5.1 What is fuse? Define its characteristic.

- Fuse is the simplest device, which break the circuit under abnormal condition.
- It is only a current interrupting device under fault condition.
- It is not able to make or brake the circuit under normal condition.
- A fuse consists of a metal strip of mounted between a pair of electrical terminals, and enclosed by a non-conducting and non-combustible housing.
- The fuse is arranged in series to carry all the current passing through the protected circuit.

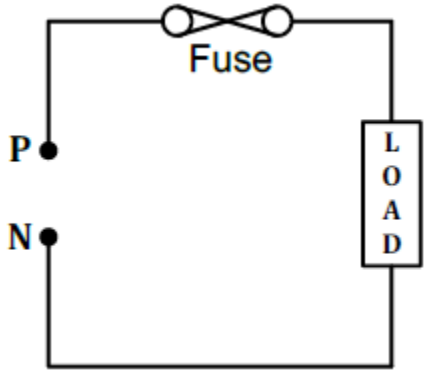

Figure 5.1 Fuse connected in circuit

- The fuse element is made of zinc, copper, silver, aluminum, or alloys.
- The fuse element may be surrounded by air or by materials to quench the arc. Silica sand or non-conducting liquids may be used.
- It is used for overload short circuit protection in medium voltage (up to 33 kv) and low voltage (up to 400v) installation.
- Fuse characteristics are drawn between current and time scale. The curve shows that fault current and operating time is inversely proportional to each other.
- The time considered is précising time and current is prospective current.
- The fuse characteristics become asymptotic and there is a minimum current below which the fuse does not operate. This is called minimum fusing current.

FUSE Characteristics

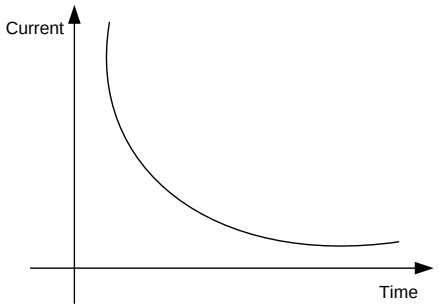

Figure 5.2 Fuse Characteristics

They should have a following desirable characteristic:-

- Low melting point
- High conductivity
- Free from deterioration from oxidation
- Low cost

5.2 Write short note on HRC fuse.

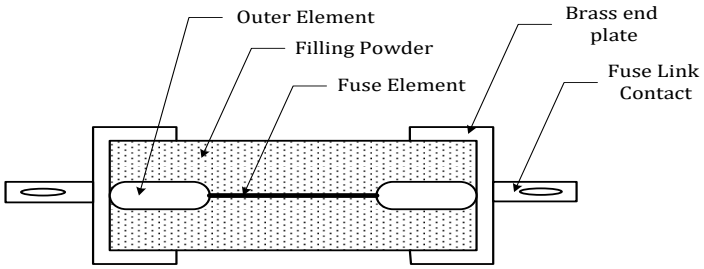

Figure 5.3 HRC Fuse

- When the load capacity is very high the level of fault current will also increase. So faulty clearing device will be under heavy stress.
- HRC fuse is preferred for heavy duty and rapid operation.
- It consists of heat resisting ceramic cylindrical body having low co-efficient of thermal expansion.
- The fuse element is made up of silver or silver alloy to improve fuse life.
- It is filled with incombustible powder which absorbs the arc produced at the time of blowing.
- The rating is much more accurate. It is widely used because of silent operation and non-deteriorating characteristics.
- It is maintenance free and easy to install.

Advantages:-

- Speed of operation is very high.
- Maintenance cost is practically is zero.
- They deteriorate with age.
- They provide reliable operation.
- They cheaper than other protecting devices.

Disadvantages:-

- Heat produced by arc may affect the associate switches.
- They have to be replaced after each operation.

5.3 Compare Fuse with MCB.

Fuse	MCB
○ Melts the wire when fault occurs	○ Cut-off circuit when the fault occurs
○ Fuse wire available may not be standard rating	○ MCB available is of standard rating
○ Operated at 50 to 100 % over load capacity	○ Operated at 5 to 15 % over load capacity
○ Hand tools are required to re-wire the fuse when blown off	○ No hand tool required to reset
○ Cheapest among all safety device	○ Initial cost is very high
○ Fuse board (mounting arrangement) is not compact	○ MCB board (mounting arrangement) is compact

5.4 Compare MCB with ELCB.

MCB	ELCB
○ MCB is an electromechanical device which protects an electrical circuit from an over current and in short circuit condition.	○ The ELCB is used to protect the circuit from the electrical leakage.
○ MCB has slower operation time than ELCB.	○ ELCB has rapid operation compare to MCB.
○ The operating principle of MCB is simple.	○ The operating principle of ELCB is complicated.
○ MCB does not give human protection.	○ ELCB gives human protection.
○ MCB is cheaper than ELCB.	○ ELCB is costlier than MCB.
○ Rated current is not more than 100 Ampere.	○ The range of rated current us up to 1000 Ampere.
○ This circuit breaker connects the phase and neutral terminal.	○ This circuit breaker connects the phase, earth wire and neutral terminal.
○ **Applications:** ○ Domestic and commercial purposes.	○ **Applications:** ○ Mostly in Domestic purposes.

5.5 Write short notes on MCB.

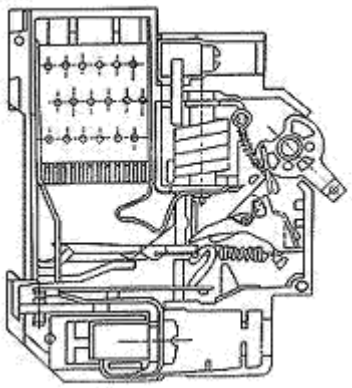

Figure 5.4 MCB Construction

- MCB have the features of good HRC fuse and a good switch.
- These are used for switching purpose under normal condition and circuit break under overloading and short circuit condition.
- It is normally operated at 1.25 times its rated current.
- It is manufactured with quick reset hand operated facility.
- It is basically operated on two type of working principles:
  - ❖ **Thermal operation:**
- It is achieved by bimetallic strip which deflects when heated by any over current flowing through it.
  - ❖ **Magnetic operation:**
- When short circuit occurs the rising current energizes the solenoid further operating plunger to strike the trip lever immediately releasing of latch mechanism.

