Unit-I

Introduction:

In the early power systems were mainly Neutral ungrounded due to the fact that the first ground fault did not require the tripping of the system. An unscheduled shutdown on the first ground fault was particularly undesirable for continuous process industries. These power systems required ground detection systems, but locating the fault often proved difficult. Although achieving the initial goal, the ungrounded system provided no control of transient over-voltages.

A capacitive coupling exists between the system conductors and ground in a typical distribution system. As a result, this series resonant L-C circuit can create over-voltages well in excess of line-to-line voltage when subjected to repetitive re- strikes of one phase to ground. This in turn, reduces insulation life resulting in possible equipment failure.

Neutral grounding systems are similar to fuses in that they do nothing until something in the system goes wrong. Then, like fuses, they protect personnel and equipment from damage. "Damage comes from two factors, how long the fault lasts and how large the fault current is. Ground relays trip breakers and limit how long a fault lasts and Neutral grounding resistors limit how large the fault current is".

Importance of Neutral Grounding:

There are many neutral grounding options available for both Low and Medium voltage power systems. The neutral points of transformers, generators and rotating machinery to the earth ground network provides a reference point of zero volts. This protective measure offers many advantages over an ungrounded system, like,

1. Reduced magnitude of transient over voltages
2. Simplified ground fault location
3. Improved system and equipment fault protection
4. Reduced maintenance time and expense
5. Greater safety for personnel
6. Improved lightning protection
7. Reduction in frequency of faults.

Method of Neutral Earthing:

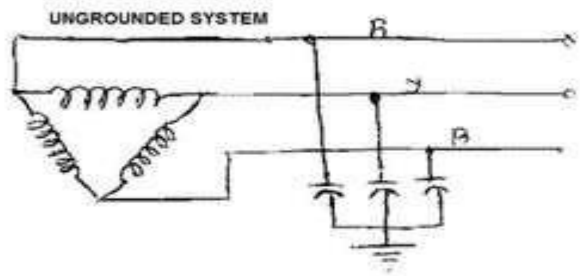
There are five methods for Neutral earthing.

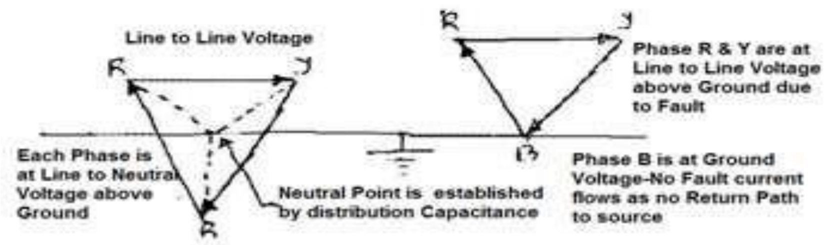
1. Unearthed Neutral System
2. Solid Neutral Earthed System.
3. Resistance Neutral Earthing System.
    1. Low Resistance Earthing.
    2. High Resistance Earthing.
4. Resonant Neutral Earthing System.
5. Earthing Transformer Earthing.

(1) Ungrounded Neutral Systems:

- In ungrounded system there is no internal connection between the conductors and earth. However, as system, a capacitive coupling exists between the system conductors and the adjacent grounded surfaces. Consequently, the

  "ungrounded system" is, in reality, a "capacitive grounded system" by virtue of the distributed capacitance.
- Under normal operating conditions, this distributed capacitance causes no problems. In fact, it is beneficial because it establishes, in effect, a neutral point for the system; As a result, the phase conductors are stressed at only line-to- neutral voltage above ground.
- But problems can rise in ground fault conditions. A ground fault on one line results in full line-to-line voltage appearing throughout the system. Thus, a voltage 1.73 times the normal voltage is present on all insulation in the system. This situation can often cause failures in older motors and transformers, due to insulation breakdown.





Advantage:

1. After the first ground fault, assuming it remains as a single fault, the circuit may continue in operation, permitting continued production until a convenient shut down for maintenance can be scheduled.

Disadvantages:

1. The interaction between the faulted system and its distributed capacitance may cause transient overvoltage (several times normal) to appear from line to ground during normal switching of a circuit having a line-to ground fault (short). These over voltages may cause insulation failures at points other than the original fault.

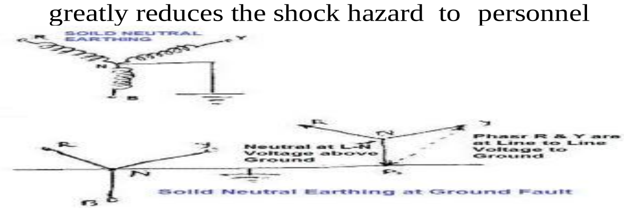
2. A second fault on another phase may occur before the first fault can be cleared. This can result in very high line-to-line fault currents, equipment damage and disruption of both circuits.

3. The cost of equipment damage.

4. Complicate for locating fault(s), involving a tedious process of trial and error: first isolating the correct feeder, then the branch, and finally, the equipment at fault. The result is unnecessarily lengthy and expensive down downtime.

(2) Solid Neutral Earthed System:

- Solidly grounded systems are usually used in low voltage applications at 600 volts or less.
- In solidly grounded system, the neutral point is connected to earth.
- Solidly Neutral Grounding slightly reduces the problem of transient over voltages found on the ungrounded system and provided path for the ground fault current is in the range of ***25 to 100% of the system three phase fault current.*** However, if the reactance of the generator or transformer is too great, the problem of transient over voltages will not be solved.
- While solidly grounded systems are an improvement over ungrounded systems, and speed up the location of faults, they lack the current limiting ability of resistance grounding and the extra protection this provides.
- To maintain systems health and safe, Transformer neutral is grounded and grounding conductor must be extend from the source to the furthest point of the system within the same raceway or conduit. Its purpose is to maintain very low impedance to ground faults so that a relatively high fault current will flow thus insuring that circuit breakers or fuses will clear the fault quickly and therefore minimize damage. It also greatly reduces the shock hazard to personnel



- If the system is not solidly grounded, the neutral point of the system would “float” with respect to ground as a function of load subjecting the line-to-neutral loads to voltage unbalances and instability.
- The single-phase earth fault current in a solidly earthed system may exceed the three phase fault current.
- The magnitude of the current depends on the fault location and the fault resistance. One way to reduce the earth fault current is to leave some of the transformer neutrals unearthed.

Advantage:

1. The main advantage of solidly earthed systems is low over voltages, which makes the earthing design common at high voltage levels (HV).

Disadvantage:

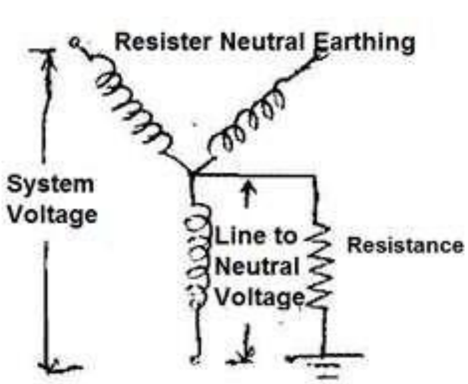
1. This system involves all the drawbacks and hazards of high earth fault current: maximum damage and disturbances.
2. There is no service continuity on the faulty feeder.
3. The danger for personnel is high during the fault since the touch voltages created are high.

Applications:

1. Distributed neutral conductor.
2. 3-phase + neutral distribution.
3. Used when the short-circuit power of the source is low.

3) Resistance earthed systems:

- Resistance grounding has been used in three-phase industrial applications for many years and it resolves many of the problems associated with solidly grounded and ungrounded systems.
- Resistance Grounding Systems limits the phase-to-ground fault currents. The reasons for limiting the Phase to ground Fault current by resistance grounding are:
  - To reduce burning and melting effects in faulted electrical equipment like switchgear, transformers, cables, and rotating machines.
  - To reduce mechanical stresses in circuits/Equipments carrying fault currents.
  - To reduce electrical-shock hazards to personnel caused by stray ground fault.
  - To reduce the arc blast or flash hazard.
  - To reduce the momentary line-voltage dip.
  - To secure control of the transient over-voltages while at the same time.
  - To improve the detection of the earth fault in a power system.
- Grounding Resistors are generally connected between ground and neutral of transformers, generators and grounding transformers ***to limit maximum fault current as per Ohms Law to a value which will not damage the equipment*** in the power system and allow sufficient flow of fault current to detect and operate Earth protective relays to clear the fault.
- Therefore, it is the most common application to limit single phase fault currents with low resistance Neutral Grounding Resistors to approximately rated current of transformer and / or generator.
- In addition, limiting fault currents to predetermined maximum values permits the designer to selectively coordinate the operation of protective devices, which minimizes system disruption and allows for quick location of the fault.
- There are two categories of resistance grounding:
  (1) Low resistance Grounding. (2) High resistance Grounding
- Ground fault current flowing through either type of resistor when a single phase faults to ground will increase the phase-to-ground voltage of the remaining two phases. As a result, ***conductor insulation and surge arrestor ratings must be based on line-to-line voltage***. This temporary increase in phase-to ground voltage should also be considered when selecting two and three pole breakers installed on resistance grounded low voltage systems.

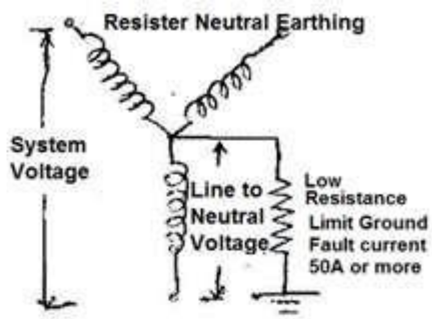


- Neither of these grounding systems (low or high resistance) reduces arc-flash hazards associated with phase-to-phase faults, but both systems significantly reduce or essentially eliminate the arc-flash hazards associated with phase-to- ground faults. Both types of grounding systems limit mechanical stresses and reduce thermal damage to electrical equipment, circuits, and apparatus carrying faulted current.

- The difference between Low Resistance Grounding and High Resistance Grounding is a matter of perception and, therefore, is not well defined. ***Generallyspeakinghigh-resistancegroundingreferstoasysteminwhich the NGR let-through current is less than 50 to 100 A. Low resistance grounding indicates that NGR current would be above 100 A.***
- A better distinction between the two levels might be alarm only and tripping. An alarm-only system continues to operate with a single ground fault on the system for an unspecified amount of time. In a tripping system a ground fault is automatically removed by protective relaying and circuit interrupting devices. Alarm-only systems usually limit NGR current to 10 A or less.

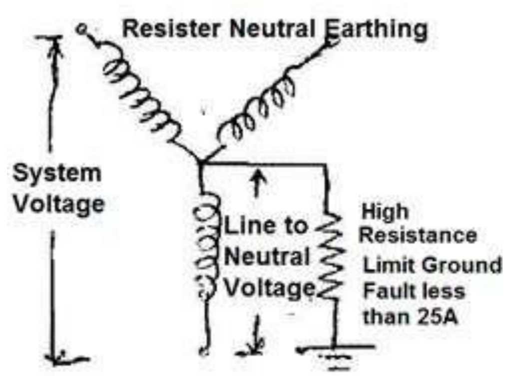
(A).Low Resistance Grounded:

Low Resistance Grounding is used for large electrical systems where there is a high investment in capital equipment or prolonged loss of service of equipment has a significant economic impact and it is not commonly used in low voltage systems because the limited ground fault current is too low to reliably operate breaker trip units or fuses. This makes system selectivity hard to achieve. Moreover, low resistance grounded systems are not suitable for 4-wire loads and hence have not been used in commercial market applications



(B).High Resistance Grounded:

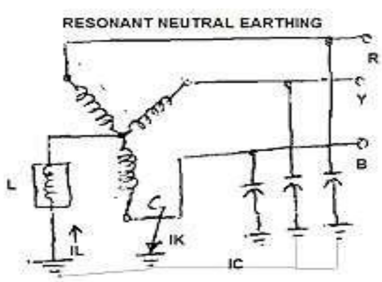
- High resistance grounding is almost identical to low resistance grounding except that the ground fault current magnitude is typically limited to ***10 amperes or less***. High resistance grounding accomplishes two things.
  - The first is that the ***ground fault current magnitude is sufficientlylow enough such*** that no appreciable damage is done at the fault point. This means that the faulted circuit need not be tripped off-line when the fault first occurs.
  Means that once a fault does occur, we do not know where the fault is located. In this respect, it performs just like an ungrounded system.
  - The second point is it can ***controlthetransientovervoltagephenomenon*** present on ungrounded systems if engineered properly.



4) Resonant earthed system:

- Adding inductive reactance from the system neutral point to ground is an easy method of limiting the available ground fault from something near the maximum 3 phase short circuit capacity (thousands of amperes) to a relatively low value (200 to 800 amperes).
- To limit the reactive part of the earth fault current in a power system a neutral point reactor can be connected between the transformer neutral and the station earthing system.

- A system in which at least one of the neutrals is connected to earth through an
    1. Inductive reactance.
    2. Petersen coil / Arc Suppression Coil / Earth Fault Neutralizer.
- The current generated by the reactance during an earth fault approximately compensates the capacitive component of the single phase earth fault current, is called a resonant earthed system.
- The system is hardly ever exactly tuned, i.e. the reactive current does not exactly equal the capacitive earth fault current of the system.
- A system in which the inductive current is slightly larger than the capacitive earth fault current is over compensated. A system in which the induced earth fault current is slightly smaller than the capacitive earth fault current is under compensated
- However, experience indicated that this inductive reactance to ground resonates with the system shunt capacitance to ground under arcing ground fault conditions and creates very high transient over voltages on the system.
- To control the transient over voltages, the design must permit at least 60% of the 3 phase short circuit current to flow underground fault conditions.
- Example. A 6000 amp grounding reactor for a system having 10,000 amps 3 phase short circuit capacity available. Due to the high magnitude of ground
  fault current required to control transient over voltages, inductance grounding is ***rarely used withinindustry.***



Petersen Coils:

Petersen Coil is connected between the neutral point of the system and earth, and is rated so that the capacitive current in the ***earth fault is compensated by an inductive current passed by the Petersen Coil***. A small residual current will remain, but this is so small that any arc between the faulted phase and earth will not

be maintained and the fault will extinguish. Minor earth faults such as a broken pin insulator, could be held on the system without the supply being interrupted. Transient faults would not result in supply interruptions.

- Although the standard 'Peterson coil' does not compensate the entire earth fault current in a network due to the presence of resistive losses in the lines and coil, it is now possible to apply 'residual current compensation' by injecting an additional 180° out of phase current into the neutral via the Peterson coil.
- The fault current is thereby reduced to practically zero. Such systems are known as 'Resonant earthing with residual compensation', and can be considered as a special case of reactive earthing.
- Resonant earthing can reduce EPR to a safe level. This is because the Petersen coil can often effectively act as a high impedance NER, which will substantially reduce any earth fault currents, and hence also any corresponding EPR hazards (e.g. touch voltages, step voltages and transferred voltages, including any EPR hazards impressed onto nearby telecommunication networks).

Advantages:

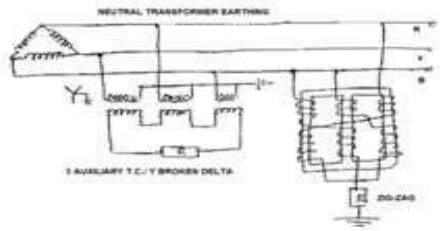
1. Small reactive earth fault current independent of the phase to earth capacitance of the system.
2. Enables high impedance fault detection.

Disadvantages:

1. Risk of extensive active earth fault losses.
2. High costs associated.

(5) Earthing Transformers:

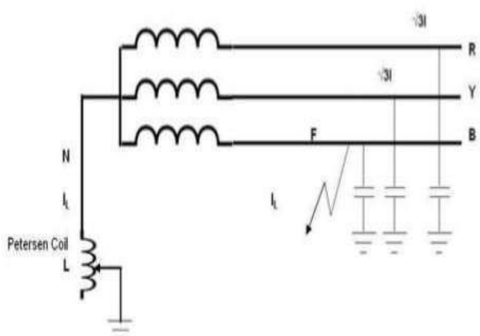
For cases where there is no neutral point available for Neutral Earthing (e.g. for a delta winding), an earthing transformer may be used to provide a return path for single phase fault currents In such cases the impedance of the earthing transformer may be sufficient to act as effective earthing impedance. Additional impedance can be added in series if required. A special 'zig-zag' transformer is sometimes used for earthing delta windings to provide a low zero-sequence impedance and high positive and negative sequence impedance to fault currents.

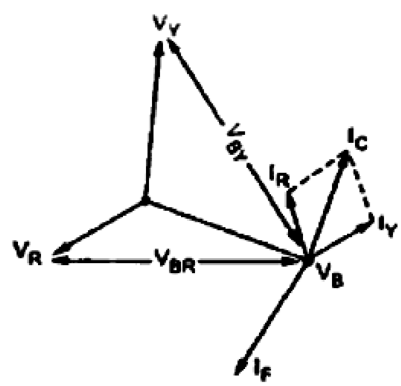


This coil is known as ground fault neutralizer or arc suppressor coil.
It's an iron cored reactor connected between the neutral point and the ground and capable of behind turned with the capacitance of the healthy phase.to produce resonance when a L-G fault occurs.

It's mainly used to prevent arcing ground which lead to overvoltage on system with an under grounded neutral. Peterson coil make arcing ground fault self-extinguishing and in case of sustained ground faults on one of the lines it reduces the faults current to a very low value so that the healthy phases can be kept in a select the proper value of inductive reactance Peterson coil is provided with toppings.

In an undergrounded system when a ground fault occurs on any one line the voltage of the healthy phases is in*creased by √3 times. √3Vp.when Vp phase voltage hence the charging current of √3I ⁄ Phase. Where is the*





charging current of the line to ground of one phase, the phase sum of the charging current of the healthy phases because three time s the normal line to neutral charging current of one phase has shown in pharos diagram of above1 .hence,

$$\text{Charging current, } I_C = 3I = \frac{3V_p}{X_c} = \frac{3V_p}{(1/\omega C)} = 3V_p\omega C$$

Where Ic is the resultant charging current and I is the charging current of line to ground of one phase.
If L is the inductance of the Peterson coil connected between the neutral and the ground, then

$$I_L = \frac{V_p}{X_L} = \frac{V_p}{\omega L}$$

In order to obtain satisfactory cancellation of arcing ground. The fault current Il following through the Peterson coil should be equal to the resultant charging ground Ic.
Therefore for balance condition $I_L = I_C$

Inductance of the Peterson coil.

$$\frac{V_p}{\omega L} = 3V_p\omega C$$

$$L = \frac{1}{3\omega^2 c}$$

UNIT-II

1. **(Nov/Dec**produce restraining force. When the current through coil increases beyond the limit under fault conditions, armature gets attracted. Due to this it makes contact with contacts of a trip circuit, which results in an opening of a circuit breaker.

