Necessity of Earthing

Consider a single phase machine which is not earthed. The windings and coils inside the frame of the machine carry the current. The potential between line and neutral is V volts. The resistance between the windings and the frame is say R_i called **insulation resistance**. And R_{body} be the **resistance of the body** of a person who happens to touch to the machine.

Neutral is generally earthed at supply system as shown in the Fig. 7.9.

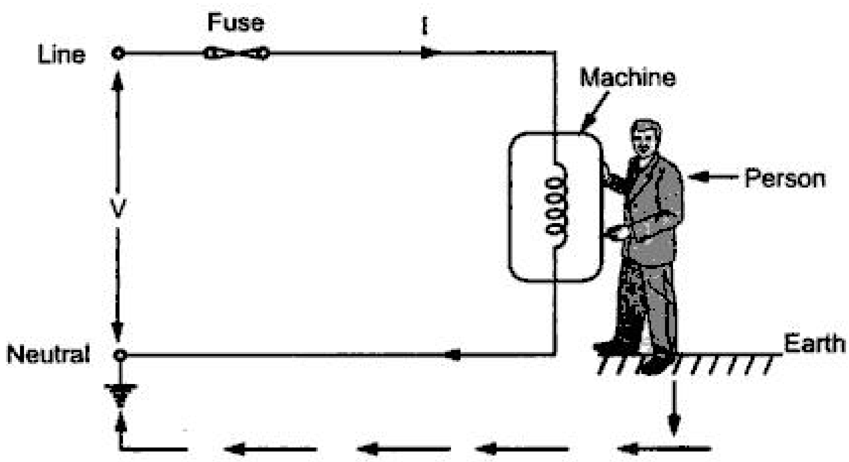

Fig. 7.9 Machine is not earthed

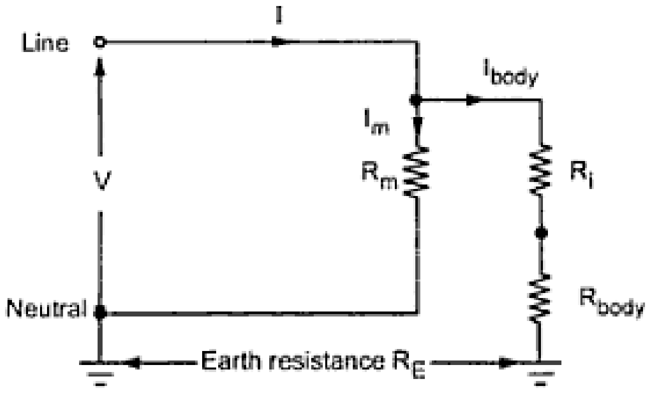

Fig. 10.13 Equivalent circuit

The equivalent electric circuit of the above condition can be shown as in the Fig. 10.13.

In the equivalent circuit we have,

I_m = Machine Current

I_{body} = Current passing through the body of the person.

When a person, standing on the earth touches the machine, current *I* gets an alternative path through the body of the person to earth from the insulation resistance, finally to the neutral of the supply. From the equivalent circuit we can write,

$$I_{body} = \frac{V}{R_i + R_{body} + R_E} \quad ...(1)$$

When the insulation of the machine is perfect, the insulation resistance is of the order of few mega ohms and practically can be considered as infinity.

So $R_i = \infty$ ... .Insulation perfect

$$\therefore \quad I_{body} = \frac{V}{R_E + \infty + R_{body}} = 0 \quad ...(2)$$

So in normal operating conditions, there is no current passing through the body of the person and hence there is no danger of the shock.

But when the insulation becomes weak or defective or if one of the windings is touching to the frame directly due to some fault then R_i i..e. insulation resistance becomes almost zero. Now resistance of body and earth are not very high and hence I_{body} increases to such a high value that the person receives a fatal shock. Such a current is called a leakage current. Hence when the machine is not earthed, there is always a danger of the shock, under certain fault conditions.