Construction of MCB

- The casing of MCB is made of moulded thermoplastic polyester. This material is fire retardant and non-hygroscopic. They are installed directly on Rail in distribution boards, control panels simply by fixing.
- The contacts are made of Silver- Copper alloy which ensure longer life of contacts. These have low resistance resulting in low watt loss. The contacts are designed to have zero Bounce during closing operation.
- Operating Mechanism of MCB has quick make, quick break, and trip-free mechanism.

Application:-

- MCB are used extensively in low voltage domestic, commercial and industrial.

5.6 Write short notes on MCCB.

Definition

- MCCB is a switching device which is used in LT electrical system. It provides protection against overload & short circuit. Fault sensing arrangements are installed inside MCCBs & shunt release is provided for remote tripping of MCCB.
- It is available between 100A & 630Acurrent.

Working Principle

- MCCB provides **protection against overload** through thermal mechanism.
- It has bimetallic contacts which expand & contract on temperature changes *(same like an automatic iron).*
- Under normal condition these contacts allow normal current to flow but when current exceeds its trip limit, the bimetallic contacts start heating up & expand until the circuit is isolated/tripped.
- When MCCB is tripped, faulty circuit is isolated from circuit & the temperature of bimetallic contacts starts getting normal & MCCB again is ready for next operation.
- MCCB provides protection against short circuit – if current is very high, fault current should be interrupted immediately.
- This is achieved by electromagnetic induction. Whenever fault occurs, the high current induces a magnetic field in a solenoid coil located inside the breaker, this magnetic induction trips a contact & current is interrupted.
- In the tripping process, arc is produced & that is dissipated by taking suitable measures inside the breaker.
- These breakers can be manually switched off or on also which is required during maintenance or other purpose.

Figure 5.5 MCCB

- **Current rating of MCCB**
- A typical range of **Three phase MCCB** are – 100A, 125A, 150A, 200A, 250A, 315A, 400A, 630A (These ranges are standard rating that available in the market)
- **Application:**
- Especially for industrial purposes where load current are more than 100A.
- It is used in cement industries, ceramic industries, food processing industries etc.

5.7 List various device used in Electrical Circuit. Write the brief note on ELCB.

Followings Protective Device used in Electrical Circuit:-

(1) Fuse
(2) Miniature Circuit Breaker (MCB)
(3) Earth Leakage Circuit Breaker (ELCB)
(4) Relay

ELCB:-

- Earth Leakage Circuit Breaker (ELCB). An Earth Leakage Circuit Breaker (ELCB) is a device used to directly detect currents leaking to earth from an installation and cut the power and mainly used in TT earthing systems.
- For the protection of human body from the electric shock protective device like fuse or MCB are used.
- But generally this device are incapable of measuring small current flowing in human body, so requirement is to have a device which can sense small current and cut-off the supply instantly.
- The device used for this purpose is known as Earth Leakage Circuit Breaker (ELCB).

There are two types of ELCBs:

- 1. Voltage Earth Leakage Circuit Breaker (Voltage-ELCB)
- 2. Current Earth Leakage Current Earth Leakage Circuit Breaker (Current-ELCB).

Circuit Diagram:-

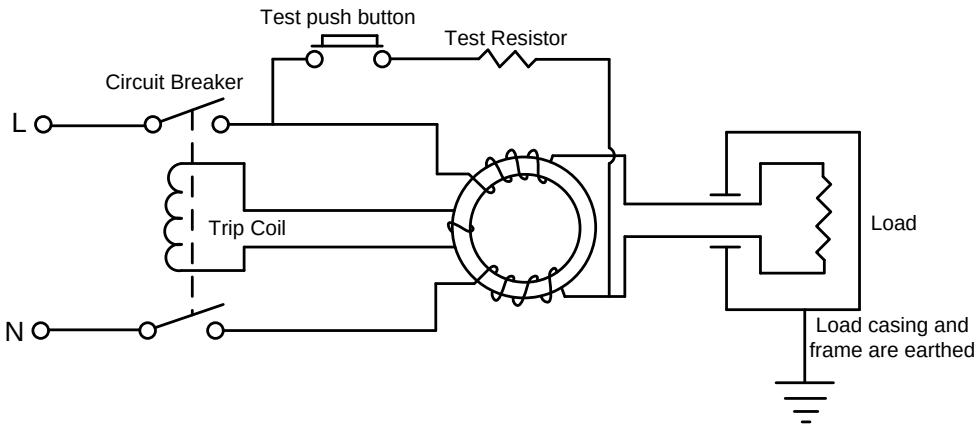

Figure 5.6 ELCB Circuit Diagram

Working of ELCB

- It is current operated device designed to operate when a leakage current exceeds the predefined value.
- It consists of a operating coil and a trip mechanism which operated the circuit when required.
- The coil is supplied through 1-Φ supply so current in phase & neutral wire will be same.
- This current will produce flux linkages same in magnitude but of opposite direction. This will result zero net flux in tripping coil of relay.
- When fault or leakage current exceeds the limit higher current will flow in phase conductor than neutral current.
- Resultant flux now is out of balance in tripping coil of relay. Difference of flux will induce emf in the coil which opens the contact of ELCB and isolate the circuit from the supply.

5.8 Explain types of wire

- There are different types of wire are listed below:
- Triplex wire: Triplex wires are usually used in single-phase service drop conductors, between the power pole and weather heads. They are composed of two insulated aluminum wires wrapped with a third bare wire which is used as a common neutral.
- **Non-metallic sheathed wires:** Non-metallic sheath wire is used in most homes and has 2-3 conductors, each with plastic insulation, and a bare ground wire. The individual wires are covered with another layer of non-metallic sheathing. Since it's relatively cheaper and available in ratings for 15, 20 and 25 amps, this type is preferred for in-house wiring.

Triplex wire | Non-metallic sheathed wire | Single strand wire

Figure 5.7 Types of wire

- **Single Strand Wire**: Single strand wire also uses THHN (Thermoplastic High Heat-resistant Nylon-coated) wire, though there are other variants. Each wire is separate and multiple wires can be drawn together through a pipe easily. Single strand wires are the most popular choice for layouts that use pipes to contain wires.

