UNIT – II ELECTROMAGNETIC PROTECTION RELAYS

TECHNICAL TERMS

1. **Protective relay:** Device that detects the fault and initiates the operation of the circuit breaker to isolate the defective element from the rest of the system
2. **Selectivity:** Ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system
3. **Sensitivity:** Ability of the relay system to operate with low value of actuating quantity
4. **Reliability:** Ability of the relay system to operate under the pre-determined conditions.
5. **Primary Protection:** Main protection and serves as the first line of defense
6. **Backup Protection:** In case of failure of the primary protection it will acts
7. **Instantaneous relay:** Relay contacts are closed immediately after current in the relay coil exceeds the minimum value
8. **Inverse-time relay:** Operating time is approximately inversely proportional to the magnitude of the actuating quantity
9. **Definite time lag relay:** Definite time elapse between the instant of pickup and the closing of relay contacts.
10. **Pick-up current:** Minimum current in the relay coil at which the relay starts to operate
11. **Current setting:** Adjust the pick-up current to any required value
12. **Time-setting multiplier:** Adjust the time of operation of relay
13. **Differential relay:** Operates when the phasor difference of two or more similar electrical quantities exceeds a pre-determined value.

PRINCIPLES AND NEED FOR PROTECTIVE SCHEMES

In a power system consisting of generators, transformers, transmission and distribution circuits, it is inevitable that sooner or later some failure will occur somewhere in the system. When a failure occurs on any part of the system, it must be quickly detected and disconnected from the system. There are two principal reasons for it. Firstly, if the fault is not cleared quickly, it may cause unnecessary interruption of service to the customers. Secondly, rapid disconnection of faulted apparatus limits the amount of damage to it and prevents the effects of fault from spreading into the system.

The detection of a fault and disconnection of a faulty section or apparatus can be achieved by using fuses or relays in conjunction with circuit breakers. A fuse performs both detection and interruption functions automatically but its use is limited for the protection of low-voltage circuits only. For high voltage circuits (say above 3·3 kV), relays and circuit breakers are employed to serve the desired function of automatic protective gear. The relays detect the fault and supply information to the circuit breaker which performs the function of circuit interruption.

Nature and causes of faults

- Faults in insulation or conducting path.
- Over voltage due to switching or lighting in transmission lines.
- External conducting objects falling on OH lines.
- Over voltage due to flashover on insulator surface.
- Bridging of conductors by birds.
- Breaking or snapping of conductors creates open circuit and short circuit, falls on ground creating unbalances.
- Cables, transformers and generators faults.

Types of faults

a. symmetrical faults

- A three phase fault is called as symmetrical faults.
- All the three lines are short circuited without an earth connection at the fault.
- All the three lines short circuited with an earth connection at the fault.
- When such a fault occurs, it gives rise to symmetrical fault currents. Although symmetrical faults are the most severe and impose heavy duty on the circuit breakers, the analysis of such faults can be made with a fair degree of ease. It is because the

balanced nature of fault permits to consider only one phase in calculations, the conditions in the other two phases being similar.

b. Unsymmetrical faults

Those faults on the power system which give rise to unsymmetrical fault current are known as Unsymmetrical faults. There are 3 ways unsymmetrical faults may occur in a power system

- Single line to ground fault
- Line to line fault
- Double line to ground fault

PROTECTIVE RELAYS

A protective relay is a device that detects the fault and initiates the operation of the circuit breaker to isolate the defective element from the rest of the system. The relays detect the abnormal conditions in the electrical circuits by constantly measuring the electrical quantities which are different under normal and fault conditions. The electrical quantities which may change under fault conditions are voltage, current, frequency and phase angle. Through the changes in one or more of these quantities, the faults signal their presence, type and location to the protective relays. Having detected the fault, the relay operates to close the trip circuit of the breaker. This results in the opening of the breaker and disconnection of the faulty circuit.

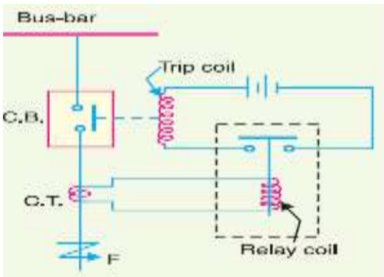

Figure 1.1 Relay circuit

A typical relay circuit is shown in Figure. 1.1. This diagram shows one phase of 3-phase system for simplicity. The relay circuit connections can be divided into three parts viz.

- First part is the primary winding of a current transformer (C.T.) which is connected in series with the line to be protected.
- Second part consists of secondary winding of C.T. and the relay operating coil.

- Third part is the tripping circuit which may be either a.c. or d.c. It consists of a source of supply, the trip coil of the circuit breaker and the relay stationary contacts.

When a short circuit occurs at point F on the transmission line, the current flowing in the line increases to an enormous value. This results in a heavy current flow through the relay coil, causing the relay to operate by closing its contacts. This in turn closes the trip circuit of the breaker, making the circuit breaker open and isolating the faulty section from the rest of the system. In this way, the relay ensures the safety of the circuit equipment from damage and normal working of the healthy portion of the system.

Protective zone

- The protective zone is the separate zone which is established around each system element.
- The significant of this protective zone is that any fault occurring within a given zone will cause the tripping of relays which causes the opening of all circuit breakers located within the zone.
- The components of the protective zones are generators, transformers, transmission lines, bus bars, cables, capacitors etc.,
- No part of the system is left unprotected.
- The boundaries of protective zones are decided by the locations of the current transformers.
- In practice, various protective zones are overlapped.
- The overlapping of protective zones is done to ensure complete safety of each and every element of the system.
- The zone which is unprotected is called dead spot.
- The zones are overlapped and hence there is no chance of existence of a dead spot in a system.
- For the failures within the region where two adjacent protective zones are overlapped, more circuit breakers get tripped than minimum necessary to disconnect the faulty element.
- If there are no overlaps, then dead spot may exist, means the circuit breakers lying within the zone may not trip even though the fault occurs.
- This may cause damage to the healthy system.
- The extent of overlapping of protective zones is relatively small.

The probability of the failures in the overlapped regions is very low, the tripping of too many circuit breakers will be also infrequent

ESSENTIAL QUALITIES OF PROTECTION

The principal function of protective relaying is to cause the prompt removal from service of any element of the power system when it starts to operate in an abnormal manner or interfere with the effective operation of the rest of the system. In order that protective relay system may perform this function satisfactorily, it should have the following qualities

- Selectivity
- Speed
- Sensitivity
- Reliability
- Simplicity
- Economy

Selectivity

It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system. A well designed and efficient relay system should be selective i.e. it should be able to detect the point at which the fault occurs and cause the opening of the circuit breakers closest to the fault with minimum or no damage to the system. This can be illustrated by referring to the single line diagram of a portion of a typical power system shown in Figure. 1.2.

It may be seen that circuit breakers are located in the connections to each power system element in order to make it possible to disconnect only the faulty section. Thus, if a fault occurs at bus-bars on the last zone, then only breakers nearest to the fault viz. 10, 11, 12 and 13 should open. In fact, opening of any other breaker to clear the fault will lead to a greater part of the system being disconnected.

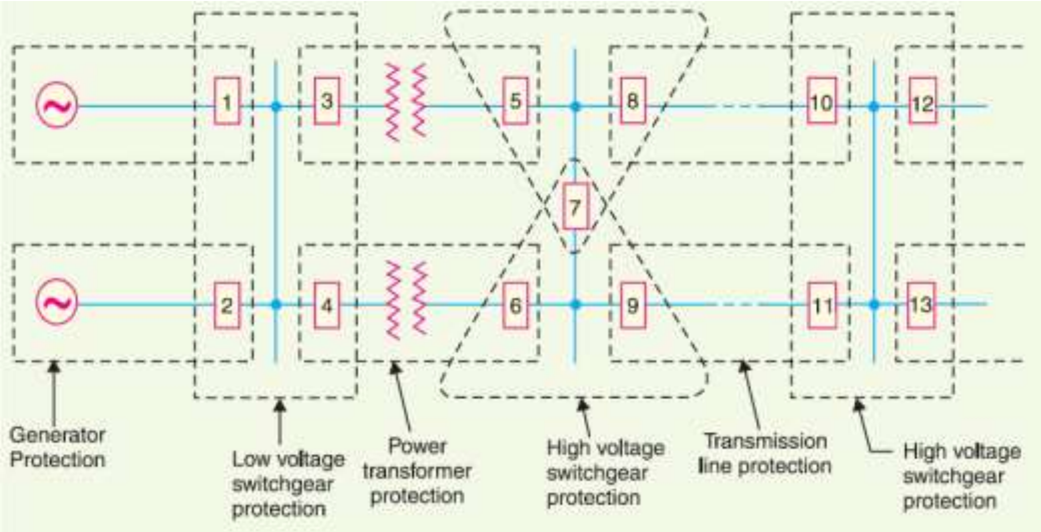

Figure 1.2 Protection of power system

In order to provide selectivity to the system, it is a usual practice to divide the entire system into several protection zones. When a fault occurs in a given zone, then only the circuit breakers within that zone will be opened. This will isolate only the faulty circuit or apparatus, leaving the healthy circuits intact. The system can be divided into the following protection zones

- ✓ Generators
- ✓ Low-tension switchgear
- ✓ Transformers
- ✓ High-tension switchgear
- ✓ Transmission lines

It may be seen in Figure. 1.2 that there is certain amount of overlap between the adjacent protection zones. For a failure within the region where two adjacent zones overlap, more breakers will be opened than the minimum necessary to disconnect the faulty section. But if there were no overlap, a failure in the region between zones would not lie in either region and, therefore, no breaker would be opened. For this reason, a certain amount of overlap* is provided between the adjacent zones.

Speed

The relay system should disconnect the faulty section as fast as possible for the following reasons

- ✓ Electrical apparatus may be damaged if they are made to carry the fault currents for a long time.

- ✓ A failure on the system leads to a great reduction in the system voltage. If the faulty section is not disconnected quickly, then the low voltage created by the fault may shut down consumers motors and the generators on the system may become unstable.
- ✓ The high speed relay system decreases the possibility of development of one type of fault into the other more severe type.

Sensitivity

It is the ability of the relay system to operate with low value of actuating quantity Sensitivity of a relay is a function of the volt-amperes input to the coil of the relay necessary to cause its operation. The smaller the volt-ampere input required to cause relay operation, the more sensitive is the relay. Thus, a 1 VA relay is more sensitive than a 3 VA relay. It is desirable that relay system should be sensitive so that it operates with low values of volt-ampere input.

Reliability

It is the ability of the relay system to operate under the pre-determined conditions. Without reliability, the protection would be rendered largely ineffective and could even become a liability.

Simplicity

The relaying system should be simple so that it can be easily maintained. Reliability is closely related to simplicity. The simpler the protection scheme, the greater will be its reliability.

Economy

The most important factor in the choice of a particular protection scheme is the economic aspect. Sometimes it is economically unjustified to use an ideal scheme of protection and a compromise method has to be adopted. As a rule, the protective gear should not cost more than 5% of total cost. However, when the apparatus to be protected is of utmost importance (*e.g.* generator, main transmission line etc.), economic considerations are often subordinated to reliability.

PROTECTION SCHEME

When a fault occurs on any part of electric power system, it must be cleared quickly in order to avoid damage and/or interference with the rest of the system. It is a usual practice to divide the protection scheme into two classes *viz.* primary protection and back-up protection.

