# Module 4 :- Substations & Grounding ①

## Introduction to Substation equipment :-

The major equipments and accessories that may be used in a substation are described as follows-

1] **Bus-bar** :- An electric bus collects electric energy at one location and the bus bar is the conductor through which electric current flows. Outdoor busbars are supported by pedestal or post insulators and the spacing of bus supports should limit bus sag under maximum loading. The busbars may be of rigid type or strain type.

2] **Circuit breaker** :- A circuit breaker is a device which can interrupt a section or a circuit automatically if an abnormal or faulty condition exists in that section.

↳ It can be operated manually also.

↳ A three phase circuit breaker essentially comprises of three pair of contacts - one of each pair is a movable contact and the other is a fixed contact.

↳ Under normal operating condition, the contacts of each pair close on themselves and the circuit breaker is said to be closed.

↳ In the event of any abnormal variations, the movable contacts of each pair is made to open against spring forces by a mechanical device through a trip circuit energized by a battery.

↳ The trip circuit is activated by one or more relays which sense the abnormal condition.

↳ The relays and circuit breakers acts as components of protective devices.

Depending upon the basis of rated voltages, circuit breakers are classified as,

↳ Low voltage circuit breaker (upto 1kV)

↳ High voltage circuit breaker (more than 1kV)

Based on mode of arc extinction, circuit breakers are classified as

↳ High resistance interruption

↳ Low resistance (or zero point) interruption.

Based on the medium of arc extinction, circuit breakers are classified as,

↳ Air blast circuit breaker.

↳ Minimum oil circuit breaker.

↳ Vaccum circuit breaker etc.

→ The circuit breakers are decided based on the voltage and fault current of the place where it should be installed. The voltage rating of the circuit breaker is normally from 1.05 to 1.10 times more than the normal operating voltage. If fault persist, the circuit breaker will be in open position.

3] Fuses :-

↳ A fuse is the simplest current interrupting device for protection of excessive currents due to the overload or fault.

↳ A fuse is a non-adjustable, direct acting, single phase device that responds to both the magnitude and duration of current flowing through it.

↳ fuses may be used in both low voltage and high voltage lines.

↳ High Rupturing capacity cartridge (HRC) fuses are more reliable and give better discrimination and accurate characteristics.

4] Isolators :-

↳ Motor operated disconnect switches (also known as isolating switches or isolators) should be provided for isolating all circuit breakers for maintenance and repair.

↳ Isolators are also used for disconnecting line and allow the equipments to be taken out of the system for repair, maintenance and testing.

↳ Isolators are used in addition to circuit breakers which can make and break circuit under normal and short circuit conditions.

↳ Isolators are interlocked with circuit breakers to prevent operation on load, thus isolators are not supposed to be operated opened under loaded conditions.

5] Lightening Arrestors :-

↳ It is also known as surge arrestor which is normally connected between phase and ground at the substation, to protect the substation equipments from lightning and switching surges.

↳ These lightning arrestors offer low resistance to the high voltage surge for diverting to the ground.

↳ After discharging the surge energy to ground, it blocks the normal current flowing to ground by offering a high resistance path.

6] Reactors and capacitors :-

↳ These capacitors supply reactive power to the loads and thus help in improving power factor.

↳ Sometimes reactor may also be used to absorb reactive power supplied by the line.

↳ To limit the line charging current, long distance extra high voltage lines are connected with the line reactors at both the ends. These reactors are permanently connected to the line.

↳ Bus reactors are separately connected to the substation bus where as tertiary reactors are connected in the tertiary winding of the transformers.

↳ By using these reactors, the Ferranti effect is reduced.

↳ When a short circuit occurs at a point in a large generating and transmission scheme, the short circuit current flowing is very large.

↳ To limit the short circuit current flowing to a safe value and for the purpose of protecting the plant, current limiting reactors are employed.

↳ They also tend to localize the effects of a fault by limiting the amount of power that can flow into it from other parts of the system. In this way, complete shut-down of the plant is avoided.

↳ Capacitors are normally connected in low voltage systems. During peak load conditions, the system voltage falls and therefore capacitive power is required.

↳ In distributed system or in sub-transmission system, capacitors are connected to improve the power factor of the system.

7 Current and potential transformers (CT's & PT's)-

↳ These transformers are used for two purposes.
  → for metering
  → for relaying & protection

↳ Current transformers step down the system current to a lower value and potential transformers step down the system voltage.

↳ These step down currents and voltages are used for measurement of current, voltage, active, reactive and ~~apparatus~~ apparent power, energy, power factor, frequency etc.

↳ Large number of CT's and PT's are to be used to get information of system condition at various sections of the substation and so, are ~~insulated~~ installed at various locations.

8] Earthing (or grounding) :-

↳ A proper grounding is must for safe and reliable operation of the substation.

↳ All the power systems operate with grounded neutral due to several advantages.

Earthing switch :- It is connected between the conductor and earth. Normally it is in open condition. However, when the line is disconnected, this switch is closed to discharge trapped charge to ground.

9] Control Room :-

↳ The control room of the substation houses: instrument panels, various types of relays, battery and battery charging equipments required for trip circuit, supervisory control apparatus.

↳ Electrical and electronic instruments like ammeters, voltmeters, wattmeter, VAR meters, frequency meters and power factor meters are located in the control room.

10] Voltage Regulators :-

→ Every alternator is provided with an automatic voltage regulators which performs the following functions :-

↳ Control of system voltage within prescribed limits.

↳ Proper division of reactive power between the alternators operating in parallel.

↳ Prevention of dangerous over-voltages on the occurrence of sudden loss of load on the system.

↳ Increase of excitation under system fault conditions so that maximum synchronising power exists at the time of clearance of fault, to prevent loss of synchronism.

11] Switches :-

↳ A switch is used in an electric circuit as a device for making or breaking the electric circuit in a convenient way.

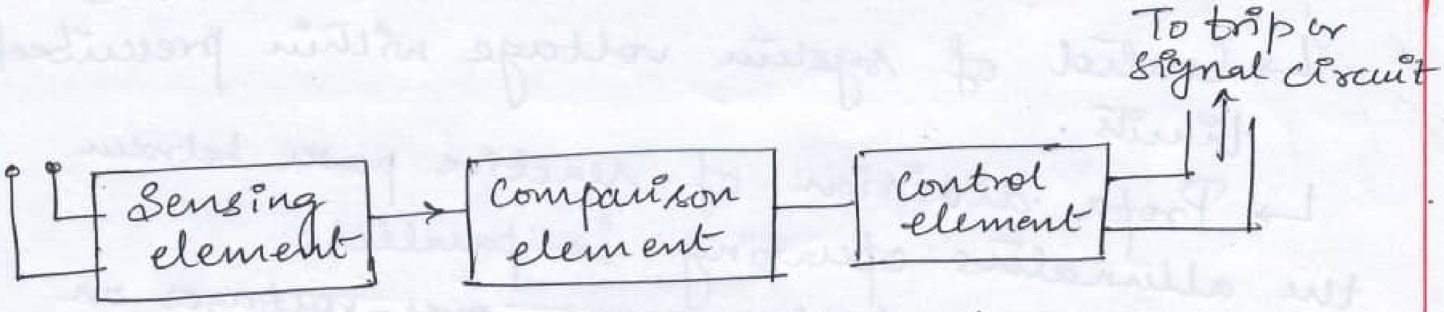
↳ Classification → Air switches → Air-break switches; → Isolators (disconnect switches)
→ Oil switches.

↳ Air switches – whose contacts are opened in air.

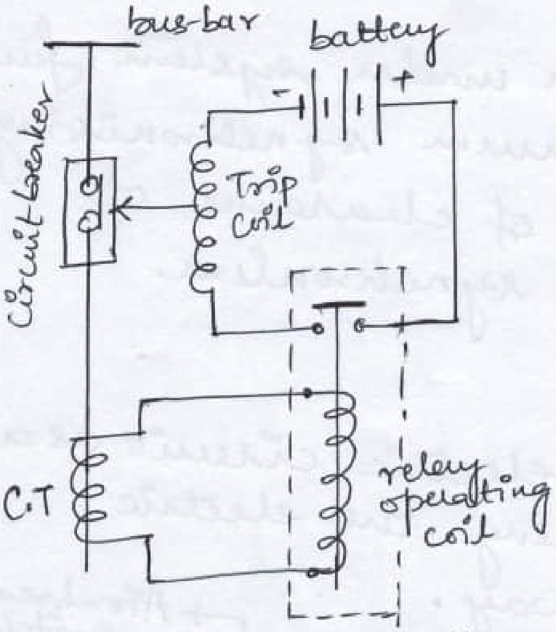
Oil switches – whose contacts are opened under oil.
– employed in very high voltage heavy current circuits.