5.9 Explain types of Cable

Under ground cable are classified as follow:

(1) According to voltage level:

- **Low voltage (L.T.) cable:** It consist of one circular core of tinned stranded copper (or aluminum) insulated by layers of impregnated paper. These cable are used up to 1 kV.
- **High voltage (H.T.) cable:** It consist of either circular shaped or oval or sector shaped 3 core stranded copper or aluminum. These cable are used up to 11 kV.
- **Super tension (S.T.) cable:** The insulation on each core is covered with aluminum foil or own lead sheath or metallized paper. These cable are used up to 33 kV.
- **Extra high tension (E.H.T.) cable:** oil filled cable and gas pressure cable are types of E.H.T. cable. Oil filled cable is consist of oil channel at the center of core by stranding the conductors wire around the hollow cylindrical steel spiral tape.Gas pressure cable is laid in a gas tight steel pipe which is filled with dry nitrogen at 12 to 15 atmosphere pressure produces radial compression and closes the voids. These cable are used up to 66 kV.
- **Extra super voltage cable:** These cable are used up to 132 kV and above.

(2) According to insulating material :

- Insulation is provided on conducting material to block the path of leakage current from the conductor,thus minimizing the risk shock and fire. Normally cables are classified according to the insulation used over the conductor. The various classification of cable commonaly used for domestic wiring are as follow:
- **Vulcanized rubber sheathed (V.I.R.) insulated cables:** These consists of a copper conductor covered with a insulation layer of Vulcanized Indian Rubber (VIR). A cotton tape covering is provided over this insulation layer to protect the wire from moisture and to provide mechanical strength to the wire. The thickness of the Vulcanized Indian Rubber depends on the voltage.
- **Cab Type sheathed (T.R.S.) cables:** These C.T.S or T.R.S wires consists of vulcanized rubber insulated conductor. This insulation layer is covered by a layer made of tough rubber (or) tough rubber sheathed covering is provided over this insulation layer. This covering will be very hard and protects the wire from moisture and provides mechanical strength to the wire. These wires are available in single core, twin core, triple core etc. As these wires have tough rubber covering no additional protection or strength is required.
- **Weather –proof cables:** These wires consists of conductor provided with an insulation layer made up of hard rubber. Over this cotton sheathed and cotton tape covering is provided especially to protect the wire from moisture. These wires are used where the moisture is present.
- **Polyvinyl chloride (P.V.C.) insulated cables:** These wires consists of a conductor over which an insulation layer made up of Polyvinyl Chloride is provided. These wires cannot resist much heat and they have relatively low melting points, so they aren't used in hot places and also these wires are not used with heating appliances. PVC wires are available in almost all colors.
- **Lead sheathed cables:** These wires consists of vulcanized Indian rubber insulated conductor over which a Lead sheath is provided which gives mechanical strength to the

wire and it also protects the wire from moisture. These wires are generally used where there is chances of moisture like in snowy places. As Lead is a good conductor of electricity the Lead covering may give electric shock to us so to prevent this the Lead covering is provided with earth wire. These wires are available in single core, twin core, triple core etc size.

(3) According to number of conductor :

- **Single core:** Single core cable means,it consists of one conductor only.
- **Multi core:** Multi core cable has more than one core.
  - **2 core cable:** In 2 core cable, one conductor act as a phase and another act as a neutral. Both conductor have a equal cross sectional area.
  - **3 core cable:** In 3 core cable, all the conductors have a equal cross sectional area. Three strand carry R,Y and B phases respectively.
  - **3 ½ core cable:** In 3 ½ core cable, 3 conductors have a equal cross sectional area. Three strand carry R,Y and B phases respectively. Fourth core having cross sectional are half than that the other. Fourth core are used as a neutral.
  - **4 core cable:** In 4 core cable, all the conductors have a equal cross sectional area. All strand carry R,Y ,B phases and neutral respectively.

5.10 Cable construction with neat sketch diagram

- Construction of cable as shown in figure. Different parts of cable are given below.
- **Conductor:** Conductors used for cables are generally made up of tinned copper or aluminium.To provides the sufficient flexibility conductors are used in stranded form. Cable may consist of one, two, three of four conductors depending upon the service required.
- **Paper insulation:** The type and thickness of insulation depends upon the voltage level. Insulating materials should provide the following properties: High insulation resistance, High mechanical strength, Non-porous, Chemically inert, high die-electric strength, Non-inflammable etc.
- Following are the different materials used for cable insulation: Rubber, Vulcanized India Rubber, Impregnated paper, PVC etc.

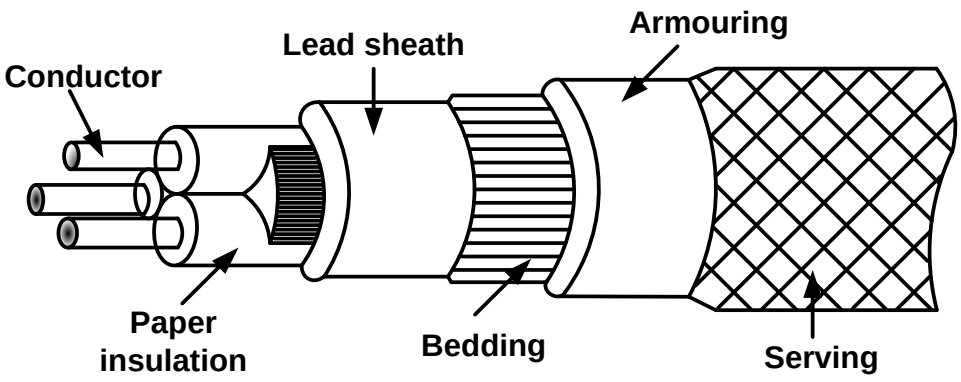

Figure 5.8 Construction of cable

- **Lead Sheath:** As the cable is placed under ground, soil may present moisture, gases and some other liquids. Therefore, to protect the cable metallic sheath made up of lead or aluminum is provided over the insulation.
- **Bedding:** To protect the metallic sheath from corrosion and some mechanical injury, bedding is provided. It is made up of some fibrous material such as jute.
- **Armoring:** Armoring is used to protect the cable from mechanical injury while handling. It consists of one or two layers of galvanized steel wire or steel tape.
- **Serving:** Serving is provided to protect the armoring from atmospheric conditions. It is made up of some fibrous material like jute.

5.11 Eatrhing System

❖ **What is Eatrhing? Explain the purpose of Earthing. *OR* Grounding.**

- "The earthing is the connection of general mass of earth to electrical apparatus in such a manner as to ensure all time an immediate energy discharge without danger".
- The earth is made up of a material that is electrically conductive. A fault current will flow to earth through the live conductor, provided it is earthed.
- The Conventional system of Earthing is done by digging of a large pit into which a GI pipe or a Copper plate is positioned with the layers of charcoal and salt.
- When system is without earthing and if short circuit occurs and human body touches the metal part, current will get return path through human body.
- When system is properly earthed and if short circuit occurs and human body touches the metal part, current will not get path through human body. Because circuit is already provided with low resistance path through earthing.
- An effective earthing is made through any wire, pipe, rod or metal plate known as earth electrode.
- The connecting wire between electrical apparatus and earth electrode is known as earthing lead or main earthing conductor.

