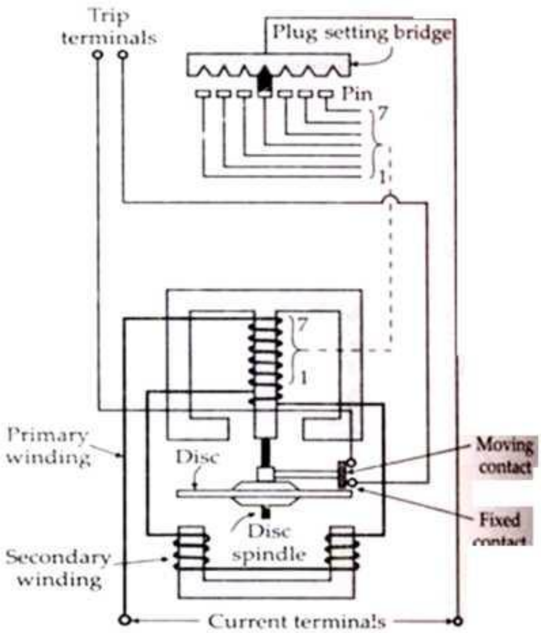
<u>Module 2</u> Induction Type Relay

Course objectives: - To explain relay construction and operating principles.
- To explain over current protection using electromagnetic and static relays
- To discuss types of distance relays.

<u>NON-DIRECTIONAL OVER-CURRENT OR EARTH-LEAKAGE (INDUCTION TYPE) RELAY</u>

The over current relay operates when the current in the circuit exceeds a certain preset value.

Such a relay consists of a metallic disc which is free to rotate between the poles of two electromagnets (Shown in below Fig) The spindle of this disc carries a moving contact which bridges two fixed contacts when the disc rotates through an angle which is adjustable between 0° and 360°. By adjusting this angle the travel of the moving contact can be adjusted so that the relay can be given any desired time setting which is indicated by a pointer on a time setting dial. The dial is calibrated from 0 to 1. 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 into the actual operating time.



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 provided with tappings. (With the help of this bridge, number of turns of primary winding can be adjusted. Thus the desired current setting for the relay can be obtained), These tappings are connected to a plug setting bridge which is usually arranged to give seven selections of tapping, the over current range being 50 per cent to 200 per cent in steps of 25% and the earth fault 10% to 70% or 20% to 80% in steps of 10%. These values are percentages of the current rating of the relay.

Thus a relay may have a current rating of 5 A, indicating that it is suitable for use on CT having a secondary current rating of 5 A but with a setting of 50% the relay would start to operate at 2.5 A. similarly, if set at 200% it would start to operate at any desired tapping and, therefore, current setting can be selected by inserting a pin between the spring loaded jaws of the bridge type socket at the appropriate tap due.

When the pin is withdrawn for the purpose of hanging the setting while the relay is in service, the relay automatically adopts a high setting, thus, ensuring that the C.T. secondary is not open circuited and that the relay remains operative for faults during the process of changing the settings.

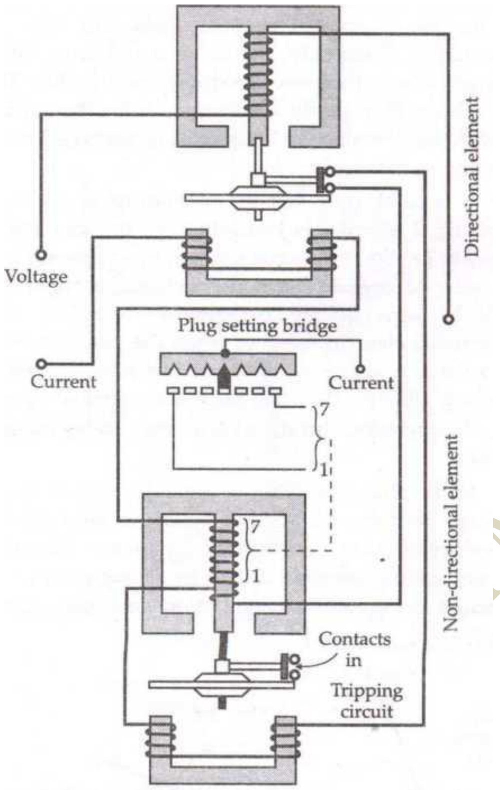
The secondary winding on the central limb of upper magnet is connected in series with the lower electro magnet winding. This secondary winding is energized by the induction from primary winding so by this arrangement the leakage flux of both the magnet are sufficiently displacement in phase, The torque exerted on the disc is due to the interaction of eddy currents produced therein by means of the leakage flux from the upper electromagnet and the flux from the lower electromagnet: the control torque is produce by spiral spring.

The torque is produced due to induction principle, as explained above. This torque is opposed by Control torque produced by spiral springs **under normal conditions the Control force is more than driving force hence disc remains stationary**. Under fault conditions when current becomes high, the disc rotates through the preset angle and makes contact with the fixed contacts to trip circuit The trip circuit opens the circuit breaker, isolating the faulty part from rest of the healthy system.

DIRECTIONAL RELAY (OVERCURRENT OR EARTH FAULT RELAY)

Construction and Operating Principle

The non-directional relay discussed above 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 to the non-directional element. Such a relay which responds to fault flow in a particular direction is called a directional relay. Fig. shows a schematic arrangement of such a directional relay



The upper magnet of the directional element carries a winding connected through a potential transformer (not shown) to the system voltage. This is called the voltage coil of the relay. The lower magnet of the same element carries another winding (current coil of the relay) which is energised, through a C .T. by the fault current. This winding is carried over the upper magnet of the non-directional element. The contacts of the directional element are connected in series with another winding over the lower magnet of the non-directional element.

When a fault takes place, the fault current flows through current coil of the relay which produces a flux in the lower magnet of the directional element while the current in the voltage coil produces another flux in this upper-magnet of the directional element. The two fluxes produce a torque tending to close its contacts (directional element contacts).

The relay current also flows through the winding over the upper magnet of the non-directional element and therefore produces a flux in this magnet. This flux induces an e.m.f in the winding over the lower magnet of the non-directional element. Since this winding provides a closed path, the induced e.m.f circulates a current which, therefore, produces another flux. The two fluxes then produce a torque on the disc of the non-directional element to close the contacts in the trip circuit

It is to be seen that the movement of the non- directional element is controlled by the directional element i.e., the directional element must operate first in order to operate the non-directional element. As will be seen in the paragraphs to follow, the directional element operates when the power flow is in a definite designed direction. The non-directional element will operate when there is a sufficient torque i.e., the operating current is sufficient (~=relay current setting).

