PIE Tech
POLLACHI INSTITUTE OF ENGINEERING AND TECHNOLOGY
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sky is the limit

Department of Electrical and Electronics Engineering

Regulation 2021

III Year – VI Semester

EE3601- PROTECTION AND SWITCHGEAR

UNIT I **PROTECTION SCHEMES**

~~Principles~~ Significance and need for protective schemes – nature and causes of faults – types of faults – Methods of Grounding - Zones of protection and essential qualities of protection – Protection scheme

UNIT II **~~ELECTROMAGNETIC~~ BASICS OF RELAYS**

Operating principles of relays - the Universal relay – Torque equation – R-X diagram – Electromagnetic Relays – Over current, Directional, Distance, Differential, Negative sequence and Under frequency relays.

UNIT III **~~APPARATUS~~ OVERVIEW OF EQUIPMENT PROTECTION**

Current transformers and Potential transformers and their applications in protection schemes -Protection of transformer, generator, motor, bus bars and transmission line.

UNIT IV **STATIC RELAYS AND NUMERICAL PROTECTION**

Static relays – Phase, Amplitude Comparators – Synthesis of various relays using Static comparators – Block diagram of Numerical relays – Over current protection, transformer differential protection, distant protection of transmission lines.

UNIT V **CIRCUIT BREAKERS**

Physics of arcing phenomenon and arc interruption - DC and AC circuit breaking – re-striking voltage and recovery voltage - rate of rise of recovery voltage - resistance switching – current chopping - interruption of capacitive current - Types of circuit breakers – air blast, air break, oil, SF6, ~~MCBs, MCCBs~~ and vacuum circuit breakers – comparison of different circuit breakers – ~~Rating and selection of Circuit breakers~~. HVDC Breaker

Relay

- Relay: Relays are **electrically operated switches that open and close the circuits by receiving electrical signals from outside sources**.
- https://amperite.com/blog/relays/#:~:text=Relays%20can%20reduce%20the%20need,space%20of%20the%20same%20size.
- Relay: A relay is an automatic device by means of which an electrical circuit is indirectly controlled (opened or closed) and is governed by a change in the same or another electrical circuit
- Protective Relay: A protective relay is an automatic device which detects an abnormal condition in an electrical circuit and causes a circuit breaker to isolate the faulty element of the system. In some cases it may give an alarm or visible indication to alert operator.

Power-system protection is a branch of electrical power engineering that deals with the **protection of electrical power systems from faults through the isolation of faulted parts from the rest of the electrical network**.

Switchgear is the combination of electrical disconnect switches, fuses or circuit breakers used to control, protect and isolate electrical equipment.

Name some Protection devices

Versus

Circuit breakers

- Quickly reset
- Minimum downtime
- Stable performance over time
- More options
- Combined with other components
- Precisely matched to loads
- 100% tested

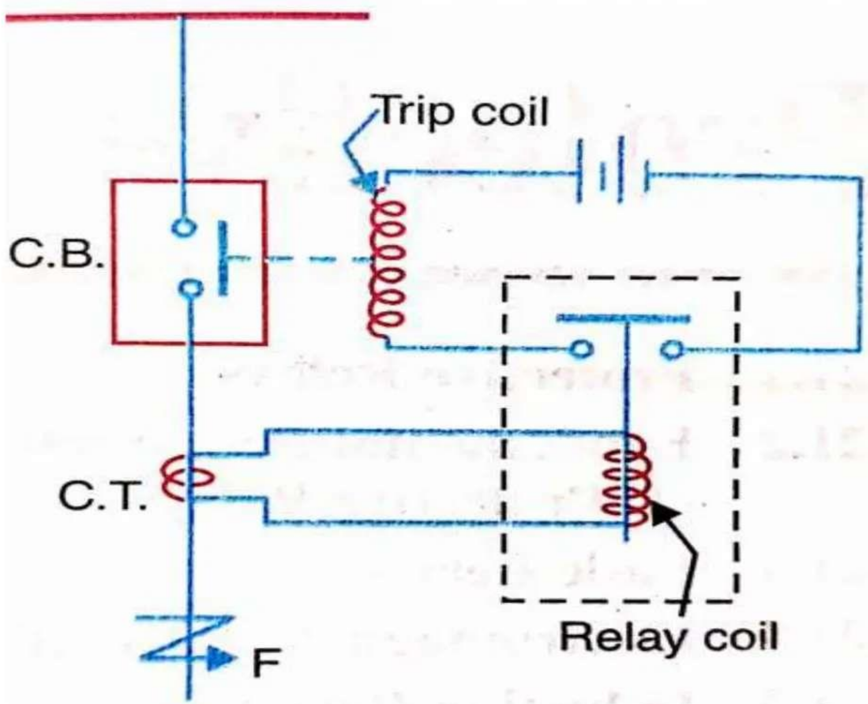
Fuses

- No assurance that replacement will be properly rated
- Fuses age
- Trip characteristics change
- Lead to nuisance tripping
- Increases downtime
- Cannot be tested

Can we design electrical System without protection

If so what will happen ?

Principles of Protection System



Components of Protection System

When a fault occurs in the protected circuit, the relay connected to the CT and PT actuates and closes its contacts to complete the trip circuit. Current flows from the battery in the trip circuit. As the trip coil of the circuit breaker energized, the circuit breaker operating mechanism is actuated and it operates for the opening operation to disconnect the faulty element.

NEED FOR PROTECTIVE SCHEMES

- To avoid damage to the equipment's in a power system under abnormal conditions
- To isolate a faulty section of electrical power system from rest of the live system so that the rest portion can function satisfactorily without any severe damage due to fault current.
- To avoid electric shock
- To maintain stability in the electrical system
- Protection system is necessary to isolate the faulty element as quickly as possible to keep the healthy section of the system in normal operation
- To improve the system performance, system reliability, system stability and service continuity.
- The fault can not be completely avoided but can be minimized. Thus the protective relaying plays an important role in sensing the faults, minimizing the effects of faults and minimizing the damage due to the faults.

Nature and causes of Fault

Causes of fault:

- Insulation failures
- Conducting path failures
- Lightning
- Switching surges

Insulation Failures : Insulation failures results in short circuits which are very harmful as they may damage some equipment of the power system

Conducting path failures: If the conductors are broken, there is a failure of the conducting path and the conductor becomes open-circuited, causes unbalancing in the power system

Lightning: When lightning fall on the OH line, there is a heavy over voltages occur in the system, which damages the equipment.

Switching surges: During energizing and de-energizing of lines, charging capacitor banks causes over voltage in the power system

Types of Fault

- Two broad classification of faults are:
  - Symmetrical faults
  - Unsymmetrical faults

Symmetrical faults:

A three phase fault is called a symmetrical types of fault, all the three phases are short circuited. There may be two situations

(i)LLL

(ii)LLL-G

Unsymmetrical faults:

Fault current is unsymmetrical,

(i)Single Phase to Ground fault (L-G)

(ii)Two phase to ground fault (LL-G)

(iii)Phase to Phase (L-L) fault

(iv)Open circuited phases

(v)Winding faults

Simultaneous faults

Two or more faults occurring simultaneously on a system are known as multiple or simultaneous fault.

Effects of Faults

The following effects on a power system, if it remains unchanged

- Heavy short circuit current may cause damage to equipment.
- Arcs associated with short circuits may cause fire hazards.
- Reduction in the supply voltage of the healthy feeders, resulting in the loss of industrial loads
- Short circuits may cause unbalancing of supply voltages and current
- Overheating
- Loss of system stability
- Interruption of supply to consumers, thereby causing a loss of revenue

High grade, high speed, reliable protective devices are the essential requirements of a power system to minimize the effects of faults and other abnormalities

Relay Terminologies

Protective Relay:

A protective relay is an automatic device which detects an abnormal condition in an electrical circuit and causes a circuit breaker to isolate faulty element of the system.

Pick-up value:

The threshold value of the actuating quantity (voltage, current, etc) to which relay responds.

Reset on drop-out:

The threshold value of the actuating quantity below which the relay is deenergised.

Operating time:

It is the time which elapses from the instant at which the actuating quantity exceeds the relay pick-up value to the instant at which relay closes its contact

Reset time:

It is the time which elapses from the instant at which the actuating falls below its reset value to the instant at which relay comes back to its normal position.

Setting:

The value of the actuating quantity at which the relay is set to operate

Electromagnetic Relay:

A relay which operates on the electromagnetic principle

Static Relay:

A relay employs semiconductor diodes, transistors, thyristors, logic gates, ICs etc

Numerical Relay:

A micro processor is used to perform all the functions of the relay

Overcurrent Relay:

A relay which operates when the actuating current exceeds a certain preset value

Under Voltage Relay:

A relay which operates when the system voltage falls below a certain preset value

Directional relay or reverse power relay:

A directional relay is able to detect whether the point of fault lies in the forward or reverse direction with respect to the relay location.

Polarised relay:

A relay whose operation depends on the direction of current or voltage.

Instantaneous Relay:

An instantaneous relay has no intentional time delay in its operation. It operates immediately (0.1 sec)

Inverse Time Relay:

A relay in which operating time is inversely proportional to the magnitude of the operating current.

Definite time Relay:

A relay in which operating time is independent of the magnitude of the operating current.

