LECTURE NOTES

ON

SWITCH GEAR PROTECTION

IV B. Tech I semester (JNTUH-R15)

P SHIVAKUMAR
Assistant Professor

ELECTRICAL AND ELECTRONICS ENGINEERING

INSTITUTE OF AERONAUTICAL ENGINEERING
(Autonomous)
DUNDIGAL, HYDERABAD - 500 043

Circuit Breaker

UNIT - I

Introduction:

During the operation of power system, it is often desirable and necessary to switch on or off the various circuits (e.g., transmission lines, distributors, generating plants etc.) under both normal and abnormal conditions. In earlier days, this function used to be performed by a switch and a fuse placed in series with the circuit. However, such a means of control presents two disadvantages.

1. Firstly, when a fuse blows out, it takes quite sometime to replace it and restore supply to the customers.
2. Secondly, a fuse cannot successfully interrupt heavy fault currents that result from faults on modern high-voltage and large capacity circuits.

- ***A circuit breaker is a piece of equipment which can***

  (i) Make or break a circuit either manually or by remote control under normal conditions.

  (ii) Break a circuit automatically under fault conditions

  (iii) Make a circuit either manually or by remote control under fault conditions

Thus a circuit breaker incorporates manual (or remote control) as well as automatic control for switching functions. The latter control employs relays and operates only under fault conditions.

Operating principle:

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. Of course, the contacts can be opened manually or by remote control whenever desired. When a fault occurs on any part of the system, the trip coils of the circuit breaker get energized and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

- When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them. The current is thus able to continue until the discharge ceases.
- The production of arc not only delays the current interruption process but it also generates enormous heat which may cause damage to the system or to the circuit breaker itself.
- Therefore, the main problem in a circuit breaker is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

Arc Phenomenon:

When a short circuit occurs, a heavy current flows through the contacts of the circuit breaker before they are opened by the protective system. At the instant when the contacts begin to separate, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature. The heat produced in the medium between contacts (usually the medium is oil or air) Is sufficient to ionize the air or vaporize and ionize the oil. The ionized air or vapor acts as conductor and an arc is struck between the contacts.

- The potential difference between the contacts is quite small and is just sufficient to maintain the arc.
- The arc provides a low resistance path and consequently the current in the circuit remains UN interrupted so long as the arc persists.
- During the arcing period, the current flowing between the contacts depends upon the arc resistance. The greater the arc resistance, the smaller the current that flows between the contacts.

The arc resistance depends upon the following factors:

1. **Degree of ionization-** the arc resistance increases with the decrease in the number of ionized particles between the contacts.
2. **Length of the arc**— the arc resistance increases with the length of the arc i.e., separation of contacts.
3. **Cross-section of arc**— the arc resistance increases with the decrease in area of X-section of the arc.

Principles of Arc Extinction:

Before discussing the methods of arc extinction, it is necessary to examine the factors responsible for the maintenance of arc between the contacts. These are:

1. Potential difference between the contacts.
2. Ionized particles between contacts taking these in turn.

- When the contacts have a small separation, the Potential difference between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that Potential difference becomes inadequate to maintain the arc. However, this method is impracticable in high voltage system where a separation of many meters may be required.

- The ionized particles between the contacts tend to maintain the arc. If the arc path is demonized, the arc extinction will be facilitated. This may be achieved by cooling the arc or by bodily removing the ionized particles from the space between the contacts.

Methods of Arc Extinction (or) Interruption:

There are two methods of extinguishing the arc in circuit breakers viz.

1. High resistance method.
2. Low resistance or current zero method

High resistance method:

In this method, arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc. Consequently, the current is interrupted or the arc is extinguished.

- The principal disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in D.C. circuit breakers and low-capacity a.c. circuit breakers.

The resistance of the arc may be increased by:

1. **Lengthening the arc:** The resistance of the arc is directly proportional to its length. The length of the arc can be increased by increasing the gap between contacts.

2. **Cooling the arc:** Cooling helps in the deionization of the medium between the contacts. This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

3. **Reducing X-section of the arc:** If the area of X-section of the arc is reduced, the voltage necessary to maintain the arc is increased. In other words, the resistance of the arc path is increased. The cross-section of the arc can be reduced by letting the arc pass through a narrow opening or by having smaller area of contacts.
4. **Splitting the arc**: The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthening and cooling. The arc may be split by introducing some conducting plates between the contacts.

Low resistance or Current zero method:

In this method is employed for arc extinction in a.c. circuits only. In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally and is prevented from restriking in spite of the rising voltage across the contacts. All Modern high power a.c. circuit breakers employ this method for arc extinction.

- In an a.c. system, current drops to zero after every half-cycle. At every current zero, the arc extinguishes for a brief moment.

- Now the medium between the contacts contains ions and electrons so that it has small dielectric strength and can be easily broken down by the rising contact voltage known as restriking voltage.
- If such a breakdown does occur, the arc will persist for another half cycle.
- If immediately after current zero, the dielectric strength of the medium between contacts is built up more rapidly than the voltage across the contacts, the arc fails to restrike and the current will be interrupted.

The rapid increase of dielectric strength of the medium near current zero can be achieved by:

- Causing the ionized particles in the space between contacts to recombine into neutral molecules.
- Sweeping the ionized particles away and replacing them by un ionized particles.

Therefore, the real problem in a.c. arc interruption is to rapidly de ionize the medium between contacts as soon as the current becomes zero so that the rising contact voltage or restriking voltage cannot breakdown the space between contacts.

The de-ionization of the medium can be achieved by:

1. **Lengthening of the gap:** The dielectric strength of the medium is proportional to the length of the gap between contacts. Therefore, by opening the contacts rapidly, higher dielectric strength of the medium can be achieved.
2. **High pressure:** If the pressure in the vicinity of the arc is increased, the density of the particles constituting the discharge also increases. The increased density of particles causes higher rate of de-ionization and consequently the dielectric strength of the medium between contacts is increased.
3. **Cooling:** Natural combination of ionized particles takes place more rapidly if they are allowed to cool. Therefore, dielectric strength of the medium between the contacts can be increased by cooling the arc.
4. **Blast effect:** If the ionized particles between the contacts are swept away and replaced by UN ionized particles, the dielectric strength of the medium can be increased considerably. This may be achieved by a gas blast directed along the discharge or by forcing oil into the contact space.

There are two theories to explain the Zero current interruption of the Arc:

1. Recovery rate theory (Slepain‘s Theory)
2. Energy balance theory (Cassie‘s Theory)

Recovery rate theory (Slepain's Theory):

The arc is a column of ionized gases. To extinguish the arc, the electrons and ions are to be removed from the gap immediately after the current reaches a natural zero. Ions and electrons can be removed either by recombining them in to neutral molecules or by sweeping them away by inserting insulating medium (gas or liquid) into the gap. The arc is interrupted if ions are removed from the gap recovers its dielectric strength is compared with the rate at which the restriking voltage (transient voltage) across the gap rises. If the dielectric strength increases more rapidly than the restriking voltage, the arc is extinguished. If the restriking voltage rises more rapidly than the dielectric strength, the ionization persists and breakdown of the gap occurs, resulting in an arc for another half cycle.

Energy balance theory (Cassie's Theory):

The space between the contacts contains some ionized gas immediately after current zero and hence, it has a finite post –zero moment, power is zero because restriking voltage is zero. When the arc is finally extinguished, the power gain becomes zero, the gap is fully de-ionized and its resistance is infinitely high. In between these two limits, first the power increases, reaches a maximum value, then decreases and finitely reaches zero value as shown in figure. Due to the rise of restriking voltage and associated current, energy is generated in the space between the contacts. The energy appears in the form of heat. The circuit breaker is designed to remove this generated heat as early as possible by cooling the gap, giving a blast air or flow of oil at high velocity and pressure. If the rate of removal of heat is faster than the rate of heat generation the arc is extinguished. If the rate of heat generation is more than the rate of heat dissipation, the space breaks down again resulting in an arc for another half cycle.

Important Terms:

The following are the important terms much used in the circuit breaker analysis:

1. **Arc Voltage:**

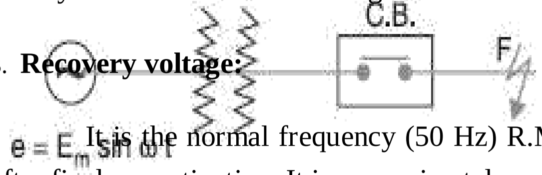
It is the voltage that appears across the contacts of the circuit breaker during the arcing period. As soon as the contacts of the circuit breaker separate, an arc is formed. The voltage that appears across the contacts during arcing period is called the arc voltage. Its value is low except for the period the fault current is at or near zero current point. At current zero, the arc voltage rises rapidly to peak value and this peak voltage tends to maintain the current flow in the form of arc.

2. **Restriking voltage:**

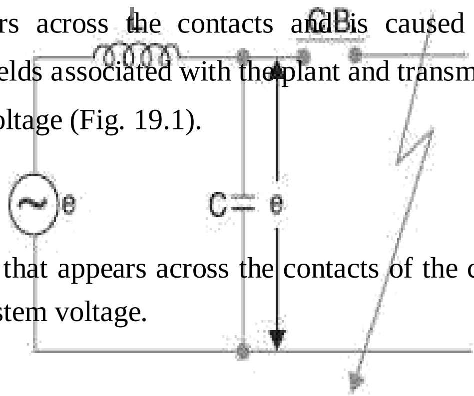
It is the transient voltage that appears across the contacts at or near current zero during arcing period. At current zero, a high-frequency transient voltage appears across the contacts and is caused by the rapid distribution of energy between the magnetic and electric fields associated with the plant and transmission lines of the system. This transient voltage is known as restriking voltage (Fig. 19.1).

3. **Recovery voltage:**

It is the normal frequency (50 Hz) R.M.S. voltage that appears across the contacts of the circuit breaker after final arc extinction. It is approximately equal to the system voltage.



(i)



(ii)

Fig. 19.17

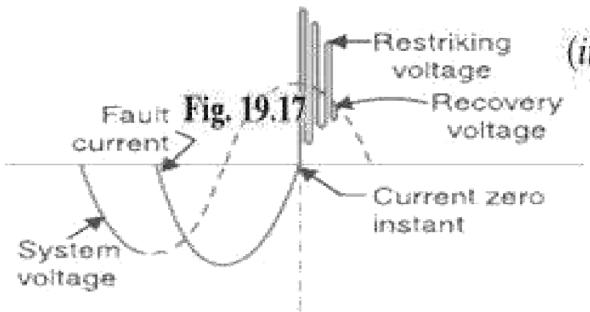


Fig. 19.1

Expression for Restriking voltage and RRRV:

The power system contains an appreciable amount of inductance and some capacitance. When a fault occurs, the energy stored in the system can be considerable. Interruption of fault current by a circuit breaker will result in most of the stored energy dissipated within the circuit breaker, the remainder being dissipated during oscillatory surges in the system. The oscillatory surges are undesirable and, therefore, the circuit breaker must be designed to dissipate as much of the stored energy as possible.

Rate of rise of re-striking voltage:

When the contacts are opened and the arc finally extinguishes at some current zero, the generator voltage e is suddenly applied to the inductance and capacitance in series.

Which appears across the capacitor C and hence across the contacts of the circuit breaker. This transient voltage, as already noted, is known as re-striking voltage and may reach an instantaneous peak value twice the peak phase-neutral voltage i.e. 2 E_m . The system losses cause the oscillations to decay fairly rapidly but the initial overshoot increases the possibility of re-striking the arc.

It is the rate of rise of re-striking voltage (R.R.R.V.) which decides whether the arc will re-strike or not. If R.R.R.V. is greater than the rate of rise of dielectric strength between the contacts, the arc will re-strike. However, the arc will fail to re-strike if R.R.R.V. is less than the rate of increase of dielectric strength between the contacts of the breaker.

The value of R.R.R.V. depends up on:

1. Recovery voltage
2. Natural frequency of oscillations

For a short-circuit occurring near the power station bus-bars, C being small, the natural frequency $\mathbf{f_n}$ will be high. Consequently, R.R.R.V. will attain a large value. Thus the worst condition for a circuit breaker would be that when the fault takes place near the bus-bars.

Current chopping:

It is the phenomenon of current interruption before the natural current zero is reached. Current chopping mainly occurs in air-blast circuit breakers because they retain the same extinguishing power irrespective of the magnitude of the current to be interrupted. When breaking low currents (e.g., transformer magnetizing current) with such breakers, the powerful de-ionizing effect of air-blast causes the current to fall abruptly to zero well before the natural current zero is reached. This phenomenon is known as current chopping and results in the production of high voltage transient across the contacts of the circuit breaker as discussed below:

The prospective voltage e is very high as compared to the dielectric strength gained by the gap so that the breaker restrike. As the de-ionizing force is still in action, therefore, chop occurs again but the arc current this time is smaller than the previous case. This induces a lower prospective voltage to re-ignite the arc. In fact, several chops may occur until a low enough current is interrupted which produces insufficient induced voltage to re-strike across the breaker gap. Consequently, the final interruption of current takes place.

Capacitive current breaking:

Another cause of excessive voltage surges in the circuit breakers is the interruption of capacitive currents. Examples of such instances are opening of an unloaded long transmission line, disconnecting a capacitor bank used for power factor improvement etc. Consider the simple equivalent circuit of an unloaded transmission line shown in Fig.19.20. Such a line, although unloaded in the normal sense, will actually carry a capacitive current I on account of appreciable amount of capacitance C between the line and the earth.

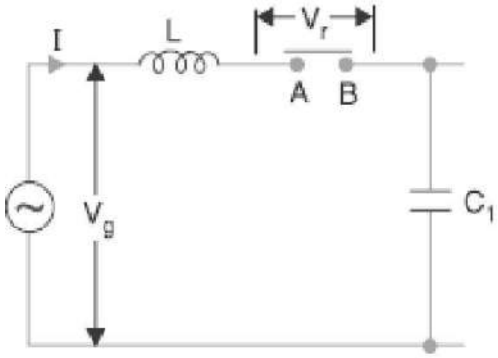


Fig. 19.20

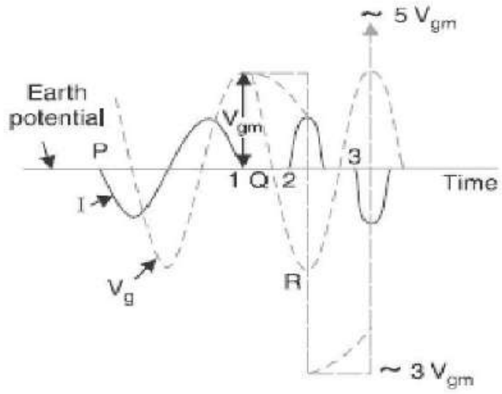


Fig. 19.21

Resistance Switching:

It has been discussed above that current chopping, capacitive current breaking etc. give rise to severe voltage oscillations. These excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R connected across the circuit breaker contacts as shown in the equivalent circuit in Fig. 19.22. This is known as resistance switching.

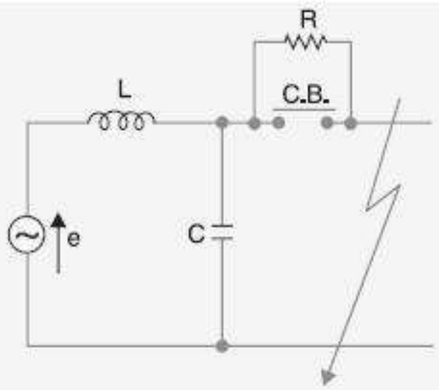


Fig. 19.22

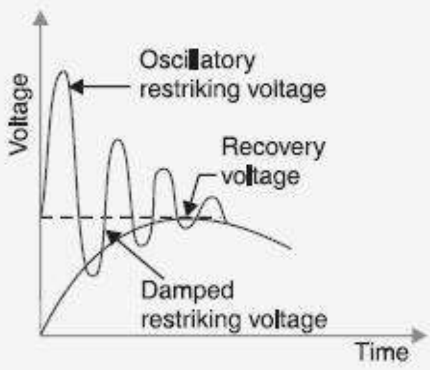


Fig. 19.23

Switchgear Components:

The following are some important components common to most of the circuit breakers:

1. Bushings
2. Circuit breaker contacts
3. Instrument transformers
4. Bus-bars and conductors

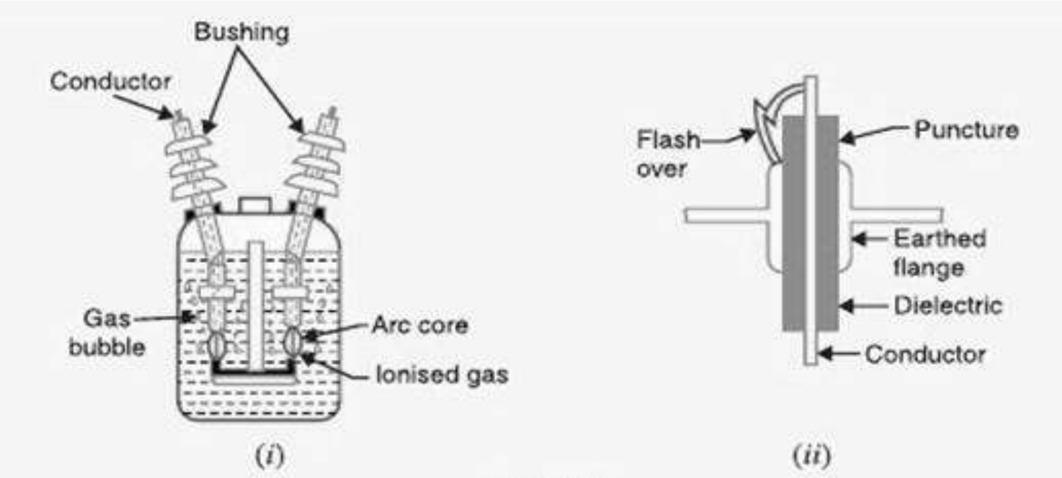


Fig. 19.13

Circuit breaker contacts:

The circuit breaker contacts are required to carry normal as well as short-circuit current. In carrying the normal current, it is desirable that the temperature should not rise above the specified limits and that there should be low voltage drop at the point of contact. In carrying breaking and making short-circuit currents, the chief effects to be dealt with are melting and Vaporization by the heat of the arc and those due to electromagnetic forces. Therefore, the design of contacts is of considerable importance for satisfactory operation of the circuit breakers. There are three types of circuit breaker contacts viz.

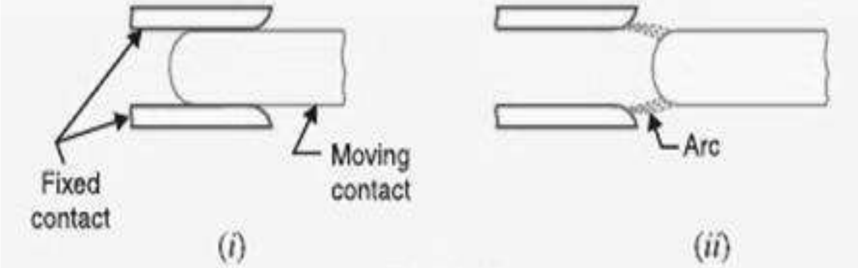


Fig. 19.14

(a) **Tulip type contacts:** Fig. 19.14 (i) shows the Tulip type contact. It consists of moving contact which moves inside the fixed contacts. At contact separation, the arc is generally established between the tips of the fixed contacts and the tip of the moving contact as shown in Fig. 19.14 (ii). The advantage of this type of contact is that arcing is confined to the regions which are not in contact in the fully engaged position.

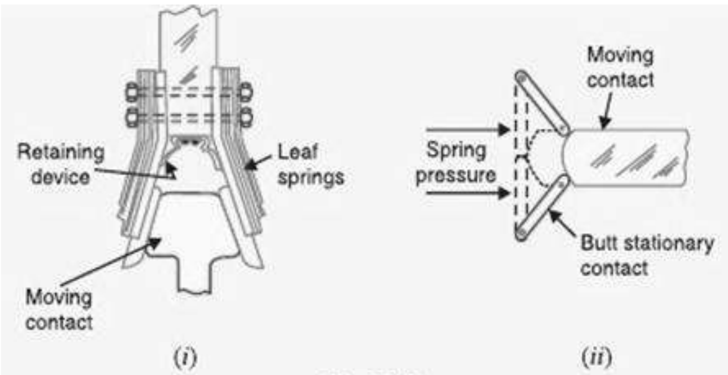


Fig. 19.15

(b) **Finger and wedge contacts:** Fig. 19.15 (i) shows the finger and wedge type contact. This type of contact is largely used for low-voltage oil circuit breakers owing to the general unsuitability for use with arc control devices.

(c) **Butt contacts**: Fig. 19.15 (ii) shows the butt type contact and is formed by the springs and the moving contact. It possesses two advantages. Firstly, spring pressure is available to assist contact separation. This is useful in single-break oil circuit breakers and air-blast circuit breakers where relatively small ―loop‖ forces are available to assist in opening. Secondly, there is no grip force so that this type of contact is especially suitable for higher short circuit rating.

Instrument transformers:

In a modern power system, the circuits operate at very high voltages and carry current of thousands of amperes. The measuring instruments and protective devices cannot work satisfactorily if mounted directly on the power lines. This difficulty is overcome by installing instrument transformers on the power lines. The function of these instrument transformers is to transform voltages or currents in the power lines to values which are convenient for the operation of measuring instruments and relays.