In the phasor diagram of below Fig, 'V' is the relay voltage. In directional relays, voltage is taken as the reference quantity. Let 'I' be the relay current. Here it is shown leading the relay voltage by an angle θ.
V and I produce flux Φv and Φ1 respectively.
Φv lagging V by an angle Φ
And Φ1 being in phase with current 'I'

Torque, therefore, is **T α Φv*Φ1*Sin (Φ+θ),** where Φv α V and Φ1 α I so
So that the torque equation for the directional element of the relay is

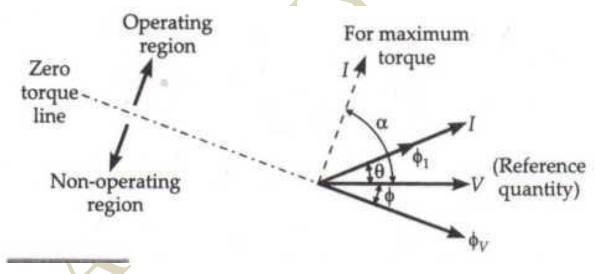
T α V*I***Sin (Φ+θ),**

Maximum torque occurs when **Sin(θ+Φ)** is a maximum i.e., when (θ+Φ) =90°, the condition shown by the dotted line in above Fig.
Zero torque will occur when sin(θ+Φ)= 0 i.e., (θ+Φ)= 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 elements will therefore operate provided the current phasor lies within ± 90° of the maximum torque line, if the current phasor is displaced by more than 90° the element will restrain. The operating and the non-operating region are shown in the above Fig.

Angle α in the figure is the relay maximum torque angle (MTA) and is defined as the angle by which the current supplied to the relay leads the voltage supplied to the relay for maximum relay torque. It may be seen that
α= 90-Φ, so that Φ=90-α, equation becomes T = K*V*I Sin (θ+90-α) = KVI Cos (θ-α)

It may be noted that though the system current in general lags the system voltage the relay current is made to lead the relay voltage, by suitable connections, ensure that the relay operates correctly for all types of faults under all system conditions



Induction Type Directional Power Relay

This type of relay operates when power in the circuit flows in a specific direction. Unlike a nondirectional overcurrent 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.

Constructional details. Below Fig. 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 (called *potential coil*) 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 (called *current coil*) 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 Plugsetting Bridge (not shown for clarity). 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.

Operation. The flux $\mathbf{\Phi_1}$ due to current in the potential coil will be nearly 90º lagging behind the applied voltage *V*. The flux $\mathbf{\Phi}_2$ due to current coil will be nearly in phase with the operating current *I*

The interaction of fluxes $\varphi 1$ and $\varphi 2$ with the eddy currents induced in the disc produces a driving torque given by : $T \propto \varphi 1\ \varphi 2 \sin \alpha$

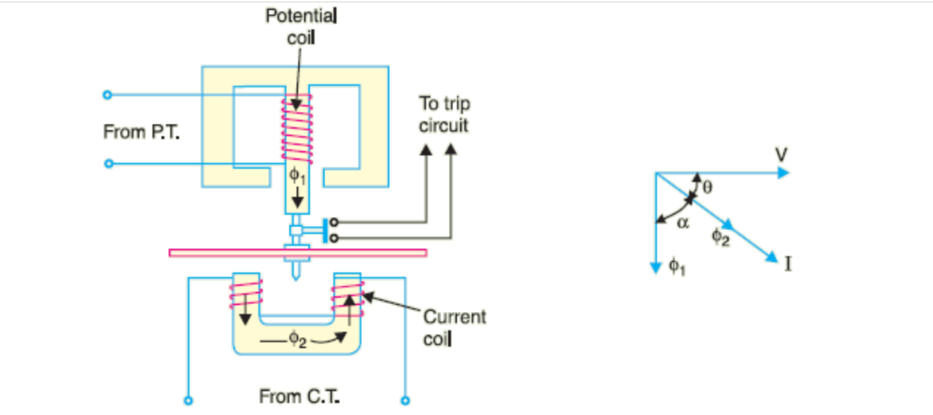
Since $\varphi 1 \propto V$, $\varphi 2 \propto I$ and $\alpha = 90 - \theta$

$\therefore T \propto V\ I \sin (90 - \theta)$

$\propto V\ I \cos \theta$

$\propto$ 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 the faulty section.



(*i*) (*ii*)

Protection of Lines

The probability of faults occurring on the lines is much more due to their greater length and exposure to atmospheric conditions. This has called for many protective schemes which have no application to the comparatively simple cases of alternators and transformers. The requirements of line protection are :

(i) In the event of a short-circuit, the circuit breaker closest to the fault should open, all other circuit breakers remaining in a closed position.

(ii) In case the nearest breaker to the fault fails to open, back-up protection should be provided by the adjacent circuit breakers.

(iii) The relay operating time should be just as short as possible in order to preserve system stability, without unnecessary tripping of circuits.

The protection of lines presents a problem quite different from the protection of station apparatus such as generators, transformers and busbars. While differential protection is ideal method for lines, it is much more expensive to use. The two ends of a line may be several kilometres apart and to compare the two currents, a costly pilot-wire circuit is required. This expense may be justified but in general less costly methods are used. The common methods of line protection are :

(i) Time-graded overcurrent protection

(ii) Differential protection

(iii) Distance protection

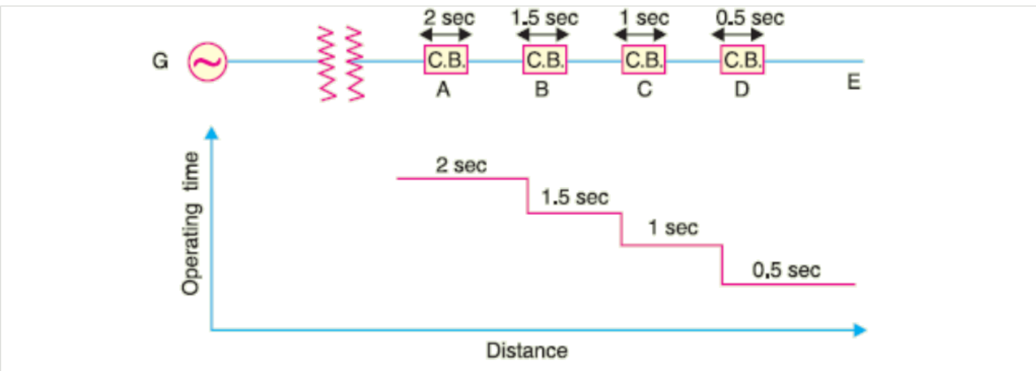
Fig.

Fig. . shows the symbols indicating the various types of relays.

Time-Graded Overcurrent Protection

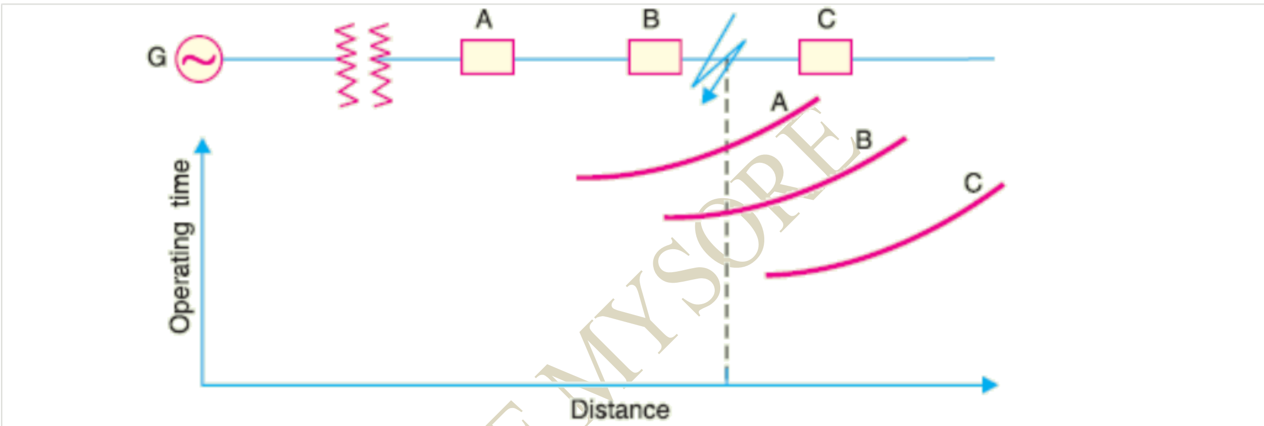
In this scheme of overcurrent protection, time discrimination is incorporated. In other words, the time setting of relays is so graded that in the event of fault, the smallest possible part of the system is isolated. We shall discuss a few important cases.