Purpose of Earthing

- To avoid electric shock to human body.
- To avoid risk of fire due to earth leakage current through unwanted path.
- Ensure that all exposed conductive parts do not reach a dangerous potential
- Maintain the voltage at any part of an electrical system.

The qualities of a good Earthing

- Must be of low electrical resistance
- Must be of good corrosion resistance
- Must be able to dissipate high fault current repeatedly

5.12 State the different method of earthing and explain one.

Following are the different methods of earthing.

- Pipe earthing
- Plate earthing
- Coil earthing

Pipe Earthing:-

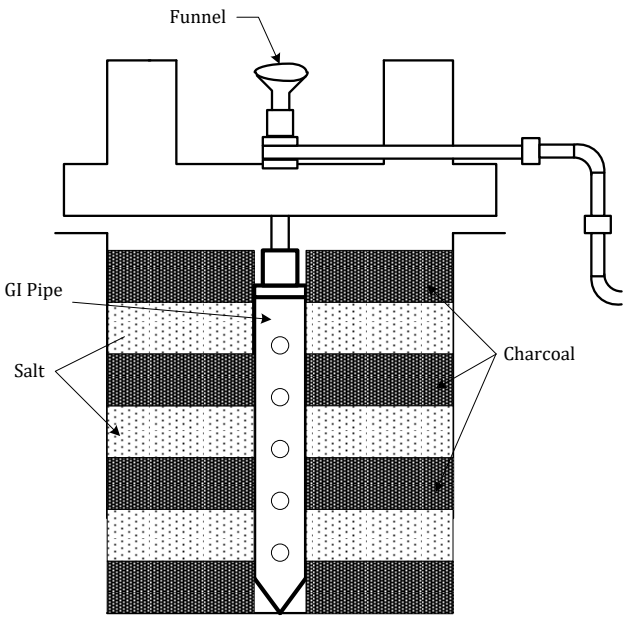

Figure 5.9 Pipe Earthing

- Pipe earthing is the most commonly adopted method and is a best system of earthing compared to the others system.
- In this method of earthing pipe of sufficient diameter is selected whose size is depend upon (a) Maximum earth current of that installation (b) Type of Soil
- As per IS-732-1963, The GI pipe shall not be less than 38mm diameter and 2 meter long for ordinary soil.
- If Cast Iron is used then internal diameter should be 10 mm.
- The depth at which pipe should be buried depends upon condition of soil and moisture.
- For pipe earthing at pit of 40sq.mm is dug in the soil and the pipe having tapered at the bottom is placed vertical in the pit.
- The charcoal and salt are filled in that pit alternately in layers about 2 meters from bottom and for a distance of about 15cm around the pipe. This is done to increase the dampness and moisture of soil surrounding pipe.
- The pipe placed has 12mm diameter holes drilling in it so that water poured from top is easily spread in the media surrounding the pipe which helps in maintaining the resistance of earth.
- At a top a cement concrete work is done to provide protection against mechanical damage.
- A water pouring arrangement is provided by a funnel with wire mesh at the top.

Plate Earthing:-

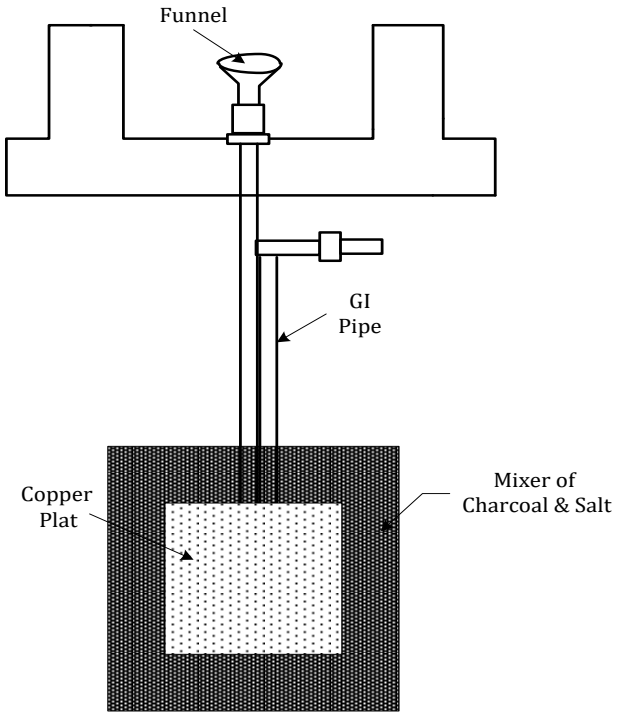

Figure 5.10 Plate Earthing

- In case of plate earthing electrodes may made of GI or steel or copper.
- For copper plate thickness is not less than 3.15mm and for GI or steel plate thickness is not less than 6.30mm.
- The size of plate electrode should be 60×60 cm.
- Plate electrode should be buried such that top edge is a depth of not less than 1.5 meter below the surface of the ground.
- For the plate earthing a pit of a 4 meter dug in to the ground and the earthing plate is placed vertical in that pit.
- The space around the plate is filled with layers of charcoal and salt for a minimum thickness of 15 cm.
- For connection of earth wire to the earth electrode a GI pipe of 12.7 mm diameter is connected to the electrode (earthing plate).
- Earth wire is properly secured to earth electrode with the help of nut, bolt and washer.
- The pit filled with charcoal and salt is also connected with a pipe for carrying water from concrete work that area.
- This will help in increasing the dampness and moisture surrounding the plate.
- No earth electrode should have a resistance more than 3 ohm measured by an earth resistance meter. In rocky soil the resistance may be up to 8 ohm. Copper plate earthing needs to be changed every 12 years due to corrosion attacks.

5.13 Write short note on Neutral Earthing.

- Neutral Earthing is the process of connecting a star point of transformer, generator and motor to ground.
- Protects system against arcing ground
- Keeps balanced voltage with respect to earth
- Greater safety to lightning
- Maintenance and operating cost is low
- Reliable in operation

Types of Neutral Earthing

- All A.C. power system of today is operated with neutral grounded. It is classified as per voltage level as below.

