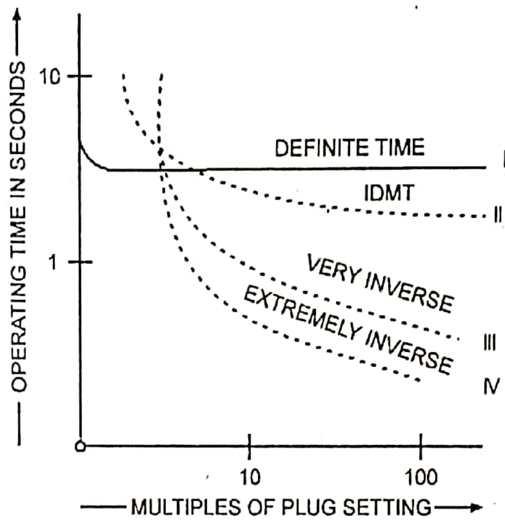
6.10. OVER-CURRENT RELAYS

Depending upon the time of operation, already defined in Art 6.2, over-current relays may be categorized as (*i*) instantaneous over-current relays (*ii*) inverse-time over-current relay (*iii*) define time over-current relay (*iv*) inverse definite minimum time (IDMT) over-current relay (*v*) very inverse over-current relay and (*vi*) extremely inverse over-current relay.

(*i*) ***Instantaneous Over-Current Relay.*** An instantaneous over-current relay is one in which no intentional time delay is provided for operation. In such a relay, the relay contacts close immediately after the current in the relay coil exceeds that for which it is set. Although there will be a short time interval between the instant of pick-up and the closing of the relay contacts, no intentional time delay is provided. This characteristic can be achieved with the help of hinged armature relays. Such relay has a unique advantage of reducing the time of operation to a minimum for faults very close to the source where the fault current is the greatest. The instantaneous relay is effective only where the impedance between the relay and source is small compared with the impedance of the section to be protected.

One of the most important considerations in over-current and over-voltage protection is the speed of operation. With hinged armature relays, the time of operation of 0.01 second at three times the setting can be obtained. Such relays are employed for restricted earth-fault and other types of circulating current protection. With so fast an operation it is likely that the relay may operate on transients beyond the normal range of setting.

(*ii*) ***Inverse-time Over-Current Relay.*** An inverse time relay is one in which the operating time is approximately inversely proportional to the magnitude of the actuating quantity. Fig. 6.9 illustrates the time-current characteristics of an inverse-current relay. At values of current less than pick-up value, the relay never operates. At higher values, the operating time of the relay decreases steadily with the increase of current. The more pronounced the effect is the more inverse the characteristic is said to be. In fact, all time-current curves are inverse to a greater or lesser degree. They are normally more inverse near the pick-up value of the actuating quantity and become less inverse as it is increased.



Characteristics of Various Over-Current Relays
Fig. 6.17

The operating time of all over-current relays tends to become asymptotic to a definite minimum value with increase in the value of actuating quantity. This is inherent in electro-magnetic relays due to saturation of the magnetic circuit. So by varying the point of saturation different characteristics are obtained. These are (*i*) definite time (*ii*) inverse definite minimum time (*iii*) very inverse and (*iv*) extremely inverse, as shown in fig 6.17.

These characteristics can be obtained by induction disc and induction cup relays, already explained in Art 6.6.

(*iii*) If the core is made to saturate at a very early stage, the time of operation remains same over the working range. This characteristic is shown by curve I in fig 6.17 and is known as **definite time characteristic.** Such a relay operates after a specified time irrespective of the magnitude of the fault current.

The definite-time relays are used in (*i*) radial or loop circuits having a few sections (*ii*) as back-up protection for other types of protection and (*iii*) on systems with wide variations of fault current due to source impedance.

Selectivity amongst such relays is obtained if there is difference of 0.5 s in the time settings of the two successive relays.

(*iv*) ***Inverse Definite Minimum Time (IDMT) Relays.*** Such a relay is one in which operating time is approximately inversely proportional to fault current near pick-up value and becomes substantially constant slightly above the pick-up value of the relay, as illustrated by curve II in fig 6.17. This is achieved by using a core of the electro-magnet which gets saturated for currents slightly greater than the pick-up current.

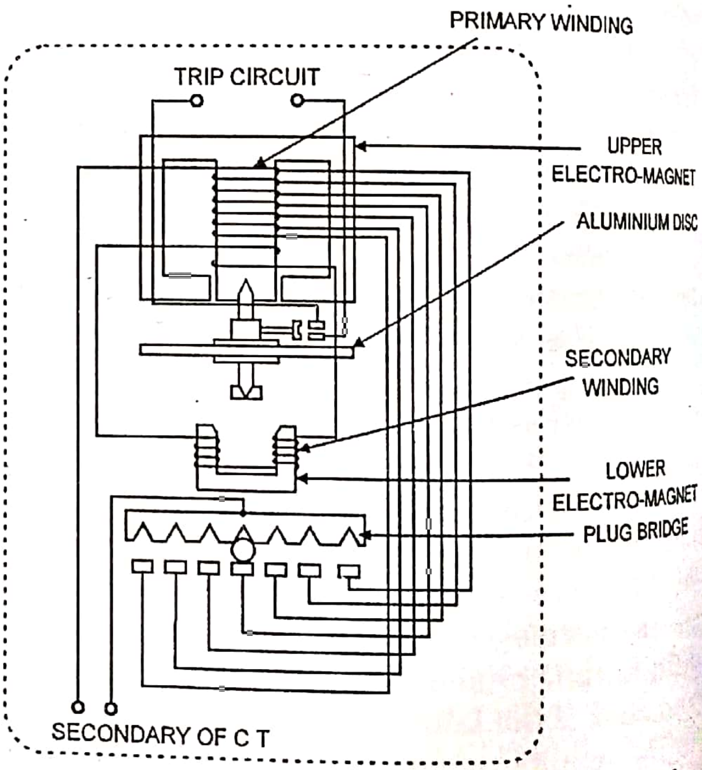
(*v*) ***Very Inverse Relay.*** In such a relay the saturation of the core occurs at a still later stage, as illustrated by curve III in fig 6.17. This curve is known as *very inverse characteristic curve.* The time-current characteristic is inverse over a greater range and after saturation tends to definite time. Relays with very inverse time-current characteristics are employed on feeders and long sub-transmission lines.