Radial feeder. The main characteristic of a radial system is that power can flow only in one direction, from generator or supply end to the load. It has the disadvantage that continuity of supply cannot be maintained at the receiving end in the event of fault. Time-graded protection of a radial feeder can be achieved by using (*i*) definite time relays and (*ii*) inverse time relays



(i) Using definite time relays. Above Fig. shows the overcurrent protection of a radial feeder by definite time relays. The time of operation of each relay is fixed and is independent of the operating current. Thus relay *D* has an operating time of 0·5 second while for other relays, time delay* is successively increased by 0·5 second. If a fault occurs in the section *DE*, it will be cleared in 0·5second by the relay and circuit breaker at *D* because all other relays have higher operating time. In this way only section *DE* of the system will be isolated. If the relay at *D* fails to trip, the relay at *C* will operate after a time delay of 0·5 second *i.e.* after 1 second from the occurrence of fault. The disadvantage of this system is that if there are a number of feeders in series, the tripping time for faults near the supply end becomes high (2 seconds in this case). However, in most cases, it is necessary to limit the maximum tripping time to 2 seconds. This disadvantage can be overcome to a reasonable extent by using inverse-time relays.

(ii) Using inverse time relays. below Fig. shows overcurrent protection of a radial feeder using inverse time relays in which operating time is inversely proportional to the operating current. With this arrangement, the farther the circuit breaker from the generating station, the shorter is its relay operating time. The three relays at *A*, *B* and *C* are assumed to have inverse-time characteristics. A fault in section *BC* will give relay times which will allow breaker at *B* to trip out before the breaker at *A*.



Parallel feeders. Where continuity of supply is particularly necessary, two parallel feeders may be installed. If a fault occurs on one feeder, it can be disconnected from the system and continuity of supply can be maintained from the other feeder. The parallel feeders cannot be protected by non-directional overcurrent relays only. It is necessary to use directional relays also and to grade the time setting of relays for selective trippings

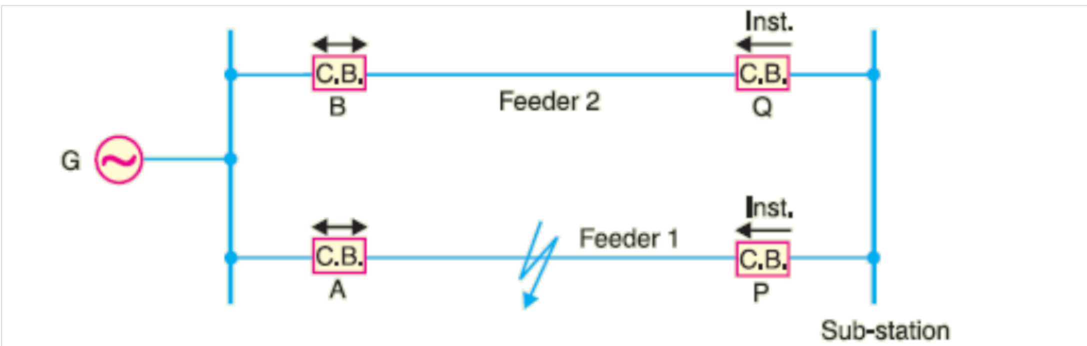


Fig. 23.6 shows the system where two feeders are connected in parallel between the generating station and the sub-station. The protection of this system requires that

(i) each feeder has a non-directional overcurrent relay at the generator end. These relays should have inverse-time characteristic.

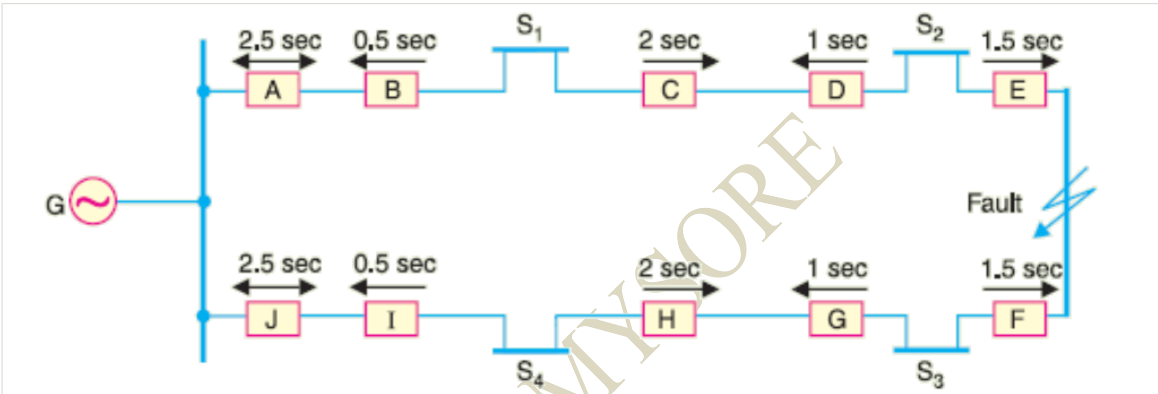
(ii) each feeder has a reverse power or directional relay at the sub-station end. These relays should be instantaneous type and operate only when power flows in the reverse direction i.e. in the direction of arrow at P and Q. Suppose an earth fault occurs on feeder 1 as shown in Fig. 23.6. It is desired that only circuit breakers at A and P should open to clear the fault whereas feeder 2 should remain intact to maintain the continuity of supply. In fact, the above arrangement accomplishes this job. The shown fault is fed via two routes, viz.

(a) directly from feeder 1 via the relay A

(b) from feeder 2 via B, Q, sub-station and P

Therefore, power flow in relay Q will be in normal direction but is reversed in the relay P. This causes the opening of circuit breaker at P. Also the relay A will operate while relay B remains inoperative. It is because these relays have inverse-time characteristics and current flowing in relay A is in excess of that flowing in relay B. In this way only the faulty feeder is isolated.