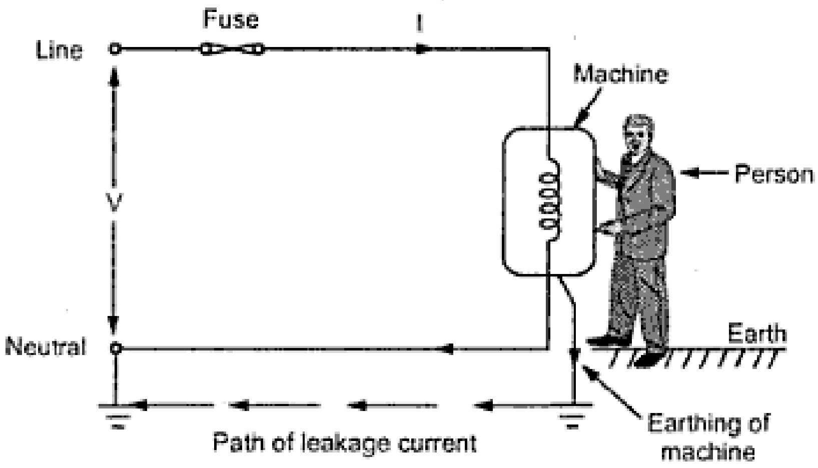

Fig. 10.14 Machine is earthed

Let us see now, what happens due to earthing. In case of earthing, the frame of the machine is earthed as shown in the Fig. 10.14.

The resistance of the path from frame to earth is very

very low. When the person touches to the frame, and if there is a leakage due to fault condition, due to earthing a leakage current takes a low resistance path i.e. path from frame to earth, bypassing the person. So body of the person carries very low current which is not sufficient to cause any shock.

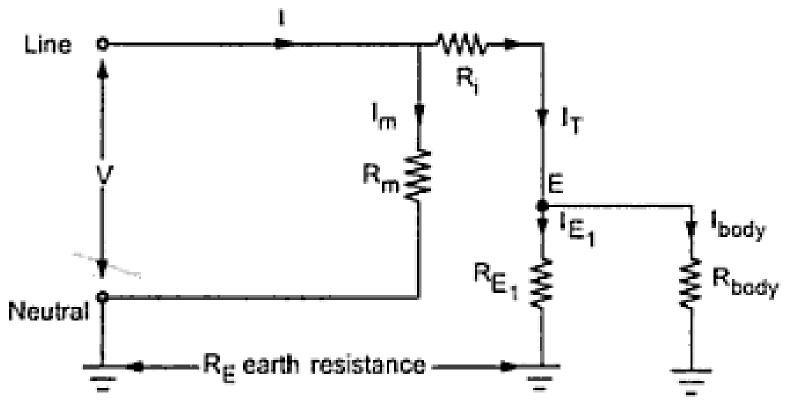

Fig.10.15 Equivalent circuit when machine is earthed

The equivalent circuit of the earthed condition is shown in the Fig. 10.15.

When there is a leakage current due to deterioration of an insulation R_i approaches to zero. So current is sufficiently high to cause a fatal shock. But at point E shown in the Fig.10.15 the current I_T has two paths :

i) One flowing through R_{body} through the person.

ii) Other through new earthing connection having resistance R_{E1}.

The current through the body of the person can be obtained by using the results of current division in a parallel combination.

$$I_{body} = I_T \times \frac{R_{E1}}{R_{body} + R_{E1}} \quad ...(3)$$

Now R_{E1} is very very small about 5 while R_{body} under worst condition is 1000 Ω but generally higher than 1000 Ω. Hence current I_{body} is negligibly small compared to current I_{E1}. So entire leakage current I_T passes through the earthing contact bypassing the body of the person. The value of I_{body} is not sufficient to cause any shock to the person.

Not only this but the current I_T, is high due to which fuse blows off and thus it helps to isolate the machine from the electric supply.

10.10.1 Uses of Earthing

Apart from basic use of earthing discussed above, the other uses can be stated as

1) To maintain the line voltage constant.
2) To protect tall buildings and structures from atmospheric lightening strikes.
3) To protect all the machines, fed from overhead lines, from atmospheric lightening.
4) To serve as the return conductor for telephone and traction work. In such case, all the complications in laying a separate wire and the actual cost of the wire, is thus saved.

5) To protect the human being from disability or death from shock in case the human body comes into the contact with the frame of any electrical machinery, appliance or component, which is electrically charged due to leakage current or fault.

10.11 Methods of Earthing

Earthing is achieved by connecting the electrical appliances or components to earth by employing a good conductor called **'Earth Electrode'**. This ensures very low resistance path from appliance to the earth. The various methods of earthing are

i) Plate earthing

ii) Pipe earthing

iii) Earthing through water main

iv) Horizontal strip earthing

v) Rod earthing

Let us discuss in detail, the two methods of earthing which are commonly used in practice.