IDMT Relay:

Inverse Definite minimum time relay, which gives an inverse time characteristics at lower values of operating current, and definite time characteristics at higher values of current

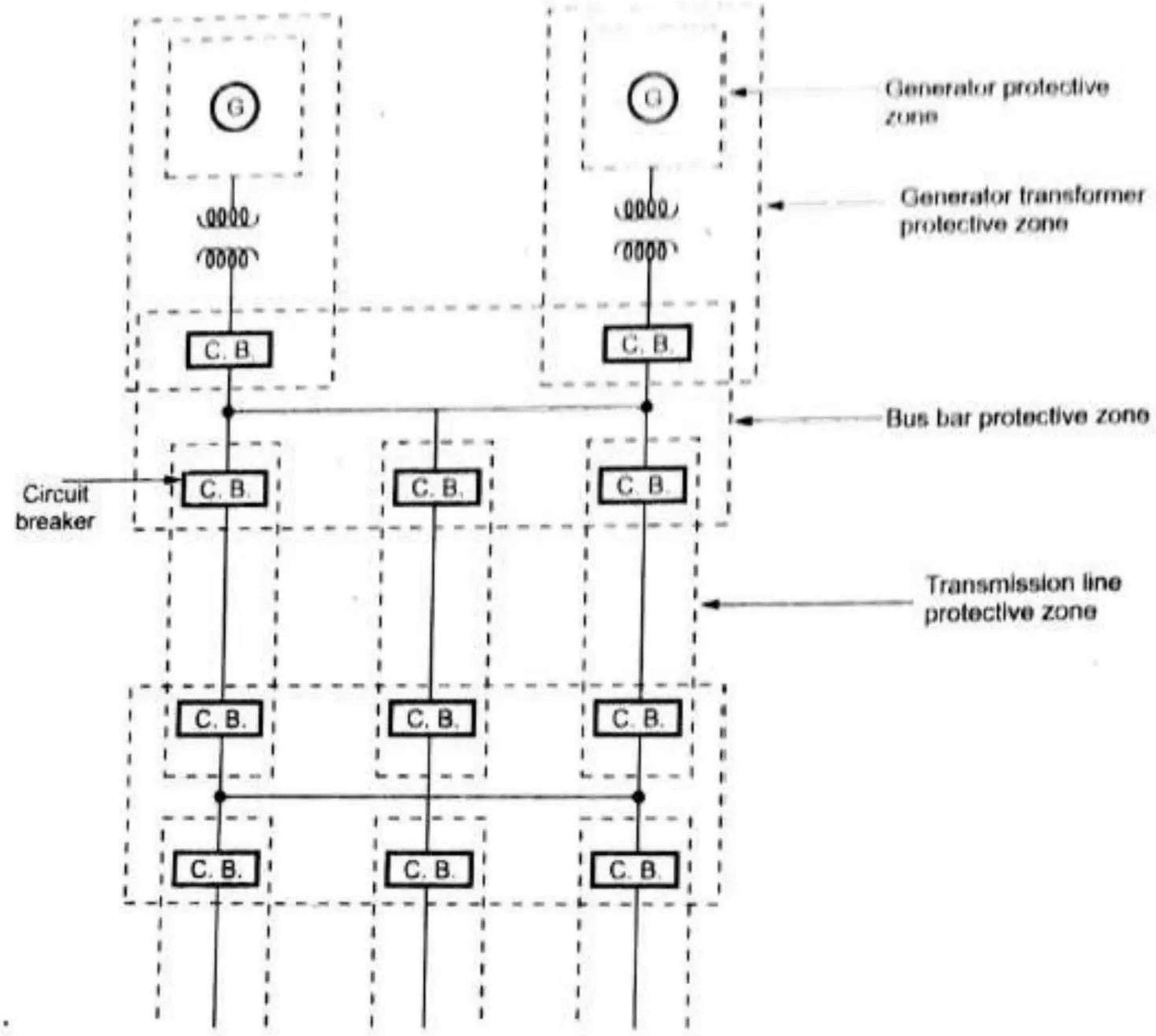
Over Reach:

Some times a relay operate even when a fault point is beyond its reach.

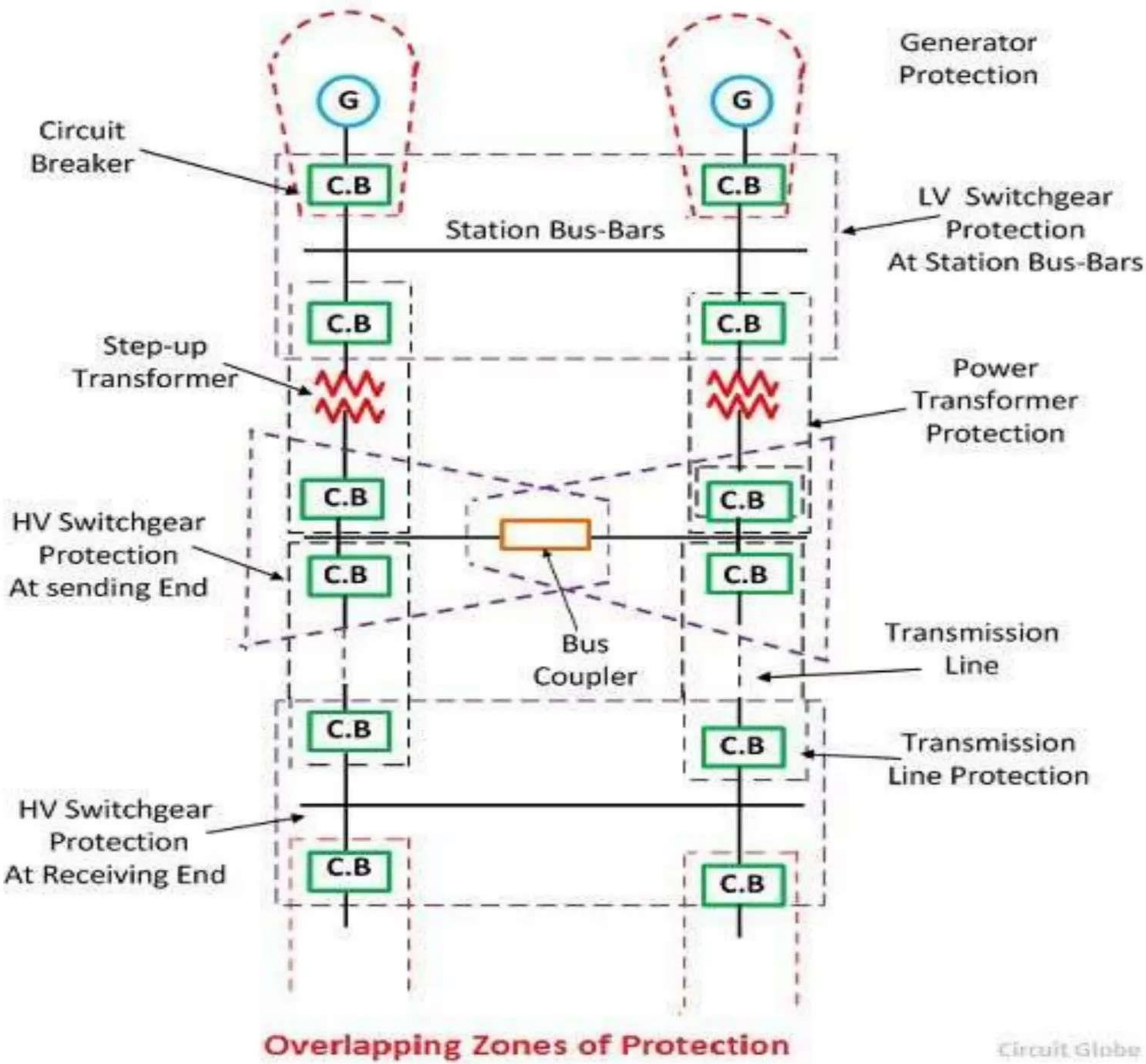
Under Reach:

Some times a relay fail to operate even when a fault point is within its reach.

Protective Zones



Zones of Protection



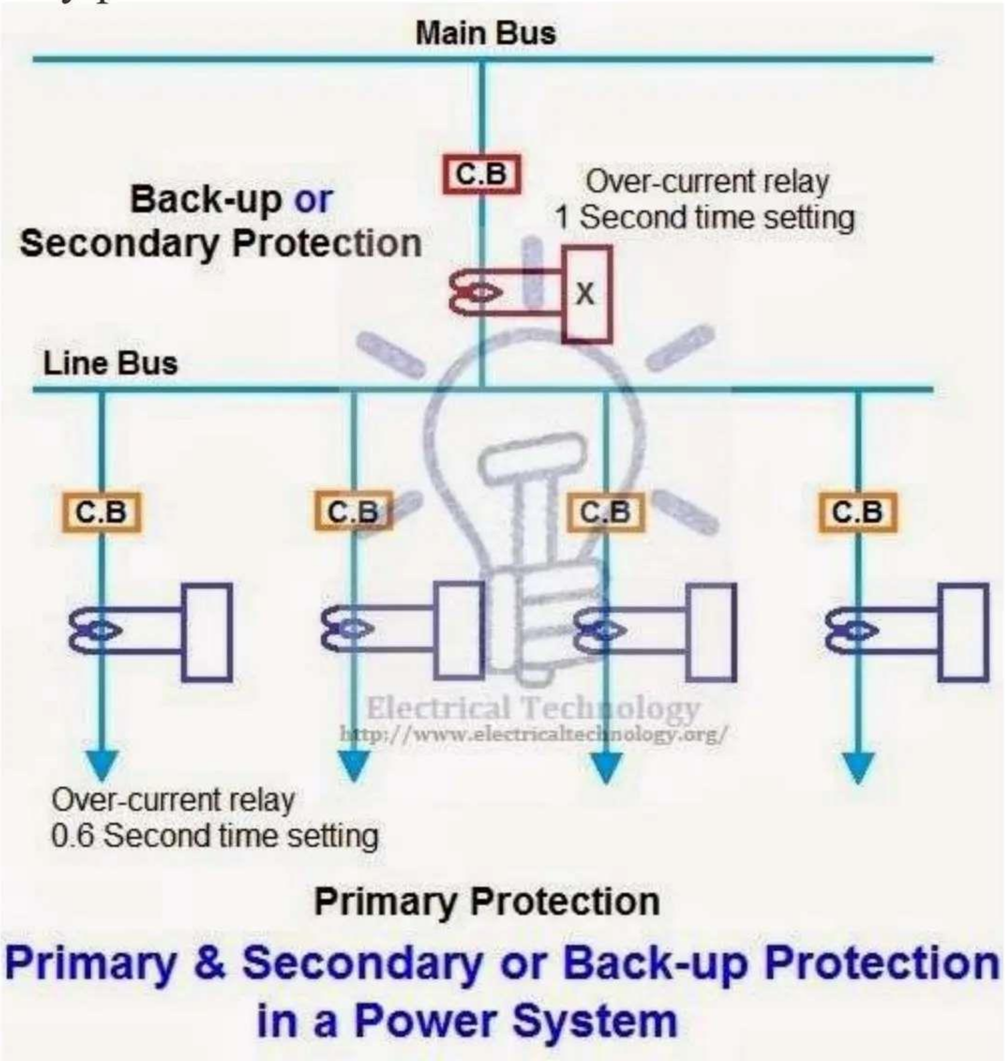
Why overlapping in Zones of protection?

If there were no overlapping in the protective zone, then the failure occurs in the equipment will not lie in any one of the zones and hence no circuit breaker would be tripped. The fault occurs in the unprotective system will damage the equipment and hence disturb the continuity of the supply.

Primary and Back-up Protection

1. Primary protection
2. Backup protection.

The primary protection is the first line of defence and is responsible to protect all the power system elements from all the types of faults. The backup protection comes into play only when the primary protection fails.



Say some Reasons why primary protection fails

1. Failure in circuit breaker
2. Failure in protective relay
3. Failure in tripping circuit
4. Failure in D.C. tripping voltage
5. Loss of voltage or current supply to the relay

Methods of Back-up Protection

The methods of back-up protection can be classified as follows :

1.Relay Back-up

2.Breaker Back-up

3.Remote back-up

4.Centrally Coordinated Back-up

Essential Qualities of Protection

- Selectivity or Discrimination
- Fast Operation
- Sensitivity
- Reliability
- Stability

Selectivity:

The selectivity id the ability of the protective system to identify the faulty part correctly and disconnect that part without affecting the rest of the healthy part of system.