Ring main system. In this system, various power stations or sub-stations are interconnected by alternate routes, thus forming a closed ring. In case of damage to any section of the ring, that section may be disconnected for repairs, and power will be supplied from both ends of the ring, thereby maintaining continuity of supply



Above Fig. shows the single line diagram of a typical ring main system consisting of one generator G supplying four sub-stations S1, S2, S3 and S4. In this arrangement, power can flow in both directions under fault conditions. Therefore, it is necessary to grade in both directions round the ring and also to use directional relays. In order that only faulty section of the ring is isolated under fault conditions, the types of relays and their time settings should be as follows :

(i) The two lines leaving the generating station should be equipped with non-directional overcurrent relays (relays at A and J in this case).

(ii) At each sub-station, reverse power or directional relays should be placed in both incoming and outgoing lines (relays at B, C, D, E, F, G, H and I in this case).

(iii) There should be proper relative time-setting of the relays. As an example, going round the loop GS1 S2 S3 S4G ; the outgoing relays (viz at A, C, E, G and I) are set with decreasing time limits e.g.

A = 2·5 sec, C = 2 sec, E = 1·5 sec G = 1 sec and I = 0·5 sec

Similarly, going round the loop in the opposite direction (i.e. along G S4 S3 S2 S1 G), the outgoing relays (J, H, F, D and B) are also set with a decreasing time limit e.g.

J = 2·5 sec, H = 2 sec, F = 1·5 sec, D = 1 sec, B = 0·5 sec.

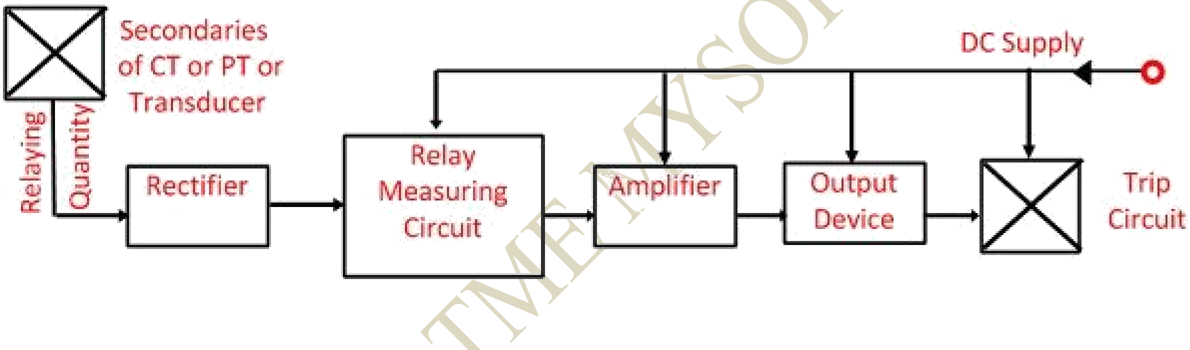
Suppose a short circuit occurs at the point as shown in Fig. 23.7. In order to ensure selectivity, it is desired that only circuit breakers at E and F should open to clear the fault whereas other sections of the ring should be intact to maintain continuity of supply. In fact, the above arrangement accomplishes this job. The power will be fed to the fault via two routes viz (i) from G around S1 and S2 and (ii) from G around S4 and S3. It is clear that relays at A, B, C and D as well as J, I, H and G will not trip. Therefore, only relays at E and F will operate before any other relay operates because of their lower time-setting.

Static Relays

These are solid state relays and employ semiconductor diodes, transistors, thyristors, logic gates, ICs, etc. The measuring circuit is a static circuit and there are no moving parts. In some static relays, a slave relay which is a D.C. polarised relay is used as the tripping device

Static relays contain electronic circuitry which may include transistors, ICs, diodes and other electronic components. There is a comparator circuit in the relay, which compares two or more currents or voltages and gives an output which is applied to either a slave relay or a thyristor circuit. The slave relay is an electromagnetic relay which finally closes the contact. A static relay containing a slave relay is a semi-static relay. A relay using a thyristor circuit is a wholly static relay. Static relays possess the advantages of having low burden on the CT and VT, fast operation, absence of mechanical inertia and contact trouble, long life and less maintenance. Static relays have proved to be superior to electromechanical relays and they are being used for the protection of important lines, power stations and sub-stations. Yet they have not completely replaced electromechanical relays. Static relays are treated as an addition to the family of relays. Electromechanical relays continue to be in use because of their simplicity and low cost. Their maintenance can be done by less qualified personnel, whereas the maintenance and repair of static relays requires personnel trained in solid state

The component of the static relay is shown in the figure below. The input of the current transformer is connected to the transmission line, and their output is given to the rectifier. The rectifier was rectifying the input signal and pass it to the relaying measuring unit.



Block Diagram of Static Relay

The rectifying measuring unit has the comparators, level detector and the logic circuit. The output signal from relaying unit obtains only when the signal reaches the threshold value. The output of the relaying measuring unit acts as an input to the amplifier.

The amplifier amplifies the signal and gives the output to the output devices. The output device activates the trip coil only when the relay operates. The output is obtained from the output devices only when the measurand has the well-defined value. The output device is activated and gives the tripping command to the trip circuit.

The static relay only gives the response to the electrical signal. The other physical quantities like heat temperature etc. is first converted into the analogue and digital electrical signal and then act as an input for the relay.

Advantages of Static Relay

The following are the benefits of static relays.

1. The static relay consumes very less power because of which the burden on the measuring instruments decreases and their accuracy increases.
2. The static relay gives the quick response, long life, high reliability and accuracy and it is shockproof.
3. The reset time of the relay is very less.
4. It does not have any thermal storage problems.
5. The relay amplifies the input signal which increases their sensitivity.
6. The chance of unwanted tripping is less in this relay.

7. The static relay can easily operate in earthquake-prone areas because they have high resistance to shock.

Limitations of Static Relay

- The components used by the static relay are very sensitive to the electrostatic discharges. The electrostatic discharges mean sudden flows of electrons between the charged objects. Thus special maintenance is provided to the components so that it does not affect by the electrostatic discharges.
- The relay is easily affected by the high voltage surges. Thus, precaution should be taken for avoiding the damages through voltage spikes.
- The working of the relay depends on the electrical components.
- The relay has less overloading capacity.
- The static relay is more costly as compared to the electromagnetic relay.
- The construction of the relay is easily affected by the surrounding interference.

For integrated protection and monitoring systems programmable microprocessor controlled static relays are preferred.

Numerical Relays

A numerical relay is that in which the measured ac quantities are sequentially sampled and converted into numerical (digital) data form. A microprocessor or a microcontroller processes the data numerically (i.e., performs mathematical and/or logical operations on the data) using an algorithm to calculate the fault discriminants and make trip decisions.

Numerical relays are the latest development in this area. These relays acquire the sequential samples of the ac quantities in numeric (digital) data form through the data acquisition system, and process the data numerically using an algorithm to calculate the fault discriminants and make trip decisions. Numerical relays have been developed because of tremendous advancement in VLSI and computer hardware technology. They are based on numerical (digital) devices, e.g., microprocessors, microcontrollers. Digital Signal Processors (DSPs), etc. At present microprocessor/ microcontroller-based numerical relays are widely used. These relays use different relaying algorithms to process the acquired information. Microprocessor/micro- controller-based relays are called numerical relays specifically if they calculate the algorithm numerically. The term ‘digital relay’ was originally used to designate a previous-generation relay with analog measurement circuits and digital coincidence time measurement (angle measurement) using microprocessors. Now' a days the term ‘numerical relay’ is widely used in place of ‘digital relay’. Sometimes, both terms are used in parallel. Similarly, the term ‘numerical protection’ is widely used in place of ‘digital protection’. Sometimes both these terms are also used in parallel.