10.11.1 Plate Earthing

The earth connection is provided with the help of copper plate or galvanized iron (G.I.) plate. The copper plate size is 60 cm × 60 cm × 3.18 mm while G.I. plate size is not less than 60 cm × 60 cm × 6.3 mm. The G.I. plates are commonly used now-a-days. The plate is embedded 3 meters (10 feet) into the ground. The plate is kept with its face vertical.

The plate is surrounded by the alternate layer of coke and salt for minimum thickness of about 15 cm. The earth wire is drawn through G.I. pipe and is perfectly bolted to the earth plate. The nuts and bolts must be of copper plate and must be of galvanized iron for G.I. plate.

The earth lead used must be G.I. wire or G.I. strip of sufficient cross-sectional area to carry the fault current safely. The earth wire is drawn through G.I. pipe of 19 mm diameter, at about 60 cm below the ground.

The G.I. pipe is fitted with a funnel on the top. In order to have an effective earthing, salt water is poured periodically through the funnel.

The earthing efficiency, increases with the increases of the plate area and depth of embedding. If the resistivity of the soil is high, then it is necessary to embed the plate vertically at a greater depth into the ground.

The only disadvantage of this method is that the discontinuity of the earth wire from the earthing plate below the earth can not be observed physically. This may cause misleading and may result into heavy losses under fault conditions.

The schematic arrangement of plate earthing is shown in the Fig. 10.16.