(*vi*) ***Extremely Inverse Relay.*** The curve IV in fig 6.17 illustrate extremely inverse characteristic i.e., core saturation occurs at a very late stage. The equation describing the curve IV in the figure is approximately of the form $I^2t = K$ where I is the operating current and t is the operating time. Such relays are quite suitable for the protection of transformers, cables etc, as it is possible to achieve accurate discrimination with fuses and auto-reclosures in their case, which can seldom be made selective with standard IDMT relays. This is because of their ability to ride through starting currents and surges, providing at the same time fast operation under fault conditions. They are, thus more suitable for installations with large in-rush currents after an outage.

Relays with *inverse time-current characteristics* are widely employed in distribution networks and industrial plant systems. Their relatively flat time-current characteristic permits them to achieve reasonably fast operation over a wide range of short-circuit currents.

IDMT is the only characteristic which is specified by Indian Standards (IS: 3231-1965) the remaining are all relative curves.

6.10.1 Induction Type Over-Current Relay. An induction type over-current relay giving inverse-time operation with a definite minimum time characteristic is shown in fig. 6.18. It consists essentially of an ac energy meter mechanism with slight modification to give required characteristics. The relay has two electro-magnets. The upper electro-magnet has two windings, one of these is primary and is connected to the secondary of a CT 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 turns in use can be adjusted, thereby giving the desired current setting. The plug bridge is usually arranged to give seven sections of tappings to give over-current range from 50% to 200% in steps of 25%. If the relay is required to response for earth fault the steps are arranged to give a range from 10 % to 70 % or 20 to 80% in steps of 10%. The values assigned to each tap are expressed in terms of percentage of full-load rating of CT with which the relay is associated and represents and value above which the disc commences to rotate and finally closes the trip circuit. Thus pick-up current equals the rated secondary current of CT multiplied by current setting. For example suppose that an over-current relay having a current setting of 150% is connected to a supply circuit through a CT of 500/5 A. The rated secondary current of CT is 5 A and therefore, the pick-up value will be 1.5 × 5 i.e., 7.5 A. It means that with above current setting, the relay will actually operate for a relay current equal to or greater than 7.5 A. Similarly for current settings of 50, 100 and 200%



Induction Type Non-Directional Over-Current Relay
Fig. 6.18

the relay will operate for relay currents of 2.5 A, 5 A and 10 A respectively. Adjustment of current setting is made by inserting a pin between the spring loaded jaw of the bridge socket at the tap value required. When the pin is withdrawn for the purpose of changing the setting value while the relay in service, the relay automatically adopts higher setting, thus the CT's secondary is not open-circuited.

The second winding is energized by induction from the primary, and is connected in series with the winding on the lower magnet. By this arrangement, leakage fluxes of upper and lower electro-magnets are sufficiently displaced in space and phase to set up a rotational torque on the aluminium disc suspended between the two magnets, as in the shaded pole induction disc motor. This torque is controlled by the spiral spring and also sometimes by a permanent magnet brake on the disc. The torque is given by the expression

$$T = K_1 I^2_{rms} - K_2$$

where I_{rms} is the current through the coil and K_2 is the restraining torque of the spring. The disc spindle carries a moving contact which bridges two fixed contacts (trip circuit contacts) when the disc has rotated through a pre-set angle. The angle can be set to any value between 0° and 360° and thereby giving desired time setting. This adjustment is known as *time-setting multiplier*. Time multiplier setting is generally in the form of an adjustable back-stop which decides the arc length through which the disc travels, by reducing the length of travel, the operating time is reduced. The time setting multiplier is calibrated from 0 to 1 in steps of 0.05. These figures do not represent the actual operating times but are multipliers to be used to convert the time known from the relay name plate curve (time-PSM curve) into the actual operating time. Thus if time setting is 0.2 and the operating time obtained from the time-PSM curve of the relay is 5 seconds, then actual operating time of the relay will be equal to 0.2 × 5 i.e., 1 second.

Since the time required to rotate the disc through a pre-set angle depends upon the torque which varies as the current in the primary circuit, therefore, more the torque lesser will be the time required. So the relay has inverse-time characteristic.

In more recent designs the definite minimum time characteristic is obtained by saturating iron in the upper electro-magnet so that there is practically no increase in flux after the current has reached a certain value and any further increase in current will not affect the relay operation.

The ratio of reset to pick-up is inherently high in induction relays because their operation does not involve any change in the air gap. It lies between 95% and 100%.