The present downward trend in the cost of Very Large Scale Integrated (VLSI) circuits has encouraged wide application of numerical relays for the protection of modern complex power networks. Economical, powerful and sophisticated numerical devices (e.g. microprocessors, microcontrollers, DSPs, etc) are available today because of tremendous advancement in computer hardware technology. Various efficient and fast relaying algorithms which form a part of the software and are used to process the acquired information are also available today. Hence, there is a growing trend to develop and use numerical relays for the protection of various components of the modern complex power system. Numerical relaying has become a viable alternative to the traditional relaying systems employing electromechanical and static relays. Intelligent numerical relays using artificial Intelligence techniques such as Artificial Neural Networks (ANNs) and Fuzzy Logic Systems are presently under active research and development stage.

The main features of numerical relays are their economy, compactness, flexibility reliability, self-monitoring and self-checking capability, multiple functions, low burden on instruments transformers and improved performance over conventional relays of electromechanical and static types.

Microprocessor-based relay:

A microprocessor is used to perform all functions of a relay. It measures electrical quantities, makes comparisons, performs computations, and sends tripping signals. It can realize all sorts of relaying characteristics, even irregular curves which cannot be realised by electromechanical or static relays easily.

Microcontroller-based relay:

A microcontroller is used for performing all the function of the relay. It measures the electrical quantities by acquiring them in digital form through a data acquisition system, makes comparisons, processes the digital data to calculate the fault discriminants and make trip decisions. It can realised all sorts of relaying characteristics

Microprocessor-based over current relay

An over current relay is the simplest form of protective relay which operates when the current in any circuit exceeds a certain predetermined value, i.e. the pick-up value. It is extensively used for the protection of distribution lines, industrial motors and equipment. Using a multiplexer, the microprocessor can sense the fault currents of a number of circuits. If the fault current in any circuit exceeds the pick-up value, the microprocessor sends a tripping signal to the circuit breaker of the faulty circuit. As the microprocessor accepts signals in voltage form, the current signal derived from the current transformer is converted into a proportional voltage signal using a current to voltage converter. The a.c.

voltage proportional to the load current is converted into D.C. using a precision rectifier. Thus, the microprocessor accepts D.C. voltage proportional to the load current.

The block schematic diagram of the relay is shown in Fig. (a). the output of the rectifier is fed to the multiplexer. The microcomputer sends a command to switch on the desired channel of the multiplexer to obtain the rectified voltage proportional to the current in a particular circuit. The output of the multiplexer is fed to the A/D converter to obtain the signal in digital form. The A/D converter ADC0800 has been used for this purpose. The microcomputer sends a signal to the ADC for starting the conversion.

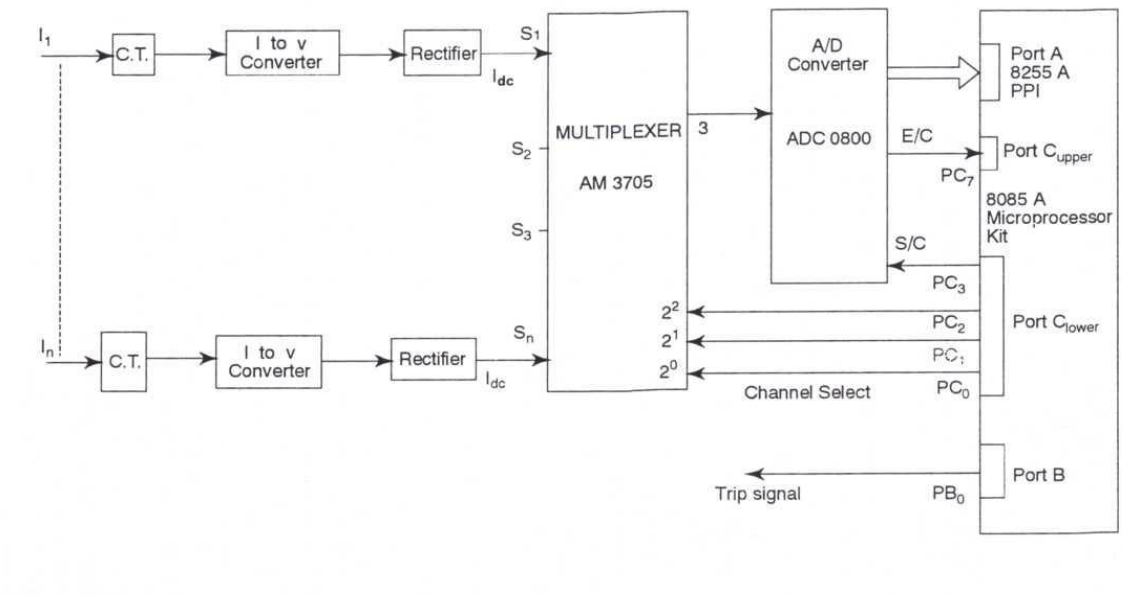
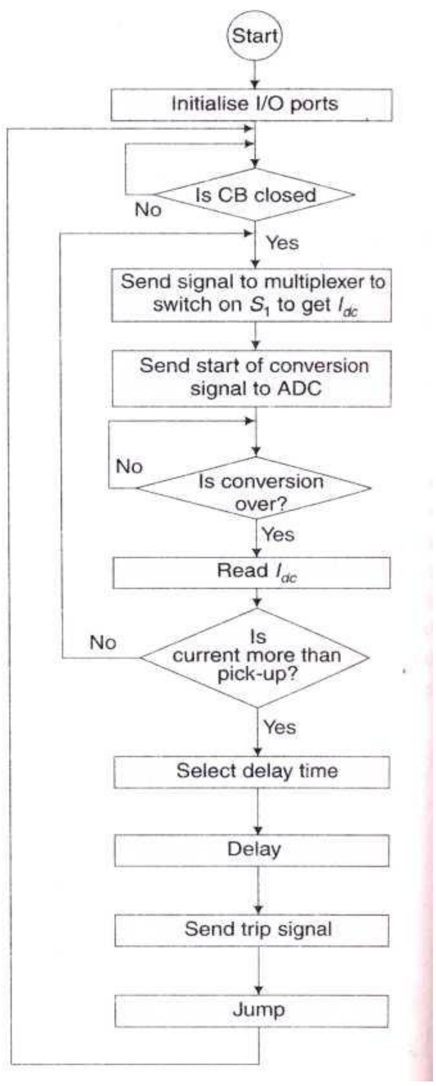


FIGURE (a) Block schematic diagram of overcurrent relay

The microcomputer reads the end of conversion signal to examine whether the conversion is over or not. As soon as the conversion is over, the microcomputer reads the current signal in digital form and then compares it with the pick-up value.