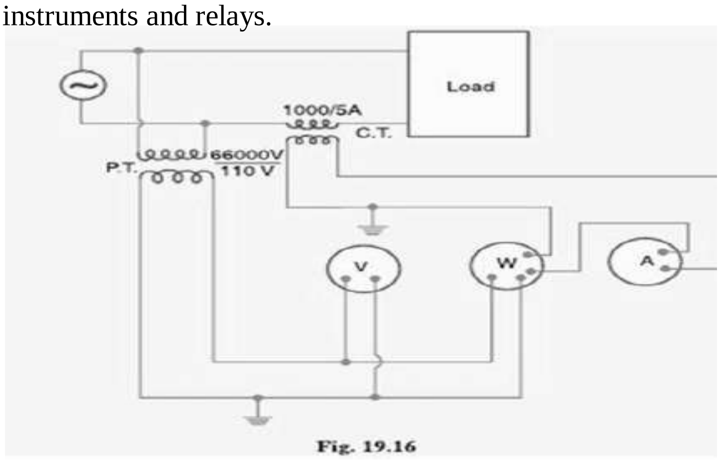


Fig. 19.16

There are two types of instrument transformers viz.

1. Current transformer (C.T.)
2. Potential transformer (P.T.)

The use of instrument transformers permits the following advantages:

(a) They isolate the measuring instruments and relays from high-voltage power circuits.

(b) The leads in the secondary circuits carry relatively small voltages and currents. This permits to use wires of smaller size with minimum insulation.

Bus-bars and conductors: The current carrying members in a circuit breaker consist of fixed and moving contacts and the conductors connecting these to the points external to the breaker. If the switchgear is of outdoor type, these connections are connected directly to the overhead lines. In case of indoor switchgear, the incoming conductors to the circuit breaker are connected to the bus bars.

Circuit Breaker Ratings:

(i) It must be capable of opening the faulty circuit and breaking the fault current.

(ii) It must be capable of being closed on to a fault.

(iii) It must be capable of carrying fault current for a short time while another circuit breaker (in series) is clearing the fault.

Corresponding to the above mentioned duties, the circuit breakers have three ratings viz.

1. Breaking capacity
2. Making capacity and
3. Short-time capacity.

Breaking capacity: It is current (r.m.s.) that a circuit breaker is capable of breaking at given recovery voltage and under specified conditions (e.g., power factor, rate of rise of restriking voltage).

Fig. 19.24, the contacts are separated at DD´ At this instant, the fault current has

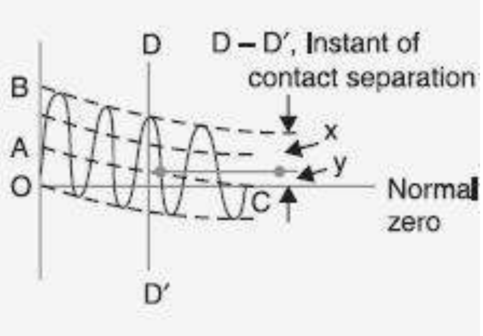


Fig. 19.24

Making capacity:

There is always a possibility of closing or making the circuit under short circuit conditions. The capacity of a breaker to ―make‖ current depends upon its ability to withstand and close successfully against the effects of electromagnetic forces. These forces are proportional to the square of maximum instantaneous current on closing. Therefore, making capacity is stated in terms of a peak value of current instead of r.m.s. value.

The peak value of current (including d.c. component) during the first cycle of current wave after the closure of circuit breaker is known as making capacity.

Making capacity =2·55 X Symmetrical breaking capacity

Short-time rating:

The oil circuit breakers have a specified limit of 3 seconds when the ratio of symmetrical breaking current to the rated normal current does not exceed 40. However, if this ratio is more than 40, then the specified limit is 1 second.

Normal current rating:

It is the r.m.s. value of current which the circuit breaker is capable of carrying continuously at its rated frequency under specified conditions. The only limitation in this case is the temperature rise of current-carrying parts.

Circuit Breaker

Classification of Circuit Breakers:

There are several ways of classifying the circuit breakers. However, the most general way of classification is on the basis of medium used for arc extinction. The medium used for arc extinction is usually oil, air, sulphur hexafluoride (SF6) or vacuum. Accordingly, circuit breakers may be classified into:

1. **Oil circuit breakers:** which employ some insulating oil (e.g., transformer oil) for arc extinction?
2. **Air-blast circuit breakers:** in which high pressure air-blast is used for extinguishing the arc.
3. **Sulphur hexafluoride circuit breakers:** in which sulphur hexafluoride (SF6) gas is used for arc

extinction.

4. **Vacuum circuit breakers:** in which vacuum is used for arc extinction.

Each type of circuit breaker has its own advantages and disadvantages. In the following sections, we shall discuss the construction and working of these circuit breakers with special emphasis on the way the arc extinction is facilitated.

Oil Circuit Breakers:

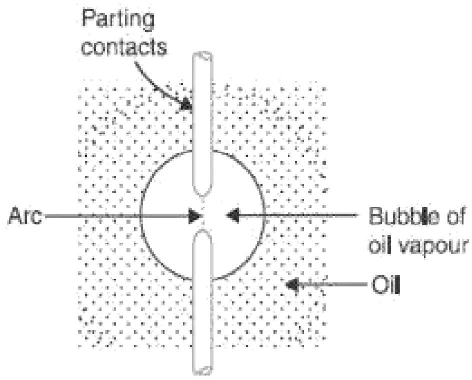


Fig. 19.2

The advantages of oil as an arc quenching medium are:

1. It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.
2. It acts as an insulator and permits smaller clearance between live conductors and earthed components.
3. The surrounding oil presents cooling surface in close proximity to the arc.

The disadvantages of oil as an arc quenching medium are:

1. It is inflammable and there is a risk of a fire.
2. It may form an explosive mixture with air
3. The arcing products (e.g., carbon) remain in the oil and its quality deteriorates with successive operations. This necessitates periodic checking and replacement of oil.

Types of Oil Circuit Breakers:

The oil circuit breakers find extensive use in the power system. These can be classified into the following types:

1. Bulk oil circuit breakers
2. Low oil circuit breakers

Bulk oil circuit breakers:

1. Plain break oil circuit breakers

2. Arc control oil circuit breakers.

exposed to the whole of the oil in the tank. However, in the latter type, special arc control devices are employed to get the beneficial action of the arc as efficiently as possible.

Plain Break Oil Circuit Breakers:

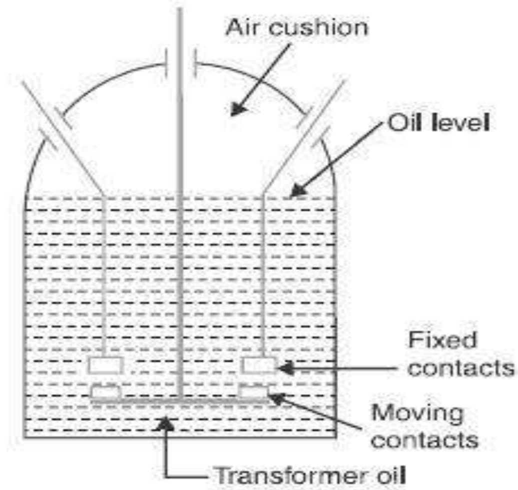


Fig. 19.3

Arc Control Oil Circuit Breakers:

There are two types of such breakers, namely:

1. **Self-blast oil circuit breakers**— in which arc control is provided by internal means i.e. the arc itself is employed for its own extinction efficiently.

2. **Forced-blast oil circuit breakers**— in which arc control is provided by mechanical means external to the circuit breaker.

.

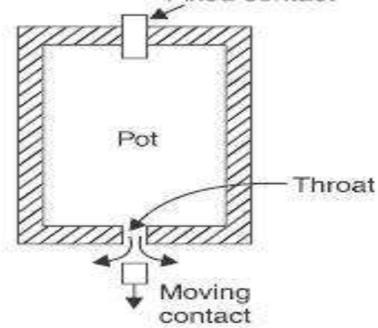


Fig. 19.4

The principal limitation of this type of pot is that it cannot be used for very low or for very high fault currents. With low fault currents, the pressure developed is small, thereby increasing the arcing time. On the other hand, with high fault currents, the gas is produced so rapidly that explosion pot is liable to burst due to high pressure. For this reason, plain explosion pot operates well on moderate short-circuit currents only where the rate of gas evolution is moderate

Cross jet explosion pot:

.

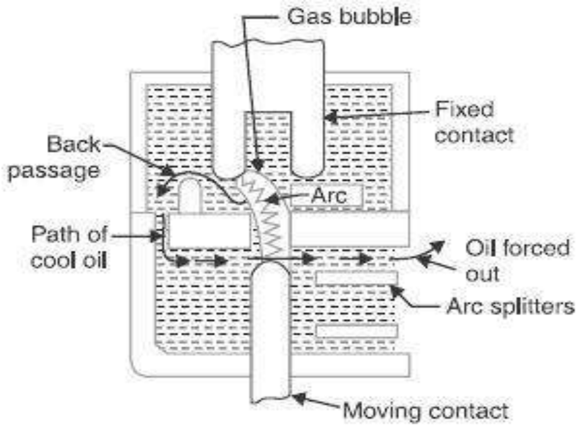


Fig. 19.5

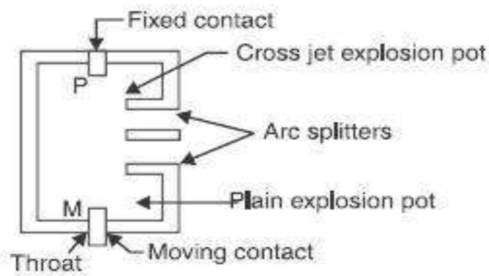


Fig. 19.6

Self-compensated explosion pot:

It may be noted that as the severity of the short circuit current increases, the device operates less and less as a plain explosion pot and more and more as a cross-jet explosion pot. Thus the tendency is to make the control self-compensating over the full range of fault currents to be interrupted.

Forced-blast oil circuit breakers:

Advantages:

1. Since oil pressure developed is independent of the fault current to be interrupted, the performance at low currents is more consistent than with self-blast oil circuit breakers.

2. The quantity of oil required is reduced considerably.

Low Oil Circuit Breakers:

Supporting chamber:

It is a porcelain chamber mounted on a metal chamber. It is filled with oil which is physically separated from the oil in the circuit breaking compartment. The oil inside the supporting chamber and the annular space formed between the porcelain insulation and bakelised paper is employed for insulation purposes only.

Circuit-breaking chamber:

It is a porcelain enclosure mounted on the top of the supporting compartment. It is filled with oil and has the following parts:

1. upper and lower fixed contacts
2. Moving contact
3. Turbulator

The moving contact is hollow and includes a cylinder which moves down over a fixed piston. The turbulator is an arc control device and has both axial and radial vents. The axial venting ensures the interruption of low currents whereas radial venting helps in the interruption of heavy currents.

Top chamber:

It is a metal chamber and is mounted on the circuit-breaking chamber. It provides expansion space for the oil in the circuit breaking compartment. The top chamber is also provided with a separator which prevents any loss of oil by centrifugal action caused by circuit breaker operation during fault conditions.

Operation:

Under normal operating conditions, the moving contact remains engaged with the upper fixed contact. When a fault occurs, the moving contact is pulled down by the tripping springs and an arc is struck. The arc energy vaporizes the oil and produces gases under high pressure. This action constrains the oil to pass through a central hole in the moving contact and results in forcing series of oil through the respective passages of the tabulator. The process of tabulation is orderly one, in which the sections of the arc are successively quenched by the effect of separate streams of oil moving across each section in turn and bearing away its gases.

A low oil circuit breaker has the following advantages over a bulk oil circuit breaker:

1. It requires lesser quantity of oil.
2. It requires smaller space.
3. There is reduced risk of fire.
4. Maintenance problems are reduced.

A low oil circuit breaker has the following disadvantages as compared to a bulk oil circuit breaker:

1. Due to smaller quantity of oil, the degree of carbonization is increased.
2. There is a difficulty of removing the gases from the contact space in time.
3. The dielectric strength of the oil deteriorates rapidly due to high degree of carbonization.

Maintenance of Oil Circuit Breakers:

The maintenance of oil circuit breaker is generally concerned with the checking of contacts and dielectric strength of oil. After a circuit breaker has interrupted fault currents a few times or load currents several times, its contacts may get burnt by arcing and the oil may lose some of its dielectric strength due to carbonization. This results in the reduced rupturing capacity of the breaker. There fore, it is a good practice to inspect the circuit breaker at regular intervals of 3 or 6 months.

Air-Blast Circuit Breakers:

These breakers employ a high pressure *air-blast as an arc quenching medium. The contacts are opened in a flow of air-blast established by the opening of blast valve. The air-blast cools the arc and sweeps away the arcing products to the atmosphere. This rapidly increases the dielectric strength of the medium between contacts and prevents from re-establishing the arc. Consequently, the arc is extinguished and flow of current is interrupted.

An air-blast circuit breaker has the following advantages over an oil circuit breaker:

1. The risk of fire is eliminated.
2. The arcing products are completely removed by the blast whereas the oil deteriorates with successive operations; the expense of regular oil replacement is avoided.
3. The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small. This reduces the size of the device.
4. The arcing time is very small due to the rapid build up of dielectric strength between contacts. Therefore, the arc energy is only a fraction of that in oil circuit breakers, thus resulting in less burning of contacts.
5. Due to lesser arc energy, air-blast circuit breakers are very suitable for conditions where frequent operation is required.
6. The energy supplied for arc extinction is obtained from high pressure air and is independent of the current to be interrupted.

The use of air as the arc quenching medium offers the following disadvantages:

1. The air has relatively inferior arc extinguishing properties.
2. The air-blast circuit breakers are very sensitive to the variations in the rate of rise of re striking voltage.
3. Considerable maintenance is required for the compressor plant which supplies the air-blast.
4. The air blast circuit breakers are finding wide applications in high voltage installations.
5. Majority of the circuit breakers for voltages beyond 110 kV are of this type.

Types of Air-Blast Circuit Breakers:

Depending upon the direction of air-blast in relation to the arc, air-blast circuit breakers are classified into:

1. **Axial-blast type** in which the air-blast is directed along the arc path as shown in Fig. 19.8(i).
2. **Cross-blast type** in which the air-blast is directed at right angles to the arc path as shown in Fig. 19.8 (ii).
3. **Radial-blast type** in which the air-blast is directed radially as shown in Fig. 19.8 (iii).

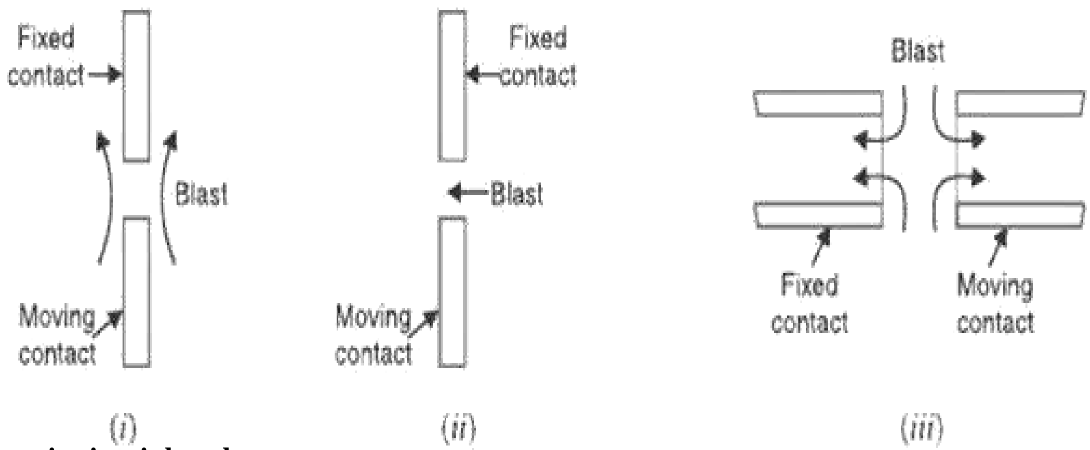


Fig. 19.8

Axial-blast air circuit breaker:

Fig 19.9 shows the essential components of a typical axial blast air circuit breaker. The fixed and moving contacts are held in the closed position by spring pressure under normal conditions. The air reservoir is connected to the arcing chamber through an air valve. This valve remains closed under normal conditions but opens automatically by the tripping impulse when a fault occurs on the system.

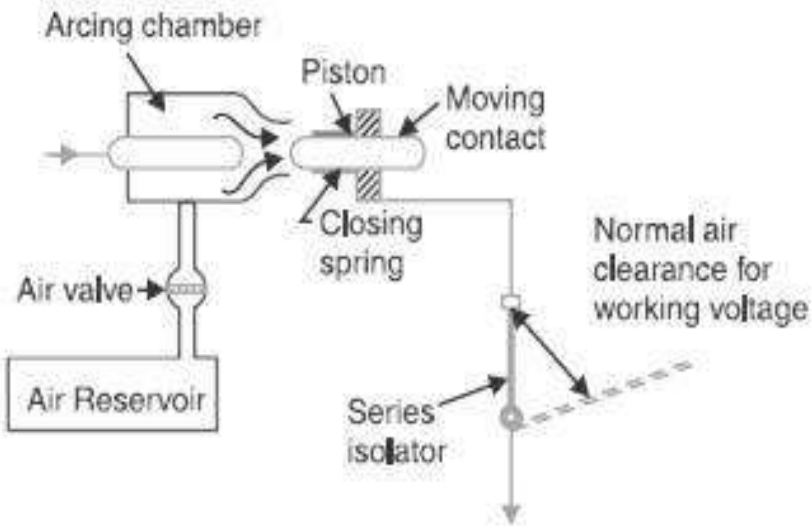


Fig. 19.9

Cross-blast air breaker:

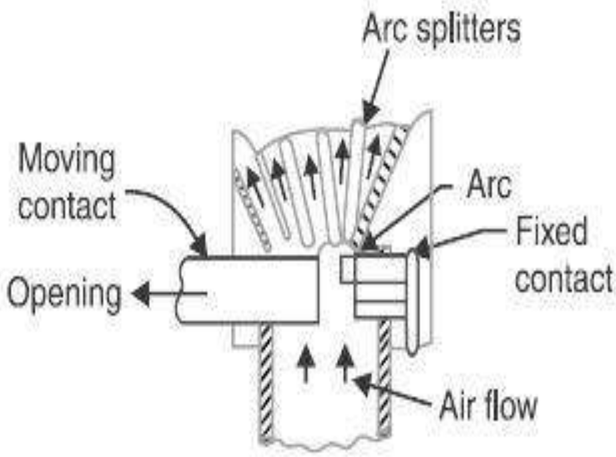


Fig. 19.10

Sulphur Hexafluoride (SF6) Circuit Breakers:

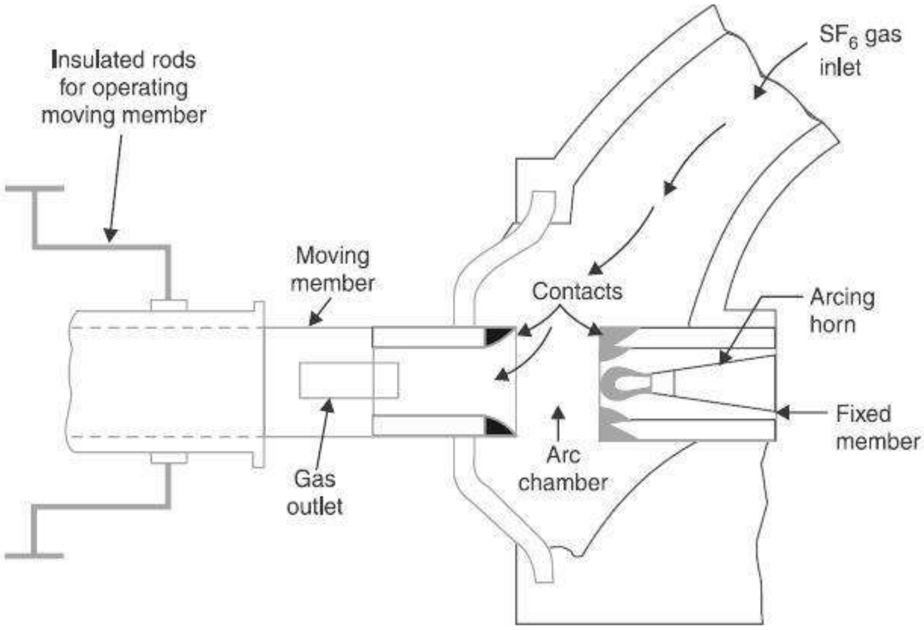


Fig. 19.11

Construction:

Advantages:

Due to the superior arc quenching properties of SF6 gas, the SF6 circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below:

1. Due to the superior arc quenching property of SF6, such circuit breakers have very short arcing time.
2. Since the dielectric strength of SF6 gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.
3. The SF6 circuit breaker gives noiseless operation due to its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker
4. The closed gas enclosure keeps the interior dry so that there is no moisture problem.

Disadvantages:

1. SF6 breakers are costly due to the high cost of SF6.

2. Since SF6 gas has to be reconditioned after every operation of the breaker, additional equipment is required

for this purpose.