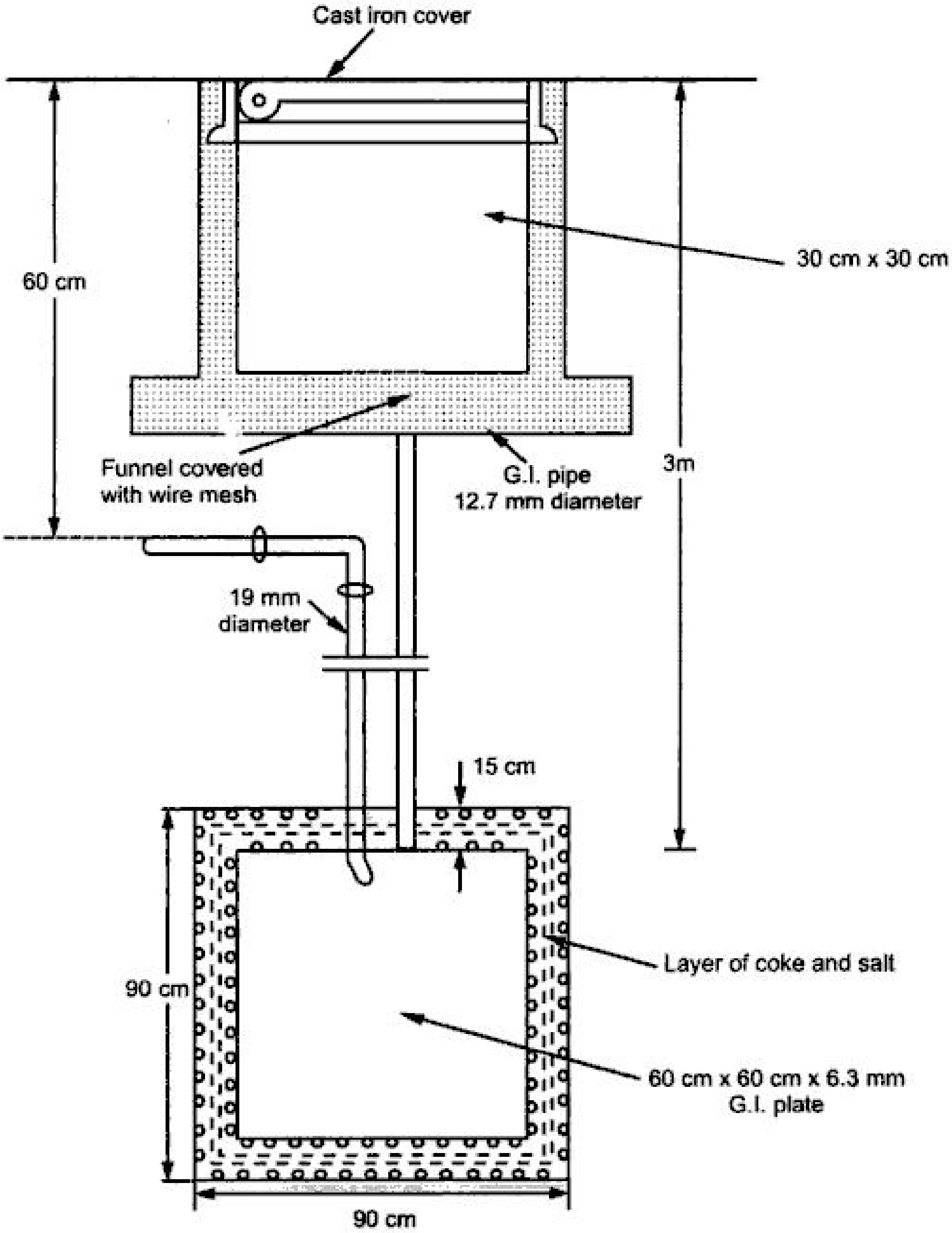

Fig. 7.13 Plate earthing

7.5.2 Pipe Earthing

In this method of earthing a G.I. pipe of 38 mm diameter and 2 meter (7 feet) length is embedded vertically into the ground. This pipe acts as an earth electrode. The depth depends on the condition of the soil.

The earth wires are fastened to the top section of the pipe above the ground level with nut and bolts.

The pit area around the pipe is filled with salt and coal mixture for improving the condition of the soil and earthing efficiency. The schematic arrangement of pipe earthing system is shown in the Fig. 7.14.