Current-Time Characteristics of an Over-Current Induction Disc Relay. A set of typical time-current characteristics of the above relay is given in fig. 6.19. 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. The abscissa is taken as multiple of pick-up value so that the same curves can be used for any value of pick-up i.e., if the curves are known for pick-up value of 5 A, then the characteristics remain same for 2.5 A, 6.25 A, 7.5 A, 10 A or any other pick-up value. This is possible with induction type relays where the pick-up adjustment is by coil, because the ampere-turns at pick-up are the same for each tap and hence at a given multiple of pick-up, the coil ampere-turns, and hence the torque are the same regardless of the tap used.

These curves are normally plotted on log-log graph papers as illustrated in the figure. The advantages of plotting the curves on log-log sheets is that if the characteristic for one particular pick-up value and one time multiplier setting is known, then the characteristics for any other pick-up value and time multiplier settings can be obtained.

Theoretically the time ordinates of these curves should be in proportion to the time multiplier setting so that, if the times for a given current are divided by the TMS all the curves should coincide. Owing to inertia of the disc which takes a little time for the disc to accelerate from standstill to its steady speed at low values of current they may not exactly coincide. It introduces some error in time which might affect the discrimination of the whole scheme.

The curves are used to estimate not only the operating time of the relay for a given multiple of pick-up value and time multiplier setting but also it is possible to know how far the relay moving contact would have travelled towards the fixed contacts within any time interval.

This method is also useful in finding out whether the relay will pick-up and how long it will take for the relay operation when the actuating quantity is changing as for example during the in-rush current period of starting a motor etc.

Current-time characteristics of an IDMT relay are given below:

Operating current expressed as a multiple of setting	*Operating time in seconds at the maximum time setting (TMS = 1.0)*
20	2.2
10	3.0
5	4.0
2	10.0

Setting of Induction Relays. The setting for a phase-fault relay is usually of the order of 150-200% of the full-load current. An induction relay will not operate at a current equal to or less than its setting and minimum operating current of the relay must not exceed 130% of the setting.

The setting of the earth fault relays should be in the range of 20 to 80%. An earth fault relay is subject to mal-operation if its setting is too low. This mal-operation can be due to unbalance in load currents, unbalance in output of CTs, switching surges or saturation of CTs during phase faults. As such, settings lower than 20% are not recommended. Also, the more sensitive an earth fault relay, the greater will be the chances of its mal-operation.

A time interval of 0.4 to 0.5 second may be allowed in the time settings of two adjacent induction relays for proper selectivity. Shorter interval of 0.35 second may be used with very inverse over-current relays.

Whenever a protective system comprises of a series of over-current relays with graded time settings, it is imperative that the current-time characteristics of all such relays must flatten out in the same fashion so that a flawless relay operation is ensured howsoever severe may be the nature of the fault.

6.10.2. Determination of Relay Operating Time. For determination of actual operating time of a relay, the data required is (*i*) Time-PSM curve (*ii*) Current setting (*iii*) Time setting (*iv*) Fault current (*v*) CT ratio.

The actual operating time of a relay is determined by following the steps given below :

(*i*) Determination of relay current from fault current I_f and CT ratio $x : y$ from the expression

$$\text{Relay current, } I_R = \frac{I_f \times y}{x} \qquad \text{...(6.3)}$$

(*ii*) Determination of relay current setting multiplier (i.e., PSM) which is given as

$$\text{PSM} = \frac{\text{Fault current in relay coil}}{\text{Pick - up value}}$$

$$= \frac{I_R}{\text{Current setting} \times \text{rated secondary current of CT}}$$

$$= \frac{I_R}{\frac{I_p}{100} \times y} = \frac{I_R \times 100}{I_p \times y} = \frac{I_f \times 100 \times y}{x \times I_p \times y} = \frac{I_f \times 100}{x \times I_p} \quad ...(6.4)$$

where I_p is the per cent current setting of the relay

(*iii*) Determination of operating time of relay corresponding to calculated PSM from Time-PSM curve.

(*iv*) Determination of actual operating time of relay by multiplying the time obtained in step (*iii*) by the time–setting multiplier in use.

Example 6.1. An IDMT type over-current relay is used to protect a feeder through 500/1 A CT. The relay has a PS of 125% and TMS = 0.3. Find the time of operation of the said relay if a fault current of 5,000 A flows through the feeder. Make use of the following characteristic

PSM	2	3	5	8	10	15
Time for unity TMs	10	6	4.5	3.2	3	2.5

(100% current = 1 A) [*A.M.I.E. Sec B. Advanced Power Systems Summer 1994*]

Solution:

Fault current, I_f = 5,000 A

CT ratio = 500 : 1

$$\text{Relay current, } I_R = \frac{I_f}{\text{CT ratio}} = \frac{5{,}000}{500} = 10 \text{ A}$$

Pick-up value of relay = Current setting × rated secondary current of CT

$$= \frac{125}{100} \times 1 = 1.25 \text{ A}$$

$$\text{Plug setting multiplier of the relay, PSM} = \frac{\text{Fault current in relay coil, } I_R}{\text{Pickup value of relay}} = \frac{10}{1.25} = 8$$

Time corresponding to the PSM of 8 from the given data is 3.2 seconds

So actual operating time = 3.2 × Time setting multiplier

= 3.2 × 0.3 = 0.96 second **Ans.**

Example 6.2. Determine the time of operation of a 1 A, 3s over-current relay having plug setting of 125 per cent and a time multiplier of 0.6. The supplying CT is rated 400 : 1 A and fault current is 4,000 A. The relay characteristic curve is given below :

PSM	1.3	2	4	8	10	20
Time of Operation (in seconds)	30	10	5	3.3	3	2.2

[*A.M.I.E. Sec B. Power System Protection and Communication Summer 1996*]