12] Protective Relays :-

↳ It is an electrical device interposed between the main circuit and the circuit breaker such that any abnormality in the circuit acts on the relay, causes the breaker to open and to isolate the faulty element.




Basic elements of a relay.




Typical Relay circuit.

→ Under normal operating conditions, the voltage induced in the secondary winding of the CT is small and current flowing in the relay operating coil is insufficient in magnitude to close the relay contacts. This keeps the trip coil of the circuit breaker deenergised.

→ When a fault occurs, a large current flows through the primary of the CT. This increases the voltage induced in the secondary and hence the current flowing through the relay operating coil. The relay contacts are closed and the trip coil of the breaker gets energized to open the breaker contacts.

13 Batteries:-

↳ All power plants and substations require dc supply for protection and control purposes and dc supply is obtained from secondary or storage batteries.

↳ Storage batteries are of two types namely lead acid and alkaline batteries.
Lead acid batteries are most commonly used in power stations and substations because of their higher cell voltage and lower cost.

14] Carrier - current Equipment :-

↳ Such an equipment is installed in an electrical power station for communication, relaying, telemetering or for supervisory control.
↳ This equipment is suitably mounted in a room known as carrier room and connected to the high voltage power circuit.

15] Measuring Instruments :-

↳ The functions of the instruments are
(i) operating guidance (ii) economical supervision (iii) performance calculations (iv) cost and cost allocation and (v) maintenance / repair guidance.

↳ Classification of Instruments :- → Mechanical, → Electrical.

↳ Mechanical Instruments include temperature measuring devices, pressure measuring instruments, flow meters, fuel measuring instruments, gas analysis instruments, speed measuring instruments, level recorders, gong alarms, steam calorimeters and fuel calorimeters, atmospheric measuring instruments.

↳ Electrical instruments include ammeters, voltmeters, wattmeters, kWh meters, kVARh meters, synchroscopes, power factor meters, reactive - volt ampere meters, ground detectors.

## Substations :-

↳ In between the power house and the consumer, a ~~aut~~ number of transformation and switching stations have to be created. These are generally known as substations.

Types of Substations:-

Depending upon the purpose, the substations may be classified into -

⇒ Generating substations or step-up substations:-

Normally the generating voltages are limited, thus needs to be stepped upto the transmission voltage so that large amount of power can be transmitted economically over long distance.

⇒ Grid substations :-

These substations are located in the intermediate points between the generating stations and the load centers. The main purpose of these substations are to provide connections to low-voltage lines, some compensating devices etc.

⇒ Secondary substations :-

These substations are connected with the main grid substations which help of secondary transmission lines. The voltages at these substations are stepped down to the substation transmission voltage. At this substation, few large consumers are also connected.

⇒ Distribution Substation :-

These substations are created where the sub transmission voltage or primary distribution voltage is stepped down to supply voltage;

these substations feed the actual consumers through a network of distributors and service lines.

→ Special purpose substations :-
Some special substation for bulk power and some industrial loads are set up.
Ex:- Traction substations and mining substations.
The mobile sub-stations are of special purpose and designs. They are needed for temporary requirements such as for construction purposes or cinematograph etc.

Depending on the physical features, substations are further classified into :

⇒ Outdoor type :-
Normally outdoor substations are used for 33kV and above for cost and safety reasons.
All equipments lie open in air, however control and monitoring is performed inside the control rooms.

→ Indoor type :-
All equipments of these substations lie in a room. The operating voltage is normally 400V and 11kV. These substations are situated in big cities.

⇒ Pole mounted or open or kiosk type :-
These substations are mounted on the poles. These substations are very simple and cheap as no building is required for housing these equipments. These substations are usually of low capacity, ie upto 500kVA transformers.

⇒ Underground substation :- (Basement type)
These are used when the space is not available. whole substation is made underground.
The size of the substation can be high or low depending upon the capacity. The substation design aims at achieving a high degree of continuity, maximum reliability and flexibility to meet these objectives with the highest possible economy.

Advantages and Disadvantages of Outdoor substations over indoor substations :-
The outdoor substations have the following main advantages over indoor substations.
↳ All the equipment is within view and therefore fault location is easier.
↳ The extension of the installation is easier, if required.
↳ The time required in erection of such substations is lesser.
↳ The smaller amount of building materials is required.
↳ The construction work required is comparatively smaller and cost of the switchgear installation is low.
↳ 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.

↳ Repairing work is easy.

Disadvantages of outdoor installations in comparison of indoor installations are –

↳ The various switching operations with the isolators as well as supervision and maintenance of the apparatus is to be performed in the open air during all kinds of weather.

↳ More space is required for the substation.

↳ Protection devices are required to be installed for protection against lightning surges.

↳ The length of control cables required is more.

↳ The influence of rapid fluctuation in ambient temperature and dust and dirt deposits upon the outdoor substations equipment makes it necessary to install apparatus specially designed for outdoor service and more costly.

## Selection & location of site for a substation:-

→ Type of Substation :-

Power from various sources is stepped up for long distance transmission, should be located as close to the generating stations as possible to minimize the transmission losses.

Similarly a step-down substation should be located nearer to the load centre to reduce transmission losses, cost of distribution system and better reliability of supply.

⇒ Availability of suitable and sufficient Land:-
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.

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

⇒ 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 loaden, is deteromental to the proper running of power system and therefore substations should not be located near factories or sea coast.

⇒ Availability of Essential Amenities to the staff:-
The site should be such when staff can be provided essential amenities like school, hospital, drinking water, housing etc.

⇒ 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.

## Busbar arrangement schemes :-

↳ The layout of the electrical equipments in the power plant consists of the arrangement of the busbars, circuit breakers, transformers and controlling switch-board.

↳ The choice of particular arrangement depend on various factors such as system voltage, position of the substation in the system, flexibility, reliability of supply and cost, ease of maintenance, available ground area, ease of rearrangement, safety, simplicity of relaying, provision for future expansion etc.

Few common arrangements of busbars :-

- ↳ Single bus scheme
- ↳ Double bus with Double breaker
- ↳ Double bus with Single Breaker.
- ↳ Main and transfer bus
- ↳ Ring bus or Mesh scheme
- ↳ Breaker and a half with two main buses.
- ↳ Double Bus-bar with bypass isolators.

Description & single line diagram of each of these arrangements are given below-

⇒ Single bus arrangement :-

↳ The single bus arrangement has the simplest design and is generally used in small ~~condu~~ outdoor substations having relatively few incoming and outgoing lines.

↳ The single bus bar arrangement is as shown in the fig.(a).

↳ Each circuit is protected by its own circuit breaker and each circuit breaker is equipped by two isolators.

↳ Maintenance of these circuit breakers involves loss of the circuit, thus difficult to do any maintenance.

↳ A fault on the bus causes complete shut-down of the substation. Sectionalizing of the single bus, as shown in fig (b) improves reliability.

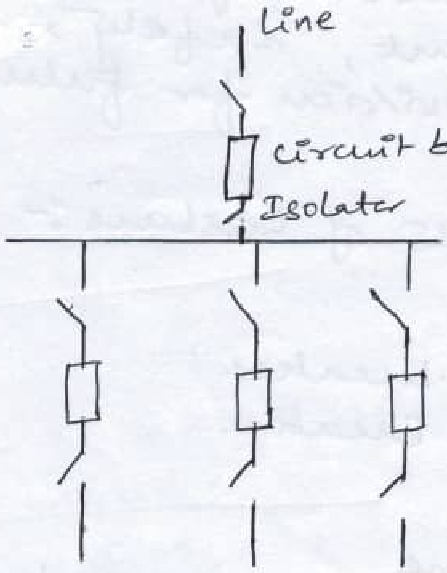



fig (a) Single bus scheme without bus sectionalizer

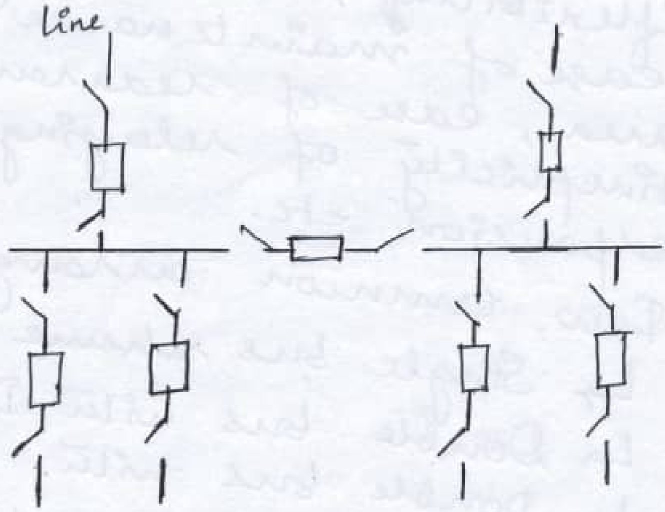



fig (b) Single bus scheme with bus sectionalizer

↳ from fig (b), the two sections of the bus are connected through a sections circuit breaker and two isolators

↳ A fault on the bus section circuit breaker causes complete shut down. All sections may be restored after isolating the faulty circuit breaker.