Applications:

A typical SF6 circuit breaker consists of interrupter units each capable of dealing with currents up to 60 kA and voltages in the range of 50—80 kV. A number of units are connected in series according to the system

Vacuum Circuit Breakers (VC B):

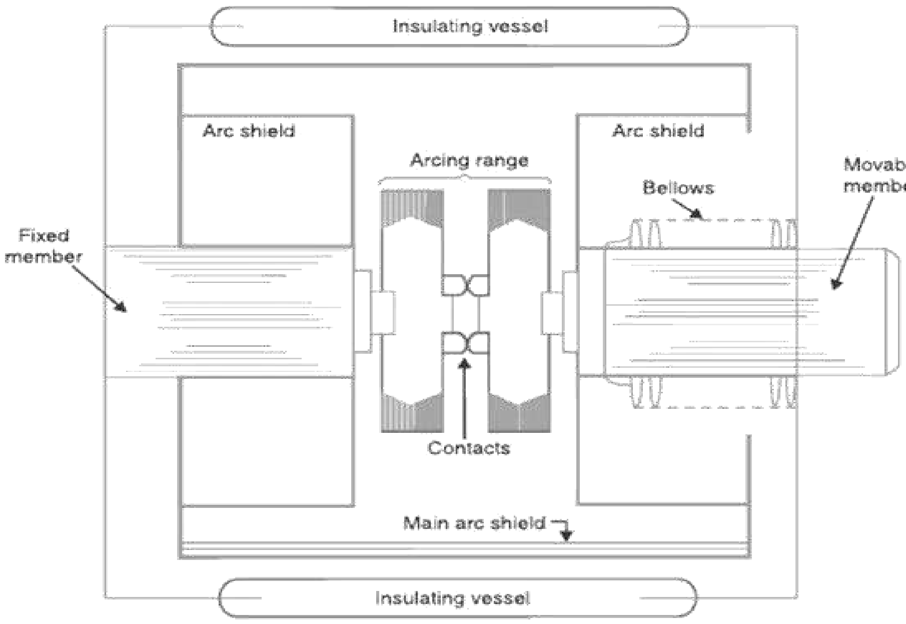


Fig. 19.12

Working:

When the breaker operates, the moving contact separates from the fixed contact and an arc is struck between the contacts. The production of arc is due to the ionization of metal ions and depends very much upon the material of contacts. The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in a short time and seized by the surfaces of moving and fixed members and shields. Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker occurs with a short contact separation (say 0·625 cm).

Vacuum circuit breakers have the following advantages:

1. They are compact, reliable and have longer life.
2. There is no generation of gas during and after operation.
3. They can interrupt any fault current. The outstanding feature of a V C B is that it can break any heavy fault current perfectly just before the contacts reach the definite open position.

Applications:

For a country like India, where distances are quite large and accessibility to remote areas difficult, the installation of such outdoor, maintenance free circuit breakers should prove a definite advantage. Vacuum circuit breakers are being employed for outdoor applications ranging from 22 kV to 66 kV. Even with limited rating of say 60 to 100 MVA, they are suitable for a majority of applications in rural areas.

UNIT - II

3.2 ELECTROMAGNETIC RELAY

The following are the important types of electromagnetic relays.

1. Attracted Armature type Relay
2. Balanced Beam Relay
3. Induction Disc Relay
4. Induction Cup Relay

The Electro magnetic Relay operator when operating torque/force is greater than the retraining torque/force.

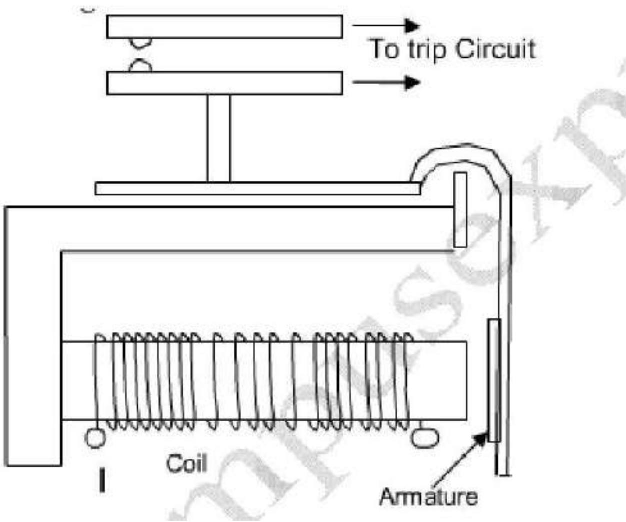
Attracted Armature Relay

This is one of the simplest type of electromagnetic relay. Attracted armature relay has two types of constructions.

1. Hinged armature constructed
2. Plunger type construction.

Hinged armature type relay is shown in the figure 3.1(a) drawn below.

Figure:3.1

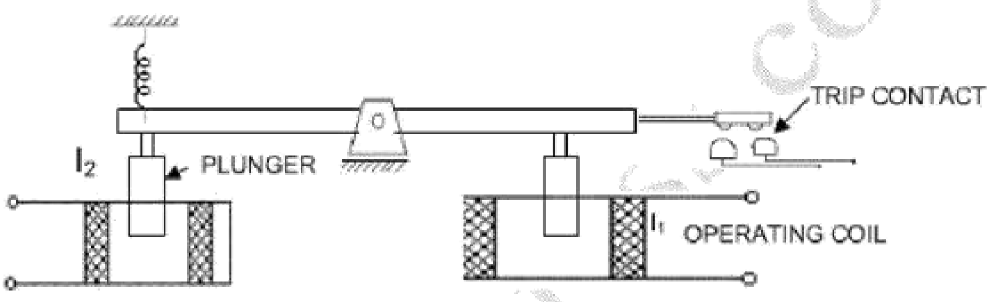


Balanced Beam Relay

Balanced Beam Relay consists of a horizontal relay pivoted at the centre. At the two ends of the beam, one armature is attached, and each armature is energized by two coils- operating coil and restraining coil.

When operating force is less than the restraining force, the beam remains in horizontal or slightly tilted position by means of spring such that the contacts are open. When operating force is greater than the restraining force the beam tilts down to close the contacts. The construction is shown in figure 3.2

Figure 3.2



Operating Principle

The net electromagnetic torque is given by

$$\tau = k_1 I_1^2 - k_2 I_2^2$$

Where I_1 = Current in operating coil

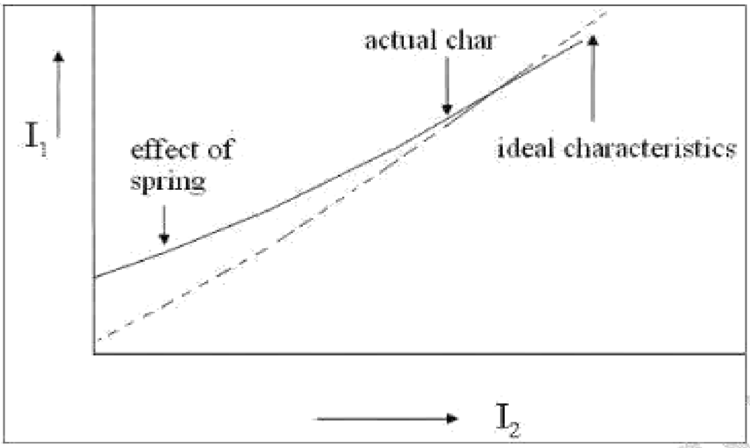
I_2 = Current in restraining coil

At the end of operation $\tau = 0$

$$k_1 I_1^2 = k_2 I_2^2$$

$$\Rightarrow \frac{I_1}{I_2} = \sqrt{\frac{K_2}{K_1}} = \text{Constant}$$

The operating characteristic is shown in the figure.



The curve is straight line, which is slightly tilted due to effect of spring. Balanced beam relay is difficult to design for large current because force is proportional to restraining current I_2.

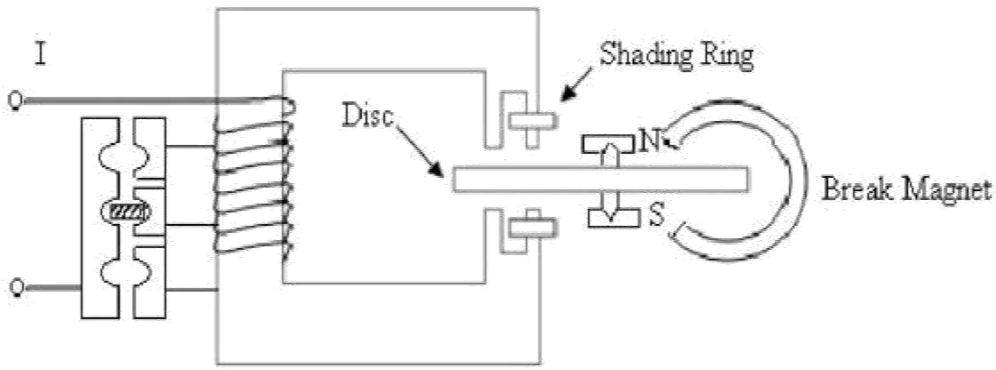
Induction Disc Relay

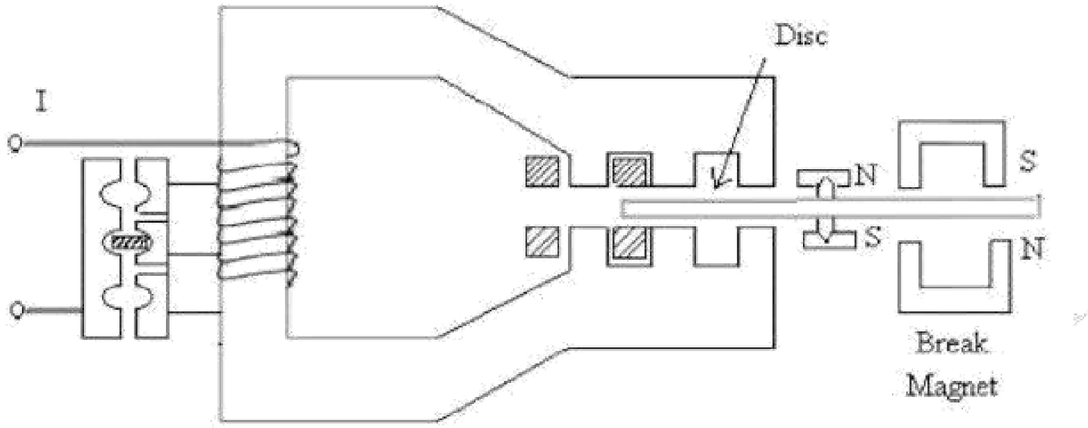
Induction Disc Relay has two types of constructions – shaded pole type induction disc relay and watt metric type induction disc relay.

Shaded – pole type disc relay

Simple construction of shaded – pole type disc relay is shown in figure 3.3(a) where as actual construction used practically is shown in figure 3.3(b).

Figure 3.3





It consists of a disc shaped electromagnet made of aluminum and a c-shaped electromagnet. One half of each pole is surrounded by a copper ring known as shaded ring. The flux produced by the pole with shading ring is displaced in phase with that of flux developed by the pole with out shading ring. These two flux induces eddy currents in electromagnet. The flux produced by one pole interacts with the eddy current produced by the flux of another pole and produces electromagnetic torque which rotates the disc.

Watt metric type Induction relay:

The construction for watt metric type induction relay is shown in the figure 3.4 drawn below.

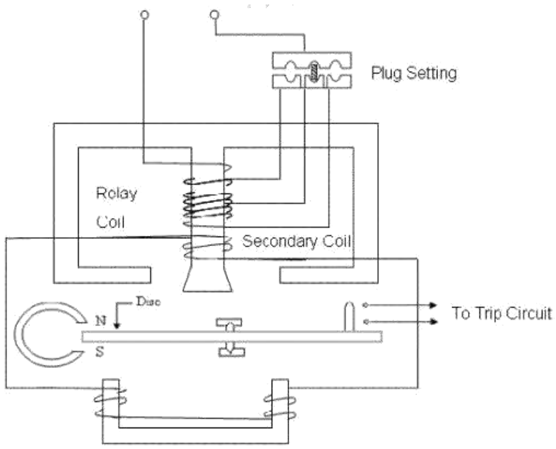


Figure 3.4

In this type of relay, these are two electromagnets wound with coils upper and lower one. These two coils are energized by two different supplies or a single supply with different resistance and reactance which causes phase displacement between two supplies.

The flux developed by each torque produces electromagnetic torque which tends to rotate the electromagnetic coil. The disc rotates at a speed proportional to the electromagnetic torque (or) driving torque. This driving torque is produced when operating current exceeds pick-up value; the disc remains stationary by the tension of the control spring.

Here we define two important settings for an induction disc relay.

Current Setting:

Current setting is provided by the tapping provided on coil. We can select a desired pick-up value by selecting a particular tapping.

Time Setting:

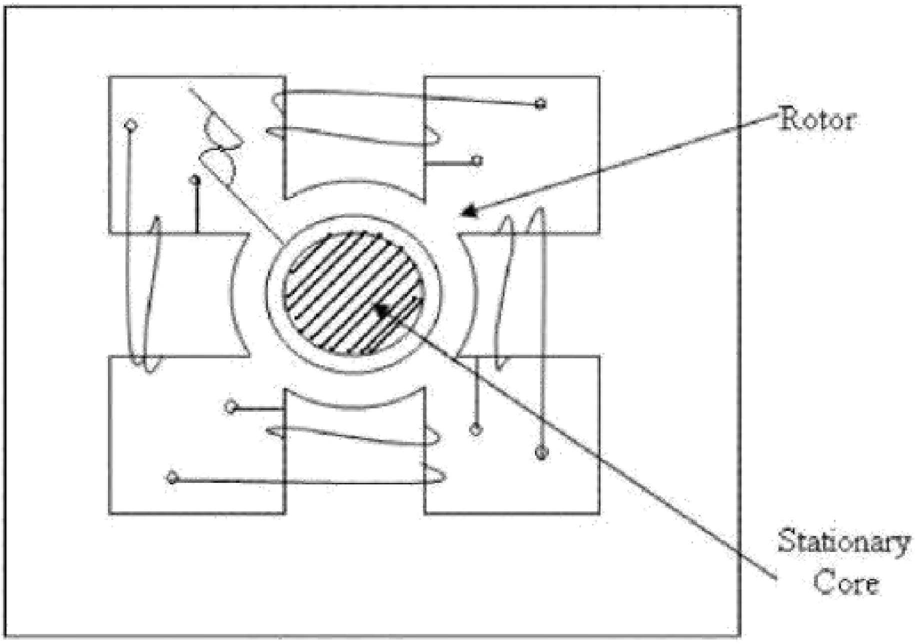
By adjusting the position of the back stop, the distance by which the disc travels before it closes the relay contact can be varied. If the back stop is advanced, the distance and hence operating time of the relay can be reduced.

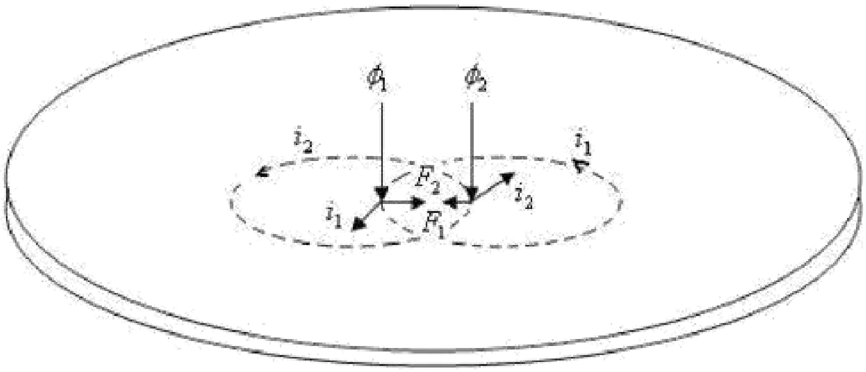
Induction Cup relay:

Induction cup relay consists of an inverted cup (Rotor) which is a hollow as Linder. It is enclosed by a 4 or 8-pole structure. To decrease the air gap with out increasing inertia, a stationary iron core is placed inside the cup. An arm is attached to spindle of cup, so that when cup is rotated, the contacts opens or closes.

Two pairs of coils are wound around the poles shown in the figure 3.5.

Figure 3.5





These currents produce flux which induces current in the cup. Due to the interaction of flux with the current, electromagnetic torque is developed which tends to rotate the cup and hence open or close the contacts.

The inertia of the cup is very much less. The magnetic leakage of the circuit is also less and hence this relay is more efficient. Its operating speed is also high. The dc transients in it are self eliminated. Magnetic saturation can be avoided in this type of relay.

Theory of Induction relay torque.

In both induction cup and disc relays, the force on the rotor is produced to interaction of one flux with the current produced by other flux.

If Φ_1 is flux produced by one coil and Φ_2 is flux produced by other coil with a phase difference of θ (i.e., Φ_2 leads Φ_1 by θ) they are expressed as

$\phi_1 = \phi_{1m} \sin \omega t$ and

$\phi_2 = \phi_{2m} \sin(\omega t + \theta)$

$\therefore$ Voltage induced in the rotor

$$e_1 \propto \frac{d\phi_1}{dt}$$
$$\propto \phi_{1m} \cos \omega t$$
$$e_2 \propto \frac{d\phi_2}{dt}$$
$$\propto \phi_{2m} \cos(\omega t + \theta)$$

The eddy current induced in the rotor are in phase with their voltage.

$$\therefore i_1 \propto e_1 \propto \phi_{1m} \cos \omega t$$
$$i_2 \propto e_2 \propto \phi_{2m} \cos(\omega t + \theta)$$

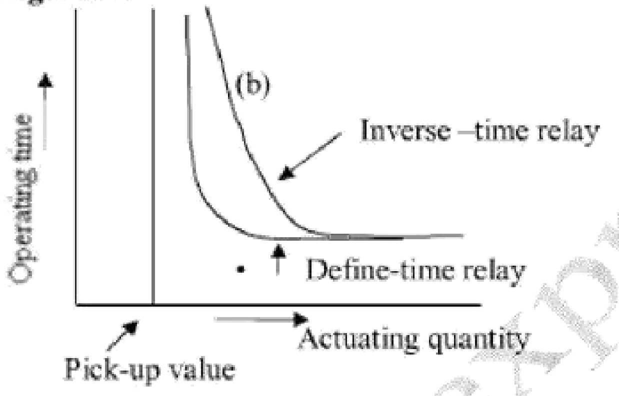
The eddy current induced in the rotor are in phase with their voltage.

$$\therefore i_1 \propto e_1 \propto \phi_{1m} \cos \omega t$$
$$i_2 \propto e_2 \propto \phi_{2m} \cos(\omega t + \theta)$$

The torque or force produced in the rotor is proportional to the product of flux linking it and eddy current produced by other flux.

$$\therefore F_1 \propto \phi_1 i_2$$
$$\propto \phi_{1m} \sin \omega t \times \phi_{2m} \cos(\omega t + \theta)$$

Figure 3.6



The predetermined definite time is set up by a time – delay mechanism.

Inverse – time relay:

Inverse – time relay operates when the actuating quantity exceeds pick – up value. The operating time depends upon the actuating quantity. If the actuating quantity (eg: current) increases, then the current decreases and vice-versa. The inverse time characteristics is shown in the figure 3.6(b)

Inverse Definite Minimum Time Over current (I.D.M.T) Relay:

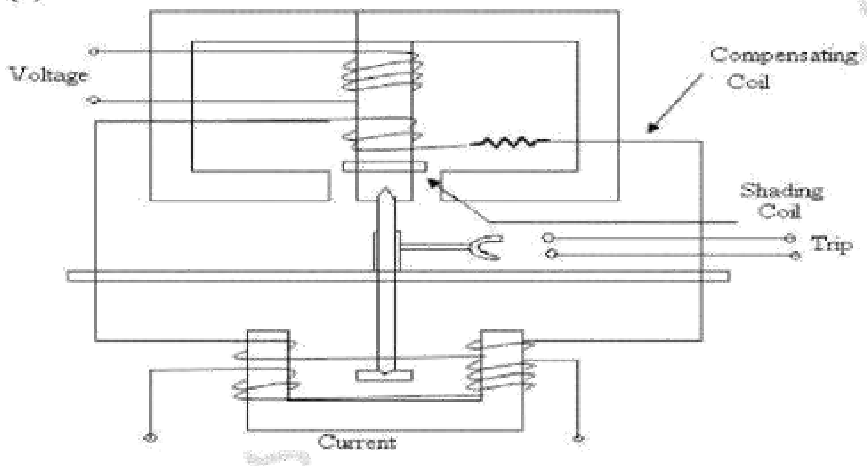
I.D.M.T Relay acts as inverse – time relay for low values of fault current and as definite – time relay for high value of fault current. If the plug setting multiplier is below 10, it shows inverse – time characteristics.

3.4. DIRECTIONAL RELAY:

A Directional Relay can be formed from an over current relay by adding a directional element to it. The directional relay operates, only when the current exceeds the pick – up value in only one direction. If the power flow is opposite to the specified direction, the directional relay does not operate. The directional relay does not measure the magnitude of the power flow, but it senses the direction of the power flow.

The figure drawn below shows electromagnetic induction disc type directional relay.

