total power capacity not exceeding 5000 KVA.

# Resistance Grounding

- When the neutral point of a 3 phase system (e.g. 3-phase generator, 3-phase transformer etc) is connected to earth (i.e. soil) through resistor is called resistance grounding.
- In order to limit the magnitude of earth fault current, the neutral point of a 3-phase system is connected to earth through a resistor.
- The value of resistance R should be neither very high nor very low.



# Resistance Grounding (contd.)

- If the value of earthing resistance R is very low, the earth fault current will be large and the system becomes similar to the solid grounding system.

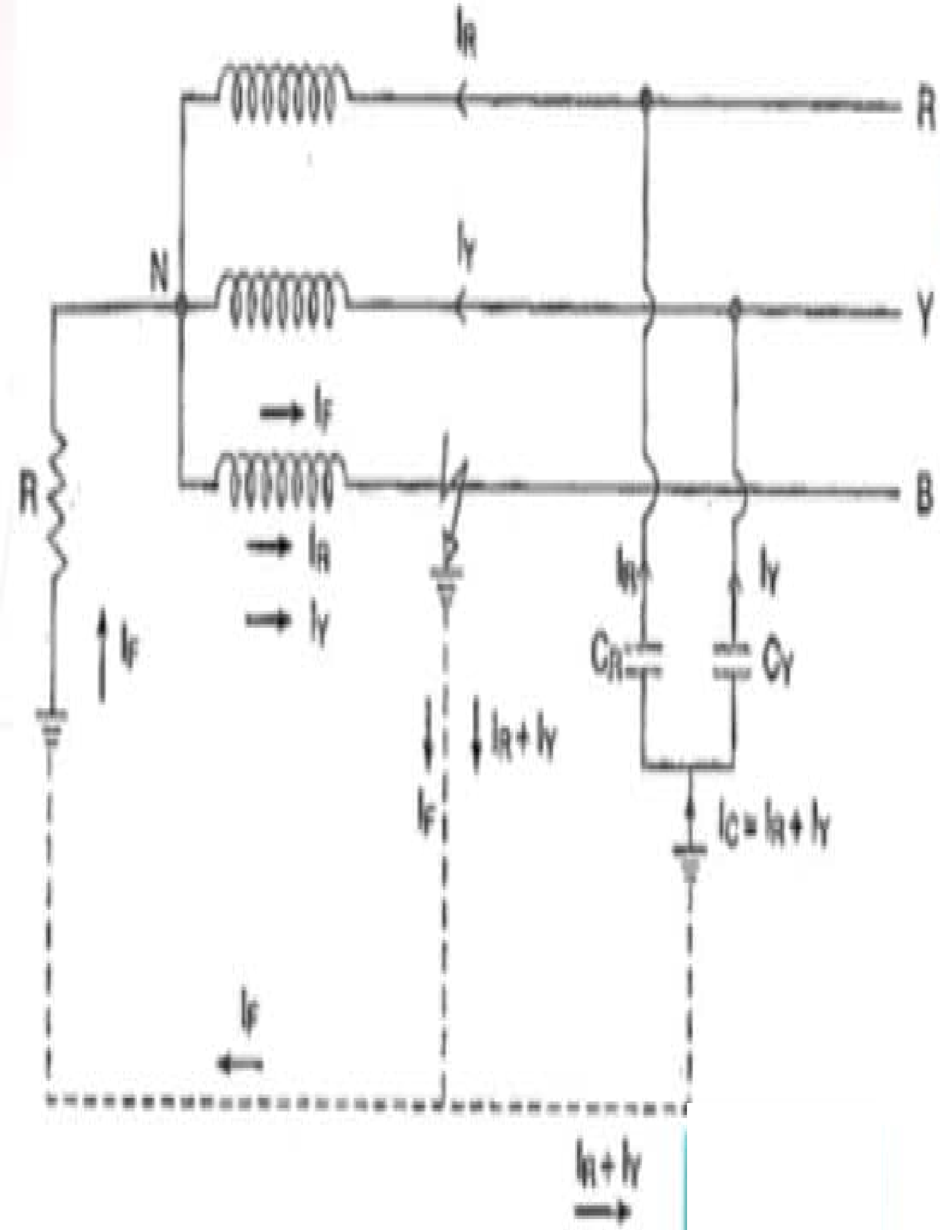
- If the earthing resistance R is very high, the system conditions become similar to ungrounded neutral system.