Fast Operation:

A protective system must disconnect the faulty system as fast as possible. If the faulty system is not disconnect for a long time then,

1. The devices carrying fault currents may get damaged.
2. The failure leads to the reduction in system voltage. Such low voltage may affect the motors and generators running on the consumer sude.
3. If fault persists for long time, then subsequently other faults may get generated

Sensitivity:

The protective system should be sufficiently sensitive so that it can operate reliably when required. The sensitivity of the system is the ability of the relay system to operate with low value of actuating quantity.

Reliability:

The protective system must function whenever it is called upon to operate, since the consequences of non-operation can be very severe

Stability:

The stability is the quality of the protective system due to which the system remains inoperative and stable under certain specified conditions such as transients, disturbance, through faults etc. For providing the stability, certain modifications are required in the system design. In most of the cases time delays, filter circuits, mechanical and electrical bias are provided to achieve stable operation during the disturbances.

Grounding

The process of connecting the metallic frame (i.e. non-current carrying part) of electrical equipment or some electrical part of the system (e.g. neutral point in a star-connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called Grounding or earthing.

If grounding is done systematically in the line of the power system, we can effectively prevent accidents and damage to the equipment of the power system and at the same time continuity of supply can be maintained

Human Body Resistance Value:

Under dry conditions, the resistance offered by the human body may be as high as **100,000 Ohms**. Wet or broken skin may drop the body's resistance to **1,000 Ohms**," adding that "high-voltage electrical energy quickly breaks down human skin, reducing the human body's resistance to **500 Ohms**

Grounding (or) Earthing

- In power system, *grounding or earthing* means connecting frame of electrical equipment (non-current carrying part) or some electrical part of the system (*e.g.* neutral point in a star-connected system, one conductor of the secondary of a transformer etc.) to earth *i.e.* soil.
- This connection to earth may be through a conductor or some other circuit element (e.g. a resistor, a circuit breaker etc.) depending upon the situation.

Grounding (or) Earthing

Advantages of Grounding:

- First, it provides protection to the power system. For example, if the neutral point of a star-connected system is grounded through a circuit breaker and phase to earth fault occurs on any one line, a large fault current will flow through the circuit breaker. The circuit breaker will open to isolate the faulty line.

Grounding (or) Earthing

Advantages of Grounding:

- Secondly, earthing of electrical equipment (*e.g.* domestic appliances, hand-held tools, industrial motors etc.) ensures the safety of the persons handling the equipment.
- For example, if insulation fails, there will be a direct contact of the live conductor with the metallic part (*i.e.* frame) of the equipment. Any person in contact with the metallic part of this equipment will be subjected to a dangerous electrical shock which can be fatal.

Grounding (or) Earthing

- The process of connecting the metallic frame (i.e. non-current carrying part) of electrical equipment or some electrical part of the system (e.g. neutral point in a star-connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called **grounding** or **earthing.**
- Grounding or earthing may be classified as :

(*i*) Equipment grounding

(*ii*) System grounding.

Grounding (or) Earthing

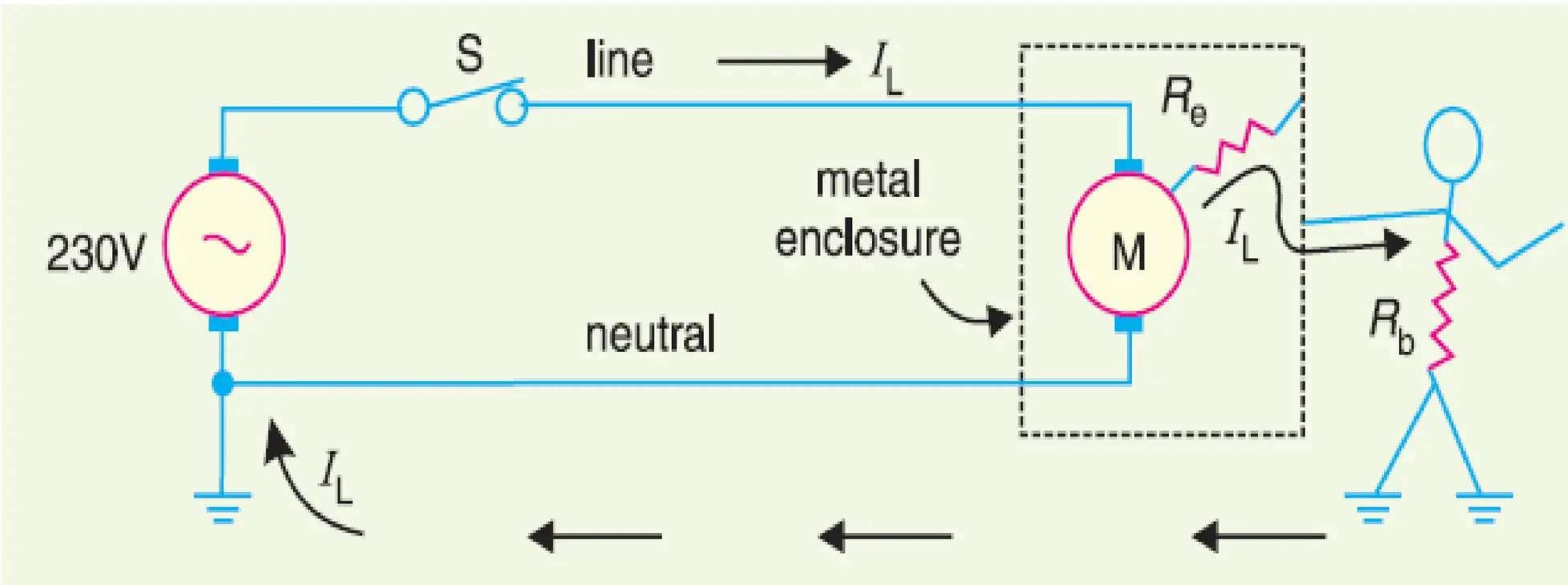
- Equipment grounding deals with earthing the non-current-carrying metal parts of the electrical equipment.
- On the other hand, system grounding means earthing some part of the electrical system *e.g.* earthing of neutral point of star-connected system in generating stations and sub-stations.

Equipment Grounding

- *The process of connecting non-current-carrying metal parts (i.e. metallic enclosure) of the electrical equipment to earth (i.e. soil) in such a way that in case of insulation failure, the enclosure effectively remains at earth potential is called* **equipment grounding.**
- we shall divide the equipment grounding into three heads *viz.*
- **(*i*)** Ungrounded enclosure
- **(*ii*)** enclosure connected to neutral wire
- **(*iii*)** ground wire connected to enclosure.