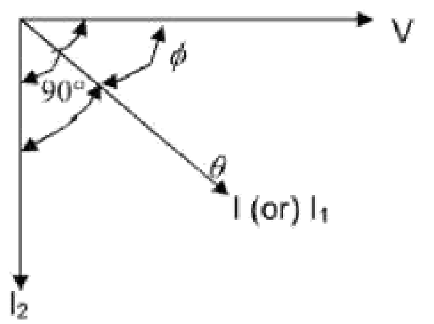
Figure 3.7(a)



It is energized two quantities current I (operating quantity) and voltage V (restraining quantity). The V and I sets up flux Φ_1 and Φ_2 respectively in the disc. Eddy current produced by Φ_1 interacts with Φ_2 and produces a torque. Similarly, eddy current produced by Φ_2 interact with Φ_1 also produces a torque. This torques tends to rotate the disc. Let the current in the voltage coil be I_L which lags the voltage V by 90^o. The load current I_1 lags the voltage V by Φ.

There fore the angle between I_1 and I_2 is $\theta = 90^o - \Phi$, the phasor diagram is shown below.

Figure 3.7 (b)



$\therefore$ Torque produced is given by

$$\tau \propto I_1 I_2 \sin\theta$$
$$\propto I_1 I_2 \sin(90^\circ - \phi)$$
$$\propto I_1 I_2 \cos\phi$$
$$\tau \propto VI \cos\phi$$

$\therefore$ Maximum torque is produced when

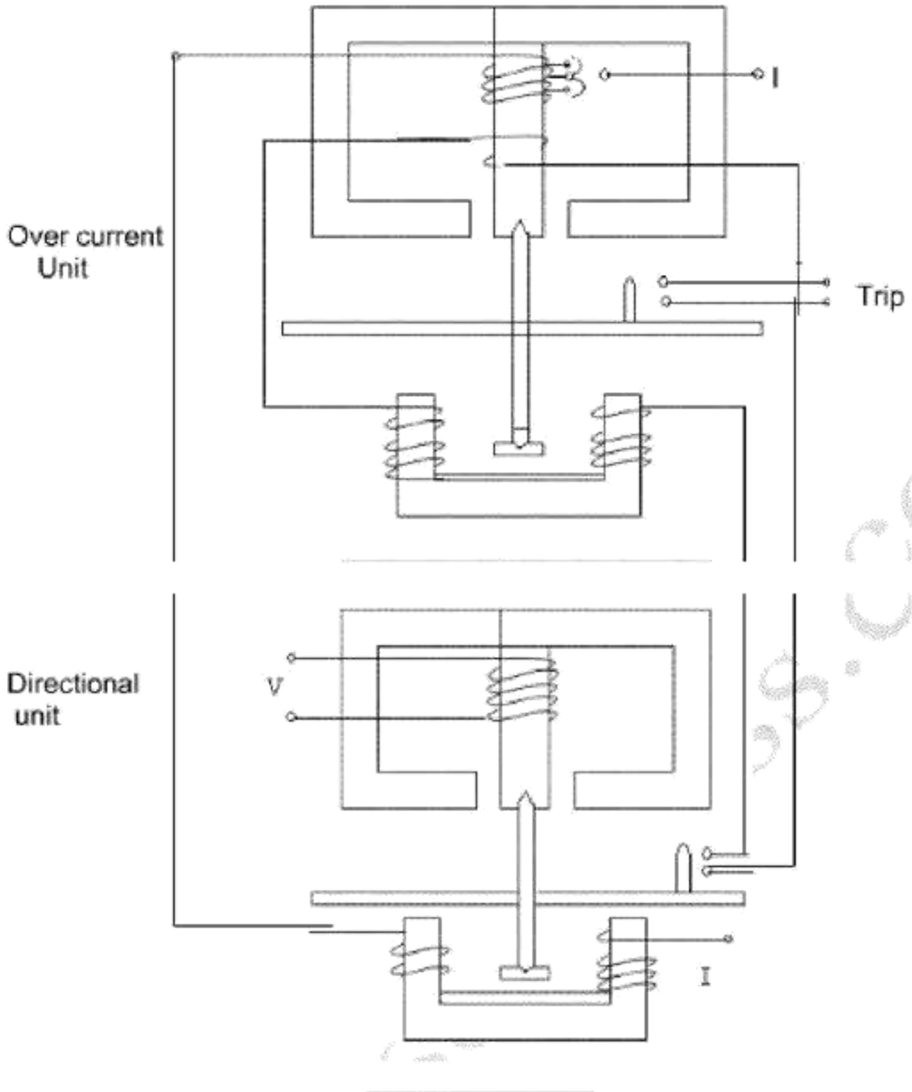
$$\cos\Phi = 1 \Rightarrow \Phi = 0$$

i.e., the voltage and current are in phase with each other.

Directional over Current Relay:

The figure drawn below shows directional over current relay.

Figure 3.8



In this a over current relay is used in conjunction with directional relay. The secondary winding of over current relay is kept open. When the directional relay operates, it closes the contacts of the secondary winding of the over current unit. Thus the directional feature is given to the over current relay.

Differential Relay:

A differential relay is one which responds to the vector difference between two or more similar electrical quantities. For example, a differential relay responds to the vector difference of two currents I_1, I_2 i.e., magnitude $|\bar{I}_1 - \bar{I}_2|$ and phase angle difference $<(\bar{I}_1 - \bar{I}_2)$, so differential protection needs two actuating quantities.

Operating Principle:

The operating principle can be explained by considering the circulating differential protection of generators or transformers. The figure below shows the one with no internal fault.

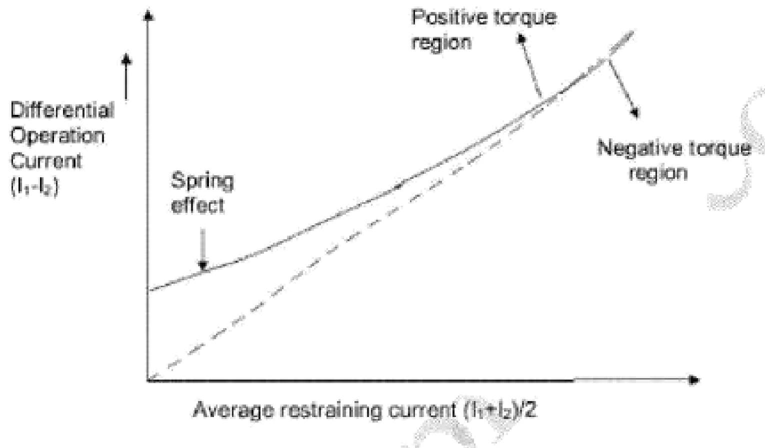
Figure 3.9(a)

$$= \left(\frac{I_1 + I_2}{2} \right) N$$

$$\therefore \text{Average restraining current } = \left(\frac{I_1 + I_2}{2} \right) \text{ in N turns}$$

If there is an external fault then $I_1$and I_2 increases, so that the average restraining current increases. When restraining torque becomes more than the operation, The characteristics of percentage differential relay is shown below.

Figure 3.11



The ratio of the differential operating current to average restraining current is a fixed percentage. There fore the relay is also called percentage differential relay. It is also called biased differential relay.

3.5 APPLICATION OF RELAY:

Over Current Relay:

An over current relay is the relay which operates when the magnitude of current exceeds a pick up level. Over current relays are of following types.

1. Instantaneous over current relay
2. Definite – time over current relay
3. Inverse – minimum time over current relay
4. Inverse Definite minimum time over current relay

Over current relay protects the system from over loads, short circuits such as 3-phase faults, earth faults etc.,

Applications:

An over current relay has wide range of applications. They are

1. Motor Protection:

Over current relay is used for the protection of motor against over loads, short circuits in stator windings.

2. Transformer protection:

Transformer is protected against faults using over current relay in addition with differential relay.

3. Line protection:

The lines can be protected by using instantaneous, inverse time, directional over current relays.

4. Protection of utility equipment:

The industrial, commercial and domestic equipment can be protected using over current relays.

3.5.2 Directional Relay:

A Directional Relay can be formed from an over current relay by adding a directional element to it. The directional relay operates, only when the current exceeds the pick-up value in only one direction. If the current or power flow is in opposite direction, the directional relay does not operate.

The directional relay does not measure the magnitude of the power flow, but it senses the direction of the power flow.

Applications:

Directional relay is used where the selectivity can be achieved by directional relaying. Some of the applications of directional relay are

1. In feeders:

Directional relay set in feeders is used to regulate power flow in certain directions.

2. In generators:

Directional relays are used in reverse power protection of generator. The directional relay operates when the power flow is in opposite direction to that of normal power flow.

3.5.3 Differential relay:

A Differential relay is one which responds to the vector difference between two or more similar electrical quantities.

For example, the differential relay responds to the vector difference of two currents I_1, I_2 i.e. magnitude and phase angle difference $|\bar{I}_1 - \bar{I}_2|$ and $< \bar{I}_1 - \bar{I}_2$ respectively. Hence differential relay needs two actuating quantities.

Applications:

1. Protection of Transformers
2. Protection of generators
3. Protection of Transmission line
4. Protection of feeders
5. Protection of large motors
6. Bus – zone protection

Distance Relays:

Distance protection is the protection and High Voltage (HV) and Extra High Voltage (EHV) transmission lines. It employs a number of distance relays. Each distance relay measures the impedance of the line from the fault point to the location of relay. Since the impedance is proportional to the line-length which in turn depends on the distance, the relay is called distance relay.

The distance protection provides both primary and back-up protection. Various types of distance relays are

i. Impedance Relay
ii. Reactance Relay
iii. MHO Relay
iv. Quadrilateral Relay
v. Elliptical Relays
vi. Angle impedance Relays

Here we discuss only first three types of relays.

3.6. IMPEDANCE RELAY:

An Impedance relay measures the impedance of the line from fault point to the point of location of relay. This impedance is proportional to the distance of the relay from the fault point. Impedance includes both resistance and reactance.

Operating Principle:

The Operating torque of an electromagnetic impedance relay is the sum of torques due to current, voltage and control-spring. Current produces operating torque (positive) and voltage produces restraining torque (negative).

$$\therefore \tau = K_1 I^2 - K_2 V^2 - K_3$$

where K_1, K_2 and K_3 are constants.

Since K_3 is very small, it is neglected

$$\tau = K_1 I^2 - K_2 V^2$$

For the relay to operate

Operating torque > restraining torque

$$\therefore K_1 I^2 > K_2 V^2$$

$$\Rightarrow \frac{V^2}{I^2} < \frac{K_1}{K_2}$$

$$\Rightarrow \frac{V}{I} < K$$

$$\Rightarrow Z < K \text{ ——— (1)}$$

For static or micro processor based impedance relays

$$K_1 I > K_2 V$$

$$\Rightarrow \frac{V}{I} < K$$

$$\Rightarrow Z < K \text{ ——— (2)}$$

From both equation (1) and (2),

We can say that the relay operates only when the measured impedance is less than the given constant.

Characteristics:

The V – I characteristics of impedance relay is shown in the graph drawn below.

Figure 3.12

The characteristic circle is z_1 is smaller, z_2 is medium and z_3 is larger. t_1, t_2 and t_3 are operating time for three relays.

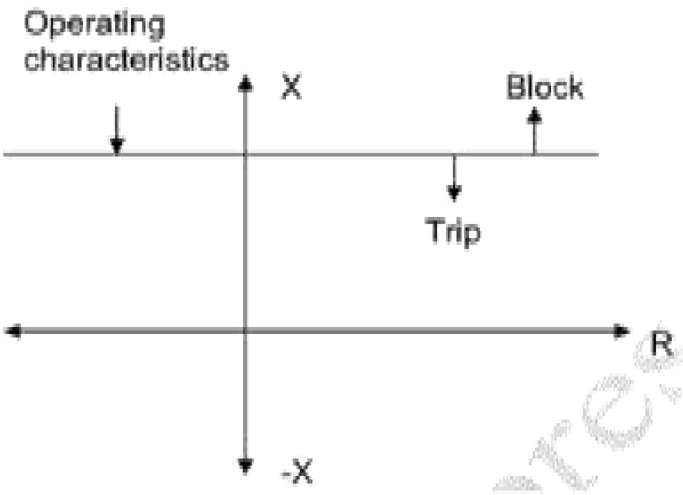
When a fault lies with in small circle and in the region of directional relay, the z_1 operates at a time t_1. When the fault lies outside z_1 but inside z_2, then T_2 closes after time t_2 when the circuit breaker trips. If the fault lies inside z_3 but outside z_1 and z_2, the circuit breaker trips after closure of contact T_3 at time t_3. The circuit breaker auxiliary switch is a normally closed switch. When the circuit breaker trips, the auxiliary switch is opened to prevent damage of battery. A seal in relay is used to protect of contacts of main relay.

Reactance Relay:

Similar to the impedance relay, reactance relay measures the reactance of the line between the relay location and fault point. The operation of this relay is independent of resistance but depends only on reactance of line.

Hence the operating characteristics of reactance relay on R-X diagram is a straight line parallel to R-axis as shown in the figure drawn below.

Figure 3.16



Induction – cup type reactance relay:

The figure drawn below shows Induction cup type reactance relay. The current produces polarizing flux in the upper, lower and right hand side poles. The flux in right hand side pole is out of phase with that of upper and lower poles due to its secondary winding closed through a phase shifting network.

The actuating quantity for left hand side pole is voltage through a phase shifting circuit.

There fore the polarizing flux interacts with right hand side pole to develop torque K_1I^2 (operating torque) and the flux interacts with left hand side pole to develop torque $K_2VI\cos(90^\circ-\Phi)$.

There fore the total torque is given by $\tau = K_1I^2 - K_2VI\cos(90^\circ-\Phi)-K_3$

Where K_3 is due to control spring.

For the relay to operate

Operating torque > Restraining torque

$\therefore K_1I^2 > K_2VI\cos(90^\circ-\Phi)$

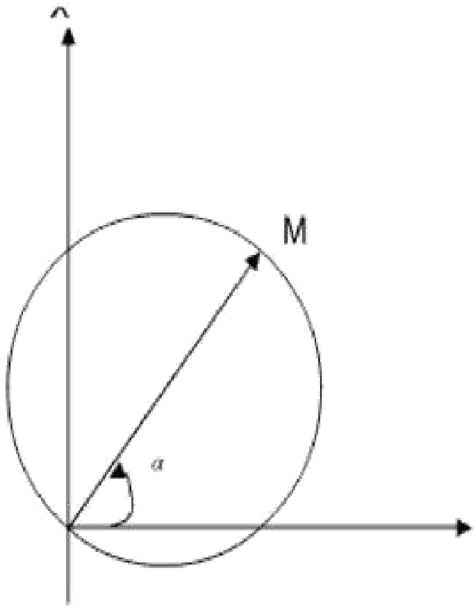
$K_1I > K_2V\sin\Phi$

$$\Rightarrow \frac{V}{I}\sin\Phi < \frac{K_1}{K_2}$$

$$\Rightarrow Z\sin\Phi < K$$

MHO Relay:

A MHO Relay or angle admittance relay measures a component of admittance | y |< θ. It is a directional relay. The operating characteristics of MHO relay is a circle passing through origin when plotted in R-X diagram. When plotted in admittance diagram (G-B axes), its characteristics is a straight line.



Electro magnetic MHO relay:

Electro magnetic induction cup type MHO relay is shown in the figure drawn below.

Figure 3.19

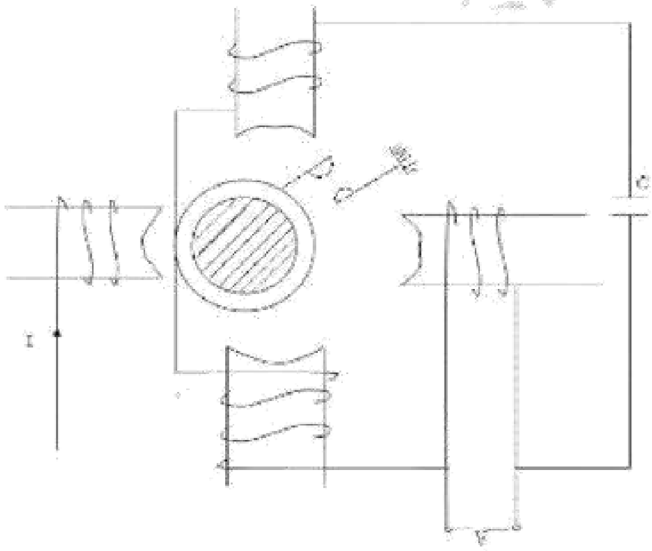
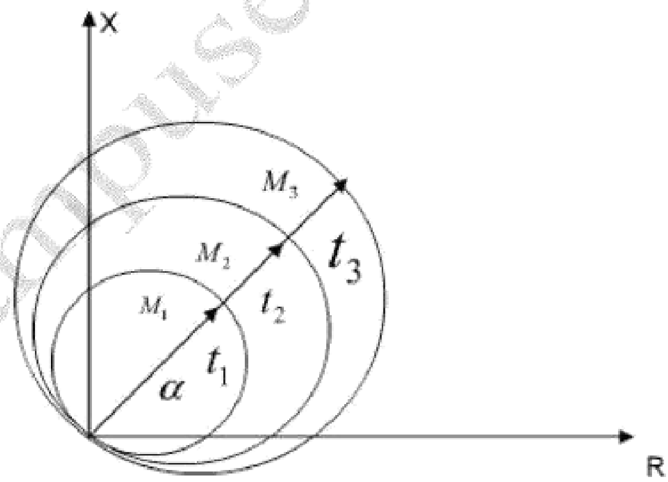


Figure 3.21

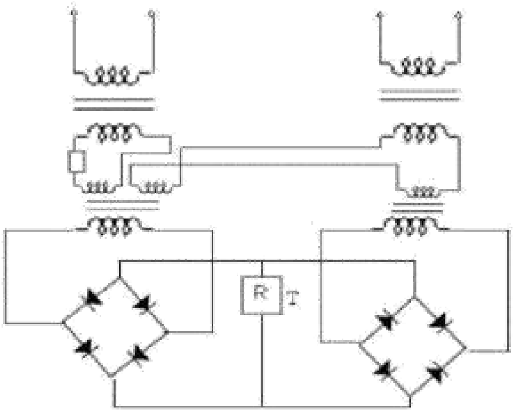


Unit I protects 80-90% of the protected section. Unit II protects 50% of the adjacent section. Unit III provides back-up protection.

Offset MHO Relay:

Offset MHO Relay can be realized using static MHO relay which is shown in figure below.

Figure 3.22



Here one actuating quantity is I (operating) and the other is [(V/z_r)-nI] (restraining). Here n represents are a fraction out put current of C.T is given to restrained circuit.

The relay operates only when

Operating quantity > Restraining quantity.

$$I > \left| \frac{V}{z_r} - nI \right|$$

Multiplying by z_r

$$|Iz_r| > |V - nIz_r|$$

Dividing by z

$$|z_r| > \left| \frac{V}{I} - nz_r \right|$$

$$=> |z_r| > |z - nz_r|$$

Notice that the characteristics of offset relay M_3 does not pass through origin. Unit III has following applications.

i. Busfar zone back-up
ii. Carrier starting unit
iii. Power swing blocking

Comparison of characteristics of Distance Relay:

Impedance Relay:

Impedance relay is slightly affected by arc resistance as well as power and voltage surges. But it fails to detect a fault within 80% of protected line. Hence it is extensity used for medium lines for phase fault relay.

Reactance Relay:

Reactance relay is less affected by are resistance and hence it is mainly used for ground fault relaying. It is also suitable for protection of short lines against phase faults. The main disadvantage of MHO relay is it is affected by power surges. So they are not suitable for longer lines since in long lines, power surges stays for a longer period.

MHO Relay:

MHO relay is less affected by power surges. MHO characteristics are best suited for protection of long lines against phase faults. But it is most affected by arc resistance.

3.7 STATIC RELAYS:

Static relay compares two electrical quantities using a static circuit and sends a tripping signal to the circuit breaker. The static circuit includes semiconductor diodes, transistors, thyristors, logic gates, diodes etc., static relays uses electromagnetic or dc polarized relays as slave relays. Slave relay do not actually measure the electrical quantity but it simply closed contact.

Static relays verses electromagnetic relays:

The advantages of static relays over electromagnetic are as follows:

1. Static relay is compact in size
2. Less maintenance is required
3. High resistance to shocks
4. Static relays consume less power. So it provides fewer burdens of potential transformers and current transformers.
5. There are no moving contacts.
6. A single static relay is used for several functions.
7. A static relay employs logic circuits. So it can do the process of reasoning.
8. It is used for remote back-up and network monitoring.

But the limitations of static relays are

1. The price of static relays is higher than the electromagnetic relays.
2. The device in the static circuit is very much affected by temperature.
3. Static devices such as thyristors are sensitive electro-static discharges (ESD).
4. The semi conductor devices are sensitive to voltage transistors. So they may get damaged.

Protection of Alternators and transformers

Unit-III

22.1 Protection of Alternators

The generating units, especially the larger ones, are relatively few in number and higher in individual cost than most other equipments. Therefore, it is desirable and necessary to provide protection to cover the wide range of faults which may occur in the modern generating plant.

Some of the important faults which may occur on an alternator are :

(*i*) failure of prime-mover
(*ii*) failure of field
(*iii*) overcurrent
(*iv*) overspeed
(*v*) overvoltage
(*vi*) unbalanced loading
(*vii*) stator winding faults

(*i*) **Failure of prime-mover.** When input to the prime-mover fails, the alternator runs as a synchronous motor and draws some current from the supply system. This motoring condi-tions is known as ―inverted running‖.