- The value of R is so chosen such that the earth fault current is limited to safe value but still sufficient to permit the operation of earth fault protection system.

- In practice, that value of R is selected that limits the earth fault current to 2 times the normal full load current of the earthed generator or transformer.

# Resistance Grounding

- By adjusting the value of R, the arcing grounds can be minimized.
- Suppose earth fault occurs in phase B as shown in Fig.
- The capacitive currents $I_R$ and $I_Y$ flow in the healthy phases R and Y respectively.
- The fault current $I_F$ lags behind the phase voltage of the faulted phase by a certain angle depending upon the earthing resistance R and the reactance of the system upto the point of fault.
- The fault current $I_F$ can be resolved into two components . $I_{F1}$ in phase with the faulty phase voltage. $I_{F2}$ lagging behind the faulty phase voltage by 90°.



# Resistance Grounding (contd.)

- The lagging component $I_{F2}$ is in phase opposition to the total capacitive current $I_C$.

- If the value of earthing resistance R is so adjusted that $I_{F2} = I_C$, the arcing ground is completely eliminated and the operation of the system becomes that of solidly grounded system.

- However, if R is so adjusted that $I_{F2} < I_C$ the operation of the system becomes that of ungrounded neutral system.

## Applications

- It is used on a system operating at voltages between 2.2KV and 33 KV with power source capacity more than 5000 KVA.

# Resistance Grounding (contd.)

## Advantages

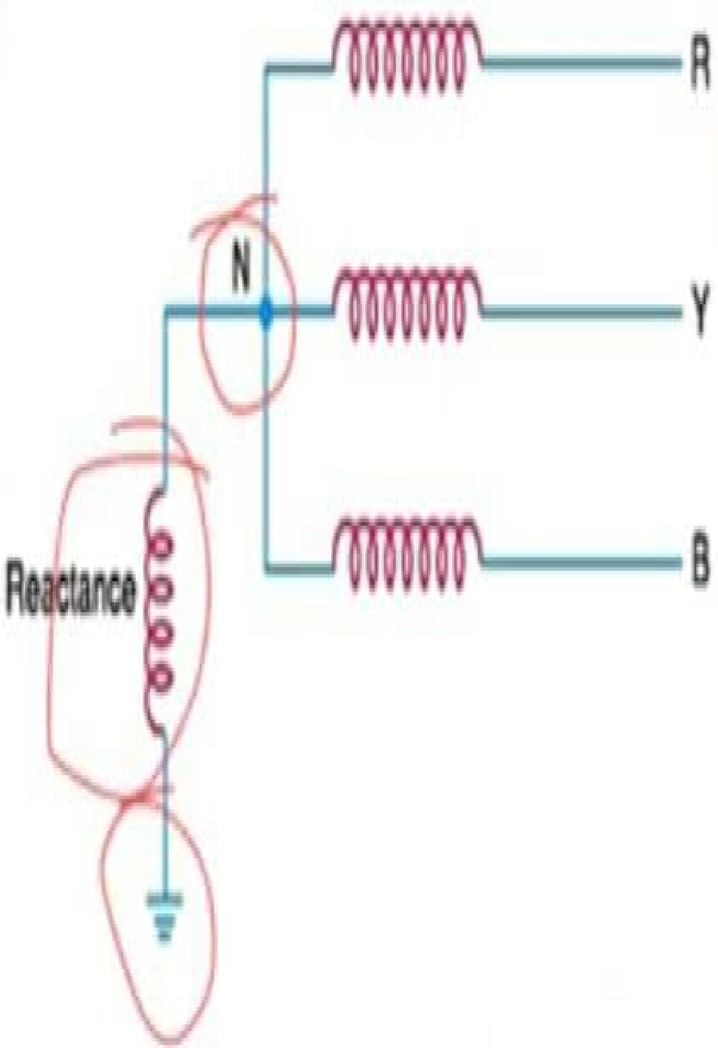
- The fault current is small due to the presence of earthing resistance. So the interference with communication circuit is reduced.
- Improve the system stability.