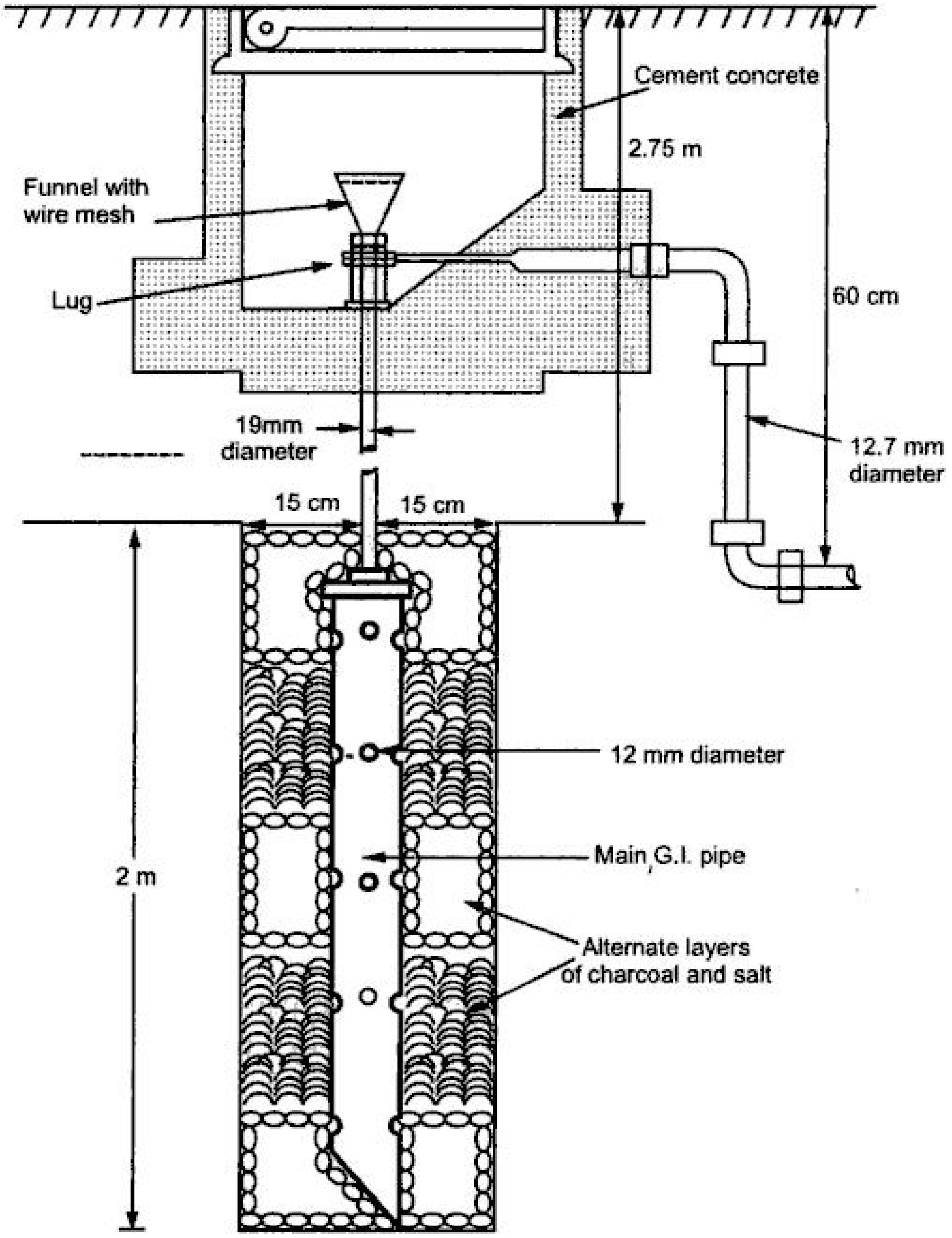

Fig. 7.14 Pipe earthing

The contact surface of G.I. pipe with the soil is more as compared to the plate due to its circular section and hence can handle heavier leakage current for the same electrode size.

According to Indian standard, the pipe should be placed at a depth of 4.75 m. Impregnating the coke with salt decreases the earth resistance. Generally alternate layers of salt and coke are used for best results.

In summer season, soil becomes dry, in such case salt water is poured through the funnel connected to the main G.I. pipe through 19 mm diameter pipe. This keeps the soil wet.

The earth wires are connected to the G.I. pipe above the ground level and can be physically inspected from time to time. These connections can be checked for performing continuity tests. This is the important advantage of pipe earthing over the plate earthing. The earth lead used must be G.I. wire of sufficient cross-sectional area to carry fault current safely. It should not be less than electrical equivalent of copper conductor of 12.97 mm^2 cross-sectional area.

The only disadvantage of pipe earthing is that the embedded pipe length has to be increased sufficiently in case the soil specific resistivity is of high order. This increases the excavation work and hence increased cost. In ordinary soil condition the range of the earth resistance should be 2 to 5 ohms.

In the places where rocky soil earth bed exists, horizontal strip earthing is used. This is suitable as soil excavation required for plate or pipe earthing is difficult in such places. For such soils earth resistance is between 5 to 8 ohms.

7.6 Introduction to Fuse

The **fuse** is a protecting device of simplest form. It consists of a small piece of metal. When excessive current flows through it, the metal element melts and the current is interrupted and circuit gets disconnected from the supply. Thus it protects the circuit from dangerous excessive current. So fuse is used to interrupt a fault current.

The fuse was invented by the scientist Edison in the year 1880. It is a simple protective device which works on the principle of current interruption, if current through it becomes excessive. Hence it protects the equipment from the effects of excessive high currents such as overheating, short circuiting, firing, damage etc. Its working and construction is very simple and can be designed very easily. It is used for overload and short circuit protection in medium voltage range upto 66 kV.

A fuse is basically a small piece of metal connected between the two terminals mounted on the insulated base. The fuse is always connected in series with the circuit or appliance to be protected. A small piece of metal used in a fuse is called **fusing element**.

The fusing element carries the normal working current safely but melts due to excessive current under abnormal conditions like overload and short circuit. As it is in series, melting of fusing element causes current interruption and breaking of the circuit, protecting the equipment from excessive current.. The fusing element melts due to the heat produced by the excessive current. So the melting point of the fusing element plays an important role in the design of the fuse.

The Table 7.1 gives various metals which can be used as fusing elements, with the corresponding melting point and specific resistance values.

Metal	Melting point in		Specific resistance in μ Ω-cm
	°F	°C	
Aluminium	240	658.7	2.86
Copper	2000	1084	1.72
Lead	624	327	21.0
Zinc	787	419	6.1
Tin	463	231.85	11.3
Silver	1830	960.5	1.64

Table 7.1

Key Point: *The copper or lead-tin alloy is mostly used as fusing element.*

7.7 Fuse Element Material

The desirable characteristics of any fuse element are,

1. Low melting point
2. High conductivity
3. Free from deterioration due to oxidation
4. Low cost

No metal can posses all these characteristics.

It is seen earlier that the various metals which are used as fuse elements are lead, zinc, tin, copper, aluminium and sliver. The melting points and specific resistance values of these metals are given in the Table. 7.1. Low melting point is available with high specific resistance metal.

For small value of currents lead-tin alloy is used for making the fuse element. The most preferred lead-tin alloy consists of 37 percent of lead and 63 percent of tin. Such an alloy is called eutectic alloy. It is preferred because,

1. It has less tendency to spread over. 2. It is quite homogeneous

In rupturing small values of currents such an alloy is used because the fusing current for such a type of fuse wire is about 50 percent over load. Such an alloy is used upto current capacity of 10 A.