In the case of a definite time over current relay, the microcomputer sends the tripping signal to the circuit breaker after a predetermined time delay if the fault current exceeds the pick-up value. In case of instantaneous over current relay there is no intentional time delay. In order to obtain inverse-time characteristics, the operating times for different values of currents are noted for a particular characteristic. These values are stored in the memory in tabular form. The microcomputer first determines the magnitude of the fault current and then selects the corresponding time of operation from the look-up table. A delay subroutine is started and the trip signal is sent after the desired delay. Using the same program, any characteristic such as IDMT, very inverse or extremely inverse can be realised by simply changing the data of the look-up table according to the desired characteristic to be realised. The microcomputer continuously measures the current and moves in a loop and if the measured current exceeds the pick-up value, it compares the measured value of the current with the digital values of current given in the look-up table in order to select the corresponding count for a time delay. Then it goes in delay subroutine and sends a trip signal to the circuit breaker after the predetermined time delay. The program flowchart is shown in Fig. (b).

In order to avoid false tripping of an over current relay due to transients the program can be modified slightly. When the fault current exceeds the pick-up value, the fault current is measured once again by the microprocessor to confirm whether it is a fault current or transient. In case of any transient of short duration, the measured current above pick-up value will not appear in the second measurement. But if there is an actual fault, it will again appear in the second measurement also, and then the microprocessor will issue a tripping signal to disconnect the faulty part of the system.



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. Principle types of distance relays are

- impedance relay
- Reactance relay
- Admittance or mho relay

Distance relay 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 realy are actually actuating realy with one coil energized by voltage and the other by current. The current element produces a positive or pick up torque while the voltage element produce 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 of the PT location depends on the distance between PT and fault. If the fault is nearer, the measured voltage is lesser and if the fault is farther, measured voltage is more. Hence assuming constant fault impedance each value of V/I measure 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 protected zone is not exact. The distance protection is high speed protection and is simply to apply. It can be employed as primary as well as back up protection. Distance protection is very commonly used in protection of transmission line. Distance relay is used where overcurrent relaying is too slow and is not so selective. Distance relays are used for both phase fault and ground fault protection and they provide high speeds for clearing faults than overcurrent relays. Distance realy is 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 of faults near the power source required by overcurrent relays if used for the purpose.

Distance protection schemes are commonly employed for providing the primary or main protection and backup protection for AC transmission and distribution line against 3 phase faults, phase se to phase fault and phase to ground faults.
In some schemes for short lines, the phase to ground fault protection sensing may be by distance realy and measurement by overcurrent relays because distance protection for shorter lines are susceptible to errors due to arc fault resistance. In general, choice of type of distance protection depends on length of line, tripping time required and coordination requirements

Application of Distance Protection Relay
Distance protection relay is widely spread employed for the protection of high-voltage AC transmission line and distribution lines. They have replaced the overcurrent protection because of the following reasons.

- It provides faster protection as compared to overcurrent relay.
- It has a permanent setting without the need for readjustments.
- Direct protection relay has less effect of an amount of generation and fault levels.
- Their fault current magnitude permits the high line loading.

Distance protection schemes are commonly employed for providing the primary or main protection and backup protection for AC transmission line and distribution line against three phase faults, phase-to-phase faults, and phase-to-ground faults.

Impedance Type Distance Relay

Definition: The relay whose working depends on the distance between the impedance of the faulty section and the position on which relay installed is known as the impedance relay or distance relay. It is a voltage controlled equipment. The relay measures the impedance of the faulty point, if the impedance is less than the impedance of the relay setting, it gives the tripping command to the circuit breaker for closing their contacts. The impedance relay continuously monitors the line current and voltage flows through the CT and PT respectively. If the ratio of voltage and current is less than the relay starts operating then the relay starts operating.

Principle of Operation of Impedance Relay

In the normal operating condition, the value of the line voltage is more than the current. But when the fault occurs on the line the magnitude of the current rises and the voltage becomes less. The line current is inversely proportional to the impedance of the transmission line. Thus, the impedance decreases because of which the impedance relay starts operating.

The figure below explains the impedance relay in much easier way. The potential transformer supplies the voltage to the transmission line and the current flows because of the current transformer. The current transformer is connected in series with the circuit.

Consider the impedance relay is placed on the transmission line for the protection of the line AB. The Z is the impedance of the line in normal operating condition. If the impedances of the line fall below the impedance Z then the relay starts working.

Let, the fault F1 occur in the line AB. This fault decreases the impedance of the line below the relay setting impedance. The relay starts operating, and its send the tripping command to the circuit breaker. If the fault reached beyond the protective zone, the contacts of the relay remain unclosed.

Operating Characteristic of an Impedance Relay

The voltage and the current operating elements are the two important component of the impedance relay. The current operating element generates the deflecting torque while the voltage storage element generates the restoring torque. The torque equation of the relay is shown in the figure below

$$T = k_1 I^2 - k_2 V^2 - k_3$$

The $-K_3$ is the spring effect of the relay. The V and I are the value of the voltage and current. When the relay is in normal operating condition, then the net torque of the relay becomes zero.

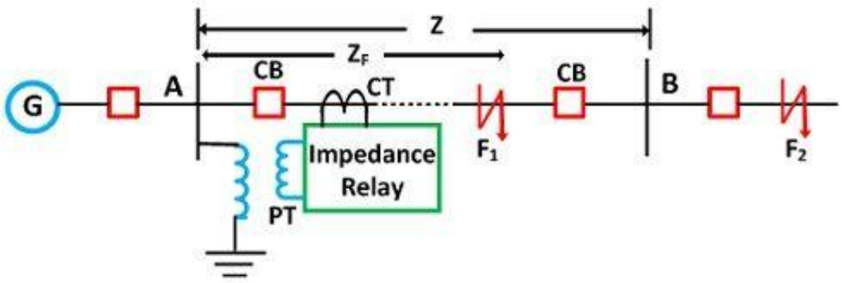
$$k_2 V^2 = k_1 I^2 - k_3$$

$$\frac{V}{I} = Z = \sqrt{\frac{k_1}{k_2} - \frac{k_3}{k_2 I^2}}$$

If the spring control effect becomes neglected, the equation becomes

$$Z = \sqrt{\frac{k_1}{k_2}} = Constant$$

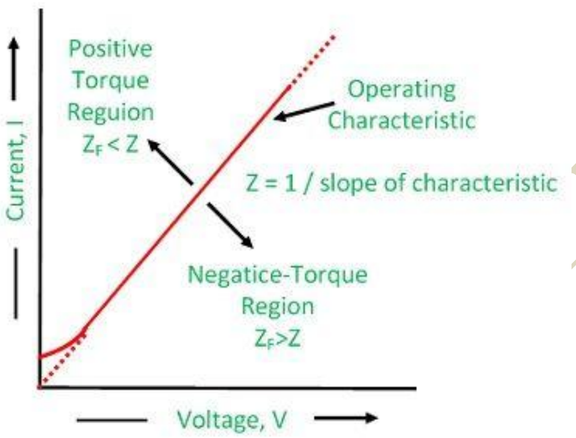
The operating characteristic concerning the voltage and current is shown in the figure below. The dashed line in the image represents the operating condition at the constant line impedance.