The minimum current at which the armature gets attracted to close the trip circuit is called pickup current.

Generally the number of tappings is provided on the relay coil with which its turns can be selected as per the requirement. This is used to adjust the set value of an operating quantity at which relay should operate.

An important advantage of such relays is their high operating speed. In modern relays an operating time as small as 0.5 msec is possible. The current-time characteristic of such relays is hyperbolic, as shown in the Fig. 2.6.

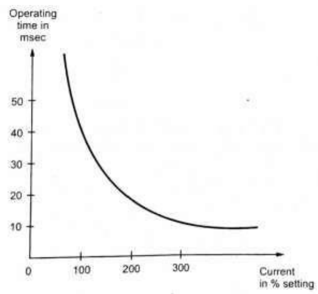


Fig. 2.6 Current-time characteristics

Solenoid and Plunger Type Relay

- The Fig. 2.7 shows the schematic arrangement of solenoid and plunger type relay which works on the principle of electromagnetic attraction.
- It consists of a **solenoid** which is nothing but an electromagnet. It also consists a movable iron plunger. Under normal working conditions, the spring holds the plunger in the position such that it cannot make contact with trip circuit contacts.
- Under fault conditions when current through relay coil increases, the solenoid draws the plunger upwards. Due to this, it makes contact with the trip circuit contacts, which results in an opening of a circuit breaker.

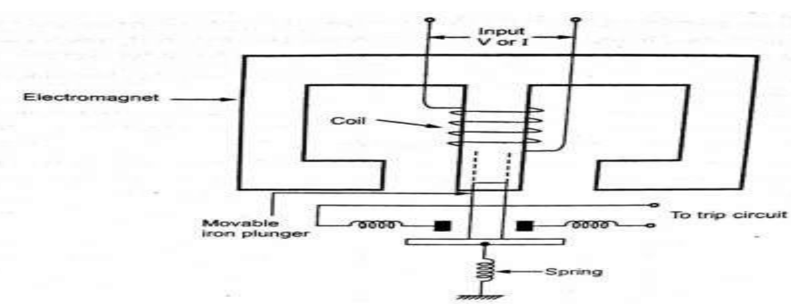


Fig. 2.7 Solenoid and plunger type relay

Operating Principle *of* Electromagnetic Attraction Relays

The electromagnetic force produced due to operating quantity which is exerted on armature, moving iron or plunger is proportional to the square of the flux in the air gap. Thus neglecting the saturation effect, the force is proportional to the square of the operating current. Hence such relays are useful for a.c. and d.c. both.

Ford.c.operation: In d.c. operation, the electromagnetic force is constant. When this force exceeds the restraining force, the relay operates.

Now $F_e = K_1 I^2$

F_e = *Electromagnetic force*

K_1 = *constant*

I = *operating current in a coil*

$$And \qquad F_r = K_2$$

Where F_r = Restraining force due to spring including friction

$$K_2 = constant$$

.

On the verge of relay operating, electromagnetic force is just equal to the restraining force.

$$F_e = F_r$$

$$K_1 I^2 = K_2$$

$$I^2 = \frac{K_2}{K_1} = constant$$

$$I = \sqrt{\frac{K_2}{K_1}}$$

This is the current at which relay operates in case of d.c. operation.

For a.c. operation: In a.c. electromagnetic relays, the electromagnetic force is proportional to square of the current but it is not constant. It is given by,

$$F_e = K_1 I^2 = \frac{1}{2} K I_m^2 - \frac{1}{2} K I_m^2 \cos 2\omega t$$

where I_m = Maximum value of the operating current K = constant

It shows that the electromagnetic force consists of two components,

- Constant, independent of time.
- Pulsating at double the frequency of applied voltage.

Advantages of Electromagnetic Relays

The various advantages of electromagnetic relays are,

- Can be used for both a.c. and d.c.
- They have fast operation and fast reset.
- These are almost instantaneous. Though instantaneous, the operating time varies with current. With extra arrangements like dashpot, copper ring etc. slow operating and resetting times can be obtained.
- High operating speed with operating time in few milliseconds also can be achieved.
- The pickup can be as high as 90-95% for d.c. operation and 60 to 90% for the d.c. operation.
- Modern relays are compact, simple, reliable and robust.

Disadvantages of Electromagnetic Relays

The few disadvantages of these relays are,

- The directional feature is absent.
- Due to fast operation the working can be affected by the transients. As transients contain d.c. as well as pulsating component, under steady state value less than set value, the relay can operate during transients.

Applications of Electromagnetic Relays

The various applications of these relays are,

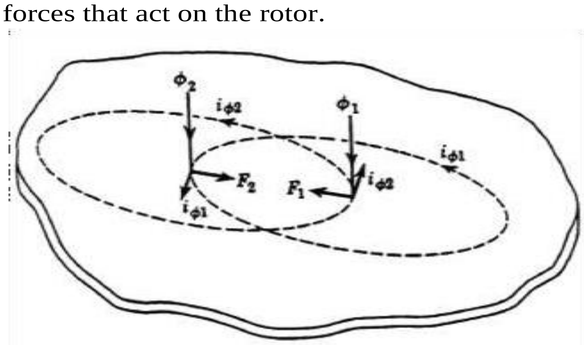
- The protection of various a.c. and d.c.equipments.
- The over/under current and over/under voltage protection of various a.c. and d.c.equipments.
- In the definite time lag over current and earth fault protection along with definite time lag over current relay.
- For the differential protection.
- Used as auxiliary relays in the contact systems of protective relaying schemes.

2. Derive the torque equation for induction type relay.(May-2010,2011)

Induction-type relays are the most widely used for protective-relaying purposes involving ac quantities. They are not usable with d-c quantities, owing to the principle of operation. An induction-type relay is a split-phase induction motor with contacts. Actuating force is developed in a movable element that may be a disc or other form of rotor of non-magnetic current conducting material by the interaction of electromagnetic fluxes with eddy currents that are induced in the rotor by these fluxes.

The Production of Actuating Force

Figure shows how force is produced in a section of a rotor that is pierced by two adjacent a-c fluxes. Various quantities are shown at an instant when both fluxes are directed downward and are increasing in magnitude. Each flux induces voltage around itself in the rotor, and currents flow in the rotor under the influence of the two voltages. The current produced by one flux reacts with the other flux, and vice versa, to produce forces that act on the rotor.



The quantities involved in Fig. above may be expressed as follows:

$$\phi_1 = \Phi_1 \sin \omega t$$

$$\phi_2 = \Phi_2 \sin (\omega t + \theta),$$

here q is the phase angle by which I2 leads I1. It may be assumed with negligible error that the paths in which the rotor currents flow have negligible self-inductance, and hence that the rotor currents are in phase with their voltages.

$$i\phi_2 \ \alpha \ \frac{d\phi_2}{dt} \ \alpha \ \Phi_2 \cos (\omega t + \theta)$$

We note that Fig. shows the two forces in opposition, and consequently we may write the Equation for the net force (F) as follows:

$$F = (F_2 - F_1) \ \alpha \ (\phi_2 i_{\phi 1} - \phi_1 i_{\phi 2}) \quad \text{................(1)}$$

Substituting the values of the quantities into equation (1) we get:

$$F \ \alpha \ \Phi_1\Phi_2 [\sin (\omega t + \theta) \cos \omega t - \sin \omega t \cos (\omega t + \theta)] \quad \text{..............(2)}$$

This reduces to.

$$F \ \alpha \ \Phi_1\Phi_2 \sin \theta \quad \text{.........................(3)}$$

Since sinusoidal flux waves were assumed, we may substitute the rms values of the fluxes for the crest values in equation 3.

It is important to note that the net force or torque acting on the disc is same at every instant. The action of relay under such a force is free from vibrations.

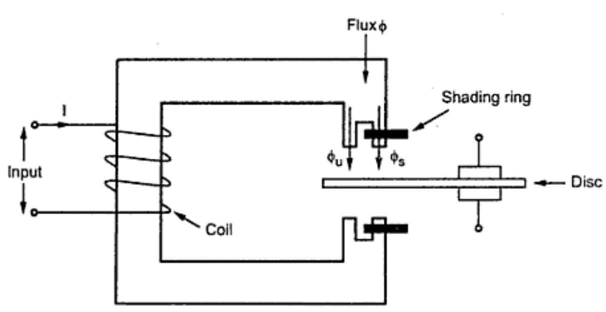
It can be observed from equation (3) if θ is zero than net force is zero and disc cannot rotate. Hence there must exists a phase difference between the two fluxes .the torque is maximum when phase difference θ is 90^{deg}.

The direction of net force which decides the direction of rotation of disc depends on which flux is leading the other.

The different types of structure that have been used are commonly called: (1) the "shaded pole" structure; (2) the "watt-hour-meter" structure; (3) the "induction- cup" and the"double-induction-loop" structures; (4) the "single-induction-loop" structure.

Shaded-Pole Structure.

The shaded-pole structure, illustrated in Fig. is generally actuated by current flowing in a single coil on a magnetic structure containing an air gap. The air gap flux produced by this current is split into two out-of-phase components by a so-called "shading ring," generally of copper, that encircles part of the pole face of each pole at the Air gap.



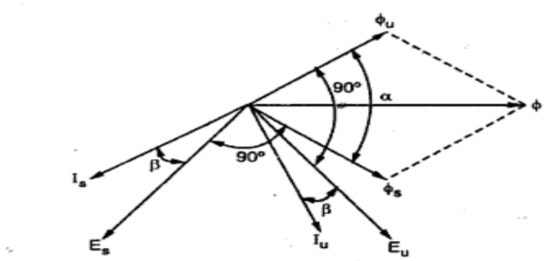
Shaded pole induction relay

The rotor shown edgewise in Fig. is a copper or aluminum disc, pivoted so as to rotate in the air gap between the poles. The phase angle between the fluxes piercing the disc is fixed by design, and consequently it does not enter into application considerations. The shading rings may be replaced by coils if control of the operation of a shaded-pole relay is desired. If the shading coils are short-circuited by a contact of some other relay, torque will be produced; but, if the coils are open-circuited, no torque will be produced because there will be no phase splitting of the flux. Such torque control is employed where "directional control" is desired.

Due to the alternating flux, E.M.F gets induced in the shading ring. This E.M.F drives the current causing the flux to exist in shaded portion. This flux lags behind the flux in the unshaded portion by an angle α.

φ_s= flux in the shaded portion φ_u= flux in the unshadedportion
E_s=E.M.F induced in the disc due to φ_s E_u= E.M.F induced in the disc due to φ_u I_S=Induced current due to E_s
I_u= Induced current due to E_u.

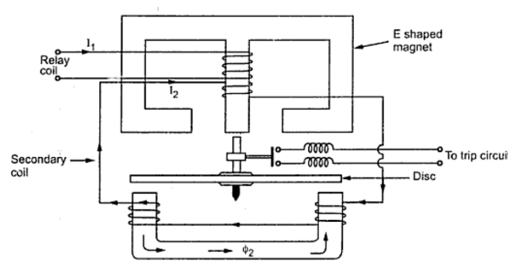
$E_u$lagsbehindφ_u by 90˙ while E_s lags behind φ_s by 90˙.the current I_S lags $E_s$by small angle β while I_u lags E_u by small angle β. This angle is generally neglected and I_S and I_u are assumed to be in phase with E_s and E_u respectively. The phasor diagram shown in below.



The torque equation $T \propto \varphi_s \varphi_u \sin\alpha$ T=Torque
Assuming the fluxes φ_s and $\varphi_u$to be proportional to the current I tn the relay coil we can write,
$T \propto I^2 \sin\alpha$
$T = kI^2$
As α is constant for the given design. Thus the torque is proportional to the square of the current through the coil.

Watthour-Meter Structure.

This structure gets its name from the fact that it is used for watthour meters. As shown in Fig. this structure contains two separate coils on two different magnetic circuits, each of which produces one of the two necessary fluxes for driving the rotor



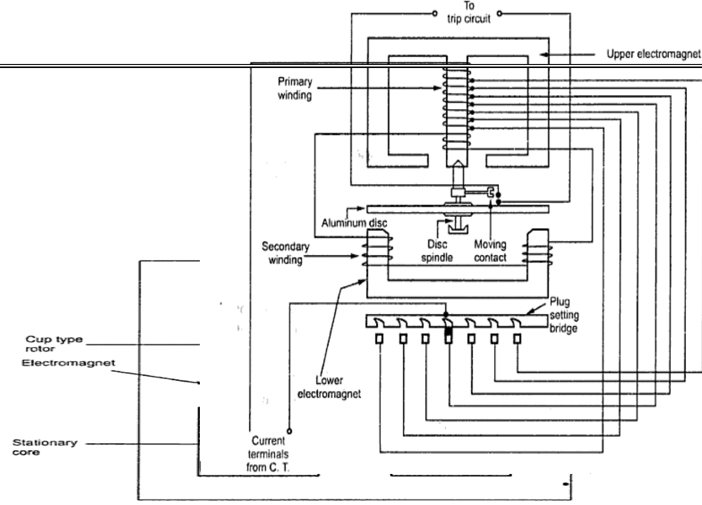
It consists of two magnets, one E shaped magnet and other U shaped magnet. The disc is free to rotate in between these magnets. The upper E shaped magnet carries both primary winding which is relay coil and secondary winding. The primary carries the relay current I_1 which produces the flux φ_1. The E.M.F gets induced inthe secondary due to this flux. This drives current I_2, flux φ_2 gets produced in the lower magnet. This flux lags behind the main flux φ_1 by an angle α. Due to the interaction of two fluxes, the torque is exerted on the disc and disc rotates.

Assuming that the entire flux φ_1 enters the disc from upper magnet and entire flux φ_2 enters the disc from lower magnet, we can write the torque equation.
$T \propto \varphi_1 \varphi_2 \sin\alpha$

In this relay, the tapping can be provided on the primary. With the help of this suitable number of primary turns can be selected and hence current setting can be adjusted.

An important feature is that its operation can be controlled by opening or closing of secondary winding .it can be open, no current can flow through secondary hence flux φ_2 cannot be produced and hence no torque can be produced. Thus relay can made inoperative opening the secondary winding.

INDUCTION CUP TYPE RELAY



The construction of this type of relay is very similar to an induction motor. The arrangement shown in fig.

The stator consists of two, four or more poles. These are energized by the relay coils the four pole structure and two pair of coil. The coil1 and 1' are connected while coil2 and 2' are connected to form two pairs of coils. The rotor is hollow cylindrical cup type in structure. Compared to induction motor the difference is that in this relay the rotor core is stationary and only rotor conductor portion is free to rotate its axis.

The current and respective fluxes produced by the two pairs of coils are displaced from each other by an angleα. This is the resultant flux in the air gap is rotating. So rotating magnetic field is produced by two pairs of coils. Due to this, eddy currents are induced in the cup type rotor. This current produces the flux. The interaction of two fluxes produce the torque and rotor rotates in the same direction as that of rotating magnetic field. A control spring and back stop carried on an arm attached to the spindle of cup are responsible to prevent continuous rotation.

These relay are very fast in operation. The operating time of the other of 10ms is possible with this type. This is because the rotor is light having very low moment of inertia. The induction cup structure can be used for two quantity or single quantity relay.

Asingle quantity relay means both coils are fed by the same actuating quantity with fixed phase angle shift in between them. To reduce rotor inertia and make the operation more fast, double induction loop structure is used.Such a structure shown in bellow.

In all the induction relay widely used for productive relays involving A.C quantities.High,low and adjustable speeds are possible in these relays.Various shapes of time against operating quantity curves can be obtained**.**

The over current relay operates when the current in the circuits exceeds a certain preset value. The induction type non directional over current relay has a construction similar to a Watthour meter, with slight modification.

NON DIRECTIONAL INDUCTION OVER CURRENT RELAY

It consists of two electro magnet .the upper is E shaped while the lower is U shaped. The aluminum disc is free to rotate between the two magnets. The spindle of the disc carries moving contacts and when the disc rotates the moving conducts and when the disc rotates the moving contacts come in contacts which are the terminals of a trip circuit.

The upper magnet has two windings, primary and secondary. The primary connected to the secondary of C.T. on the line to be protected. This winding is tapped at intervals. The trappings are connected to plug setting bridge.

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. There are usually seven sections of tapping to have a over current rang from 50%to 200% in steps of 25%. These values are percentages of current rating of the relay. Thus a relay current rating may be 10A i.e. it can be connected to C.T. with secondary current rating of 10A but with 50% setting the relay will start operating at 5A. So adjustment

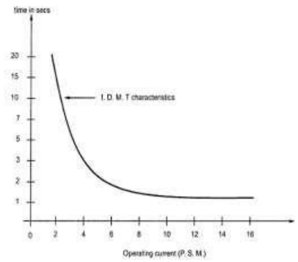
of the current setting is made by inserting a pin between spring loaded jaw of the bridge socket, at the proper tap value required. When the pin is withdrawn for the purpose of changing the setting wile relay is in service then relay automatically adopts a higher current setting thus secondary of C.T. is not open circulated. So relay remains operative for the fault occurring the process of changing the setting.

The secondary winding on the central limb of upper magnet is connected in series with winding on thelower magnet. This winding is energized by the induction from primary. By this arrangement of secondary winding, leakage flux of upper and lower magnets are sufficiently displayed in space and time to provide a rotational torque on the alumimium disc. The control torque is provided by the spiral spring.

When the current exceeds its preset value, disc rotates and moving contacts on spindle make connection with trip circuit terminal. Angle through which the disc rotates is between 0˚to 360˚.the travel of moving contacts can be adjusted by adjusting angle of rotation of disc. This gives the relay any desired time setting which is indicated by pointer on a time a time scale dial. The dial is calibrated from 0 to 1.This does not give direct operating time but it gives multiplier which can be used along with the Time-Plug Setting multiplier curve to obtain actual operating time of the relay.

$$P.S.M = \frac{faultcurrentinrelaycoli}{RatedsecondaryC.Tcurrent \times currentsetting}$$

Fault current in relay coil=line fault current ×C.T. ratio



Time – current characteristics

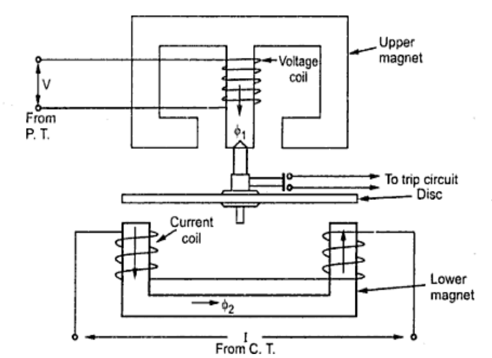
OPERATION

The torque is produced due to induction principle; this torque is opposed by restraining force produced by spiral springs. Under normal conditions the restraining 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 of trip circuit. The trip circuit opens the circuit breaker, isolating the fault part from rest of the healthy system.

