

UNIT-II

OVER-CURRENT PROTECTION

1. Time-current characteristics: \searrow

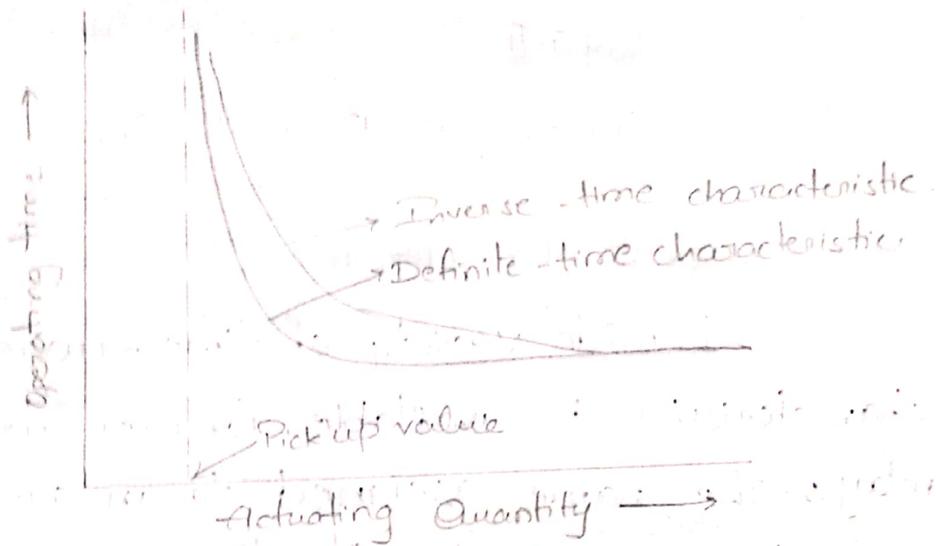
A wide variety of time-current characteristics is available for over current relays. The name assigned to an over current relay indicates its time-current characteristic as described below.

Definite-time overcurrent Relay: -

A definite time over-current relay is a relay that operates after a definite period of time once the current exceeds the pick up value. Hence, this relay has current setting range as well as time setting range.

Instantaneous Overcurrent Relay.

We refer the pre-set value of current in the relay coil as pick up setting current. This relay is referred as instantaneous over current relay. As ideally, the relay operates as soon as the current in the coil gets higher than pick up setting current. There is no intentional time delay applied.



Inverse-time overcurrent Relay:

An inverse-time overcurrent relay operates when the current exceeds its pick up value. The operating time depends on the magnitude of the operating current. The operating time decreases as the current increases.

Inverse Definite minimum Time Overcurrent (IDMT) Relay :-

This type of a relay gives an inverse time current characteristic at lower values of the fault current and definite-time characteristic at higher values of the fault current. Generally, an inverse-time characteristic is obtained if the value of the plug setting multiplier is below 10. For values of plug setting multiplier between 10 and 20, the characteristic tends to become a straight line i.e. towards the definite time characteristic

IDMT relays are widely used for the protection of distribution lines. Such relays have a provision for current and time settings which will be discussed later on.

Very Inverse-time overcurrent Relay:

Very inverse time overcurrent Relay. Gives more inverse characteristics than that of IDMT. Used where there is a reduction in fault current, as the distance from source increases. Particularly effective with ground faults because of their speed characteristics.

$$t = \frac{13.5}{I-1} ; t = \frac{k}{I^n-1}$$

Extremely Inverse-time overcurrent Relay:

The characteristic time of the relay is extremely large as compared to IDMT and the very inverse relay. This relay is used for protecting the cable, transformer etc. The relay can operate instantly when the pickup value of the current is more than the relay setting time. The relay provides faster operation even under the fault current. It is used to sensing the overheating of the machines.

Over current relays, having their time-current characteristics steeper than those of extremely inverse relays are required

for certain industrial applications. These relays have time-current characteristic, $I^n t = k$ with $n=2$. To protect rectifier transformers, a highly inverse characteristic of $I^8 t = k$ is required. The characteristics having $n=2$ are realised by static relays or micro-processor-based over current relays. Enclosed fuses have a time-current characteristic of $I^{2.5} t = k$. A static relay or microprocessor-based relay can be designed to give $I^{2.5} t = k$ characteristic, suitable to be graded with fuse.

Method of Defining shape of Time-current characteristics.

The general expression for time-current characteristics is given by:

$$t = \frac{k}{I^n - 1}$$

$$t = \frac{k}{I^n}$$

(i) I.D.M.T: $t = \frac{0.14}{I^{0.02} - 1}$

(ii) Very inverse: $t = \frac{13.5}{I - 1}$

(iii) Extremely inverse: $t = \frac{80}{I^2 - 1}$

Current setting:

The minimum pick up the value of the deflecting force of an electrical relay

is constant. Again the deflecting force of the coil is proportional to its number of turns and the current flowing through the coil.

Now if we can change the number of active turns of any coil, the current required to reach at a minimum pickup value of deflecting force, in the coil also changes. That means if the number of active turns of the coil also changes. That means if the number of turns of the relay coil are reduced, a proportionately more current is required to produce the desired relay actuating force.

Particularly same model relays are used in different systems. As per the system requirements, the pickup current of the relay is adjusted. This is known as the current setting of the relay. The current setting of the relay is expressed in percent ratio of relay pickup current to the secondary current of CT.

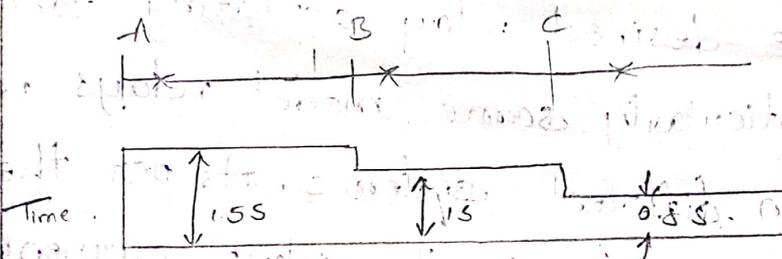
$$\text{Current setting} = \frac{\text{Pick up current}}{\text{Secondary current of CT}} \times 100$$

Overcurrent protective schemes

- (i) Time-graded system
- (ii) Current graded system
- (iii) A combination of time and current grading.