Solution :

$$\text{Relay current, } I_R = \frac{\text{Fault current, } I_f}{\text{CT ratio}} = \frac{4{,}000}{400} = 10 \text{ A}$$

Pick-up value of relay = Current setting × rated current of secondary of CT

= 1.25 × 1 = 1.25

$$\text{PSM of relay} = \frac{I_R}{\text{Pick-up value of relay}} = \frac{10}{1.25} = 8$$

From the given data, the operating time for PSM of 8 is 3.3 seconds

Actual operating time of relay = 3.3 × TSM = 3.3 × 0.6 = 1.98 seconds **Ans.**

Time corresponding to PSM of 3.33 from PSM-time curve shown in fig 6.19 is 5.6 seconds

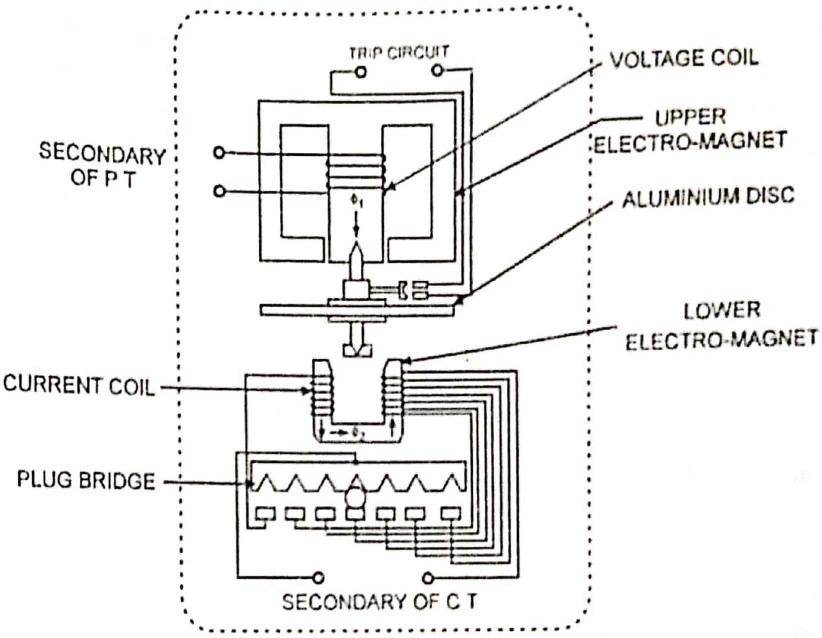
Time setting for transformer relay = Actual operating time of feeder relay + time grading margin

= 0.9 + 0.5 = 1.4 seconds

$$\text{Time setting multiplier} = \frac{1.4}{5.6} = 0.25 \text{ Ans.}$$

6.11. INDUCTION TYPE DIRECTIONAL POWER RELAY

The non-directional relay discussed in Art 6.10.1 can operate for fault flow in either direction. In order to achieve operation for the fault flowing in a specific direction, it is necessary to add a directional element (fig 6.22) to the non-directional element.



Induction Type Directional Power Relay
Fig. 6.22

The directional (or reverse) power relay operates when the power through the relay will be reversing i.e. generator supply to the network fails and the power from the other sources in the system try to feed the power to this unit in the reverse direction. In the case of motors such a relay is employed to prevent the motors reversing the direction of rotation.

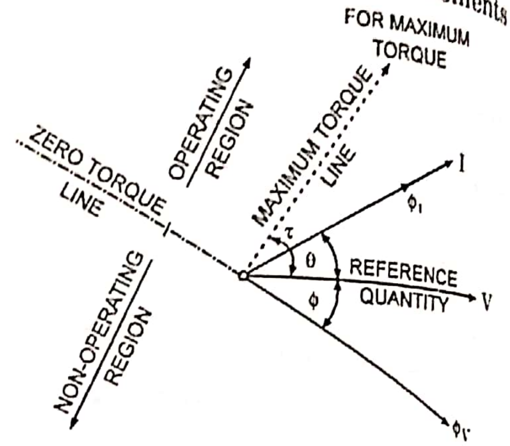
The principle of operation of this relay is similar to that of an over-current (non-directional) induction relay shown in fig 6.18. The difference lies in the fact that in case of over-current relay the torque is developed due to interaction of magnetic fields obtained from the current in the circuit through CT, while in case of directional power relay the driving torque is derived from the interaction of the fields produced from both voltage and current sources of the circuit it protects. Since the relay has both voltage and current coils, the relay is essentially a wattmeter and the direction of the torque developed in the relay depends upon the direction of current in relation to the voltage with which it is associated i.e. the relay recognizes the phase difference between voltage and current.

Constructional Details. The induction type directional power relay is shown in fig 6.22. It essentially consists of an aluminium disc which is free to rotate in between the poles of two electro-magnets. The upper electro-magnet has a winding, called the *voltage* or *potential coil*, on the middle limb connected to the circuit voltage source through a potential transformer (PT). The lower electro-magnet has a separate winding, called the *current coil*, connected to the secondary of CT in the line to be protected. The current-coil is provided with a number of tappings connected to the plug bridge, so as to give the desired current setting. The restraint torque is provided by a spiral spring.