Direction Power Relay

The directional relay means the relay operates for the specific direction of the actuating quantity in the circuit. The directional power relay operates when the power in the circuit floes in the specific direction. The construction and principle of operation of this relay is similar to the induction type Watt-hour meter relay. The difference is that in watt-hour meter type relay the torque is produced by only the current derived from secondary of C.T.while in directional power relay the torque is produced due to interaction of the fluxes produced from both voltage and current in the circuit. The relay has two winding one act as voltage coil while other as current coil which is energized from C.T. in the line to protected.

The of trappings are provided to the current coil with which desired current setting can be achieved. The restraining torque is produced by the spiral spring. The spindle of disc carries the moving contacts which make contact with tripping circuit terminals when the disc rotates. The voltage coil provided on the upper magnet produces the flux $\varphi 1$. This lags the voltage by 90˙.the current I is sensed by the current coil on lower magnet which produces the flux $\varphi 2$.this is in phase with current I. The current I lags voltage V by an angle φ. the angle between $\varphi 1$and $\varphi 2$ is α .shown in phasor diagram.



DIRECTIONAL POWER RELAY

The interaction of fluxes $\varphi 1$and $\varphi 2$ produces the torque.

$$T \propto \phi_1 \phi_2 \sin\alpha$$

$$\phi_1 \propto V \quad and \quad \phi_2 = I$$

$$\alpha = 90° - \phi$$

$$T \propto VI \sin(90° - \phi)$$

$$\boldsymbol{T \propto VI \cos\phi}$$

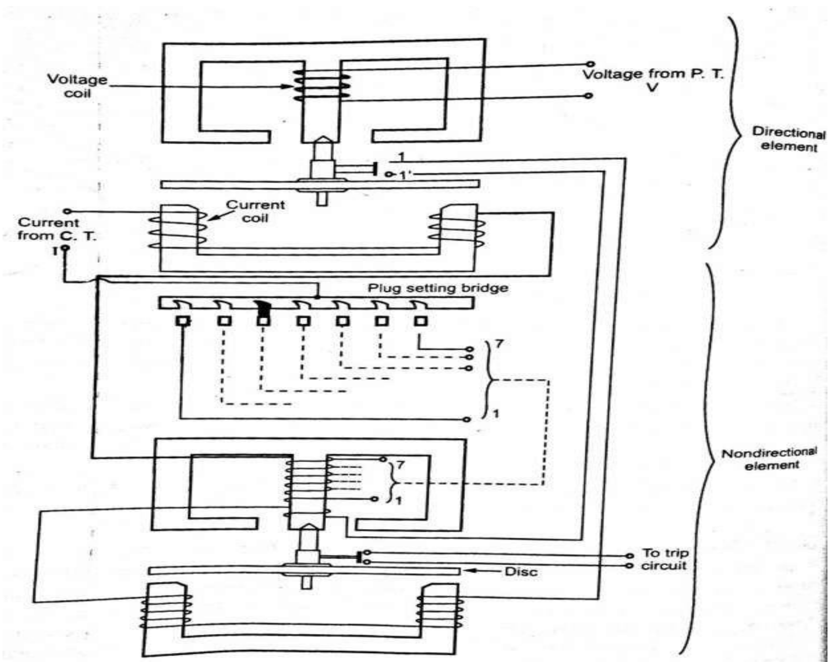
Under normal working conditions, the driving torque acts in the same direction as that of restraining torque. This moves the moving contacts away from the fixed tripping circuit conditions. Thus relay remains inoperative as power flow is in one particular direction.But when there is a current reversal and hence the power reversal then the driving torque acts in opposite direction to the restraining torque in such a manner that the moving contacts close the tripping circuit contacts. This opens the circuit breaker to isolate the faulty part.

This relay is used for providing reverse power protection to synchronous machines.The relay can be single phase or three phase.

The directional power relay is not suitable under short circuit conditions because as short circuit occurs the system voltage falls to a low value resulting in insufficient torque to cause relay operations. This difficulty is overcome in the directional over current relay, which is independent of system voltage and power factor.

Constructional details: – Figure shows the constructional details of a typical induction type directional over current relay. It consists of two relay elements mounted on a common case viz. (i) directional element and (ii) non-directional element.

(i) Directional element: It is essentially a directional power relay, which operates when power flows in a specific direction. The potential of this element is connected through a potential transformer (PT.) to the system voltage. The current coil of the element is energized through a CT by the circuit current. This winding is



carried over the upper magnet of the non-directional element. The trip contacts (1 and

2) of the directional element are connected in series with secondary circuit of the over current element. The latter element cannot start to operate until its secondary circuit is completed. In other words, the directional element must first operate (ie. contacts 1 and 2 should close) in order to operate the over current element.

(ii) Non-directional element: – It is an over current element similar in all respects to a non-directional over current relay. The spindle of the disc of this element carries a moving contact which closes the fixed contact after the operation of directional element. Plug setting bridge is rovided for current setting. The tappings are provided on the upper magnet of over current element and are connected to the bridge.

Operation:

During normal conditions, power flow in the proper direction and hence directional element of the relay is in-operation, thus the secondary winding of lower magnet of non-direction element is open and hence non-directional element is also in-operative.

Under faulty conditions, current flows through current coil of directional element which produces flux. The current in voltage coil produces another flux. The two fluxes interact to produce the torque due to which the disc rotates. As disc rotates the trip contact gets closed, the current coil is mainly responsible for disc rotation.

The design of directional element is so sensitive that it can operate even at 2% of power flow in reverse direction. From the current coil of directional element, the current flows to primary winding of upper magnet which is the non-directional element.

The energies to produce the flux. This flux induces the emf in the secondary winding of non directional relay. As the contacts are closed(1-1'),the secondary winding has a closed path. Hence, Induced e.m.f drives current through it, producing another flux. These two fluxes interact to produce torque and rotates disc. This makes contacts with trip circuit and it opens C.B to isolate faulty sections. Directional element should operate first to operate non-directional element.

The following condition must satisfy for relay operations:

1. The direction of current in the circuit must reverse to operate directional element.
2. The current value in the reverse direction must be greater than the current setting.
3. The high value of current must persists for a long period which is greater than time setting of the relay.

Directional Characteristics

Torque equations and Pharos diagram:

Let

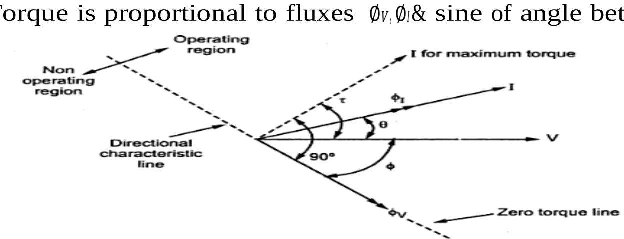
V=relay voltage through PT I=Relay coil current through CT θ =angle between V ant I
Due to this, correct operation or relay at all types of fault is,

So current I leads voltage V by angle θ.

 =Flux produced by voltage v. Flux lags voltage v by an angle
$\emptyset_I$ =Flux produced by current I.

Flux $\emptyset_I$ v is in-phase with the current I, considering V as reference.

Torque is proportional to fluxes $\emptyset_V, \emptyset_I$ & sine of angle between the two fluxes.



$$T \propto \emptyset_V \emptyset_I sin(\emptyset_V + \emptyset_I)$$

$$\propto \emptyset_V \emptyset_I sin(\theta + \ )$$

Now $\emptyset_V \propto V$ and $\emptyset_I \propto I$

K=constant

$T = KVI\ Sin\ (\theta + \emptyset)$

Maximum torque occurs when $\sin(\theta + \emptyset)=1$

$$(\theta + \emptyset) = 90°$$

The condition for the maximum torque is shown in dotted The torque is zero when $\sin(\theta + \emptyset)$=0 or 180
This line of 0 is called ***zero torque line*** it is right angles to maximum torque condition line.

Maximum torque angle

The angle by which the current supplied to the relay leads the voltage supplied to the relay so as to obtain the maximum torque is called ***maximum torque angle.***

It is denoted by τ We can write,
$(\emptyset = 90^o - \tau)$

Substituting in the torque equation, T=KVI Sin $(\emptyset + 90^o - \tau)$
T=KVI Cos $(\emptyset - \tau)$

The typical values of the maximum torque angle are 0^0,30^0,45^0.etc.

Most of the protection relays consist of some arrangement of electromagnets with armature or induction disc, which carry contacts. The relays also carry the closing or opening of contacts control devices like trip coils of circuit breaker. The electromagnets have voltage or both the types of windings. Currents through windings produce magnetic fluxes and torque is developed by the integration between the fluxes of same windings or between the fluxes of both the windings. In general the torque produced by current winding is proportional to square of the current the torque produced by voltage winding is proportional to square of the voltage, and the torque produced by the windings is proportional to product of voltage and the current.

Mathematically we can write,

Torque produced by current coil=$\mathbf{k_1 I^2}$ Torque produced by voltage coil=$\mathbf{K_2 V^2}$

Torque produced by both the coils=$\mathbf{K_3 VI\cos(\theta - \tau)}$

Where K_1,K_2 and K_3 = constant =angle between V and I

τ is maximum torque angle

Torque produced by control spring=$\mathbf{k_4}$

The control springs are used as restraining elements

If all the elements are present in a relay then total torque produced by all the causes can be expressed by a general equation as,
$\mathbf{T=K_1 I^2+K_2 V^2+K_3\ VI\cos(\theta - \tau) +K_4}$

This equation is called universal torque equation the term k4 can be restraing torque due to springs or gravity.
By assigning positive and negative signs to certain constants and lets other constants to be zero and sometimes by adding similar other terms, the operating characteristics equation of all the types of protective relays can be obtained from universal equation.
For example, for over current relay K_2=K_3=0 and the spring torque is negative so we get, $\mathbf{T=K_1 I^2-K_4}$

For the directional relay K_1=K_2=0 and the spring torque is negative so we get,
$\mathbf{T=K_3\ VI\cos(\theta - \tau) -K_4}$

Differential Relays

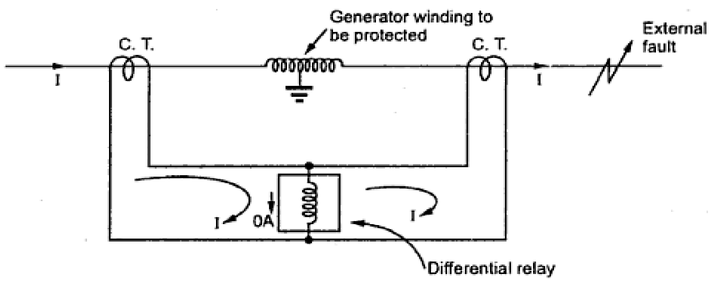
A differential relay is defined as the relay that operates when the phasor difference of two or more similar electrical quantities exceeds a predetermined value

The various types of differential relays are,

- Current differential relay
- Biased beam relay or percentage differential relay
- Voltage balance differential relay

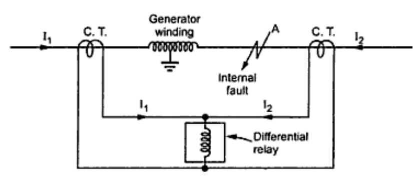
Current Differential Relay(Dec-2010)

Most of the differential relays are of current differential type. Consider an over current relay connected in the circuit so as to operate as the current differential relay.



Two current transformers are used having same ratio are connected on the either side of the section to be protected. The secondaries of current transformers are connected in series, so they carry induced currents in the same direction. Let current I is flowing through the primary of current transformers towards the external fault. As the current transformers are identical, the secondaries of current transformers will carry equal currents. Due to the connection of relay, no current will flow through the operating coil for the relay. Hence relay will remain inoperative. So relay cannot operate if there is an external fault.

Consider now that an internal fault occurs at point A, as shown in the diagram.



The current flows through the fault from both sides. The two secondary currents through C.T.s are not equal. The current flowing through the relay coil is now I_1+I_2. This high current causes the relay to operate.

It should be noted that the fault current need not always flow to the fault from both sides. A flow on one side only or even some current flowing out of one side while a large current entering the other side can cause differential relay to operate. Thus the amount of current flowing through a relay coil depends upon the way the fault is being fed.

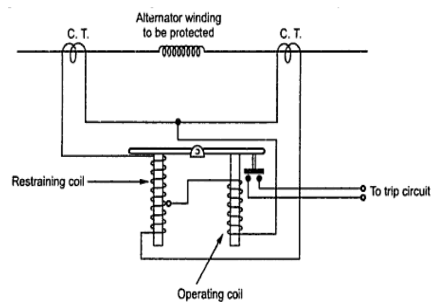
This relay suffers from the following disadvantages,

1. The current transformers are connected through cables called pilot cables. The impedance of such pilot cables generally causes a slight difference between the currents at the ends of the section to be protected. A sensitive relay can operate to a very small difference in the two currents, though there is no fault existing.
2. The relay is likely to operate inaccurately with heavy through current flows. This is because the assumed identical current transformers may not have identical secondary currents due to the constructional errors and pilot cable impedances.
3. Under severe through fault conditions, the current transformers may saturate and cause unequal secondary currents. The difference between the currents may approach the pick value to cause the inaccurate operation for the relay.
4. Under heavy current flows, pilot cable capacitances may cause inaccurate operation of the relay.

All these disadvantages are overcome in biased beam relay.

Biased Beam Relay or Percentage Differential Relay.

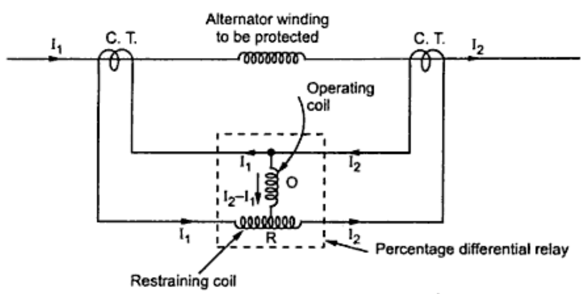
As the name suggests, this relay is designed to operate to the differential current in terms of its fractional relation with the actual current flowing through the protected circuit. The diagramshows the arrangement of a biased beam relay.



Biased Beam Relay

Biased Beam Relay

The simple circuit connection of this type of relay is shown in the **Fig**



Simple circuit biased beam relay

The operating coil **O** of the relay carries a differential current (I_1-I_2) while the restraining coil R carries the current proportional to **(** $\frac{I_1-I_2}{2}$ **)** as the operating coil is connected at the midpoint of the restraining coil. This can be explained as, Let

N = Total number of turns of restraining coil.

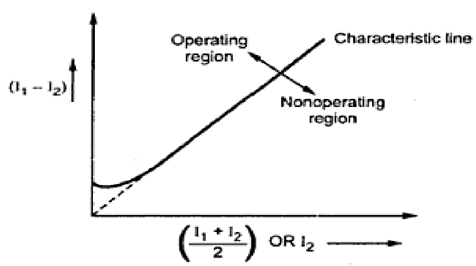
So current I_1 flows through $\frac{N}{2}$ turns of while current I_2 flows through $\frac{N}{2}$

Effective ampere turns = $I_1 N/2 + I_2 N/2 = N\left(\frac{I_1+I_2}{2}\right)$

Thus it can be assumed that the current $\frac{I_1-I_2}{2}$ flows through the entire N turns of the restraining coil.

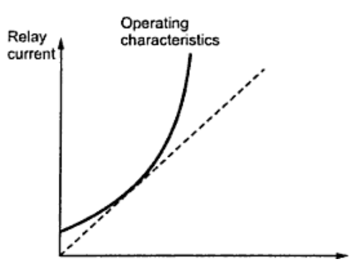
Under normal and through load conditions, the bias force produced due to the restraining coil is greater than the operating force produced by the operating coil hence relay is inoperative. When internal fault occurs, the operating force becomes more than the bias force. Due to this, beam moves and the trip contacts are closed to open then circuit breaker.

The operating characteristics of this type of relay are shown in the **Fig.**



It can be seen that except at low currents, the characteristics is a straight line.Thus the ratio of the differential operating current to the average restraining current is a fixed percentage. Hence the relay name is percentage differential relay.

The relays with constant slope characteristics are called constant slope percentage differential relays.In some relays, the slope of the characteristics increases as the short circuit current increases. Such characteristics are shown in the **Fig.**

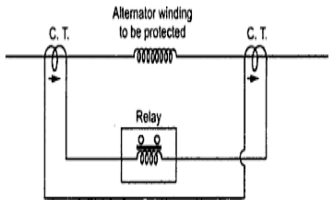


Such relays are called increasing slope percentage differential relays.

The important fact about increasing slope type relays is that their cost is more but requires less accuracy in the performance of their current transformers. Constant slope type relays require good accuracy in the performance of the current transformers.

Voltage Balance Differential Relay

This is also called opposed voltage method. In this type, the over current relay is connected in series with the secondaries of the current transformers. This is shown in the Fig.



- Under normal conditions, the current at the two ends of the section to be protected is same. Hence there is no voltage drop across the relay to cause the current to flow.
- Under fault conditions, the currents in the two secondaries of current transformers are different. This causes a large voltage drop across the relay. Thus the voltage balance of the circuit gets disturbed. Hence large current flows through the relay due to which the relay operates to open the circuit breaker.

1. Frame leakage protection. 2. Circulating current protection.

3. High impedance differential protection. Busbar Protection

The busbar plays an important role in the supply system. The busbar faults are rare but if occurs there can be interruption of supply, considerable damage and loss. Hence busbar protection is must and it must be fast, stable and reliable. The busbar protection needs to protect not only the busbar but the apparatus associated with it such as circuit breakers, isolating switches, instrument transformers etc.

Bus bar Faults

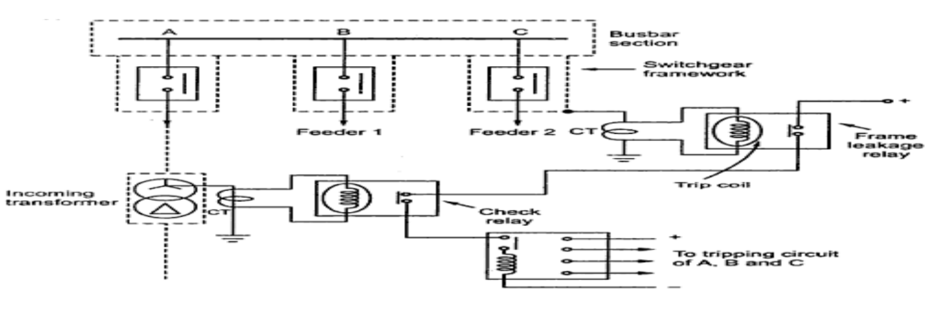
The various bus bar faults can be classified as,

1. Failure of insulation due to material deterioration.
2. Failure of circuit breaker.
3. Earth fault due to failure of support insulator.
4. Flashover due to sustained excessive over voltages.
5. Errors in the operation and maintenance of switchgear.
6. Earthquake and mechanical damage.
7. Accidents due to foreign bodies falling across the bus bars.
8. Flashover due to heavily polluted insulator.

