8 Electrical Installation

Learning Outcomes

After reading this chapter, the reader will able to

- Classify the cables along with their specifications
- List the factor effecting the choice of wiring
- Illustrate different types of electric wiring schemes
- Illustrate first-aid for electric shock
- Explain the necessity of earthing/grounding
- Illustrate various methods of earthing
- Illustrate the components of low voltage switchgear
- Differentiate fuse and circuit breaker
- Outline the batteries along with its types
- Compare primary and secondary cells
- Outline the energy consumption calculations

8.1 Wire and Cable

The use of conductors and their insulation is regulated by Indian Electricity (IE) regulation and Indian Standard (IS) code of practice. Wires and cables are the most common forms of conductors. They carry electric current through all types of circuits and systems. A conductor is a wire or cable or any other form of metal, suitable for carrying current from generating station to the point where it is used.

8.1.1 Difference Between Wire and Cable

According to Bureau of Indian Standards (BIS), wire and cable can be defined as follows:

Bare Conductors: They have no covering. The best example is overhead transmission and distribution lines.

Wire: If a bare conductor is provided with insulation, then it is known as a wire. The insulation separates the conductor electrically from other conductors.

Cable: It consists of two or more conductors covered with suitable insulation and surrounded by a protecting cover. The necessary requirements of a cable are that it should conduct electricity efficiently, cheaply, and safely. This should neither be so small that it has a large internal voltage drop nor be too large so that it costs too much. Its insulation should be such that it prevents leakage of current in unwanted direction to minimize risk of fire and shock.

The cable essentially consists of three parts:

(i) *conductor or core*- the metal wire, or strand of wires, carrying the current
(ii) *insulation or dielectric*- a covering of insulating material to avoid leakage of current from the conductor and
(iii) *protective covering* for protection of insulation from mechanical damage

Basically, there is no difference between a cable and a wire. It is a relative term. The term cable is used for all heavy section insulated conductors, whereas a wire means a thin (i.e., smaller) section insulated conductor used for carrying current from one point to another point.

8.1.2 Classifications of Wires/Cables

The wires/cables used for domestic or industrial wiring are classified into different groups as follows:

(i) According to the conductor material used
   (a) Copper conductor cables
   (b) Aluminium conductor cables

(ii) According to number of cores
   (a) Single core cables (SCC)
   (b) Double core or twin core cables (DCC)
   (c) Three core cables
   (d) Four core cables
   (e) Two core with earth continuity conductor cables

(iii) According to type of insulation
   (a) Vulcanized Indian rubber (VIR) insulated wires/cables
   (b) Tough rubber sheathed (TRS) or cable tyre sheathed (CTS) cables
   (c) Polyvinyl chloride (PVC) cables
   (d) Lead sheathed cables
   (e) Weather proof cables
   (f) Flexible cords and cables
   (g) XLPE cables

(iii) According to the voltage at which they are manufactured
   (a) Low tension (LT) cables — up to 1000V
   (b) High tension (HT) cables — up to 11kV
   (c) Super tension (ST) cables — from 22–33kV
   (d) Extra high tension (EHT) cables — from 33–66kV
   (e) Extra super voltage cables — beyond 132kV

8.1.3 Specifications of Cables

Cables are specified by providing

(i) Size of the cable in metric system (e.g., 19/2.24, 7/1.70, 7/2.24, 7/2.50 etc.) giving the number of strands used and diameter of each strand, or giving the area of cross-section of conductor used.
(ii) Type of conductor used in cables (copper or aluminium).
(iii) Number of cores that cable consists of e.g. single core, twin core, three core, four core etc.
(iv) Voltage grade (240/415V or 650/1100V grade).
(v) Type of cable with clear description regarding insulation, shielding, armouring, bedding etc.

A few specifications of a cable are given below:

(i) $\frac{7}{20}$, VIR, aluminium conductor, twin core, 650/1100 grade.

In this case, the numerator 7 indicates the number of strands in a cable and denominator 20 represents the gauge number of each strand. The cable has two cores made with aluminium, with VIR insulation and is used for 650/1100 voltage

(ii) $\frac{19}{1.12}$, aluminium conductor, $3\frac{1}{2}$ core, 1100V, PVC cable, PVC sheathed.

In this case, the cable consists of 19 strands, each strand has a diameter of 1.12mm. The conductor is made with aluminium, insulation is made with PVC, is covered with PVC sheathing, and is used for 1100V supply system.

8.2 Electrical Wiring

State electricity board provides electric supply up to a point outside the consumer premises. From this point the consumer takes the connection to his main board. Insulated electrical wires will be taken out to various places in the premises to supply power to different types of loads. A network of wires/cables connecting various electrical accessories for distribution of electrical energy from the supplier meter board to the numerous electrical energy consuming devices such as lamps, fans, televisions, refrigerators, and other domestic appliances through controlling and safety devices is known as a wiring system.

The supply used in houses for lighting and power purposes is single phase AC supply, where as for industries 3-phase AC supply is employed. The single phase circuit is connected to 220V, across one phase and neutral.

8.2.1 Factors Affecting the Choice of Wiring

(i) Durability: Type of wiring selected should confirm to standard specifications, so that it is durable, i.e., without being affected by the weather conditions, fumes etc.

(ii) Safety: The wiring must provide safety against leakage, shock, and fire hazards for the operating personnel.

(iii) Appearance: Electrical wiring should give an artistic appeal to the interiors.

(iv) Cost: Electrical wiring should not be expensive and the maintenance cost should be minimum.

(v) Accessibility: The switches and plug points provided should be easily accessible. There must be provision for further extension of the wiring system, if necessary.

(vi) Mechanical Safety: The wiring must be protected against any mechanical damage.

8.2.2. Types of Electrical Wiring

Electrical wiring system can be classified into the following five categories:

(i) Cleat wiring
(ii) CTS wiring or TRS wiring or Batten wiring
(iii) Metal sheathed wiring or lead sheathed wiring
(iv) Casing and capping
(v) Conduit wiring

(i) Cleat Wiring

Material Used: The various materials used in cleat wiring are VIR or PVC insulated wires, weather proof cables, porcelain or plastic cleats (two or three grooves), and screws.

Procedure: In this type of wiring, insulated conductors (usually VIR, Vulcanized Indian Rubber) are supported on porcelain or wooden cleats as shown in figure (8.1). The cleats have two halves- one base and the other cap. The cables are placed in the grooves provided in the base and then the cap is placed. Both are fixed securely on the walls by 40mm long screws. The cleats are easy to erect and are fixed 4.5–15cms apart. This wiring is suitable for temporary installations where cost is the main criteria but not the appearance.

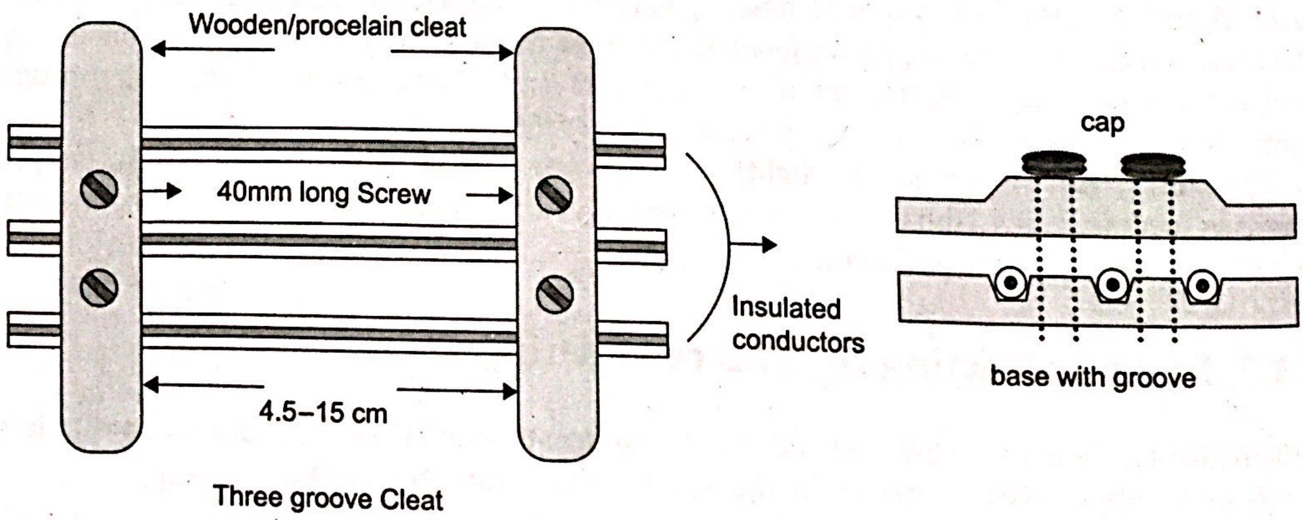


Figure (8.1): *Cleat wiring*

Advantages:
The advantages of this type of wiring are

- Cheap and easy wiring
- Easy to fault detection
- Easy to repair
- Alteration and addition is easy.
- Skilled manpower not required

Disadvantages:
The disadvantages of this type of wiring are

- Appearance is not good.
- Higher risk of mechanical injury i.e., chances of shock or fire
- Open system of wiring requiring regular cleaning

Applications:
This type of wiring is used for purely temporary purposes like army camps, etc.