Primary Protection

It is the protection scheme which is designed to protect the component parts of the power system. Thus referring to figure. 1.3, each line has an over current relay that protects the line. If a fault occurs on any line, it will be cleared by its relay and circuit breaker. This forms the primary or main protection and serves as the first line of defense. The service record of primary relaying is very high with well over ninety percent of all operations being correct. However, sometimes faults are not cleared by primary relay system because of trouble within the relay, wiring system or breaker. Under such conditions, back-up protection does the required job.

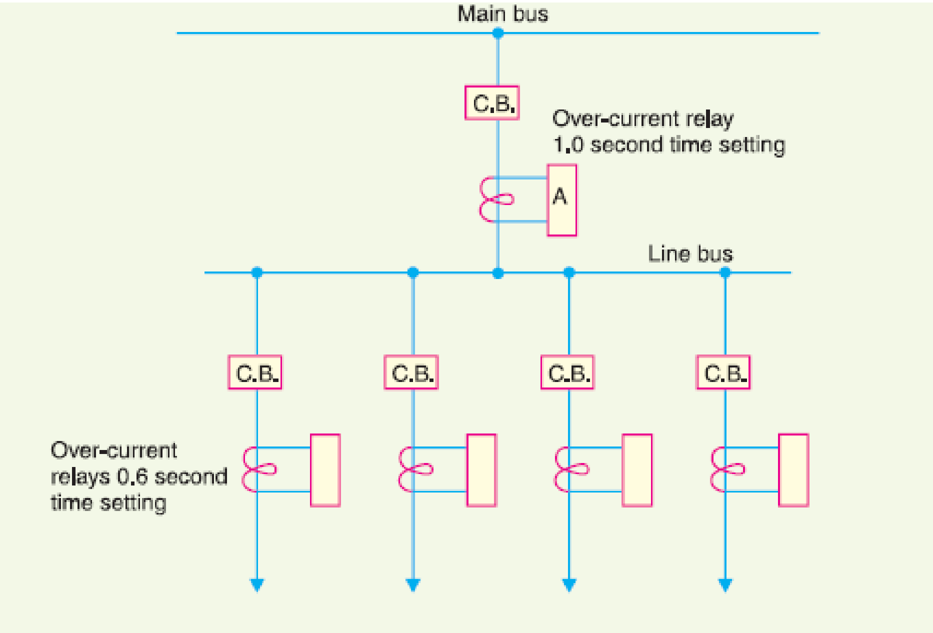

Figure 1.3 Types of protection.

Backup Protection

It is the second line of defense in case of failure of the primary protection. It is designed to operate with sufficient time delay so that primary relaying will be given enough time to function if it is able to. Thus referring above figure, relay *A* provides back-up protection for each of the four lines. If a line fault is not cleared by its relay and breaker, the relay *A* on the group breaker will operate after a definite time delay and clear the entire group of lines. It is evident that when back-up relaying functions, a larger part is disconnected than when primary relaying functions correctly. Therefore, greater emphasis should be placed on the better maintenance of primary relaying.

BASIC RELAYS

Most of the relays used in the power system operate by virtue of the current and/or voltage supplied by current and voltage transformers connected in various combinations to the system element that is to be protected. Through the individual or relative changes in these two quantities, faults signal their presence, type and location to the protective relays. Having detected the fault, the relay operates the trip circuit which results in the opening of the circuit breaker and hence in the disconnection of the faulty circuit. Most of the relays in service on electric power system today are of electro-mechanical type. They work on the following two main operating principles

- ✓ Electromagnetic attraction
- ✓ Electromagnetic induction

Electromagnetic Attraction Relays

Electromagnetic attraction relays operate by virtue of an armature being attracted to the poles of an electromagnet or a plunger being drawn into a solenoid. Such relays may be actuated by d.c. or a.c. quantities. The important types of electromagnetic attraction relays are

- **Attracted armature type relay**

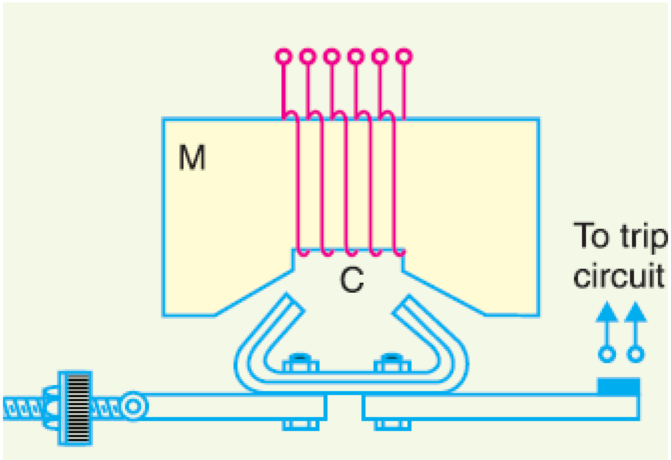

Figure 1.3 Attracted armature type relay

Figure. 1.3 shows the schematic arrangement of an attracted armature type relay. It consists of a laminated electromagnet *M* carrying a coil *C* and a pivoted laminated armature. The armature is balanced by a counterweight and carries a pair of spring contact fingers at its free end. Under normal operating conditions, the current through the relay coil *C* is such that counterweight holds the armature in the position shown. However, when a short circuit occurs, the current through the relay coil increases sufficiently and the relay armature is attracted upwards. The contacts on the relay armature bridge a pair of stationary contacts attached to the relay frame. This completes the trip circuit which results in the opening of the circuit breaker and, therefore, in the disconnection of the faulty circuit. The minimum current at which the relay armature is attracted to close the trip circuit is called *pickup* current. It is a usual practice to provide a number of tappings on the relay coil so that the number of turns in use and hence the setting value at which the relay operates can be varied.

- **Solenoid type relay**

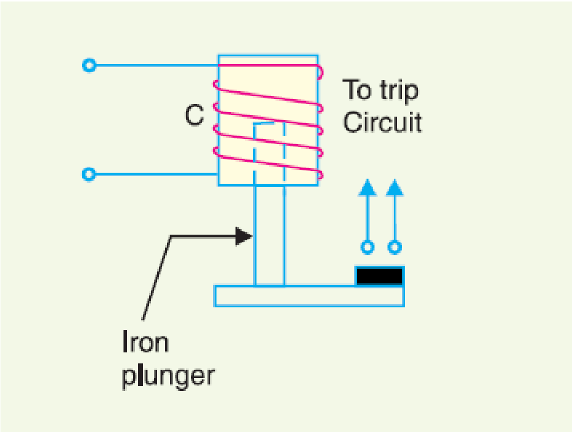

Figure 1.4 Solenoid type relay

Figure. 1.4 shows the schematic arrangement of a solenoid type relay. It consists of a solenoid and movable iron plunger arranged as shown. Under normal operating conditions, the current through the relay coil *C* is such that it holds the plunger by gravity or spring in the position shown. However, on the occurrence of a fault, the current through the relay coil becomes more than the pickup value, causing the plunger to be attracted to the solenoid. The upward movement of the plunger closes the trip circuit, thus opening the circuit breaker and disconnecting the faulty circuit.

- **Balanced beam type relay**

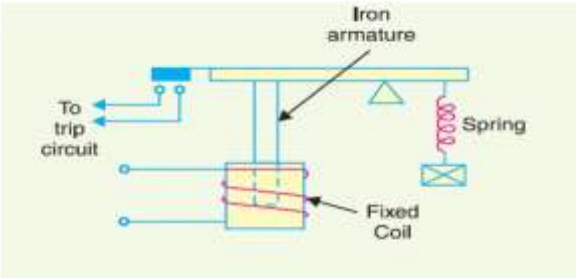

Figure 1.5 Balanced beam type relay

Figure. 1.5 shows the schematic arrangement of a balanced beam type relay. It consists of an iron armature fastened to a balance beam. Under normal operating conditions, the current through the relay coil is such that the beam is held in the horizontal position by the spring. However, when a fault occurs, the current through the relay coil becomes greater than the pickup value and the beam is attracted to close the trip circuit. This causes the opening of the circuit breaker to isolate the faulty circuit.

Induction Relays

Electromagnetic induction relays operate on the principle of induction motor and are widely used for protective relaying purposes involving a.c. quantities. They are not used with d.c. quantities owing to the principle of operation. An induction relay essentially consists of a pivoted aluminium disc placed in two alternating magnetic fields of the same frequency but displaced in time and space. The torque is produced in the disc by the interaction of one of the magnetic fields with the currents induced in the disc by the other.

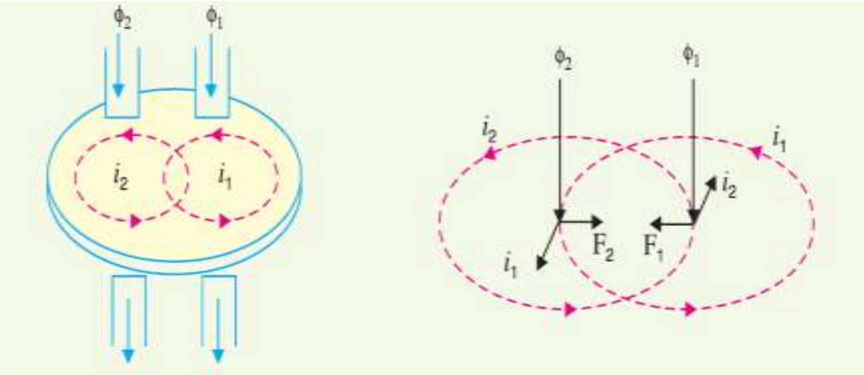

Figure 1.6 Induction relay

To understand the production of torque in an induction relay, refer to the elementary arrangement shown in Figure. 1.6

(*i*). Two a.c. fluxes φ_2 and φ_1 differing in phase by an angle α induce e.m.f.s' in the disc and cause the circulation of eddy currents *i*2 and *i*1 respectively. These currents lag behind their respective fluxes by 90°.Referring to Figure. 1.6

(*ii*) Where the two a.c. fluxes and induced currents are shown separately for clarity, let

$$\emptyset_1 = \emptyset_{1max} Sin\ \omega t$$

$$\emptyset_1 = \emptyset_{1max} Sin\ (\omega t + \alpha)$$

where φ_1 and φ_2 are the instantaneous values of fluxes and φ_2 leads φ_1 by an angle α. Assuming that the paths in which the rotor currents flow have negligible self-inductance, the rotor currents will be in phase with their voltages.

$$i_1 = \frac{d\phi_1}{dt} \propto \frac{d}{dt}\ \phi_{1max} sin\omega t$$

$$\propto \phi_{1max} Cos\omega t$$

$$i_2 \propto \frac{d}{dt}\, \phi_{2max} Cos(\omega t + \alpha)$$

$$F_1 \propto \emptyset_1 i_2$$

$$F_2 \propto \emptyset_2 i_1$$

Net force *F* at the instant considered is

$$F \;\propto\; F_2 - F_1$$

$$\propto\; \emptyset_2 i_1 \;-\; \emptyset_1 i_2$$

$$\propto\; \emptyset_1 \emptyset_2\, Sin\, \alpha$$

The following points may be noted from above equation

- The greater the phase angle α between the fluxes, the greater is the net force applied to the disc. Obviously, the maximum force will be produced when the two fluxes are 90o out of phase.
- The net force is the same at every instant. This fact does not depend upon the assumptions made in arriving at above equation
- The direction of net force and hence the direction of motion of the disc depends upon which flux is leading.