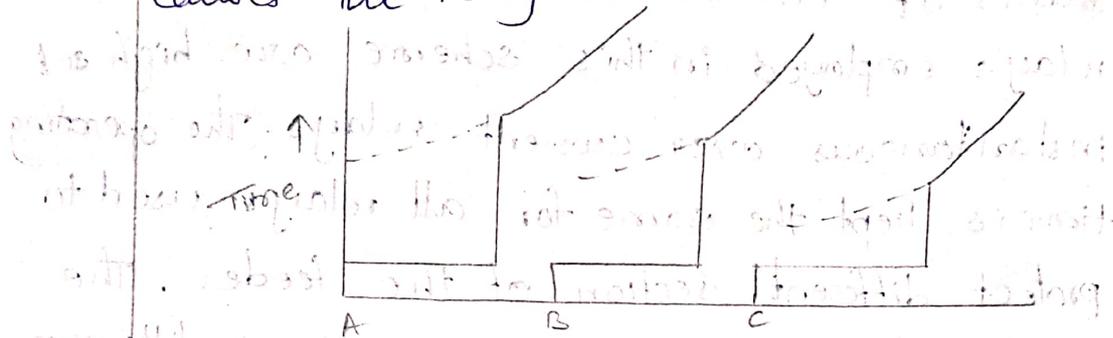
Time-graded system:-

In this scheme, definite-time overcurrent relays are used. When a definite-time relay operates for a fault current, it starts a timing out which trips the circuit breaker after a preset time, which is independent of the fault current.



When a fault occurs beyond C, all relays come into action as the fault current flows through all them. The least time setting is for the relay placed at C. So it operates after 0.5s and the fault is cleared. Now the relay at A and B are reset. If the relay or circuit breaker at C fails, the fault remains uncleared. In this situation, after 1s, the relay at B also fails to operate after 1.5s circuit breaker at A will trip.

The performance of instantaneous relay is affected by the dc component of transients. The error introduced by the dc offset components causes the relay to overreach.



The advantage of this system as compared to the time-graded scheme is that the operating time is less near the power source.

Combination of current and time-grading.

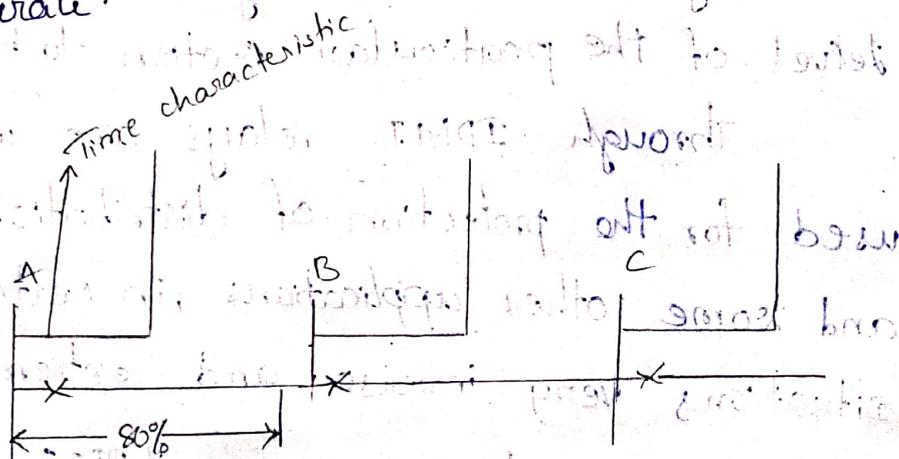
This scheme is widely used for the protection of distribution lines. IDMT relays are employed in this scheme. They have the combined features of current and time grading. IDMT relays have current as well as time setting arrangements. The current setting of the relay is made according to the fault current level of the particular section to be protected.

Through IDMT relays are widely used for the protection of distribution systems and some other applications, in certain situations very inverse and extremely inverse relays are used instead of IDMT relays.

Current-graded system :- ... (a)

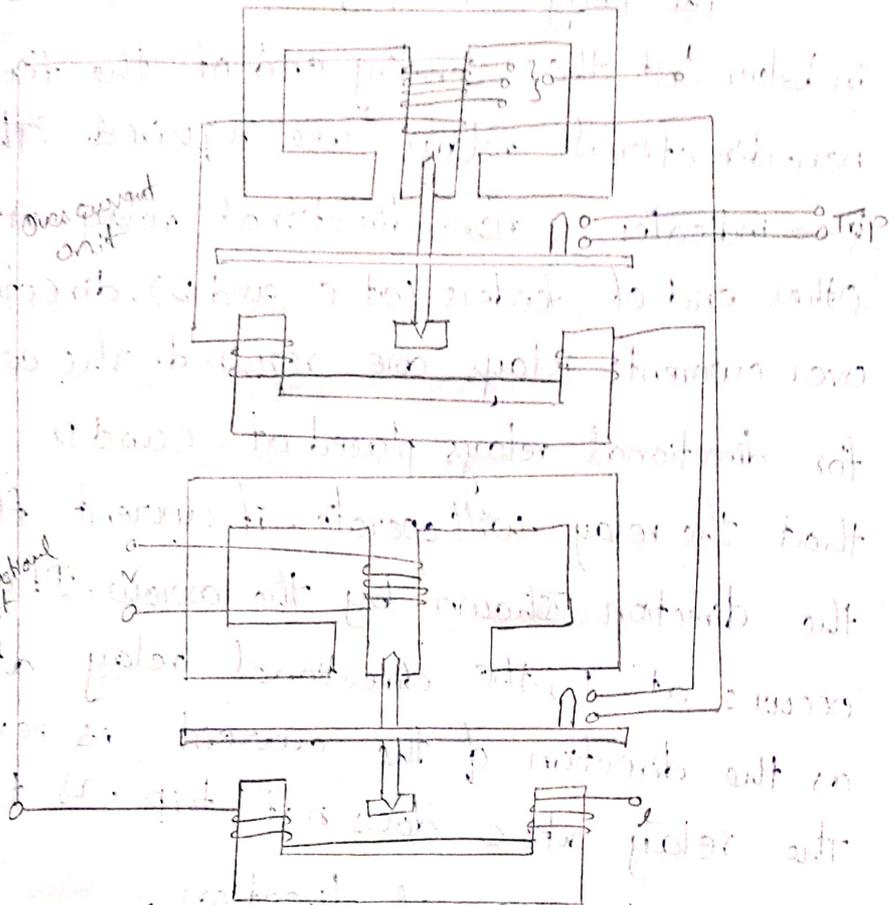
In a current-graded scheme, the relays are set to pick-up at progressively higher values of current towards the source. The relays employed in this scheme are high set instantaneous over current relays. The operating time is kept the same for all relays used to protect different section of the feeder. The ideal operation is not achieved due to the following reasons:

- i) The relay at A is not able to differentiate between faults very close to B which may be on either side of B. If a fault in the section BC is very close to the station B.
- ii) The magnitude of the fault current cannot be accurately determined as all the circuit parameters may not be known.
- iii) During a fault, there is a transient condition and the performance of the relays is not accurate.



Directional Overcurrent Relay

- A directional overcurrent relay operates when the current exceeds a specified value in a specified direction.

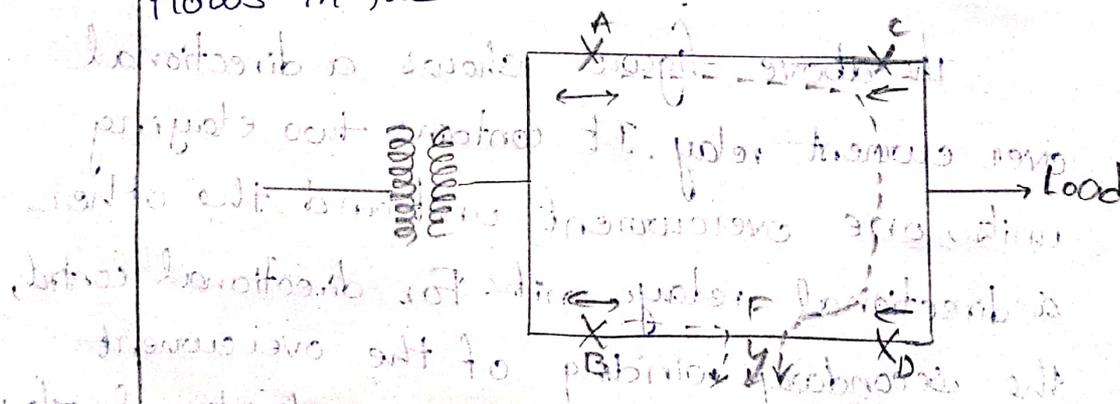


The above figure shows a directional over current relay. It contains two relaying units, one overcurrent unit and the other a directional relay unit. For directional control, the secondary winding of the overcurrent unit is kept open. When the directional relay unit operates, it closes the open contacts of the secondary winding of the overcurrent unit. Thus, a directional feature is attributed to the overcurrent relay. The overcurrent unit may be of either a wattmeter or shaded pole type.

In shaded pole type, the opening is made in the shading coil which is in this case a wound coil instead of an ordinary copper strip.

Protection of parallel Feeders.

The diagram of parallel feeders is shown in below. At the sending end of the feeders, non-directional relays are required. The symbol \longleftrightarrow indicates a non-directional relay. At the other end of feeders (at C and D), directional over current relays are required. The arrow mark for directional relays placed at C and D indicate that the relay will operate if current flows in the direction shown by the arrow. If a fault occurs at F, the directional relay at D trips, as the direction of the current is reversed. The relay at C does not trip, as the current flows in the normal direction.



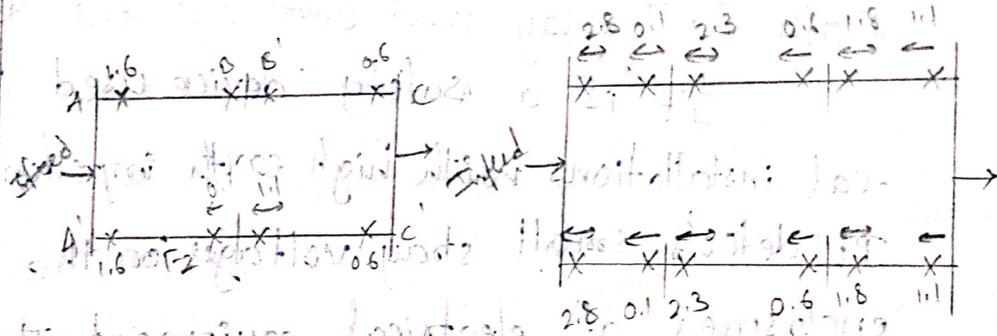
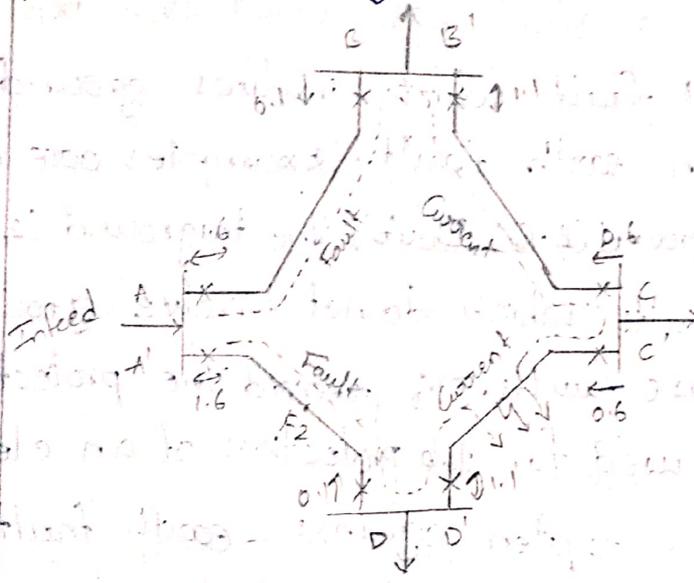
The relay at B trips for a fault at F. Thus, the faulty feeder is isolated and the supply of the healthy feeder is maintained.