1. Solid Earthing

- Neutral point is connected to earth without intentional resistance or reactance.
- It is used below 660 V.

2. Resistance Earthing

- Neutral point is connected to earth through resistance.
- It is used between 3.3 KV to 11 KV.

3. Reactance Earthing

- Neutral point is connected to earth through resistance.
- It is good as compared to resistance earthing for same voltage level (i.e. 3.3 KV to 11 KV)

4. Resonant Earthing

- The value of reactance is selected so as to neutralise the power frequency capacitive current between line and earth.
- It is used for medium voltage transmission line which connected to generator with intervening power transformer.

5.14 Safety precautions for electrical appliances

- It is extremely important to take safety precautions when working with electricity. Safety must not be compromised and some ground rules must be followed.
- The basic guidelines regarding safe handling of electricity are as given below:
  - Avoid water at all times when working with electricity. Never touch or try to repair any electrical equipment with wet hands, as it increases the possibility of shock.
  - Never use any equipment with frayed cords, damaged insulation or broken plugs.
  - Never work on any receptacle at your home with mains supply ON. Always turn it OFF before working.
  - Always use insulated tools while working.
  - Always use standard pins to tap the supply of power from any plug.
  - Always use the standard lSI marked materials and equipments even though they cost a little more.

- Avoid electrical hazards by not letting the energized parts and unguarded electric equipment exposed because they are a shock risk especially for children in the house.
- Never use an aluminum or steel ladder to work on any appliance at height. Instead use a bamboo, wooden or fiberglass ladder.
- Know the wire code of your country.
- Always check all your GFCIs (Ground Fault Circuit Interrupters) once a month. These devices are commonly used nowadays to avoid electric shock hazards.
- Plug points of high power appliances like refrigerators, wet grinders, washing machine, water heaters etc must have a proper earthing and power should be drawn only through the three pin plugs.
- Always use .a circuit. breaker (MCB) with the appropriate current rating, in each electrical circuit.
- Take care while removing a capacitor from a circuit. A capacitor stores energy and if not removed properly then it may cause an electric shock.

5.15 Basic introduction of Battery

- It is known that the electrical current can easily flow through the metallic conductors. Current can also flow through same liquids called electrolytes.
- When current passes through an electrolytic solution chemical action occur and produced chemical charges.
- Thus in this process electrical energy is converted into chemical energy and chemical energy also converted into electrical energy. The device which is converting chemical energy into electrical energy is called electrical cell.

5.16 Explain following terms

(1) Cells

- The smallest element of a battery is a cell. A cell is defined as a source of emf in which chemical energy is converted into electrical energy.
- A cell consists of two metal plates of different materials. These plates are immersed in a suitable solution. The value of emf produced by a cell depends on: (1) Material used for the plates or electrodes (2) Types of electrolyte

(2) Battery

- A battery is a group of cells. Depending on the voltage and current requirements, the cells are suitably connected in series parallel configurations. Batteries absorb electrical energy at the time of charging and release it at the time of discharging.
- The batteries give out electrical energy due to chemical reaction taking place, while discharging. During the charging process, the batteries chemical changes take place, which absorb the energy.
- The entire resistance encountered by a current as if it flows through a battery from the negative terminal to the positive terminal is known as internal resistance of battery.

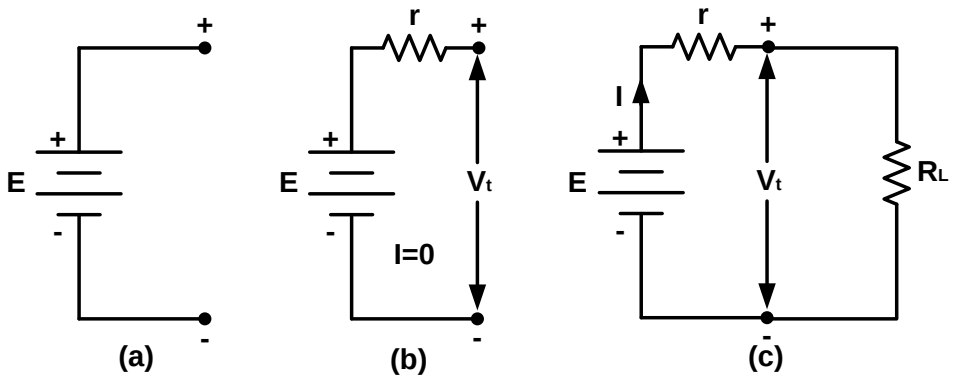

Figure 5.11 Battery

When load (R_L) is connected to battery,

$E = V_t + I\,r$

Where, E = Emf of battery

V_t = Terminal voltage of battery

I = Current delivered by battery

r = Internal resistance of battery

5.17 Classification of Cells

- The cells are classified into two categories: (1) Primary cells (2) Secondary cells

(1) Primary Cells

- The chemical action taking place in the primary cells is irreversible (permanent). Hence once the terminal voltage goes down, we have to replace the primary cell by a new one. The energy producing capacity of primary cells is limited. Examples: Dry cell, alkaline cell, mercury cell, zinc-chloride cell etc.

(2) Secondary Cells

- The secondary cells are also called as storage cells or rechargeable cells. The chemical action taking place in secondary cell.
- The secondary cells are reversible (No permanent). So, it is possible to recharge the cell if it is in the discharged state. The electrical energy is stored in the form of chemical form, when the charging current is passed.
- Secondary cells are capable of producing large amount of energy. Examples: Lead-acid cell, Nickel iron alkaline cell, Nickel cadmium-alkaline cell etc.

5.18 What is Requirements of Batteries?

Requirements:

- It should be capable of supplying large current at constant output power.
- Its output voltage should remain constant for all the load currents.
- Storage time should be as long as possible.
- The battery should be compact and occupy less space.
- It should be rechargeable and maintenance free.
- It should be cost effective.

5.19 Explain A-h Capacity and W-h Capacity

(a) **A-h Capacity**

- An ampere hour (abbreviated Ah, or sometimes amp hour) is the amount of energy charge in a battery that will allow one ampere of current to flow for one hour. An ampere is a unit of measure of the rate of electron flow or current in an electrical conductor.

$A\text{-}h\,capacity = I_d T_d$

Where,

I_d = Rated current during discharging

T_d = discharging time in hour

(b) **W-h Capacity**

- The watt-hour (symbolized Wh) is a unit of energy equivalent to one watt (1 W) of power expended for one hour (1 h) of time. The watt-hour is not a standard unit in any formal system, but it is commonly used in electrical applications.