The following three types of structures are commonly used for obtaining the phase difference in the fluxes and hence the operating torque in induction relays

1. Shaded-pole structure
2. Watt-hour-meter or double winding structure
3. Induction cup structure

Shaded-pole structure

The general arrangement of shaded-pole structure is shown in Figure.1.7. It consists of a pivoted aluminium disc free to rotate in the air-gap of an electromagnet. One half of each pole of the magnet is surrounded by a copper band known as *shading ring*.

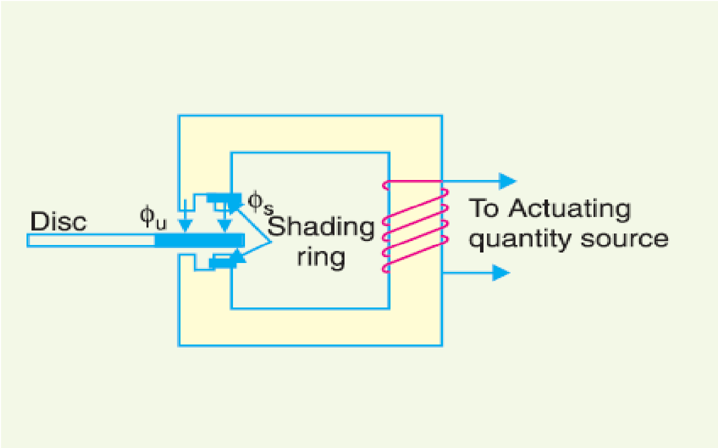

Figure 1.7 shaded pole structure

The alternating flux φ_s in the shaded portion of the poles will, owing to the reaction of the current induced in the ring, lag behind the flux φ_u in the un shaded portion by an angle α. These two a.c. fluxes differing in phase will produce the necessary torque to rotate the disc. As proved earlier, the driving torque *T* is given by

$$T \propto \emptyset_s \emptyset_u sin\alpha$$

Assuming the fluxes φ_s and φ_u to be proportional to the current *I* in the relay coil,

$$T \propto I^2 sin\alpha$$

This shows that driving torque is proportional to the square of current in the relay coil.

Watt-hour-meter structure

This structure gets its name from the fact that it is used in watt-hour meters. The general arrangement of this type of relay is shown in Figure. 1.8. It consists of a pivoted aluminum disc arranged to rotate freely between the poles of two electromagnets. The upper electromagnet carries two windings primary and the secondary. The primary winding carries the relay current I_1 while the secondary winding is connected to the winding of the lower magnet. The primary current induces e.m.f. in the secondary and so circulates a current I_2 in it. The flux φ_2 induced in the lower magnet by the current in the secondary winding of the upper magnet will lag behind φ_1 by an angle α. The two fluxes $\varphi 1$and φ_2 differing in phase by α will produce a driving torque on the disc proportional to $\varphi_1\varphi_2$ sin α.

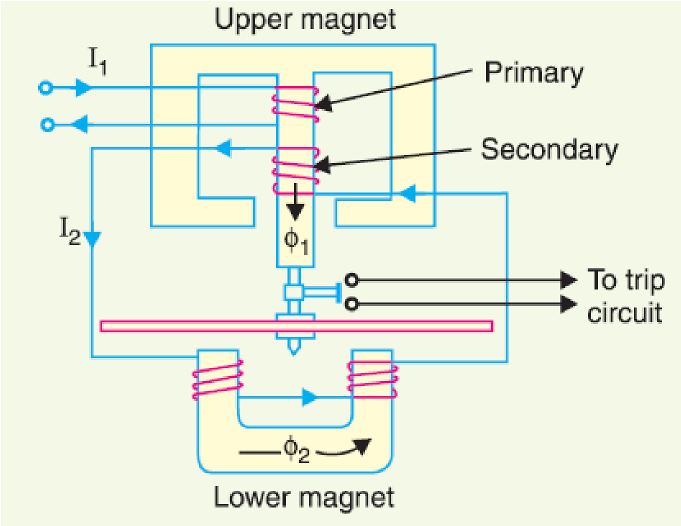

Figure 1.8 Watt-hour meter structure

An important feature of this type of relay is that its operation can be controlled by opening or closing the secondary winding circuit. If this circuit is opened, no flux can be set by the lower magnet however greater the value of current in the primary winding may be and consequently no torque will be produced. Therefore, the relay can be made inoperative by opening its secondary winding circuit.

Induction cup structure

Figure. 1.9 shows the general arrangement of an induction cup structure. It most closely resembles an induction motor, except that the rotor iron is stationary, only the rotor conductor portion being free to rotate. The moving element is a hollow cylindrical rotor which turns on its axis. The rotating field is produced by two pairs of coils wound on four poles as shown. The rotating field induces currents in the cup to provide the necessary driving torque. If φ_1 and φ_2 represent the fluxes produced by the respective pairs of poles, then torque produced is proportional to $\varphi_1\varphi_2 \sin \alpha$ where α is the phase difference between the two fluxes.

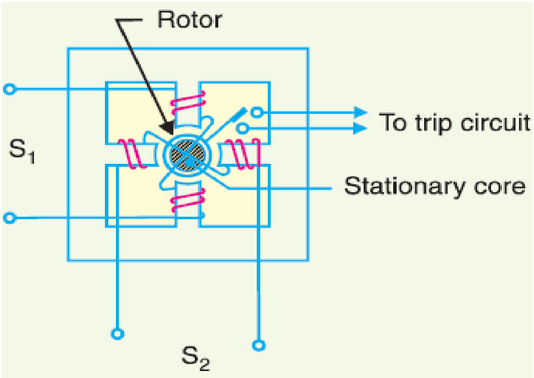

Figure 1.9 Induction cup structure

A control spring and the back stop for closing of the contacts carried on an arm are attached to the spindle of the cup to prevent the continuous rotation. Induction cup structures are more efficient torque producers than either the shaded-pole or the watt-hour meter structures. Therefore, this type of relay has very high speed and may have an operating time less then 0·1 second.

RELAY TIMING

An important characteristic of a relay is its time of operation. By 'the time of operation' is meant length of the time from the instant when the actuating element is energized to the instant when the relay contacts are closed. Sometimes it is desirable and necessary to control the operating time of a relay. For this purpose, mechanical accessories are used with relays.

Instantaneous relay

An instantaneous relay is one in which no intentional time delay is provided. In this case, the relay contacts are closed immediately after current in the relay coil exceeds the minimum calibrated value.

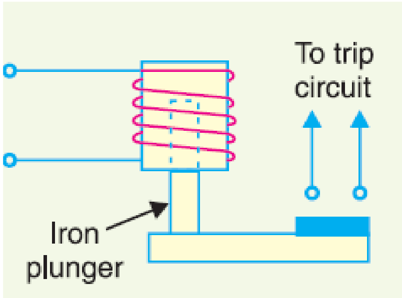

Figure 1.10 Instantaneous solenoid type relay

Figure. 1.10 shows an instantaneous solenoid type of relay. Although there will be a short time interval between the instant of pickup and the closing of relay contacts, no intentional time delay has been added. The instantaneous relays have operating time less than 0·1 second. The instantaneous relay is effective only where the impedance between the relay and source is small compared to the protected section impedance. The operating time of instantaneous relay is sometimes expressed in cycles based on the power-system frequency *e.g.* one-cycle would be 1/50 second in a 50-cycle system.

Inverse-time relay

An inverse-time relay is one in which the operating time is approximately inversely proportional to the magnitude of the actuating quantity. Figure. 1.11 shows the time current characteristics of an inverse current relay. At values of current less than pickup, the relay never operates. At higher values, the time of operation of the relay decreases steadily with the increase of current. The inverse-time delay can be achieved by associating mechanical accessories with relays.

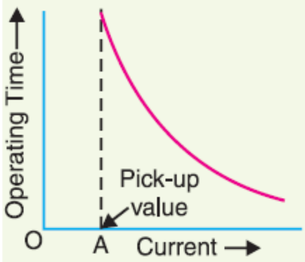

Fig. 1.11

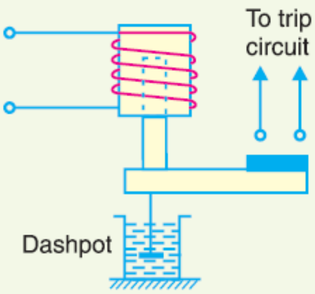

Fig. 1.12

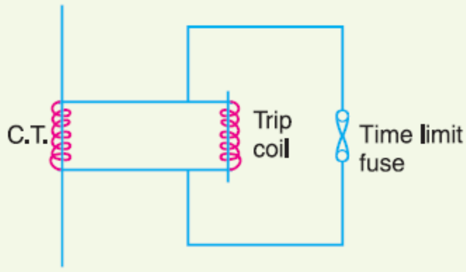

Fig. 1.13

- In an induction relay, the inverse-time delay can be achieved by positioning a permanent magnet (known as a drag magnet) in such a way that relay disc cuts the flux between the poles of the magnet. When the disc moves, currents set up in it produce a drag on the disc which slows its motion.
- In other types of relays, the inverse time delay can be introduced by oil dashpot or a time limit fuse. Figure. 1.12 shows an inverse time solenoid relay using oil dashpot. The piston in the oil dashpot attached to the moving plunger slows its upward motion. At a current value just equal to the pickup, the plunger moves slowly and time delay is at a maximum. At higher values of relay current, the delay time is shortened due to greater pull on the plunger.

The inverse-time characteristic can also be obtained by connecting a time-limit fuse in parallel with the trip coil terminals as shown in Figure. 1.13. The shunt path formed by time-limit fuse is of negligible impedance as compared with the relatively high impedance of the trip coil. Therefore, so long as the fuse remains intact, it will divert practically the whole secondary current of CT from the trip oil. When the secondary current exceeds the current carrying capacity of the fuse, the fuse will blow and the whole current will pass through the trip coil, thus opening the circuit breaker. The time lag between the incidence of excess current and the tripping of the breaker is governed by the characteristics of the fuse. Careful selection of the fuse can give the desired inverse-time characteristics, although necessity for replacement after operation is a disadvantage.

Definite time lag relay

In this type of relay, there is a definite time elapse between the instant of pickup and the closing of relay contacts. This particular time setting is independent of the amount of current through the relay coil; being the same for all values of current in excess of the pickup value. It may be worthwhile to mention here that practically all inverse-time relays are also provided with definite minimum time feature in order that the relay may never become instantaneous in its action for very long overloads.

- **Pick-up current**

It is the minimum current in the relay coil at which the relay starts to operate. So long as the current in the relay is less than the pick-up value, the relay does not operate and the breaker controlled by it remains in the closed position. However, when the relay coil current is equal to or greater than the pickup value, the relay operates to energise the trip coil which opens the circuit breaker.

- **Current setting**

It is often desirable to adjust the pick-up current to any required value. This is known as current setting and is usually achieved by the use of tapping's on the relay operating coil. The taps are brought out to a plug bridge as shown in Figure. 1.14. The plug bridge permits to alter the number of turns on the relay coil. This changes the torque on the disc and hence the time of operation of the relay. The values assigned to each tap are expressed in terms of percentage full-load rating of C.T. with which the relay is associated and represents the value *above* which the disc commences to rotate and finally closes the trip circuit.