Principle of operation of an Impedance Relay

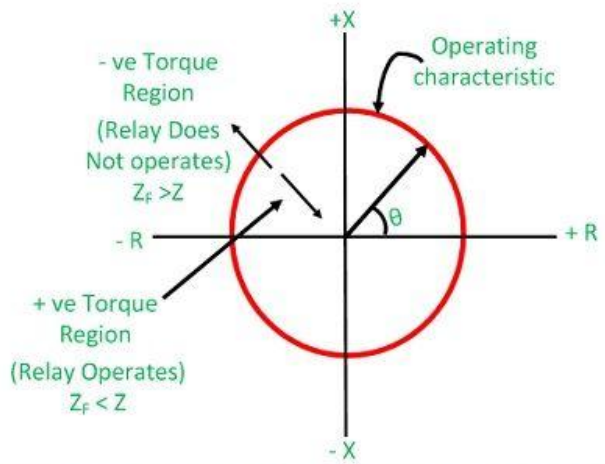
Circuit Globe

The operating characteristic of the impedance relay is shown in the figure below. The positive torque region of the impedance relay is above the operating characteristic line. In positive torque region, the impedance of the line is more than the impedance of the faulty section. Similarly, in negative region, the impedance of the faulty section is more than the line impedance



Opening Characteristic of an Impedance Relay

Circuit Globe



Operating Characteristic of an Impedance Relay on an R-X Diagram

Circuit Globe

The impedance of the line is represented by the radius of the circle. The phase angle between the X and R axis represents the position of the vector. If the impedance of the line is less than the radius of the circle, then it shows the positive torque region. If the impedance is greater than the negative region, then it represents the negative torque region.

Drawbacks of Plan Impedance Relay

The following are the disadvantages of the impedance relay.

1. It gives the response on both the side of the CT and PT. Thus, it becomes difficult for the breaker to determine whether the fault is external or internal.
2. The relay is easily affected by the arc resistance of the line.
3. It is very sensitive to the power swing. The powerful wings generate the faults on the line because of which the impedances of the line vary.

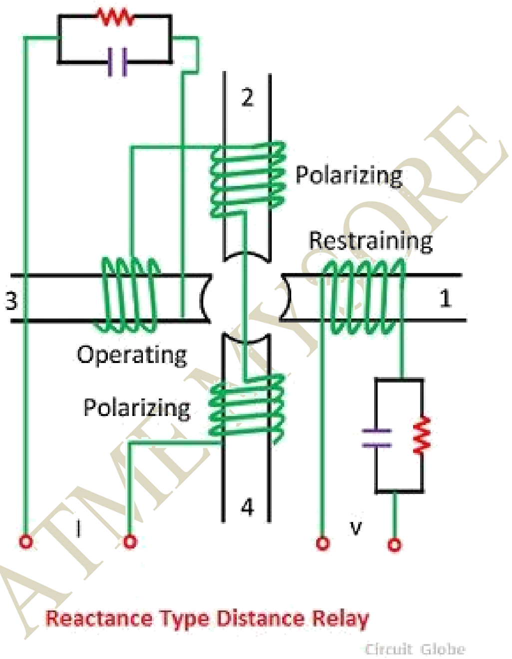
The relay always operates when the impedance of the line is less than the relay settings. This type of relay is called the high-speed relay

Reactance Relay

The reactance relay is a high-speed relay. This relay consists of two elements an overcurrent element and a current-voltage directional element. The current element developed positive torque and a current-voltage developed directional element which opposes the current element depending on the phase angle between current and voltage.
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 relays.

Construction of Reactance Relay

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



A typical reactance relay using the induction cup structure is shown in the figure below. It has a four-pole structure carrying operating, polarizing, and restraining coils, as shown in the figure below. The operating torque is developed by the interaction of fluxes due to current carrying coils, i.e., the interaction of fluxes of 2, 3 and 4 and the restraining torque is produced by the interaction of fluxes due to poles 1, 2 and 4.
The operating torque will be proportional to the square of the current while the restraining torque will be proportional to VI cos (Θ – 90°). The desired maximum torque angle is obtained with the help of resistance-capacitance circuits, as illustrated in the figure. If the control effect is indicated by –k3, the torque equation becomes

$$T = K_1 I^2 - K_2 VI\cos(\theta - 90^{\circ}) - K_3$$

$$T = K_1 I^2 - K_2 \sin\theta - K_3$$

where Θ, is defined as positive when I lag behind V. At the balance point net torque is zero, and hence

$$K_1I^2 - K_2VIcos(\theta - 90°) - K_3$$

$$K_1I^2 = K_2VIsin\theta + K_3$$

$$K_1 = K_2\frac{V}{I}sin\theta + \frac{K_3}{I^2}$$

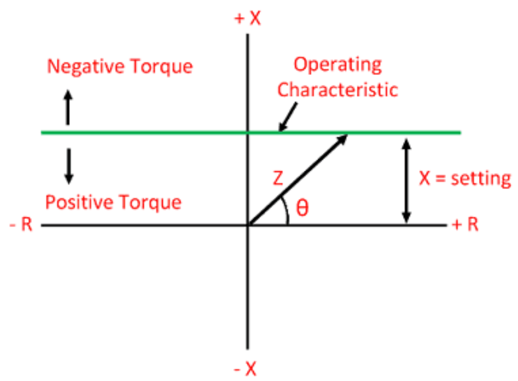
$$\frac{V}{I}sin\theta = \frac{K_1}{K_2} - \frac{K_3}{K_2I^2}$$

$$Zsin\theta = \frac{K_1}{K_2}$$

The spring control effect is neglected in the above equation, i.e., K3 = 0.

Operating Characteristic of Reactance Relay

The operating characteristic of a reactance relay is shown in the figure 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.



Operating Characteristic of Reactance Type Distance Relay

If the value of τ, in the general torque equation, expressed below is made any other 90º, a straight line characteristic will still be obtained, but it will not be parallel to R-axis. Such a relay is called an angle impedance relay.

$$T = K_1I^2 - K_2VIcos(\theta - \tau) - K_3$$

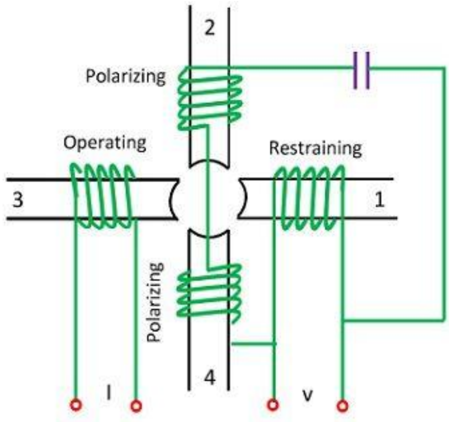
This type of relay is not capable of selecting whether the fault has taken place in the section where the relay is located, or it has taken place in the adjoining section when used on the transmission line. The directional unit used with the reactance relay will not be same as used with the impedance type relay because the restraining reactive volt-ampere, in that case, will be nearly equal to zero.

Therefore the reactance type distance relay needs a directional unit that is inoperative under load conditions. Reactance type relay is very suitable as a ground relay for ground fault because its reach is not affected by fault impedance.