$W\text{-}h\,capacity = I_d T_d V_d$

Where,

I_d = Rated current during discharging

T_d = Discharging time in hour

V_d = The average voltage during discharging

5.20 Give the classification of Battery

(i) Non-rechargeable batteries

- Zinc-chloride batteries
- Zinc-Carbon
- Mercuric Oxide Batteries
- Zinc Silver Oxide Batteries

(ii) Rechargeable batteries

- Lead-acid batteries
- Li-ion batteries
- Nickel-cadmium batteries
- Nickel hybrid batteries

5.21 Explain Lead acid battery with charging & discharging equations

Working of Lead Acid Battery

- The storage battery or secondary battery is such battery where electrical energy can be stored as chemical energy and this chemical energy is then converted to electrical energy as when required. The conversion of electrical energy into chemical energy by applying external electrical source is known as charging of battery.
- Whereas conversion of chemical energy into electrical energy for supplying the external load is known as discharging of secondary battery. During charging of battery, current is passed through it which causes some chemical changes inside the battery. This chemical changes absorb energy during their formation.

- When the battery is connected to the external load, the chemical changes take place in reverse direction, during which the absorbed energy is released as electrical energy and supplied to the load.
- Now try to understand working principle of lead acid battery and for that we will first discuss about lead acid battery which is very commonly used as storage battery or secondary battery.

Materials used for Lead Acid Storage Battery Cells

- The main active materials required to construct a lead acid battery are
  - Lead peroxide (PbO_2).
  - Sponge lead (Pb) and
  - Dilute sulfuric acid (H_2SO_4).

(i) Lead Peroxide (PbO_2)

- The positive plate is made of lead peroxide. This is dark brown, hard and brittle substance.

(ii) Sponge Lead (Pb)

- The negative plate is made of pure lead in soft sponge condition.

(iii) Dilute Sulfuric Acid (H_2SO_4)

- Dilute sulfuric acid used for lead acid battery has ration of water: acid = 3:1.

Discharging process

- The lead acid storage battery is formed by dipping lead peroxide plate and sponge lead plate in dilute sulfuric acid. A load is connected externally between these plates. In diluted sulfuric acid the molecules of the acid split into positive hydrogen ions (H+) and negative sulfate ions (SO_4−−).
- The hydrogen ions when reach at PbO_2 plate, they receive electrons from it and become hydrogen atom which again attack $PbO_2$and form PbO and H_2O (water). This PbO reacts with $H_2SO_4$and forms $PbSO_4$ and H_2O (water).

$$PbO_2 + 2H \rightarrow PbO + H_2O$$
$$PbO_2 + H_2SO_4 + 2H \rightarrow PbSO_4 + 2H_2O$$

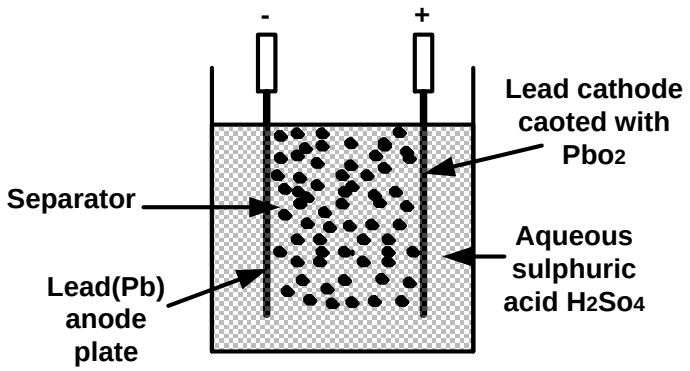

Figure 5.12 Lead acid battery

- SO_4 −− ions are moving freely in the solution so some of them will reach to pure Pb plate where they give their extra electrons and become radical SO_4.
- As the radical SO_4 cannot exist alone it will attack Pb and will form $PbSO_4$. As H+ ions take electrons from PbO_2 plate and SO_4 −− ions give electrons to Pb plate, there would be an inequality of electrons between these two plates.
- Hence there would be a flow of current through the external load between these plates for balancing this inequality of electrons. This process is called discharging of lead acid battery. The lead sulfate ($PbSO_4$) is whitish in color.

Charging process

- Both of the plates are covered with $PbSO_4$.Specific gravity of sulfuric acid solution falls due to formation of water during reaction at PbO_2 plate.
- As a result, the rate of reaction falls which implies the potential difference between the plates decreases during discharging process.
- Now we will disconnect the load and connect $PbSO_4$ covered PbO_2 plate with positive terminal of an external DC source and PbO_2 covered Pb plate with negative terminal of that DC source.
- During discharging, the density of sulfuric acid falls but there still sulfuric acid exists in the solution. This sulfuric acid also remains as H+ and SO_4 −− ions in the solution. Hydrogen ions being positively charged, move to the electrode (cathode) connected with negative terminal of the DC source.
- Here each H+ ion takes one electron from that and becomes hydrogen atom. These hydrogen atoms then attack $PbSO_4$ and form lead and sulfuric acid.

$$PbSO_4 + 2H \rightarrow H_2SO_4 + Pb$$

- SO_4 −− ions move towards the electrode (anode) connected with positive terminal of DC source where they will give up their extra electrons and become radical SO_4. This radical SO_4 cannot exist alone
- Hence reacts with $PbSO_4$ of anode and forms lead peroxide (PbO_2) and sulfuric acid (H_2SO_4)

$$PbSO_4 + 2H_2O + SO_4 \rightarrow PbO_2 + 2H_2SO_4$$

- Hence by charging the lead acid storage battery cell,
  - Lead sulfate anode gets converted into lead peroxide.
  - Lead sulfate of cathode is converted to pure lead.
  - Terminal potential of the cell increases.
  - Specific gravity of sulfuric acid increases.

5.22 Nickel cadmium battery with charging & discharging equations

Construction of Ni-Cd Battery:

- The construction of a nickel - cadmium cell is shown in Figure. The positive plate is made of nickel hydroxide Ni(OH)4 and the negative plate is of spongy cadmium (Cd).

- A 21% solution of potassium hydroxide (KOH) in distilled water is used as the electrolyte. The specific gravity is approximately 1.2.
- The construction of Ni-Cd battery is very similar to that of the nickel-iron battery.
- The positive plates are of nickel hydroxide. The negative plates are made of a mixture of cadmium and iron. KOH (potassium hydroxide) is used as electrolyte in this battery.
- The internal resistance of Ni-Cd batteries is low due to the use of cadmium. Electrical characteristics are almost same as those of the nickel-iron batteries.