Pick-up current = Rated secondary current of C.T. × Current setting

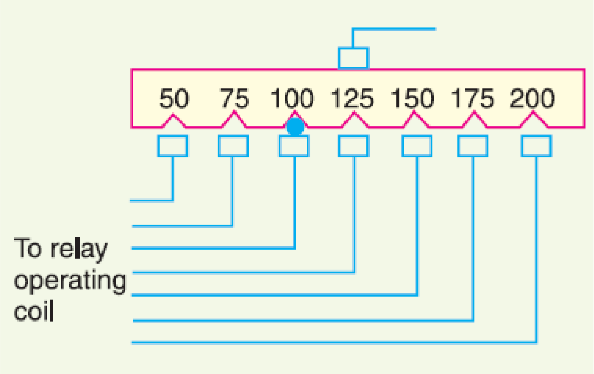

Figure 1.14 Current setting for relays

For example, suppose that an over current relay having current setting of 125% is connected to a supply circuit through a current transformer of 400/5. The rated secondary current of C.T. is 5 amperes. Therefore, the pick-up value will be 25% more than 5 A *i.e.* 5 × 1·25 = 6·25 A. It means that with above current setting, the relay will actually operate for a relay coil current equal to or greater than 6·25 A. The current plug settings usually range from 50% to 200% in steps of 25% for over current relays and 10% to 70% in steps of 10% for earth leakage relays. The desired current setting is obtained by inserting a plug between the jaws of a bridge type socket at the tap value required.

- **Plug-setting multiplier (P.S.M.).**

It is the ratio of fault current in relay coil to the pick-up current,

$$P.S.M. = \frac{Fault\ current\ in\ relay\ coil}{Pick\ up\ current}$$

- **Time-setting multiplier.**

A relay is generally provided with control to adjust the time of operation. This adjustment is known as time-setting multiplier. The time-setting dial is calibrated from 0 to 1 in steps of 0.05 sec (see Figure. 1.15).

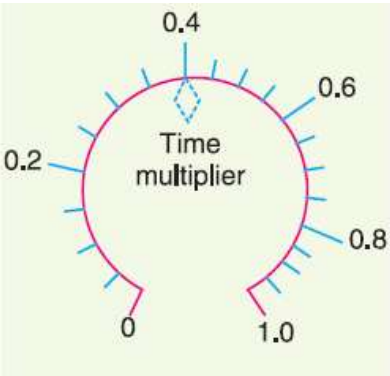

Figure 1.15 Time setting multiplier

These figures are multipliers to be used to convert the time derived from time/P.S.M. curve into the actual operating time. Thus if the time setting is 0·1 and the time obtained from the time/P.S.M. curve is 3 seconds, then actual relay operating time = 3 × 0·1 = 0·3 second. For instance, in an induction relay, the time of operation is controlled by adjusting the amount of travel of the disc from its reset position to its pickup position. This is achieved by the adjustment of the position of a movable backstop which controls the travel of the disc and thereby varies the time in which the relay will close its contacts for given values of fault current. A so-called "time dial" with an evenly divided scale provides this adjustment. The acutal time of operation is calculated by multiplying the time setting multiplier with the time obtained from time/P.S.M. curve of the relay.

- **Time/P.S.M. Curve:**

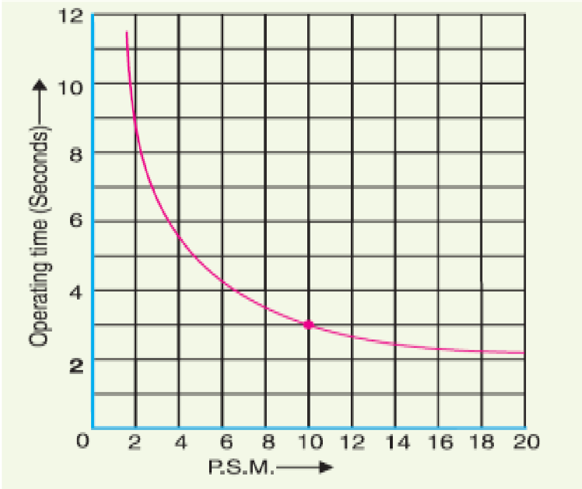

Figure 1.16 Time/PSM curve

Figure. 1.16 shows the curve between time of operation and plug setting multiplier of a typical relay. The horizontal scale is marked in terms of plug-setting multiplier and represents the number of times the relay current is in excess of the current setting. The vertical scale is marked in terms of the time required for relay operation. If the P.S.M. is 10, then the time of operation (from the curve) is 3 seconds. The actual time of operation is obtained by multiplying this time by the time-setting multiplier.

It is evident from Figure. 1.16 that for lower values of over current, time of operation varies inversely with the current but as the current approaches 20 times full-load value, the operating time of relay tends to become constant. This feature is necessary in order to ensure discrimination on very heavy fault currents flowing through sound feeders.

FUNCTIONAL RELAY TYPES

Most of the relays in service on power system today operate on the principle of electromagnetic attraction or electromagnetic induction. Regardless of the principle involved, relays are generally classified according to the function they are called upon to perform in the protection of electric power circuits. For example, a relay which recognizes over current in a circuit and initiates corrective measures would be termed as an over current relay irrespective of the relay design. Similarly an overvoltage relay is one which recognizes overvoltage in a circuit and initiates the corrective measures. Although there are several types of special function relays, only the following important types will be discussed

1. Induction type over current relays
2. Induction type reverse power relays
3. Distance relays
4. Differential relays

5. Translay scheme

Induction Type Over current Relay (non-directional)

This type of relay works on the induction principle and initiates corrective measures when current in the circuit exceeds the predetermined value. The actuating source is a current in the circuit supplied to the relay from a current transformer. These relays are used on a.c. circuits only and can operate for fault current flow in either direction.

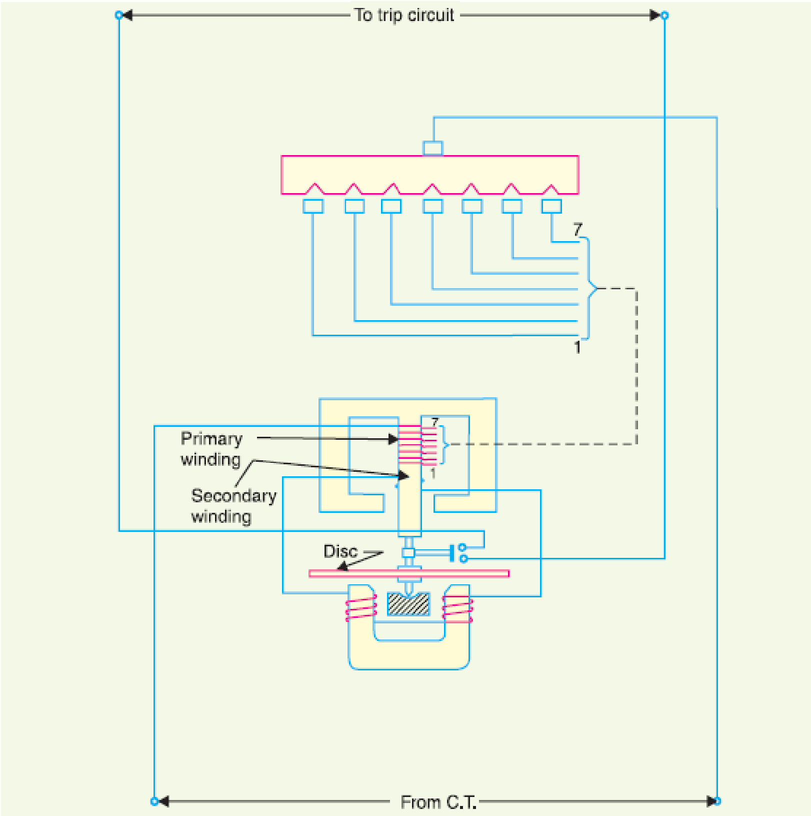

Figure 1.17 Non directional induction type over current relay

Figure. 1.17 shows the important constructional details of a typical non directional induction type over current relay. It consists of a metallic (aluminium) disc which is free to rotate in between the poles of two electromagnets. The upper electromagnet has a primary and a secondary winding. The primary is connected to the secondary of a C.T. in the line to be protected and is tapped at intervals. The tappings are connected to a plug-setting bridge by which the number of active turns on the relay operating coil can be varied, thereby giving the desired current setting.

The secondary winding is energized by induction from primary and is connected in series with the winding on the lower magnet. The controlling torque is provided by a spiral spring. The spindle of the disc carries a moving contact which bridges two fixed contacts (connected to trip circuit) when the disc rotates through a pre-set angle. This angle can be adjusted to any value between 0^o and 360^o. By adjusting this angle, the travel of the moving contact can be adjusted and hence the relay can be given any desired time setting.

The driving torque on the aluminium disc is set up due to the induction principle. This torque is opposed by the restraining torque provided by the spring. Under normal operating conditions, restraining torque is greater than the driving torque produced by the relay coil current. Therefore, the aluminium disc remains stationary. However, if the current in the protected circuit exceeds the pre-set value, the driving torque becomes greater than the restraining torque. Consequently, the disc rotates and the moving contact bridges the fixed contacts when the disc has rotated through a pre-set angle. The trip circuit operates the circuit breaker which isolates the faulty section.

Induction Type Directional Power Relay

This type of relay operates when power in the circuit flows in a specific direction. Unlike a non directional over current relay, a directional power relay is so designed that it obtains its operating torque by the interaction of magnetic fields derived from both voltage and current source of the circuit it protects. Thus this type of relay is essentially a wattmeter and the direction of the torque set up in the relay depends upon the direction of the current relative to the voltage with which it is associated.

Figure. 1.18 shows the essential parts of a typical induction type directional power relay. It consists of an aluminum disc which is free to rotate in between the poles of two electromagnets. The upper electromagnet carries a winding on the central limb which is connected through a potential transformer (P.T.) to the circuit voltage source. The lower electromagnet has a separate winding connected to the secondary of C.T. in the line to be protected. The current coil is provided with a number of tappings connected to the plug setting bridge (not shown for clarity).

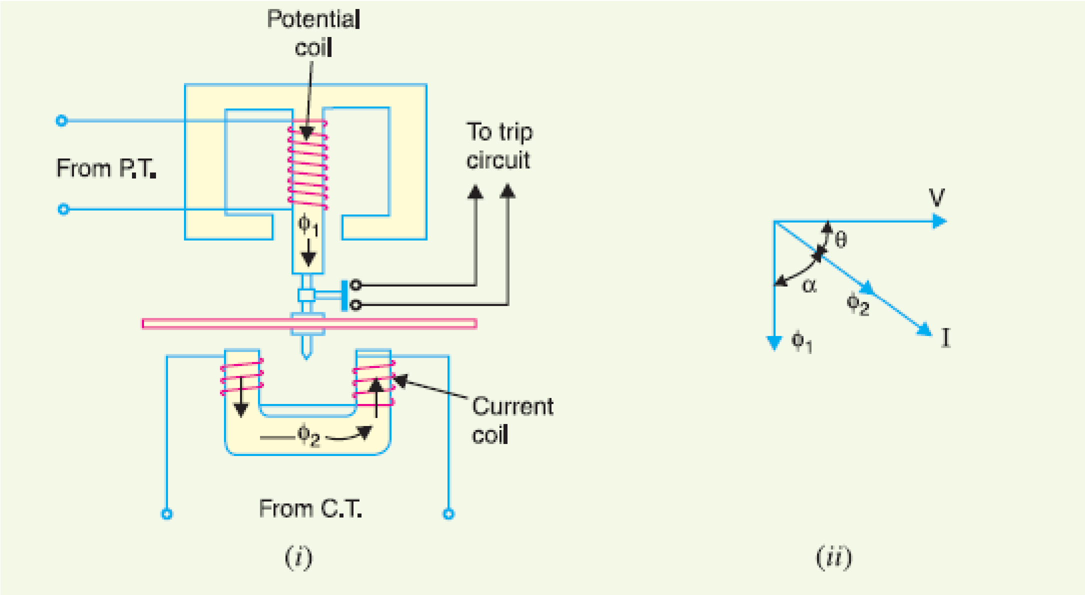

Figure 1.18 Induction type directional power relay

This permits to have any desired current setting. The restraining torque is provided by a spiral spring. The spindle of the disc carries a moving contact which bridges two fixed contacts when the disc has rotated through a pre-set angle. By adjusting this angle, the travel of the moving disc can be adjusted and hence any desired time-setting can be given to the relay.