(ii) Cable Tyre Sheathed or Tough Rubber Sheathed or Batten wiring
Material Used: The various materials used in batten wiring are CTS or TRS cable, straight teak wooden batten (at 10 mm thick), tinned brass link clip (buckle clip), and brass pins

Procedure: In this type of wiring system, wires sheathed in tough rubber are used which are quite flexible. They are clipped on wooden battens with brass clips (link or joint) and fixed on to the walls or ceilings by flat head screws, as shown in figure (8.2). These cables are moisture and chemical proof. They are suitable for damp climate but not suitable for outdoor use in sunlight. TRS wiring is suitable for lighting in low voltage installations. Buckle clips are fixed with brass pin on the wooden batten at an interval 10 cm for horizontal runs and 15 cm for vertical runs.

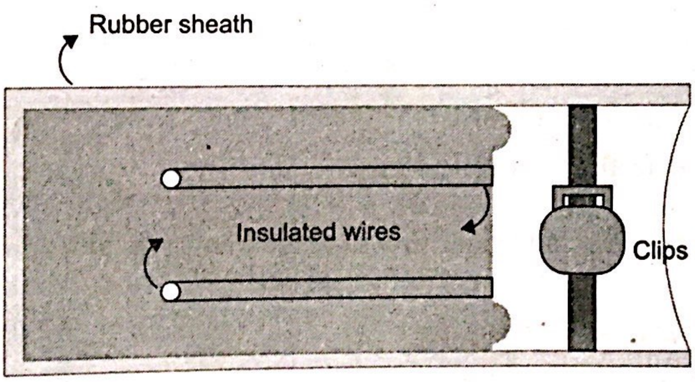


Figure (8.2): *Batten wiring*

Advantages:
The advantages of this type of wiring are

- Easy installation and durability
- Cheap in material cost
- Gives a good appearance if properly erected.
- Customization is easy
- Low risk of short circuit

Disadvantages:

The disadvantages of this type of wiring are

- Not suitable for outdoor wiring
- Humidity, smoke, steam, etc. directly affect wires.
- Heavy wires are not recommended for this wiring scheme.
- Only suitable for below 250 V
- High risk of fire
- Skilled workmen are required.

Applications:

This wiring is suitable for low voltage installations used for lighting purpose in all places, such as domestic, industrial, commercial, etc.

(iii) Metal Sheathed or Lead Sheathed Wiring

Material Used: The various materials used in this type of wiring are CTS or TRS cable, straight teak wooden batten, tinned brass link clip (buckle clip), and brass pins.

Procedure: The wiring is similar to that of CTS but the conductors (two or three) are individually insulated and covered with a common outer lead-aluminum alloy sheath. The sheath protects the cable against dampness, atmospheric extremities and mechanical damages. The sheath is earthed at every junction to provide a path to ground for the leakage current. They are fixed by means of metal clips on wooden battens. The wiring system is very expensive. It is suitable for low voltage installations.

Precautions to be Taken During Installation:

- The clips used to fix the cables on battens should not react with the sheath.
- Lead sheath should be properly earthed to prevent shocks due to leakage currents.
- Cables should not be run in damp places and in areas where chemicals (may react with the lead) are used.

Advantages:

The advantages of this type of wiring are

- Easy installation and aesthetic in appearance
- Highly durable
- Suitable in adverse climatic conditions provided the joints are not exposed

Disadvantages:

The disadvantages of this type of wiring are

- Requires skilled labour
- Very expensive
- Unsuitable for chemical industries

Applications:

This wiring is suitable for low voltage installations used for lighting purpose in all places such as domestic, industrial, commercial, etc.

(iv) Casing and Capping Wiring

Material Used: The various materials used in casing wiring are VIR or PVC insulated wires, casing enclosure (made of wood or plastic), capping (made of wood or plastic) and casing, and capping joints.

Procedure: It consists of insulated conductors laid inside rectangular, teakwood or PVC boxes having grooves inside it. A rectangular strip of wood called capping, having same width as that of the casing, is fixed over it. Both the casing and the capping are screwed together at every 15cms. Casing is attached to the wall. Two or more wires of same polarity are drawn through different grooves.

Advantages:

The advantages of this type of wiring are

- Cheap and easy to install
- Strong and durable wiring
- Customization can be done easily
- Safe from smoke, dust, rain, and steam, etc.
- Due to casing and capping no risk of shock.

Disadvantages:

The disadvantages of this type of wiring are

- Very costly
- Not suitable for weather with high humidity and acidic conditions.
- Insects, like termites or ants, can damage wooden casing and capping.
- High risk of fire.

Applications:

This type of wiring is suitable for indoor and low voltage domestic installations.

(v) Conduit Wiring

Material Used:

Metallic Conduit: The various materials used in metallic conduit wiring are thin layer steel sheet low gauge conduit in Class A and thick sheet of steel high gauge conduit in Class B.

Non-metallic Conduit: The various materials used in non-metallic conduit wiring are 13, 16.2, 18.75, 20, 25, 37, 50 and 63 mm (diameter) PVC conduit, VIR or PVC insulated cables, GI wire of 18SWG , Screw, Coupling, Elbow, Rigid off set, 2-hole strap, and lock nut.

Procedure: In general, conduit means tube or channel. Tubular conduits are most commonly used in electrical installations. When wire/cables are drawn through the conduit and terminated at the outlets (switches, holders, ceiling rose etc.), such a system of wiring is known as conduit wiring.

Conduit wiring consists of PVC wires taken through either steel or PVC conduit pipes as shown in figure (8.3). On the surface of the wall or ceiling, conduit pipes (with GI wire inside) are attached with the help of 2-hole strap and base clip at a regular distance. When conduits are run over the surface of the wall, the wiring is called surface conduit wiring. When conduits are run inside wall, the wiring is called concealed conduit wiring. Conduit wiring is water proof and replacement of defective wire is very easy.

Advantages:

The main advantages of this type of wiring are

- No risk of fire and good protection against mechanical injury
- Appearance is better
- No risk of damage of cable insulation
- Safe from humidity, smoke, steam, etc.
- No risk of shock

- Long lasting

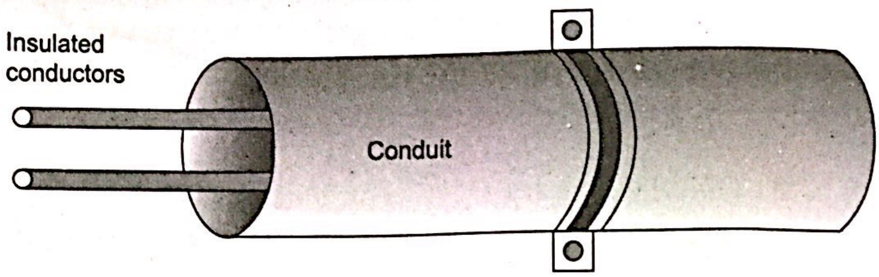


Figure (8.3): *Conduit wiring*

Disadvantages:

The disadvantages of this type of wiring are

- Very expensive
- Installation is not easy
- Not easy to customize for future
- Hard to detect the faults

Applications:

Due to its good protection against mechanical damage, most commonly used in places like textile mills, flour mills, saw mills, workshops, factories, etc.

8.2.3 Comparison between different Wiring Systems

The following table shows the comparison between all the above mentioned wiring systems.

S. No.	Particulars	Cleat Wiring	Casing and Capping Wiring	Batten Wiring	Conduit Wiring
01	Life	Short	Fairly long	Long	Very long
02	Cost	Low	Medium	Medium	Highest
03	Possibility of fire	Nil	Good	Good	Nil
04	Mechanical protection	None	Fair	None	Very good
05	Protection from dampness	None	Little	None	Good
06	Type of labour required	Semi skilled	Highly skilled	Semi skilled	Highly skilled
07	Installation	Very easy	Difficult	Easy	Difficult
08	Inspection	Easy	Easy	Easy	Difficult

Continued

S. No.	Particulars	Cleat Wiring	Casing and Capping Wiring	Batten Wiring	Conduit Wiring
09	Repair	Easy	Little bit difficult	Easy	Difficult
10	Popularity	Nil	Fair	Nil	Very high
11	Applications	For temporary installations e.g., functions, marriages, etc.	For residential, commercial and office buildings	For residential, commercial and office buildings	Workshops, factories, godowns, etc

8.3 Electric Shock

The human body has an electrical conducting property. Without sweating, the resistance of the human body is approximately 80000Ω and during sweating resistance of the human body is approximately 1000 Ω. If we touch the current carrying conductor, the current is conducted through our body to the earth. So the electric circuit is closed and we get electric shock, due to which nervous structure, heart, lungs and brain are affected. If the current is large, death may occur. Therefore, we must know that even though current is essential, if it is used in a wrong manner, it will cause heavy loss. i.e., death and economical loss.

To prevent this electrical shock, we know about the methods of preventive care and protective methods for safety precautions.

8.3.1 Preventive Method to Avoid Electric Shock

The points should be kept in mind to avoid electric chock are

(i) The operation of electrical equipment must be known.
(ii) Damaged wire not to be used for wiring works or electrical connection.
(iii) The electrical instruments used for connections (i.e., switch, plug, pushings, etc.) do not have any scratch or break; otherwise they should be replaced by a new one.
(iv) The hand tools are insulated essentially.
(v) Proper earthing is provided.
(vi) If the supply is taken from the socket, only the plug top is used. To avoid, the supply is taken by inserting the wire with stick in the socket.
(vii) Depending upon the load, rated ampere fuse wire is used.
(viii) The electrical equipment is repaired after the main source is switched off.
(ix) For any reason do not operate, overlooking the safety rules.