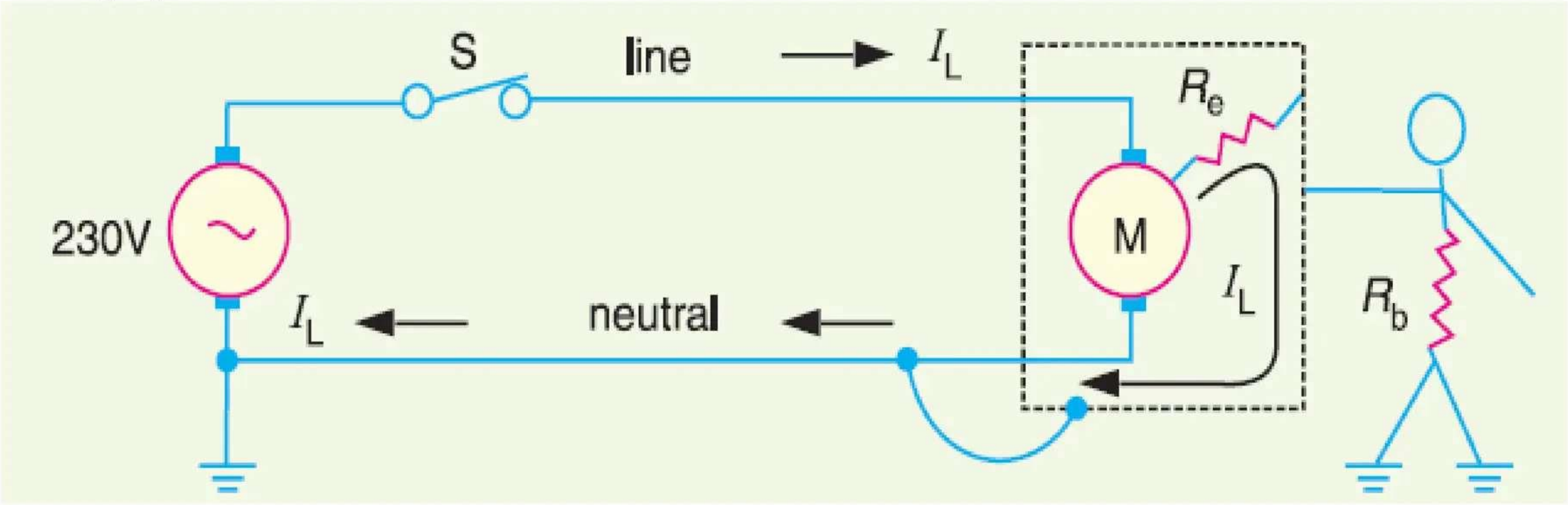
Equipment Grounding

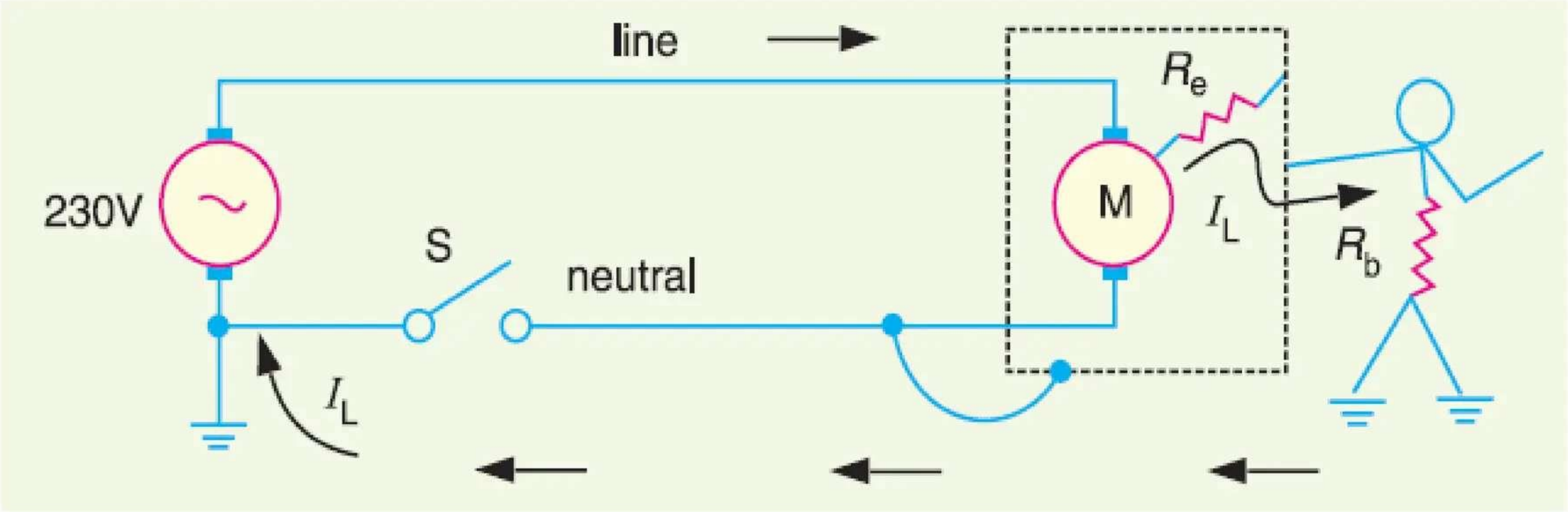
- (*i*) **Ungrounded enclosure.**



Equipment Grounding

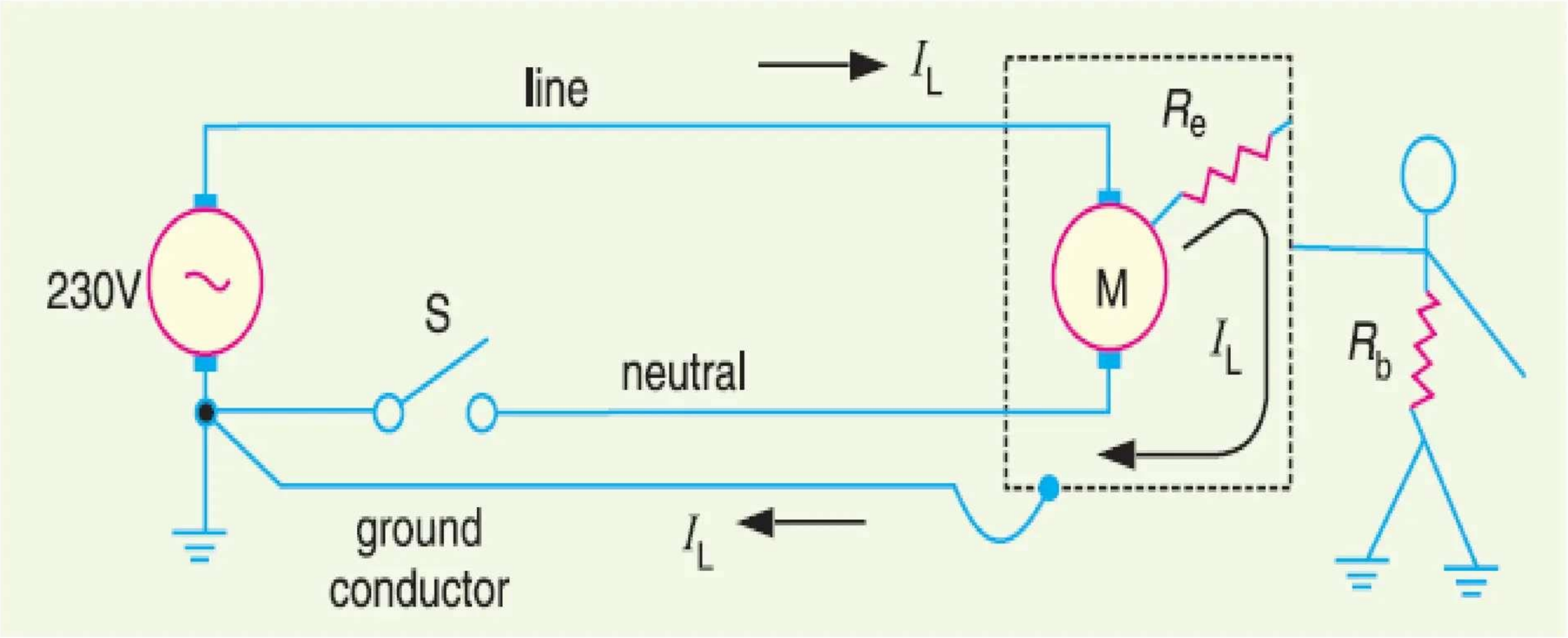
- (*ii*) **Enclosure connected to neutral wire.**





Equipment Grounding

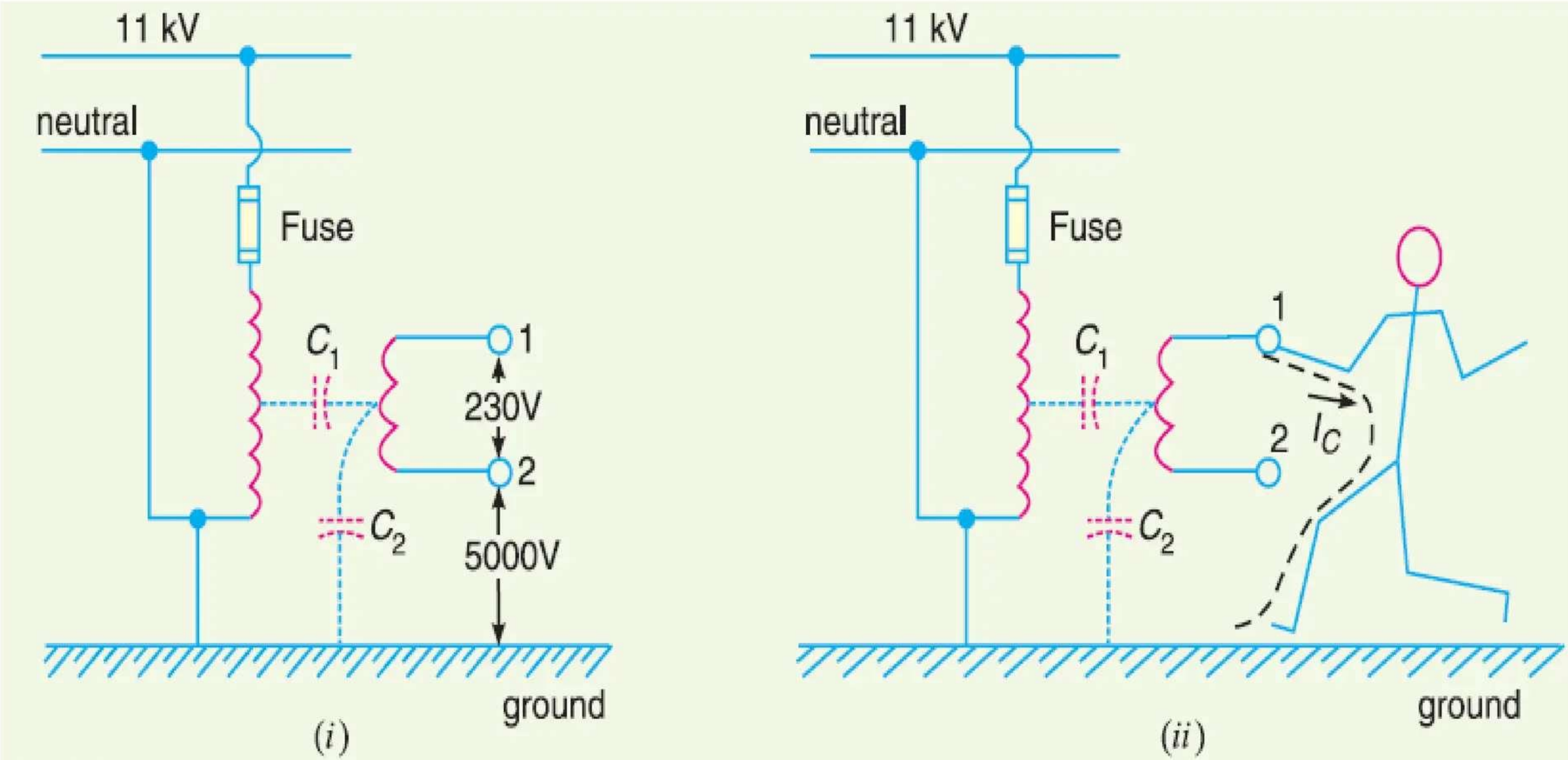
- (*iii*) **Ground wire (Green color) connected to enclosure.**