The flux φ1 due to current in the potential coil will be nearly 90º lagging behind the applied voltage *V*. The flux φ_2 due to current coil will be nearly in phase with the operating current *I* The interaction of fluxes φ1 and φ2 with the eddy current induced in the disc produces a driving torque given by

$T \propto \emptyset_1 \emptyset_2 Sin\alpha$

Since $\emptyset_1 \propto V$, $\quad\emptyset_2 \propto V$, $\quad\alpha = 90 - \theta$

$T \propto VISin(90 - \theta)$

$T \propto VICos\theta$

$T \propto Power\ in\ the\ circuit$

It is clear that the direction of driving torque on the disc depends upon the direction of power flow in the circuit to which the relay is associated. When the power in the circuit flows in the normal direction, the driving torque and the restraining torque (due to spring) help each other to turn away the moving contact from the fixed contacts. Consequently, the relay remains inoperative. However, the reversal of current in the circuit reverses the direction of driving torque on the disc. When the reversed driving torque is large enough, the disc rotates in the reverse direction and the moving contact closes the trip circuit. This causes the operation of the circuit breaker which disconnects the faulty section.

Induction Type Directional over current Relay

The directional power relay discussed above is unsuitable for use as a directional protective relay under short-circuit conditions. When a short circuit occurs, the system voltage falls to a low value and there may be insufficient torque developed in the relay to cause its operation. This difficulty is overcome in the directional overcurrent relay which is designed to be almost independent of system voltage and power factor.

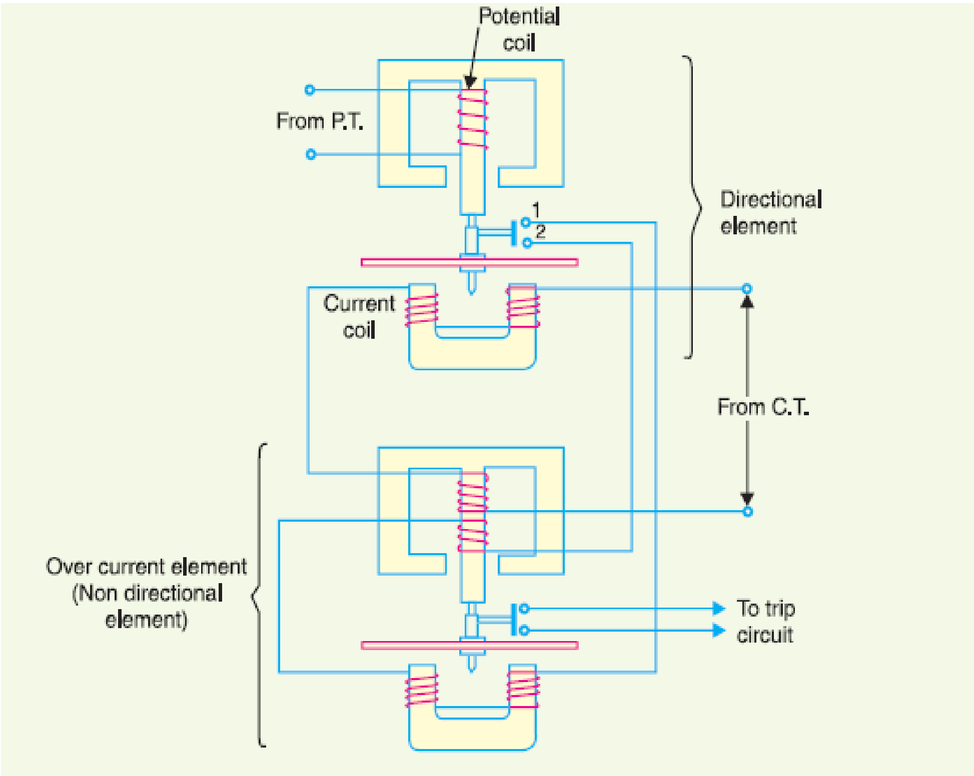

Figure 1.19 Induction type directional over current relay

Figure.1.19 shows the constructional details of a typical induction type directional over current relay. It consists of two relay elements mounted on a common case *viz.* directional element and non-directional element.

- **Directional element:** It is essentially a directional power relay which operates when power flows in a specific direction. The potential coil of this element is connected through a potential transformer (P.T.) to the system voltage. The current coil of the element is energized through a C.T. by the circuit current. This winding is carried over the upper magnet of the non-directional element. The trip contacts (1 and 2) of the directional element are connected in series with the secondary circuit of the over current element. Therefore, the latter element cannot start to operate until its secondary circuit is completed. In other words, the directional element must operate first (*i.e.* contacts 1 and 2 should close) in order to operate the over current element.

- **Non-directional element:** It is an over current element similar in all respects to a non directional over current relay. The spindle of the disc of this element carries a moving contact which closes the fixed contacts (trip circuit contacts) after the operation of directional element. It may be noted that plug-setting bridge is also provided in the relay for current setting but has been omitted in the figure for clarity and simplicity. The tappings are provided on the upper magnet of over current element and are connected to the bridge.

Under normal operating conditions, power flows in the normal direction in the circuit protected by the relay. Therefore, directional power relay (upper element) does not operate, thereby keeping the over current element (lower element) unenergized. However, when a short circuit occurs, there is a tendency for the current or power to flow in the reverse direction. Should this happen, the disc of the upper element rotates to bridge the fixed contacts 1 and 2. This completes the circuit for over current element. The disc of this element rotates and the moving contact attached to it closes the trip circuit. This operates the circuit breaker which isolates the faulty section. The two relay elements are so arranged that final tripping of the current controlled by them is not made till the following conditions are satisfied

- Current flows in a direction such as to operate the directional element.
- Current in the reverse direction exceeds the pre-set value.
- Excessive current persists for a period corresponding to the time setting of over current element.

Impedance Relays

The operation of the relays discussed so far depended upon the magnitude of current or power in the protected circuit. However, there is another group of relays in which the operation is governed by the ratio of applied voltage to current in the protected circuit. Such relays are called distance or impedance relays. In an impedance relay, the torque produced by a current element is opposed by the torque produced by a voltage element. The relay will operate when the ratio *V/I* is less than a predetermined value.

Figure. 1.20 illustrates the basic principle of operation of an impedance relay. The voltage element of the relay is excited through a potential transformer (P.T.) from the line to be protected. The current element of the relay is excited from a current transformer (C.T.) in series with the line. The portion *AB* of the line is the protected zone. Under normal operating conditions, the impedance of the protected zone is *ZL*. The relay is so designed that it closes its contacts whenever impedance of the protected section falls below the pre-determined value *i.e. ZL* in this case.

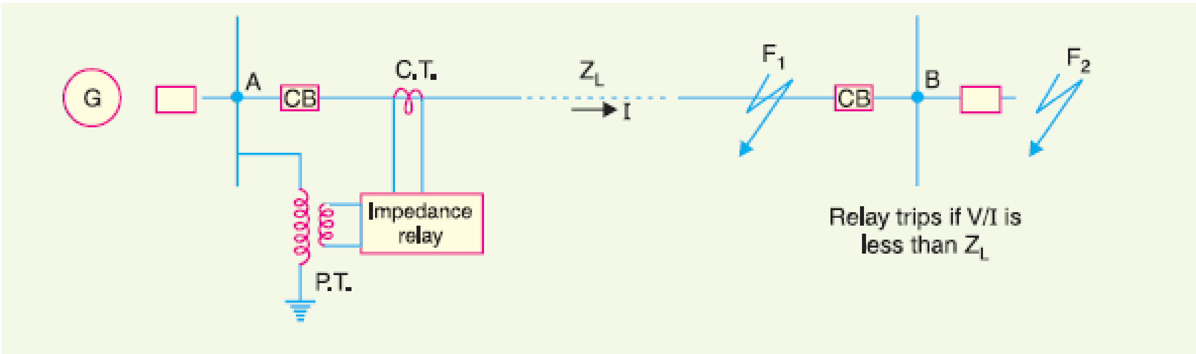

Figure 1.20 Impedance relay operation

Now suppose a fault occurs at point *F*1 in the protected zone. The impedance *Z* (= **V/I*) between the point where the relay is installed and the point of fault will be less than *ZL* and hence the relay operates. Should the fault occur beyond the protected zone (say point *F*2), the impedance *Z* will be greater than *ZL* and the relay does not operate.

A distance or impedance relay is essentially an ohmmeter and operates whenever the impedance of the protected zone falls below a pre-determined value. There are two types of distance relays in use for the protection of power supply namely;

- **Definite-distance relay** which operates instantaneously for fault upto a pre-determined distance from the relay.
- **Time-distance relay** in which the time of operation is proportional to the distance of fault from the relay point.

A fault nearer to the relay will operate it earlier than a fault farther away from the relay. It may be added here that the distance relays are produced by modifying either of two types of basic relays; the balance beam or the induction disc.

Definite – Distance Type Impedance Relay

Figure.1.21 shows the schematic arrangement of a definite-distance type impedance relay. It consists of a pivoted beam *F* and two electromagnets energized respectively by a current and voltage transformer in the protected circuit. The armatures of the two electromagnets are mechanically coupled to the beam on the opposite sides of the fulcrum.

The beam is provided with a bridging piece for the trip contacts. The relay is so designed that the torques produced by the two electromagnets are in the opposite direction.

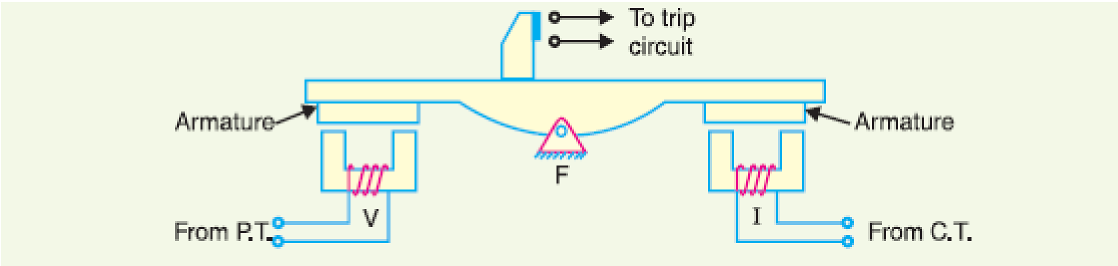

Figure 1.21 Definite distance relay

Under normal operating conditions, the pull due to the voltage element is greater than that of the current element. Therefore, the relay contacts remain open. However, when a fault occurs in the protected zone, the applied voltage to the relay decreases whereas the current increases. The ratio of voltage to current (*i.e.* impedance) falls below the pre-determined value. Therefore, the pull of the current element will exceed that due to the voltage element and this causes the beam to tilt in a direction to close the trip contacts. The pull of the current element is proportional to I^2 and that of voltage element to V^2. Consequently, the relay will operate when $K_1V^2 < K_2I^2$

The value of the constants k_1 and k_2 depends upon the ampere-turns of the two electromagnets. By providing tappings on the coils, the setting value of the relay can be changed.