## Disadvantages

- System costlier than the solid grounded system.
- Large amount of energy produced during earth faults. Sometimes it becomes difficult to dissipate energy to the atmosphere.
- Since the system neutral is displaced during earth faults, the equipment has to be insulated for higher voltages.

# Reactance Grounding

- Reactance is introduced between neutral and ground.
- Purpose of reactance is to limit the earth fault current.
- By changing the earthing reactance, the earth fault current can be changed to obtain the conditions similar to that of solid grounding.
- This method is rarely using method

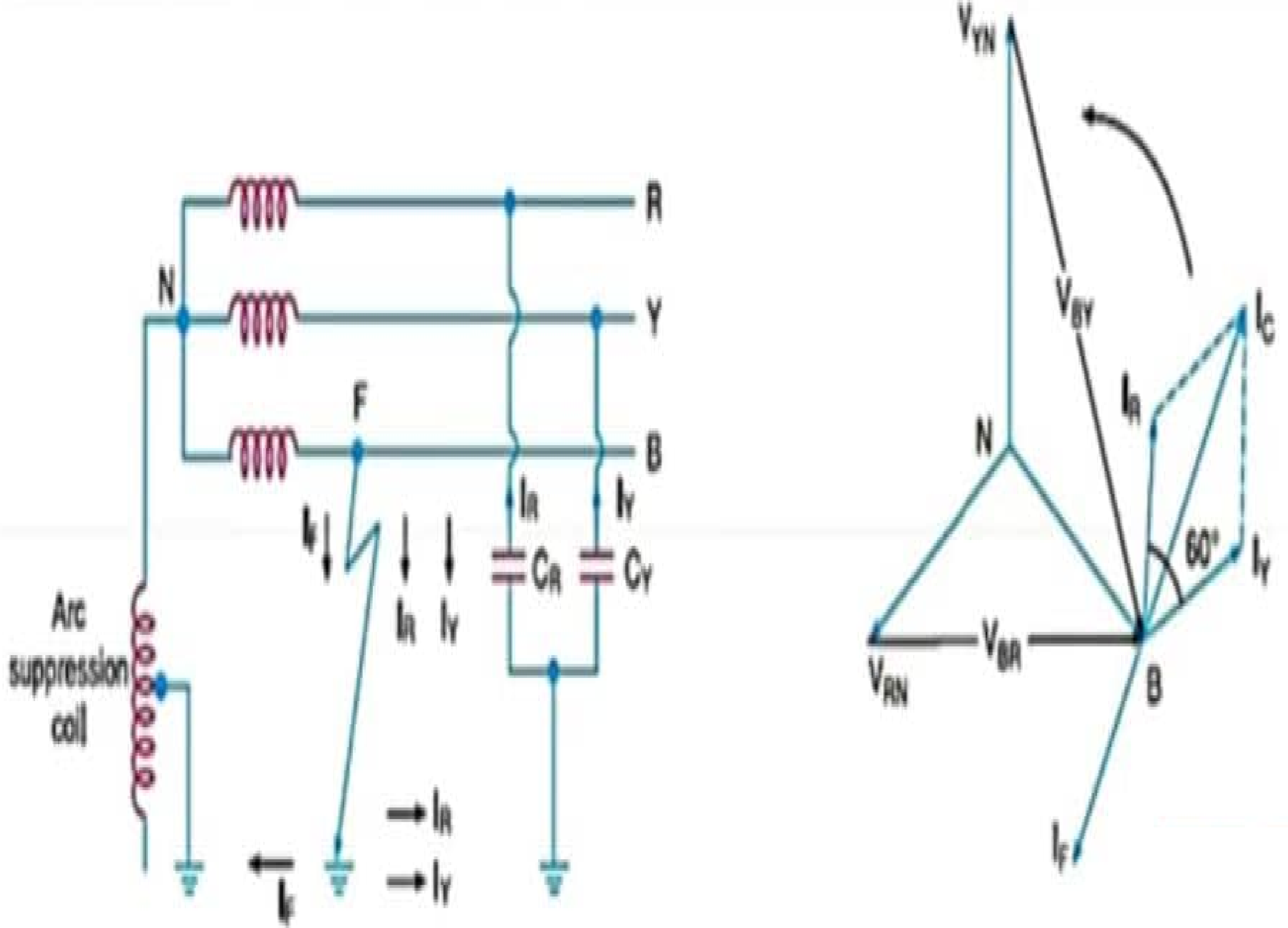


# Reactance Grounding (contd.)

## Disadvantages

- High transient voltages appear during fault conditions.
- In this system, the fault current required to operate the protective device is higher than that of resistance grounding for the same fault conditions.

# Resonant Grounding (OR) Arc Suspension Coil Grounding



# Resonant Grounding (OR) Arc Suspension Coil Grounding

## Circuit Details

- An arc suppression coil (also called Peterson coil) is an iron-cored coil connected between the neutral and earth.

- The value of L of arc suppression coil is such that the fault current $I_F$ exactly balances the capacitive current Ic is called as resonant grounding.

- The reactor is provided with tapping to change the inductance of the coil.