For large values of current copper or silver is used for making fuse element. The lead-tin alloy is not used because after fusing there is excessive metal released in case of alloys as diameters of such wires are large.

2.3 Types of Fuses

The various types of fuses are,

1. Expulsion fuse
2. Rewirable fuse or Semienclosed fuse
3. Cartridge fuse
4. Drop-out fuse
5. Liquid fuse
6. Open fuse
7. Striker fuse
8. Switch fuse
9. HRC fuse

1. Expulsion fuse : The expulsion fuse consist of modern cut-outs. In such fuse the arc occurring during the current interruption is extinguished by the expulsion produced by the arc.

2. Rewirable fuse or Semienclosed fuse : In such a fuse, the fuse element is placed in a semiclosed carrier. The fuse carrier can be pulled out and the fuse element can be replaced, after the fuse operation. The carrier can then be placed in a fuse base. Such fuses are very commonly used in our houses.

The semienclosed fuses suffer from the following disadvantages,

a) When the fuse melts, then it is possible to rewire the fuse with improper fuse element.

b) The protective capacity is not certain. This means, for a particular fusing current of this fuse, practically fuse may melt at some lower or higher than this current value.

c) The fuse wire is subjected to the deterioration due to oxidation through the continuous heating up of the element. Due to this, the current rating of the fuse is decreased and it starts operating at lower current.

d) Accurate calibration of the fuse wire is impossible. This is because the fusing current depends on the length of the fusing element.

e) It has low breaking capacity and hence cannot be used for high fault level circuits.

f) Slow speed

g) Risk of external flame and fire.

These fuses are made upto about 500 A rated current. The only advantages of such fuses are, very simple, cheap and easily replaceable.

3. Cartridge fuse : This fuse is totally enclosed fuse. The fuse element is placed in a totally enclosed carrier with two metal contacts provided on the two sides of a carrier. The entire cartridge is required to be replaced once fuse operates.

4. Drop-out fuse : In such a fuse, the fuse carrier drops out, once the fuse operates. The dropping out of fuse carrier provides the necessary isolation between the terminals.

5. Liquid fuse : When fuse operates, in case of high currents, there exists an arc. The arc must be extinguished properly. The fuse in which the arc is extinguished using a liquid medium is called liquid fuse. The liquid medium used is generally oil. The various types of a liquid fuse are,

i) Oil-break circuit breaker fuse ii) Oil-expulsion fuse

iii) Oil-blast fuse

6. Open fuse : This fuse consists of a plain fuse wire and the fuse operates without any provision for extinguishing the arc.

7. Striker fuse : In this fuse, there exists a combination of a fuse and a mechanical device. When the fuse operates, striker gets released under pressure which gives the tripping indication.

8. Switch fuse : This fuse is a combination of a switch and a fuse. The combined unit is called switch fuse.

9. HRC fuse : It is high rupturing capacity fuse. It is also called breaking capacity cartridge fuse. In such a fuse, the arc is extinguished with a help of a quartz sand powder. Such a powder provides very high resistance which helps to extinguish the arc. It is basically a low voltage fuse which is used for various distribution purposes.

After discussing the classification of fuses, let us study definitions of some common terms related to the fuse.

2.4 Definitions

In the study of fuse, it is necessary to know the definitions of some commonly used terms, related to a fuse. These terms can be defined as,

2.4.1 Fuse

The fuse is a device which consists of small piece of metal, which is connected in series circuit. When current through it increases beyond some predetermined value, the metal melts to interrupt the circuit current, which protects the circuit from excessive high current.

2.4.2 Fuse Element

The part of the fuse which melts when excessive current flows through it is called fuse element or fuse wire.

2.4.3 Current Rating of Fuse

It is that maximum current which fusing element can normally carry without any undue overheating or melting. It depends on,

1. Temperature rise of fuse contacts of fuse holder
2. Fusing element material
3. Deterioration of fuse due to oxidation

2.8 Advantages of Fuse

The advantages of using fuse as a protecting device are,

1. It is simplest and cheapest form of protecting device.
2. It requires no maintenance.
3. The operation of fuse is automatic while circuit breaker needs a tripping circuit to operate for its operation.
4. The minimum operating time can be made much smaller than that of circuit breaker.
5. Inverse time-current characteristic enables it to use for the overload protection.
6. With the help of a fuse, heavy currents can be interrupted without noise, smoke, gas and flame.
7. The fuse can produce a current limiting effect under short circuit conditions.