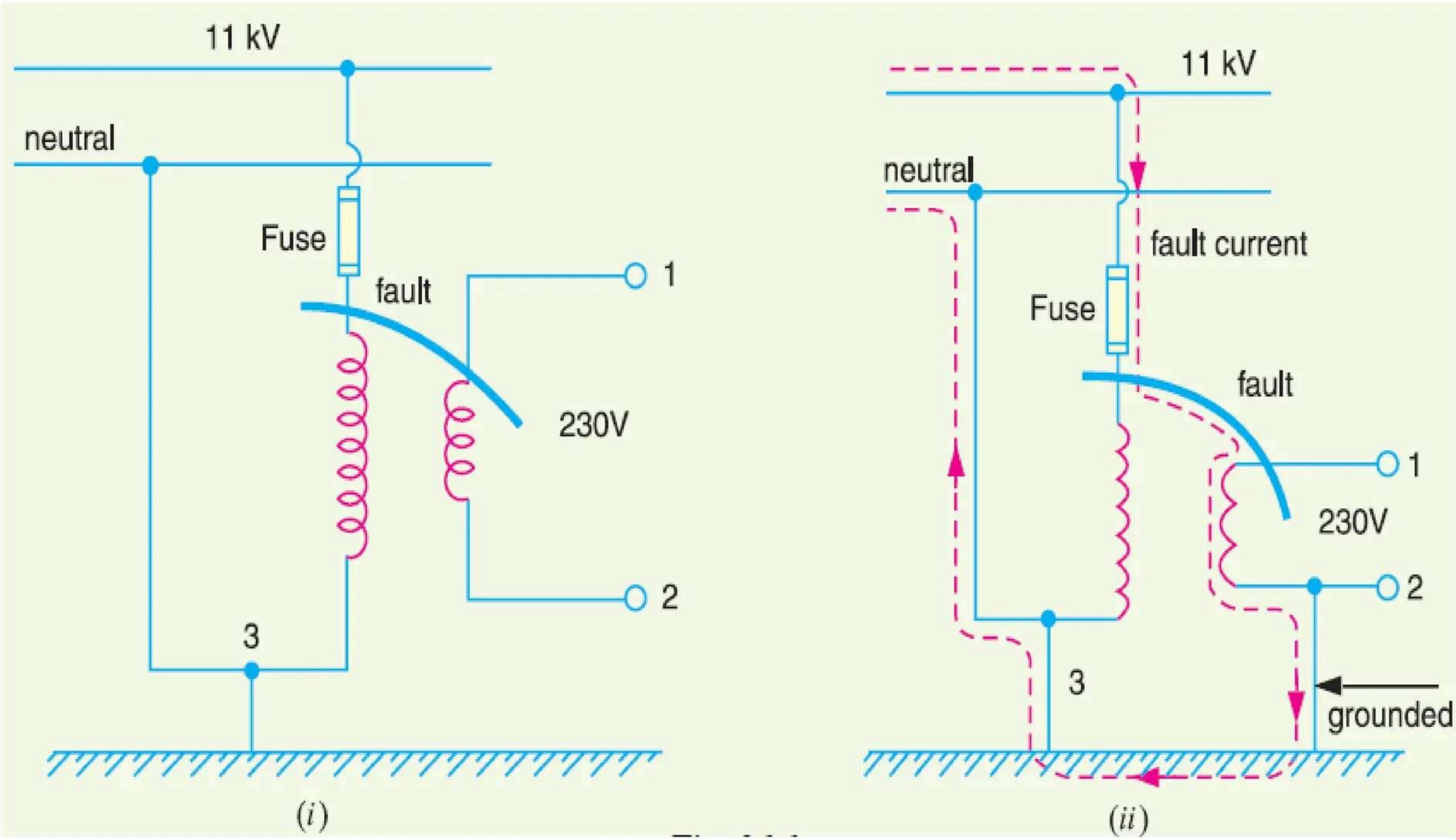
System Grounding

- *The process of connecting some electrical part of the power system (e.g. neutral point of a star connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called* **system grounding.**
- The system grounding has assumed considerable importance in the fast expanding power system.
- By adopting proper schemes of system grounding, we can achieve many advantages including protection, reliability and safety to the power system network.

System Grounding



System Grounding



Ungrounded Neutral System Grounding

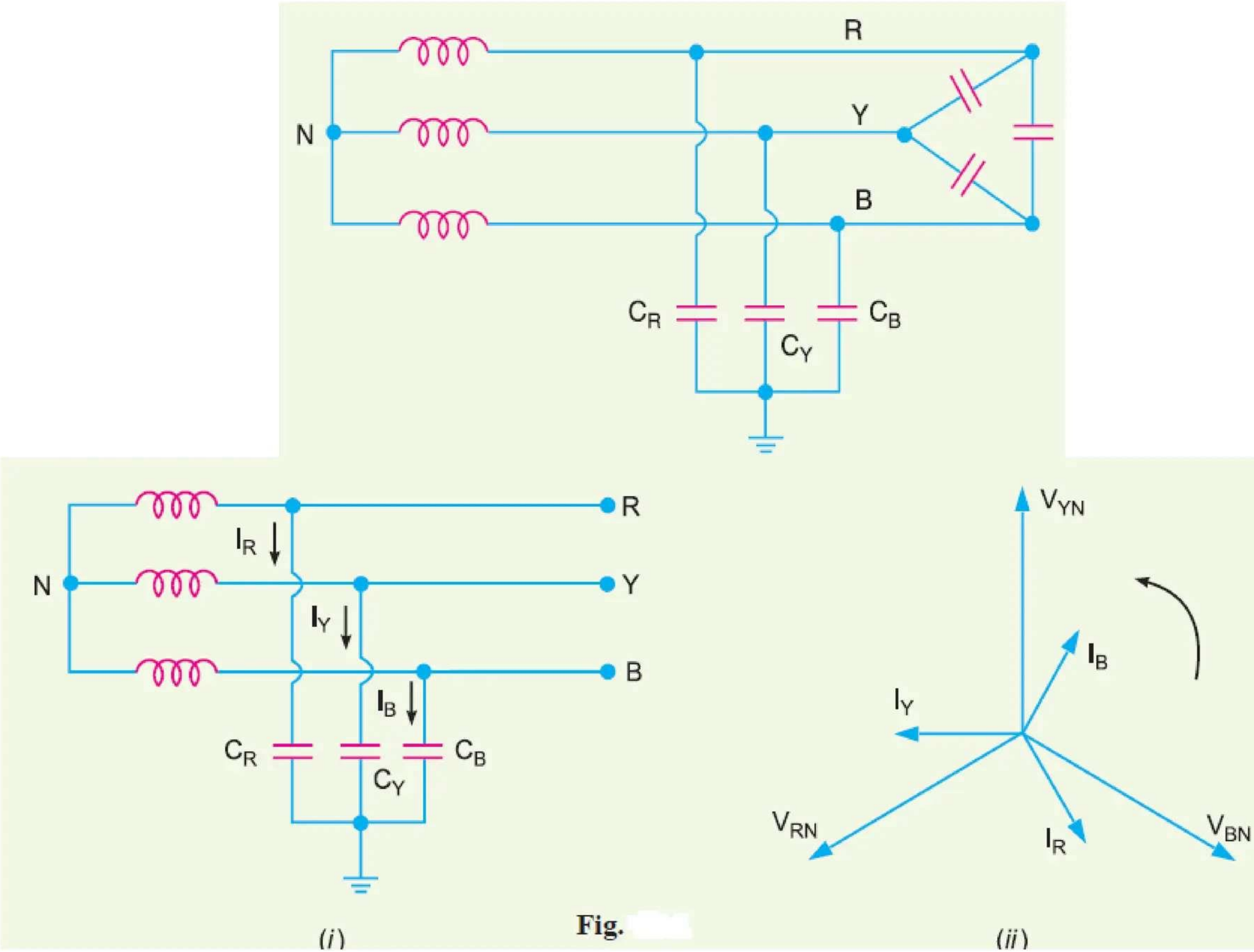
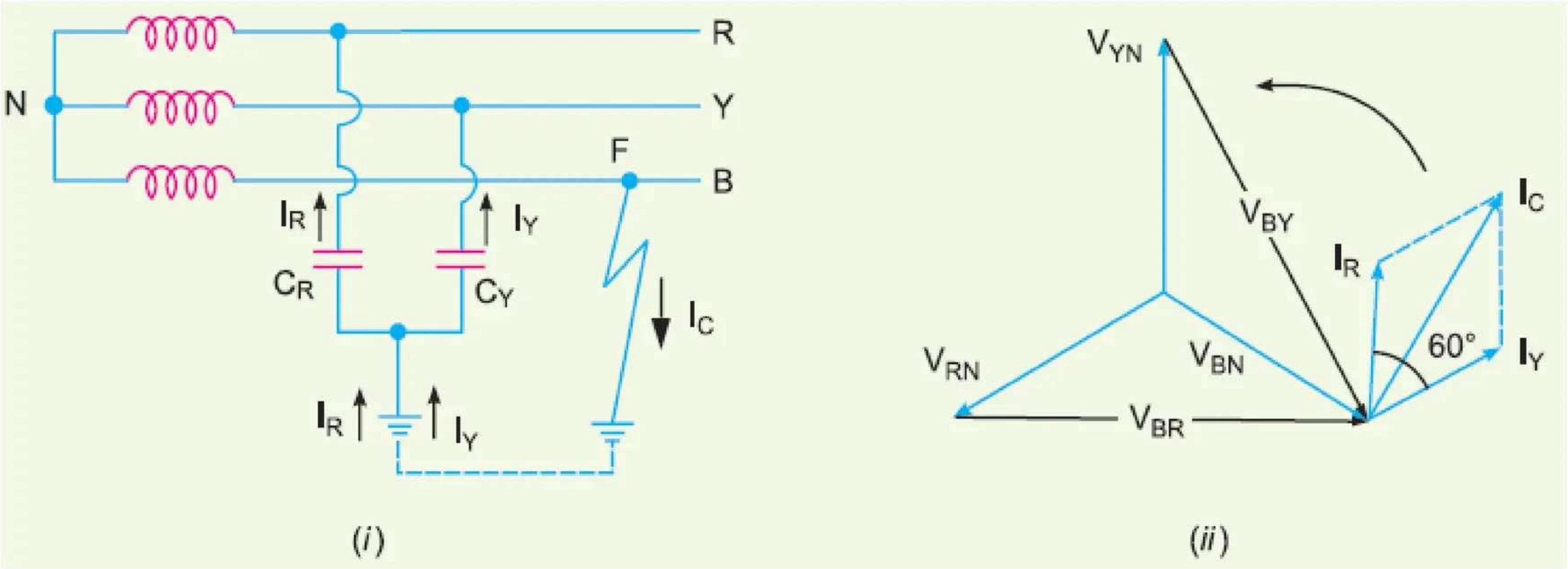


Fig.

Ungrounded Neutral System Grounding

Circuit behavior under single line to ground-fault.



- The capacitive currents I_R and I_Y flow through the lines *R* and *Y* respectively. The voltages driving I_R and I_Y are V_{BR} and V_{BY} respectively. Note that V_{BR} and V_{BY} are the line voltages [See Fig. (*ii*)]. The paths of I_R and I_Y are essentially capacitive. Therefore, I_R leads V_{BR} by 90° and I_Y leads V_{BY} by 90° as shown in Fig. (*ii*). The capacitive fault current I_C in line *B* is the phasor sum of I_R and I_Y.

Ungrounded Neutral System Grounding

Circuit behavior under single line to ground-fault.

Fault current in line B, $I_C = I_R + I_Y$ .... Phasor sum

Now, $$I_R = \frac{V_{BR}}{X_C} = \frac{\sqrt{3}\, V_{ph}}{X_C}$$

and $$I_Y = \frac{V_{BY}}{X_C} = \frac{\sqrt{3}\, V_{ph}}{X_C}$$

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

$= \sqrt{3} \times$ Per phase capacitive current under normal conditions

Capacitive fault current in line B is

$I_C =$ Phasor sum of I_R and I_Y

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

$$\therefore \quad I_C = \frac{3\, V_{ph}}{X_C} = 3 \times \frac{V_{ph}}{X_C}$$

$= 3 \times$ Per phase capacitive current under normal conditions

Ungrounded Neutral System Grounding

Circuit behavior under single line to ground-fault.

when single line to ground fault occurs on an ungrounded neutral system, the following effects are produced in the system.

- **(*i*)** 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.
- **(*ii*)** The capacitive current in the two healthy phases increase to 3 times the normal value.
- **(*iii*)** The capacitive fault current (I_C) becomes 3 times the normal per phase capacitive current.
- **(*iv*)** 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.