8.3.2 First-Aid for Electric Shock

If anyone suffers an electric shock, the electricity source should be cut off immediately. Conduct the first-aid only after the victim is in a safe place. Check the victim's breath and pulse. If the person is unconscious but is breathing normally, he or she should be placed in a recovery position. If the victim is not breathing and has no pulse, cardiopulmonary resuscitation should be conducted.

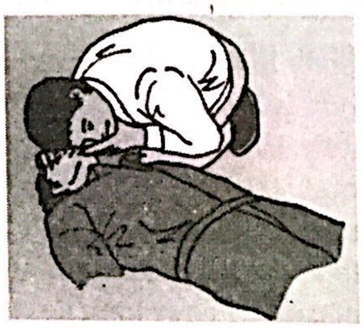
Note: Cardiopulmonary resuscitation should be carried out only by competent first-aid personnel.

Cardiopulmonary Resuscitation:

(i) Open the Airway
Lift the jaw and tilt the head back to open the airway. Clear any obstacles.

(ii) Check the Breaths

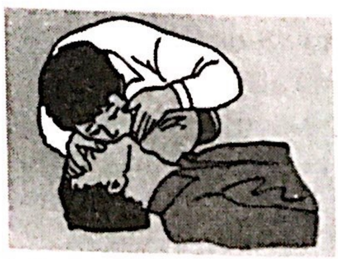
See : See if the chest rises and falls.
Listen : Listen for breathing.
Feel : Feel breathing on your cheek.



(iii) Check the Pulse (Circulation)
Use your fingers to feel the pulse.

(iv) Recovery Position
If the casualty is unconscious but is breathing normally, place them in the recovery position (as shown in figure along side).

(v) Mouth to Mouth Expired Air Resuscitation
If the person is not breathing, mouth-to-mouth resuscitation should be used to help the resumption of breathing.



(vi) External Chest Compression

If the casualty has no pulse, cardiopulmonary resuscitation should be carried out (combining the expired air resuscitation and external chest compression).

8.4 Earthing or 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 the earth (i.e., soil) is called grounding or earthing. The potential of the earth is to be considered zero for all practical purposes. Earthing is to connect any electrical equipment to earth with a very low resistance wire, making it to attain earth's potential. This ensures safe discharge of electric energy due to failure of the insulation line coming in contact with the casing, etc. Earthing brings the potential of the body of the equipment to zero i.e., to the earth's potential, thus protecting the operating personnel against electrical shock.

The earth resistance is affected by the following factors:

(a) Material properties of the earth, wire and the electrode
(b) Temperature and moisture content of the soil
(c) Depth of the pit
(d) Quantity of the charcoal used

8.4.1 Necessity of Earthing

The requirement for provision of earthing can be listed as follows:

- To protect the operating personnel from the danger of shock.
- To maintain the line voltage constant, under unbalanced load condition.
- To avoid risk of fire due to earth leakage current through unwanted path.
- Protection of the equipments.
- Protection of large buildings and all machines fed from overhead lines against lightning.

8.4.2 Methods of Earthing

The various methods of earthing in common use are

(i) Plate earthing
(ii) Pipe earthing
(iii) Rod earthing
(iv) Strip or wire earthing

(i) Plate Earthing

In this method either a copper plate of 60cm × 60cm × 3.18 or GI plate of 60cm × 60cm × 6.35 is used for earthing. The plate is buried into the ground not less than 3m from the ground level. The earth plate is embedded in alternate layers of coal and salt for a thickness of 15 cm as shown in figure (8.4). In addition, water is poured for keeping the earth's electrode resistance value below a maximum of 5Ω. The earth wire is securely bolted to the earth plate. A cement masonry chamber is built with a cast iron cover for easy regular maintenance.

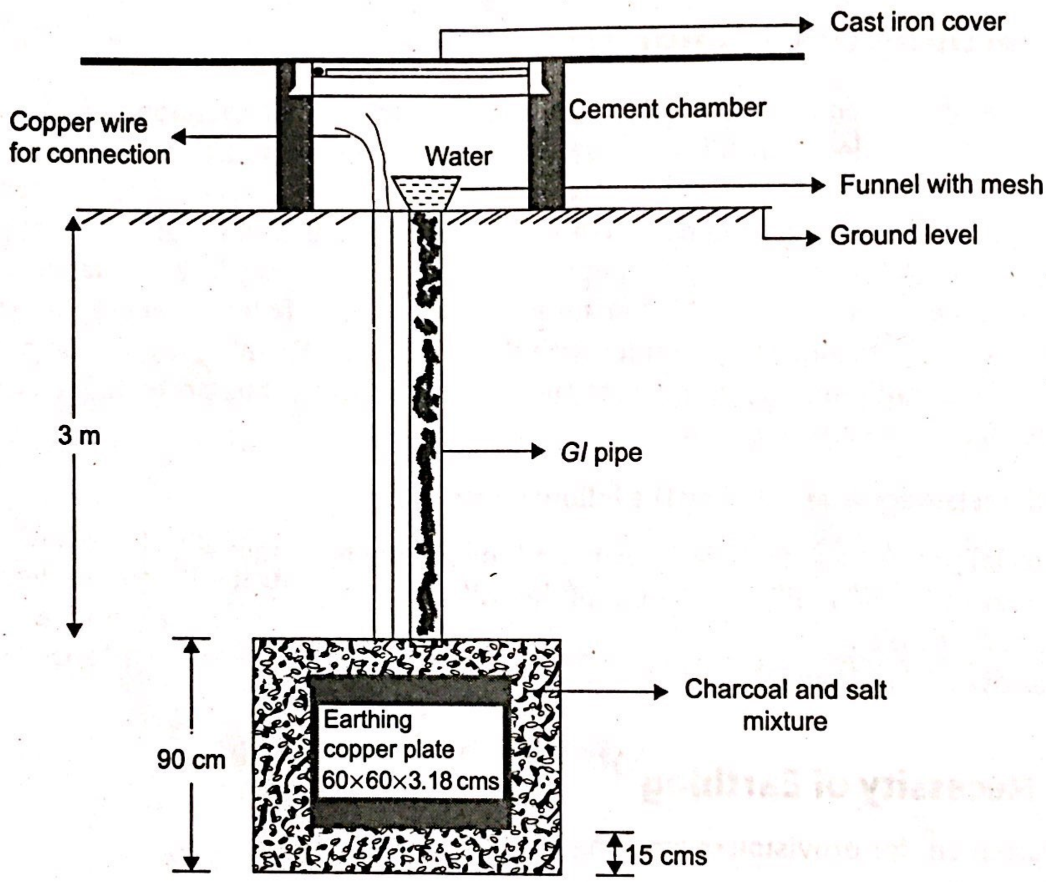


Figure (8.4): *Plate earthing*

(ii) Pipe Earthing

Earth electrode made of a GI (galvanized iron) pipe of 38mm in diameter and length of 2m (depending on the current) with 12mm holes on the surface is placed upright at a depth of 4.75m in a permanently wet ground. To keep the value of the earth resistance at the desired level, the area (15 cm) surrounding the GI pipe is filled with a mixture of salt and coal. The efficiency of the earthing system is improved by pouring water through the funnel periodically. The GI earth wires of sufficient cross-sectional area are run through a 8.7mm diameter pipe (at 60cm below) from the 19mm diameter pipe and secured tightly at the top as shown in figure (8.5).

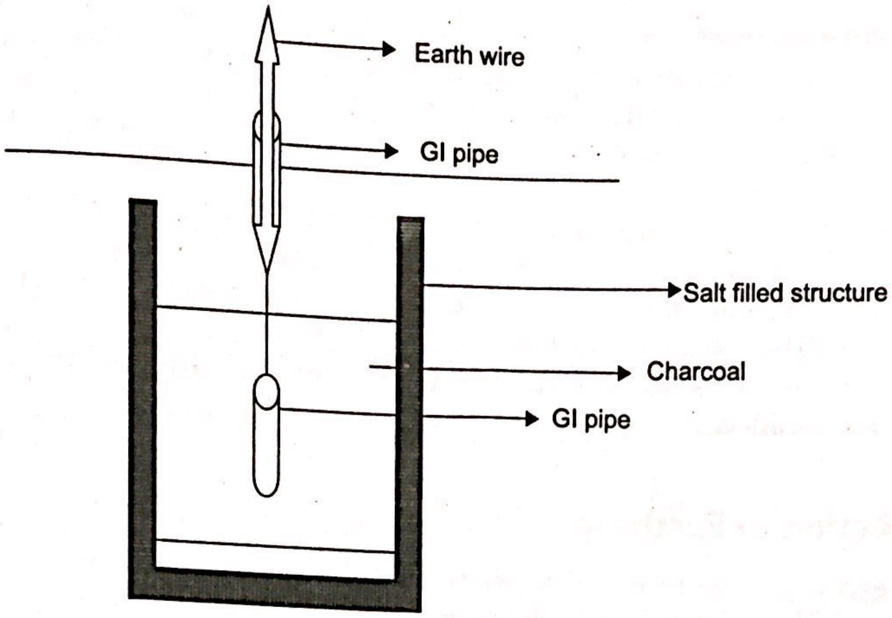


Figure (8.5): *Pipe earthing*

When compared to the plate earth system the pipe earth system can carry larger leakage currents due to larger surface area is in contact with the soil for a given electrode size. This system also enables easy maintenance as the earth wire connection is housed at the ground level.