If non-directional relays are used at C and D, both relays placed at C and D will trip.

Protection of Ring mains

⑥

Figure (a) shows an overcurrent scheme for the protection of a ring feeder. Figure (b) is another way of drawing the same scheme. Compared with radial feeders, the protection of ring feeders is costly and complex.



Each feeder requires two relays, a non-directional relay is required at one end and a directional relay at the other end. The operating times for relays are determined by considering the grading, first in one direction and then in the other direction.

If a fault occurs at F₁, the relays at C' and D' will trip to isolate the faulty feeder.

The relay at c will not trip as the fault current is not flowing in its tripping direction, though its operating time is the same as that of c. Similarly, the relay at B and D will not trip as the fault currents are not in their tripping direction.

Earth fault and phase fault protection.

A fault which involves ground is called an earth fault. Examples are single line to ground (L-G), Double line to ground (2L-G) fault. Faults which do not involve ground are called phase faults. To provide the protective scheme used for the protection of an element of a power system against earth fault is known as earth fault protection.

Earth fault Relay and over current Relay.

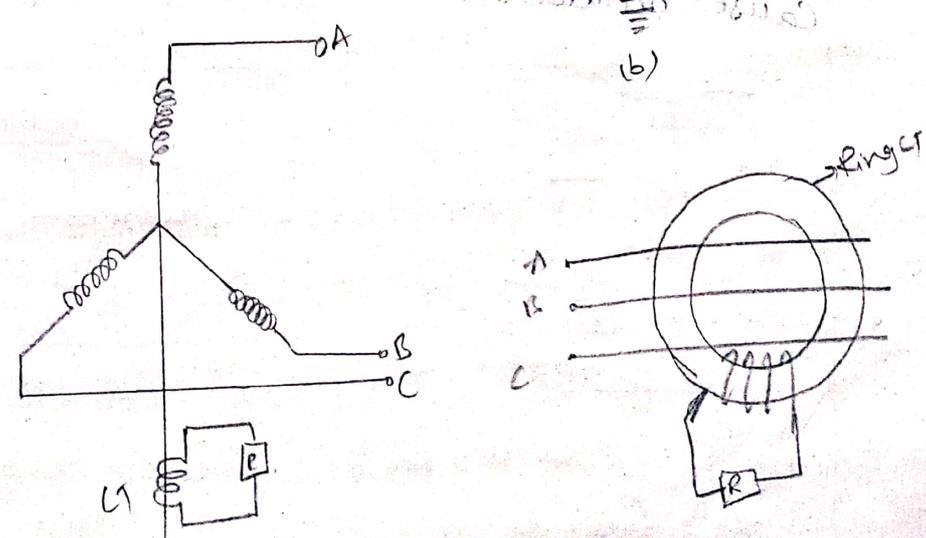
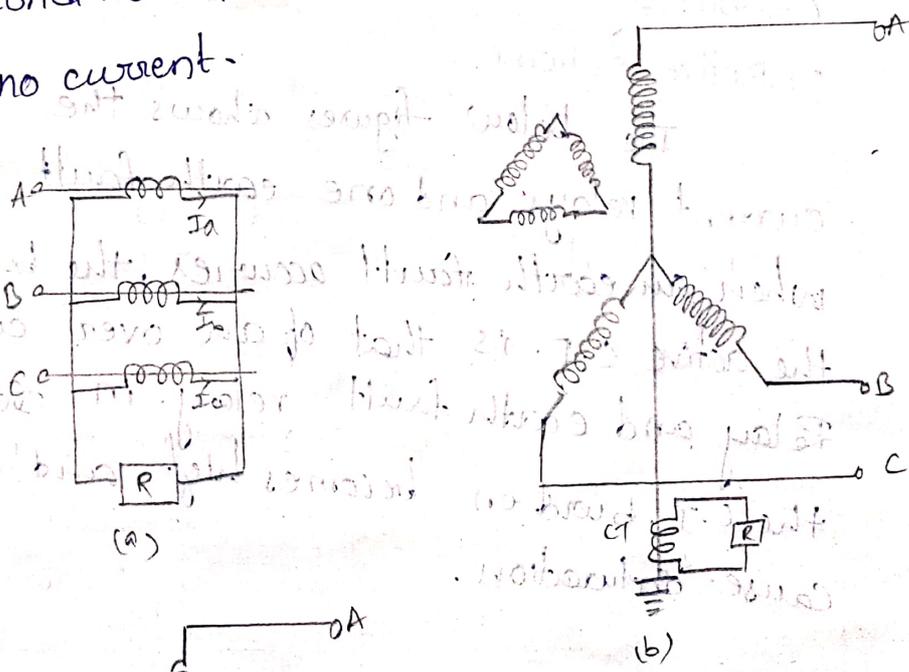
It is a safety device used in electrical installations with high earth impedance.

It detects small stray voltages on the metal enclosures of electrical equipment. The result is to interrupt the circuit if a dangerous voltage is detected. The earth fault relay is protected against tripping from transients and prevents shock.