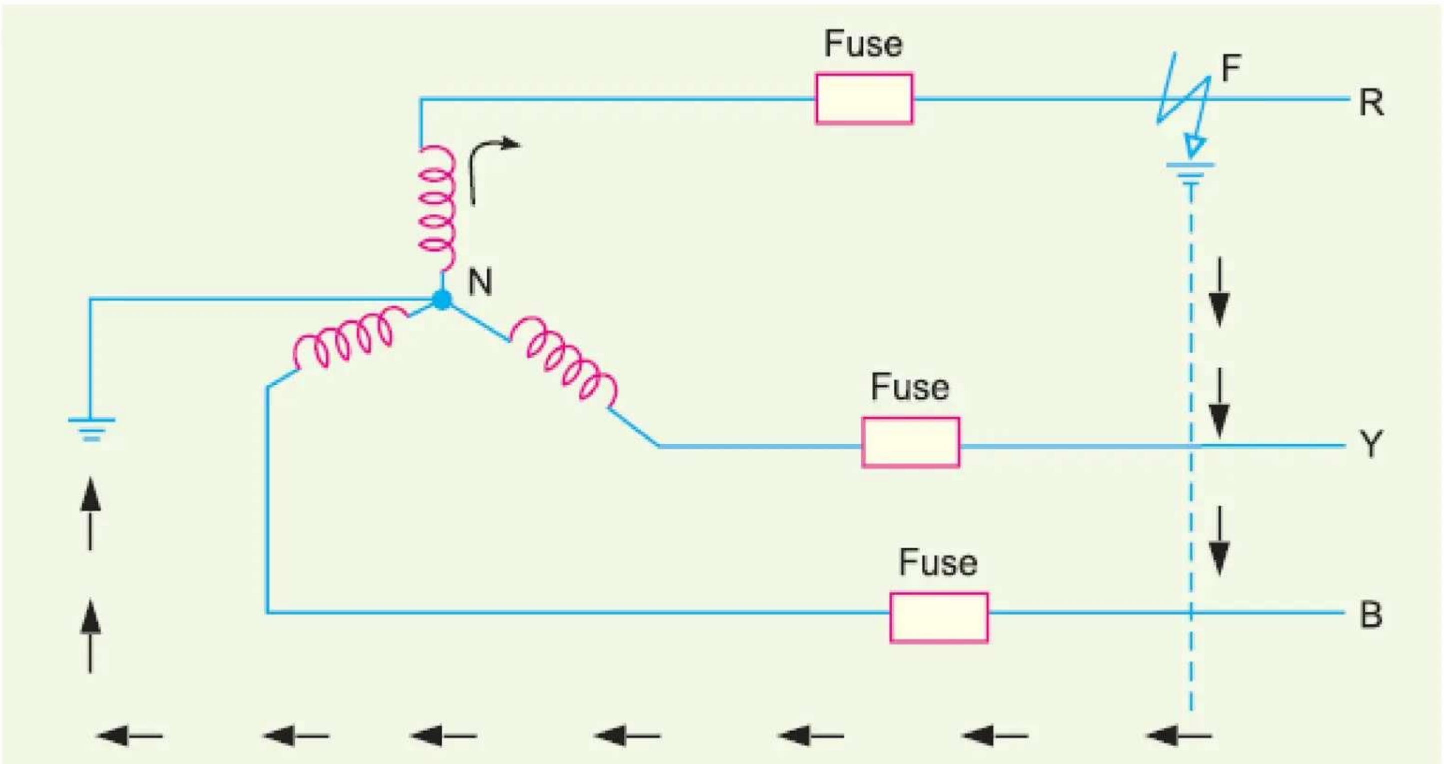
Ungrounded Neutral System Grounding

Circuit behavior under single line to ground-fault.

- **(*v*)** The capacitive fault current I_C flows into earth. Experience shows that I_C 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 sets 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.

Neutral Grounding

- *The process of connecting neutral point of 3-phase system to earth (i.e. soil) either directly or through some circuit element (e.g. resistance, reactance etc.) is called* **neutral grounding.**



Advantages of Neutral Grounding

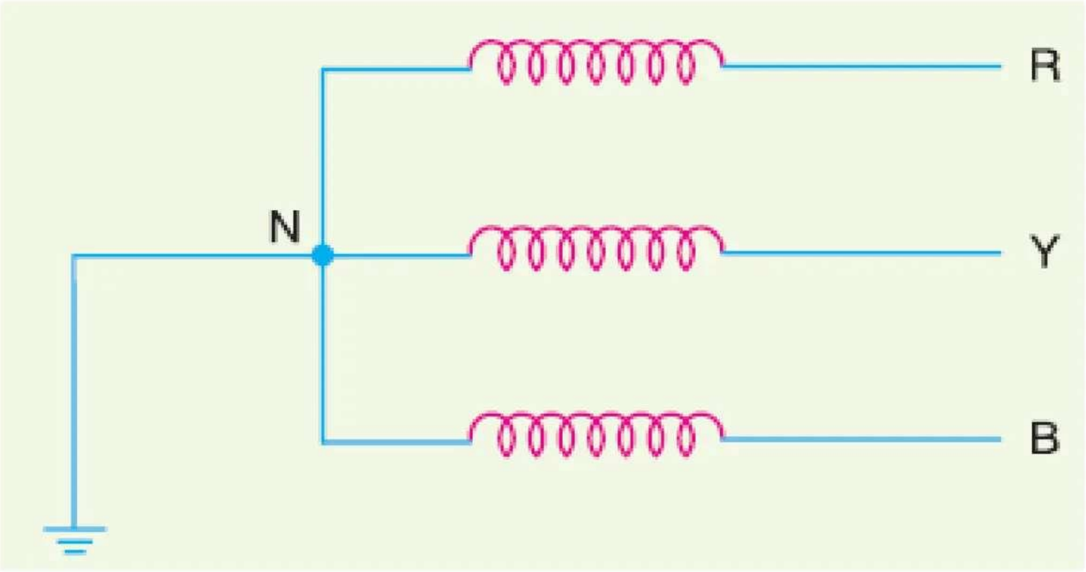
- **(*i*)** Voltages of the healthy phases do not exceed line to ground voltages *i.e.* they remain nearly constant.
- **(*ii*)** The high voltages due to arcing grounds are eliminated.
- **(*iii*)** The protective relays can be used to provide protection against earth faults. In case earth fault occurs on any line, the protective relay will operate to isolate the faulty line.
- **(*iv*)** The overvoltages due to lightning are discharged to earth.
- **(*v*)** It provides greater safety to personnel and equipment.
- **(*vi*)** It provides improved service reliability.
- **(*vii*)** Operating and maintenance expenditures are reduced.

Methods of Neutral Grounding

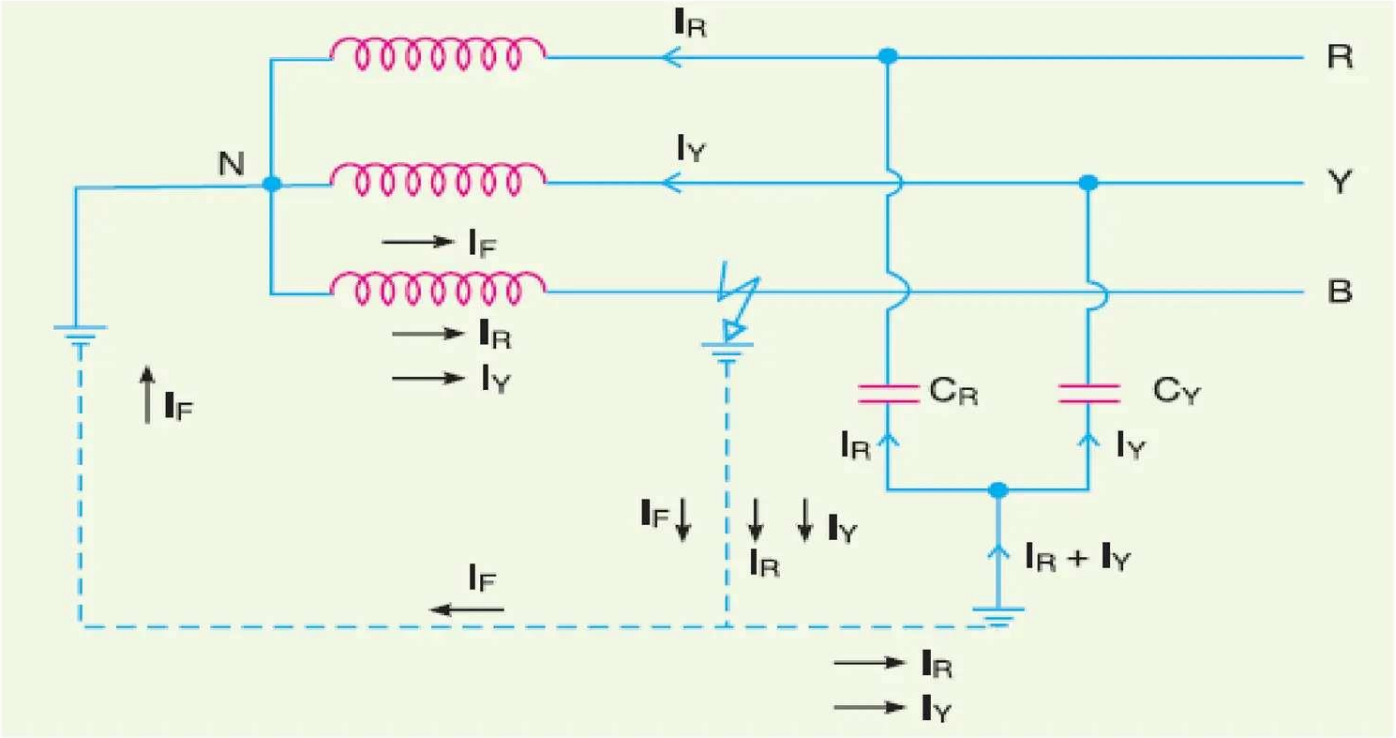
- **(*i*)** Solid or effective grounding
- **(*ii*)** Resistance grounding
- **(*iii*)** Reactance grounding
- **(*iv*)** Peterson-coil grounding

Solid Grounding

- *When the neutral point of a 3-phase system (e.g. 3-phase generator, 3-phase transformer etc.) is directly connected to earth (i.e. soil) through a wire of negligible resistance and reactance, it is called* **solid grounding** *or* **effective grounding**.