Frame Leakage Protection of Bus bar

All bus bar protection schemes are mostly designed for earth faults. Each conductor is surrounded by the earthed metal barrier. All the metal frameworks are bonded together and insulated from earth. The switchgear framework is also insulated from lead cable sheaths.

The arrangement of frame leakage protection to a single bus bar substation with a switchgear unit is shown in the **fig.**



Frame Leakage Protection

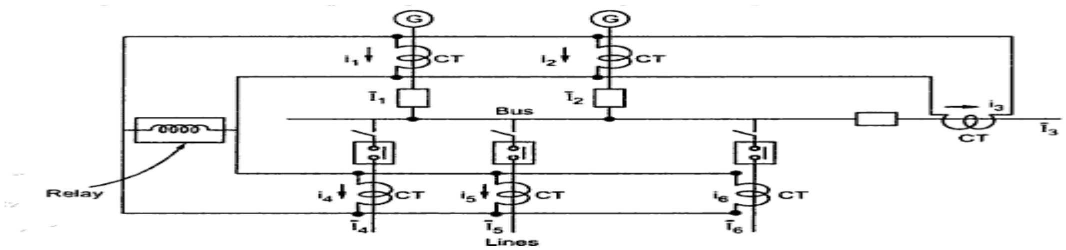
Metal supporting framework known as fault bus is earthed through a CT. When the fault is there, a contact between conductor and earth results. This drives current through this CT. This energizes the frame leakage relay.

The CT energizing the check relay is mounted in neutral earth of the transformer. The contacts of check relay and frame leakage relay are in series.

Thus before tripping circuit gets energized both the relays must operate. Once both the relays operate due to earth fault, all the breakers will trip connecting the equipment to the busbar, due to check relay; accidental operation of single relay to trip the circuit gets avoided.

Circulating Current Protection of Bus bar

This is nothing but the differential scheme of the protection of bus bar . The circulating current principle states that under normal working conditions or external fault condition, sum of the currents entering the bus equals sum of the currents leaving the bus. Under any abnormal conditions in the protected zone i.e. short circuit or phase to phase faults, the current condition gets distributed and sensing this relay can be operated.



I1,I2....I6 are the current in the circuit connected to the bus bar. Under normal condition, ∑I=0.
i.e.

$$I_1 + I_2 + I_3 + I_4 + I_5 + I_6 = 0 (vector\ sum)$$

No current flows through the relay and hence remains inoperative. Under fault conductions,

$$I_1 + I_2 + I_3 + I_4 + I_5 + I_6 = I_f$$

Where I_f = *fault current = unbalanced current*

- Under normal conditions, currents in the secondary's of CT balance each other and no current flows through the relay. Thus relay is inoperative. Under any fault conditions, the fault current flows through relay coil to activate it.
- To obtain exact balance of currents, all current transformers must have same ratio. But in practice there exists a difference in the magnetic conditions of iron cored current transformers and false operation of the relay is possible, at the time of external faults. For large fault currents there is a possibility of saturation of the cores of current transformers. To overcome such difficulties, a special type of CT having no iron core is used. It is called linear coupler.

The linear coupler has a property that its secondary voltage is proportional to the primary current and the secondary winding of all the linear couplers are connected in series to the relay.

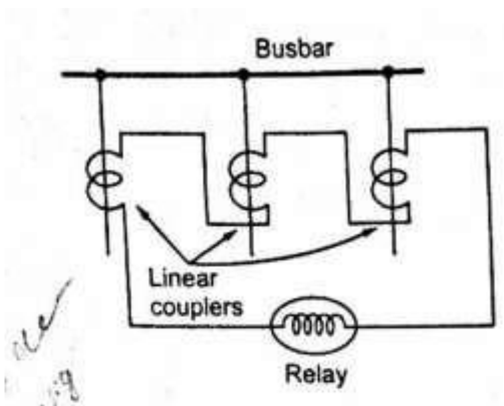


Fig. 3.10

The sum of the voltage outputs of linear couplers is equal to the vector sum of the voltages in the circuits connected to the busbars. Hence under normal condition overall voltages in the secondary circuits are zero and relay is inoperative. Under fault conditions, there is resultant voltage in the secondary and relay operates.

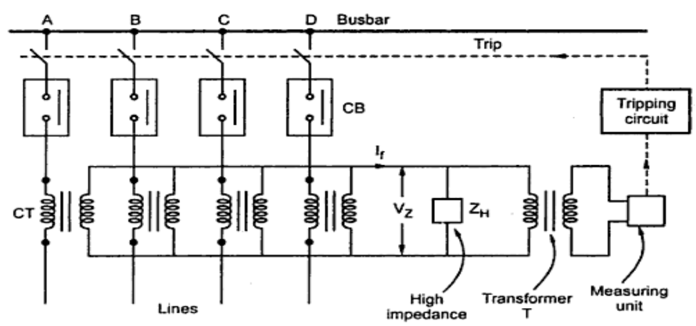
A high impedance relay can differentiate properly the internal and external faults compared to normal low impedance relay. Hence in circulating current protection, high impedance relay are used. A high

the relay operating coil to get high impedance relay. This resistance is called

3. **fferential protection. (Dec-2010)**

sensing a voltage drop across a high impedance, under fault conductions. Shown in FIG.

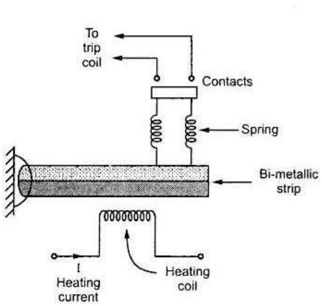
The basic principle remains same as differential scheme. Under normal conditions vector sum of the currents in the lines is zero. Hence I_f current flowing through high impedance Z_H is zero. And the relay is inoperative.



During the fault conditions, unbalanced currents exist. Such an out of balance current I_f flows through Z_H causing a high voltage drop V_Z across it. It is given to a transformer. A Measuring Unit Is connected to secondary of this transformer which measures this drop and trips the relay accordingly. Main advantage is that as voltage drop is sensed, saturation of core of one of the current transformer has no effect on the protection scheme.

Thermal relay:

It works on the principle of heating effect of an electric current in the relay coil. They sense the temperature rise produces by the current.



Under normal conditions, the heating due to current I increases beyond safe value producing very high I^2R losses and corresponding large heat. Thus the strip gets heated up & bends. Due to bending of strips, spring opens the contact and I is interrupted.

Impedance Relay

The impedance relay works corresponding to the ratio of voltage V and current I of the circuit to be protected. There are two elements in this relay, the one produces a torque proportional to current while the other produces a torque proportional to voltage. The torque produced by the current element is balanced against torque produced by the voltage element. Thus the current element produces operating torque, Pickup torque which can be said to be positive torque. The voltage element produces restraining torque, reset torque which can be said to be negative torque. So this relay is ***voltage restrained overcurrent relay***.

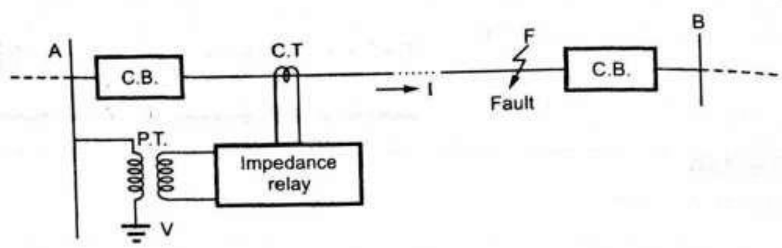


Fig. 4.1 Basic operation of impedance relay

- The current element is energized by current through C.T. while voltage element is energized by voltage through P.T. The section AB of the line is protected zone.
- Under normal conditions, the ratio of voltage V and current I is denoted As Z_L which is impedance of line. The relay is inoperative under this condition.
- When the fault occurs at point F in the protected zone then the voltage drops while current increases. Thus the ratio V/I i.e. the impedance reduces drastically. This is the impedance of line between the point at which relay is connected and the point F at which fault occurs. So when the impedance reduces than its predetermined value Z_L it trips and makes the circuit breaker open.

Torque Equations:

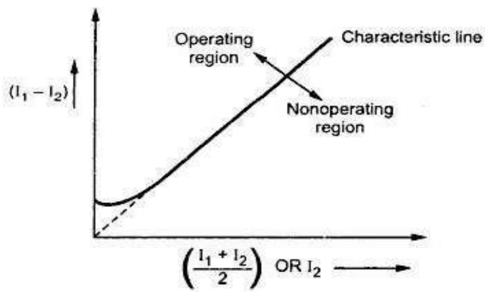
The torque element produced by current element is $\propto$ to I^2 and –ve torque produced by voltage element is $\propto$ to V^2

Let control spring effect produces a constant torque of $-K_3$ Hence the torque equation becomes,

$T=K_1I^2-K_2V^2-K_3$v

Operating Characteristics:

For a particular fault position, V/I is constant, and it changes when fault position changes. If fault is nearer to relay this ratio will be low and as fault position moves away from the relay the ratio becomes higher and higher. So it can be installed to operate for the section to be protected and once installed and adjusted for a particular section, it is in-operative beyond that section.

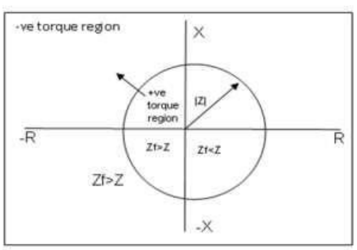


R-X Diagram:

Operating character of impedance relay is easily represented by a diagram called as R- X diagram. It's X-axis is rep. as "R" while y-axis as X-axis as

This plane is called R-X plan. The impedance "Z" can be

$$Z = R + jx$$



$$Z = \sqrt{R^2 + X^2}$$
$$Z^2 = R^2 + X^2$$

$X^2 + y^2 = Q^2$representing a circle's eqn.

$$tan\emptyset = \frac{X}{R} \quad \therefore \emptyset = tan^{-1}\left(\frac{X}{R}\right)$$

"Z" can be determined by numerical value of V&I, While "Φ" can be determined by angle b/w V&I.

case 1;

If 'I' is in-phase with "v",Z-vector lies along R-axis.

Case 2:

If "I" lags vector "V"then "X" is negative.

Case 3:

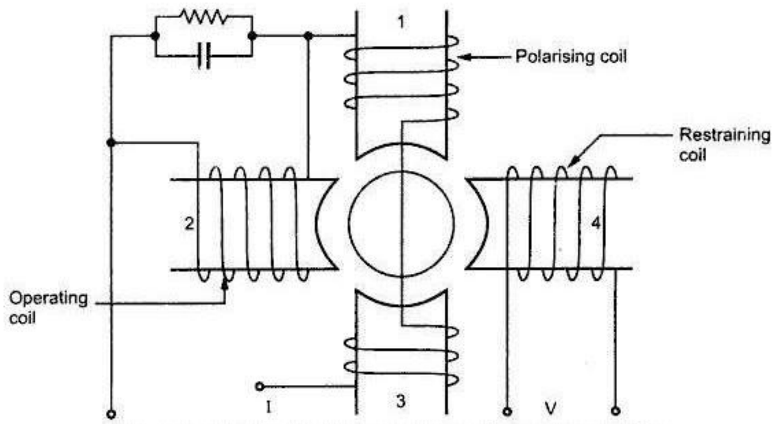
If "I" leads vector "V" then "X" is positive.

At any pt of value of "Z" less than the radius of the circle the relay operates. Hence the entire position inside the Ole is +ve torque region.

While the portion exterior to the circle is –ve torque region i.e –ve torque region. Where,
Zf=Impedance between relay and fault pt. Z=Set value for impedance=Radius of the circle, Zf<Z□Relay operates.
Zf>Z□Relay is in-operative.

In this relay the over current element develops a +ve torque and directional element produces –ve torque.

The directional element is designed that maximum torque angle is 90.



It has an operating coil, polarizing coil, and a restraining coil. The "I" flows from pole 1,through Iron Core stacks –ve to pole 3.The winding on pole 4 is fed from voltage v, The operating torque is produced by interacting fluxes, due to winding carrying current coils. While the restraining torque produced by coils (1, 2& 4).Hence operating torque is to square of the "I" & restraining torque is to product of "V &I".Desired max. Torque is obtained with the help of RC circuit.

Torque Equation:

The driving torque is proportional to the square of the current while the restraining torque is proportional to the product of V and I.

Hence the net torque neglecting the effect of spring is given by,

$$T = K_1 I^2 - K_2 VI \cos(\theta - \tau)$$

At the balance point net torque is zero,

$$\therefore 0 = K_1 I^2 - K_2 VI \cos(\theta - \tau)$$

$$\therefore K_1 I^2 = K_2 VI \cos(\theta - \tau)$$

$$\therefore K_1 = K_2 \frac{VI}{I^2} \cos(\theta - \tau)$$

$$\therefore K_1 = K_2 Z \cos(\theta - \tau)$$

Adding capacitor, the torque angle is adjusted as 90°,

$$\therefore K_1 = K_2 Z \cos(\theta - 90°)$$

$$\therefore K_1 = K_2 Z \sin\theta$$

$$\therefore Z \sin\theta = \frac{K_1}{K_2}$$

Consider an impedance triangle shown in the Fig. 4.10.

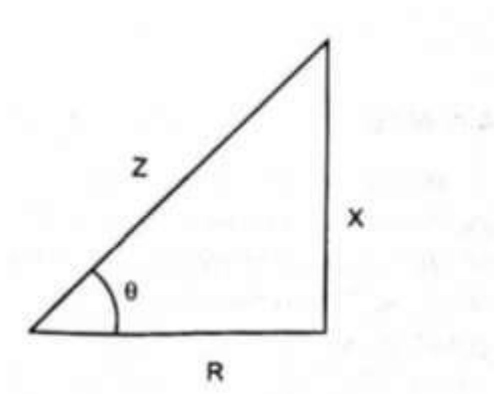


Fig. 4.10

$$Z \sin\theta = X = \text{reactance}$$

$$Z \cos\theta = R = \text{resistance}$$

$$\therefore X = \frac{K_1}{K_2} = \text{constant}$$

Thus the relay operates on the reactance only. The constant X means a straight lineparallel to X-axis on R-X diagram. For the operation of the relay, the reactance seen by the relay should be smaller than the reactance for which the relay is designed

Operating Characteristics

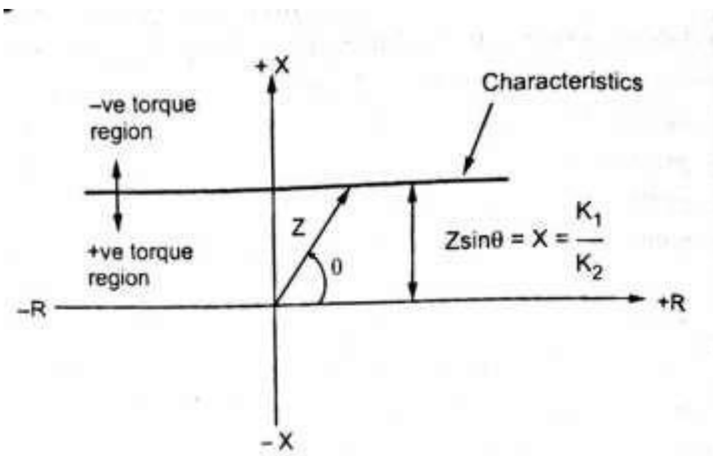


Fig. 4.11 Operating characteristics of reactance relay

The relay will operate for all the impedances whose heads lie below the operating characteristics, whether below or above the R-axis.

Disadvantages

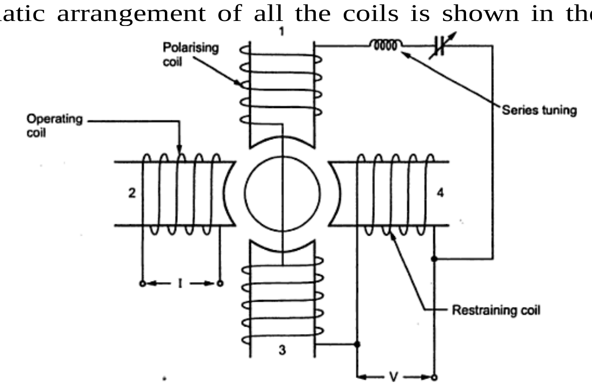
- This relay as can be seen from the characteristics is a ***non- directionalrelay***
- This will not be able discriminate when used on transmission line, whether the fault has taken place in the section where relay is located or it has taken place in the adjoining section.
- The reactance relay with directional feature called ***mho relay*** or ***admittance relay***

MHO Relay (or) ADMITANCE RELAY:

The reactance relay with directional feature is called a MHO relay. It is inherently a direction relay as it detects the fault only in forward direction. It works on the measurement of admittance Y. It is also called angle impedance relay.

CONSTRUCTION

This relay also uses an induction cup type structure. It also has an operating coil, polarizing coil and restraining coil. The schematic arrangement of all the coils is shown in the Fig. 4.12.In this relay the operating torque is



obtained by V and I element while the restraining torque is obtained by a voltage element. Thus an admittance relay is a voltage restrained directional relay.

- The operating torque is produced by the interaction of the fluxes due to the windings carried by the poles 1, 2 and 3. While the restraining torque is produced by the interaction of the fluxes due to the windings carried by the poles 1, 3 and 4.
- Thus the restraining torque is proportional to the square of the voltage (V^2) while the operating torque is proportional to the product of voltage and current (VI). The torque angle is adjusted using series tuning circuit.

Torque Equation:

The operating torque is proportional to VI while restraining torque is proportional to V^2. Hence net torque is given by,

$$T = K_1 \; I \cos(\theta - \tau) - K_2 V^2 - K$$

Operating Characteristics

As seen from the torque equation, the characteristics of *this* relay is a circle passing through origin with diameter as K_1/K_2

$= Z_r$ = *ohmic setting of relay* = *diameter*The *circle is* shown in the Fig. 4.13.

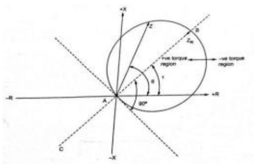


Fig. 4.13 Operating characteristics of mho relay

The relay operates when the impedance seen by the relay falls within this circle Consider two lines AB and AC with mho relay located at the point A. The relay will operate for the faults occurring in the section AB only and not for the faults occurring in the section AC. This shows that this relay is inherently directional without any additional directional unit required.

The angle τ can be adjusted to be 45°, 60°, 75° and so on. This angle is maximum torque angle. The setting of 45° is used for high voltage (33 or 11 kV) distribution lines, the setting of 60° is used for 66 or 132 kV lines while the setting of 75° is used for 275 and 400 kV lines.

Classification of Distance Relays

we have seen that the distance relay basically measures ohmic values and operates hen the impedance is below the preset, value The distance relays are classified as,

1. **Definite distance relays:** These can be of impedance type, reactance type or mho type. This operates instantaneously for the faults up to certain predetermined distance from the relay.
2. **Distancetimerelays:** These can be also of impedance type, reactance type or mho type, in these relays the time of operation, is proportional to the distance of the fault from the point where relay is installed. The fault nearer to the relay operates it faster than for the faults further away from the relay.