(iii) Rod Earthing

It is the same method as pipe earthing. A copper rod of 8.5mm (1/2 inch) diameter or 16mm (0.6in) diameter of galvanized steel or hollow section 25mm (1 inch) of GI pipe of length above 2.5m (8.2 ft) are buried upright in the earth manually or with the help of a pneumatic hammer. The length of embedded electrodes in the soil reduces earth resistance to a desired value.

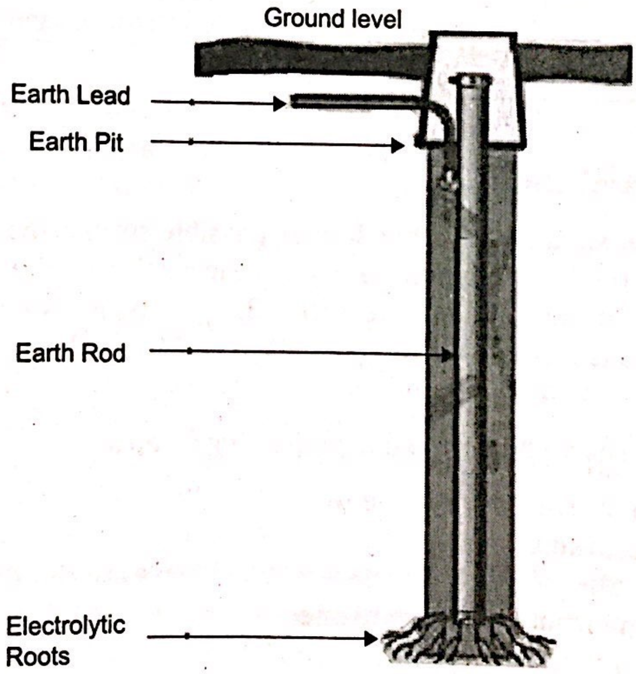


Figure (8.6): *Rod earthing*

(iv) Strip or Wire Earthing

In this method of earthing, strip electrodes of cross-section not less than 25mm × 1.6mm (1in × 0.06in) is buried in a horizontal trenches of a minimum depth of 0.5m. If copper with a cross-section of 25mm × 4mm (1in × 0.15in) is used and a dimension of 3.0mm² if it's a galvanized iron or steel.

If at all round conductors are used, their cross-section area should not be too small, say less than 6.0mm² if it's a galvanized iron or steel. The length of the conductor buried in the ground would give a sufficient earth resistance and this length should not be less than 15m. The electrodes shall be as widely distributed as possible in a single straight or circular trenches radiating from a point. This type of earthing is used where the earth bed has a rocky soil and excavation work is difficult.

8.4.3 Selection of Earthing

The type of earthing to be provided depends on many factors such as type of soil, type of installation, etc.. The following table helps in selecting a type of earthing for a particular application

S. No.	Type of Earthing	Application
01	Plate earthing	Large installations such as transmission towers, all sub-stations, generating stations
02	Pipe earthing	• For domestic installations such as heaters, coolers, refrigerators, geysers, electric iron, etc. • For 11kV/400V distribution transformers • For induction motors rating upto 100HP • For conduit pipe in a wall, all wall brackets
03	Rod earthing	In areas where the soil is loose or sandy
04	Strip or wire earthing	In rocky ares

8.4.4 Earth Resistance

The earth resistance should be kept as low as possible so that the neutral of any electrical system, which is earthed, is maintained almost at the earth potential. The earth resistance for copper wire is 1Ω and that of GI wire less than 3Ω. The typical value of the earth resistance at large power stations is 0.5 Ω, major sub-stations is 1Ω, small sub-stations is 2 Ω and in all other cases 5 Ω.

The resistance of the earth depends on the following factors

- Condition of soil.
- Moisture content of soil.
- Temperature of soil.
- Depth of electrode at which it is embedded.
- Size, material and spacing of earth electrode.
- Quality and quantity of coal and salt in the earth pit.

8.4.5 Difference Between Earth Wire and Neutral Wire

Neutral Wire:

(i) In a 3-phase 4-wire system, the fourth wire is a neutral wire.
(ii) It acts as a return path for 3-phase currents when the load is not balanced.
(iii) In domestic single phase AC circuit, the neutral wire acts as a return path for the line current.

Earth Wire:

(i) Earth wire is actually connected to the general mass of the earth and metallic body of the equipment.
(ii) It is provided to transfer any leakage current from the metallic body to the earth.

8.5 Low Voltage Switchgear

Generally electrical switchgear rated upto 1kV is termed as low voltage switchgear. The term LV Switchgear includes low voltage circuit breakers, switches, off load electrical isolators, HRC fuses, earth leakage circuit breaker, miniature circuit breakers (MCB), and molded case circuit breakers (MCCB), etc. i.e., all the accessories required to protect the LV system.

The protective circuit or device must be fast acting and isolate the faulty part of the circuit immediately. It also helps in isolating only the required part of the circuit without affecting the remaining circuit during maintenance.

Protection for electrical installation must be provided in the event of faults such as (i) Short circuit (ii) Overload and (iii) Earth faults

(i) Short Circuit: In this phenomenon, the current is diverted from its desired path. Its magnitude may be 10–20 times the full load current and power losses are 100–400 times the normal value. During short circuit, the rate of heat dissipation is very low or nil, but the rate of rise of conductor temperature is very high.

(ii) Overload: Any increase in the conductor temperature above the recommended maximum temperature of associated insulation is called an overload. If insulation fails, it will result in short circuit. Overload is a very slow process and is not a fault, but may lead to fault.

(iii) Earth Faults: Leakage currents are of a small magnitude in milli amperes or a few amperes. Due to small magnitudes, earth leakage currents are not detected by overload or short circuit protecting devices. If not detected, it may result into local heating and short circuit. These leakage currents, if flowing through human body even for few seconds, may prove to be fatal for any human being.

8.6 Fuse

The electrical equipments are designed to carry a particular rated value of current under normal conditions. Under abnormal conditions such as short circuit, overload, or any fault; the current rises above this value, damaging the equipment and sometimes resulting in fire hazard. Fuses come into operation under fault conditions.

A fuse is a short piece of metal, inserted in the circuit, which melts when excessive current flows through it and thus breaks the circuit. Under normal operating conditions it is designed to carry the full load current. If the current increases beyond this designed value due to any of the reasons mentioned above, the fuse melts, isolating the power supply from the load.

(a) Desirable Characteristics of a Fuse Element

The material used for fuse wires must have the following characteristics:

- Low melting point e.g., tin, lead.
- High conductivity e.g., silver, copper.
- Free from deterioration due to oxidation e.g., silver.
- Low cost e.g., lead, tin, copper.

(b) Materials

Materials used are tin, lead or silver having low melting points. Use of copper or iron is dangerous, though tinned copper may be used.

(c) Types of Fuses

Fuses are classified into following types

(i) Re-wireable or kit-kat fuse and

(ii) High rupturing capacity (H.R.C.) cartridge fuse

8.6.1 Re-Wreable or Kit-Kat Fuse

Re-wireable fuse is used where low values of fault current are to be interrupted. These fuses are simple in construction, cheap and available up to a current rating of 200A. They are erratic in operation and their performance deteriorates with time. An image of re-wireable fuse is as shown in figure (8.7).

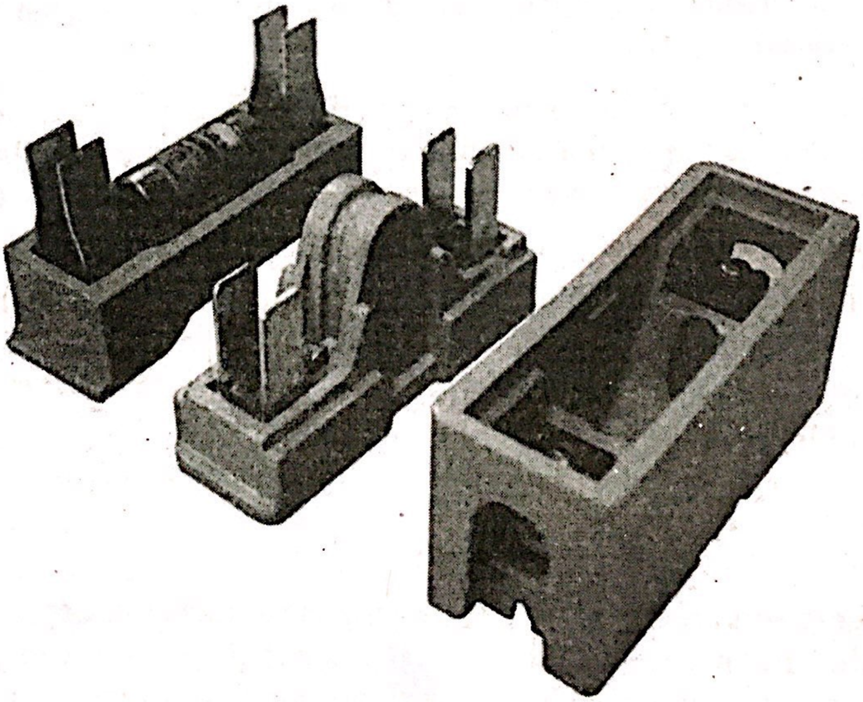


Figure (8.7): *Re-wireable or kit-kat fuse*

8.6.2 High Rupturing Capacity (HRC) Cartridge Fuse

Figure (8.8) shows an image of HRC cartridge fuse and figure (8.9) shows the essential parts of a typical HRC cartridge fuse. It consists of a heat resisting ceramic body having metal end-caps to which a silver current-carrying element is welded. The space within the body surrounding the element is completely packed with a filling powder. The filling material may be chalk, plaster of paris, quartz or marble dust and acts as an arc quenching and cooling medium.