Solid Grounding



Solid Grounding

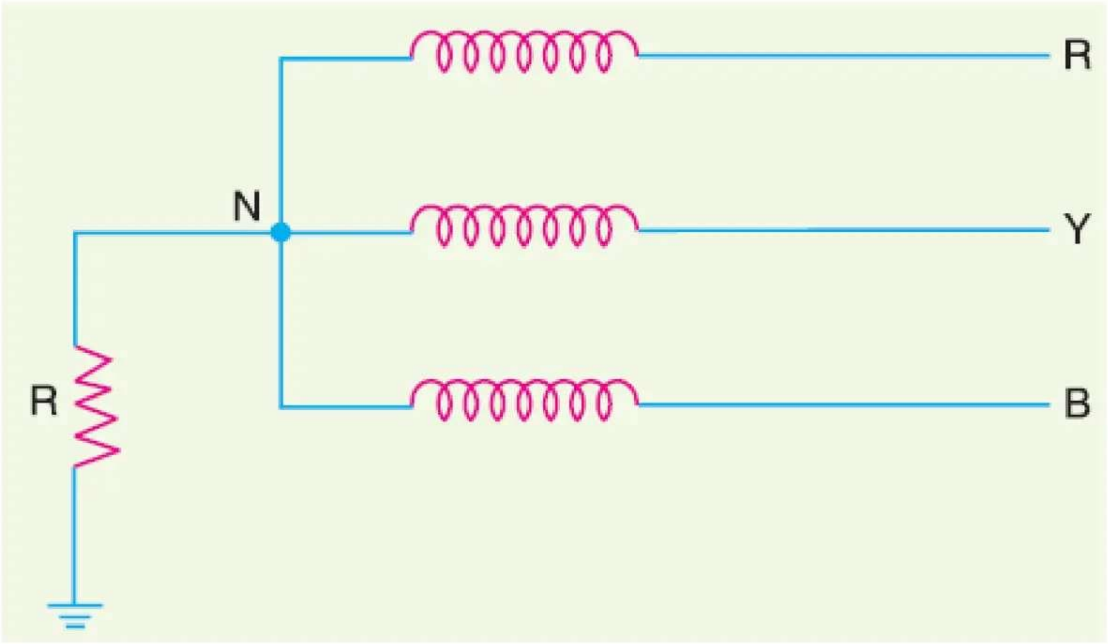
- **Disadvantages.** The following are the disadvantages of solid grounding :
- **(*i*)** Since most of the faults on an overhead system are phase to earth faults, the system has to bear a large number of severe shocks. This causes the system to become unstable.
- **(*ii*)** The solid grounding results in heavy earth fault currents. Since the fault has to be cleared by the circuit breakers, the heavy earth fault currents may cause the burning of circuit breaker contacts.
- **(*iii*)** The increased earth fault current results in greater interference in the neighbouring communication lines.

Solid Grounding

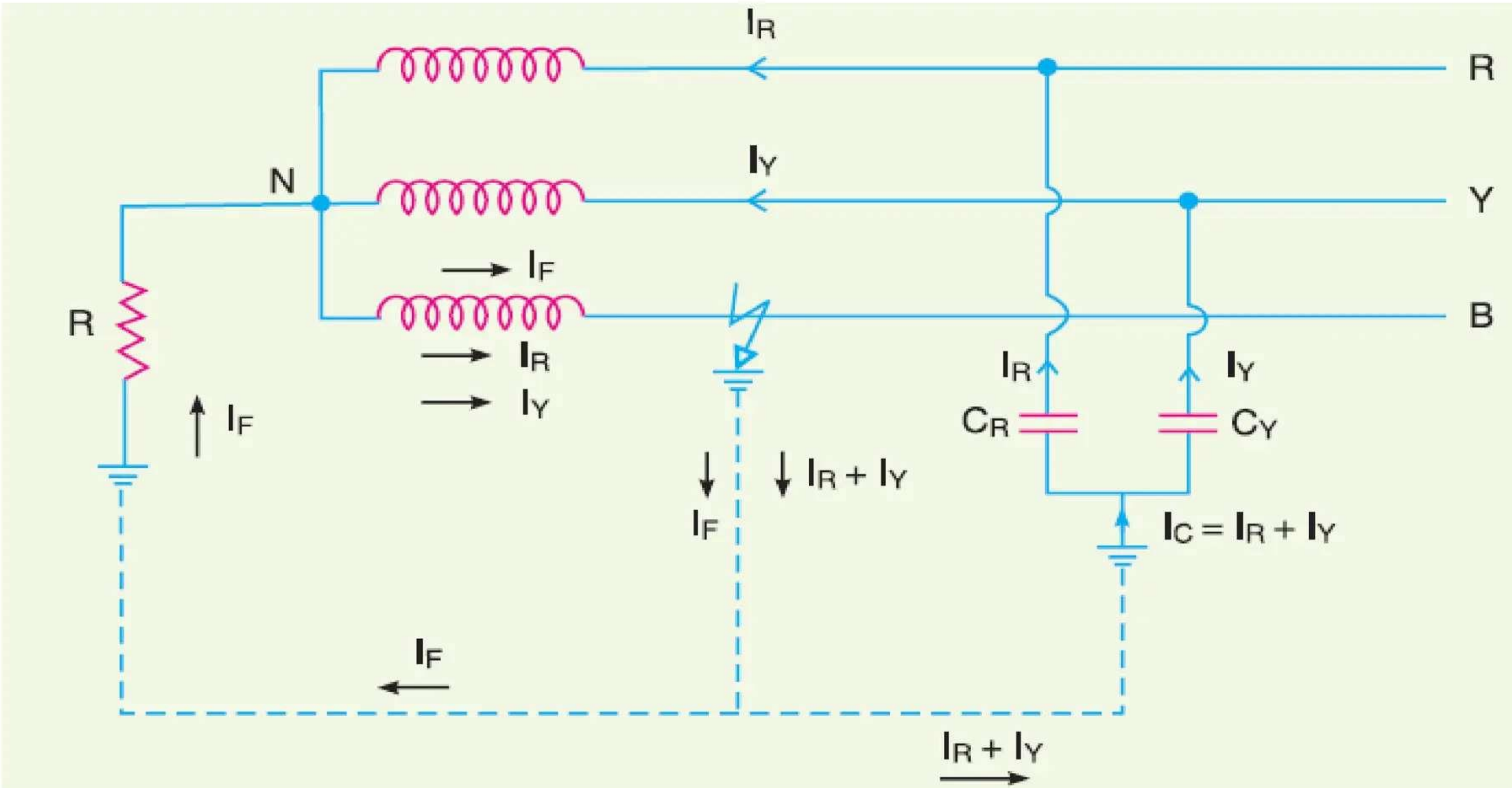
- **Applications.** Solid grounding is usually employed where the circuit impedance is sufficiently high so as to keep the earth fault current within safe limits. This system of grounding is used for voltages upto 33 kV with total power capacity not exceeding 5000 kVA.

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 a resistor, it is called* **resistance grounding.**



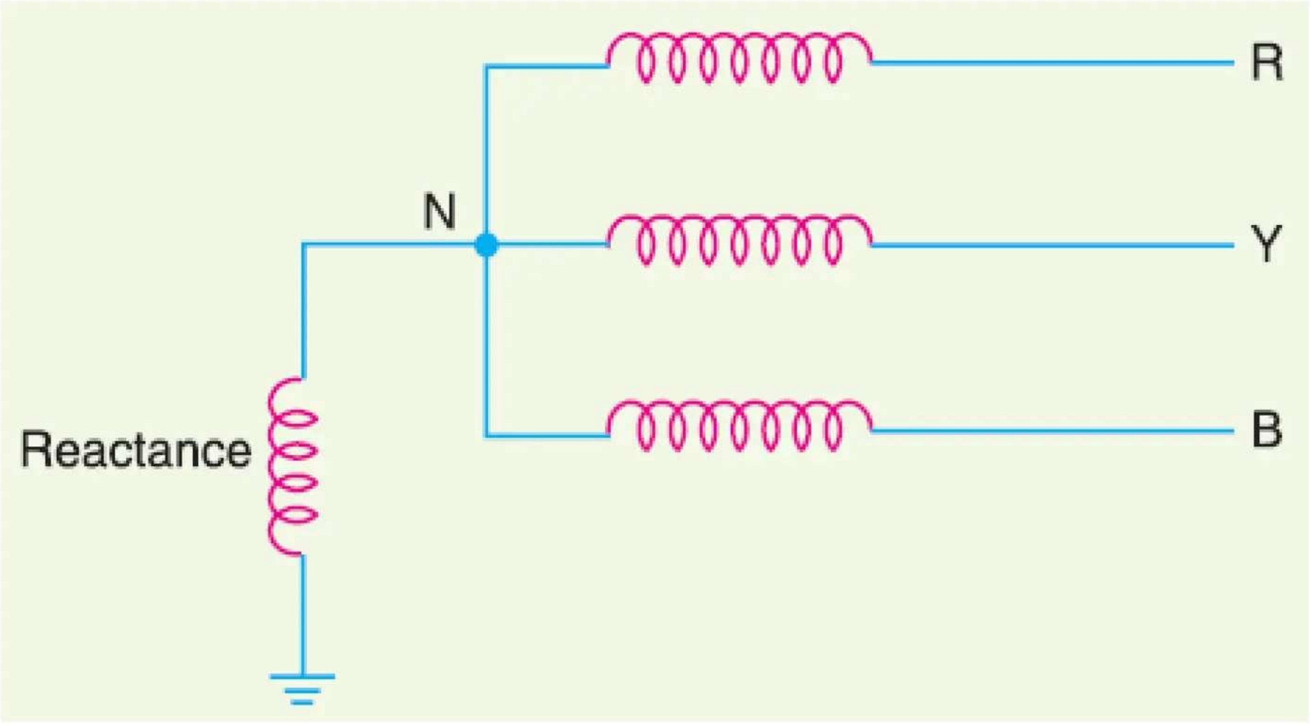
Resistance Grounding



Resistance Grounding

- **Disadvantages.**
- **(*i*)** Since the system neutral is displaced during earth faults, the equipment has to be insulated for higher voltages.
- **(*ii*)** This system is costlier than the solidly grounded system.
- **(*iii*)** A large amount of energy is produced in the earthing resistance during earth faults. Sometimes it becomes difficult to dissipate this energy to atmosphere.
- **Applications.** It is used on a system operating at voltages between 2.2 kV and 33 kV with power source capacity more than 5000 kVA.