1. Definite Distance Type Impedance Relay

The construction of this relay can be balanced beam type or induction disc type. The balanced beam type construction of definite distance impedance relay is shown in the Fig. 4.15.

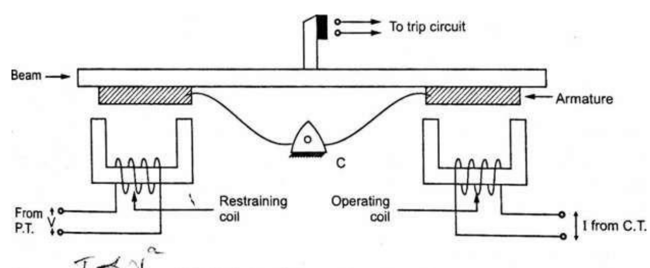


Fig. 4.15 Definite distance type impedance relay

It consists of a balanced beam pivoted at the central point G. The beam carries the armatures of the two electromagnets. The two electromagnets are energized by a current from C.T, and voltage from P.T., which are located in the circuit to be protected. The voltage coil acts as restraining coil while the current coil acts as operating coil. The beam also carries the moving contacts which can bridge the two fixed contacts of a trip circuit when the relay operates.

The torque produced by voltage coil is proportional to square of the voltage (K_1V^2) while the torque produced by current coil is proportional to the square of the current ($K_2 I^2$). Under normal operating conditions, the torque produced by voltage coil is more than the torque produced by the current coil. Thus restraining torque is more than the operating torque and hence the relay is inoperative. On the occurrence of any fault, the voltage of system decreases and current increases. Thusthe ratio V/I which is impedance also decreases. It falls below its preset value. The torque produced by current coil becomes greater than the torque produced by the voltage coil. Hence beam experiences a pull on the current coil side. As the beam tilts, the moving contacts of beam bridges the fixed contacts of the trip circuit. This operates the trip circuit and opens the circuit breaker.

Torque Equation:

The torque by voltage coil is proportional to V^2 while that by current coil is I^2.

The relay will operate when torque produced by voltage coil is less than that produced by current coil. So we can write,

$$K_1V^2 < K_2I^2 \qquad \text{..... relay operates}$$

Where K_1, K_2 are constants

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

$$\therefore \frac{V}{I} < \sqrt{\frac{K_2}{K_1}}$$

$$\therefore Z < \sqrt{\frac{K_2}{K_1}}$$

So for impedance value less than $\sqrt{\frac{K_2}{K_1}}$, the relay operate.

The constants K_1 and K_2 are dependent on the ampere turns of the two electromagnets. By providing tappings on the coils K_1 and K_2 can be changed and hence any preset value for the impedance can be adjusted as per the requirement.

Characteristics

The Fig. 4.16 shows the characteristics of the definite distance type impedance relay. The Y-axis represents time for *operation* while the X-axis represents distance which is measured intermso*f impedance between* fault position and the *point* where relay installed.

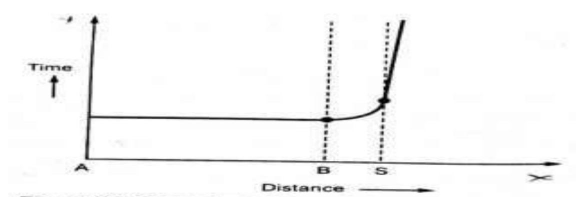


Fig. 4.16 Characteristics of definite distance impedance relay

For the entire length of the line, the time of operation remains constant, irrespective of distance. But if fault occurs in the section of line which is not protected, the operating time becomes suddenly infinite as shown in the figure. Towards end of the protected zone, the curve rises gradually

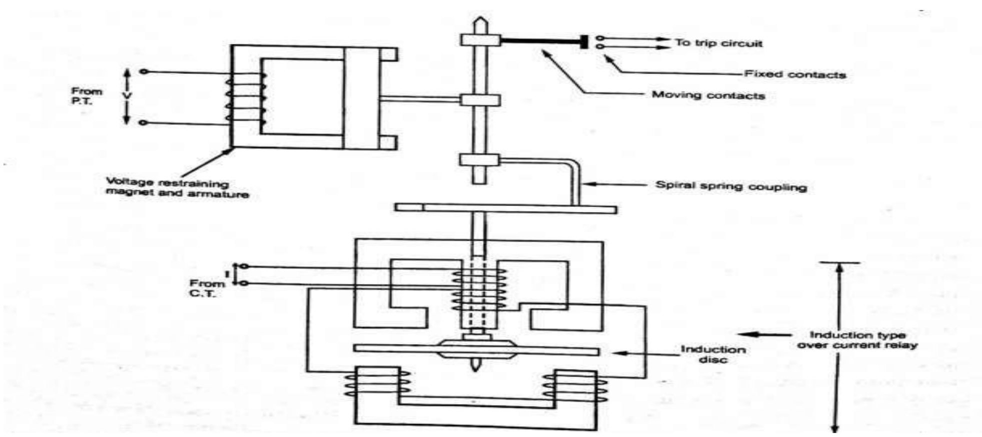
Its advantages are,

- Superior to the time graded over current relay
- Number of feeders in series which can be protected is unlimited as the relay time is constant

2. Distance Time Impedance Relay

This relay adjusts automatically, its time of operation corresponding to the distance of the fault from the relay

Operating time ∝ Z∝ distance



It consists of an induction type over current relay unit which is a current driven element The spindle which is carrying the disc of the element is connected to a second spindle with the help of spiral spring coupling) this second spindle carries moving contacts which is nothing but a bridging piece which can bridge the trip contacts when relay operates

Operation:

- Under normal conditions, the force exerted by voltage restraining magnet is more than that produced by an overcurrent induction element. Thus the trip contacts remain open and the relay is inoperative
- When the fault occurs, the induction disc starts rotating. The speed of the disc is proportional to the operating current
- *As* the disc rotates, spiral spring is wound. This exerts a force on armature so as to pull it away from the voltage restrained magnet. The disc continues to rotate till the tension of the spring is sufficient to overcome the restraining force produced by voltage restraining magnet on the armature. Immediately the moving contacts bridge the fixed contacts of tripping circuit. This opens the circuit breaker to isolate the faulty section.

Time of operation of relay $\propto \frac{V}{I} \propto Z \propto distance$

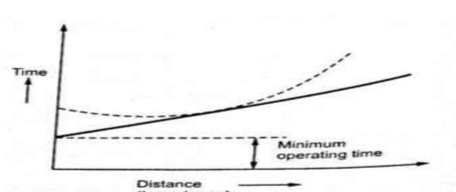


Fig. 4.18 Time-distance characteristics of distance time impedance relay

Applications and Advantages of Distance Relays

The various advantages of the distance relays are.

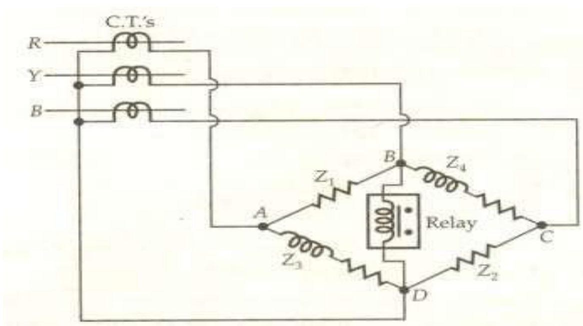
- Gives faster operation
- Simpler to co-ordinate

- Less effect of fault levels and fault current magnitudes
- Permits high line loading.
- With the need at readjustments, permanent settings can be done.

Thus the distance relays are used for providing the primary i.e. main protection and backup protection for a.c. transmission and distribution lines against the following faults,

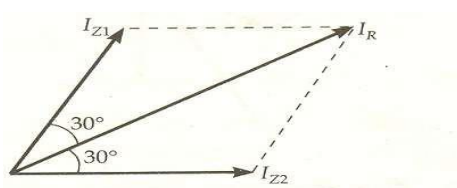
- Three phase faults
- Phase to phase faults
- Phase to earth faults.

A negative sequence relay provides protection to generators and motors against unbalanced loading that may result from phase to phase fault. **Fig** shows the phase imbalance protective equipment. The equipment consist of network energized from three current transformer and a single pole relay having an inverse time characteristic connected across the network. The network consist of four impedances Z_1,Z_2,Z_3,Z_4 of equal magnitude connected in a bridge formation. Z_1 and Z_2 are non inductive resistances while Z_3 and Z_4 are composed of both resistance and reactance.The values of Z_2 and Z_4 are also adjusted that the current flowing in these lag behind those inthe impedances Z_1 and Z_2 by 60°.the relay is assumed to have a negligible impedance.



Current from R phase divide in to two equal components I_{Z1} and I_{Z3} at A,I_{Z1} being ahead of I_{Z3} by 60°from **vector diagram**.

$I_{Z1}=I_{Z3}=\frac{IR}{\sqrt{3}}$



Similarly,the current from phase B divide in two equal components I_{Z2} and I_{Z4} each equal to $\frac{IB}{\sqrt{3}}$ and I_{Z2} leadings I_{Z4} by 60°.

∴The current entering the relay at point B=$I_{Z1}+I_{Z4}+I_y$

Let us now study the operation during the flow of +ve and –ve zero sequence currents.

Flow of +ve sequence currents.

Figshows –ve sequence current I_R,I_Y,I_B.since the current through the relay is$I_{Z1}+I_{Z4}+I_y=0$

$I_{Z1}+I_{Z4}=-I_y$

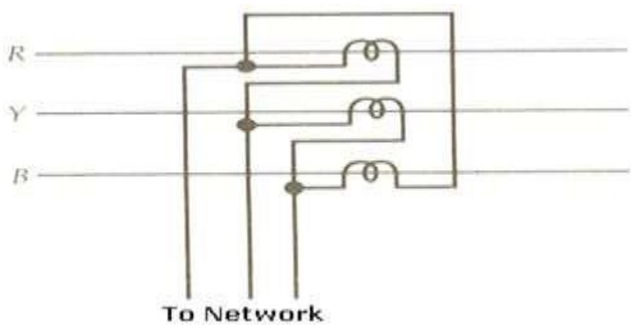
∴the relay remains inoperative.

Flow of -ve sequence currents.

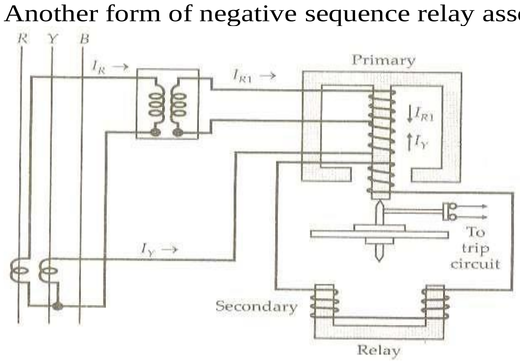
The –ve sequence currents in the 3 phases. resolving I_R and I_B in to their components I_{Z1},I_{Z3} and I_{Z2},I_{Z4},we find that the act current flowing in the relay=I_Y since I_{Z4} cancels out I_{Z4}.the relay is operate under the influence of I_Y. A low setting value well below the normal full-load rating of the machine is provided since comparatively small values of unbalance current produce a great danger.

Flow of zero sequence currents.

It is observed that I_{Z1}+I_{Z2}=I_Y, so that a total current of twice the zero sequence current would flow through the relay and would therefore cause its operation. To make the relay inoperative under the influence of zero sequence current can flow in the network circuit. The delta connection of CTs shown fig.

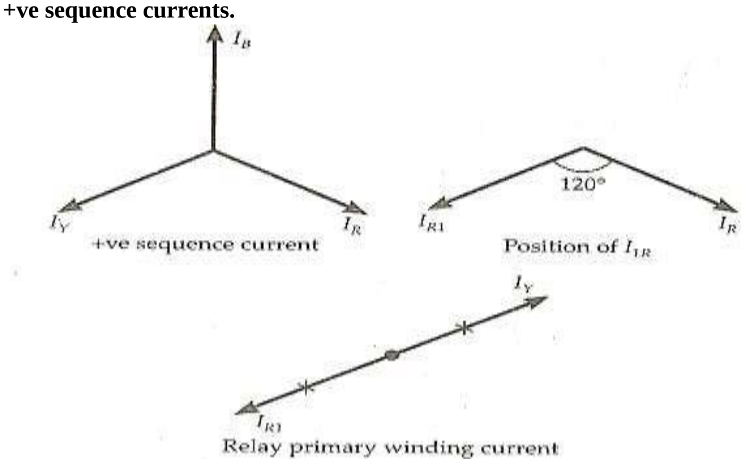


Another form of negative sequence relay associated with equipment by metropolitan Vickers fig



The primary winding is provided with a centre tap, one half of the winding is energized direct from the Y phase while the other half is energized from R phase through an auxiliary transformer. The auxiliary transformer is provided with an air gap in its magnetic circuits and its possible to adjust the phase displacement between $I_R$and I_{R1} to any angle (phase shift of 180°) the adjustment is made that I_{R1} lag behind I_R by 120° the relay primary current is, the phaser difference to $I_{R1}$and I_Y

Operation under the Flow of +ve sequence currents.

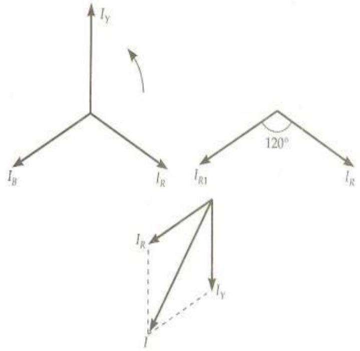


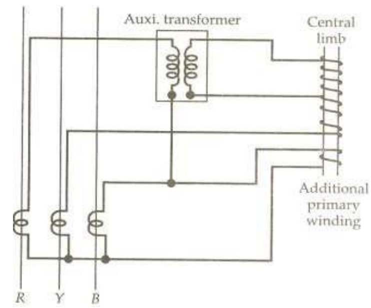
Itis clear from the vector diagram, the relay primary winding current is zero. thus the relay does not respond to the flow of +ve sequence current.

Operation under the Flow of -ve sequence currents.

Thevector diagram theflow of current Iin the primary winding and thus the relay will operate.

This relay can made response to the flow of zero sequence currents as well by providing another winding on the central limb of the upper electroma gnet, connected in the residual circuit of three line CTs shown fig below.





<u>Unit-IV</u>

Static Relays

It is seen that the conventional electromagnetic relays use moving parts such as armature in their control circuitry. The relays which do not use moving parts and use the solid state electronic components such as diodes, transistors etc are called **static relays.** The circuits such as comparators, level detectors, zero crossing detectors etc, designed using electronic components are used in the static relays for measurement and comparison of electrical quantities. The static relay is designed in such a way that whenever a quantity under consideration exceeds a particular level, the static circuit produces a response without any moving parts such as armature. This response is then manipulated and given to a tripping circuit which may be electronic or electromagnetic. **Thus static relay response circuit does not have moving parts andmadeup**of **electroniccomponentsbutitstrippingcircuitmaybe**electronic **or electromagnetic.** Let us study the basic elements of a static relay.

The relays which do not use moving parts and use the solid state electronic components such as diodes, transistors etc are called static relays.

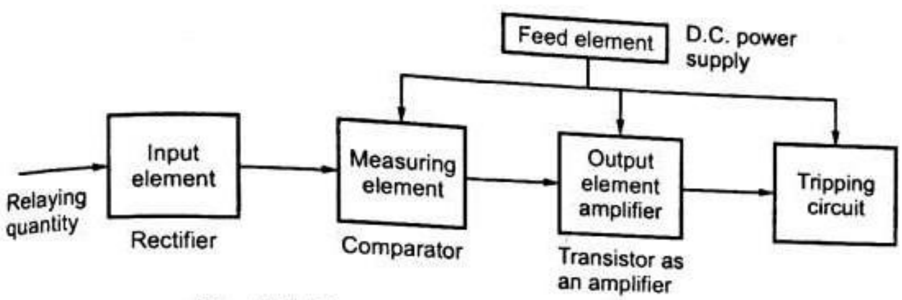


Fig. 8.7 Block diagram of a static relay

Input element: The relaying quantity can be the output of C.T. or P.T. or it may be the output of a transducer or it may be combination of various signals. Thus an electronic circuit such as rectifier is required as an input element to get the input signal in a convenient form before applying it to a measuring element. Some mixing circuits such as op-amp adder may also be required as an input element.

Measuring Element: This is the heart of the static relay. It compares the output of an input element with a set value and decides the signal to be applied to the output element which ultimately drives the tripping circuit. Thus measuring element is a deciding signal generator.

Measuring element can be classified as,

- ♦ Single input device
- ♦ Two input device
- ♦ Multi-input device

Single input device

The single input devices, depending on the protection and control schemes are further classified as,

a) Noncritical Repeat Function (All or Nothing Relay)

As the name suggests, these devices are completely unenergized or energized much higher than the marginal condition required, to produce very fast response. It can be represented as shown in the Fig. 8.8. The input R is either zero or too higher than the marginal operating level. Such devices are instantaneous response time less than 20 ms.The switching power gain associated with thern generally 10^3. Such devices have multiple output contacts.

The main functions of such devices in the protection are,

- To produce final tripping signal to the circuit breaker.
- To produce signals to perform supplementary functions such as **alarming** inter tripping etc.
- To act as intermediate switching stages in a complex protection scheme

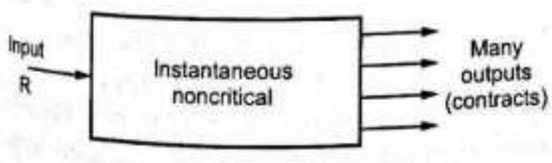


Fig. 8.8 Noncritical repeat function

b) Critical Measuring Function :

This device is a sort of on-off controller. It activates when the input signal reaches to some critical level decided by the protection scheme. Such a device is shown in the Fig. 8.9.

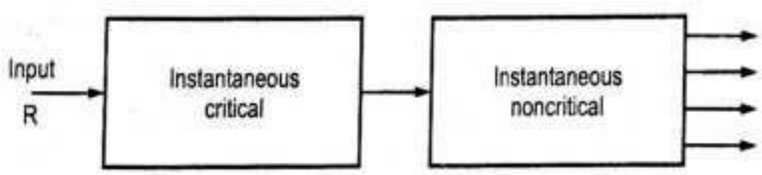


Fig. 8.9 Instantaneous critical function

Thus when input R is greater than some critical value P, it operates. While for reset, input R must be less than kP ($k < 1$).

It has only one output and switching gain need not be high. The output of such device then can be connected to instantaneous noncritical to obtain multiple outputs.