Time Distance Impedance Relay

A time-distance impedance relay is one which automatically adjusts its operating time according to the distance of the relay from the fault point.

Operating time,

$$T \propto V/I$$
$$\propto Z$$
$$\propto distance$$

Figure. 1.22 shows the schematic arrangement of a typical induction type time distance impedance relay. It consists of a current driven induction element similar to the double winding type induction over current relay (refer back to Figure. 21.8). The spindle carrying the disc of this element is connected by means of a spiral spring coupling to a second spindle which carries the bridging piece of the relay trip contacts. The bridge is normally held in the open position by an armature held against the pole face of an electromagnet excited by the voltage of the circuit to be protected.

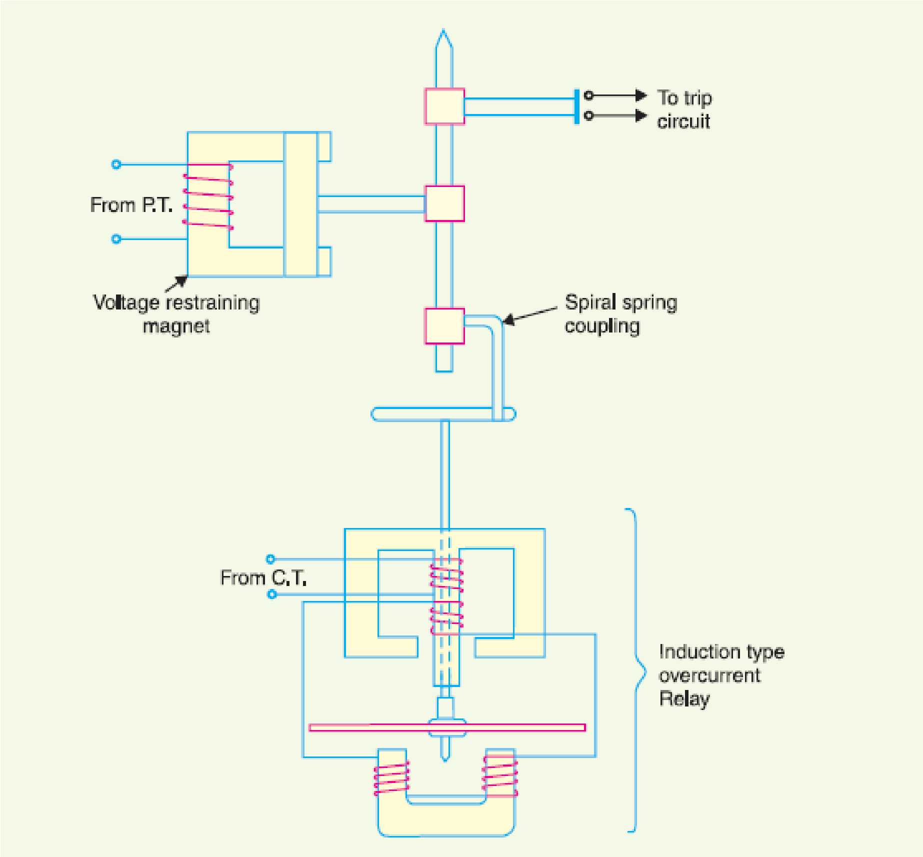

Figure 1.22 Induction type time distance impedance relay

Under normal load conditions, the pull of the armature is more than that of the induction element and hence the trip circuit contacts remain open. However, on the occurrence of a short circuit, the disc of the induction current element starts to rotate at a speed depending upon the operating current. As the rotation of the disc proceeds, the spiral spring coupling is wound up till the tension of the spring is sufficient to pull the armature away from the pole face of the voltage-excited magnet. Immediately this occurs, the spindle carrying the armature and bridging piece moves rapidly in response to the tension of the spring and trip contacts are closed. This opens the circuit breaker to isolate the faulty section.

The speed of rotation of the disc is approximately proportional to the operating current, neglecting the effect of control spring. Also the time of operation of the relay is directly proportional to the pull of the voltage-excited magnet and hence to the line voltage V at the point where the relay is connected. Therefore, the time of operation of relay would vary as V/I *i.e.* as Z or distance.

DIFFERENTIAL RELAYS

Most of the relays discussed so far relied on excess of current for their operation. Such relays are less sensitive because they cannot make correct distinction between heavy load conditions and minor fault conditions. In order to overcome this difficulty, differential relays are used. A differential relay is one that operates when the phasor difference of two or more similar electrical quantities exceeds a pre-determined value.

Thus a current differential relay is one that compares the current entering a section of the system with the current leaving the section. Under normal operating conditions, the two currents are equal but as soon as a fault occurs, this condition no longer applies. The difference between the incoming and outgoing currents is arranged to flow through the operating coil of the relay. If this differential current is equal to or greater than the pickup value, the relay will operate and open the circuit breaker to isolate the faulty section.

It may be noted that almost any type of relay when connected in a particular way can be made to operate as a differential relay. In other words, it is not so much the relay construction as the way the relay is connected in a circuit that makes it a differential relay. There are two fundamental systems of differential or balanced protection *viz.*

- Current balance protection
- Voltage balance protection

Current Differential Relay

Figure.1.23 shows an arrangement of an over current relay connected to operate as a differential relay. A pair of identical current transformers is fitted on either end of the section to be protected (alternator winding in this case). The secondaries of CT's are connected in series in such a way that they carry the induced currents in the same direction. The operating coil of the over current relay is connected across the CT secondary circuit.

This differential relay compares the current at the two ends of the alternator winding. Under normal operating conditions, suppose the alternator winding carries a normal current of 1000 A. Then the currents in the two secondaries of CT's are equal [See Figure. 21.23]. These currents will merely circulate between the two CT's and no current will flow through the

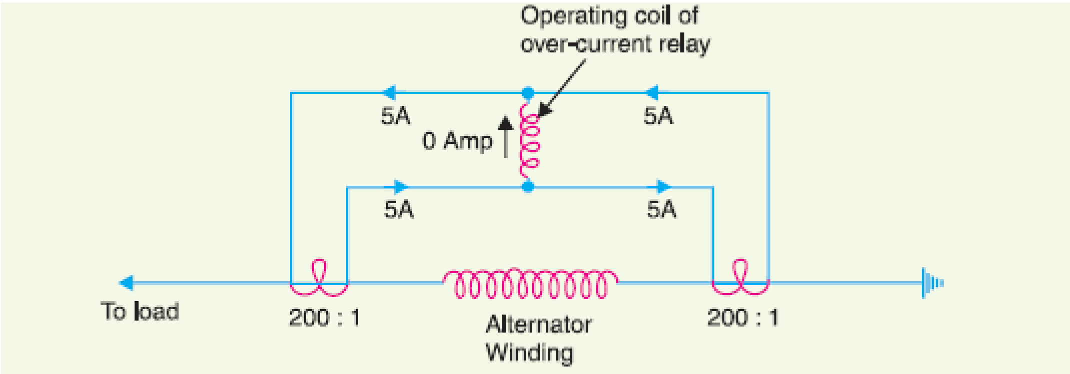

Figure 1.23 Current differential relay

differential relay. Therefore, the relay remains inoperative. If a ground fault occurs on the alternator winding as shown in Figure. 1.24 (i), the two secondary currents will not be equal and the current flows through the operating coil of the relay, causing the relay to operate. The amount of current flow through the relay will depend upon the way the fault is being fed.

- If some current (500 A in this case) flows out of one side while a larger current (2000 A) enters the other side as shown in Figure. 1.24 (i), then the difference of the CT secondary currents *i.e.* $10 - 2{\cdot}5 = 7{\cdot}5$ A will flow through the relay.

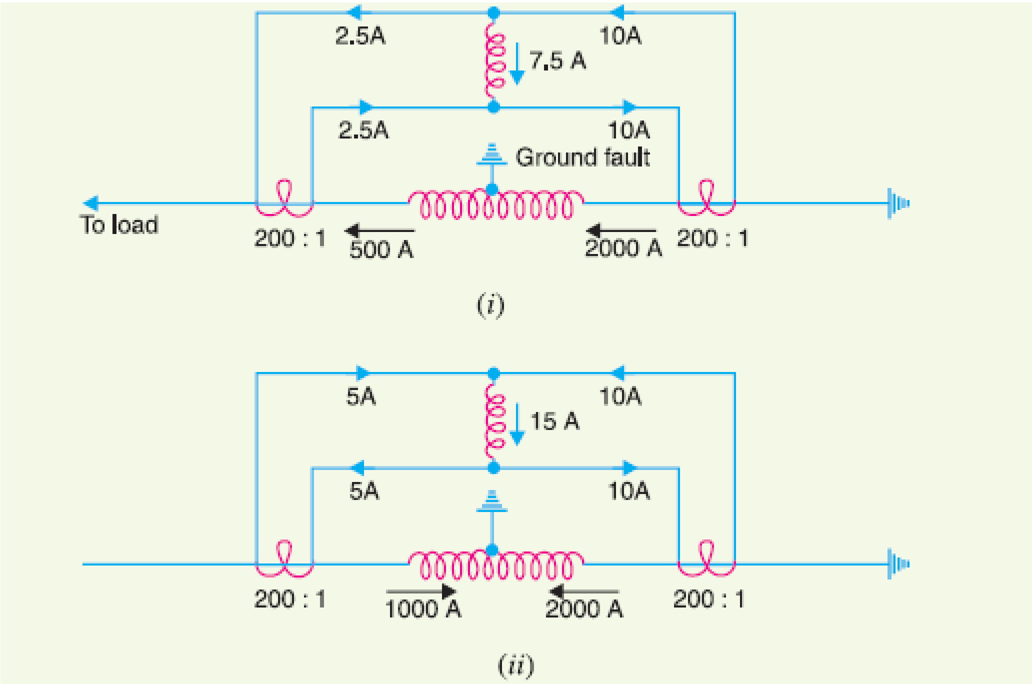

Figure 1.24 Operation of current differential relay

- If current flows to the fault from both sides as shown in Figure. 21.24 (*ii*), then sum of CT secondary currents *i.e.* 10 + 5 = 15 A will flow through the relay.

Disadvantages

- The impedance of the pilot cables generally causes a slight difference between the currents at the two ends of the section to be protected. If the relay is very sensitive, then the small
- Differential current flowing through the relay may cause it to operate even under no fault conditions.
- Pilot cable capacitance causes incorrect operation of the relay when a large through-current flows.
- Accurate matching of current transformers cannot be achieved due to pilot circuit impedance.

Voltage Balance Differential Relay

In this scheme of protection, two similar current transformers are connected at either end of the element to be protected (*e.g.* an alternator winding) by means of pilot wires. The secondaries of current transformers are connected in series with a relay in such a way that under normal conditions, their induced e.m.f.s' are in opposition.