2.9 Disadvantages of Fuse

The various disadvantages of a fuse are,

1. The fuse is required to be replaced or rewired after its operation.
2. The replacement or rewiring of fuse takes a lot of time.
3. Discrimination between fuses in series cannot be obtained unless there is much difference in relative sizes of the fuses.
4. The current-time characteristics cannot be always corelated with that of the protected equipment.
5. It is not possible to provide secondary protection to fuses.

7.12 HRC Fuse

This is High Rupturing Capacity cartridge type of fuse. It is one of the simplest form of fuse which is used for distribution purposes. The low and uncertain breaking capacity of semienclosed fuses is overcome in HRC fuses.

7.12.1 Construction

The body of this fuse is of heat resisting ceramic with metal end caps. The metal used for end caps is generally brass. Between the end caps, the fixed elements are mounted, which are welded to the end caps. The fuse element which is generally silver is attached between the fixed elements. The construction of HRC fuse is **shown** in the Fig. 7.15.

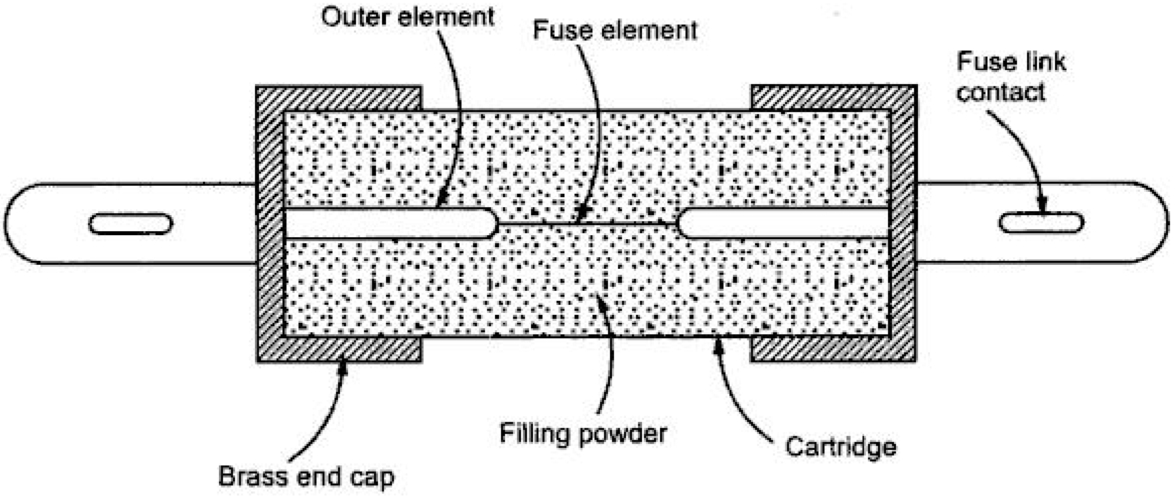

Fig. 7.15 Construction of HRC fuse

The body of the fuse is cylindrical in shape. The body space surrounding the fuse element is completely filled with a filling powder. The filling powder is generally quartz sand, plaster of paris or marble dust. The filling powder material is selected such that its chemical reaction with silver vapour forms very high resistance substance. This helps in arc quenching and acts as cooling medium. The filling powder can absorb the heat at very high rate and it does not evolve appreciable gas.

2.11.2 Operation

Under normal condition, the current flowing through the fuse element is rated or below rated. Hence the temperature of the element is well below its melting point. Hence fuse continues to carry current safely without overheating. When a short circuit of fault occurs, current increases to very high value, increasing the temperature of the element upto its melting point temperature. Hence the fuse element melts before fault current reaches to its peak value. The silver vapourises after melting. The chemical reaction between silver vapour and the filling powder forms a high resistance substance which helps in quenching the arc very quickly.

The various steps in the operation of the HRC fuse can be summarized as,

1. Occurrence of fault or short circuit.
2. Increase in current through fuse element to high value.
3. Melting of silver element.
4. Vapourization of the silver element.
5. Fusion of the silver vapour and formation of high resistance substance
6. Extinction of arc.

The **electrical phenomena** associated with the operation of the HRC fuse are,

1. Formation of high resistance substance due to chemical reaction of silver vapour with filling powder.
2. As current is cut-off, the high resistance gets converted to an insulator like glass beads.
3. Creation of transient voltage at the instant of breaking fault current.