Phase fault protection and earth fault protection, the relays which are used for the protection of the system against phase faults are called overcurrent relays.

Earth fault protective schemes.

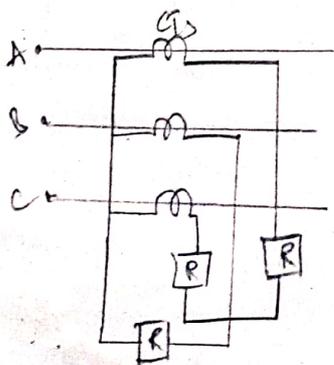
An earth fault relay may be energised by a residual current as shown in figure. (a) i_a , i_b and i_c are currents in the secondary of C.T.s of different phases. The sum ($i_a + i_b + i_c$) is called residual current. Under normal conditions the residual current is zero. When an earth fault occurs, the residual current is non-zero. When it exceeds pick-up value, the earth fault relay operates. In this scheme, the relay operates only for earth faults. During balanced load conditions, the earth fault relay carries no current.



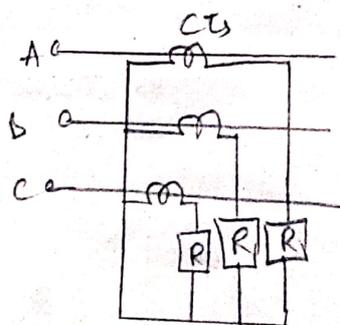
The magnitude of the earth fault current depends on the fault impedance. In case of an earth fault, the fault impedance depends on the system parameter and also on the type of neutral earthing. The neutral may be solidly grounded, grounded through resistance & reactance. The fault impedance for earth faults is much higher than that of phase faults. Hence, the earth fault current is low compared to the phase fault currents. An earth fault relay is set independent of load current.

Combined earth fault and phase fault protective scheme.

The below figures shows the two over current relays and one earth fault relay. When an earth fault occurs, the burden on the active C.T. is that of an over current Relay and earth fault relay in series. Thus, the C.T. burden becomes high and may cause saturation.



Two over current and one earth fault Relay



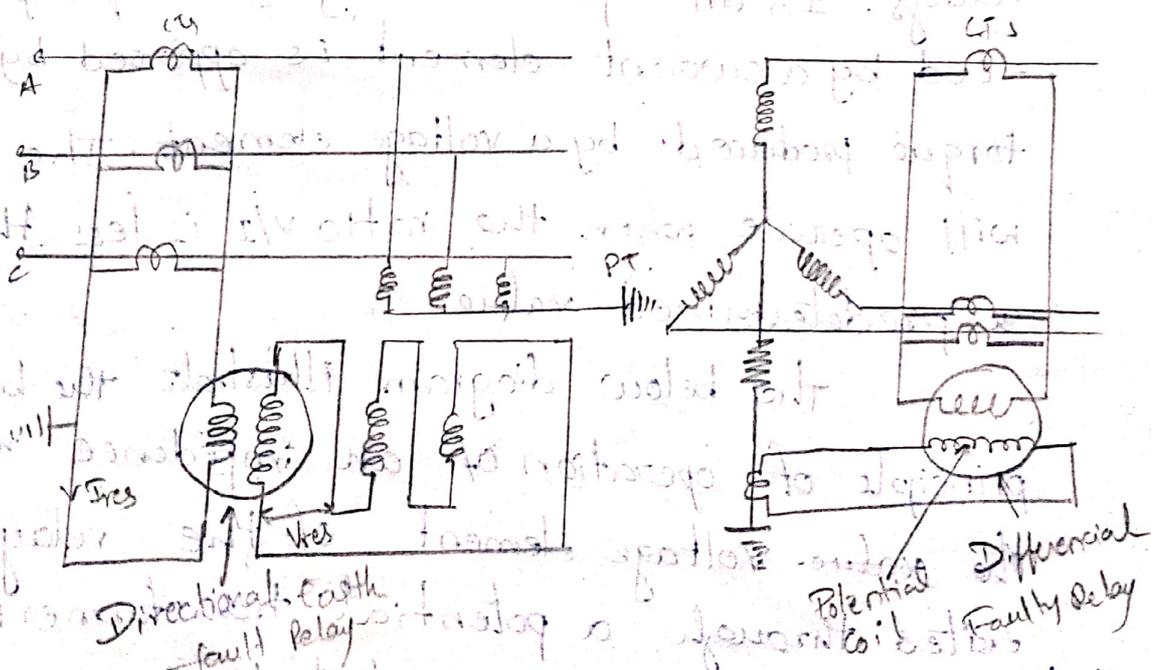
Three overcurrent relays.

Phase-fault protective scheme.

This scheme is mainly for the protection of [three-phase] system. [this scheme is mainly] against phase faults. If there is no separate scheme for earth fault protection, the over current relays used in this scheme will also sense earth faults but they will be less sensitive.

Directional earth fault Relay:-

For the protection against ground faults, only one directional overcurrent relay is required. Its operating principle and construction is similar to the directional overcurrent relays discussed earlier.



The directional element has two coils. One coil is energised by current and the other by voltage. The current coil of the directional element is energised by residual current and the potential coil by residual voltage.

DISTANCE PROTECTION :-

Distance protection is a widely used protective scheme for the protection of high and extra high voltage transmission and sub transmission lines.