(*a*) In case of turbo-alternator sets, failure of steam supply may cause inverted running. If the steam supply is gradually restored, the alternator will pick up load without disturb-ing the system. If the steam failure is likely to be prolonged, the machine can be safely isolated by the control room attendant since this condition is relatively harmless. There-fore, automatic protection is not required.

(*b*) In case of hydro-generator sets, protection against inverted running is achieved by pro-viding mechanical devices on the water-wheel. When the water flow drops to an insuf-ficient rate to maintain the electrical output, the alternator is disconnected from the system. Therefore, in this case also electrical protection is not necessary.

(*c*) Diesel engine driven alternators, when running inverted, draw a considerable amount of power from the supply system and it is a usual practice to provide protection against motoring in order to avoid damage due to possible mechanical seizure. This is achieved by applying reverse power relays to the alternators which *isolate the latter during their motoring action. It is essential that the reverse power relays have time-delay in opera-tion in order to prevent inadvertent tripping during system disturbances caused by faulty synchronising and phase swinging.

(*ii*) **Failure of field.** The chances of field failure of alternators are undoubtedly very rare. Even if it does occur, no immediate damage will be caused by permitting the alternator to run without a field for a short-period. It is sufficient to rely on the control room attendant to disconnect the faulty alternator manually from the system bus-bars. Therefore, it is a uni-versal practice not to provide †automatic protection against this contingency.

(*iii*) **Overcurrent.** It occurs mainly due to partial breakdown of winding insulation or due to overload on the supply system. Overcurrent protection for alternators is considered unnec-essary because of the following reasons :

(*a*) The modern tendency is to design alternators with very high values of internal imped-ance so that they will stand a complete short-circuit at their terminals for sufficient time without serious overheating. On the occurrence of an overload, the alternators can be disconnected manually.

(*b*) The disadvantage of using overload protection for alternators is that such a protection might disconnect the alternators from the power plant bus on account of some momen-tary troubles outside the plant and, therefore, interfere with the continuity of electric service

(*iv*) **Overspeed.** The chief cause of overspeed is the sudden loss of all or the major part of load on the alternator. Modern alternators are usually provided with mechanical centrifugal devices mounted on their driving shafts to trip the main valve of the prime-mover when a dangerous overspeed occurs.

(*v*) **Over-voltage.** The field excitation system of modern alternators is so designed that over-voltage conditions at normal running speeds cannot occur. However, overvoltage in an alternator occurs when speed of the prime-mover increases due to sudden loss of the alterna-tor load.

In case of steam-turbine driven alternators, the control governors are very sensitive to speed variations. They exercise a continuous check on overspeed and thus prevent the occurrence of over-voltage on the generating unit. Therefore, over-voltage protection is not provided on turbo-alternator sets.

(*a*) trip the main circuit breaker to disconnect the faulty alternator from the system (*b*) disconnect the alternator field circuit

(*vi*) **Unbalanced loading.** Unbalanced loading means that there are different phase currents in the alternator. Unbalanced loading arises from faults to earth or faults between phases on the circuit external to the alternator. The unbalanced currents, if allowed to persist, may either severely burn the mechanical fixings of the rotor core or damage the field winding.

Fig. 22.1 shows the schematic arrangement for the protection of alternator against unbalanced loading. The scheme comprises three line current transformers, one mounted in each phase, having their secondaries connected in parallel. A relay is connected in parallel across the transformer sec-ondaries. Under normal oper- ating conditions, equal currents flow through the different phases of the alternator and their algebraic sum is zero. Therefore, the sum of the cur-rents flowing in the secondar- ies is also zero and no current flows through the operating coil of the relay. However, if un- balancing occurs, the currents induced in the secondaries will be different and the resultant of these currents will flow through the relay. The operation of the Principles of Power System

(*b*) fault between phases

(*c*) inter-turn fault involving turns of the same phase winding

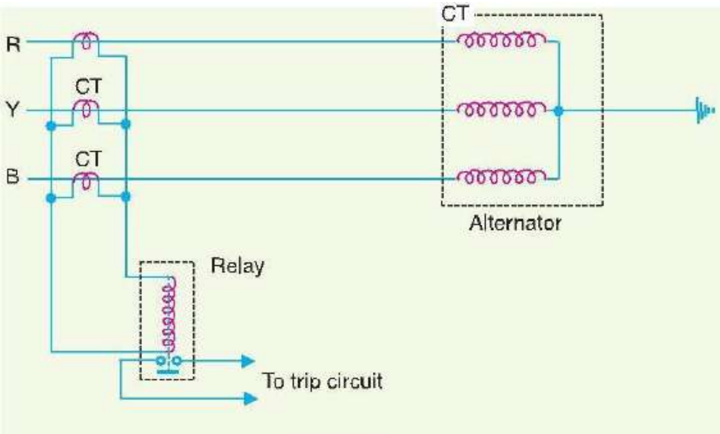


Fig. 22.1

22.2 Differential Protection of Alternators

Schematic arrangement. Fig. 22.2 shows the schematic arrangement of current differential protection for a 3-phase alternator. Identical current transformer pairs CT_1 and CT_2 are placed on either side of each phase of the stator windings. The secondaries of each set of current transformers are connected in star ; the two neutral points and the corresponding terminals of the two star groups being connected together by means of a four-core pilot cable. Thus there is an independent path for the currents circulating in each pair of current transformers and the corresponding pilot *P*.

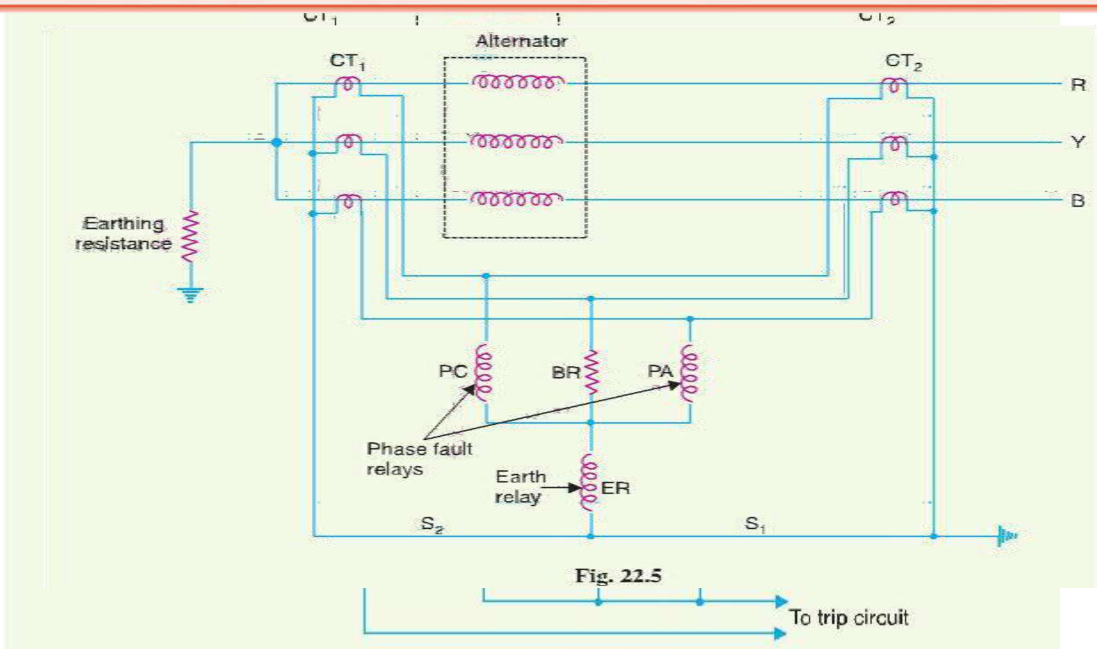


Fig. 22.2

may be insufficient voltage across the short-circuited portion to drive the necessary current round the fault circuit to operate the relay. The magnitude of unprotected zone depends upon the value of earthing resistance and relay setting.

Makers of protective gear speak of ―protecting 80% of the winding‖ which means that faults in the 20% of the winding near the neutral point cannot cause tripping *i.e.* this portion is unprotected. It is a usual practice to protect only 85% of the winding because the chances of an earth fault occurring near the neutral point are very rare due to the uniform insulation of the winding throughout.

22.3 Modified Differential Protection for Alternators

.

Operation. Under normal operating conditions, currents at the two ends of each stator winding will be equal. Therefore, there is a balanced circulating current in the phase pilot wires and no current flows through the operating coils of the relays. Consequently, the relays remain inoperative.

22.4 Balanced Earth-fault Protection

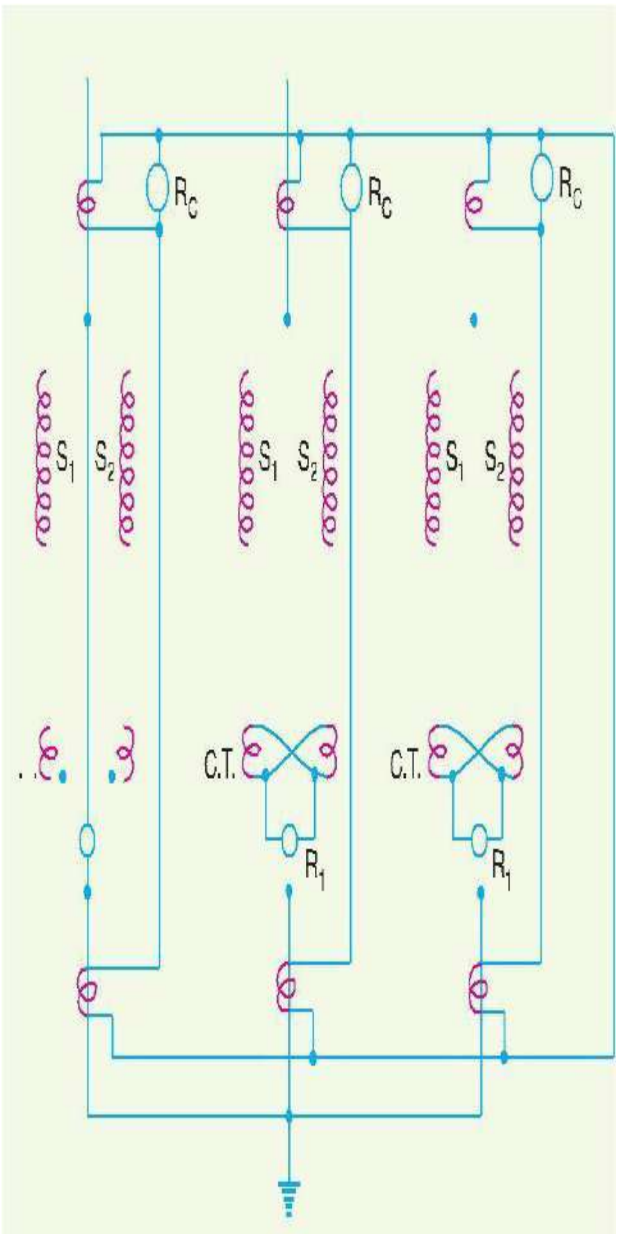
Schematic arrangement. Fig. 22.6 shows the schematic arrangement of a balanced earth-fault protection for a 3-phase alternator. It consists of three line current transformers, one mounted in each phase, having their secondaries connected in parallel with that of a single current transformer in the conductor joining the star point of the alternator to earth. A relay is connected across the transform-ers secondaries. The protection against earth faults is limited to the region between the neutral and the line current transformers.

Operation. Under normal operating conditions, the currents flowing in the alternator leads and hence the currents flowing in secondaries of the line current transformers add to zero and no current flows through the relay. Also under these conditions, the current in the neutral wire is zero and the secondary of neutral current transformer supplies no current flows through the relay. When an earth-fault occurs at F_1 or within the protected zone, these currents are no longer equal and the differential current flows through the operating coil of the relay. The relay then closes its contacts to disconnect the alternator from the system.

22.5 Stator Inter-turn Protection

Merz-price circulating-current system protects against phase-to-ground and phase-to-phase faults. It does not protect against turn-to-turn fault on the same phase winding of the stator. It is because the current that this type of fault R Y B produces flows in a local circuit between the turns involved and does not create a difference between the currents entering and leaving the winding at its two ends where current transformers are applied. However, it is usually considered unnecessary to provide protection for inter-turn faults because they invariably develop into earth-faults.

In single turn generator (*e.g.* C T large steam-turbine generators), there is no necessity of protection R_1 against inter-turn faults. However, inter-turn protection is provided for multi-turn generators such as hydro-electric generators. These generators have double-winding armatures (*i.e.* each phase wind-



Transformer Protection

Unit-IV

5.1 INTRODUCTION

The power transformer in the power system network is subjected to variety of faults. They include earth-faults, phase to phase faults, inter turns faults, over loading etc. So the transformer should be protected from theses faults.

The choice of protection of a particular transformer depends upon its rating, size and whether it has no- load or off-load tap changer for the transformer of small rating, fuses or relays may be used but for large rating transformers are protected using percentage differential protection.

5.2 PERCENTAGE DIFFERENTIAL PROTECTION

As mentioned the percentage differential protection is employed for transformer of large ratings. The differential protection responds to vector difference between two similar actuating quantities. This protection is explained in the following points

1. Two C.T's (Current Transformers) are connected at each end of the transformers
2. Pilot wires are connected between the CT's
3. The CT's are connected in Star or Delta
4. Biased coils are provided in series with pilot wires to avoid unwanted operation
5. The ratio of CT's and its connections should be set, such that the current fed into the pilot wires or equal at normal conditions
6. When there is an internal fault in the transformer such as phase –ground or phase to phase fault, the current are not equal and the difference currents (I1-I2) flows through the operating coil of relay.
7. The current flowing through the bias coil is given by $\frac{I1+I2}{2}$. This current provides the restraining torque.
8. When operating torque> restraining torque then the relay operates.

5.3 BUCHHOLZ RELAY PROTECTION

During internal faults in the transformer below oil level, an arc is formed. The heat of arc decomposes the transformer oil to form gases. The rate of formation of these gases depends on arc voltage and fault current. The gases formed can be used to detect those faults. One of the device is Buchholz relay. Buchholz relay is a gas actuated relay specifically gas accumulator relay. Buchholz relay mainly protects against incipient faults.

Principle of operation:-

Principle of operation of Buch holz can be explained in the following points with a figure drawn below.

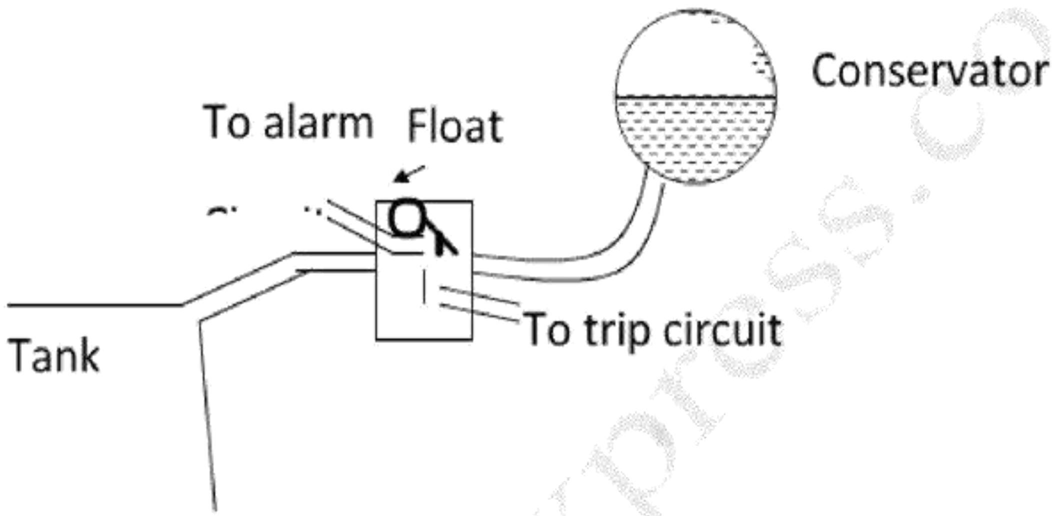


Fig Arrangement of Buchholz relay

1. The gases formed in decomposition of oil contains 70% of hydrogen gas.
2. Since hydrogen gas is light it raise up and tends to go in t conservator.
3. Buch holz relay is fitted in the pipe leading to the conservator as shown in fig 5.3(b).
4. The gases thus gets accumulated in the upper portion of buchholz relay above oil level so that the level of oil drops down.
5. Due to this the float which is floating in the oil tilts down.
6. Due to this tilting the mercury switch connected to the float closes the contacts and gives an alarm.
7. The alarm indicates there is some internal fault in the transformer and the fault should be immediately disconnected.
8. The internal faults may be phase, phase fault, phase ground fault or internal fault.
9. During severe faults the pressure in the tank increases very much.
10. Due o this the oil rushes into the conservator.
11. When the occurs the battle in the Buchholz relay gets pressed due to pressure of oil.
12. Then the mercury switch attached to battle closes its contacts and gives trip signal to stop the operation of transformer.
13. The kind of fault can be known by testing the gas for its color combustibility etc.

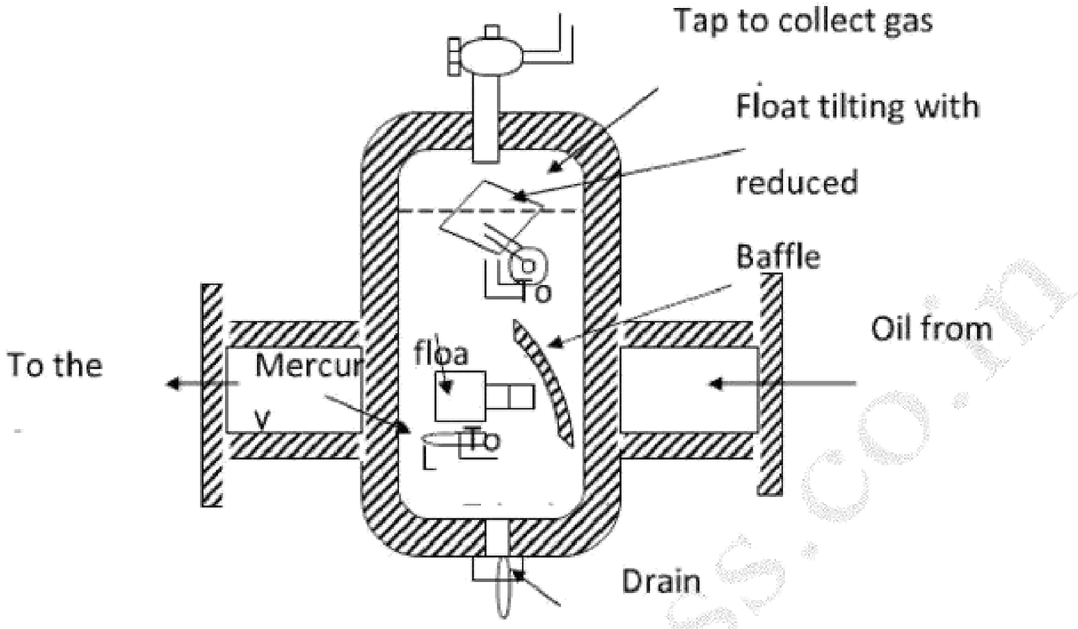


Fig: Buchholz relay principle. (Gas operated Relay)

But there are some limitations to the buch holz relay. They are

1. It cannot detect the faults above oil level.
2. It is employed only for the transformer with conservators.
3. The operating time of the relay is high. So the is very slow.
4. The setting of mercury switch should not be two sensitive other wise it is effected by shocks, vibrations quakes etc.
5. It is not used for transformers of rating below 500 KV for economical considerations.

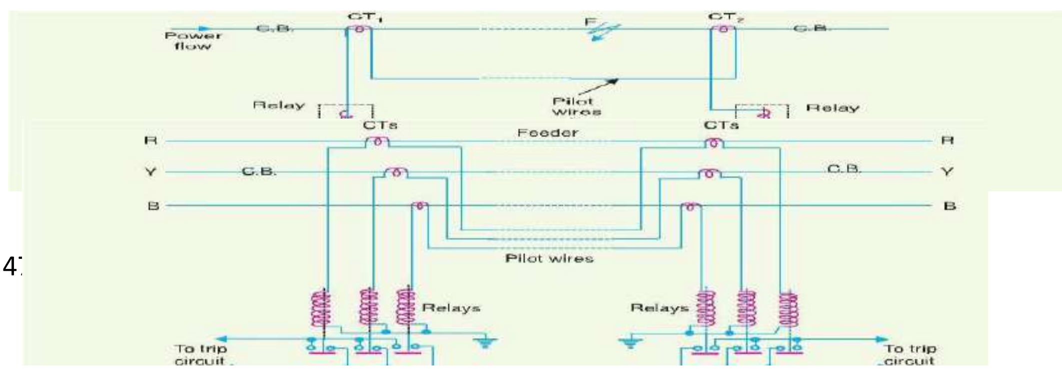
Differential Pilot-Wire Protection

Protection of Busbars and Lines

ing two schemes will be discussed :

- Merz-Price voltage balance system
- Translay scheme

1. Merz-Price voltage balance system. Fig. 23.8 shows the single line diagram of Merz-Price voltage balance system for the protection of a 3-phase line. Identical current transformers are placed in each phase at both ends of the line. The pair of *CTs* in each line is connected in series with a relay in such a way that under normal conditions, their secondary voltages are equal and in opposi-tion *i.e.* they balance each other.



Advantages

(*i*) This system can be used for ring mains as well as parallel feeders.