Under normal loading conditions, the fuse element is at a temperature below its melting point. Therefore, it carries the normal current without overheating. When a fault occurs, the current increases and the fuse element melts before the fault current reaches its first peak. The heat produced in the process vaporizes the melted silver element. The chemical reaction between the silver vapour and the filling powder results in the formation of a high resistance substance which helps in quenching the arc.

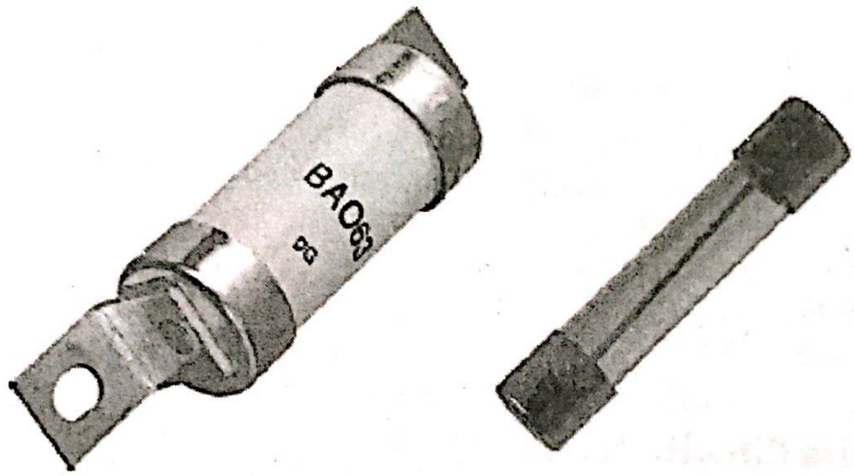


Figure (8.8): *HRC cartridge fuse*

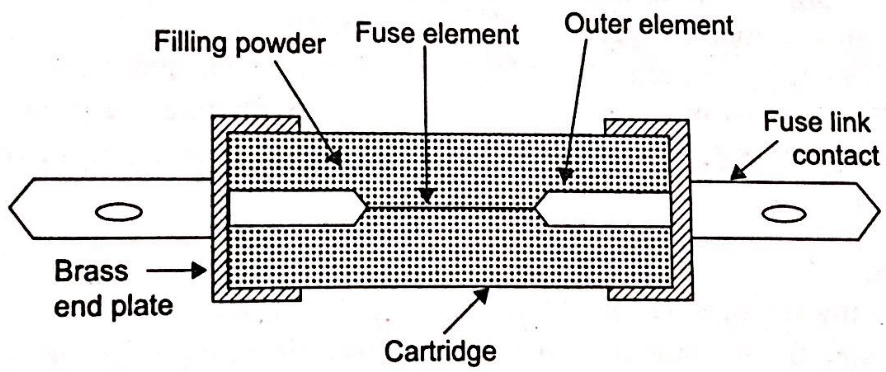


Figure (8.9): *Cross-section of HRC cartridge fuse*

8.7 Circuit Breaker

Electrical circuit breaker is a switching device which can be operated manually and automatically for the controlling and protection of electrical power system, respectively. The modern power system deals with a huge power network and huge numbers of associated electrical equipments. During short circuit fault or any other type of electrical fault, these equipments, as well as the power network, suffer a high stress of fault current, which in turn damage the equipment and networks permanently. For saving these equipment and the power networks, the fault current should be cleared from the system as quickly as possible. Again, after the fault is cleared, the system must come to its normal working condition as soon as possible for supplying reliable quality power to the receiving ends. The circuit breaker is the special device which does all the required switching operations during current carrying condition.

A circuit breaker essentially consists of fixed and moving contacts, called electrodes. Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty. The contacts can be opened manually or by remote control whenever desired. When a fault occurs in any part of the system, the trip coils of the breaker get energised and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

The main types of circuit breakers are

- Miniature circuit breakers (MCB)
- Earth leakage circuit breakers (ELCB) or Residual Current Circuit Breaker (RCCB)
- Air blast Circuit Breaker (ACB)
- Molded Case Circuit Breaker (MCCB)
- Vacuum Circuit Breaker (VCB)
- SF_6 Circuit Breaker

8.7.1 Miniature Circuit Breaker (MCB)

Miniature circuit breakers are electromechanical devices which protect an electrical circuit from over currents. Over currents in an electrical circuit may result from short circuit, overload, or faulty design. An MCB is a better alternative than fuse, since it does not require replacement once an overload is detected. An MCB functions by interrupting the continuity of electrical flow through the circuit once a fault is detected. In simple terms, MCB is a switch which automatically turns off when the current flowing through it passes the maximum allowable limit. Generally MCB is designed to protect against over current and over temperature faults (over heating).

Working Principle:

There are two contacts- one is fixed and the other is moveable. When the current exceeds the predefined limit, a solenoid forces the moveable contact to open (i.e., disconnect from the fixed contact) and the MCB turns off, thereby stopping the current from flowing in the circuit.

Operation:

An image of MCB is as shown in figure (8.10) and internal parts of an MCB are shown in figure (8.11). It mainly consists of one bi-metallic strip, one trip coil and one hand operated on-off lever. Electric current carrying path of a MCB is as follows - first left hand side power terminal - then bimetallic strip - then current coil or trip coil - then moving contact - then fixed contact and - lastly right hand side power terminal, and all are arranged in series.