# Resonant Grounding (OR) Arc Suspension Coil Grounding

- By adjusting the tappings on the boil, the coil can be tuned with the capacitance of the system i.e. resonant grounding can be achieved.

- Capacitance is existing between each line and earth.

- Connect an appropriate value of inductance connected parallel with the capacitance of the system.

- If L is so adjusted $I_L = I_C$, as a result fault will be zero.

# Value of L for the Resonant Grounding

For resonant grounding, the system behaves as an ungrounded neutral system. Therefore, full line voltage appears across capacitors $C_R$ and $C_Y$.

$$I_R = I_Y = \frac{\sqrt{3}V_{ph}}{X_C}$$

$$I_F = \frac{V_{ph}}{X_L}$$

$$I_C = \sqrt{3}\, I_R = \sqrt{3} \times \frac{\sqrt{3}V_{ph}}{X_C} = \frac{3V_{ph}}{X_C}$$

Here, $X_L$ is the inductive reactance of the arc suppression coil.

Here, $X_C$ is the line to ground capacitive reactance.

For Resonant Grounding, $I_L = I_C$

$$\frac{V_{ph}}{X_L} = \frac{3V_{ph}}{X_C}$$

$$X_L = \frac{X_C}{3}$$

$$\omega L = \frac{1}{3\omega C}$$

$$L = \frac{1}{3\omega^2 C} \quad \text{...(i)}$$

Eqn.(i) gives the value of inductance L of the arc suppression coil for resonant grounding.

# Resonant Grounding (OR) Arc Suspension Coil Grounding

## Advantages

- The Peterson coil is Completely effective in preventing any damage by arcing ground.
- The Peterson coil has advantages of ungrounded neutral system.