The various requirements of critical function devices are,

- High accuracy.
- Long term consistency.
- Fast and reliable operation.
- High controllable reset ratio.

c. Definite or Fixed Time Function:

This is nothing but a delay function element. It produces a define time delay between its input and the output. The delay may be provided between the application of input and activation of output or between removal of input and resetting of output.

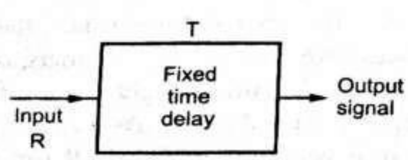


Fig. 8.10 Definite time function

d.Input Dependent Time Function:

This function depends on the input characteristics and decides the timeaccordingly.

The common form of input dependent time function characteristics is

$t = f(R^n)$ where R = input, n = negative

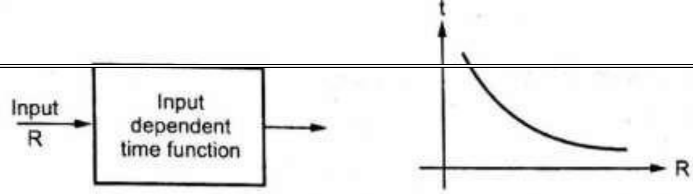


Fig. 8.11 Input dependent time function

The function and its characteristics are shown in the Fig. 8.11.

As n is negative, as the input increases the operating time decreases. So operating time is inversely proportional to some power of the input. The examples of such relays are inverse definite minimum time lag overcurrent and earth fault relays.

The two input devices are very common such as comparators, level detectors etc. while multiple input devices are extension of two input devices to extend the range of characteristics.

OutputElement: The signals obtained from the measuring element are required to be amplified before applying to the tripping circuit. Thus output element is an amplifier. **Feed element:** The feed element provides the d.c. voltage required by the various elements.

Comparison of Static and Electromagnetic Relays

The conventional electromagnetic relays use the moving parts such as an armaturedisc etc. Thus they are bulky in size. These relays are robust and highly reliable. Theseare subjected to differential forces under fault conditions and hence required to havedelicate setting of small contact gaps, special bearing arrangements, clutch assembliesetc. Thus there are lot of manufacturing difficulties and problems related**to**mechanical stability associated with electromagnetic relays. The current and**potential**transformers are subjected to high burdens in case of electromagnetic relays.

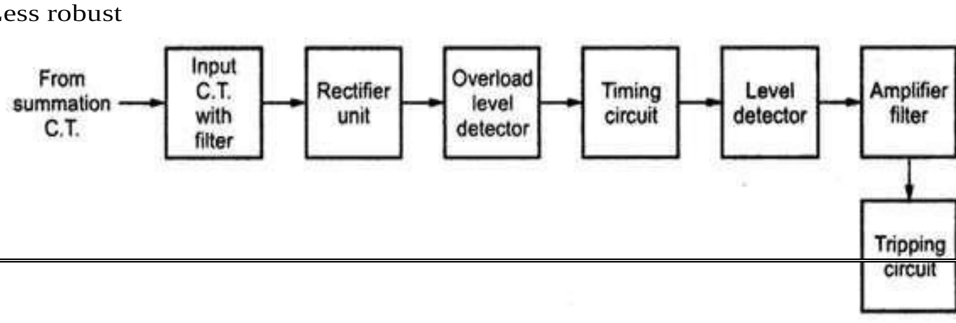
The static relays are commonly using the transistor circuits and called transistor relays.This is because transistor can be used as an amplifying device as well as a switching device.Hence any functional characteristics as per the requirement can be obtained by the staticrelays. The transistor circuits can perform functions like summation, integration, comparisonetc.

Advantages of Static Relays (Nov/Dec 2017)

- The moving parts are absent
- The burden on current transformers gets considerably reduced
- The power consumption is very low
- The response is very quick
- Minimum maintenance is required
- No bearing friction or contact troubles exist
- Resetting time can be reduced and overshoots can be reduced due to absence of mechanical inertia and thermal storage
- Sensitivity is high
- Testing and servicing is simplified.

Limitations of Static Relays

- Electronic components are temperature dependent
- Reliability is unpredictable
- low short timeoverload capacity
- Additional d.c. supply is required
- Susceptible to the voltage fluctuations and transients
- Less robust



- When the voltage across the timing capacitor reaches to a critical value then it triggers the level detector.
- The charging of capacitor in a timing circuit achieved by a voltage derived from CT current. This voltage is obtained across a nonlinear resistor by passing rectified current through it.
- The proper selection of nonlinear resistor and RC timing circuit allows to obtain desired shape of time current characteristics of the static relay.
- The current at which the level detector trips is called **threshold current**

Thus for an overcurrent relay,

When $I_{in} < I_{threshold}$ level detector does not trip When $I_{in} \geq I_{threshold}$ level detector trips

Static Time-Current Characteristics

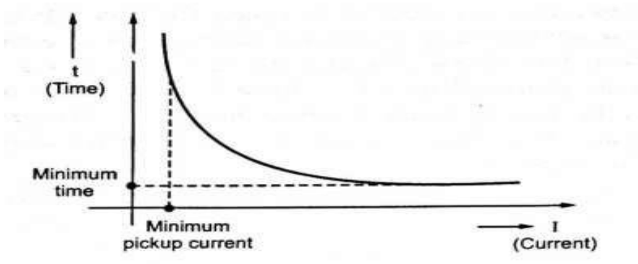


Fig. 8.13 Inverse time-current characteristics

t = Time of operation in seconds K = Design constant of relay TMS = Time multiplier setting
I = Tap current multiplier

I_p = Multiple of tap current at which pickup occurs

:x of relay

The shape of the characteristics and degree of inverse nature is standardized. According to British standards,

For standard inverse characteristics (IDMT), Kx(TMS) = 0.14, n = 0.02 and I_p = 1 A

For standard very inverse characteristics,

Kx(TMS) = 13.5, n = 1 and I_p = 1 A

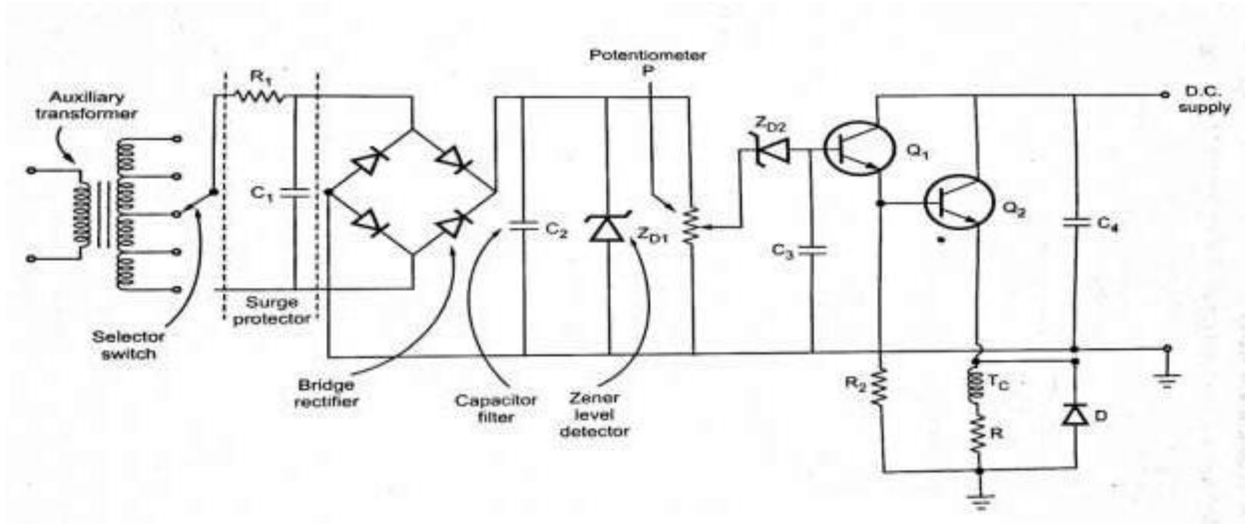
or extremely inverse characteristics, Kx(TMS) = 80, n = 2 and I_p =1 A

It can be seen that the curve is asymptotic about both the axes. Due to this, there exists minimum pickup current below which relay cannot be operated. While there exists minimum definite time of operation below which it cannot be reduced.

Static Instantaneous Over-current Relay(Nov/Dec 2017)(Apr/May 2018)

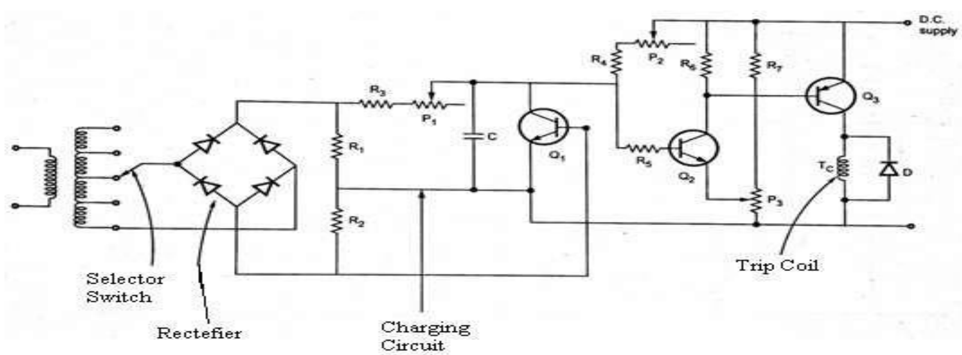
- Auxiliary transformer gives output voltage proportional to the fault current.
- Main circuit is protected from the voltage surges by using R1 C1 circuit at the input. This is surge protector.
- Output voltage from the transformer is then rectified and smoothened using capacitor filter C_2 Zener limits the rectified voltage to a safe value though the fault current is very high.
- When the rectified voltage is greater than voltage of Z_{D2}, the transistor Q1 conducts. This increases drop across R2 due to which Q2 conducts.

- This energizes the trip coil Tc of the relay..

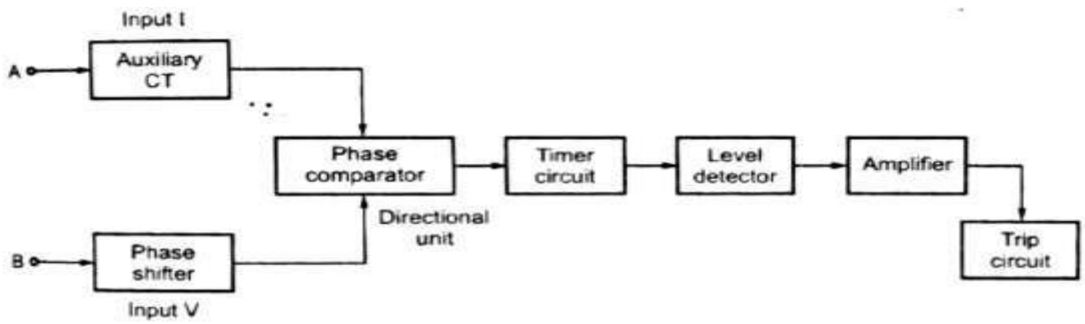


Inverse Time-Current Relay

- Under normal conditions, Q1 gets biasing from d c supply
- Hence capacitor C is short circuited.
- When fault current exceeds a pick up value set by thepotentiometer P2 and selector switch then the transistor Q1 becomes OFF.
- The capacitor C starts charging through R.
- When voltage across the capacitor reaches to a determined level set by the potentiometer P3 then the transistor Q3 conducts.
- This energizes the trip coil and the circuit breaker opens.



Directional Static Over-current Relay



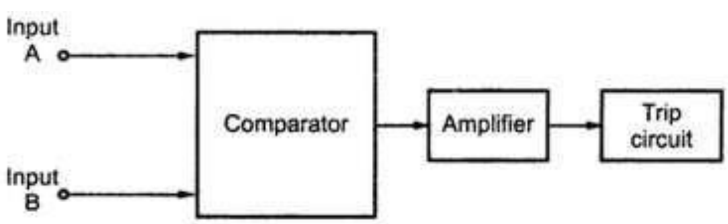
- The directional relay is nothing but a directional power relay which operates whenthe power in the circuit flows in a particular direction.
- The input A is proportional to the system current supplied to a directional unit through auxiliary transformer.
- The input B is proportional to the system voltage, supplied to a directional unit through phase shifter.
- Let this angle is □ while the relay characteristics angle is θ. Let I_p be the current setting magnitude. Then the relay operates when,

$$I_p \leq I\cos(\square - \theta)$$

- The phase comparator compares the phase angle between the two inputs.
- The output of the phase comparator is applied to a level detector
- The static directional overcurrent relays are very sensitive

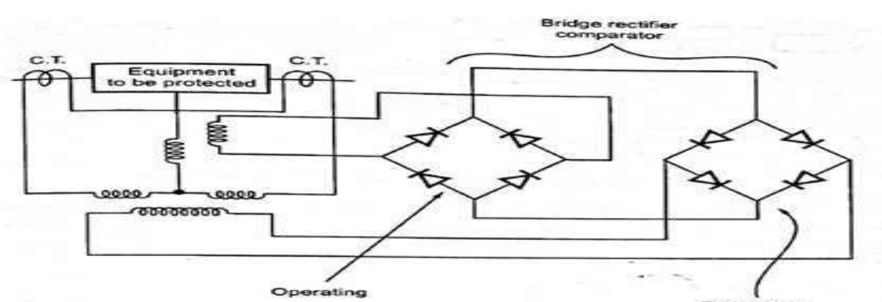
Static Differential Relay

- A differential relay is the relay which operates when the phasor difference of two or more similar electrical quantities exceed a predetermined value.



Static differential relay

- In normal conditions, the two quantities balance each other and the comparator output is zero and the relay is inoperative.
- For any internal fault conditions, the comparator senses the phase difference between the two quantities and produces the output. This is amplified and given to the trip circuit which operates the relay.
- This scheme is used for protection of the generators and transformers against any type of internal fault.



Static differential relay scheme

Let n_0 and n_r be the number of turns of operating and restraining coils respectively. Then the relay operates when,

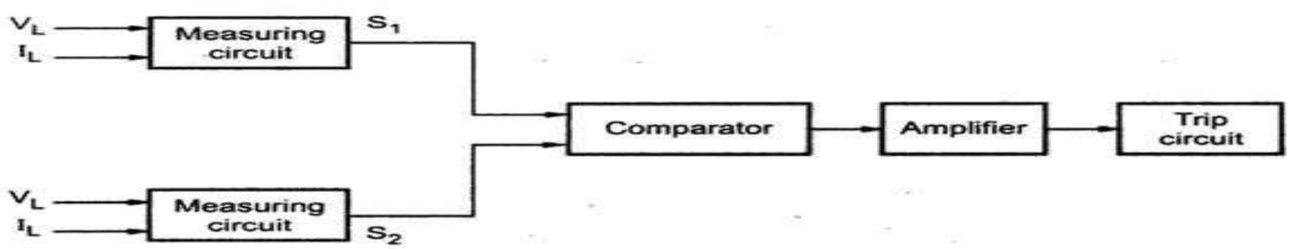
No.	Amplitude comparator		Phase comparator		Distance relay scheme
	Operating	Restraining	Operating	Restraining	
1	$\left\lvert I_L + \frac{V_L}{Z_R} \right\rvert$	$\left\lvert I_L - \frac{V_L}{Z_R} \right\rvert$	$I_L Z_R$	V_L	Directional
2	$\lvert I_L \rvert$	$\frac{\lvert V_L \rvert}{\lvert Z_R \rvert}$	$I_L Z_R - V_L$	$I_L Z_R + V_L$	Impedance
3	$\left\lvert I_L - \frac{V_L}{X_R} \right\rvert$	$\frac{\lvert V_L \rvert}{\lvert X_R \rvert}$	$I_L Z_R - V_L \sin\theta$	$I_L Z_R$	Reactance
4	$\lvert I_L \rvert$	$\left\lvert I_L - \frac{V_L}{Z_R} \right\rvert$	$I_L Z_R - V_L$	V_L	Mho

$$K_1 n_0 I_0 > K_2 n_r I_r + K'$$

Where k_1 and k_2 are design constants while K' is the spring control torque.

Static Distance Relays

- Operation is dependent on the ratio of the voltage and current, which is expressed in terms of impedance.
- The relay operates when the ratio V /I i.e. impedance is less than a predetermined value.



Basic static distance relay scheme

The line voltage V_L and the line current I_L are given as the inputs for the two measuring circuits. The circuits produce the outputs S_1 and S_2 depending upon their characteristics. Thus

$$S_1 = K_1 V_L + K_2 I_L$$
$$S_2 = K_3 V_L + K_4 I_L$$

- Where K1, K2, K3 and K4 are to be selected according to the requirement of the characteristics.

The various type of derived voltages S1 and S2 for amplitude and phase comparators to obtain particular characteristics are given in below table

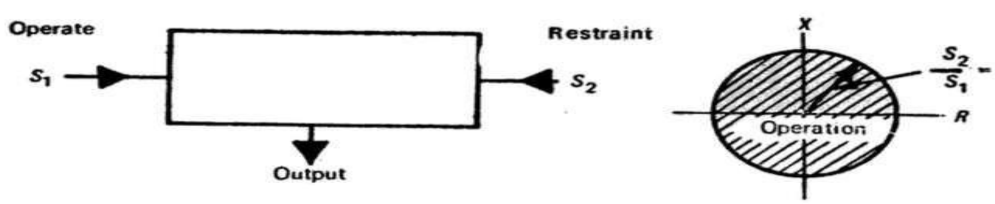
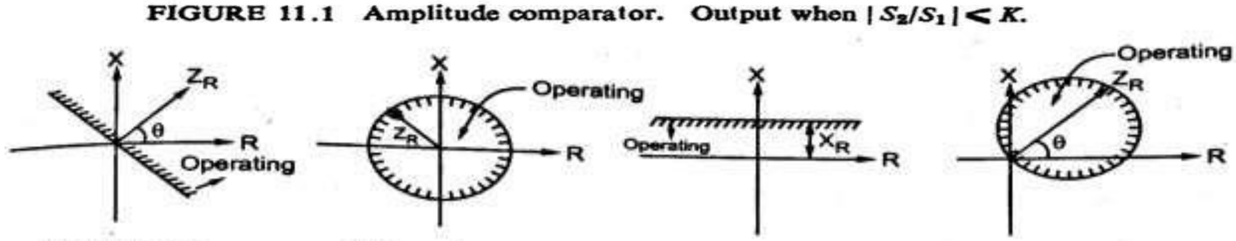


FIGURE 11.1 Amplitude comparator. Output when $\lvert S_2/S_1 \rvert < K$.