↳ However, a fault of one section causes loss of transformers or feeders connected to that section only.

↳ Provision of bypass isolators between bus-bar and circuit isolators allows circuit breaker maintenance without loss of that circuit.

→ **Double bus with Double breaker :-**

↳ The double bus double breaker arrangement is as shown in the figure.

↳ This arrangement consists of two main buses, both normally energized.

↳ Between the two buses - there are two breakers and one circuit.

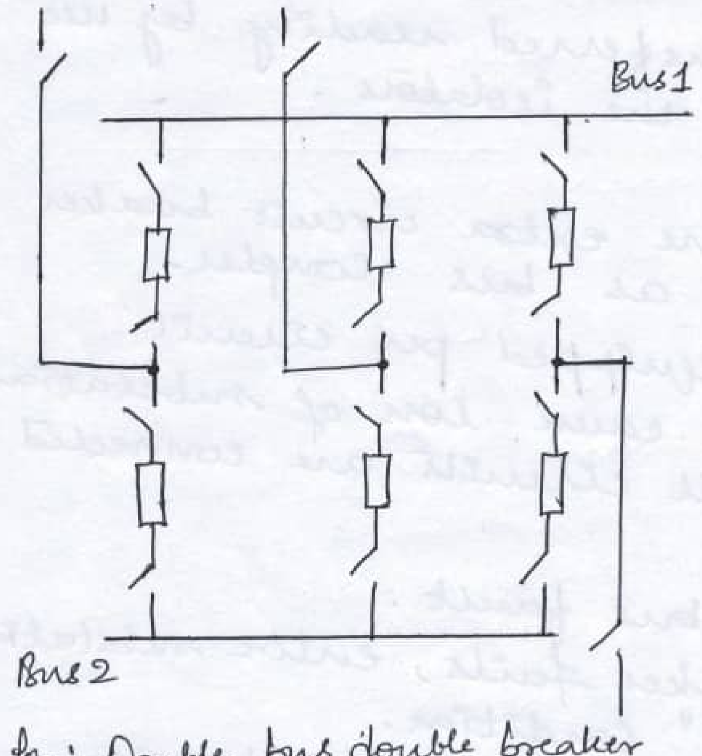



fig: Double bus double breaker scheme

↳ This arrangement allows for any breaker to be removed from service without interruption to service to its circuit.

↳ A fault on either of the main buses will cause no circuit disruption.

↳ This scheme provides double feed to each circuit.

↳ Thus, it gives very high reliability and operational flexibility.

Disadvantage :-

→ It involves high cost having two circuit breakers per circuit.

↳ A cheaper of the scheme is double bus-bar single breaker arrangement.

→ Double bus bar Single breaker scheme :-

↳ This scheme uses two main buses and it is connected with two disconnecting switches, as shown in the fig.

↳ In this scheme a bus tie-circuit breaker (or bus coupler) is used as it enables a load change over from one bus to another.

↳ Advantages -

↳ It permits some flexibility with two operating buses.

↳ Either bus1 or bus2 may be isolated for maintenance.

↳ Circuit can be transferred readily by use of bus tie breaker and the isolators.

Drawbacks -

↳ Cost increases as one extra circuit breaker is used in the system as bus coupler.

↳ Four isolators are equipped per circuit.

↳ Bus protection may cause loss of substation when it operates if all circuits are connected to that bus.

↳ High exposure to bus fault.

↳ If the bus tie breaker fails, entire substation leads to "Out of service" condition.

↳ Maintenance of the breaker is not possible without causing stoppage of supply.

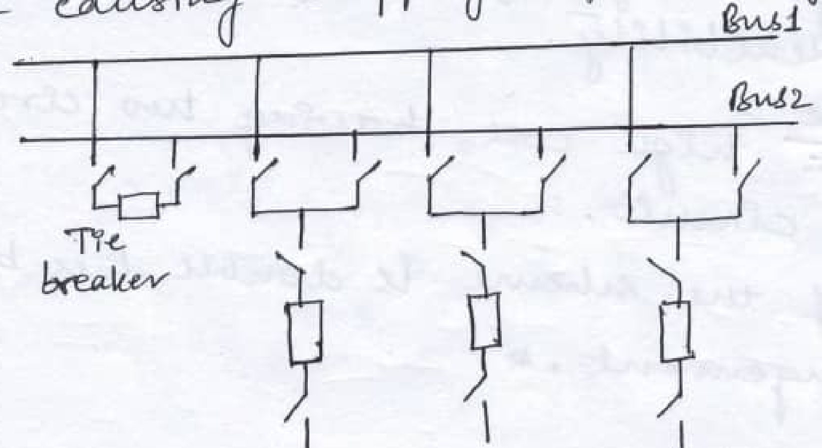



fig: Double bus single breaker scheme

→ Main and transfer bus :-

↳ The main and transfer bus scheme arrangement are as shown in the figure consists of two independent buses, one of which is normally energized.

↳ Under normal conditions, all circuits are tied to the main bus.

↳ The transfer bus is used to provide service through the transfer bus tie-breaker when it becomes necessary to remove a breaker from service. The transfer bus is a standby for emergency use only.

↳ Each busbar has the capacity to take up the entire substation load.

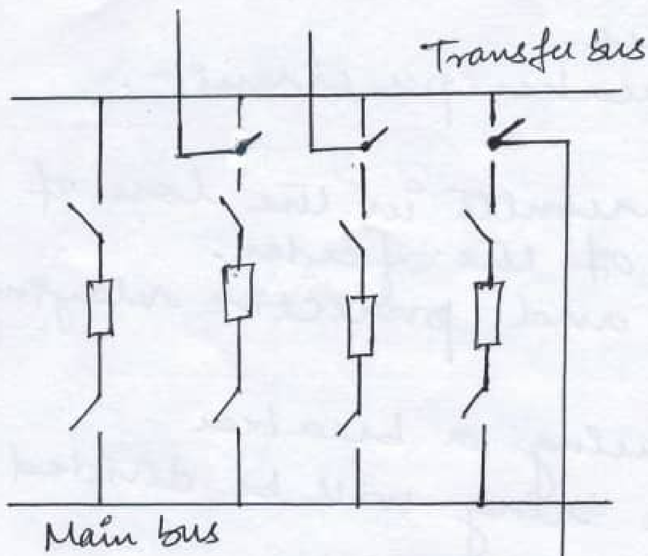



fig:- Main & transfer bus.

Advantages :-

↳ Continuity of service and protection in the feeder section during breaker maintenance.

↳ Ease of expansion.

↳ Low cost.

Drawback :-

↳ Switching is complicated when maintaining a breaker.

↳ failure of a bus or any circuit breaker results in shut down of entire substation and requires an extra breaker.

→ Ring or Mesh bus bar scheme :-

↳ The ring bus scheme is as shown in the fig. This scheme consists of a loop of bus sections with each section separated by a breaker.

↳ This arrangement allows the circuit breaker maintenance without interruption of service to any circuit.