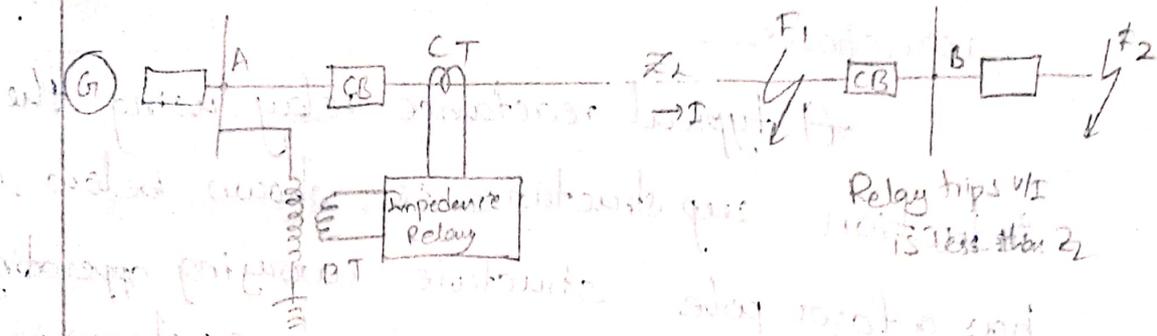
Impedance Relay :-

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.

The below diagram illustrates the basic principle of operation of an impedance relay. The ~~value~~ 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 Z_2 . The relay is so

desired that it closes its contacts whenever impedance of the protected section falls below the pre-determined value i.e. Z_2 in this case.



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 Z_2 and hence the relay operates.

Types of Impedance Relay:-

- (i) Definite-distance Relay:- which operates instantaneously for fault upto a pre-determined distance from the relay.
- (ii) 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.

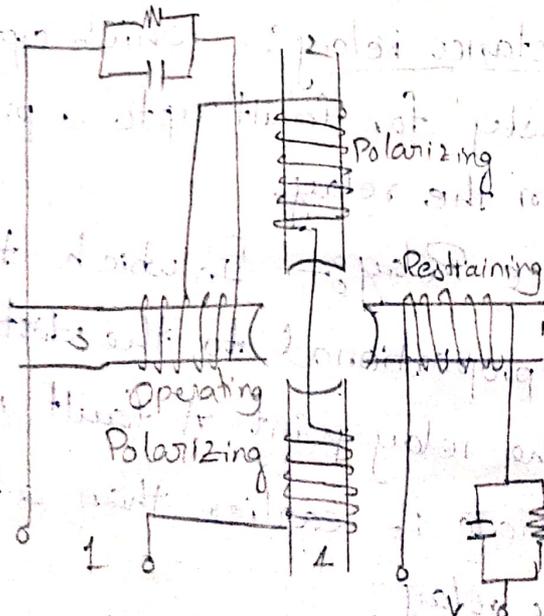
Reactance Relay:-

Reactance relay is an overcurrent relay with directional limitation. The directional element is arranged to develop maximum

negative torque when its current lag behinds its voltage by 90° . The induction cup or double induction loop structures are best suited for actuating reactance type distance Relay.

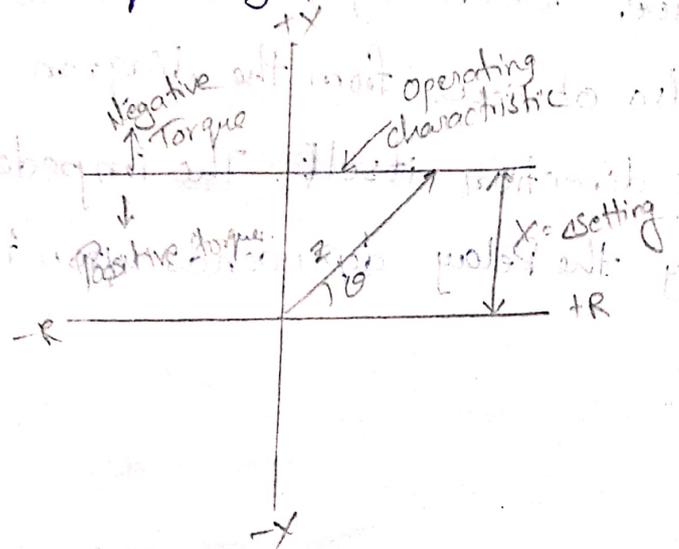
Construction:—

A typical reactance relay using the induction cup structure is shown below. It has a four pole structure carrying operating, polarizing and restraining coils, as shown in the below figure. The operating torque developed by the interaction of fluxes due to current carrying coils, i.e. the interaction of fluxes of 2,3,4 and the restraining torque is produced by the interaction of fluxes due to poles 1,2,4.



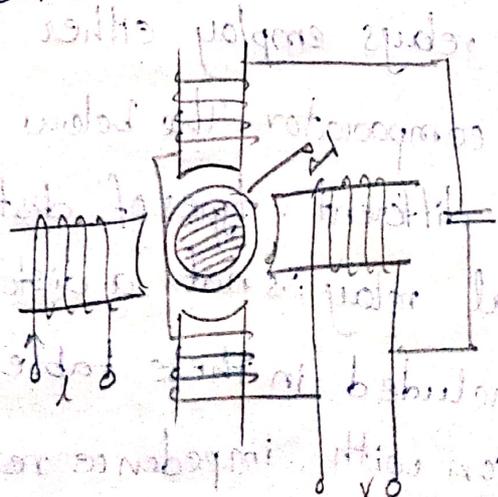
The operating characteristic of a reactance relay is shown in below. X is the reactance of the protected line between the relay location and the fault point, and R

is the resistance component of the impedance. The characteristic shows that the resistance component of the impedance has no consequence on the working of the relay, the relay reacts solely to the reactance component. The point below the operating characteristic is called the positive torque region.



MHO Relay :-

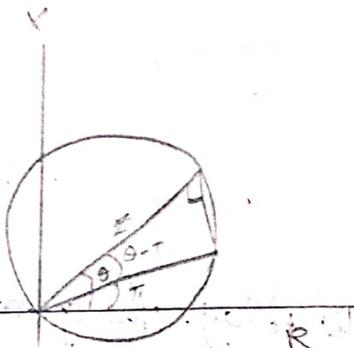
In MHO Relay, the operating torque is obtained by the V-I element and Restraining torque by the voltage element. This means MHO Relay is Voltage Restrained Directional Relay.