(a) Directional (b) Impedance (c) Reactance (d) Mho

Amplitude Comparators:

If two input signals are S_1 and S_2 the amplitude comparator gives positive output only if $S_2/S_1<K$.
S_1=Operating Quantity
S_2=Restraining Quantity

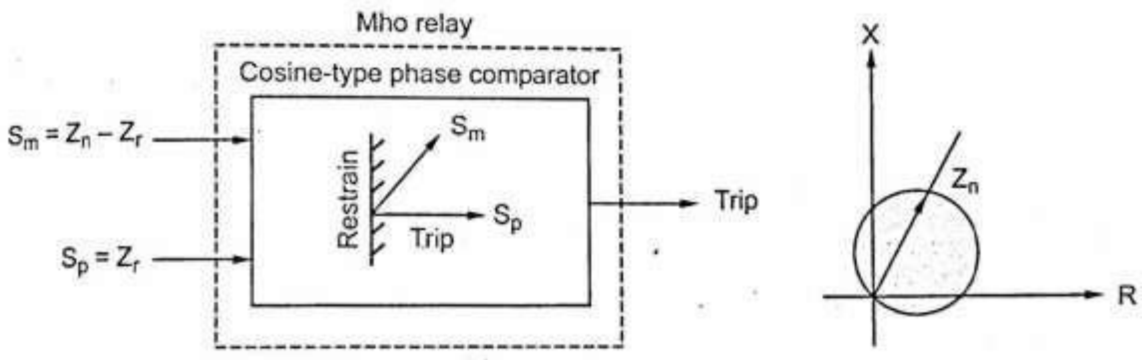
Types:

i). Integrating comparator **ii).** Instantaneous comparator **iii).** Sampling comparator

Thus, the phasor (Z_n-Z_r) and Z_r obey the law of cosine-type phase comparison. Therefore, if (Z_n-Z_r) and Z_r are used as inputs to a cosine comparator, the resulting entity would behave exactly like a mho relay

However, there is a practical problem here. The problem is that the electronic circuit of the comparator accepts only voltage signals at its input. Therefore, need to convert these two impedance phasor into voltage signals.

- If multiply both (Z_n -***Z_r)***and***Z_r*** by the current at the relay location I_r, then resultant will be (I_rZ_n - I_rZ_j) and***Z_rI_r.*** Note that***Z_rI_r*** is nothing but the voltage at the relay location V_r.
- The two modified signals therefore are:(I_rZ_n - V_r) and V_r
- The two voltage signals ***(IfZn - V_r)*** and V_r, fed to a cosine-type comparator for synthesis of a mho relay with a setting of Zn is depicted in Figure 4.22.



$$(Z_n - Z_r)I_r = Z_nI_r - V_r = S_m$$

$$Z_rI_r = V_r = S_p$$

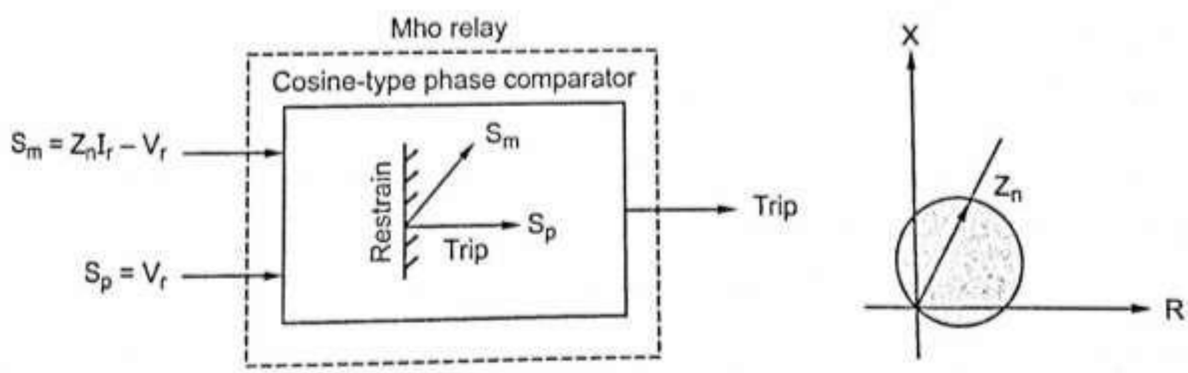


Fig. 4.22. Deriving signals for mho relay synthesis-cosine type phase comparator

At the relay location, the signals V_r and I_r are readily available. In order to form S_P and S_m inputs suitable for synthesis of mho relay, its needs to be mixed using suitable hardware to get the required signals. The circuit arrangement for mixing the relay voltage and current signals is shown in Figure 4.23.

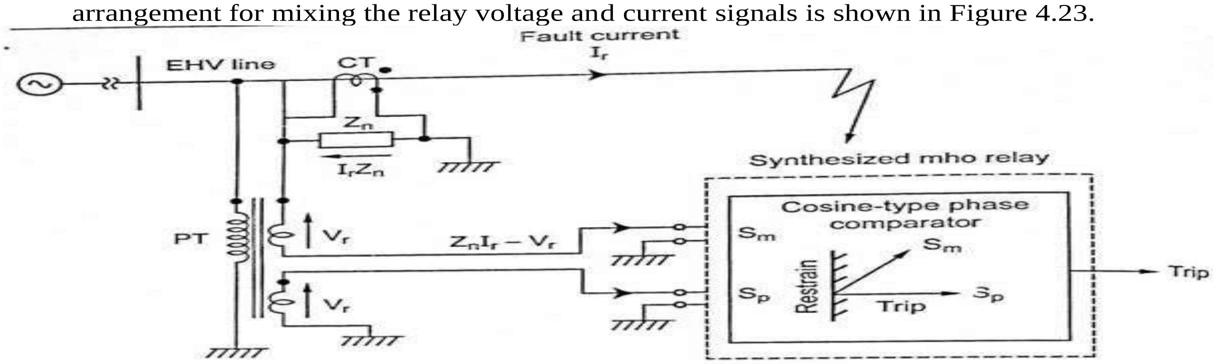


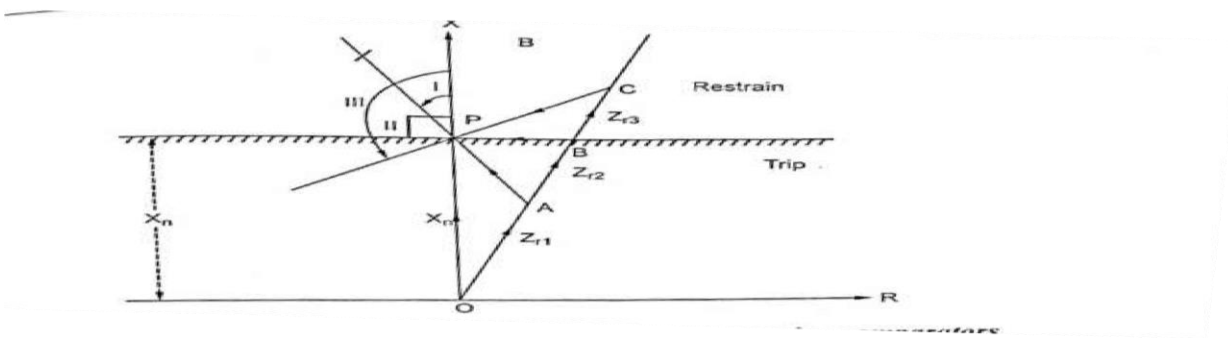
Fig. 4.23. Mho relay synthesis using cosine-type phase comparator- Arrangement for mixing the relay voltage and current signals

SYNTHESIS OF REACTANCE RELAY USING COSINE TYPE PHASE COMPARATOR

The synthesis of a reactance relay using a phase comparator is depicted in Figure 4.24. The reactance relay to be synthesized has a setting of jX_n. Thecharacteristic to be synthesized is thus a straight line parallel to the R-axis (abscissa), with an intercept of $|X_n|$ on the X-axis (ordinate).

Let the impedance of the relay be Z_{r1} which lies within the trip region at point A. Let construct the phasor (X_n - Z_{r1}) represented by line AP. (X_n - Z_{rl}) leads X_n by an angle which is definitely less than 90° is clearly depicted.

Now, as the impedance seen by the relay moves towards the boundary of the trip region, the angle between (X_n- Z_{r1}) and X_n approaches 90°. When the impedance lies on the boundary, the angle becomes exactly equal to 90°. For all points lying in the restraining region, the angle becomes greater than 90°.



$$OP = |X_n| = setting$$

$$OA = |Z_{r1}| \rightarrow Trip \qquad AP = |X_n - Z_{r1}|$$

$$OB = |Z_{r2}| \rightarrow Threshold \qquad BP = |X_n - Z_{r2}|$$

$$OC = |Z_{r3}| \rightarrow Restrain \qquad CP = |X_n - Z_{r3}|$$

$$Arg \frac{|X_n - Z_{r1}|}{|X_n|} = \angle OPA \angle I < 90° \qquad \rightarrow Trip$$

$$Arg \frac{|X_n - Z_{r2}|}{|X_n|} = \angle OPB \angle II = 90° \qquad \rightarrow Threshold$$

$$Arg \frac{|X_n - Z_{r3}|}{|X_n|} = \angle OPC \angle III > 90° \qquad \rightarrow Restrain$$

Trip law

$$If\ Arg \frac{|X_n - Z_r|}{|X_n|} < 90° \qquad ; then\ trip$$

Similar analysis is shown in fig 4.25, the impeadance of the relay lies to the left of the jX_nphasor, the angle between $(X_n - Z_{r1})$ and $X_n$is greater than -90°, as long as the impeadance falls within the trip region. It is exactly equal to 90° for impeadance lying on the boundary and is less than -90° for all impeadances lying in the restraining region to the left of the jXnphasor.

Note that $Z_{r1}I_r$ is nothing but the voltage at the relay location, i.e. V_r

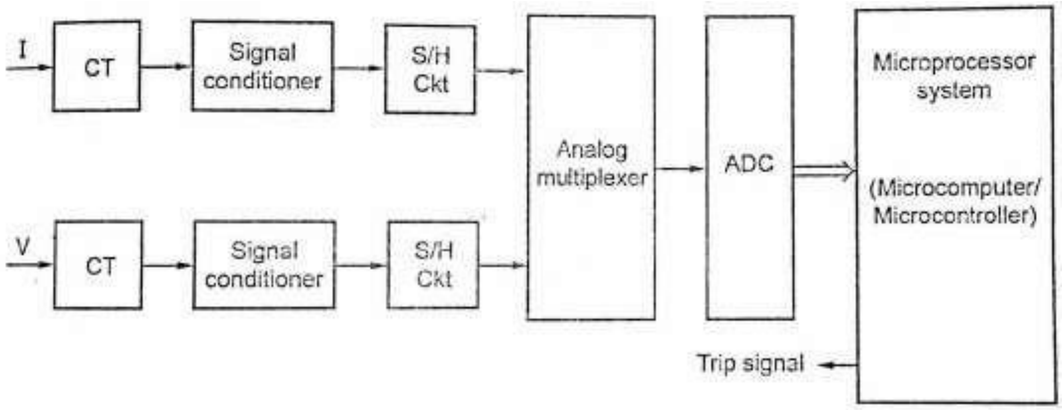


Fig. 4.61. Block diagram of a typical numerical distance relay

Unit-V

With neat diagram describe the Recovery rate theory energy balance theory of arc interruption in a circuit breaker.(Dec-14)

There are two main theories which explain the current interruptions of arc.

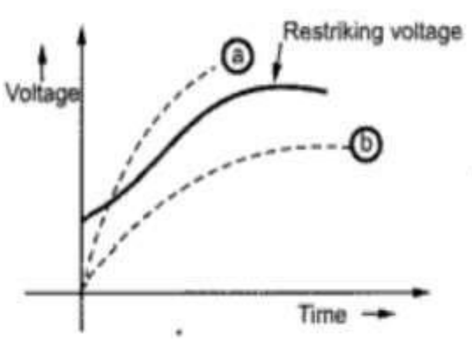
- slepias theory (or)Recovery rate theory
- Cassia’s theory (or)energy balance theory.

(a) SLEPIANS THEORY

- In this theory the restriping voltage play an important role in ARC extinction.
- After a every zero current, there will be a residual column of ionized gas.
- The rate at which the gap recovers its dielectric strength is compared to the rate at which the re-striking voltage rises.
- If dielectric strength builds up greater then Re-striking voltage , are does not prestrike.
- If dielectric strength is less, the arc will restrike. a)Di-electric strength

b) Re-striking voltage

c) di- electric strength



From graph

If di-electric strength of contact graph than the re-striking voltage the arc gets extinguished. Shows the value of re-striking voltage.

Di-electric strength of contact gaps are losses than re-striking voltage The arc retakes.
Limitations of this theory sleepiness)
It does not consider the energy relation in the arc extinction. It does not cover the arcing phase hence it is in-complete.

(b) **Carrier theory (or) energy balance theory.**

This theory suggests the restriping of arc (or0 interruption of arc both energy balance process.
If energy input to arc and continuously the arc re-strikes (or) it interrupted.

Following assumption are made in this theory.

As the arc strikes in cross section with its uniform temperature, the energy distribution is uniform. Temperature remains constant.
When the arc strikes cross section ally it will adjust to accommodate to fill the path of arc current. Power dissipation is proportional to cross-sectional area of the arc's.
Energy equations of this theory:

Where,

Q=energy content/length of arc in cm. E=volts/cm.
N=total power loss/cm.

Arc extinction can be obtained by building di-electric strength of the ARC rapidly at zero current.
This can be obtained by;

- **i)** Lengthening of the gaps.
- **ii)** by using Hydrogen gas b/w the contacts.
- **iii)** by blasting liquids into the contact space will affectingly reduce the Arc's.

Restriking voltage: It is the transient voltage appearing across the breaker contacts at the instant of arc being extinguished.

Recovery voltage: The power frequency rms voltage appearing across the breaker contacts after the arc is extinguished and transient oscillations die out iscalledrecoveryvoltage.

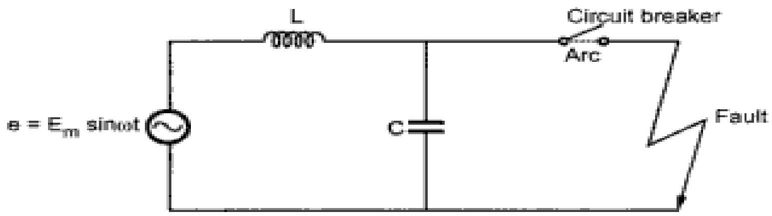
What is RRRV: It is the rate of rise of restriking voltage, expressed in volts per microsecond. It is closely associated with natural frequency of oscillation. Rate of rise of restriking voltage (RRRv) is the rate at which it is expresses in terms of volts/micro –seconds.
It represents the rate at which the transient recovery voltage.(TRV)is

$$RRRV = \frac{de}{dt} \text{ volt}/\mu\text{sec}$$

Derivation of restriking voltage;

Consider the circuit shown in the fig.

When current reaches zero at final are extinction a voltage ‘e’ is suddenly impressed across capacitor &therefore it flows across C.B contacts.

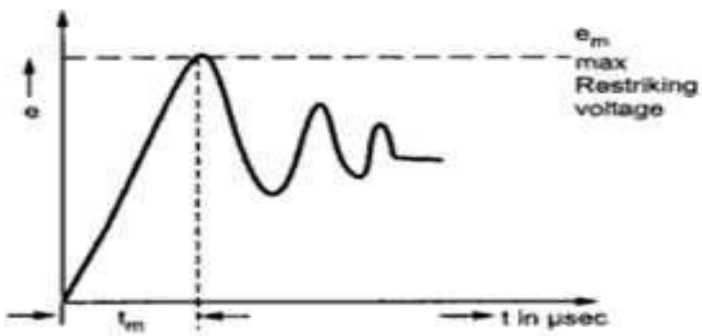


Due to opening of C.B, fault current “I” does not get in jested in capacitor & inductor

$$\therefore i = i_L + i_C$$

$$i = \int e\,dt + C\frac{de}{dt}$$

$$\frac{di}{dt} = \frac{e}{L} + C\frac{d^2e}{dt^2}$$



When, t=0 & correspondingly at I=0, &further e=E cosωt

I=will be’

$$i = \frac{E_m}{\omega L} sin\omega t$$

After opening of circuit breaker,

$$\frac{di}{dt} = \frac{E_m}{\omega L}\omega cos\omega t$$

$$= \frac{E_m}{L} cos\omega t \quad at\ t = 0$$

$$\frac{E_m}{L} cos\omega t = \frac{e}{L} + C\frac{d^2e}{dt^2}$$

This is standard equation and solution of this equation is

$$e = E_m[1 - cos(\frac{t}{\sqrt{LC}})]$$

Here ,

EM=peak value of Recovery voltage. t= time in seconds.

L=Inductance in Henry’s C= capacitance in farads.

e= restriping voltage in volts.

RRRV will be maximum, When its derivative $\frac{d^2e}{dt^2} = 0$

t

if “e” is to be maximum

$$[1-\cos(\frac{t}{\sqrt{LC}})]$$

$$\cos\left(\frac{t_m}{\sqrt{LC}}\right) = -1 \qquad where\ t = t_m$$

$$\frac{t_m}{\sqrt{LC}} = \pi$$

$\therefore$ Time at which maximum restriking voltage occurs is, $t_m = \pi\sqrt{LC}$ And peak value of restriking voltage, $e_m = 2E_m$

Where E_m is equal to active recovery voltage (i.e instantaneous value of recovery voltage at current zero).

Now

$$RRRV = \frac{de}{dt} = \frac{d}{dt}[E_m(\cos[\frac{t}{\sqrt{LC}}])]$$

$$RRRV = \frac{E_m}{\sqrt{LC}}\sin\frac{t}{\sqrt{LC}}$$

E_m

Peck Re-striking voltage is equal to,

$$e = Em(1 - \cos\pi) = 2\,Em$$

It is observed from eqn, that,

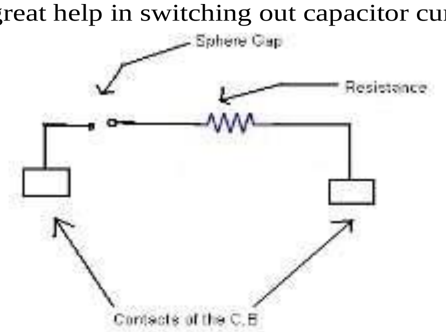
$$(RRRVMAX) = 2\pi Emfn$$

Maximum rate of rise of re-sticking voltage is proportional to the natural frequency of the circuit. Greater the fn, greater the rate of rise of T.R.V.

2. What is resistance switching? (Nov/Dec 2017)

To reduce Re-striking voltage, RRRV and severity of the transient oscillation, a resistance is connected across the contacts of the circuit breaker. This is known as resistance switching.

The resistances may be automatically switched in with the help of a sphere gap. Resistance switching is of great help in switching out capacitor current or low inductive current.



This process is mainly used in reducing or avoiding the restriking voltage. Equivalent analysis of the circuit is given by circuit analysis for resistance switching is given as.