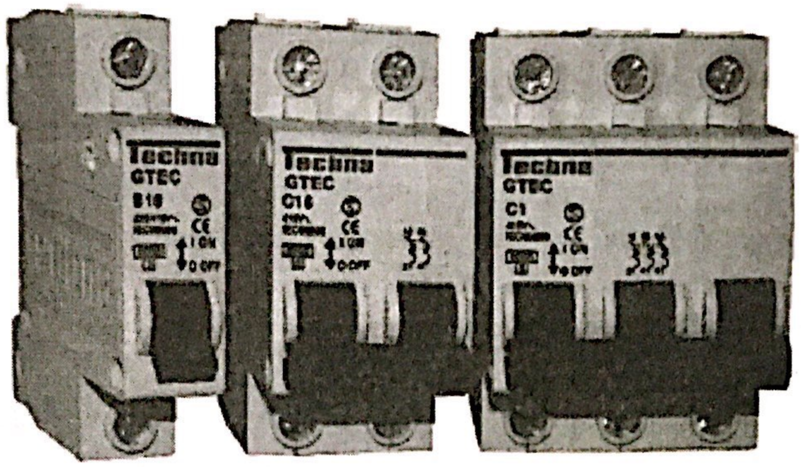


Figure (8.10): *Miniature circuit breaker*

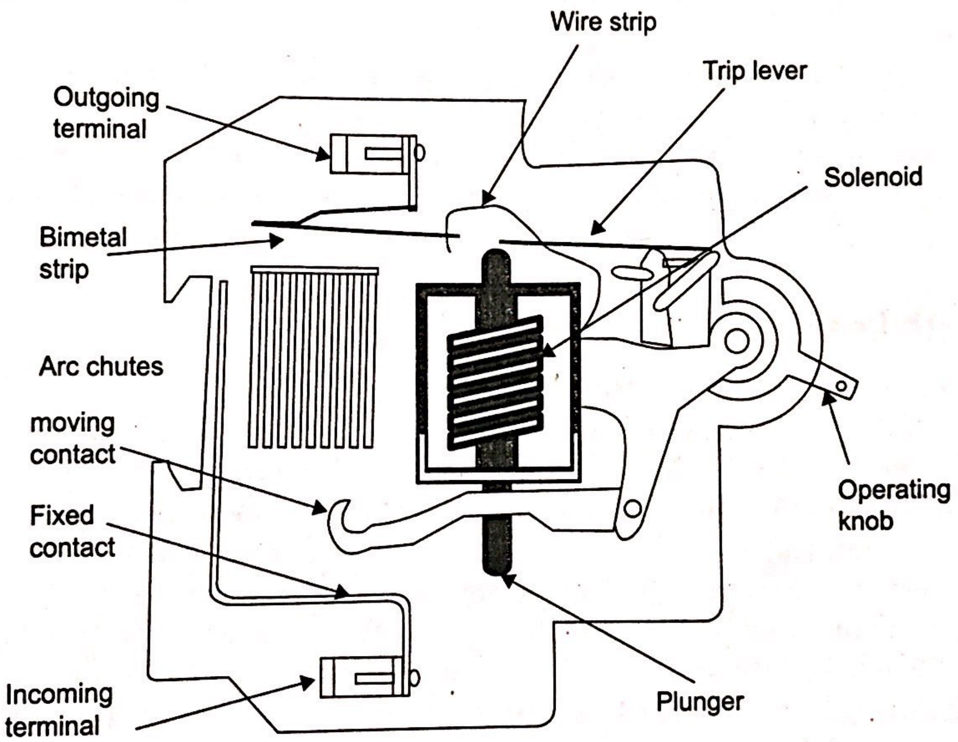


Figure (8.11): *Cross-section of MCB*

If circuit is overloaded for a long time, the bi-metallic strip becomes over heated and deformed. This deformation of bi-metallic strip causes displacement of latch point. The moving contact of the MCB is so arranged by means of spring, with this latch point, that a little displacement of latch causes release of spring and makes the moving contact to move for opening the MCB. The current coil or trip coil is placed in such a manner that during SC fault, the MMF of that coil causes its plunger to hit the same latch point and force the latch to be displaced. Hence, the MCB will open in the same manner. Again when operating lever of the MCB is operated by hand, that means when we make the MCB at off position manually, the same latch point is displaced as a result moving contact separated from fixed contact in same manner. So, whatever may be the operating mechanism, i.e., may be due to deformation of bi-metallic strip or may be due to increased MMF of trip coil or may be due to manual operation- actually the same latch point is displaced and the same deformed spring is released, which is ultimately responsible for movement of the moving contact. When the moving contact is separated from fixed contact, there may be a high chance of arc. This arc then goes up through the arc runner and enters into arc splitters and is finally quenched. When we switch on the MCB, we actually reset the displaced operating latch to its previous on position and make the MCB ready for another switch off or trip operation.

These are available in single pole, double pole, triple pole, and four pole versions with neutral poles, if required. The normal current ratings are available from 0.5–63 A with a symmetrical short circuit rupturing capacity of 3-10kA, at a voltage level of 230/440V. MCBs are generally designed to trip within 2.5 millisecond when an over current fault arises. In case of temperature rise or over heating it may take 2 seconds to 2 min. for the MCB to trip.

Advantages:

- MCBs are replacing the re-wirable switch i.e., fuse units for low power domestic and industrial applications.
- The disadvantages of fuses, like low SC interrupting capacity (say 3kA), etc. are overcome with high SC breaking capacity of 10kA.
- MCB is a combination of all three functions in a wiring system like switching, overload and short circuit protection. Overload protection can be obtained by using bi-metallic strips where as short circuit protection can be obtained by using solenoid.

8.7.2 Earth Leakage Circuit Breaker (ELCB)

None of the protection devices like MCB, MCCB, etc. can protect the human life against electric shocks or avoid fire due to leakage current. The human resistance noticeably drops with an increase in voltage. It also depends upon the duration of impressed voltage and drops with increase in time. As per IS code, a contact potential of 65V is within tolerable limit of human body for 10 seconds, where as 250V can be withstood by human body for 100 milliseconds. The actual effect of current through human body varies from person to person with reference to magnitude and duration. The body resistance at 10V is assessed to be 19 kΩ for 1 second and 8kΩ for 15 min. At 240V, it is 3 to 3.6 kΩ for dry skin and 1–1.2 kΩ for wet skin.

An Earth Leakage Circuit Breaker (ELCB) is a device used to directly detect currents leaking to earth from an installation and cut the power. There are two types of ELCBs:

(i) Voltage Earth Leakage Circuit Breaker (voltage-ELCB)

(ii) Current Earth Leakage Circuit Breaker (Current-ELCB)

(i) Voltage Earth Leakage Circuit Breaker (Voltage-ELCB)

Voltage-ELCB is a voltage operated circuit breaker. The device will function when the current passes through the ELCB. Voltage-ELCB contains relay coil and one end of the coil is connected to metallic load body and the other end is connected to ground wire as shown in figure (8.12). If the voltage of the equipment body rises (by touching phase to metal part or insulation failure of equipment), which could cause the difference between earth and load body voltage and the danger of electric shock will occur. This voltage difference will produce an electric current from the load metallic body and passes through the relay loop to the Earth. When voltage on the equipment metallic body rises to the danger level i.e., which exceed to 50V, the flowing current through relay loop could move the relay contact by disconnecting the supply current to avoid from any danger electric shock. The ELCB detects fault currents from line to the earth (ground) wire within the installation it protects. If sufficient voltage appears across the ELCB's sensing coil, it will switch off the power, and remain off until manually reset. A voltage-sensing ELCB does not sense fault currents from line to any other earthed body.

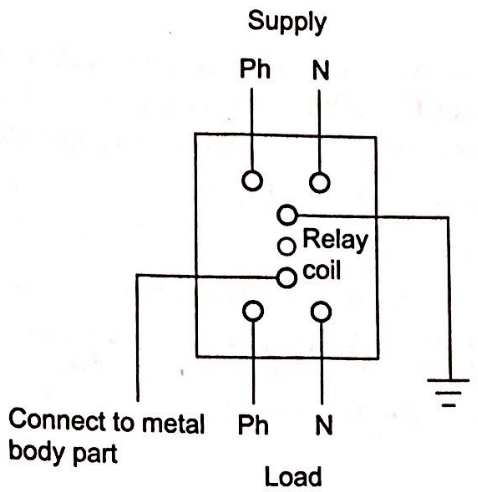


Figure (8.12): *Voltage earth leakage circuit breaker*

(ii) Current Earth Leakage Circuit Breaker (Current-ELCB)
Current-ELCB is a current operated circuit breaker which is a commonly used ELCB. Current-ELCB consists of a 3-winding transformer, which has two primary windings and 1 secondary winding as shown in figure (8.13). Neutral and line wires act as the two primary windings. A wire wound coil is the secondary winding. The current through the secondary winding is zero at the balanced condition. In the balanced condition, the flux due to the current through the phase wire will be neutralized by the current through the neutral wire, since the current which flows from the phase will be returned back to the neutral. When a fault occurs, a small current will flow to the ground also. This makes an unbalance between line and neutral currents and creates an unbalanced magnetic field. This induces a current through the secondary winding, which is connected to the sensing circuit. This will sense the leakage and send a signal to the tripping system and trips the contact.

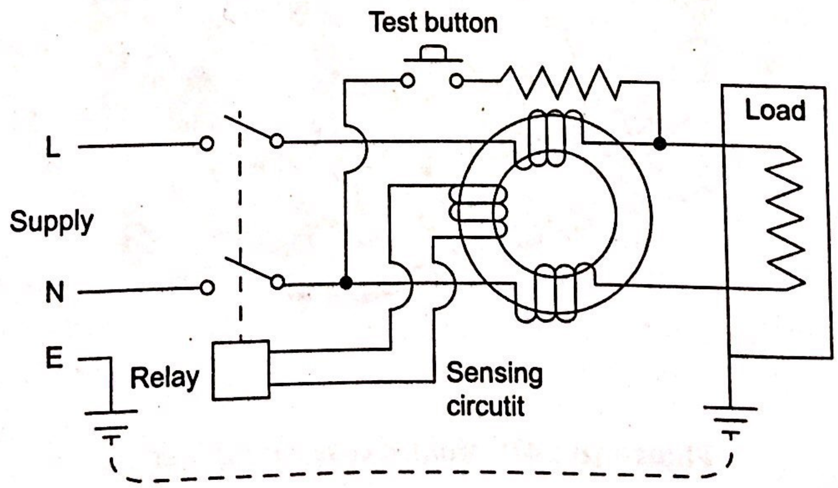


Figure (8.13): *Current earth leakage circuit breaker*

8.7.3. Molded Case Circuit Breaker (MCCB)

Molded case circuit breakers are electromechanical devices which protect a circuit from over current and short circuit. They provide over current and short circuit protection for circuits ranging from 63A up to 3000 A. Their primary functions are to provide a means to manually open a circuit and automatically open a circuit under overload or short circuit conditions respectively. The over current, in an electrical circuit, may result from short circuit, overload or faulty design.

MCCB is an alternative to a fuse, since it does not require replacement once an overload is detected. Unlike a fuse, an MCCB can be easily reset after a fault and offers improved operational safety and convenience without incurring operating cost.

Molded case circuit breakers generally have a

- Thermal element for over current and
- Magnetic element for short circuit release which has to operate faster.

The MCCBs are comprised of five major components such as molded case or frame, operating mechanism, arc extinguishers, contacts and trip components as shown in figure (8.14).