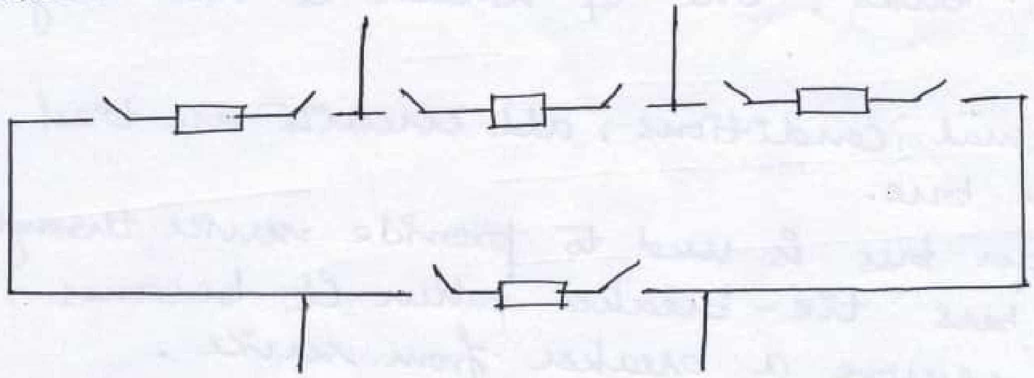


fig:- Ring bus or mesh scheme.

Advantages :-

↳ Low initial cost.

↳ High reliability

↳ Operational flexibility at a cheap cost.

↳ Do not use main bus.

↳ Requires only one breaker per circuit.

Disadvantages :-

↳ A fault on a feeder results in the loss of breakers on each side of the feeder.

↳ Automatic reclosing and protective relaying circuitry is complex.

↳ If a fault occurs during a breaker maintenance period, the ring will be divided into two sections.

* Breaker and a half scheme :-

↳ The breaker and a half scheme is as shown in fig. This scheme has two main buses, both are normally energized. Between the buses are three circuit breaker and two isolators.

↳ This scheme is an improvement 'double bus ~~double~~ double breaker scheme to save the cost of breakers.

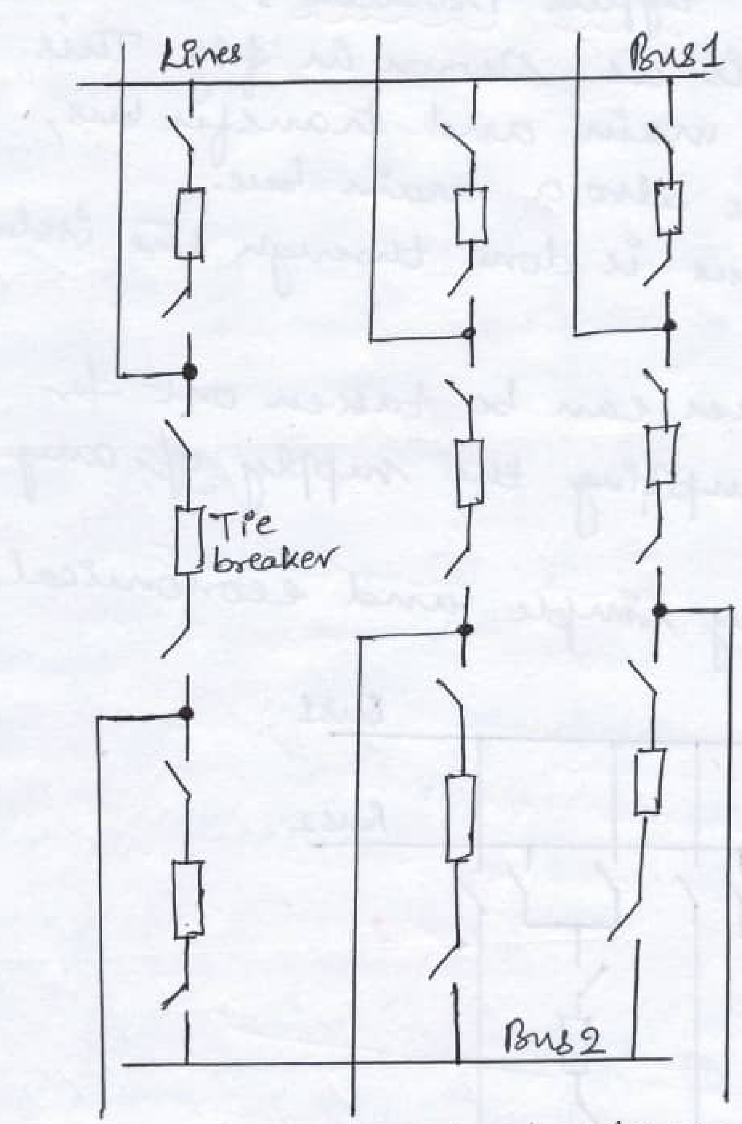



fig: Breaker and a half scheme.

↳ Under normal condition of operation, all breakers are closed and the main buses are energized.

↳ This arrangement allows for circuit breaker maintenance without interruption of service to any circuit.

Advantages :-

→ Most flexible operation.

→ High reliability

→ Breaker failure of bus side breakers removes only one circuit from service.

→ All switching is done with breakers.

→ Either of the main bus can be taken out for service without any supply interruption.

Drawback :-

→ This scheme provides complicated protection since it must be associated with the central breaker.

↳ To trip a circuit, 2 associated circuit breakers must be opened.

⇒ Double bus bar with bypass isolators :-

↳ The arrangement is as shown in fig. This scheme is similar to main and transfer bus, where transfer bus is also a main bus.

↳ The transfer of buses is done through the isolators.

Advantage :-

→ Any circuit breaker can be taken out for service without interrupting the supply of any feeder.

→ This scheme is very simple and economical.

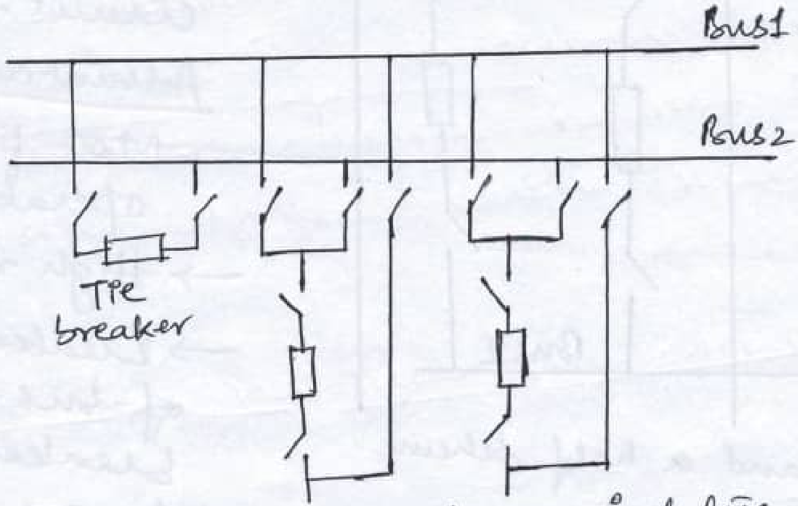



fig:- Double bus with bypass isolators.

Interconnection of power stations :-

↳ Interconnected system can provide large savings both in capacity and fuel cost. In order to achieve optimum utilization of resources and at the same time ensuring reliability and continuity of power supply, proper administration and technical setup has to be created.

↳ The rapid pace of interconnection between the power systems can greatly improve the continuity, security and integrity of power supply if it is associated with sound mechanism for monitoring & control.

Advantages of Interconnected system over single power plant are -

↳ The reliability of supply to the consumers is much greater in interconnected system than in an isolated system with only one power station.

↳ The interconnection of different power plants reduces the amount of generating capacity required to be installed as compared to that which would be required without interconnecti-on. Thus requirement of high installed capacity is also reduced.

↳ In the event of power failure at one of the stations in the interconnected system, the consumers can be fed from the other station to avoid complete shut down.

↳ The overall cost of energy per unit of an interconnected system is less. The total reserve capacity can be reduced.

↳ Benefits that can be obtained from an interconnected system are flexibility in operation, better utilization of power plants, security of power supply and reduction in the spare plant capacity.

↳ Interconnected system or integrated systems facilitate more effective use of transmission line facilities at higher voltage due to the group of generating station is being tied.

↳ Integrated systems requires less capital investment and less expense for supervision, operation and maintenance.

Drawbacks :-

↳ High switch-gear rating is to be employed at various points of the system.

↳ In case of poor supervision, fault in one system might get transferred to other parts of the system.

↳ Proper management is essential for dispatching power.

Introduction to gas insulated substations :-

↳ In a gas insulated substation, the high voltage conductors, switchgear and all other equipments are housed in metal enclosures filled with $SF_6$ gas under moderately high pressure.