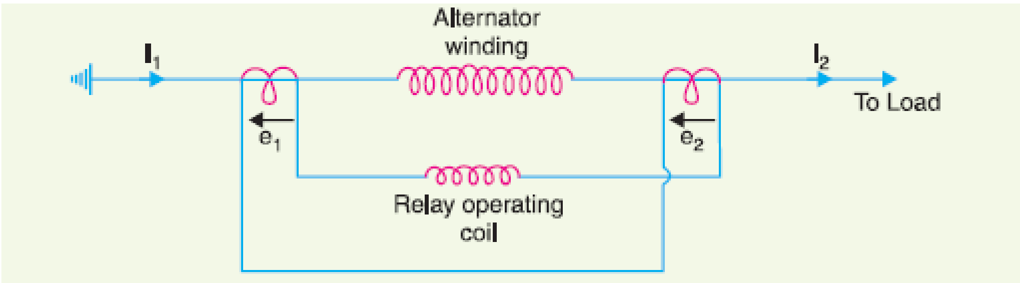

Figure 1.25 Voltage balanced differential relay

Under healthy conditions, equal currents ($I_1 = I_2$) flow in both primary windings. Therefore, the secondary voltages of the two transformers are balanced against each other and no current will flow through the relay operating coil. When a fault occurs in the protected zone, the currents in the two primaries will differ from one another (i.e. $I_1 \neq I_2$) and their secondary voltages will no longer be in balance. This voltage †difference will cause a current to flow through the operating coil of the relay which closes the trip circuit.

Disadvantages

The voltage balance system suffers from the following drawbacks

- A multi-gap transformer construction is required to achieve the accurate balance between current transformer pairs.

- The system is suitable for protection of cables of relatively short lengths due to the capacitance of pilot wires. On long cables, the charging current may be sufficient to operate the relay even if a perfect balance of current transformers is attained.

NEGATIVE SEQUENCE RELAY

The negative sequence relays are also called phase unbalance relays because these relays provide protection against negative sequence component of unbalanced currents existing due to unbalance loads. Negative sequence relay are generally used to give protection to generators and motors against unbalanced currents. It has a filter circuit which is operative only for negative sequence components.

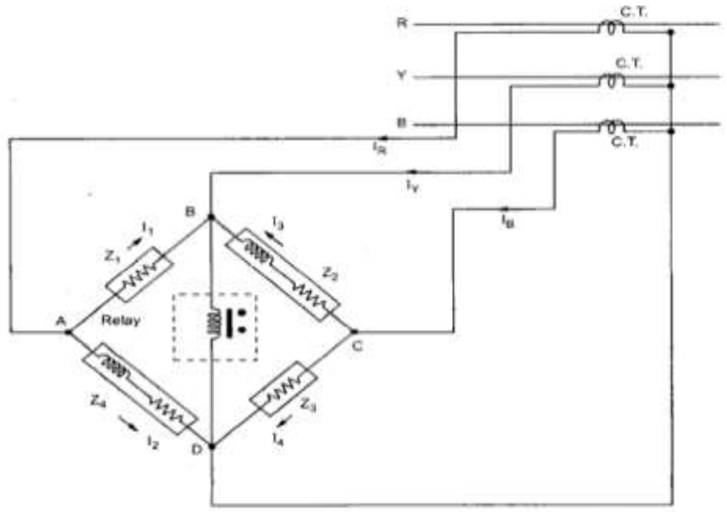

Figure 1.26 Negative Phase Sequence Relay

It consists of a resistance bridge network. The magnitudes of the impedances of all the branches of the network are equal. The impedances Z_1 and Z_3 are purely resistive while the impedances Z_2 and Z_4 are the combination of resistance and reactance. The currents in the branches Z_2 and Z_4 lag by 60˚ from the currents in the branches Z_1 and Z_3. The vertical branch B-D consists of inverse time characteristics relay. The current I_R gets divided into two equal parts I_1 and I_2. And I_2 lags I_1 by 60˚

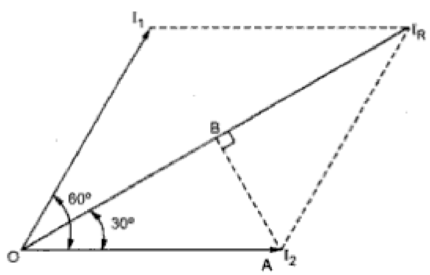

Figure 1.26 Phasor diagram

$$\bar{I}_1 + \bar{I}_2 = \bar{I}_R$$

$$I_1 = I_2 = I$$

The perpendicular is drawn from point A on the diagonal meeting it at point B, as shown in figure Now in triangle OAB,

$$\cos 30 = \frac{OB}{OA}$$

$$\frac{\sqrt{3}}{2} = \frac{\frac{I_R}{2}}{I}$$

$$I = \frac{I_R}{\sqrt{3}} = I_1 = I_2 \qquad \text{.....(1)}$$

Now I_1 leads I_R by 30˚ while I_2 lags I_R by 30˚ Similarly the current I_B gets divided into two equal parts I_3 and I_4. The current I_3 lags I_4 by 60˚ From equation (1)

$$I = \frac{I_B}{\sqrt{3}} = I_3 = I_4$$

The current I_4 leads I_B by 30˚ while current I_3 lags I_B by 30˚ The current entering the relay at the junction point B in the figure 1.27 is the vector sum of I_1, I_3 and I_Y.

$$I_{relay} = I_1 + I_3 + I_Y.$$

$$= I_Y + \frac{I_R}{\sqrt{3}} + \frac{I_B}{\sqrt{3}}$$

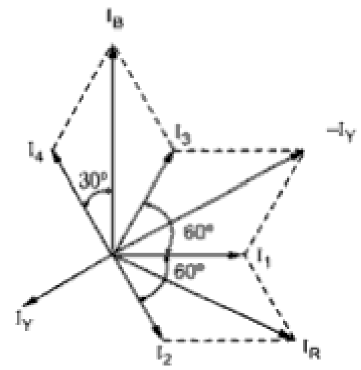

Figure 1.27 Vector Sum

The vector sum is shown in figure 6 when the load is balanced and no negative sequence current exists. It can be seen from the figure 6 that,

$$\bar{I}_1 + \bar{I}_3 = -\bar{I}_Y$$

$$\bar{I}_1 + \bar{I}_3 + \bar{I}_Y = 0$$

Thus the current entering the relay at point B is zero. Similarly the resultant current at junction D is also zero. Thus the relay is inoperative for a balanced system.

STATIC RELAY

Measurement of electrical quantities is performed by static circuit which gives an output signal for the tripping of a circuit breaker most of the present day static relays includes a d.c polarized relay as a slave relay, slave relay is an output device and does not perform the function of comparison or measurement it simply closes the contact it used because of low cost.

In fully static relay thyristor is used in place of electromagnetic slave relay. Electromagnetic relay used as a slave relay provides number of output contacts at low cost. A static relay employs semi conductor diodes, transistors, thyristors and logic gates

Advantages

- The moving parts are absent. The moving parts are present only in the actual tripping circuit and not in control circuit.
- The burden on current transformers gets considerably reduced thus smaller CTs can be used.
- The power consumption is very low as most of the circuits are electronic.
- The response is very quick.
- As moving parts are absent, the minimum maintenance is required. No bearing friction or contact troubles exist.
- The resetting time can be reduced and overshoots can be reduced due to absence of mechanical inertia and thermal storage.
- The sensitivity is high as signal amplification can be achieved very easily.
- The testing and servicing is simplified.
- The low energy levels required in the measuring circuits make the relays smaller and compact in size.

Disadvantages

- The characteristics of electronic components such as transistors, diodes etc., are temperature dependent. Hence relay characteristics vary with temperature and aging.
- The reliability is un predictable as it depends on a large number of small components and their electrical connections.
- These relays have low short time overload capacity compared to electromagnetic relays.

- Additional dc supply is required for various transistor circuits.
- Less robust compared to electromagnetic relay.

MICROPROCESSOR BASED RELAY

The characteristic if an impedance relay is realized by comparing voltage and current at the relay location.

- The ratio f voltage (V) to the current (I) gives he impedance of the line section between the relay location and the fault current.
- The rectified voltage and rectified current (v_{dc} and I_{dc}) are proportional to V and I, respectively.
- For comparison v_{dc} and i_{dc} are used.
- The following condition should be satisfied for the operation of the relay.
- The characteristic if impedance relays realized by comparing voltage and current at the relay location.
- The ratio f voltage (V) to the current I) gives he impedance of the line section between the relay location and the fault current.
- The rectified voltage and rectified current (vdc and Idc) are proportional to V and I, respectively.
- For comparison vdc and idc are used. The following condition should be satisfied for the operation of the relay.

$K_1V_{dc}< K_2I_{dc}$

$V/I<K$ $Z<K$

Where K_1, K_2 and K3 are constants.

The value of k for different zones of protection are calculated and stored in the memory as data to obtain the desired characteristic.

Z1-impedance for zone1

Z2 impedance for zone 2

Z3 impedance for zone 3

T1 operating time of or zone 1

T2 operating time of or zone 2

T3 operating time of or zone 3

- As the impedance relay is non-directional, a directional unit is used to give a directional feature so that the relay can operate for the fault in forward direction only.
- Block diagram schematic shows the levels of voltage and current signals are stepped down to the electronic level by using potential and current signals stepped down to the electronic level by using potential and current transformers.
- The current signal derived from the current transformer is converted into proportional voltage signal using a current to voltage converter.
- The voltage e and current signals are then rectified using precision rectifiers to convert them into dc.