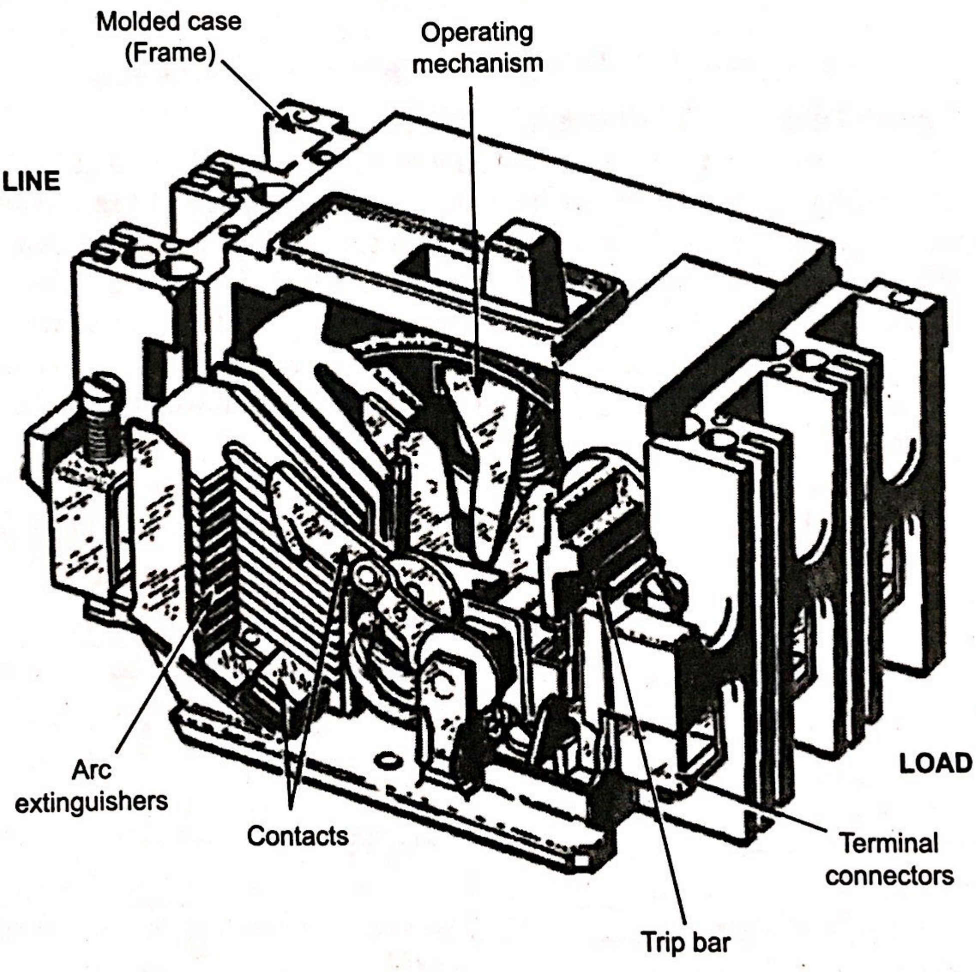


Figure (8.14): *Molded case circuit breaker*

MCCBs are manufactured such that the end user will not have access to internal workings of the over-current protection device. Generally constructed of two pieces of heavy-duty electrically insulated plastic, these two halves are riveted together to form the whole. Inside the plastic shell is a series of thermal elements and a spring-loaded trigger. When the thermal element gets too warm, from an over current situation, the spring trips, which in turn will shut off the electrical circuit.

Operating Mechanism:
At its core, the protection mechanism employed by MCCBs is based on the same physical principles used by all types of thermal-magnetic circuit breakers.

Overload protection is accomplished by means of a thermal mechanism. MCCBs have a bimetallic contact that expands and contracts in response to changes in temperature. Under normal operating conditions, the contact allows electric current through the MCCB. However, as soon as the current exceeds the adjusted trip value, the contact will start to heat and expand until the circuit is interrupted. The thermal protection against overload is designed with a time delay to allow short duration over current, which is a normal part of operation for many devices. However, any over current conditions that last more than what is normally expected represent an overload, and the MCCB is tripped to protect the equipment and personnel.

On the other hand, fault protection is accomplished with electromagnetic induction, and the response is instant. Fault currents should be interrupted immediately, no matter if their duration is short or long. Whenever a fault occurs, the extremely high current induces a magnetic field in a solenoid coil located inside the breaker – this magnetic induction trips a contact and current is interrupted. As a complement to the magnetic protection mechanism, MCCBs have internal arc dissipation measures to facilitate interruption.

As with all types of circuit breakers, the MCCB includes a disconnection switch which is used to trip the breaker manually. It is used whenever the electric supply must be disconnected to carry out field work such as maintenance or equipment upgrades.

Applications:
Molded case circuit breakers can have very high current ratings, which allows them to be used in heavy duty applications such as main electric feeder protection, capacitor bank protection, generator protection, welding applications, low current applications that require adjustable trip settings and motor protection

8.8 Batteries

A battery is a device which converts chemical energy into electrical energy and is made up of a number of cells. Batteries consist of two or more voltaic cells that are connected in series to provide a steady DC voltage at the battery's output terminals. The voltage is produced by a chemical reaction inside the cell. Electrodes are immersed in an electrolyte, which forces the electric charge to separate in the form of ions and free electrons. A battery's voltage output and current rating are determined by the elements used for the electrodes, the size of the electrodes, and the type of electrolyte used. Whether a battery may be recharged or not depends on the cells used to make up the battery.

Batteries are classified into two types such as primary batteries and secondary batteries.

(i) Primary Batteries

As the name indicates, these batteries are meant for single usage. Once these batteries are used they cannot be recharged as the devices are not easily reversible and active materials may not return to their original forms. Other name for these batteries is disposable batteries. Some of the examples for the disposable batteries are the normal AA, AAA batteries which we use in wall clocks, television remote, etc.

(ii) Secondary Batteries

Secondary batteries are also known as rechargeable batteries. These batteries can be used and charged simultaneously. A secondary battery or storage battery can be recharged because its chemical reaction is reversible. Rechargeable batteries are (re)charged by applying electric current, which reverses the chemical reactions that occur during discharge/use. Some of the examples for rechargeable batteries are the batteries used in mobile phones, MP3 players, etc.

8.8.1 Types of Primary Cells/Batteries

There are several types of primary cells in use today, such as

(i) Carbon-zinc dry cell
(ii) Alkaline cell
(iii) Zinc chloride cell
(iv) Mercury cell
(v) Silver oxide cell
(vi) Lithium cell

(i) Carbon-zinc dry cell

- This is one of the most popular primary cells (often used for type AAA, AA, C, D).
- The negative electrode is made of zinc.
- The positive electrode is made of carbon.
- The output voltage of a single cell is about 1.5 V.
- Performance of the cell is better with intermittent operation.

(ii) Alkaline cell

- The alkaline cell is another popular type also used for type AA, C, D, etc.
- It has the same 1.5V output as carbon-zinc cells, but they are longer-lasting.
- It consists of a zinc anode and manganese dioxide cathode in an alkaline electrolyte (potassium hydroxide).
- It works with high efficiency even with continuous use, due to low internal resistance.

(iii) Zinc chloride cell

- This cell is also referred to as a "heavy-duty" type battery.
- It is a modified zinc-carbon cell.
- It has little chance of liquid leakage because the cell consumes water along with the chemically active materials. The cell is usually dry at the end of its useful life.

(iv) Mercury cell

- This cell consists of a zinc anode, mercury compound cathode, and potassium or sodium hydroxide electrolyte.
- It is becoming obsolete due to the hazards associated with proper disposal of mercury.

(v) Silver oxide cell

- This cell consists of a zinc anode, silver oxide cathode, and potassium or sodium hydroxide electrolyte.
- It is typically available as 1.5V, miniature button form.
- Applications include hearing aids, cameras, and watches

(vi) Lithium cell

- This cell offers high output voltage, long shelf life, low weight, and small volume.
- It comes in two forms of 3V output in widespread use:
  (a) Lithium-sulfur dioxide ($LiSO_2$).
  (b) Lithium-thionyl chloride.
- $LiSO_2$ type batteries contain methyl cyanide liquid solvent; if its container is punctured or cracked, it can release toxic vapors.
- Safe disposal of these cells is critical.

8.8.2 Types of Secondary Cells/Batteries

There are several types of secondary cells in use today, such as

(i) Lead-acid cell
(ii) Nickel cadmium (NiCd) cell
(iii) Lithium-ion battery
(iv) Nickel-metal-hydride (NiMH) cell
(v) Nickel-iron (Edison) cell
(vi) Fuel cell
(vii) Solar cell

(i) Lead-acid cell

- This cell is a widely applied type of secondary cell, used extensively in automobiles, inverters, backup power systems, etc. requiring high values of load current.
- Anode: Porous lead
- Cathode: Lead-dioxide
- Electrolyte: Sulfuric acid, 6 molar H_2SO_4
- The output is about 2.1 V per cell.
- Cells are typically used in series combinations of 3 (6V battery) or 6 (12V battery).

(ii) Nickel Cadmium (NiCd) cell

- This type of cell delivers high current.
- It can be recharged many times.
- Anode: Nickel hydroxide, $Ni(OH)_2$
- Cathode: Cadmium hydroxide, $Cd(OH)_2$
- Electrolyte: Potassium hydroxide, KOH
- Maintain a steady voltage of 1.2V per cell until completely depleted
- It can be stored for long periods of time.
- Its specific gravity does not change with the state of charge.
- Applications include portable power tools, alarm systems, portable radio and TV equipment.

(iii) Lithium-Ion Battery

- Li-based cells are most compact ways of storing electrical energy.
- Lower in energy density than lithium metal, lithium-ion is safe.
- Anode: Graphite
- Cathode: Lithium manganese dioxide
- Electrolyte: mixture of lithium salts
- Energy density is twice of the standard nickel-cadmium.
- No memory and no scheduled cycling is required to prolong battery life.