The operating characteristics when drawn on R-X diagram is a circle passing through the origin. We can draw this by using the relation

$$Z < (K_3/K_2) \cos(\theta - T)$$

From the characteristics diagram, we observe that MHO Relay will operate if the impedance seen by it is within the circle. It is also obvious from the diagram that the Relay is directional itself. The impedance relay seen by the Relay depends upon the type of fault.



Input quantities for various types of distance Relays.

Static relays employ either voltage comparator or current comparator. The below table shows voltage inputs for different types of distance relays.

The directional relay is not a distance relay. It has been included in these tables as it is used in conjunction with impedance relays. Its characteristic is straight line passing through the origin.

Relay	Amplitude comparator operating quantity	Restraining quantity	phase comparator. Operating quantity	Polarising quantity
Impedance	$I Z_r$	V	$I Z_r - V$	$I Z_r + V$
Directional	$I Z_r + V$	$V - I Z_r$	$I Z_r$	V
Reactance	$2 I X_r - V$	V	$(I Z_r - V) \sin \alpha$ $(I X_r - V)$	$I X_r$
MHO	$I Z_r$	$2V - I Z_r$	$I Z_r - V$	V
Offset MHO	$I(Z_r - Z_0)$	$2V - I(Z_r + Z_0)$	$I Z_r - V$	$V - I Z_0$
Angle impedance	$2 I Z_r - V$	V	$I Z_r - V$	$I Z_r$

voltage inputs for different types of distance Relays.

Impedance	I	$\frac{V}{Z_r}$	$I - \frac{V}{Z_r}$	$I + \frac{V}{Z_r}$
Directional	$I + \frac{V}{Z_r}$	$\frac{V}{Z_r} - I$	I	$\frac{V}{Z_r}$
Reactance	$I - \frac{V}{2X_r}$	$\frac{V}{2X_r}$	I	$I - \frac{V}{X_r}$
MHO	I	$\frac{2V}{Z_r} - I$	$I - \frac{V}{Z_r}$	$\frac{V}{Z_r}$
offset MHO	$2I \left[\frac{V}{Z_r} + \frac{V}{Z_0} \right]$	$\frac{V}{Z_r} - \frac{V}{Z_0}$	$I - \frac{V}{Z_r}$	$\frac{V}{Z_0} - I$
Angle impedance	$2I - \frac{V}{Z_r}$	$\frac{V}{Z_r}$	I	$I - \frac{V}{Z_r}$

Currents input for different types of Distance Relays.

Effect of Arc resistance on the performance of distance Relay.

→ The arc resistance causes the distance relay to under reach.

→ Due to presence of arc resistance, the impedance seen by the relay appears to be actual [to presence] value of the impedance upto the fault point and the Relay tends to underreach.

→ Below figure shows the effect of arc resistance on the distance Relay.

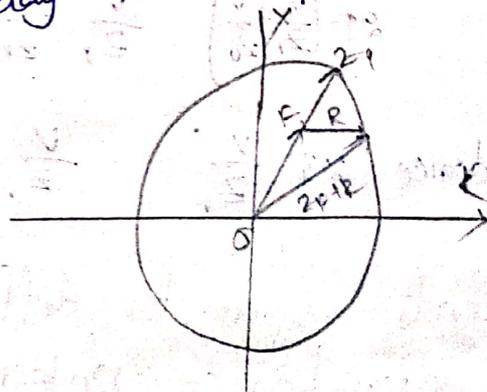
→ The relay at O has to be set to protect a line of impedance Z_1 .

→ If a fault occurs at the point F and an arc resistance R is introduced, the impedance relay will be $(Z_1 + R)$.

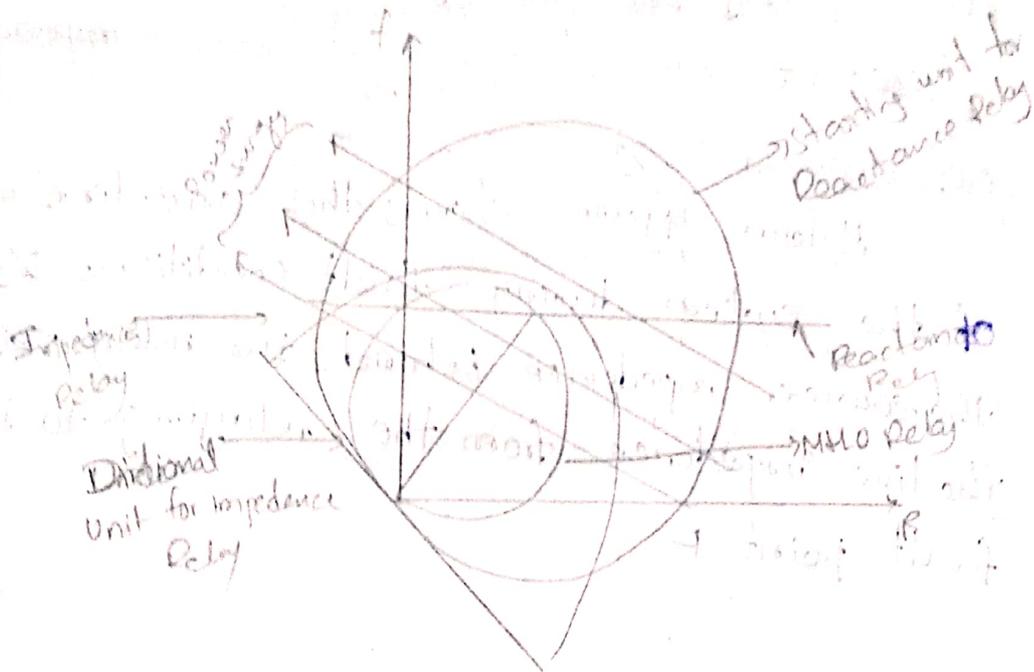
→ Through the actual impedance of the line upto the fault point is less than relay fails to operate as the impedance seen by the relay

appears to be more than twice of arc resistance

→ This shows that the arc resistance causes the distance relay to under reach



Effect of power surges (power swing) on the performance of distance relay.