GIS modules and their components :-

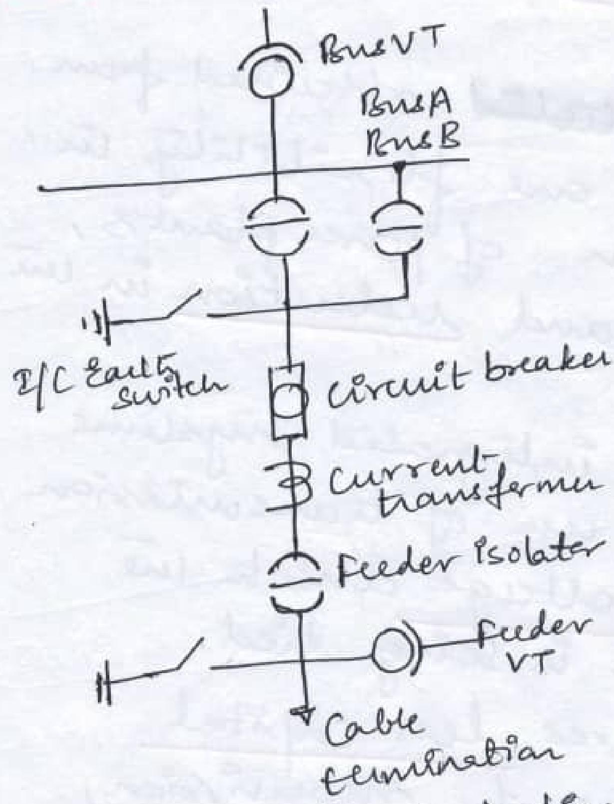


fig: GIS unit single-line diagram.

→ The module or unit comprise of (a) disconnector or isolator switch (b) busbars, (c) circuit breakers, (d) current transformers (e) earthing switches (f) potential transformers (g) surge arresters and (h) termination units.

Busbars :-

→ A bus is used to connect different modules that are not directly connected to each other.

↳ Busbars can be of different length depending on the requirements of the circuit and substation.

↳ The conductor will be made of copper or aluminium and is centrally located in cylindrical metal enclosures.

↳ Conductors are supported by either post insulators or by spacer discs.

Circuit breaker :-

↳ The most important and critical part in the GIS is CB (circuit breaker).

↳ $SF_6$ gas is used both for electrical insulation as well as for arc interruption during faults.

↳ The CB enclosures are usually the main supports for the GIS.

Current and Potential Transformers :-

→ CT's and PT's are required in substations for metering as well as for relaying purpose.

→ In GIS current transformers are in-line with coaxial geometry in construction.

Potential or voltage Transformers :-

→ Since most of the present GIS are in EHV range ≤ 400kV these are electromagnetic type only.

→ Electrostatic shielding is provided between the two windings and the terminals

are brought through a leak proof terminal box.
The other important units in GIS are the following :-

(i) Air - $SF_6$ connection :-

→ This is made by attaching a hollow insulator cylinder to a flag on the GIS enclosure.

→ The cylinder will have pressurized $SF_6$ on the inside and an air exposure to outside atmosphere on the outer side.

(ii) Transformer connections :-

→ The GIS module is directly connected to power transformer through an $SF_6$/oil or any other type bushing.

→ On oil side bushing conductor is directly connected to the transformer winding terminal, whereas on $SF_6$ end there will be a removable link or sliding constant.

(iii) Surge Arrester or Surge Diverter :-

→ The arrester is housed in a grounded metal enclosure. The surge or impulse waves enter the system (GIS) through the conductor ie connection to the GIS cables and direct connection of transformers is not exposed to lightning.

Control Panel :-

→ The local control panel is capable of communicating with the remote control panel through RS232 bus system or similar unit.

Another important aspect in GIS is gas seals and gaskets which must have
↳ resistance to decomposition in $SF_6$ oil.
↳ mechanical resistance for tension, compression and elongation.
↳ good service life in $SF_6$ and moisture permeability.

Advantages and Economics of GIS :-

Advantages :-

↳ compactness, cost-effectivity, reliability, maintenance, effective alternative to conventional air-insulated (CAIS) substations, can be upgraded in vertical direction very easily and long life and freedom from frequent maintenance.

Economics :-

→ The cost of the GIS equipment is high compared to the conventional substation. The high cost is due to its metal enclosure and assembly at the factory.

→ The site required and site development cost is very less.

→ Currently, GIS costs are being reduced by integrating functions like bus, CB, ground switch combined upto 3-position switch etc. and replacing PT's and CT's with optical VT's.

Grounding :-

Significance :-

→ Grounding is of major concern to increase the reliability of supply service, as it provides stability of voltage conditions, prevents excessive voltage peaks during the disturbances.

→ Grounding is a measure of protection against lightning.

The grounding is subdivided into
- ↳ System grounding
- ↳ Equipment grounding
- ↳ Protection grounding and
- ↳ Methodology and connections to earth.

System Grounding :-

→ Distribution system grounding is connecting or interconnection between electric conductors and ground or earth. The grounding is generally classified as -
- ↳ Ungrounded
- ↳ Solid grounding
- ↳ Resistance grounding
- ↳ Reactance grounding and
- ↳ resonant grounding.

} Grounded neutral system.

Ungrounded system or isolated neutral :-

→ Main feature - its ability to clear earth faults without interruption.

→ The self clearing feature disappears when the length of the line becomes excessive.

Explaination :-

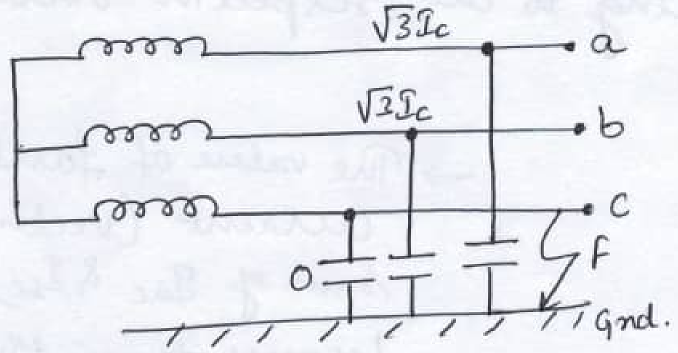
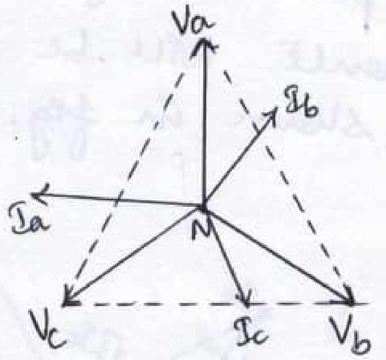



fig:- 3 phase isolated neutral system.




(a) Healthy system

→ when there is no fault, the inherent distributed capacitances of the line get charged to the respective phase voltages.

→ The charged capacitances of phase C gets discharged through the fault F between phase C and ground.

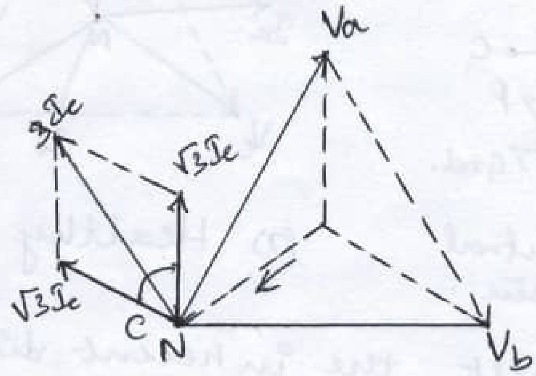
→ These capacitances again get charges in opposite direction and again discharged. Such repeated charging and discharging of line to ground is called arcing grounds.

→ This produces severe voltage oscillations reaching three to four times normal voltage. The problem of arcing ground can be solved by earthing the neutral through Peterson coil or arc suppression coil connected between neutral and earth.

→ when a fault occurs in a phase of line, the voltage of healthy phases of line is increased to $\sqrt{3}$ times of the phase voltages.

→ This causes severe stress on the insulation of the equipments connected to the system.

Let us consider a fault in line c. Before the fault, the phase voltage are $V_a$, $V_b$, $V_c$ and the charging currents will be leading to the respective voltages as shown in fig.




(b) fault on phase c

→ The value of fault current (vector sum of $I_{ac}$ & $I_{bc}$) becomes three times the normal phase charging current.