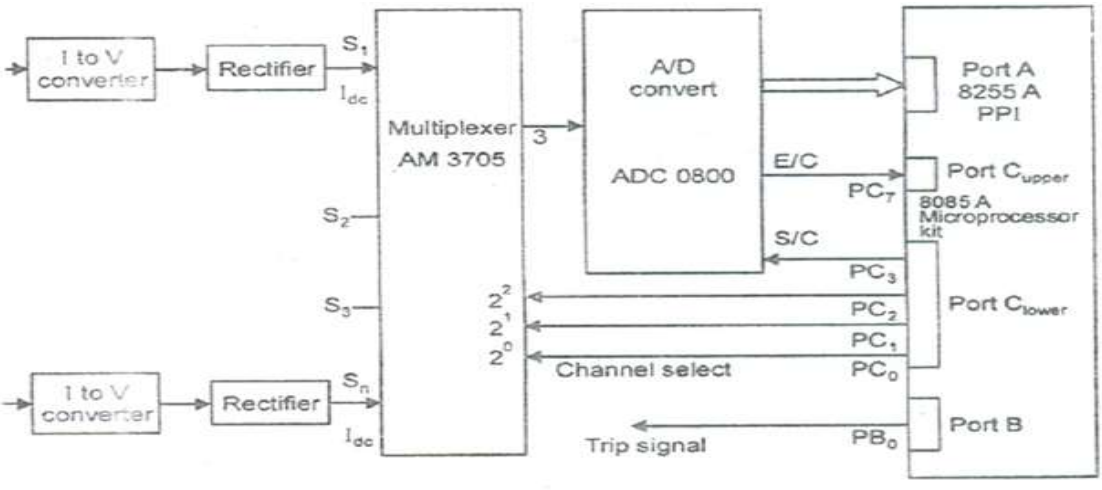

Figure 1.28 Block diagram of microprocessor based impedance relay

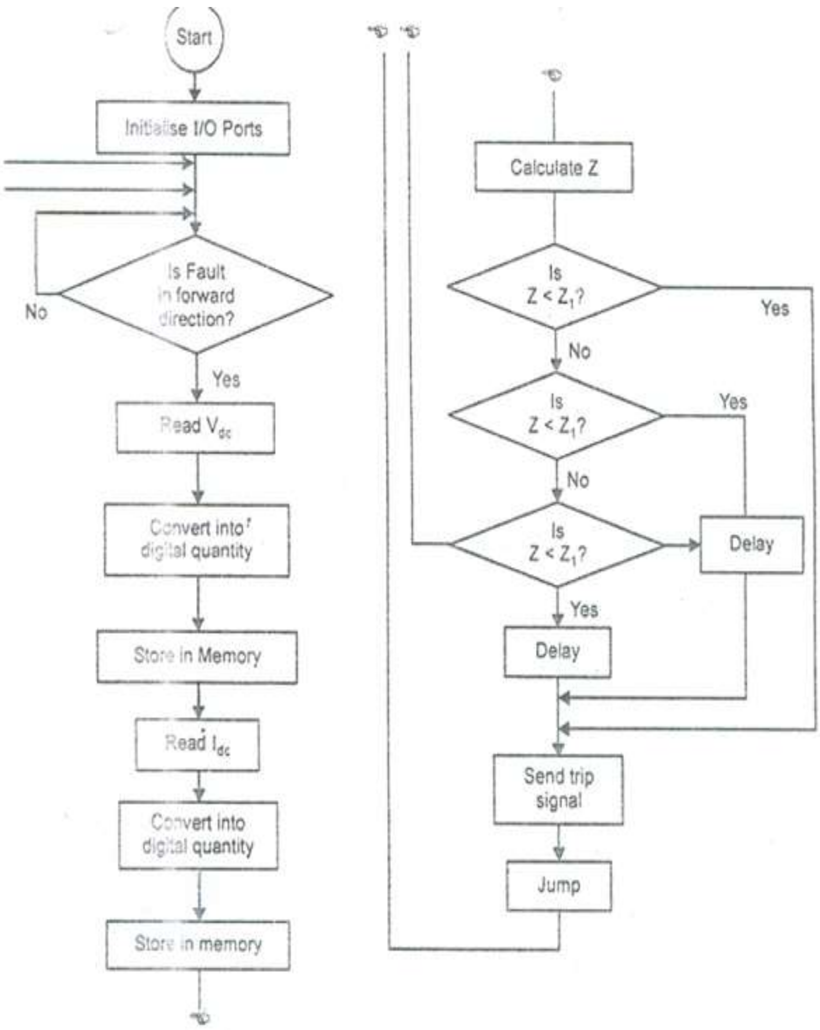

Figure 1.29 Flow chart of mp based impedance relay

- The rectified voltage and current singles are fed to two different channels of the multiplexer which are switched on sequentially by proper commands from the microprocessor.
- The o/p of the multiplexer is fed to the A/D converter through a sample and hold circuit.
- The multiplexer, sample and hold and 8-bit A/D converter ADC0800 from the data acquisition system (DAS).
- The DAS is interfaced to the mup using 8255A PPI. The controls for analog multiplexer, sample and hold, and ADC are all generated by the microcomputer under program control.
- The operation sequence is as per the flow chart given. The disadvantages of a conventional impedance relay arte overcome by using microprocessors for

realizing the operation of the relays. Microprocessor based relays perform very well and their cost is relatively low.

POWER SYSTEM EARTHING

The earthing or grounding is nothing but the connection of neutral point of the supply system to the general mass of earth in such a way that immediate discharge of electricity can take place without danger.

Neutral earthling is provided basically for the purpose of protection against arching ground, unbalanced voltages with respect to earth, protection from lighting and for improvement of the system.

Advantages of neutral grounding

- The voltages of healthy lines to earth remain at harmless.
- The life of insulation is long, due to prevention of voltage surge and less maintenance, Breakdown etc.
- Stable neutral point.
- The earth fault relaying is simple and easy.
- The over voltage due to lighting is discharged to earth.
- Life of equipment is improved.
- Greater safety to operating personnel and equipments.
- Avoidance of unnecessary tripping, due to prevention of arching ground.
- By providing resistors or reactors earth fault current is limited
- Arching grounds are reduced or eliminated.

Methods of grounding

1. Solid grounding
2. Resistance grounding
3. Reactance grounding
4. Arc suppression coil or Peterson coil
5. Voltage transformer grounding
6. Zigzag transformer grounding

Solid Grounding

- In this method of earthing, neutral is directly connected to earth by a metallic connection or a wire of negligible resistance and reactance.

- The charging currents flow through the system under normal condition similar to undergrounded system.
- Because of the connection of system neutral point to earth, it always remains at earth potential at all operating conditions and under faulty conditions voltage of healthy phase will not exceed.

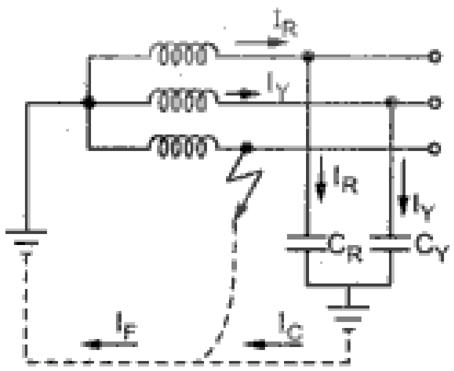

Figure 1.30 Solid grounding

Whenever there is earth fault on any one phase, the phase to earth voltage of faulty phase is zero while voltage to earth of the remaining two healthy phases will be normal phase voltages as neutral in this case is not shifted.

Resistance Earthing

- When there is necessary to limit the fault current then the current limiting element must be inserted in the neutral and earth.
- This can be achieved by using resistance earthing where one or more resistances are connected between neutral and earth.
- The resistance may be either of wire or water column resistances for voltages of 6.6 kv and above.
- Metallic resistors do not change with time and requires little maintenance.

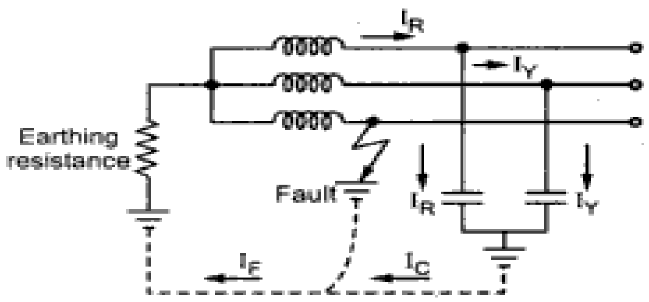

Figure 1.31 Resistance Earthing

The advantages are

1. The discriminative type of switchgears may be used for protection.
2. The hazards due to arching grounds are minimized.
3. The influence on neighboring communication circuits is minimized due to lower value of fault current flowing through earth**.**

Resonant earthing

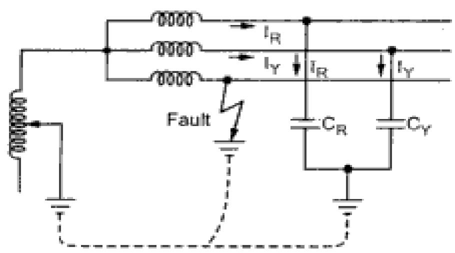

Figure 1.32 Resonant earthing

The system works on the principle that when inductance and capacitance are connected in parallel, resonance takes place between them and because of the characteristics of resonance, the fault current is reduced or can be neutralized.

Arc suppression coil (Peterson coil)

An arc suppression coil is an iron-cored reactor similar to oil immersed transformer connected between neutral of system and earth. This coil is provided with number of tappings so that it can be tuned with the capacitance which may vary due to varying operational conditions.

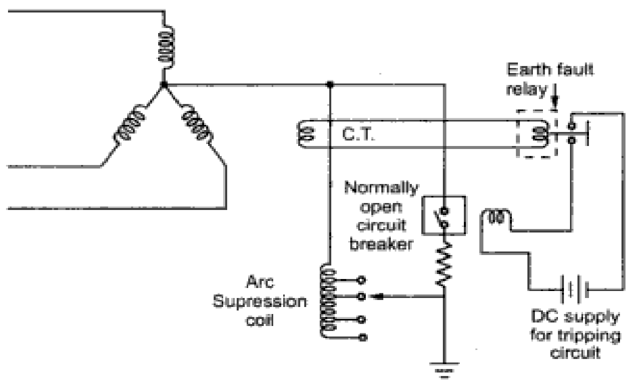

Figure 1.33 Arc Suppression coil

An arc suppression coil is an iron-cored reactor similar to oil immersed transformer connected between neutral of system and earth. This coil is provided with number of tappings so that it can be tuned with the capacitance which may vary due to varying operational conditions.

Voltage transformer earthing

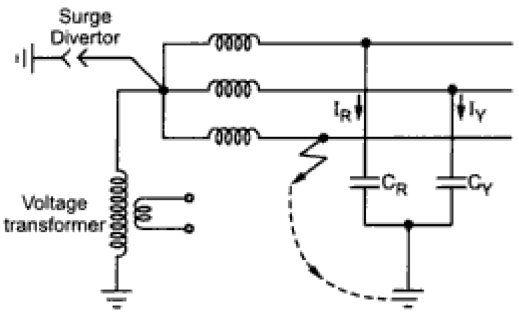

Figure 1.34 voltage transformer earthing

The voltage transformer shown in the figure measures the voltage so that earth fault on the system is shown in figure. The travelling waves passing through the machine winding are reflected through voltage transformer. A surge diverter is used between neutral and earth to avoid the rise of voltage.

Earthing transformer

- When the transformers or generators are delta connected or if the neutral points are not accessible then artificially the neutral earthing point can be created with the use of star connected earthing transformer.
- Such transformer has no secondary.
- Each phase of primary has two equal parts.
- There are three limbs and each limb has two windings providing opposite flux during normal condition as shown in figure below.

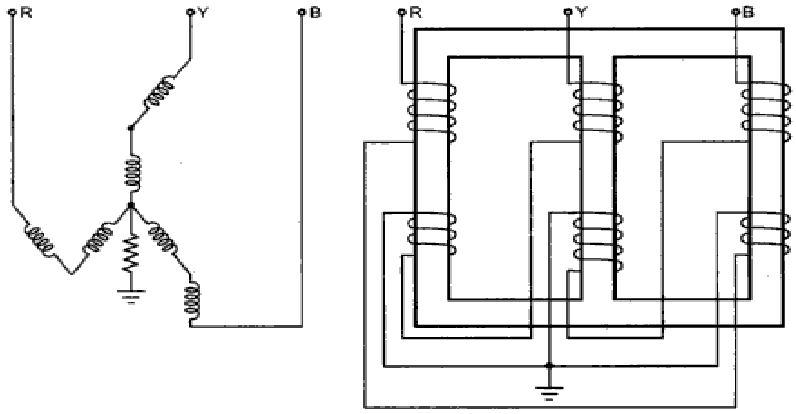

Figure 1.35 Earthing transformer

- The directions of the currents in the two windings on each limb are opposite to each other.
- The small exciting current is circulated in the windings during normal operation.
- During fault the transformer offers a low impedance path to the flow of zero phase sequence currents.
- The value of fault current is limited in some cases by the use of a resistor in series with the neutral earthing connection.