Operation. The torque developed on the disc suspended between the two magnets is proportional to V I. When the power flows in the normal direction, the torque developed on the disc assisted by the spring tends to turn away the moving contact from the fixed trip circuit contacts. Thus the relay remains inoperative. A reversal of current in the circuit reverses the torque produced on the disc and when this is large enough to overcome the control spring torque, the disc rotates in the reverse direction and the moving contact closes the trip circuit. This causes the operation of the circuit breaker to disconnect the faulty section. The relay can be made very sensitive by having a very light control spring so that a very small reversal of power will cause the relay to operate.

The relay can be a single phase or a 3-phase having two voltage and two current elements like a 3-phase energy meter.

Operating Characteristics. Let V be the voltage applied to the relay through PT and I be the relay current through CT. In phasor diagram (fig. 6.23) I is shown leading the relay voltage V by an angle θ. Here ϕ_V is the flux due to voltage coil and lags behind the voltage by angle ϕ (about 60° to 70°) and ϕ_I is the flux due to the current coil and is in phase with current I. The net torque is produced due to the interaction of ϕ_I and ϕ_V



Phasor Diagram For Directional Element

Fig. 6.23

Torque, therefore, is given as

$$T \propto \phi_V \ \phi_I \sin(\phi + \theta)$$

where $\phi_V \propto V$ and $\phi_I \propto I$

So the torque equation for the relay can be given as

$$T = K\,V\,I \sin(\phi + \theta) \qquad \text{...(6.5)}$$

The torque is maximum when the two fluxes are displaced by 90° i.e. when $(\phi + \theta) = 90°$. Here dotted line in the phasor diagram represents the desired position of ϕ_I for maximum torque. Since V is the reference quantity and ϕ_V has fixed position with respect to V for a particular design, the angle between the dotted line and the reference quantity V is known as the *maximum torque angle* and let it be denoted by τ. Zero torque will occur when $\sin(\phi + \theta) = 0$ i.e., $(\phi + \theta) = 0°$ or 180°, this being satisfied when the relay current phasor lies along the chain dotted line which is at right angles to the maximum torque line. The directional element will, therefore, operate provided the current phasor lies with in ± 90° of the maximum torque line. If the current phasor is displaced by more than 90° the directional element will restrain. The operating and the non-operating regions are shown in the figure.

It may be seen that

$$\tau = 90° - \phi$$

$$\text{or } \phi = 90° - \tau \qquad \text{...(6.6)}$$

and the torque equation becomes

$$T = KVI \sin(\theta + 90° - \tau)$$

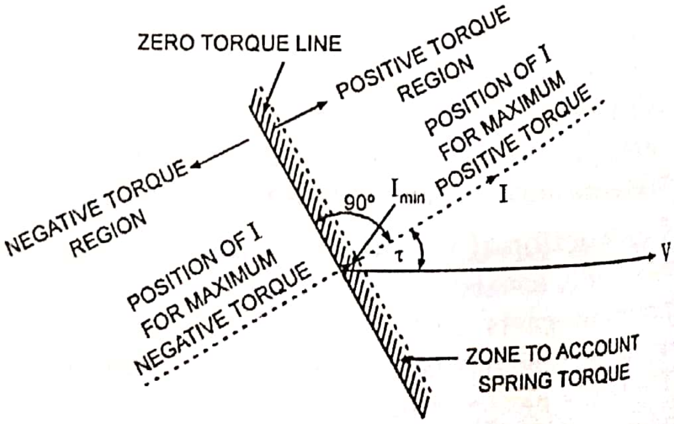
$$= KVI \cos(\theta - \tau) \qquad \text{...(6.7)}$$

When the relay is about to start, neglecting the spring constant,

$$VI \cos(\theta - \tau) = 0$$

$$\text{or } \theta - \tau = 90°$$

$$\text{or } \theta = \tau + 90° \qquad \text{...(6.8)}$$



Polar Characteristic of Directional Relay

Fig. 6.24

This is the equation describing the polar characteristic (fig 6.24) of the directional relay.

The zone between the dotted line and the line parallel to it corresponds to the spring torque. If the current phasor lies within these lines the torque developed is less than spring torque and hence the relay does not operate. If the current phasor crosses the dotted line the operating torque exceeds the spring torque and hence the relay operates. Relay will not pick-up or it will reset for any current phasor lying in the negative torque region.

It may be noted that the system current usually lags behind the system voltage but the relay current is made to lead the relay voltage by inserting resistance or capacitance or a combination of the two in series with the voltage or potential coil.

Such relays are very suitable for protection of parallel feeders. The directional over-current relay suffers from the drawback that the feeder voltage falls to a much lower value when a fault occurs resulting into non-operation of the relay. This short-coming may be overcome by compensating the relay secondary winding on the lower magnet. The compensating winding ampere-turns on the lower magnet opposes the ampere-turns produced by the current coil. Therefore turns of current coil will have to be appropriately increased. When the voltage falls due to the fault on the feeder, the resultant ampere-turns provided by the windings on the lower electro-magnet jointly increase, compensating the reduced ampere-turns provided by the voltage coil.