The charging current from healthy phases is

$$I_{ac} = \frac{V_{ac}}{X_c} = \frac{\sqrt{3}V_{ph}}{X_c} = \sqrt{3}I_c$$

$III^{ly}$ $$I_{bc} = \frac{V_{bc}}{X_c} = \frac{\sqrt{3}V_{ph}}{X_c} = \sqrt{3}I_c$$

where $X_c$ = capacitive reactance of line to ground &
$I_c$ = phase-charging current during the normal condition.

The fault current $I_F = \sqrt{3}I_{cR} = \sqrt{3} \times \frac{\sqrt{3}V_p}{X_c} = \frac{3V_p}{X_c}$

Advantages:-

→ In this system the neutral point is not shifted.

→ Earth faults can be utilized to operate protective relays to isolate the fault in case of grounded neutral system.

→ The induced static charges do not cause any disturbances as they are conducted to ground immediately.

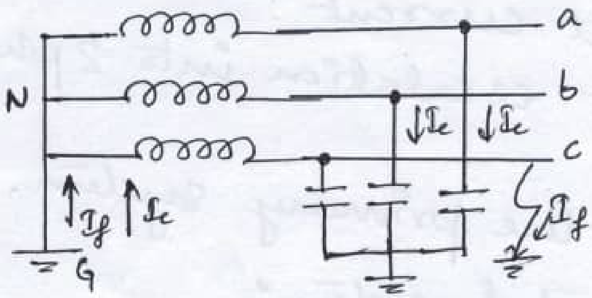
→ Improved service reliability due to limitation of arcing grounds and prevention of unnecessary tripping of circuit breakers.

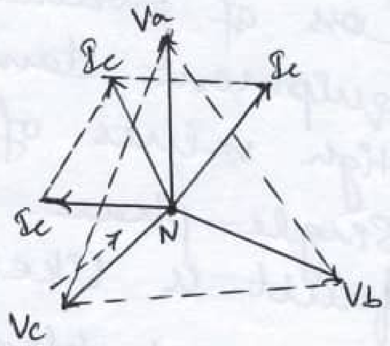
→ Life of equipments, machines, installation is improved due to limitation of voltage. Thus overall economy is achieved.

Grounded neutral system:-

Solid or Effective grounding:-

→ In this case neutral is directly connected to ground without any intentional impedance between neutral and ground.




→ Due to line to ground fault on any phase, the potential of that phase becomes the neutral potential whereas the potential of healthy phases remains approximately unchanged.

→ From phasor diagram, the total charging current is equal to the charging current of healthy phases.

→ The fault current in phase c will be totally inductive and will completely cancel the charging current. Hence the arcing grounds are substantially reduced.

→ The coefficient for earthing is less than 80%.

Applications :-

→ For circuits above 22kV, the solid grounding is used as there are enough charging current.

Advantages :-

↳ Controls transient over voltage from neutral to ground.

↳ Not difficult to locate the fault.

↳ Can be used to supply line - neutral loads.

Disadvantages :-

↳ Severe flash hazard.

↳ Main breaker required.

↳ Loss of production.

↳ Equipment damage.

↳ High values of fault current.

↳ Single-phase fault escalation into 3 phase fault is likely.

↳ Creates problems on the primary system.

Disadvantages of ungrounded system :-

↳ Difficult to locate line to ground fault.

↳ The ungrounded system does not control transient overvoltages.

↳ Cost of system maintenance is higher due to labor of locating ground faults.

↳ A second ground fault on another phase will result in a phase - phase short-circuit.

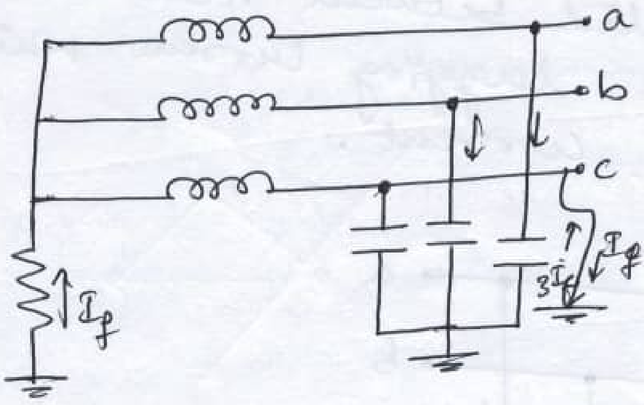
## Resistance Grounding :-

↳ For the voltage level between 3.3kV and 22kV, the ground current is not large to use the reactance grounding.

↳ The ground fault current, for solid grounding become very high. Hence, in practice the neutral point is connected with resistance and is called resistance grounding.

↳ To limit the fault current, high resistance is used which serves the power loss and improves the stability of the system during the fault.

↳ For the circuit below 3.3kV, there is no need to use external resistance because the earth fault current is limited due to inherent ground resistance i.e 1.5Ω.




→ The value of resistance is set such that the fault current is limited to the full rating of the largest generator or transformer.

→ Resister value is given by

$$R = \frac{V_{LL}}{\sqrt{3}\, I}$$

where I = full load current

→ Peterson gave the following formula for the most favourable value of resister :

$$R = (2.0 \text{ to } 1.25) \frac{1}{C_a + C_b + C_c}$$

where $C_a, C_b, C_c$ = Capacitances of each phase to earth.

## Advantages :-

→ Low value of fault current.

→ No flash hazard.

→ Controls transient overvoltage

→ No equipment damage

→ Service continuity

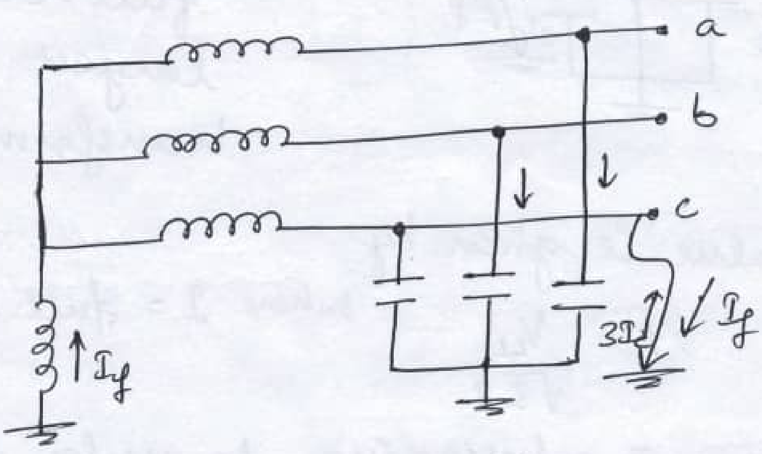
→ No impact on primary system.

## Reactance Grounding :-

↳ Between the voltage 3.3kV and 22kV, the solid grounding is not used due to excessive fault current and therefore resistance or reactance grounding must be used.

↳ To limit the fault current; 'resistance' is popular in UK, whereas 'reactance' is popular in Europe.

↳ The reactance connected between neutral and ground provides the lagging current which neutralize the capacitive current.




Reactance grounding.

↳ As the value of reactance X connected in neutral to ground connection is increased, the ground fault current decreases and neutral displacement increases.

↳ If X is very small, the system behaves as an effectively grounded system.

↳ If X is very large, the system behaves as an isolated system.

↳ Reactance grounding lies between effective or solid grounding and resonant grounding.

↳ The value of reactance required is to keep currents within safe limits.

↳ The transient voltages resulting from arcing increases as the reactance is increased.

Advantages:-

↳ Ground fault current is reduced

↳ The voltage across healthy phase are between 80 to 100 % of line-to-line voltage.

↳ Arcing grounds are avoided.

↳ Transient ground faults are converted into controlled current faults.

Application:-

→ Used for grounding the neutral of circuits where high charging currents are involved such as transmission lines, underground cables, synchronous motors, synchronous capacitors etc.