(iv) Nickel-Metal-Hydride (NiMH) cell

- These cells are used in applications demanding long-running battery performance (e.g., high-end portable electrical or electronic products like power tools).
- They offer 40% more capacity over a comparably-sized NiCd cell.
- They contain the same components as a NiCd cell, except for the negative electrode.
- They are more expensive than NiCd cells, self-discharge more rapidly, and cannot be cycled as frequently as NiCd cells.

(v) Nickel-Iron (Edison) cell

- Anode: Nickel hydroxide, $Ni(OH)_2$
- Cathode: iron
- Electrolyte: potassium hydroxide
- The specific gravity of electrolyte remains unaffected during the charging and discharging process.
- They are now almost obsolete due to lead-acid batteries.
- These are used in emergency lamps in hospitals and at places where the rate of discharge and charge are rapid.

(vi) Fuel cell

- A fuel cell is an electrochemical device that converts chemicals (such as hydrogen and oxygen) into water and produces electricity in the process.
- As long as the reactants (H and O) are supplied to the fuel cell, it will continually produce electricity and never go dead, unlike conventional batteries.
- Fuel cells are used extensively in the space program as sources of DC power.
- They are very efficient; capable of providing hundreds of kilowatts of power.

(vii) Solar cell

- Solar cells convert the sun's light energy into electric energy.
- They are made of semiconductor materials.
- They are arranged in modules that are assembled into a large solar array to produce the required power.
- An applied voltage higher than the voltage of one cell can be obtained by connecting cells in series.
- The total voltage available across the battery of cells is equal to the sum of the individual values for each cell.
- Parallel cells have the same voltage as one cell but have more current capacity.
- To provide a higher output voltage and more current capacity, cells can be connected in series-parallel combinations.

8.8.3. Comparison of Primary and Secondary Cells

S. No.	Primary Cell	Secondary Cell
01	If discharged once cannot be charged again	If discharged once can be charged again
02	Light in weight	Heavy in weight
03	Used for intermittent use with low load current rating	Used for continuous rating with high load current rating
04	Short life	Long life
05	Low cost	High cost
06	Low efficiency	High efficiency
07	Low power output	High power output
08	Less maintenance	More maintenance

8.8.4 Battery Characteristics

There are many characteristics that can help to identify a battery and we can distinguish the three main ones as: chemistry, battery capacity and voltage. However, if the battery is only a starter, it also delivers cold cranking amps (CCA), which permits to offer high current at cold temperatures.

(i) Chemistry

The main battery chemistries are lead, nickel and lithium. They all need a specific designated charger, this is why charging these batteries on a different charger from their own might cause an incorrect charge, despite it seeming to work at first. This happens because of the different regulatory requirement of each chemistry.

(ii) Battery Capacity

Battery capacity is a measure (typically in Amp-hr) of the charge stored by the battery, and is determined by the mass of active material contained in the battery. The battery capacity represents the maximum amount of energy that can be extracted from the battery under certain specified conditions. However, the actual energy storage capabilities of the battery can vary significantly from the "nominal" rated capacity, as the battery capacity depends strongly on the age and past history of the battery, the charging or discharging regimes of the battery and the temperature.

The energy stored in a battery, called the battery capacity, is measured in either watt-hours (Wh), kilowatt-hours (kWh), or ampere-hours (Ahr). The most common measure of battery capacity is Ah, defined as the number of hours for which a battery can provide a current equal to the discharge rate at the nominal voltage of the battery. The unit of Ah is commonly used when working with battery systems as the battery voltage will vary throughout the charging or discharging cycle.

(iii) Voltage

A battery features a nominal voltage. Along with the amount of cells connected in series, chemistry provides the open circuit voltage (OCV), which is about 5-7% higher on a fully charged battery. It is important to check the correct nominal voltage of a battery before connecting it.

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(iv) Cold Cranking Amps (CCA)
Every starter battery is marked with cold cranking amps, also abbreviated CCA. The number denotes the amount of amps that the battery is able to provide at $-18°C$.

8.9 Power Factor Improvement

The cosine of angle between voltage and current in an AC circuit is known as power factor. It refers to the fraction of total power (apparent power) which is utilized to do the useful work called active power. In an AC circuit, there is generally a phase difference ϕ between voltage and current. The term $\cos\phi$ is called the power factor of the circuit. If the circuit is inductive, the current lags behind the voltage and the power factor is referred to as lagging. However, in a capacitive circuit, current leads the voltage and power factor is said to be leading.

$$\cos\phi = \frac{\textit{Active power}}{\textit{Apparent power}}$$

8.9.1 Disadvantages of Low Power Factor

The power factor plays an importance role in AC circuits since power consumed depends upon this factor.

$$P = VI\cos\phi$$

$$\Rightarrow \cos\phi = \frac{P}{VI}$$

It is clear from above that for fixed power and voltage, the load current is inversely proportional to the power factor. Lower the power factor, higher is the load current and vice versa. A power factor less than unity results in the following disadvantages:

(i) Overloading of cables and transformers
(ii) Greater conductor size
(iii) Large copper losses
(iv) Poor voltage regulation i.e., decreased line voltage at point of application
(v) Reduces the handling capacity of all the elements of the system.

8.9.2 Causes of Low Power Factor

Low power factor is undesirable from economic point of view. Normally, the power factor of the whole load on the supply system in lower than 0.8. The following are the causes of low power factor:

(i) Most of the AC motors are of induction type (1-phase and 3-phase induction motors) which have low lagging power factor. These motors work at a power factor which is extremely small on light load (0.2–0.3) and rises to 0.8 or 0.9 at full load.
(ii) Arc lamps, electric discharge lamps and industrial heating furnaces operate at low lagging power factor.
(iii) The load on the power system is varying; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetisation current. This results in the decreased power factor.

8.9.3 Methods of Improving Power Factor

Normally, the power factor of the whole load on a large generating station is in the region of 0.8–0.9. However, sometimes it is lower and in such cases it is generally desirable to take special steps to improve the power factor. This can be achieved by the following methods:

(i) Static capacitors

Improving power factor means reducing the phase difference between voltage and current. Since the majority of loads are of inductive nature, they require some amount of reactive power for them to function. The capacitor or bank of capacitors installed parallel to the load provides this reactive power. They act as a source of local reactive power, and thus less reactive power flows through the line. They reduce the phase difference between the voltage and current.

(ii) Synchronous Condenser

A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor. An over-excited synchronous motor running on no load is known as synchronous condenser. When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralizes the lagging reactive component of the load. Thus the power factor is improved.

(iii) Phase Advancer

This is an AC exciter mainly used to improve power factor of induction motor. They are mounted on the shaft of the motor and connected to the rotor circuit of the motor. It improves the power factor by providing the exciting ampere turns to produce required flux at slip frequency. Further, if ampere-turns increases, it can be made to operate at leading power factor.

8.10 Energy Consumption Calculation

Energy and power are closely related. Electrical energy can be measured only when electrical power is known. So first, we understand the electrical power. Electrical power is the amount of electrical current that results from a certain amount of voltage or we can say that power is the rate at which energy is delivered. It is measured in watts. Mathematically it is written as

$$Power = Voltage \times Current$$

The measurement of electrical energy is completely dependent on power which is measured in watt, kilowatts, megawatts, gigawatts, and time which is measured in an hour. Joule is the smallest unit of energy. But for some bigger calculation, some better unit is required. So, the unit used for electrical energy is watt-hour.

Electrical energy is the product of electrical power and time, and it is measured in joules. It is defined as "1 joule of energy is equal to 1 watt of power is consumed for 1 second". i.e.,

$$Energy = Power \times Time$$

$$1\ Joule = 1\ watt \times 1\ \text{second}$$

Watts are the basic unit of power in which electrical power is measured or we can say that rate at which electric current is being used at a particular moment.

Watt-hour is the standard unit used for measurement of energy, describing the amount of watts used over a time. It shows how fast the power is consumed in the period of time.

$$\textit{Energy in watt hours} = \textit{Power in watts} \times \textit{Time in hours}$$

Kilowatt-hour is simply a bigger unit of energy when large appliances drawn power in kilowatts. It can be described as one kilowatt hour is the amount of energy drawn by the 1000 watts appliance when used for an hour.

Where, One kilowatt = 1000 watts

$$\textit{Energy in kilowatt hours} = \textit{Power in kilowatts} \times \textit{Time in hours}$$

The electrical supply companies take electric energy charges from their consumer per kilowatt hour unit basis. This kilowatt hour is board of trade (BOT) unit.

Illustration for Energy Consumption: A consumer uses a 10 kW geezer, a 6 kW electric furnace and five 100 W bulbs for 15 hours. How many units (kWh) of electrical energy have been used?

Explanation: Given that

Load-1 = 10 kW geezer
Load-2 = 6 kW electric furnace
Load-3 = 500 watt (five 100 watt bulbs)

Total load $= 10kW + 6kW + 0.5kW = 16.5kW$

Time taken = 15 hours

$$\therefore \textit{Energy consumed} = \textit{Power in kW} \times \textit{Time in hours}$$
$$= 16.5 \times 15 = 247.5\ kWh$$

For above electrical energy consumption, the tariff can be calculated as follows:

1 unit = 1kWh

So, the total energy consumption = 247.5 units

If the cost per unit is ₹ 2.5, then the total cost of energy consumption

= 247.5 × 2.5 = ₹ 618.75/-