(*ii*) This system provides instantaneous protection for ground faults. This decreases the possibility of these faults involving other phases.

(*iii*) This system provides instantaneous relaying which reduces the amount of damage to over-head conductors resulting from arcing faults.

Disadvantages

(*i*) Accurate matching of current transformers is very essential.

(*ii*) If there is a break in the pilot-wire circuit, the system will not operate.

(*iii*) This system is very expensive owing to the greater length of pilot wires required. (*iv*) In case of long lines, charging current due to pilot-wire capacitance* effects may

be suffi-cient to cause relay operation even under normal conditions. (*v*) This system cannot be used for line voltages beyond 33 kV because of

constructional diffi-culties in matching the current transformers.

~~operating windings 13, 13 *a* are~~ connected in series in such a way that voltages induced in them oppose each other. Note that relay discs and tripping circuits have been omitted in the diagram for clarit

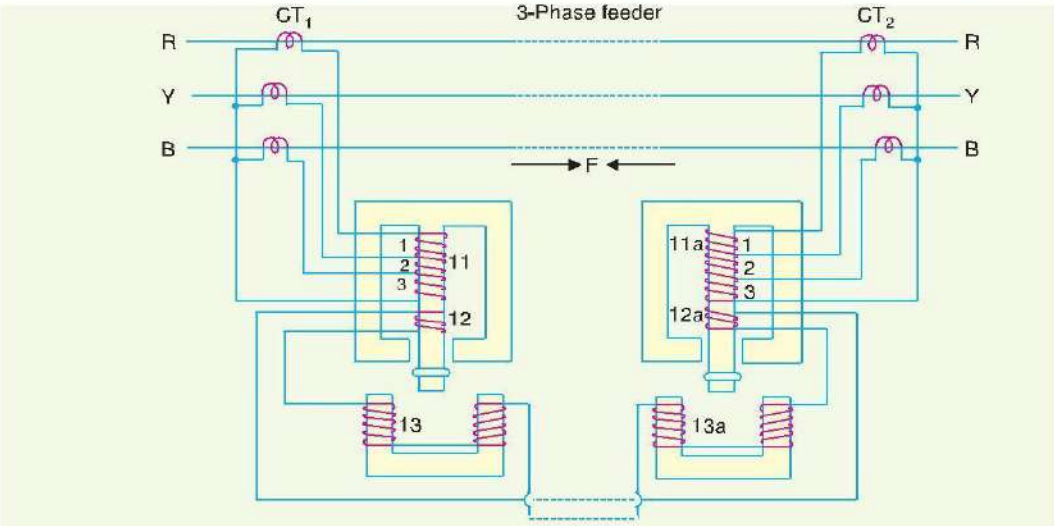


Fig. 23.11

Operation.

(*i*) Suppose a fault *F* occurs between phases *R* and *Y* and is fed from both sides as shown in Fig. 23.11. This will energise only section 1 of primary windings 11 and 11*a* and induce voltages in the secondary windings 12 and 12*a*. As these voltages are now additive*, therefore, current will circulate through operating coils 13, 13*a* and the pilot circuit. This will cause the relay contacts to close and open the circuit breakers at both ends. A fault between phases *Y* and *B* energises section 2 of primary windings 11 and 11*a* whereas that between *R* and *B* will energise the sections 1 and 2.

(*ii*) Now imagine that an earth fault occurs on phase *R*. This will energise sections 1, 2 and 3 of the primary windings 11 and 11*a*. Again if fault is fed from both ends, the voltages induced in the secondary windings 12 and 12*a* are additive and cause a current to flow through the operating coils 13, 13*a*. The relays, therefore, operate to open the circuit breakers at both ends of the line. In the event of earth fault on phase *Y* , sections 2 and 3 of primary winding 11 and 11*a* will be energised and cause the relays to operate. An earth fault on phase B will energise only section 3 of relay primary windings 11 and 11*a*.

Advantages

(*i*) The system is economical as only two pilot wires are required for the protection of a 3-phase line.

(*ii*) Current transformers of normal design can be used.

(*iii*) The pilot wire capacitance currents do not affect the operation of relays.

Neutral Grounding and Protection of Busbars and Lines

UNIT – V

Grounding or Earthing:

The process of connecting the metallic frame (i.e. non-current carrying part) of electrical equipment or some electrical part of the system (e.g. neutral point in a star-connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called grounding or earthing. It is strange but true that grounding of electrical systems is less understood aspect of power system. Nevertheless, it is a very important subject. If grounding is done systematically in the line of the power system, we can effectively prevent accidents and damage to the equipment of the power system and at the same time continuity of supply can be maintained.

Grounding or earthing may be classified as:

1. Equipment grounding
2. System grounding.

1. Ungrounded enclosure
2. Enclosure connected to neutral wire
3. Ground wire connected to enclosure.

Ungrounded enclosure:

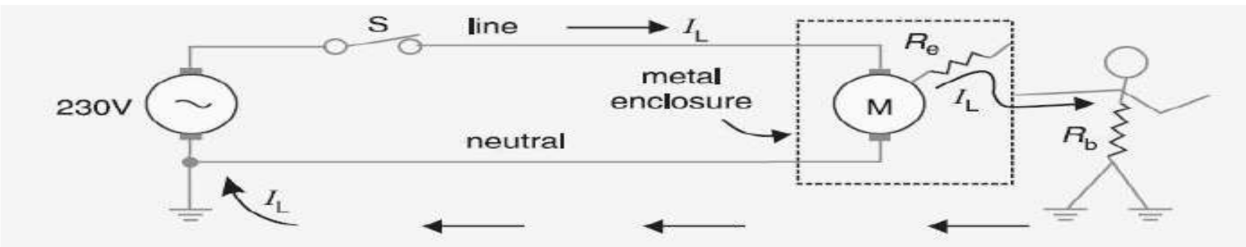


Fig. 26.1

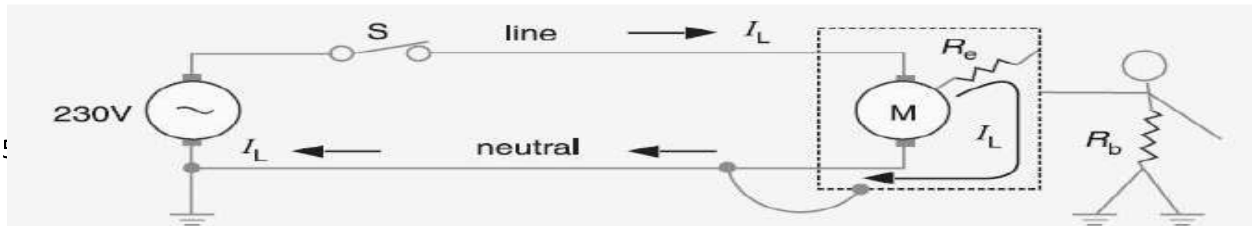


Fig. 26.2

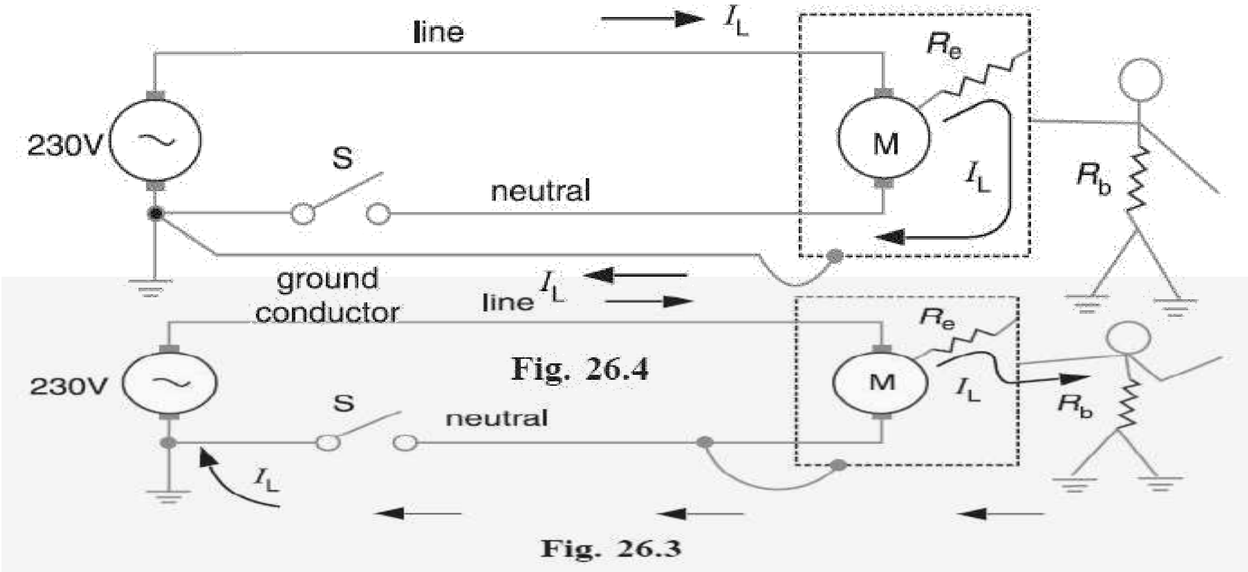


Fig. 26.4

Fig. 26.3

Electrical outlets have three contacts — one for live wire, one for neutral wire and one for ground wire.

System Grounding:

The process of connecting some electrical part of the power system (e.g. neutral point of a star-connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called system grounding.

The system grounding has assumed considerable importance in the fast expanding power system. By adopting proper schemes of system grounding, we can achieve many advantages including protection, reliability and safety to the power system network. But before discussing the various aspects of neutral grounding, it is desirable to give two examples to appreciate the need of system grounding.

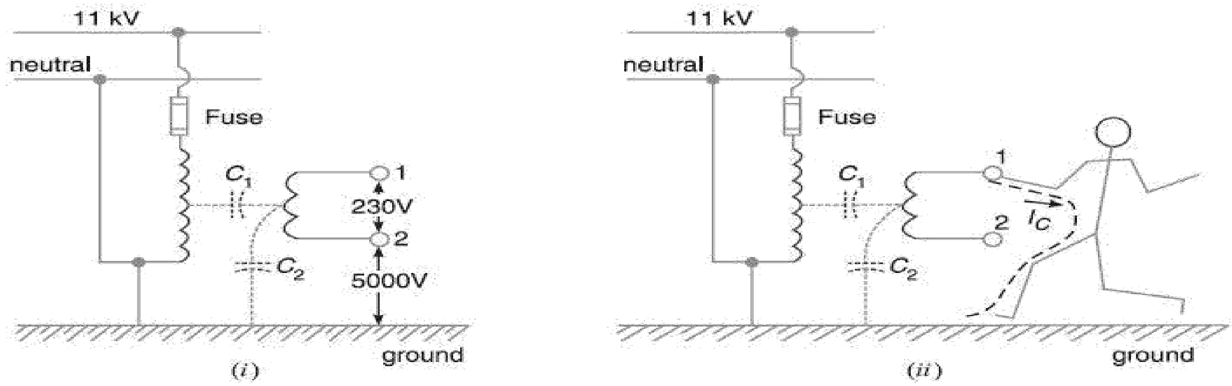


Fig. 26.5

one of the secondary conductors is grounded, the capacitive coupling almost reduces to zero and so is the capacitive current IC. As a result, the person will experience no electric shock. This explains the importance of system grounding.

(ii) Let us now turn to a more serious situation. Fig. 26.6 (i) shows the primary winding of a distribution transformer connected between the line and neutral of a 11 kV line. The secondary conductors are ungrounded. Suppose that the high voltage line (11 kV in this case) touches the 230 V conductor as shown in Fig. 26.6 (i). This could be caused by an internal fault in the transformer or by a branch or tree falling across the 11 kV and 230 V lines. Under these circumstances, a very high voltage is imposed between the secondary conductors and ground. This would immediately puncture the 230 V insulation, causing a massive flashover. This flashover could occur anywhere on the secondary network, possibly inside a home or factory. Therefore, ungrounded secondary in this case is a potential fire hazard and may produce grave accidents under abnormal conditions.

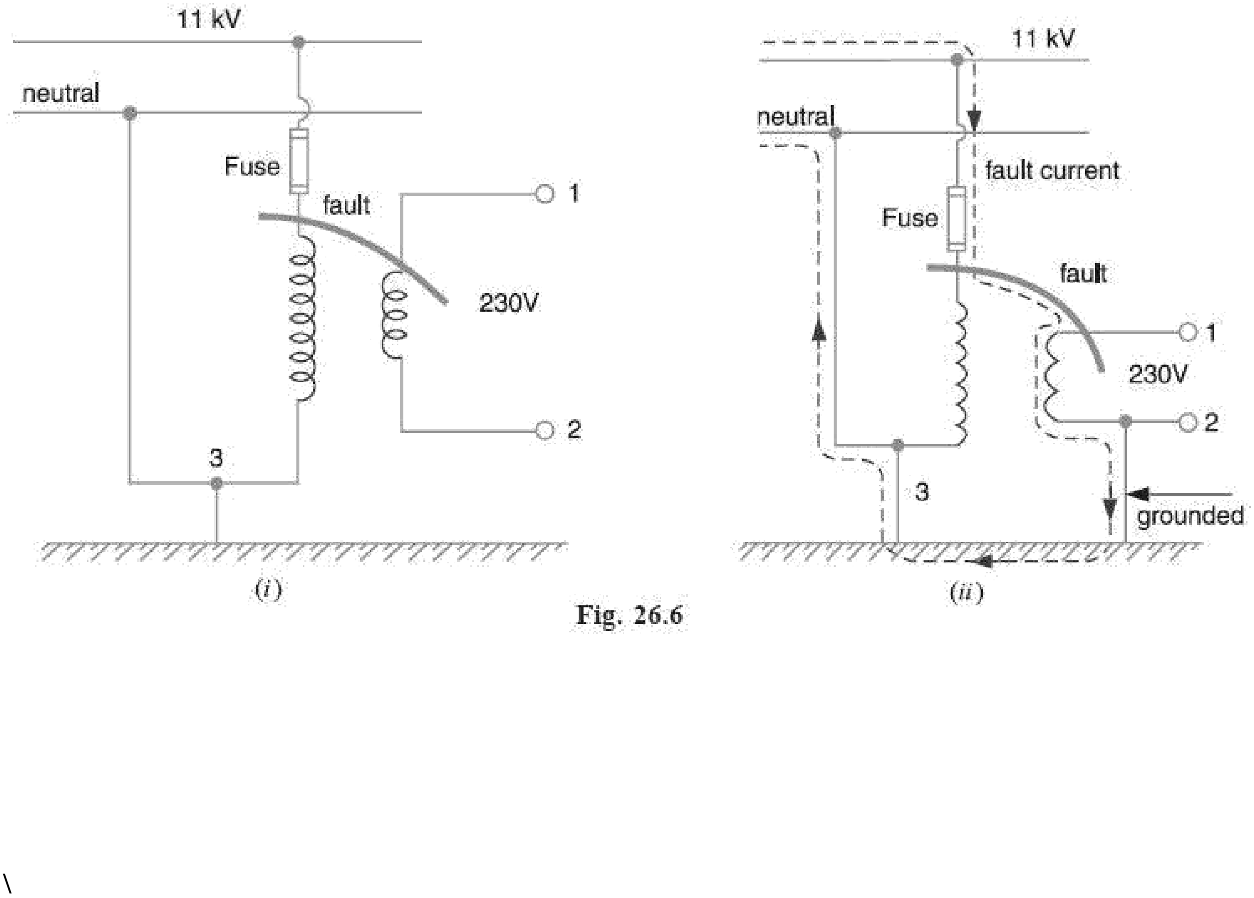


Fig. 26.6

\

Ungrounded Neutral System:

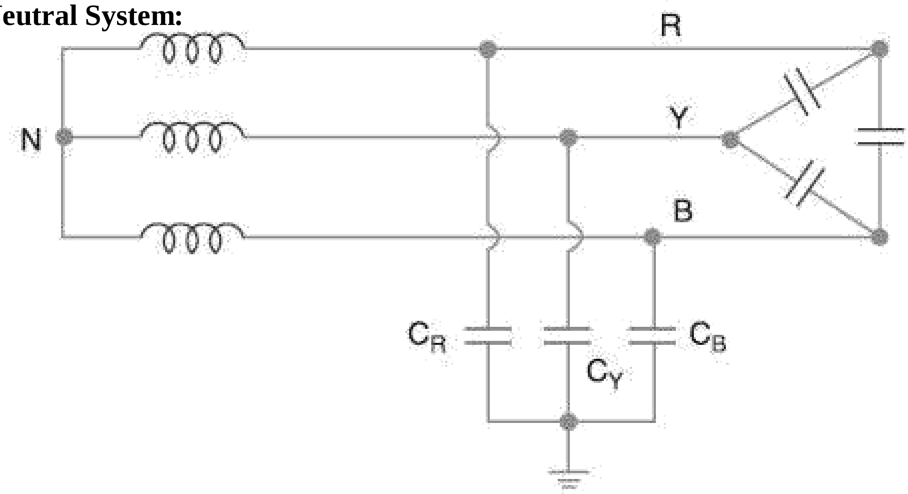


Fig. 26.7

Circuit behaviour under normal conditions. Let us discuss the behavior of ungrounded neutral system under normal conditions (i.e. under steady state and balanced conditions). The line is assumed to be perfectly transposed so that each conductor has the same capacitance to ground. Therefore, $C_R = C_Y = C_B = C$ (say). Since the phase voltages V_{RN}, V_{YN} and V_{BN} have the same magnitude (of course, displaced 120° from one another), the capacitive currents I_R, I_Y and I_B will have the same value i.e.

$$I_R = I_Y = I_B = V_{ph}/X_C \quad \text{.... in magnitude}$$

Where V_{ph} = Phase voltage (i.e. line-to-neutral voltage)

X_C = Capacitive reactance of the line to ground

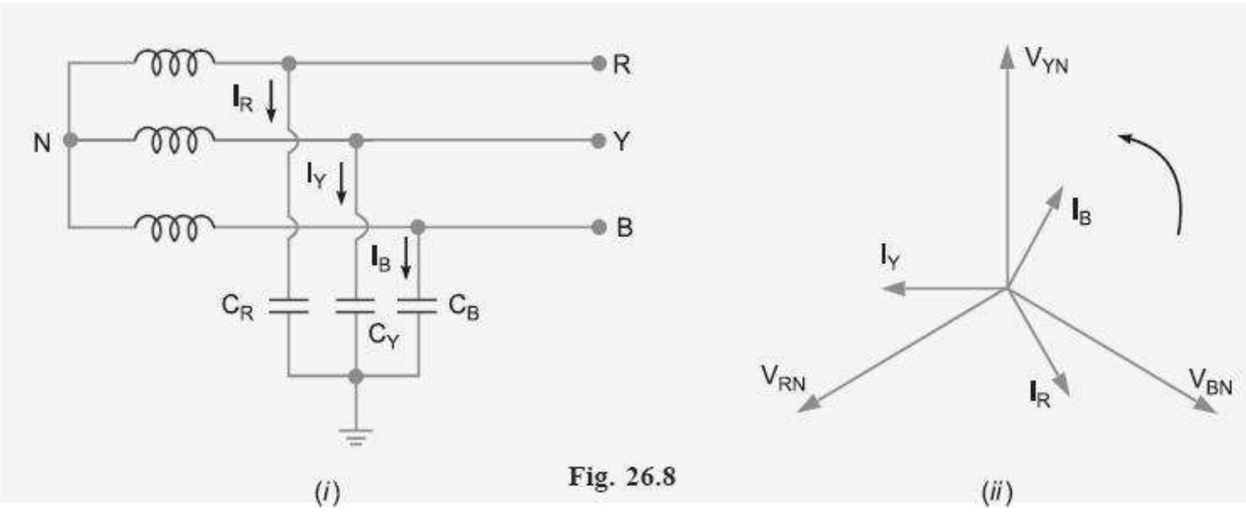


Fig. 26.8

The capacitive currents I_R, I_Y and I_B lead their respective phase voltages V_{RN}, V_{YN} and V_{BN} by 90°

Neutral Grounding

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

Neutral grounding provides protection to personal and equipment. It is because during earth fault, the current path is completed through the earthed neutral and the protective devices (e.g. a fuse etc.) operate to isolate the faulty conductor from the rest of the system. This point is illustrated in Fig. 26.10.