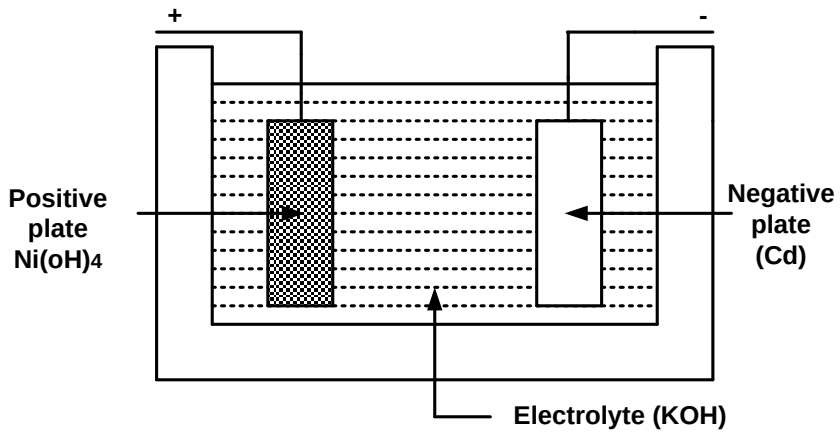

Figure 5.13 Nickel cadmium battery diagram

Action during discharging

At anode

$$Ni(OH)_4 + 2K \rightarrow Ni(OH)_2 + 2KOH$$

At cathode

$$Cd + 2OH \rightarrow Cd(OH)_2$$

Discharging action can be collectively given as,

$$\underbrace{2Ni(OH)_4}_{\text{Positive plate}} + 2KOH + \underbrace{Cd}_{\text{Negative plate}} \rightarrow \underbrace{2Ni(OH)_2}_{\text{Positive plate}} + 2KOH + \underbrace{Cd(OH)_2}_{\text{Negative plate}}$$

- The electrolyte i.e. KOH splits into the positive K ions and negative OH ions. During discharging, ions from negative plate force free electrons to positive plates.
- When the cell is discharged the positive element becomes nickelous hydroxide while negative element becomes cadmium hydroxide.

Action during charging

- During charging of the cell, positive element becomes nickelic hydroxide and negative element becomes metallic cadmium.
- When cell is fully charged it generates oxygen gas at positive element and hydrogen gas at negative element.

The charging equation is collectively given as,

$$\underbrace{2Ni(OH)_2}_{\text{Positive plate}} + 2KOH + \underbrace{Cd(OH)_2}_{\text{Negative plate}} \rightarrow \underbrace{2Ni(OH)_4}_{\text{Positive plate}} + 2KOH + \underbrace{Cd}_{\text{Negative plate}}$$

Applications of Ni-Cd Batteries:

- Following are some of the important applications of Ni-Cd batteries:
  - In helicopters, aeroplanes as auxiliary turbines.
  - For the traction applications.
  - For lighting, air conditioning etc. in trains.
  - In the automobiles.
  - In the movie cameras, electric shavers, photoflash etc.

5.23 Charging and its methods of Battery

- To charge a lead-acid battery, the following important points should be kept in mind.
  - A dc source should be used for charging. If ac source is available it should be first rectified.
  - The dc source should be connected with proper polarities to the battery to be charged.
  - The dc source voltage should be higher than the maximum terminal voltage of the battery. Typically, the charging voltage should be 2.5 V per cell.
  - The value of charging current I should be set properly.
- The charging current should not be too high in order to avoid 'excessive gassing' and heat during the charging process.
- The charging current can be set by taking one of the following two rules:
  - The charging current should be equal to number of positive plates in a single cell.
  - The charging current should be such that the full charging be achieved in 8-hours.

Charging of battery with AC Supply

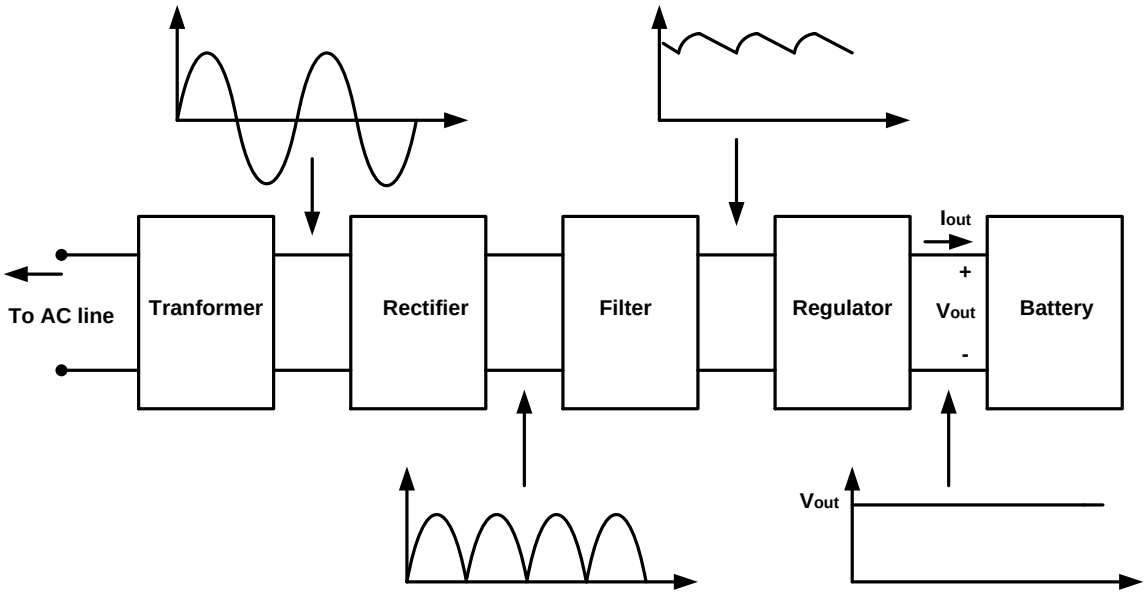

Figure 5.14 Charging of battery from AC supply

- If the source of energy is alternating then the dc voltage required for the charging of a battery is derived from the ac source by using a rectifier.
- The step down transformer reduces the high ac supply voltage to a low ac voltage. The rectifier converts this ac voltage into a dc voltage.
- Filter is use to get pure dc voltage and the output voltage of filter is given to regulator. Regulator is device which gives regulated voltage at input of battery.