Arc suppression coil Grounding-

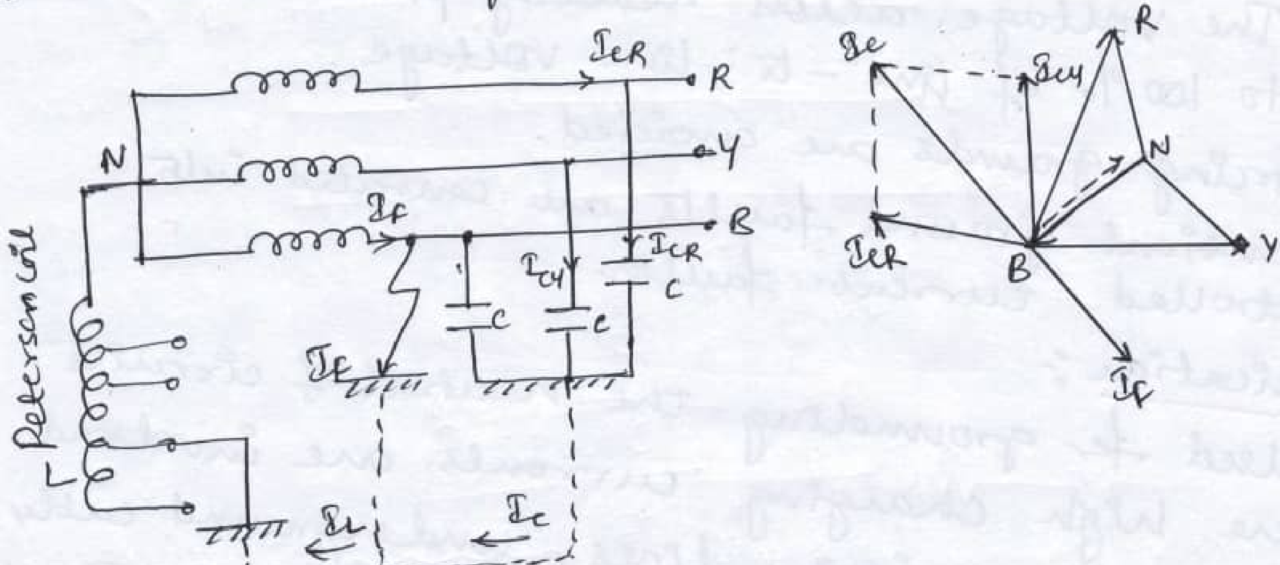
For reactance grounded system, $\frac{X_0}{X_1} > 3.0$

## Arc suppression coil grounding (or) Resonant Grounding:-

→ An arc-suppression coil is an Iron cored reactor mounted in the neutral earthing circuit and capable of being tuned to resonate with the capacitance of the system when one line becomes earthed.

→ The function of the arc suppression coil is to make arcing earth faults self-extinguishing and in the case of sustained faults to reduce the earth current to low value so that the system can be kept in operation with one line earthed.

→ The arc suppression coil is referred as a "Petersen coil" or "Ground fault neutralizer" while grounding so achieved is referred to as Resonant Grounding.




→ On occurence of a ground fault (say on phase B), a lagging reactive current flows from the faulted phase to the ground and returns to the system through the inductive coil.

→ The lagging fault current $I_F$ and leading capacitive current $I_C$ are almost in phase opposition.

→ By a proper selection of the value of inductance L of the arc suppression coil the two currents can be made almost equal so that there is no current through the ground fault and so there will be no arc.

→ The combination of neutral reactance L and line capacitance C acts as a parallel resonant circuit.

$I_C = V_{ph} \omega C$ $\quad V_{ph}$ = phase v/g before the fault

C = charging capacitance.

→ The total charging current after fault is $3I_C$.

If L is the inductance to be connected b/w the neutral point and the earth, then

$$I_f = \frac{V_{ph}}{\omega L}$$

At resonant condition,

$$I_f = 3I_C \quad \text{or} \quad \frac{V_{ph}}{\omega L} = 3 \cancel{V_{ph}} \omega C$$

$$\boxed{L = \frac{1}{3\omega^2 C}}$$

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 zig-zag transformer.

→ This transformer does not have a secondary winding.

→ Two identical windings are wounded differentially on each limb of the transformer so that total flux in normal condition is negligible.

→ ∴, the transformer draws very little magnetizing current.

→ Since the grounding transformers are of short time rating (10 seconds to 1 minute), the size of such transformers are small compared to power transformers.

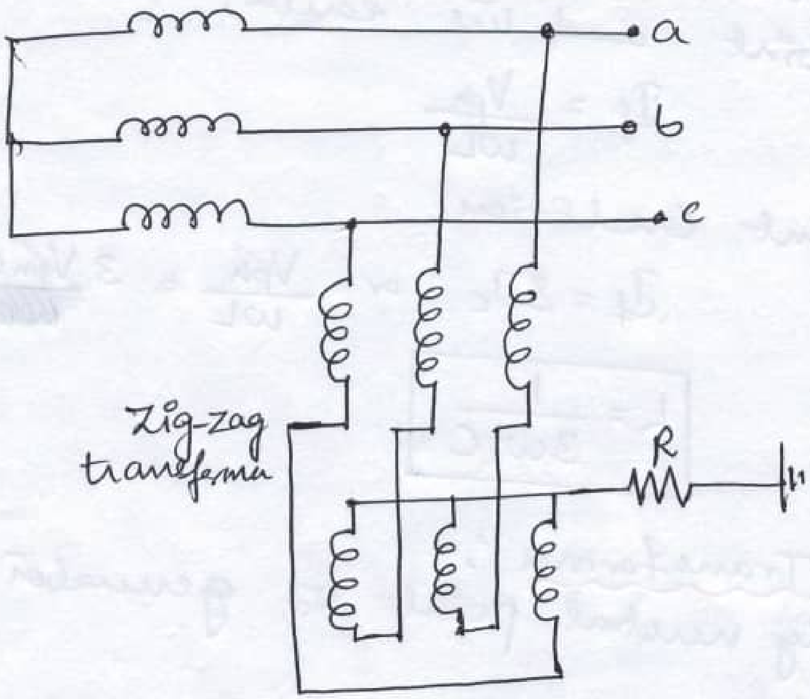



fig: Zig-zag transformer for neutral grounding.

## Neutral Grounding:-

→ The equipment 'earthing' is different from the neutral-point earthing. There are several methods of neutral grounding such as resistance grounding, low reactance for effective grounding, tuned reactance, solid grounding and ~~ground~~ grounding through a high impedance transformers.

**Advantages:-**

↳ The phase voltages on healthy lines are limited to phase to ground voltage during the fault.

↳ Earth fault protection can be used easily.

↳ The high voltages due to transient line-to-ground fault are eliminated.

↳ Neutral earthing reduces impact of lightning by discharging the stroke to earth.

↳ Arcing grounds are reduced or eliminated.

↳ By using resistance or reactance earthing, the earth fault current can be reduced.

↳ Greater safety to the personnel.

↳ It provides stable neutral point.

↳ It improves reliability, economy and performance of the system.

**Neutral Grounding Practice:-** The main grounding practices are enumerated below:-

→ Normally one neutral ground is provided at each voltage level between generator voltage level & distribution vtg level. It is desirable to have one ground at each level.

→ The grounding is provided at the source end rather than load end.

→ When several generators at a generating station are operating in parallel, only one generator neutral is grounded. If more generators are grounded, the zero sequences current will cause more interferences. Normally two grounds are available in a generating station but only one is used at a time.

→ If several generators are connected to a common neutral bus which is connected to ground directly or through reactance, the neutral point of one generator is connected with neutral bus through a circuit breaker.

→ When there are one or more power sources, no switching equipment is used in the grounding system.

→ The main station earthing should be separate from the earthing for lightning protection.

→ The resistance of earth & current path should be low enough so as to prevent voltage rise between neutral & earth.

→ For low voltage upto 3.3kV and for high voltage above 22kV solid grounding is used; whereas for voltage between 3.3kV and 22kV, a resistance or reactance grounding is used.

Current limiting Reactor :-

↳ Reactor is basically a coil which is designed to have high inductance but negligible resistance its function is to limit the magnitude of short circuit current in the event of fault.

↳ When fault occurs total impedance of the network upto the fault point reduce to a very low value. This results heavy current.

↳ The magnitude of fault current is generally many times that of working current.

↳ The rating in capacity of circuit breaker is decided on basis of magnitude of fault current.

↳ Current limiting reactors offers high impedance & tends to reduces the current in the circuit.

Classification of current limiting reactors :-

1] Bare or unshielded reactors

2] Magnetically shielded reactors

1] Bare or unshielded reactors :-

↳ A Reactor has a large number of turns of bare strands copper the turns are slightly inclined. w.r.t to the horizontal plane the wdg is circular & the reactor has magnetic or non-magnetic core or it is air core Concrete slabs are placed in b/w the turns of windings these acts as solid support for the

turns, when fault occurs eddy current flows.
→ Stress are developed due to the huge mechanical force but concrete slab absorb these stresses effectively so that the winding remains in that & does not get deformed.