## Disadvantages

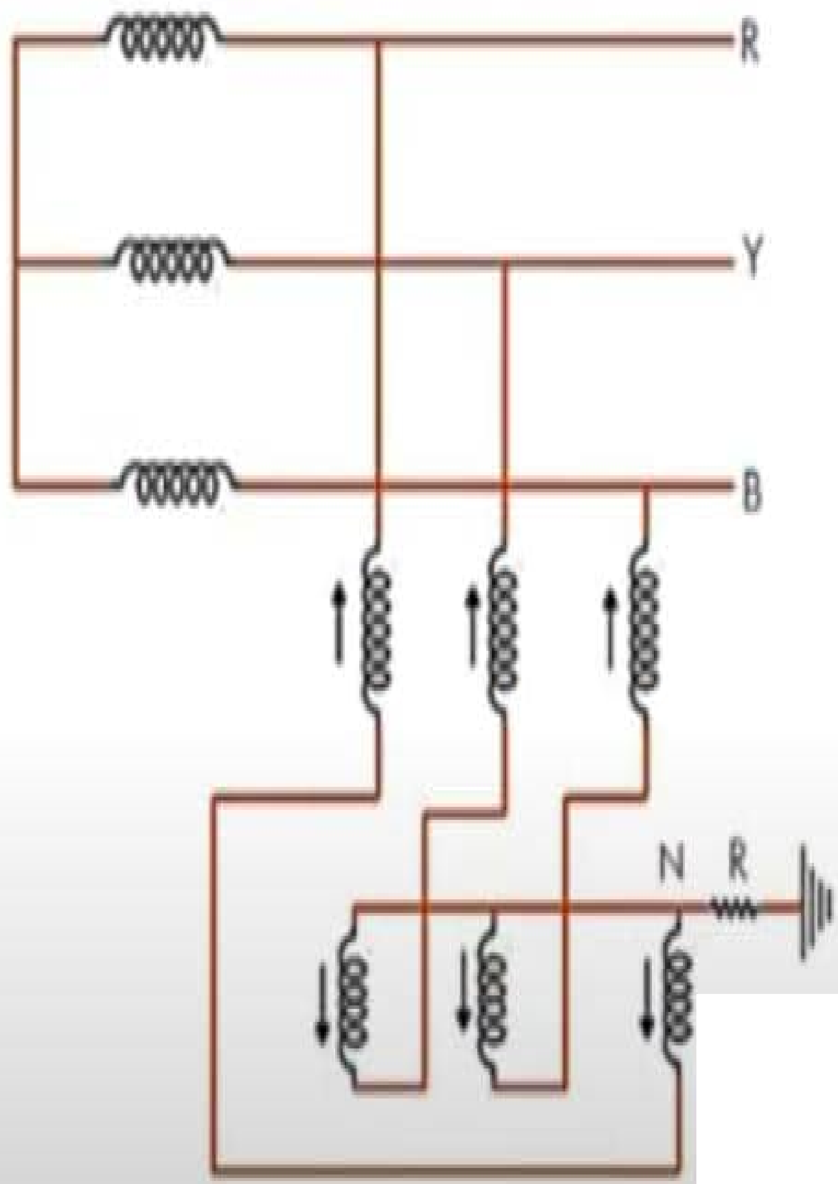
- Inductance L require readjustment.
- Due to varying operational conditions, the capacitance of the network changes from time to time. Therefore, inductance L of Peterson coil requires readjustment.
- The lines should be transposed.

# EARTHING TRANSFORMER

- Normally neutral point of generator or transformer is available.
- In some cases, it is not available such as delta connection, bus bar points etc.
- The most common method is to use a zig zag transformer.
- This transformer does not have secondary winding.
- Two identical winding are wounded differentially on each limb of the transformer so that the total flux in normal condition is negligible
- Therefore, the transformer draws very little magnetizing current.