The **physical phenomena** include the rise in temperature and generation of high internal pressure on the interruption of fault current. To obtain the satisfactory operation of the fuse, the effective control of both electrical as well as physical phenomena is necessary.

2.11.5 Advantages of a HRC Fuse

The various advantages of a HRC fuse are,

1. It can clear high values of short circuit current.
2. It does not deteriorate with high speed.
3. The operation is very fast.
4. It has inverse current - time characteristics.
5. The performance is very much consistent.
6. It provides reliable discrimination.
7. The cost is less as compared to other protecting device of same breaking capacity.
8. No maintenance is required.
9. The operation is reliable.

2.11.6 Disadvantages of a HRC fuse

The disadvantages of a HRC fuse are,

1. It must be replaced after each operation.
2. The replacement of fuse takes time.
3. Subjected to high temperature rises and hence heat produced can affect the adjacent contacts, associated switches etc.
4. Inter-locking is not possible.

2.11.7 Selection of HRC Fuse

The following points must be considered while selecting the HRC fuse for a particular application,

1. The level of the overcurrent protection required.
2. The normal current of the circuit.
3. The voltage appearing across the fuse after its operation which should not be greater than its rating.
4. The rupturing capacity must not be less than the current to be interrupted.
5. The discrimination needed when used with other fuses.

2.11.8 Applications of HRC Fuse

The main applications of HRC fuse are,

1. To protect the low voltage distribution system against the overload and short circuit conditions.
2. For the backup protection to circuit breakers.
3. Protection of meshed feeders with the steady load.

10.13 Safety Precautions

It is necessary to observe some safety precautions while using the electric supply to avoid the serious problems like shocks and fire hazards.

Some of the safety precautions are listed below :

1) Insulation of the conductors used must be proper and in good condition. If it is not so the current carried by the conductors may leak out. The person coming in contact with such faulty insulated conductors may receive a shock.
2) Megger tests should be conducted and insulation must be checked. With the help of megger all the tests discussed above must be performed, on the new wiring before starting use of it.
3) Earth connection should be always maintained in proper condition.
4) Make the mains supply switch off and remove the fuses before starting work with any installation.
5) Fuses must have correct ratings.
6) Use rubber soled shoes while working. Use some wooden supper under the feet. this removes the contact with the earth.
7) Use rubber gloves while touching any terminals or removing insulation layer from a conductor.
8) Use a line tester to check whether a 'live' terminal carries any current still better method is to use a test lamp.
9) Always use insulated screw drivers, pilers, line testers etc.
10) Never touch two different terminals at the same time.
11) Never remove the plug by pulling the wires connected to it.
12) The sockets should be fixed at a height beyond the reach of the children.

10.14 Electric Shock

A sudden agitation of the nervous system of a body, due to the passage of an electric current is called an **electric shock**.

The factors affecting the severity of the shock are,

1. Magnitude of current passed through the body.
2. Path of the current passed through the body.
3. Time for which the current is passed through the body.
4. Frequency of the current.
5. Physical and psychological condition of the affected person.

10.15 Safety Rules

Following are few of the safety rules must be observed while dealing with electricity.

1) All the electrical supply lines shall be sufficient in power and size and of sufficient mechanical strength for the work.
2) All electric supply lines, wires, fittings and apparatus at a consumer's premises should be in a safe condition and in all respects fit for supplying energy.
3) The underground cable must be properly insulated and protected under all the ordinary operating conditions.
4) A suitable earthed terminal should be provided by supplier on the consumer's premises.
5) The bare conductors, if any are ensured that they are inaccessible.
6) The conductor or apparatus, before handled by any person proper precaution is taken by earthing or suitable means to discharge electrically.
7) No person shall work on any live electric supply line or apparatus and no person shall assist such person.
8) Flexible cables shall not be used for portable or transportable motors, generators, transformers, rectifiers, electric drills, welding sets etc. unless they are heavily insulated and adequately protected from mechanical injury.
9) When a.c. and d.c. circuits are installed on the same supports they shall be so arranged and protected that they shall not come into contact with each other when live.
10) First aid boxes must be provided and maintained at generating stations and substations.
11) Fire buckets filled with clean dry sand and ready for immediate use for extinguishing fires.
12) Instructions in English, Hindi and any local languages for the restoration of person suffering from electric shock must be affixed in generating station and substation at a suitable place.
13) Each installation is periodically inspected and tested.