6.12. INDUCTION TYPE DIRECTIONAL OVER-CURRENT AND EARTH-FAULT RELAY.

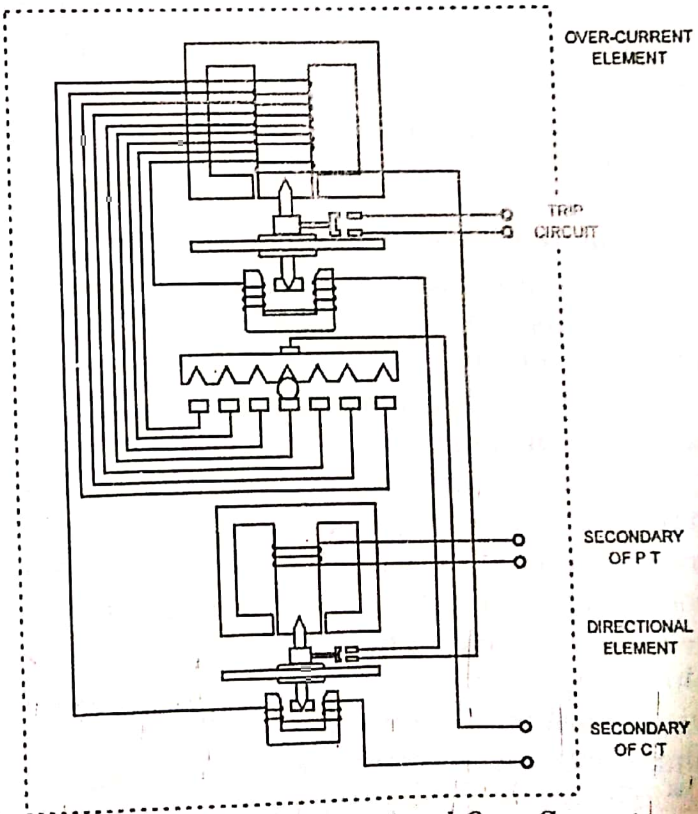
The directional power relay, discussed in Art 6.11, cannot be employed as a directional protective relay under short-circuit conditions because under short-circuit conditions the system voltage drops to a low value and therefore the torque developed in the relay may be insufficient to cause its operation. This difficulty is overcome in the directional over-current relay which is designed to be almost independent of system voltage and power factor.

Constructional Details. Constructional details of a typical induction type directional over-current and earth-fault relay are shown in fig 6.25. It consists of two relay elements. viz., (*i*) directional element and (*ii*) non-directional element, mounted in a common case.

Directional element is essentially a *directional power relay,* already discussed in Art 6.11. The voltage coil of this element is connected to the circuit voltage through a PT while its current coil is energized through a CT by circuit current. This winding is carried over the upper magnet of the non-directional element. The trip contacts of the directional element are connected in series with the secondary circuit of the over-current element. Thus over-current element cannot start to operate until its secondary circuit is completed i.e., the directional element must operate first in order to operate the over-current element.

Non-directional element is an over-current element similar in all respects to a non-directional over-current relay described in Art 6.10.1. The spindle of the disc of this element carries a moving contact which closes the trip-circuit contacts after the operation of directional element. The tappings are provided over the upper magnet of the over-current element and are connected to the bridge, thereby provide facility for current setting.

Under normal operating conditions, power flow is in the normal direction in the circuit protected by the relay. Thus the directional power relay (lower element) does not operate, thereby keeping the over-current element (upper element) unenergised. But as soon as there is a reversal of current or power the disc of the reverse power relay (lower element)



Induction Type Directional Over-Current and Earth-Fault Relay
Fig. 6.25

starts, rotating and completes the circuit for over-current element. Due to over-current a torque is produced in the disc and the action closes the trip circuit, thereby enabling the circuit breaker to operate and isolate the faulty section.

The directional element is made as sensitive as possible to ensure positive operation-even 20% of the power in the reverse direction operates it. The relay operates only when (*i*) the *direction of current is in reverse direction (ii) current in the reverse direction exceeds the pre-set value and (iii) excessive current (greater than the pre-set value) persists for duration longer than its time setting.*

Directional relays must have the following features:

(*i*) high speed of operation (*ii*) high sensitivity (*iii*) adequate short-time thermal rating (*iv*) ability to operate with low values of voltage (*v*) burden must not be excessive and (*vi*) there should be no voltage and current creep i.e., if either the voltage coil alone or the current coil alone is energized with the other one denergized there should be no movement.

Induction cup units satisfy the above requirements and are, therefore, very popular.

Such relays are employed when graded time overload protection is applied to ring mains and interconnected networks, since fault current can flow in either direction.

6.12.1. Directional Over-Current Relay Connections. Relay connections must be made so that the currents and voltages applied to the relay during different fault conditions which may arise on the protected circuit section afford the relay a positive and sufficiently large operating torque. To achieve this for all types of faults the relays cannot be connected to operate on true watts since for some faults the voltage will be extremely small and also the power factor will be very small which will result in a negligible small torque. To overcome this difficulty, and thus ensure that sufficient torque is available, each relay is supplied with current and voltage as described below.

There are two types of relay connections in use. Directional element connections are conveniently and popularly described in terms of the angle by which unity power factor (UPF) balanced load current flowing in the tripping direction leads the applied voltage applied to the relay voltage coil with due consideration given to the polarity of the relay coils.

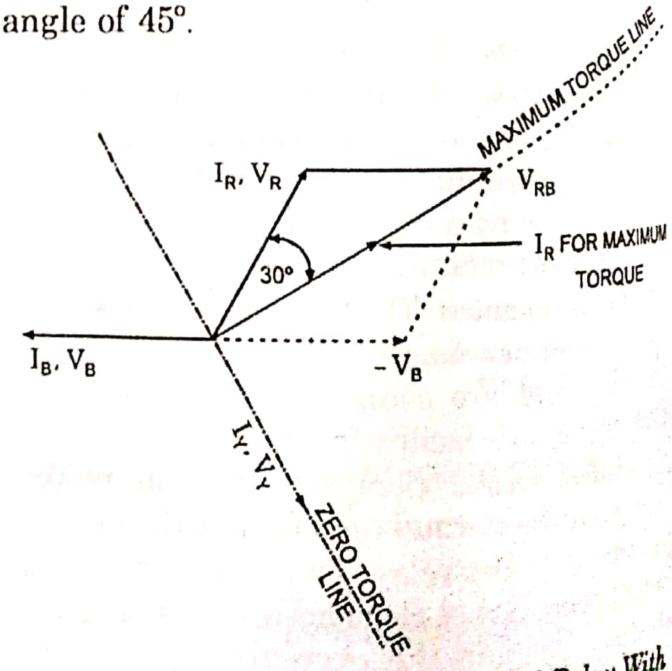
The two types of relay connections used are:

(*i*) The 30°-relay with a maximum torque angle of 0°.