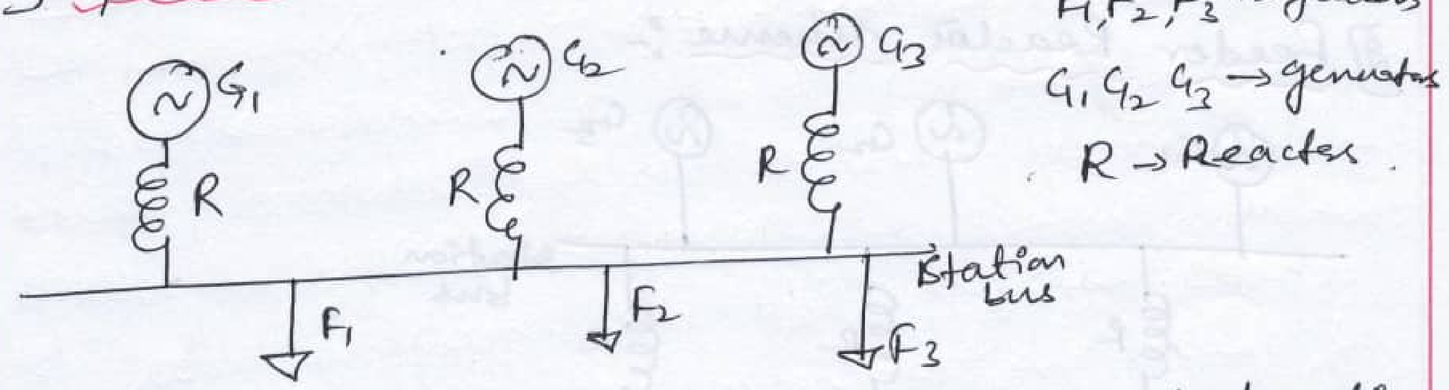
Demerits :-
↳ Large space is required for locating the reactors.
↳ Heat is developed during both normal operation & occurence of the fault, because of loss of power in the reactor. Core & the winding effective ventilation must be provided, hence large fans needs to be installed.
↳ They are not suitable for outdoor services.
↳ They are restricted to the application upto 33kV.

2] Magnetically Shielded type reactor :-
↳ A reactor has large number of turns of copper the coil is kept immersed in oil tank. The oil serve as both insulation & coolant.
↳ The reactor is shielded magnetically by means of short circuiting copper rings surrounding reactor.

↳ The purpose of shielding the reactor is that, the reactance does not decrease in event of fault it can be used for indoor & outdoor service whatever may be the system voltage.

Location of Reactors :-

I] Generator Reactor scheme :-




There are three different schemes of location of reactors :-

↳ Generator reactor scheme :- In this scheme reactors are connected in series with the generator. Every generator is connected to the station bus through a reactor.

Disadvantage :-

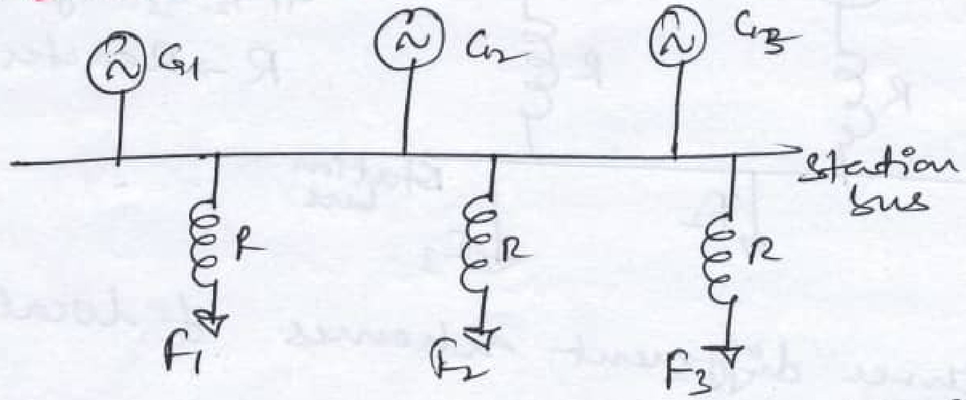
→ fault occurs on any feeder causes busbar voltage to drop. Since all generators feed into the fault.

↳ The other feeders which are quite healthy also may form out of step. Hence after isolating the faulty feeder the need for synchronization of generators may arise.

This scheme gives protection to the generators but no protection is given to the feeders.

↳ Even during normal operation full load current is carried by reactors. Hence drop of voltage across reactor. Thus there is a slight loss of power continuously takes place because of reacter resistence.

2] Feeder Reactor Scheme :-



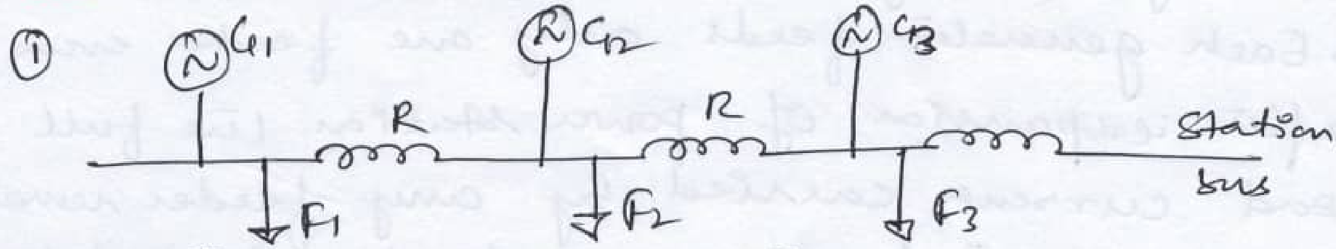

→ In this scheme current limiting reactors are inserted in series with the feeders this scheme gives protection to the feeders in the event of fault on a feeder only that particular feeder is effected. Since the station busbar voltage is not affected by the fault & remaining feeders are also not affected

→ If there is a fault on station busbar all feeders are effected equally but busbar faults are very rare.

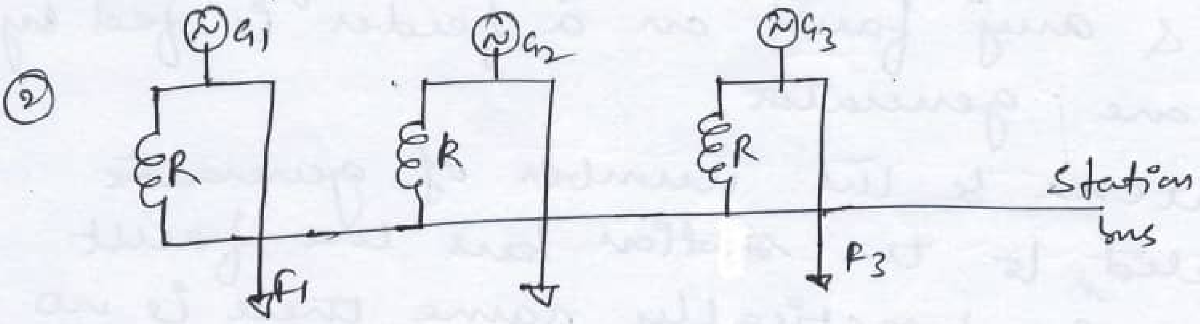
→ In this scheme there is voltage drop across each reactors & certain power loss even during normal operations.

3] Bus bar Reactor scheme :-

(1)




(2)




(1) Ring system :-
→ In this system each of the feeder is fed mainly from one generator only. Since not much power can flow across the reactors, because they are inserted in the bus itself in the event of fault on any feeder only generator connected to this particular feeder feeds into the fault & hence magnitude of fault current gets minimized and also there is no loss of power & voltage drop across reacters.

Disadvantages :-
→ With the existing switchgear further addition of generator unit is not possible.

(2) Tie-bar system :-
→ In this system the reactors are placed in the station bus.

Advantage :- Additional generators can be installed without effecting function of the existing switchgear.

→ Each generator feeds only one feeder even after expansion of power station the full load current carried by any feeder remains same & any fault on a feeder is fed by only one generator.

→ Whatever is the number of generators connected to the station bars the fault current is practically same there is no need to replace the existing ckt breaker by higher capacity circuit breakers.