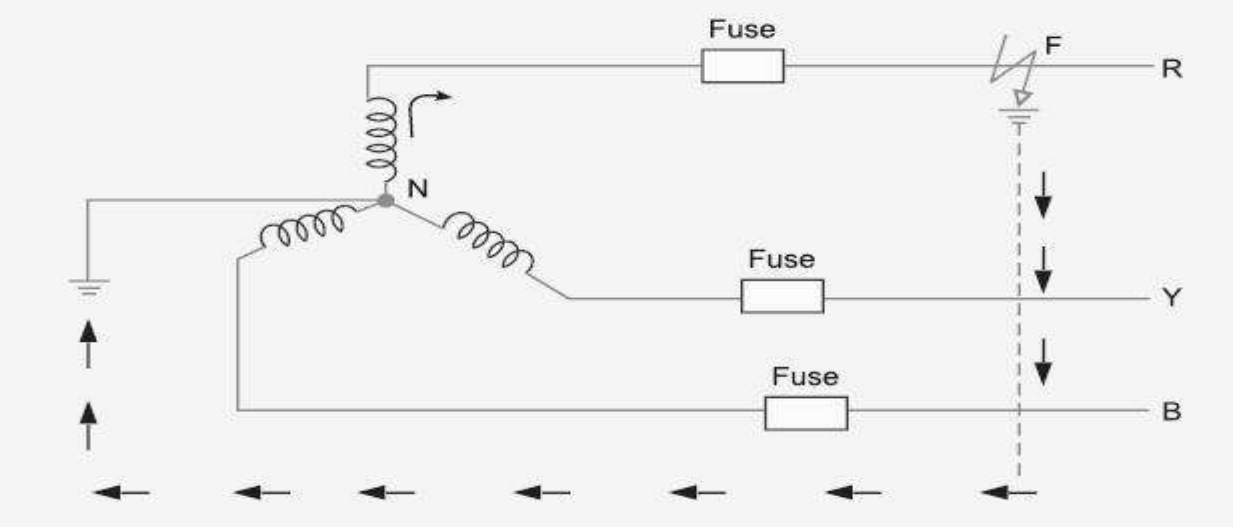


Fig. 26.10

Fig. 26.10 shows a 3-phase, star-connected system with neutral earthed (i.e. neutral point is connected to soil). Suppose a single line to ground fault occurs in line R at point F. This will cause the current to flow through ground path as shown in Fig. 26.10. Note that current flows from R-phase to earth, then to neutral point N and back to R-phase. Since the impedance of the current path is low, a large current flows through this path. This large current will blow the fuse in R-phase and isolate the faulty line R. This will protect the system from the harmful effects (e.g. damage to equipment, electric shock to personnel etc.) of the fault. One important feature of grounded neutral is that the potential difference between the live conductor and ground will not exceed the phase voltage of the system i.e. it will remain nearly constant.

Advantages of Neutral Grounding

The following are the advantages of neutral grounding :

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

Note: It is interesting to mention here that ungrounded neutral has the following advantages:

- In case of earth fault on one line, the two healthy phases will continue to supply load for a short period.
- Interference with communication lines is reduced because of the absence of zero sequence currents.
- The advantages of ungrounded neutral system are of negligible importance as compared to the advantages of the grounded neutral system. Therefore, modern 3-phase systems operate with grounded neutral points.

Methods of Neutral Grounding:

The methods commonly used for grounding the neutral point of a 3-phase system are :

1. Solid or effective grounding
2. Resistance grounding
3. Reactance grounding
4. Peterson-coil grounding

The choice of the method of grounding depends upon many factors including the size of the system, system voltage and the scheme of protection to be used.

Solid Grounding:

When the neutral point of a 3-phase system (e.g. 3-phase generator, 3-phase transformer etc.) is directly *connected to earth (i.e. soil) through a wire of negligible resistance and reactance, it is called solid grounding or effective grounding. Fig. 26.11 shows the solid grounding of the neutral point. Since the neutral point is directly connected to earth through a wire, the neutral point is held at Fig. 26.11 earth potential under all conditions. Therefore, under fault conditions, the voltage of any conductor to earth will not exceed the normal phase voltage of the system.

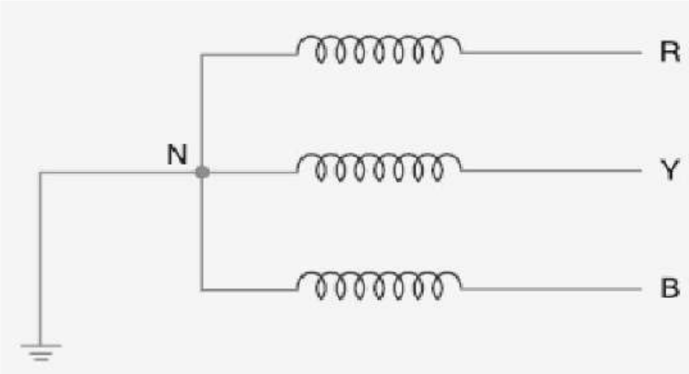


Fig. 26.11

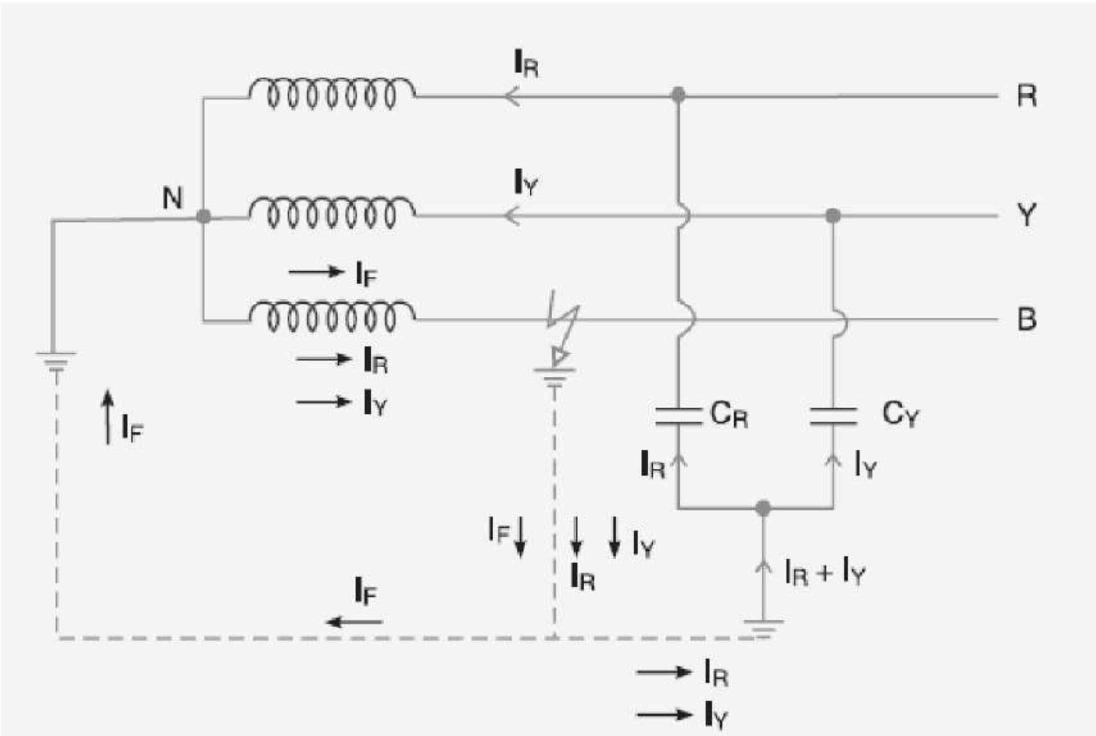


Fig. 26.12

The solid grounding of neutral point has the following advantages :

- The neutral is effectively held at earth potential.

- When earth fault occurs on any phase, the resultant capacitive current IC is in phase

The following are the disadvantages of solid grounding :

- Since most of the faults on an overhead system are phase to earth faults, the system has to bear a large number of severe shocks. This causes the system to become unstable.

- The solid grounding results in heavy earth fault currents. Since the fault has to be cleared by the circuit breakers, the heavy earth fault currents may cause the burning of circuit breaker contacts.

- The increased earth fault current results in greater interference in the neighbouring communication lines.

Applications:

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

Resistance Grounding:

In order to limit the magnitude of earth fault current, it is a common practice to connect the neutral point of a 3-phase system to earth through a resistor. This is called resistance grounding.

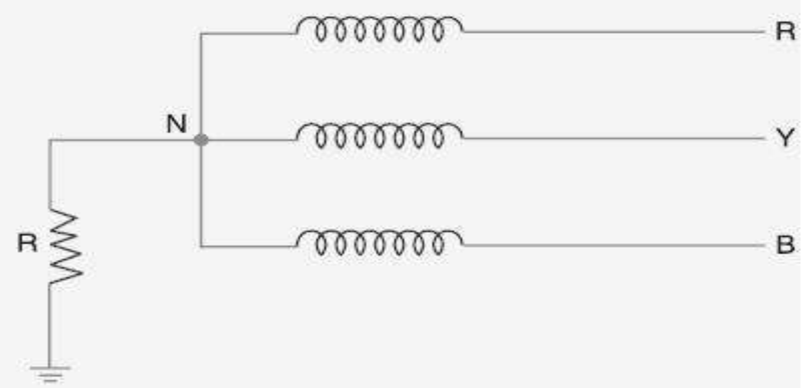


Fig. 26.13

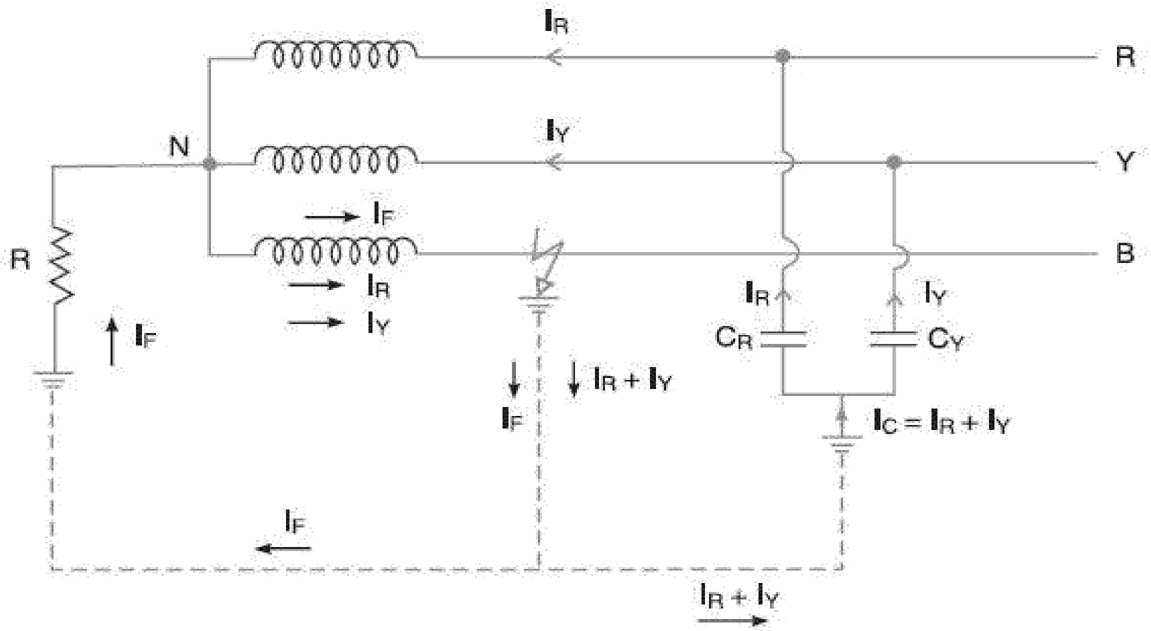


Fig. 26.14

The following are the advantages of resistance earthing:

(a) I_{F1} in phase with the faulty phase voltage.

(b) I_{F2} lagging behind the faulty phase voltage by 90°.

1. The lagging component I_{F2} is in phase opposition to the total capacitive current I_C. If the value
   of earthing resistance R is so adjusted that $I_{F2} = I_C$, the arcing ground is completely eliminated and the operation of the system becomes that of solidly grounded system. However, if R is so adjusted that $I_{F2} < I_C$, the operation of the system becomes that of ungrounded neutral system.

2. The earth fault current is small due to the presence of earthing resistance. Therefore, interference with communication circuits is reduced.

3. It improves the stability of the system.

The following are the disadvantages of resistance grounding :

1. Since the system neutral is displaced during earth faults, the equipment has to be insulated for higher voltages.
2. This system is costlier than the solidly grounded system.
3. A large amount of energy is produced in the earthing resistance during earth faults. Some times it becomes difficult to dissipate this energy to atmosphere.

Applications:

It is used on a system operating at voltages between 2.2 kV and 33 kV with power source capacity more than 5000 kVA.

Reactance Grounding:

In this system, a reactance is inserted between the neutral and ground as shown in Fig. 26.15. The purpose of reactance is to limit the earth fault current. By changing the earthing reactance, the earth fault current can to changed to obtain the conditions similar to that of solid grounding.

This method is not used these days because of the following disadvantages:

- In this system, the fault current required to operate the protective device is higher than that of resistance grounding for the same fault conditions.
- High transient voltages appear under fault conditions.

➢

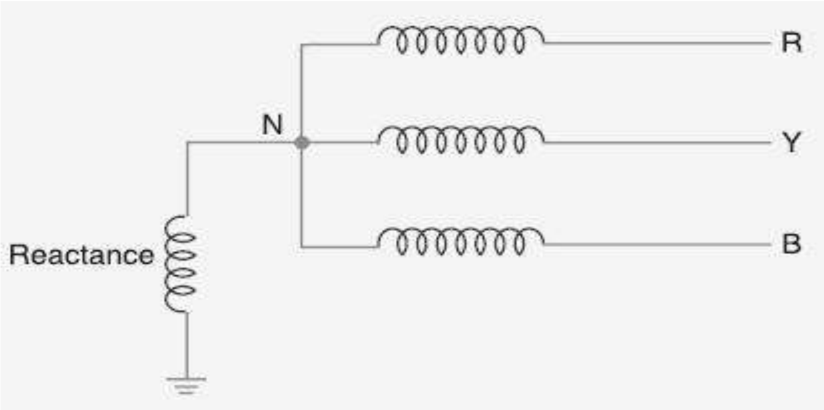


Fig. 26.15

Arc Suppression Coil Grounding (or Resonant Grounding):

exactly balances the capacitive current IC, it is called resonant grounding.

Circuit details:

An arc suppression coil (also called Peterson coil) is an iron-cored coil connected between the neutral and earth as shown in Fig. 26.16(i). The reactor is provided with tappings to change the inductance of the coil. By adjusting the tappings on the coil, the coil can be tuned with the capacitance of the system i.e. resonant grounding can be achieved.

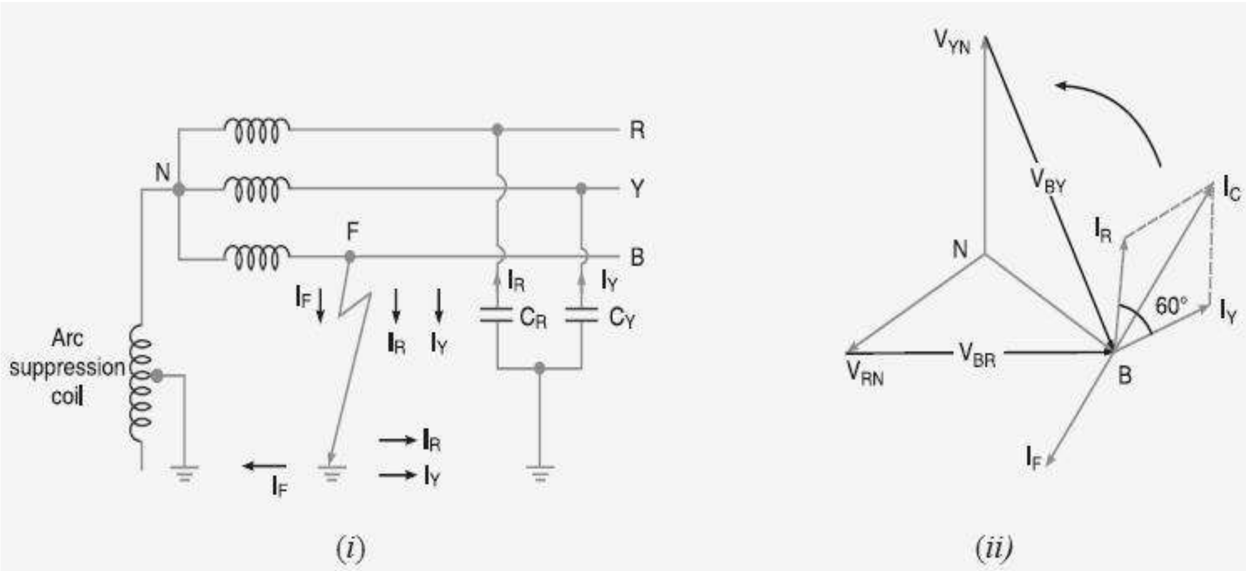


Fig. 26.16

Operation:

Fig. 26.16(i) shows the 3-phase system employing Peterson coil grounding. Suppose line to ground fault occurs in the line B at point F. The fault current IF and capacitive currents I_R and I_Y will flow as shown in Fig. 26.16 (i). Note that I_F flows through the Peterson coil (or Arc suppression coil) to neutral and back through the fault. The total capacitive current I_C is the phasor sum of I_R and I_Y as shown in phasor diagram in Fig. 26.16(ii). The voltage of the faulty phase is applied across the arc suppression coil. Therefore, fault current I_F lags the faulty phase voltage by 90°. The current IF is in phase opposition to capacitive current I_C [See Fig. 26.16(ii)]. By adjusting the tappings on the Peterson coil, the resultant current in the fault can be reduced. If inductance of the coil is so adjusted that I_L=I_C, then resultant current in the fault will be zero. Value of L for resonant grounding. For resonant grounding, the system behaves as an ungrounded neutral system. Therefore, full line voltage appears across capacitors C_R and C_Y .

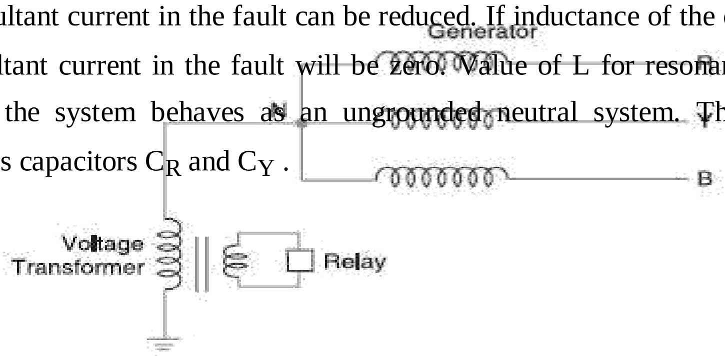


Fig. 26.17

The Peterson coil grounding has the following advantages:

1. The Peterson coil is completely effective in preventing any damage by an arcing ground.
2. The Peterson coil has the advantages of ungrounded neutral system.

The Peterson coil grounding has the following disadvantages :

1. Due to varying operational conditions, the capacitance of the network changes from time to time. Therefore, inductance L of Peterson coil requires readjustment.
2. The lines should be transposed.

Voltage Transformer Earthing:

In this method of neutral earthing, the primary of a single-phase voltage transformer is connected between the neutral and the earth as shown in Fig. 26.17. A low resistor in series with a relay is connected across the secondary of the voltage transformer. The voltage transformer provides a high reactance in the neutral earthing circuit and operates virtually as an ungrounded neutral system. An earth fault on any phase produces a voltage across the relay. This causes the operation of the protective device.

The following are the advantages of voltage transformer earthing :

1. The transient over voltages on the system due to switching and arcing grounds are reduced. It is because voltage transformer provides high reactance to the earth path.

2. This type of earthing has all the advantages of ungrounded neutral system.

3. Arcing grounds are eliminated.

The following are the disadvantages of voltage transformer earthing :

1. When earth fault occurs on any phase, the line voltage appears across line to earth capacitances. The system insulation will be overstressed.

2. The earthed neutral acts as a reflection point for the travelling waves through the machine winding. This may result in high voltage build up.

Applications:

The use of this system of neutral earthing is normally confined to generator equipments which are directly connected to step-up power transformers.

Grounding Transformer:

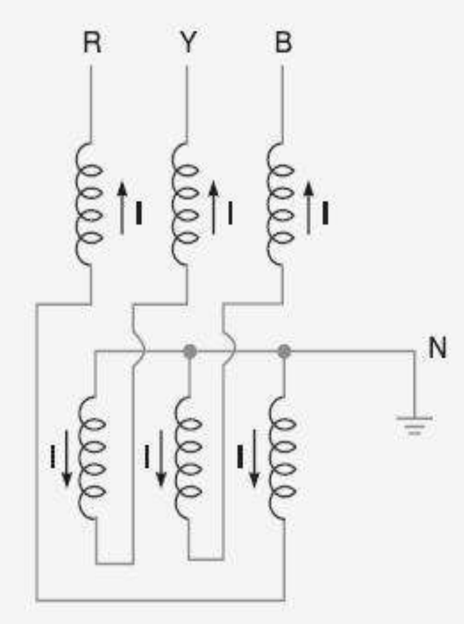


Fig. 26.18

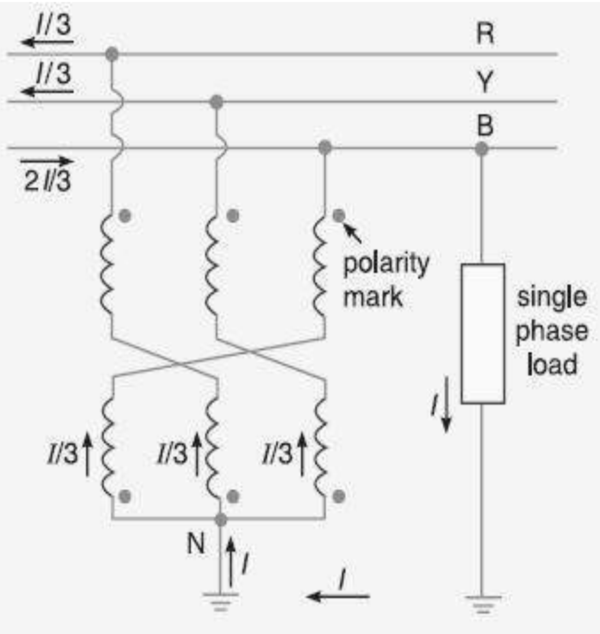


Fig. 26.19

Fig. 26.19 shows the use of grounding transformer to create neutral point N. If we connect a single-phase load between one line and neutral, the load current I divide into three equal currents in each

Grounding Practice:

1. Once the grounding is normally provided at each voltage level. Between generation and distribution, there are various voltage levels. It desirable to have ground available at each voltage level.
2. The generation is normally provided with resistance grounding and synchronous capacitors are provided with reactance grounding.
3. Where several generators are connected to a common neutral bus. The bus is connected to ground through a single grounding device. Disconnect switches can be used to ground the desired generators to the neutral bus.
4. Where the several generators are operating in parallel, only one generator neutral is grounded. This is done to avoid the interference of zero sequence components. Normally two grounds are available in a station but only one is used at a time. The other is used when the first generator is out of service.
5. For low voltages up to 600 volts and for high voltages above 33 KV solid grounding is used where as for medium voltage between 3.3 KV and 33 KV resistance or reactance grounding is used

8.1 GENERATION OF OVER VOLTAGE IN POWER SYSTEM

The generation of over voltages in power system can be classified into two categories.