Charging Methods:

(1) Constant current charging method

- The completely discharged battery is first charged at a constant charging rate. This will cause the terminal voltage of the battery to increase considerably.
- The charging current is kept constant by varying the supply voltage for overcoming the increased cell voltage. The value of charging current is adjusted carefully to avoid excessive "gasing".

(2) Constant voltage charging method

- When cell voltage reaches sufficiently high value, the constant current charging is stopped and constant voltage charging is adopted. The charging current then decreases.
- This mode of charging is known as the float or trickle charging. Typically, the voltage at which changeover from constant current to constant voltage takes place at 2.15 volts.

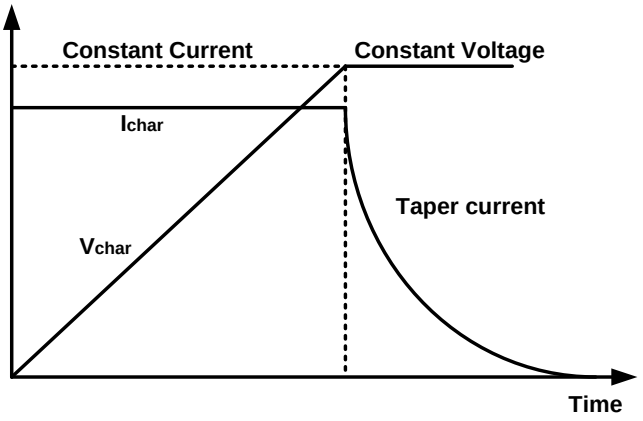

Figure 5.15 Charging modes of battery

(3) Trickle charging

- The Trickle charging is necessary to keep the battery fully charged always. It is used to compensating the charge lost due to internal discharge of the battery. The Trickle charging current is very low.
- When battery is kept as an emergency service, it is necessary to ensure that it is fully charged all the time and ready for the service any time.
- The charged battery always loses some of its charge due to internal leakage and other open circuit losses. To compensate for such loss of charge the battery is kept on trickle charging.

(4) Boost charging

- When the battery is being charged for the first time, or when it is being used after a long time, the boost charging mode is used, where the cell voltage is raised above 2.4 V up to 2.6 V.
- The boost charging is used for breaking down the crystalline PbSO4 which is formed when the battery is not in use for a long time.

5.24 Elementary Calculation of Energy Consumption

Energy consumption (E):

- The electric energy is defined as the product of power and time.

$$Energy = Power(P) x Time(t)$$

The alternate expression for energy is,

$$E = V \; x \; I \; x \; t \; Joules$$

- The S.I. units of energy are Watt-second or Joules. Practically the electrical energy is expressed in watt hour or kWh.
- The electricity meters installed by the electricity board are basically the energy meters which. Measure the electricity consumption in kWh.

Electricity bill for energy consumption:

- The monthly electricity bill is charged on the basis of monthly energy consumption in terms of number of units. (e.g. ~ 7.5 per unit for a domestic customer).

$$1 \; Unit = kWh = 1000 \; Wh$$

- The per unit rates of electricity consumption are different for different types of customers such as domestic, farmers, industrial units etc.

5.25 What is power factor? Explain the methods for power factor improvement.

Power Factor

- It is the measurement of how incoming power is being effectively used in electrical power system.

Methods for power factor improvement

- By the following methods we can improve the power factor:
  1. Static Capacitor(Capacitor Bank)
  2. Synchronous Condenser
  3. Phase Advancer

1. Static Capacitor (Capacitor Bank)

- We know that most of the industries and power system loads are inductive that take lagging current which decrease the system power factor.
- For Power factor improvement purpose, Static capacitors are connected in parallel with those devices which work on low power factor.
- These static capacitors provides leading current which neutralize (totally or approximately) the lagging inductive component of load current (i.e. leading component

neutralize or eliminate the lagging component of load current) thus power factor of the load circuit is improved.

- These capacitors are installed in Vicinity of large inductive load e.g Induction motors and transformers etc, and improve the load circuit power factor to improve the system or devises efficiency.

Advantages:

- Capacitor bank offers several advantages over other methods of power factor improvement.
- Losses are low in static capacitors
- There is no moving part, therefore need low maintenance
- It can work in normal conditions (i.e. ordinary atmospheric conditions)
- Do not require a foundation for installation
- They are lightweight so it is can be easy to installed

Disadvantages:

- The age of static capacitor bank is less (8 – 10 years)
- With changing load, we have to ON or OFF the capacitor bank, which causes switching surges on the system.
- If the rated voltage increases, then it causes damage it.
- Once the capacitors spoiled, then repairing is costly

2. Synchronous Condenser

- When a Synchronous motor operates at No-Load and over-exited then it's called a synchronous Condenser.
- Whenever a Synchronous motor is over-exited then it provides leading current and works like a capacitor.
- When a synchronous condenser is connected across supply voltage (in parallel) then it draws leading current and partially eliminates the re-active component and this way, power factor is improved. Generally, synchronous condenser is used to improve the power factor in large industries.

Advantages:

- Long life (almost 25 years)
- High Reliability
- Step-less adjustment of power factor.
- No generation of harmonics of maintenance
- The faults can be removed easily
- It's not affected by harmonics.
- Require Low maintenance (only periodic bearing greasing is necessary)

Disadvantages:

- It is expensive (maintenance cost is also high) and therefore mostly used by large power users.
- An auxiliary device has to be used for this operation because synchronous motor has no self-starting torque

- It produces noise

3. Phase Advancer

- Phase advancer is a simple AC exciter which is connected on the main shaft of the motor and operates with the motor's rotor circuit for power factor improvement.
- Phase advancer is used to improve the power factor of induction motor in industries.
- As the stator windings of induction motor takes lagging current 90° out of phase with Voltage, therefore the power factor of induction motor is low.
- If the exciting ampere-turns are excited by external AC source, then there would be no effect of exciting current on stator windings.
- Therefore the power factor of induction motor will be improved. This process is done by Phase advancer.

Advantages:

- Lagging kVAR (Reactive component of Power or reactive power) drawn by the motor is sufficiently reduced because the exciting ampere turns are supplied at slip frequency (fs).
- The phase advancer can be easily used where the use of synchronous motors is Unacceptable.

Disadvantage:

- Using Phase advancer is not economical for motors below 200 H.P. (about 150kW)

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