Mho Relay

A mho Relay is a high-speed relay and is also known as the admittance relay. In this relay operating torque is obtained by the volt-amperes element and the controlling element is developed due to the voltage element. It means a mho relay is a voltage controlled directional relay.

A mho relay using the induction cup structure is shown in the figure below. The operating torque is developed by the interaction of fluxes due to pole 2, 3, and 4 and the controlling torque is developed due to poles 1, 2 and 4.



Schematic Diagram of Mho Relay

Circuit Globe

If the spring controlling effect is indicated by $-K_3$, the torque equation becomes,

$$T = K_1 VIcos(\theta - 90°) - K_3$$

Where Θ and τ are defined as positive when I lag behind V. At balance point, the net torque is zero, and hence the equation becomes

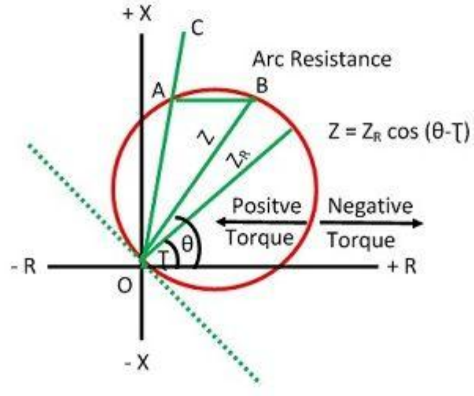
$$K_1 VIcos(\theta - \tau) - K_2 V^2 - K_3 = 0 \quad \frac{K_1}{K_2}\text{Cos}(\theta - \tau) - \frac{K_3}{K_2 VI} = \frac{V}{I} = Z$$

$$Z = \frac{K_1}{K_2}\text{Cos}\,(\theta - \tau)$$

If the spring controlled effect is neglected i.e., $k_3 = 0$.

Operating Characteristic of Mho Relay

The operating characteristic of the mho relay is shown in the figure below. The diameter of the circle is practically independent of V and I, except at a very low magnitude of the voltage and current when the spring effect is considered, which causes the diameter to decrease. The diameter of the circle is expressed by the equation as $Z_R = K_1 / K_2$ = ohmic setting of the relay

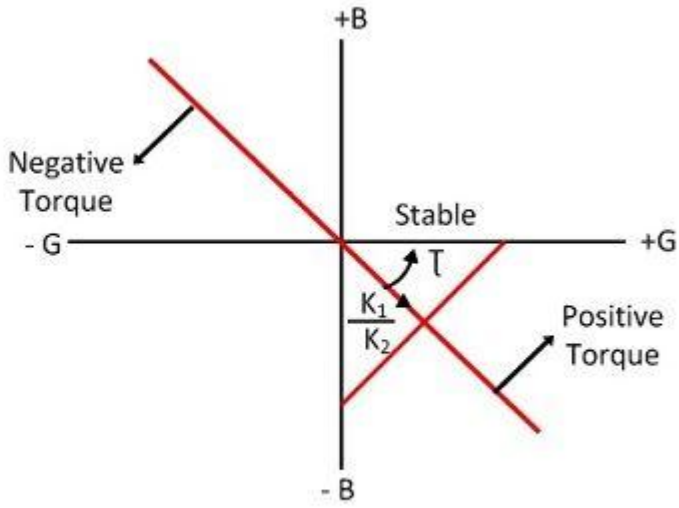


Operating Characteristic of Mho Relay

The relay operates when the impedance seen by the relay within the circle. The operating characteristic showed that circle passes through the origin, which makes the relay naturally directional. The relay because of its naturally directional characteristic requires only one pair of contacts which makes it fast tripping for fault clearance and reduces the VA burdens on the current transformer.

The impedance angle of the protected line is normally 60º and 70º which is shown by line OC in the figure. The arc resistance R is represented by the length AB, which is horizontal to OC from the extremity of the chord Z. By making the τ equal to, or little less lagging than Θ, the circle is made to fit around the faulty area so that the relay is insensitive to power swings and therefore particularly applicable to the protection of long or heavily loaded lines.

For a given relay the τ is constant, and the admittance phasor Y will lie on the straight line. The characteristic of mho relays on the admittance diagram is, therefore, a straight line and is shown in the figure below.



Characteristic of Mho Type Relay on Admittance Diagram

Mho relay is suitable for EHV/UHV heavily loaded transmission lines as its threshold characteristic in Z-plane is a circle passing through the origin, and its diameter is Z_R. Because of this, the threshold characteristic is quite compact enclosing faulty area compactly and hence, there is lesser chance to operate during power swing and also it is directional.

Angle Impedance Relay

Angle Impedance Relay measures a component of the impedance of the line at the relay location. It is also called as ohm relay. Its Characteristic on R-X diagram is a straight line and is inclined to R-Axis at any angle as shown in below fig. the reactance relay is a particular case of reactance relay. The Angle Impedance Relay is used in conjunction with others realy, for example it is used to limit the area of MHO relay on the R-X Diagram to make it less sensitive to power surges

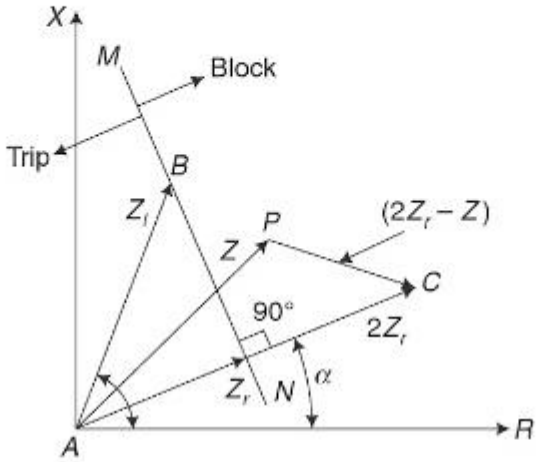
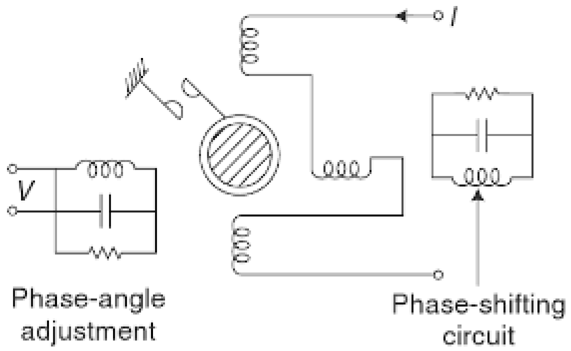


Fig. Characteristic of angle-impedance relay

Electro Mechanical Angle Impedance Relay
For this kind of relay, an induction cup construction as show in below fig. is used



the torque equation of the relay is given by $T = K_1 I^2 - K_2 VI \cos(\phi - \alpha) - K_3$

In case of reactance realy α=90º. But in case of angle impedance relay, it may have any value which governs the inclination of Characteristic with respect to the R-axis.

Course Outcome: Interpret the working of distance relays and the effects of arc resistance, power swings, line length and source impedance on performance of distance relays.

Further Readings

1. http://nptel.ac.in/downloads/108101039/
2. https://www.electrical4u.com/protection-system-in-power-system/
3. http://electrical-engineering-portal.com