1. External over voltages
2. Internal over voltages

These two categories are discussed briefly.

1. External over Voltages

The over voltages caused due to disturbances in atmosphere is termed as external over voltages. They do not depend on the system operating voltage.
The causes for over voltages are

a) Direct lighting strokes

b) Over voltages caused by electromagnetic induction due to lighting discharge taking place near the live

c) Electrostatically induced over voltage due to frictional effect of dust or show in the atmosphere

d) Electrostatically induced over voltages due to clouds in the atmosphere

e) The transmission line is lengthie such that it is subjected to various atmospheric conditions. Due to this over voltages are induced.

2. Internal Over Voltages

Internal over voltages are caused due to changes in the operating conditions of the system. These are further divided into two types.

(i) Transient Overvoltages (Switching Overvoltages)

Transient overvoltages are caused due to transient nature of the system during switching operations or fault conditions. The transient overvoltages are oscillatory with a frequency ranging from few hundred to few KHZ,

Eg:-
1) Due to switching of transformer at no load
2) Due to fault in one phase, the voltage of healthy phases shoots up

3) Due to closing of circuit breaker contacts to clear a fault which is followed by appearance of restriking voltage. Transient overvoltages are of relatively high frequency

Here we define a term called over-voltage factor. It is the ratio of peak overvoltage to the rated system-frequency phase voltage. This term is also called as amplitude factor.

(ii) Temporary Overvoltages (Steady-State Overvoltages)

These overvoltages are the steady-state over voltages of the system. These over-voltages are of power frequency.

The main cause of steady-state over voltages is due to the disconnection of loads.

The over voltages mentioned above causes damage to the equipment and also insulation of the system, so the system should be protected against these over voltages. The type of protection depends on the factors causing over voltages and also the magnitude, shape and frequency of occurrence of the over voltages.

8.2 PROTECTION AGAINST LIGHTNING OVER VOLTAGES:-

Lightning causes two kinds of over voltages. They are

1. by direct stroke to a line conductor

2. Electromagnetically induced over voltages due to indirect stroke i.e lightning discharge taking place near the line

The over voltages caused due to direct lightning stroke is more severe than due to indirect lightning stroke.

The direct lightning strokes can be approximated to a constant current source since current through the phase conductor due to direct lightning stroke is constant

The transmission lines can be protected against lightning over voltages using lighting arresters or surge diverters.

The surge diverter are connected between line and ground at the substation

These act in parallel with the equipment to be protected, and protects it by

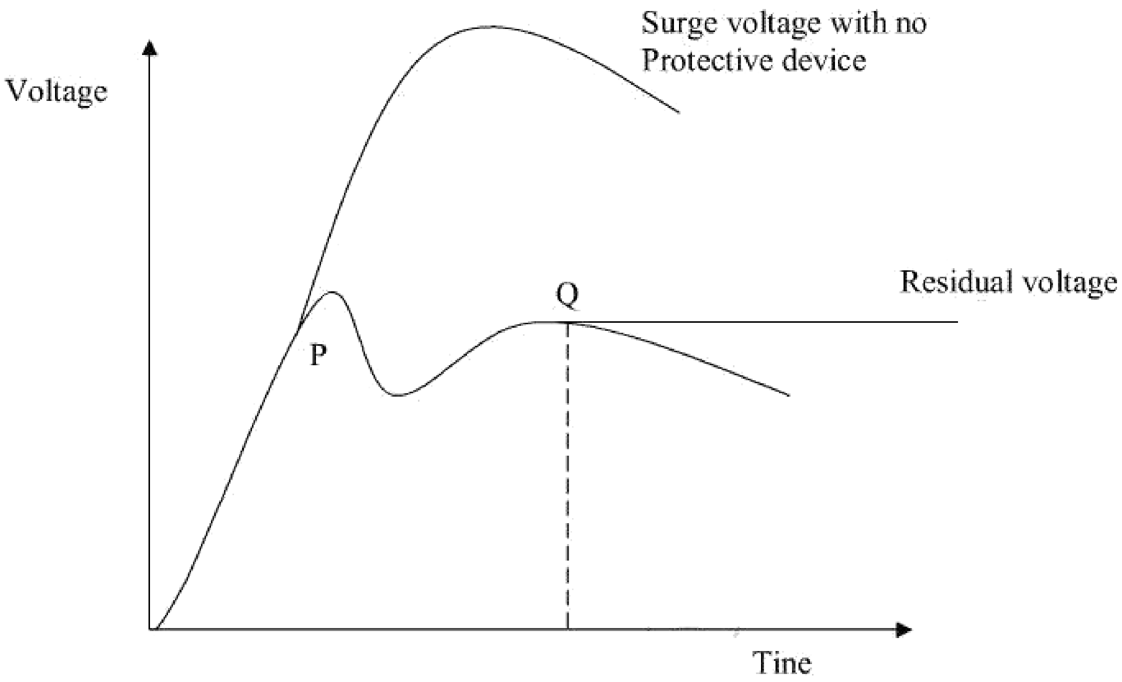


Fig-8

When the traveling wave reaches the diverter, the diverter provides a relatively low impedance path to ground for the surge current. This current limits the amplitude of the over voltage across the ling known as residual voltage to a value which protects the insulation ot equipment

The characteristics of ideal lightning arrester is

(i) During normal operations it should not draw any current

(ii) During transients, it should create low-impedance path for the surge currents

(iii) The discharge current through the diverter should not be so large such that it damages the surge diverter itself

Impulse Ratio

Impulse ratio is defined as the ratio of the breakdown impulse voltage of a wave of specified duration to the breakdown voltage of a power-frequency wave.

Impulse ratio is a function of time duration of the transient wave.

Two types of lightning arresters are discussed below.

8.2.1 Valve Type Lightning Arrester

This type of diverter is also called Non-linear surge diverter. The construction of valve type lightning arrester is shown below.

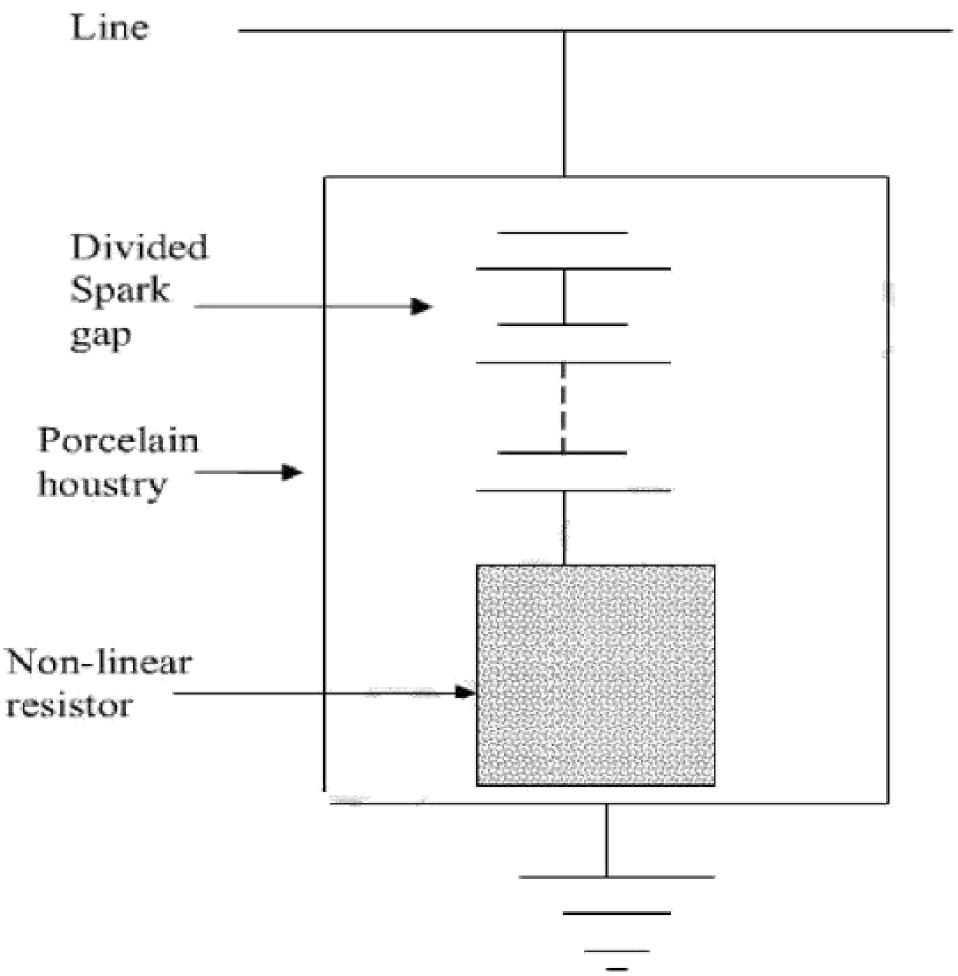


Fig 8.2

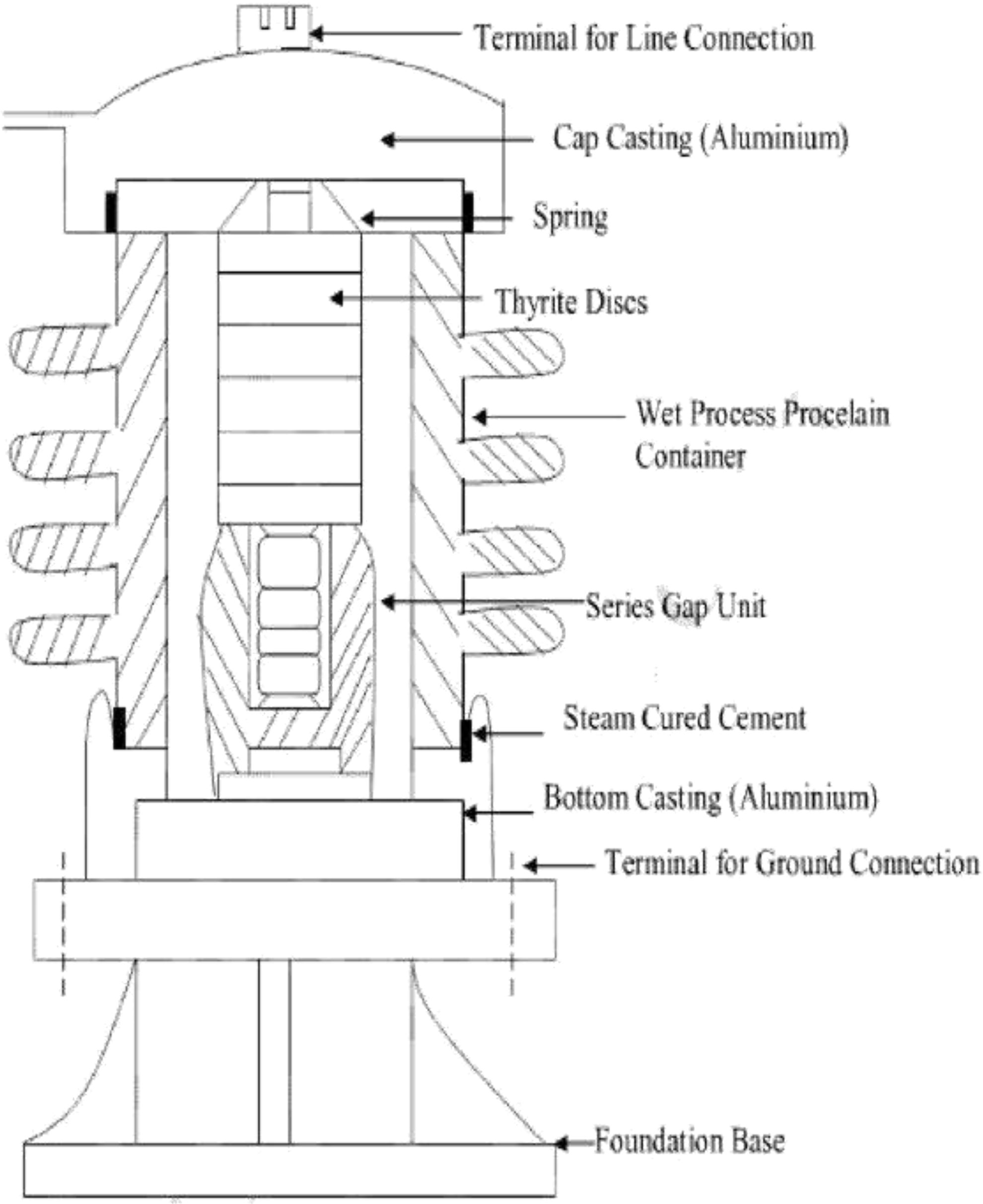


Figure 8.3

Since non-linear resistor changes its resistance inversely proportional to current to maintain voltage constant its ideal characteristics is RI = constant

The non-linear resistor is made up of material named 'thyrite', this type of lightning arrester is also known as 'Thyrite type lightning arrester'

The figure drawn below shown

Volt-ampere characteristics of the non-linear diveoter

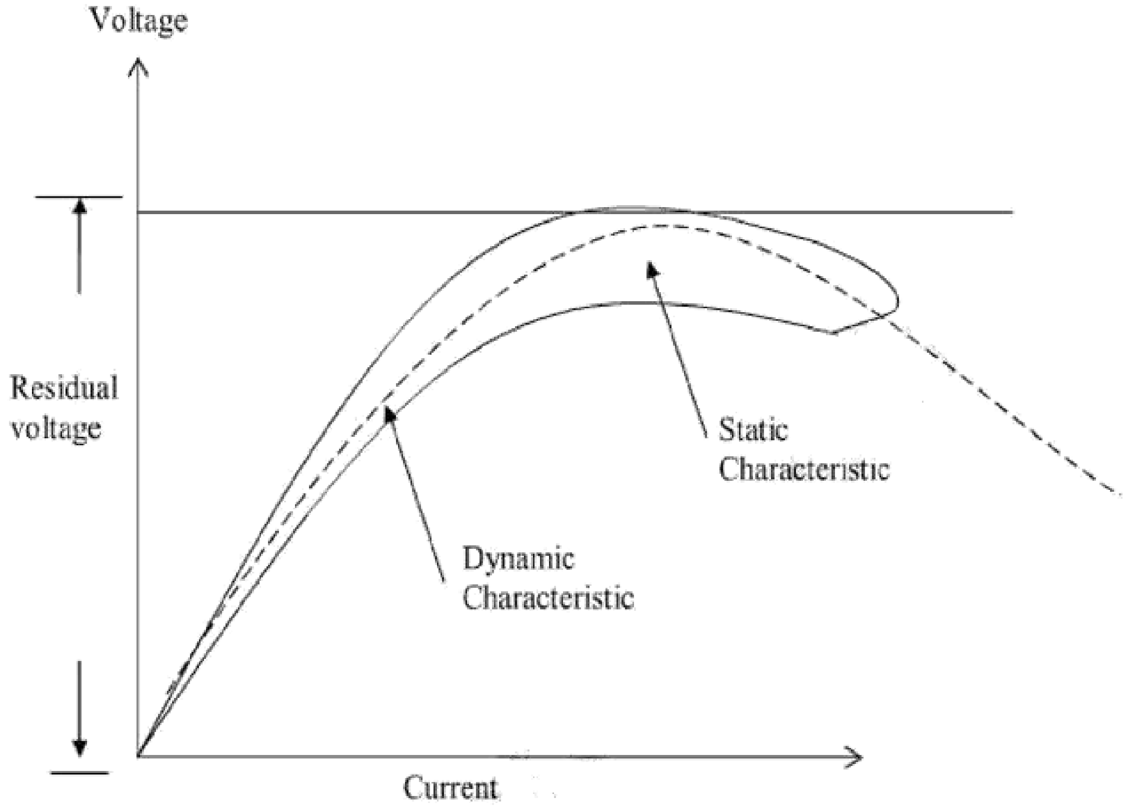


Fig 8.4

The static characteristic is shown by the dotted curve and the dynamic characteristic is shown by the solid curve. The tangent drawn to the dynamic characteristic intersects the voltage axis at a value called "residual voltage"

Hence residual voltage is defined as the "peak value of the voltage between the terminals of the surge diverter at the instant when the surge current discharges through it".

This type of lightning arrester acts as an insulator at normal working conditions. When there are voltage surges, it creates a low impedance path to the surge currents. After the voltage surges has disappeared, again it acts a, an insulator.

Since its function is similar to the valve opening at high surge currents it is called valve type lightning arrester.

8.2.2 Zinc-Oxide Lightning Arrester

The conventional non-linear lightning arresters uses silicon carbide (Sic) as the non-linear resistor. But this material does not exhibit ideal non-linear characteristics and there are some design restrictions.

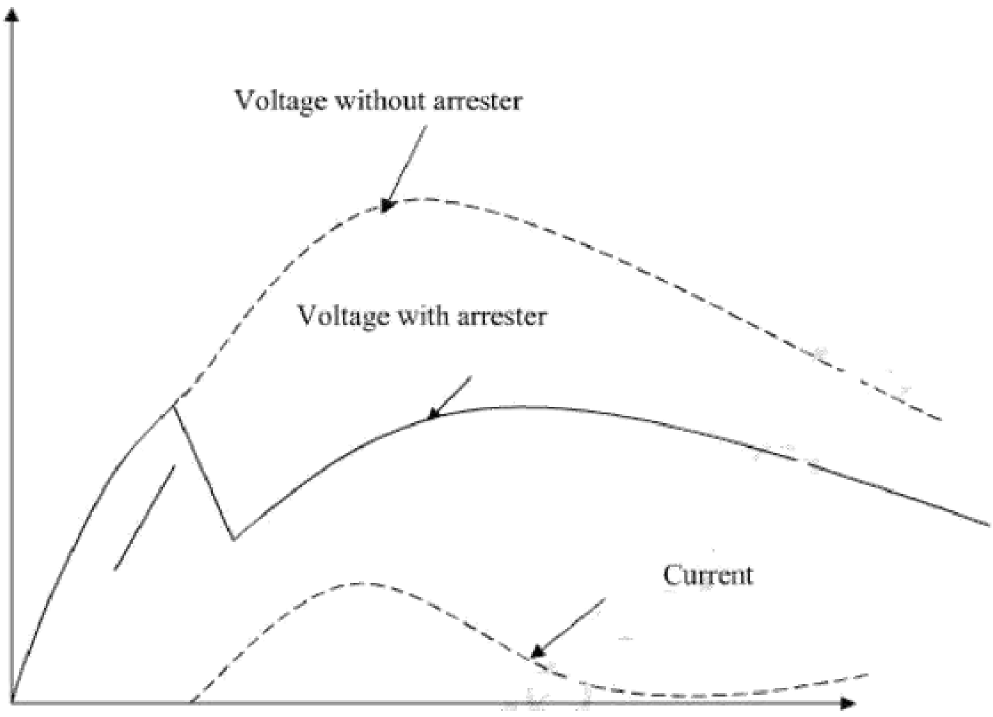


Fig 8.5(b)

Notice that in MOA there is no follow up current

The voltage of MOA expressed as

$$V = 2v(t)-Z_o i \_\_\_\_\_\_\_\_\_\_\_\_ (1)$$

Where Zo is the surge impedance and i is the instantaneuost current of the arrester At the time of spark over in a conventional arrester, the voltage is at its peak value known as spark over voltage. After spark over it follows equation

$$V = 2v(t)-Z_o i$$

From the above discussion we can say that the performance of MOA depends only on discharge voltage but the performance of conventional arrester depends both on spark over voltage and discharge voltage

Since the protection level of MOA is controlled by maximum discharge voltage, the relational between voltage and current can be expressed as

$$V=v(i) \_\_\_\_\_\_\_\_\_\_ (2)$$

By combining equations (1) and (2) the time dependence of V can be calculated. This can be solved graphically as shown in the figure (a) drawn below.

8.3 INSULATION COORDINATION

Definition:-

Insulation coordination is defined as the correlation of the insulation of electrical equipment and lines with the characteristics of protective devices such that the insulation of the whole power system is protected from excessive over voltages.

It chooses a suitable value of insulation level for a protective system and arranges in such a manner such that the equipment is protected from over voltages

The insulation level of equipment (eg:- transformer) should be higher than that of protective devices (eg:- surge arrester)

The volt-time curve of protective device (curve A) and equipment to be protected (curve B) is shown below