(*ii*) The 90°-relay with a maximum torque angle of 45°.

The relay angle is defined as the angle between the voltage and current supplied to the relay under balanced three phase unity power factor conditions.

In phasor diagram for 0° directional relay with zero maximum torque angle shown in fig. 6.26 I_R, I_Y, I_B and V_R, V_Y, V_B represent the phase currents, and phase voltages of a 3-phase balanced system with unity power factor conditions. Phasor V_{RB} representing the system red phase to blue phase voltage lags behind phasors I_R and V_R by 30°. Let the relay element be supplied with current I_R and voltage V_{RB}, in phase relation as shown i.e., I_R leads V_{RB} by 30°. The connections are, therefore, referred to as 30° relay.



Phasor Diagram For 0° Directional Relay With Zero Maximum Torque Angle

Fig. 6.26

The angle between the current and voltage supplied to the relay for maximum torque, T is zero so that the position of the relay current phasor for maximum torque will be along V_{RB}. Also since according to equation (6.7).

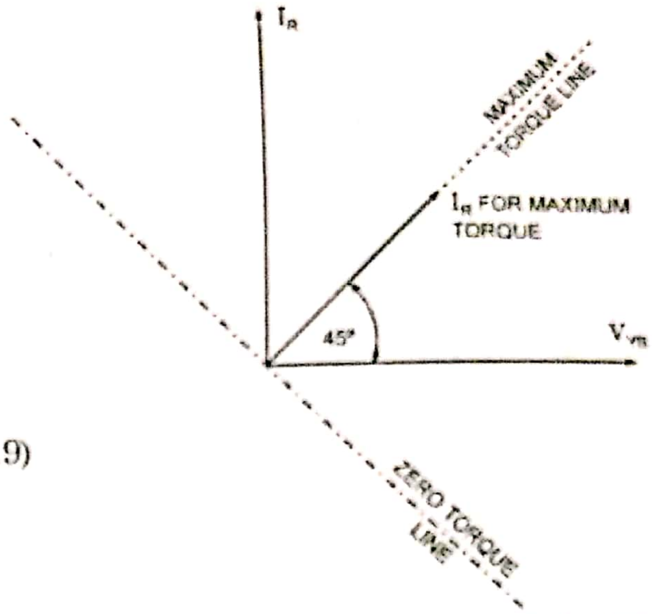
$$T = K\,V\,I\cos(\theta - \tau)$$
$$= K\,V\,I\cos\theta \quad \text{for } \tau = 0$$

Now for unity power factor condition i.e., system current I_R in phase with system voltage, the relay current I_R leads the relay voltage V_{RB} by 30° i.e., $\theta = 30°$ so that torque developed

$$T = K\,V\,I\cos 30° = 0.866\,K\,V\,I \quad \text{...(6.9)}$$

While if system current I_R lags behind the system voltage V_R by 30°, the relay current I_R will be in phase with relay voltage V_{RB} so that $\theta = 0°$ and the torque developed will be maximum and is given as