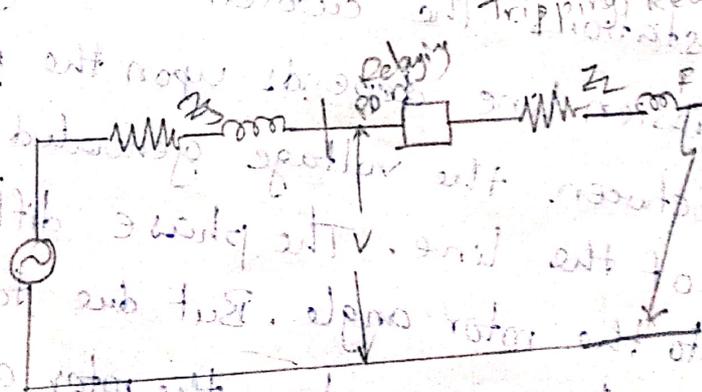
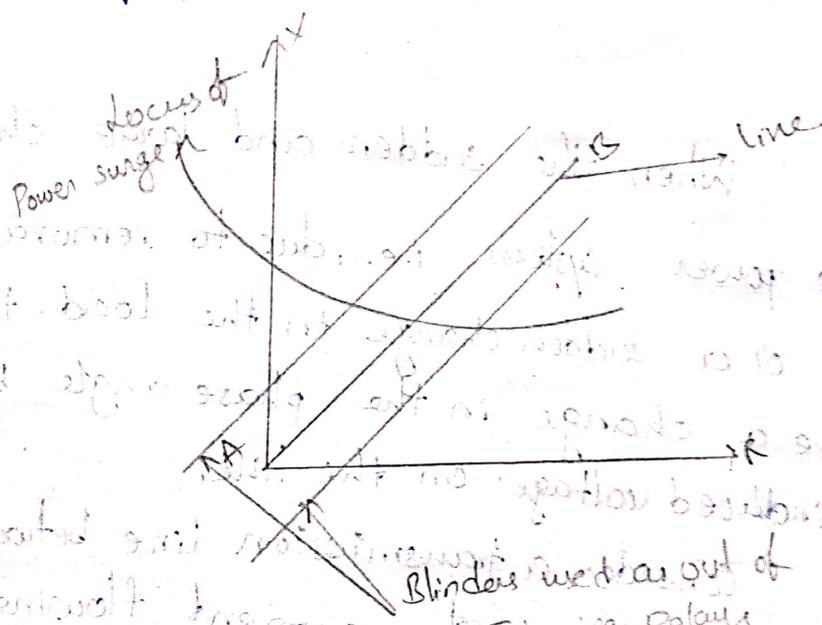
When there is a sudden and large change in the power system i.e., due to removal of a fault or a sudden change in the load, there will be a change in the phase angle between the induced voltage on the line.

Consider a transmission line between two generating stations. The current flowing through the transmission line depends upon the phase difference between the voltage generated at the two ends of the line. The phase difference is equal to the rotor angle. But due to disturbance in the transmission line, the rotor angles swing and it changes the rotor angle. Therefore to overcome the malfunction

-ing of distance relays during a power swing, the angular limits of its pickup characteristics should be reduced so as to enclose only the faulty area.

Effect of Line length and source impedance on distance Relay:

Below figure shows the one-line diagram of the system during fault conditions Z_s is the source impedance behind the relay. Z_L is the line impedance from the relaying to the fault point F.



(13)

The current flowing through the relay is given by

$$I = \frac{E}{Z_3 + Z_2}$$

The voltage at the relay location which is applied to the distance relay is

$$V = I Z_2 = \frac{E Z_2}{Z_3 + Z_2}$$

$$= \frac{E}{\frac{Z_3}{Z_2} + 1}$$

Relay manufacturers specify the minimum voltage for the relay operation.

Selection of distance Relay.

⇒ Speed of operation.

⇒ Measuring relay characteristics

⇒ Fault coverage

⇒ Economic considerations

MHO relay with Blindness

Through a MHO relay is quite suitable for the protection of long lines. For the protection of extra long lines, its area on the R-X diagram may be too large to trip under power swing conditions. Hence, further reduction in the area of a MHO characteristic is necessary to make the relay suitable for ELD lines. In the case of electromagnetic relays,

Two blinders have been used to reduce the characteristic area of a MHO relay.

Reduction of measuring units

Distance Relays are used for the protection of transmission or subtransmission lines against phase to phase and phase to ground fault. For phase to phase faults, one set consisting of 3 distance relays is required for each pair of lines (A-B), B-C and (C-A). Thus 9 distance relays are required. Each set requires 3 units as there are 3 zone of protection, one relay being necessary for each zone.

There are different types of distance protection schemes which reduce the no. of measuring relays. To reduce the cost of protection, the no. of measuring units depends upon the technical requirements but in selecting a particular scheme, the economic consideration also must be taken into account.

⇒ Scheme Using Six Measuring units

⇒ Scheme Using Twelve Measuring units

Switched schemes.

- A switched scheme may employ only one, two or three measuring units

- (14)
- 1) Delta-wye switching
 - 2) Inter phase switching
 - 3) Switch scheme using only one measuring unit
- Auto re-closing.

-Auto reclosing is an important relay used to reenergize a line after the line was tripped by main protection relay due to fault occurrence. Failure of auto-reclose relay to reenergize the line will make power can't be transmitted through the line and power system will be in stress condition.

- Single-shot auto reclosing
- Multi-shot auto reclosing
- Single-phase auto reclosing.
- Three phase auto reclosing.
- Delayed auto reclosing scheme.

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