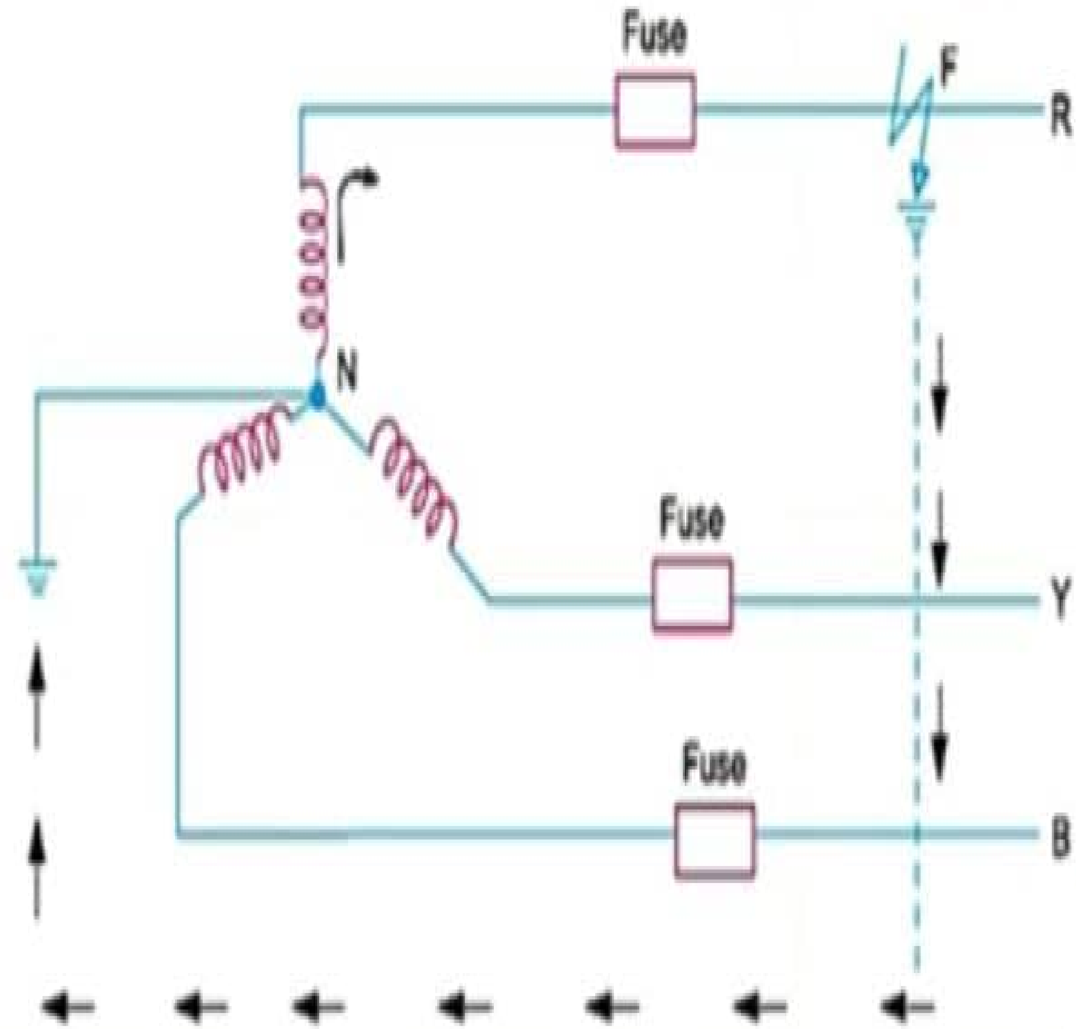
# EARTHING TRANSFORMER

The earthing or grounding transformers are of short time rating, the sizes of such transformers are small compared to power transformers.



# NEUTRAL GROUNDING

Fig. shows a 3-phase, star-connected system with neutral earthed



# NEUTRAL GROUNDING

- The process of connecting neutral point of 3 phase system either directly or through some Circuit elements (Resistance, Reactance etc.) is called neutral grounding.

- Protection to personal and equipment.

- During the earth fault the current path is completed through earthed neutral & protective devices (fuse) operate to isolate the faulty conductor from the rest of the system.

- One important feature of neutral grounding is that potential difference between live conductor & ground won't exceed the phase voltage of the system.

# ADVANTAGES

- ✓ High voltage due to arcing grounds are eliminated
- ✓ Over voltage due to lightning are discharged to earth
- ✓ Improved service reliability
- ✓ Operating and maintenance
- ✓ Protective relay can be used to provide protection against earth fault.
- ✓ Earth fault protection can be used easily
- ✓ The high voltages due to transient line to ground fault are eliminated
- ✓ Neutral earthing reduces the impact of lightning by discharging the stroke to earth
- ✓ Greater safety to the personnel
- ✓ It provides stable neutral point
- ✓ It improves reliability, economy and performance of the system

# NEUTRAL GROUNDING TRANSFORMER

- The neutral earthing transformer is used to create a neutral for the delta side .
- Transformer creates additional impedance, which would limit various imbalanced & fault current.
- Neutral grounding transformer protects power transformer & generators from damaging fault current ( typically more than 50A).
- It is also called as earthing transformer.
- Earthing Transformer or grounding transformer is the neutral grounding transformer.

# NEUTRAL GROUNDING TRANSFORMER

- Star connected on the primary and has an open delta on secondary.
- Open Delta has two terminals.
- A resistor is connected across these two terminals.
- Earthing transformer can also be called a large Potential transformer (Open delta PT).

# NEUTRAL GROUNDING TRANSFORMER