$$T = K\,V\,I \quad \text{...(6.10)}$$



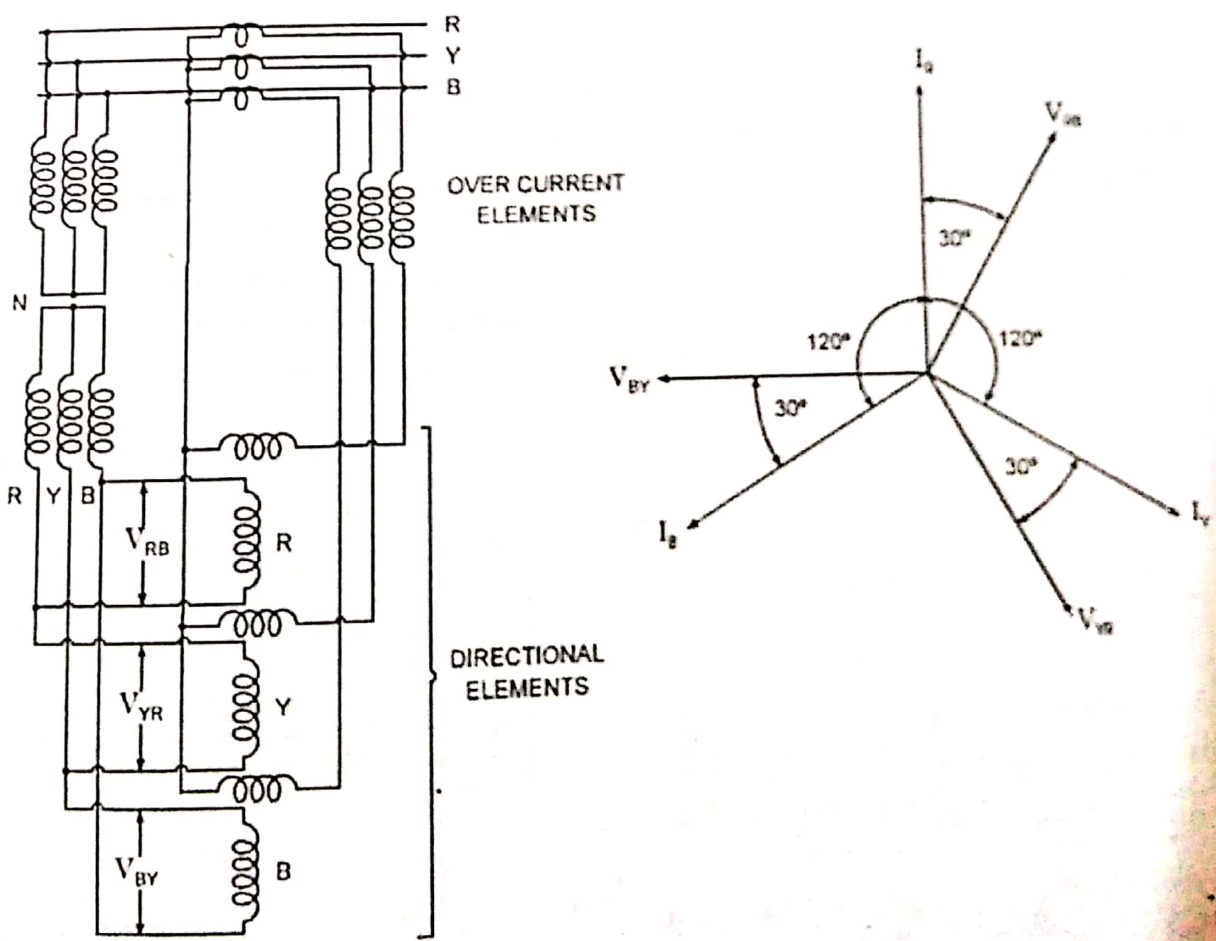
Phasor Diagram For 90° Directional Relay With 45° Maximum Torque Angle

Fig. 6.27

On occurrence of fault, I_R may lag V_R, say by 90°, and in such case θ will be 60° and the torque developed will be 0.5 T_{max}.

We thus see that the initial lead of 30° makes the relay more sensitive at low power factors. Such relays are usually satisfactory for plain feeders.

The phasor diagram for the *90°-relay with a maximum torque angle of 45°* is shown in fig 6.27.



30° Connection Diagram

Fig. 6.28

If a relay consists of all the three elements, the torque will be developed due to all the three causes and therefore, its torque in general will be given as

$$T = K_1 I^2 + K_2 V^2 + K_3 V I \cos(\theta - \tau) + K_4 \quad \text{...(6.[illegible])}$$

where K_1, K_2, K_3 are tap settings or constants of I and V and K_4 is the mechanical restraint due to spring or gravity.

By assigning plus or minus signs to certain of the constants and letting others be zero, and sometimes by adding other similar terms, the operating characteristics of all types of protective relays can be obtained.

For example, in case of an over-current relay $K_2 = K_3 = 0$ because of absence of voltage windings and therefore torque equation becomes

$$T = K_1 I^2 - K_4 \quad \text{...(6.[illegible])}$$

–ve sign is assigned to K_4 as the torque produced by spring is restraining one.

Similarly, for directional relay $K_1 = K_2 = 0$ and the torque developed will be given as

$$T = K_3 V I \cos(\theta - \tau) - K_4 \quad \text{...(6.[illegible])}$$

6.14. DISTANCE PROTECTION

Distance protection is the name given to the protection, whose action depends upon the distance of the feeding point to the fault. The time of operation of such a protection is a function of the ratio of voltage and current i.e., impedance. This impedance between the relay and the fault depends upon the electrical distance between them.

Distance-relay group is perhaps the most interesting and versatile family of relays. Principal types of distance relays are (*i*) impedance relays (*ii*) reactance relays (*iii*) admittance or mho relays.

Distance relays differ in principle from other forms of protection in that their performance is not governed by the magnitude of the current or the voltage in the protected circuit but rather on the ratio of these two quantities. Distance relays are actually double actuating quantity relays with one coil energized by voltage and the other coil by current. The current element produces a positive or pick-up torque while the voltage element produces a negative or reset torque. The relay operates only when the V/I ratio falls below a predetermined value (or set value). During a fault on a transmission line the fault current increases and the voltage at the fault point decreases. The V/I ratio is measured at the location of CTs and PTs. The voltage at PT location depends on the distance between PT and the fault. If the fault is nearer, measured voltage is lesser and if the fault is farther, measured voltage is more. Hence assuming constant fault impedance each value of V/I measured from relay location corresponds to distance between relaying point and the fault along the line. Hence such protection is called the *distance protection* or *impedance protection*.

Distance protection is non-unit type protection, the protection zone is not exact. The distance protection is high speed protection and is simply to apply. It can be employed as a primary as well as back-up protection. It can be employed in carrier aided distance schemes and in auto reclosing schemes. Distance protection is very commonly used in protection of transmission lines.

Distance relays are used where over-current relaying is too slow and is not so selective. Distance relays are used for both phase fault and ground fault protection and they provide higher speeds for clearing faults than over-current relays. Distance relays are also independent of changes in magnitude of the short-circuit currents and hence they are not much affected by changes in the generation capacity and the system configuration. Thus they eliminate long clearing times for faults near the power sources required by over-current relays if used for the purpose.