Reactance Grounding



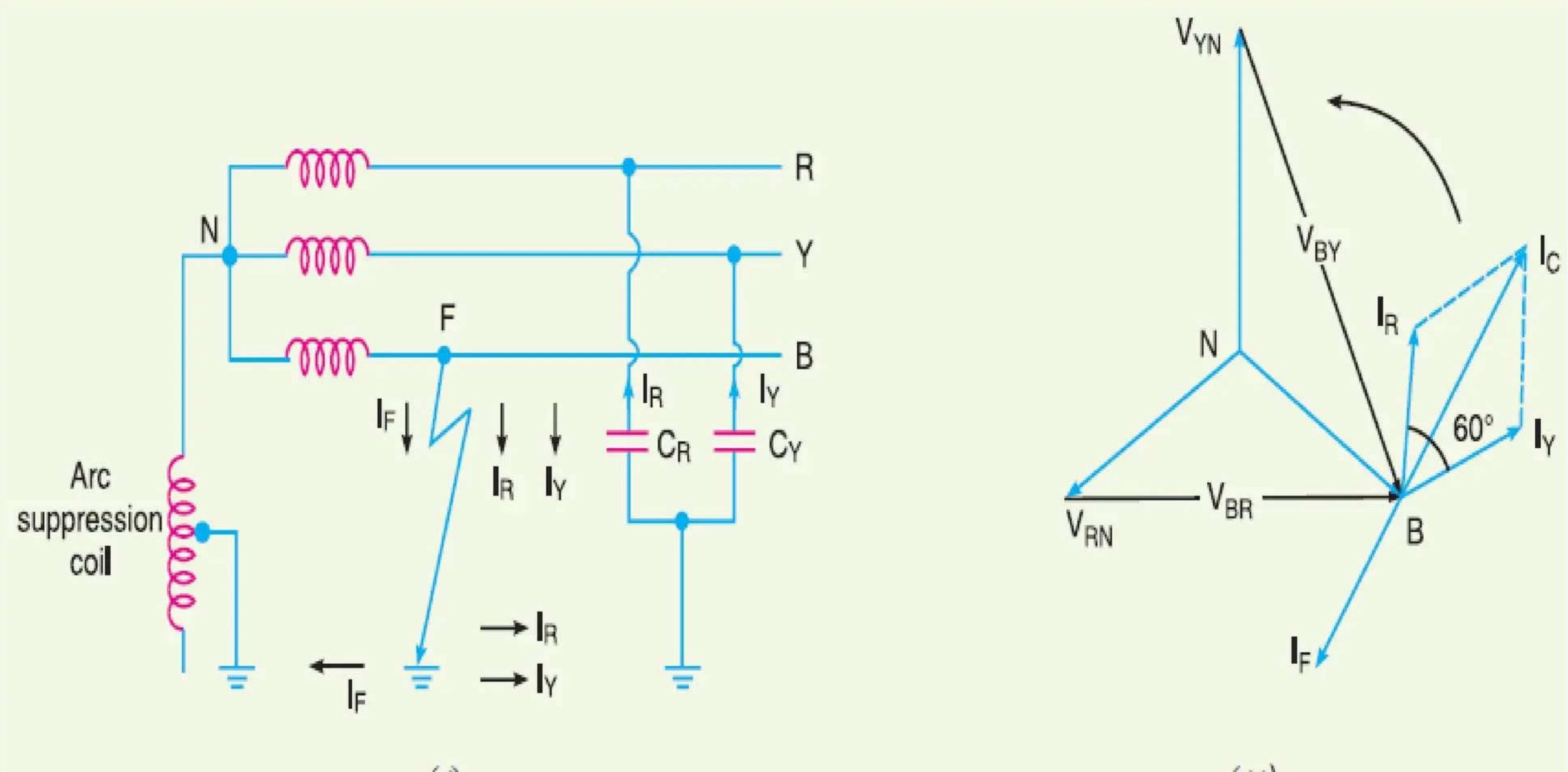
Reactance Grounding

- The purpose of reactance is to limit the earth fault current. By changing the earthing reactance, the earth fault current can to changed to obtain the conditions similar to that of solid grounding.
- This method is not used these days because of the following disadvantages :
- **(*i*)** In this system, the fault current required to operate the protective device is higher than that of resistance grounding for the same fault conditions.
- **(*ii*)** High transient voltages appear under fault conditions.

Arc Suppression Coil Grounding (or Resonant Grounding)

- We have seen that capacitive currents are responsible for producing arcing grounds. These capacitive currents flow because capacitance exists between each line and earth. If inductance L of appropriate value is connected in parallel with the capacitance of the system, the fault current I_F flowing through L will be in phase opposition to the capacitive current I_C of the system.
- If L is so adjusted that $I_L = I_C$, then resultant current in the fault will be zero. This condition is known as *resonant grounding.*
- *When the value of L of arc suppression coil is such that the fault current I_F exactly balances the capacitive current I_C, it is called* **resonant grounding**.

Arc Suppression Coil Grounding (or Resonant Grounding)



(*i*) (*ii*)

Arc Suppression Coil Grounding (or Resonant Grounding)

Value of L for resonant grounding. For resonant grounding, the system behaves as an un-grounded neutral system. Therefore, full line voltage appears across capacitors C_R and C_Y.

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

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

Here, X_C is the line to ground capacitive reactance.

Fault current, $$I_F = \frac{V_{ph}}{X_L}$$

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

For resonant grounding, $I_L = I_C$.

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

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

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

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

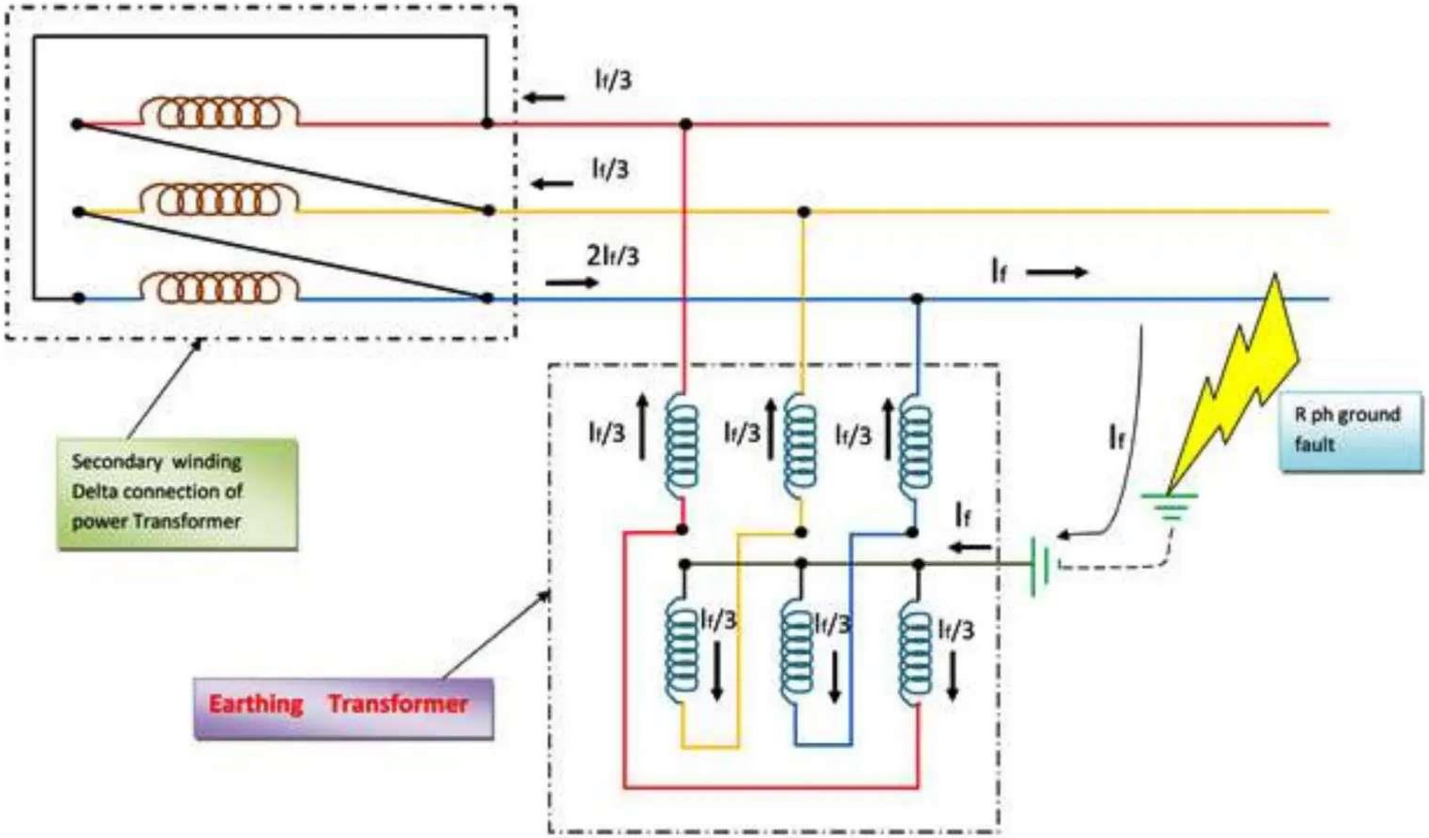
Exp. (*i*) gives the value of inductance L of the arc suppression coil for resonant grounding.

Arc Suppression Coil Grounding (or Resonant Grounding)

- **Advantages.** The Peterson coil grounding has the following advantages:
- **(*i*)** The Peterson coil is completely effective in preventing any damage by an arcing ground.
- **(*ii*)** The Peterson coil has the advantages of ungrounded neutral system.
- **Disadvantages.** The Peterson coil grounding has the following disadvantages :
- **(*i*)** Due to varying operational conditions, the capacitance of the network changes from time to time. Therefore, inductance L of Peterson coil requires readjustment.
- **(*ii*)** The lines should be transposed.

Earthing Transformer

When a transformer is used for the purpose of providing a neutral point for grounding purpose in a system where the neutral point of a three phase system are not available or where the transformers or generators are delta connected, that type of transformer is called Earthing or neutral grounding transformer.



Protective Schemes

A Protective Scheme is used to protect an equipment or a section of the line. The Common protective schemes which are usually used for the protection of a modern power system.

- ❖Over current Protection
- ❖Distance Protection
- ❖Carrier current protection
- ❖Differential Protection

Over Current Protection Scheme

❖ It is used for the protection of distribution lines, large motors, equipment, etc.

❖ It includes one or more over current relays.

❖ An over current relay operates when the current exceeds its pick-up value.

Distance Protection scheme

❖ It is used for the protection of transmission or sub transmission lines; usually 33 kV, 66 kV and 132 kV lines.

❖ It includes a number of distance relays of the same or different types.

❖ A Distance relay measures the distance between the relay location and the point of fault in terms of impedance, reactance, mho etc.

❖ It operates when the fault point lies within the protected section of the line.

Carrier current protection scheme

❖ It is used for the protection of EHV and UHV lines, generally 132 kV and above

❖ A carrier signal in the range of 50-500 kc/sec is generated for this purpose.

❖ A transmitter and receiver is installed at each end of transmission line to be protected.

❖ Depending on the information, relays placed at each end trip if the fault lies within the protected zone.

❖ Relays and tripping operation is controlled by carrier signal

Differential protection scheme

- It is used for the protection of generators, transformers, motors of very large size bus zones etc.
- CT's are placed at both end of each winding of a machine.
- The relay compares the current entering a machine winding and leaving the machine winding.
- Under normal condition or external fault both current is same, no current will flow through the relay. So the relay will not operate
- In the case of internal fault the difference in current will flow through the relay. So the relay will not operate

Unit Protection system

Only faults occurring within its protected zone are isolated.

Non Unit Protection system

It is activated even when the faults are external to its protected zone.

Pilot Protection

- ❖ It is used for the protection of transmission line sections. It is under the category of unit protection
- ❖ Interconnecting channel is used for comparing actuating quality. Such a interconnecting channel is called pilot.

1. Wire pilot
2. Carrier current pilot
3. Micowave pilot.