Equivalent circuit:

Voltage equation is gn by,

$$L\frac{di}{dt} + \frac{1}{C}\int ic * dt = E \text{ and } i = I_C + i_r$$

Above equ becomes,

$$L\frac{d(ic+iR)}{dt} + Vc = E$$

$$L\frac{dic}{dt} + L\frac{dir}{dt} \quad Vc = E$$

Therefore,

$$I_c = \frac{dr}{dt} = \frac{d(C.Vc)}{dt}$$

$$\frac{dic}{dt} = \frac{d^2(C.Vc)}{dt} = C.\frac{d^2Vc}{dt^2}$$

$$\frac{dic}{dt} = \frac{d\left(\frac{Vc}{R}\right)}{dt} = \frac{1}{R}\frac{dVc}{dt}$$

Substuting these values in the main equation we get,

$$LC\frac{d^2Vc}{dt^2} + \frac{L}{R}.\frac{dVc}{dt} + Vc = E$$

Taking laplace transformer we get,

$$LCS2.Vc(s) + \frac{L}{R}SVc(s) + Vc(s) = \frac{E}{S}$$

At (Vc, t)=0

$$LcVc(s)\left[s^2 + \frac{1}{RC}S + \frac{1}{LC}\right] = \frac{E}{S}$$

$$Vc(s) = \frac{E}{SLC\left[s^2 + \frac{1}{RC}S + \frac{1}{LC}\right]}$$

Root of Quadratic equation in the denominator should be real. For this the following conditions should be satisfied.

$$R^2 < \frac{Lc}{4c^2}; R \leq \frac{1}{2}\sqrt{\frac{L}{C}}$$

If the values of the Resistance connected across the contacts of C.B is equal to 'or' less than the $1/2\sqrt{\frac{L}{C}}$, there will not be any transient but.

If the 'R' value is greater then $1/2\sqrt{\frac{L}{C}}$ transient oscillations may occur.

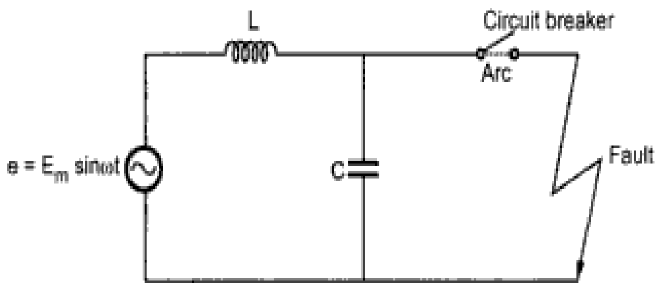
If, $R = 1/2\sqrt{\frac{L}{C}}$, it is a Critical resistance.

For a Damping oscillation, the frequency values are given by,

$$F = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{1}{4c^2R^2}}$$

It's a phenomenon of current interruptions before the natural current zero is reached. Current chopping mainly occurs in abed because they retain the same extinguishing power irrespective of magnitude of current interrupted.

When braking low current (Tr. Magnetizing current) with breakers the powerful demonizing effect of air blast cause the current to fall abruptly to zero. well before the natural current zero reached .this phenomena is current chopping it produced high voltage transient occur the contacts of CB.
Current chop occur at current i.



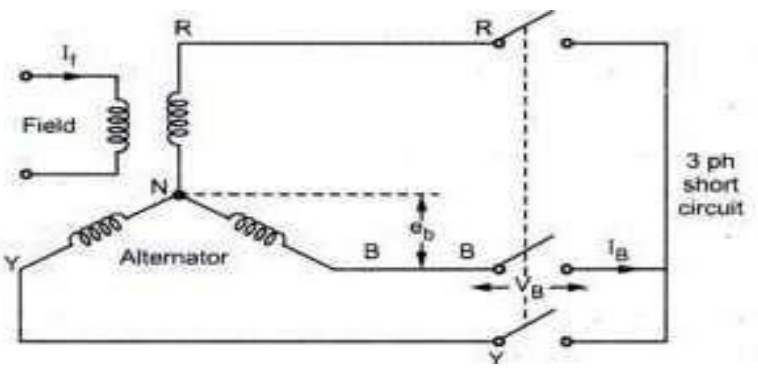
Energy stored in inductance is $1/2LI^2$ this energy will be transferred to the capacitance C is charging the latter is prospective voltage e is very high as composed to dielectric strength gained by the gap. The demonizing force still in action .therefore chop occurs gain but arc current this time is smaller than the previous case.

This induce a low prospective voltage to re-ignite the arc .infect ,several chops may occurs until or low enough current is interrupt which produce insufficient induced voltage to restripes across the breaker gap.

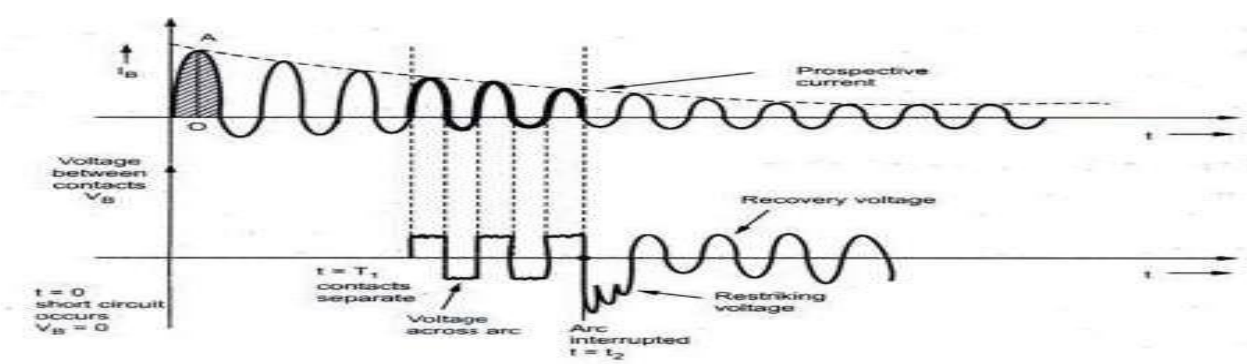
Excessive voltage surge due to current chopping are prevented by starting the contact of breaker with a resistor (resistance switching)

A.C. circuit breaking:

The arrangement of C.B connected to a generator on No-load at rated terminal voltage was considered as gnu below.



When "B" phase voltage with respect to neutral is zero, the C.B is closed. at this instant, B phase current will have maximum D.C component.
It 's current wave form will be un-symmetrical about normal zero- axis. This is depicted in fig 4.5.



Current and Voltage during fault clearing:

- The generator is on No Load before (t=0). Hence the current is zero before (t=0), the S.C is applied & the current increases to a high value during first quarter cycle.
- The peak of current loop is OM. This is the maximum value of intendances current during the S.C.
- The instantaneous value of the first major current loop is called Making current.
- Contact of circuit breaker separates after form cycle since the relay and the operating mechanism takes at least a couple of cycle.
- Assuming that C.B contacts separate at (t=T1)
- The r.m.s value of short circuit current at the instant of contact getting separated is called as "Breaking Current".

After the separation of contact of C.B and are is drawn b/w the contacts. They are current various sinusoids dally for few cycle.

At =T2, a particular current the dielectric strength of the ARC space builds cup sufficiently to present the confirmation of the ARC.

The Power frequency system voltage appearing b/w the pole after ARC extrication is called Recovery voltage.

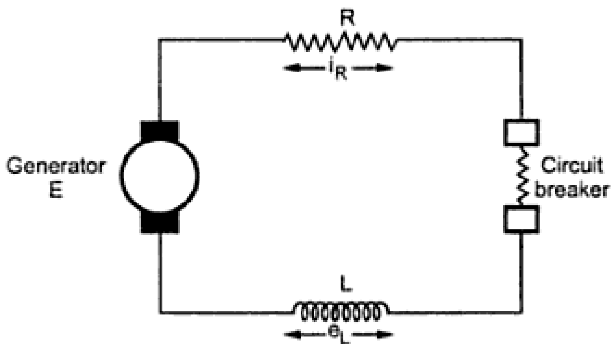
If contract space breakdown with in a period of $(1/4)^{th}$ of a cycle of initial arc extinction, this phenomenon is called "Re-ignition"

If contact space breakdown occurs after one forth of a cycle, the phenomenon is called as "RESTRIKE"

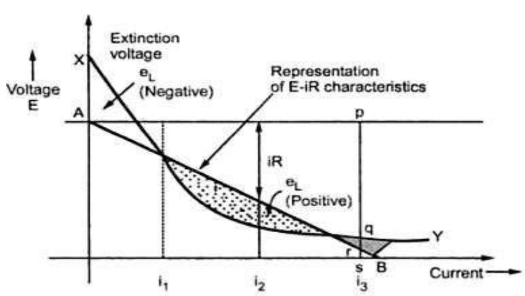
D.C circuit breaking:

D.C Circuit breaker can be explained by considering the GENERATOR ARRANGEMENTS. as given below.

D.C. circuit breaking:



Waveform:



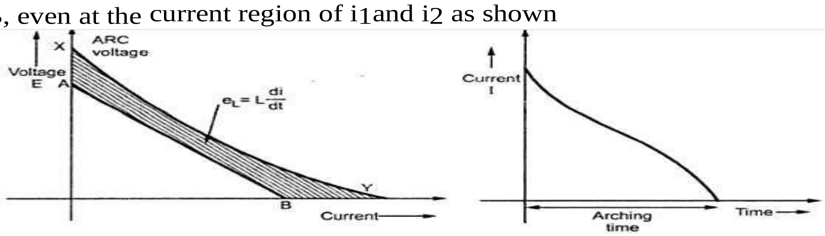
[I= $\frac{\quad}{R}$ The current is shown

When C.B starts opening it carriers the load current to reduce to i_1,$i_2$and $i_3$respectively.

'Pr' portion represents voltage drop iR undersea 'qs' represents are voltage which is greater than available voltage.

The arc becomes unstable &the difference in voltage is greater than available voltage. The arc becomes unstable &the difference in voltage is supplied by inductance 'L' across which the voltage is $e_L = L\frac{di}{dt}$

For decreasing values of current this voltage is –ve&according to Lenz's law it tries to maintain the arc. The operation in case of d.c. circuit breakers is said to be ideal if the characteristics of the arc voltage goes above the curve AB, even at the current region of $i_1$and i_2 as shown



in fig given below.

It can be seen that arc voltage is greater [E-IR] &the balance B/W the voltage is supplied by the voltage across the inductance e_L which is proportional to rate of change of current $\frac{di}{dt}$.

Thus the function of C.B is to raise the arc characteristics without affecting its stability.

Major problem of D.C. circuit breaking ARC;

- ✓ The amount of energy to be dissipated during the short internal of breaking is high is compared to A.C. breaking.
- ✓ The natural current zero does not occur as in the case of A.C. circuit breaking.

ARC PHENOMENON:

1. When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them.
2. An instant when the contacts being to separate, the area of contacts decrease which will increase the current density and hence rise in temperature. The heat which is produced in the medium is sufficient enough to ionize air or oil which will act as conductor. Thus an arc struck between the contacts.
3. The potential difference period between the contacts is sufficient to maintain the arc. The arc provides a low resistance path and consequently the current in the circuit remains uninterrupted as long as the arc persists.
4. During the arc period, the current flowing between the contacts depends upon the arc resistance. If the resistance of the arc increase, the current flowing between the contacts decrease. The arc resistance depends on the flowing factor

(a) Degree of ionization:

If the number of ionized particles between the contacts arc less, then the arc resistance increases.

(b) length of arc:

If the length increases, the arc resistance increases.

(c) cross section of arc:

If the area of cross section of the arc decreases, the arc resistance increases.

Initiation of Arc:

There are two methods by which electrons are emitted from the metal of the contacts and initiate an arc in a circuit breaker.

- By high voltage gradient at the cathode, resulting in field emission.
- By increasing of temperature, resulting in thermionic emission.

(a.) By high voltage gradient or field emission:

If any fault occurs, the moving contacts get separated from each other, the area of contacts and pressure between the separating contacts decrease. A high fault current causes potential drop (10^6 V/cm) between the contacts which will remove the electrons from cathode surface. This method is termed as "field emission".

(b.) By increasing of temperature or thermal emission:

If the contacts are separated, the contacts area decreases which will increase the current density and consequently the temperature of the surface which will cause emission of electrons termed as "thermionic emission".

Mostly, the contacts in the circuit breaker are made up of copper which is having less thermionic emission.

Maintenance of arc :

The electrons travel towards anode collides with another electron to dislodge them, ionize the medium and thus arc is maintained after field emission increases.
The ionizing is facilitated by,

- High temperature of the medium around the contacts due to high current densities. Thus the kinetic energy gained by moving electrodes is increased.
- The voltage gradient increased the kinetic energy of moving electrons
- The length of the path increased then the number of neutral molecules increases, the increase free path movement of the electrons

Thermal ionization:

When the temperature of a gas reaches very high, there is always a high probability that the kinetic energy of any particles will be great enough to cause the ionization of another such particle when a collision occurs between them. This process is called thermal ionization.

Electric Arc:

The electric arc is a self-sustained discharge of electricity between electrodes in gas or vapour. Which has a voltage drop at cathode of the order of minimum ionization or minimum existing potential of gas or vapour? Fig depicts the temperature zones in the arc. When D.C voltage applied to electrons, placed at a small clearance is gradually increased, a flow of current takes place through gas. This phenomenon is called discharge in gas.

The volt-ampere characteristic has several distinct classified as glow discharge, town send discharge and arc discharge. During arc discharge the voltage across the electrode is low and current is high. The current is limited by external impedance. The voltage across arc decreased as the current increases. The arc is self-sustained discharge.

Static characteristic of arc:

Fig (b) shows the voltage across arc reduces as the current increased. The volt-ampere characteristic of a steady arc is given by

$$V_{arc} = A + Bd + \left(\frac{c+dD}{i_{arc}}\right)$$

Where

d- length of arc

V_{arc}- voltage across arc

i_{arc}- current in arc

A,B,C,D- constants

A+[$\frac{C}{I_{arc}}$] –cathode plus anode voltages the energy dissipated in the steady stated arc in the form of heat is given by

$E_{arc}=V_{arc} i_{arc}$ **t** Where

E_{arc}- Energy in joules

V_{arc}- Voltage in volts

i_{arc}- Arc current in Amps t- Duration of arc in sec

Arc extinction:

Factors maintaining the arc between contacts:

When the contacts have a small separation, the potential difference between them is sufficient to maintain the arc. One way to extinguish the arc is separate the contacts to such a distance that potential difference becomes inadequate to maintain the arc.

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

Methods of arc extinction or current interruption:

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

1. High resistance method:

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

The arc resistance may be increased by

i. Lengthening of the arc
ii. Cooling of the arc
iii. Reducing the cross section of the arc
iv. Splitting the arc

2. Low resistance method or current zero method:

In this method, arc resistance is kept low until current zero where the arc extinguishes naturally and is prevented from restricting in spite of the rising voltage across the contacts. All modern power A.C circuit breaker employ this method for arc extinction.

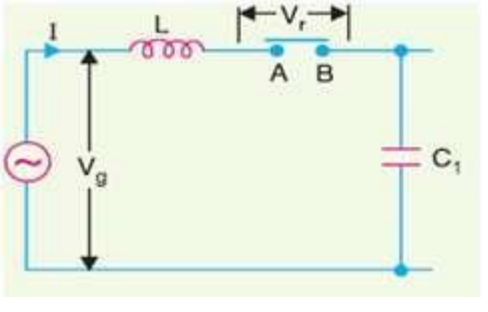
The real problems in A.C arc interruption is to rapidly deionized the medium between contacts as soon as the current becomes zero so that the rising contacts voltage or ristriking voltages cannot breakdown the space between contacts.

The deionization of the medium can be achieved by.

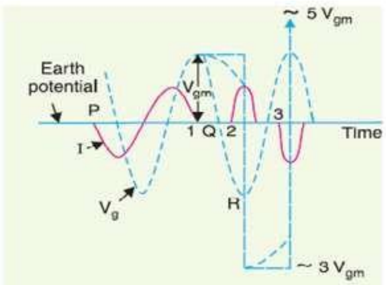
1. **Lengthening of the air gap:**
   By opening the contacts rapidly higher dielectric strength of the medium can be achieved
2. **High pressure:**
   If the pressure in the vicinity of the arc is increased, the density of the particles constituting the discharge also increased. The increased density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

3. Explain interruption of capacitive current (May-15)(Dec-2016)(May-2017)

Interruption of capacitive currents is instances of opening of unloaded long transmission line , disconnecting a capacitor bank used for power factor improvement
.consider the simple equivalent circuit of unloaded transmission line will actually carry a capacitive current I on the account of appreciable amount of capacitance C between the line and earth.



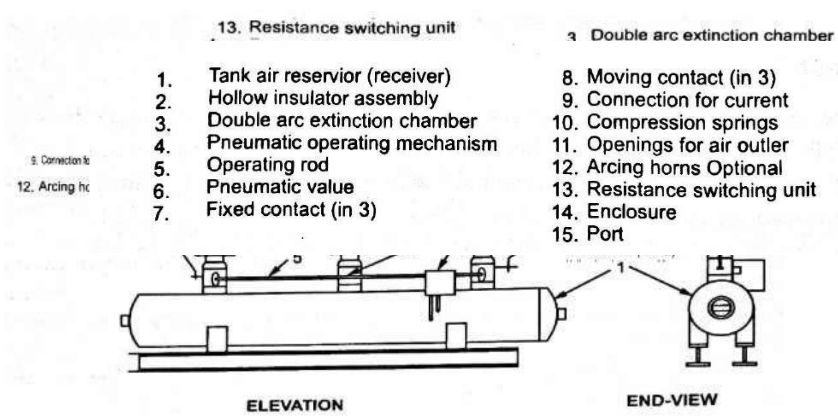
Suppose that line is opened by the circuit breaker at the instant when line capacitive current is zero. at the instant the generator voltage Vg will be maximum lag behind the current by 90˚.the opening of the line leaves a standing charge on it and capacitor C1 is charged to V gmax ,the generator end of the line continuous its normal sinusoidal variations. The voltage Vr across the CB will be difference between the voltage on the respective sides. It is initial value is zero and increases slowly in the beginning. but half a cycle latter the potential of the circuit breaker contact A becomes maximum negative which causes the voltage across the breaker Vr become 2Vgmax.this voltage may be sufficient to restrike the arc. two previously separated parts of the circuit will now be joined by an arc of very low resistance. The line capacitance discharge at once to reduce the voltage across the CB.the setting up high frequency transients will be twice the voltage at that instant i.e -4Vgmax.this will cause the transmission voltage to swing to -4Vgmax to +Vgmaxi.e -3Vgmax.



The re-strick arc current quickly reaches its first zero as it varies at natural frequency. The voltage on the line is now -3Vgmax and once again the two halves of the circuit are separated and line is isolated at this potential. After about half a cycle further, the aforesaid events are repeated even on more formidable scale and the line may be left with a potential of 5Vgmax above the earth potential .theoretically this phenomenon may proceed infinitely increasing the voltage by successive increment of 2 times Vgmax.

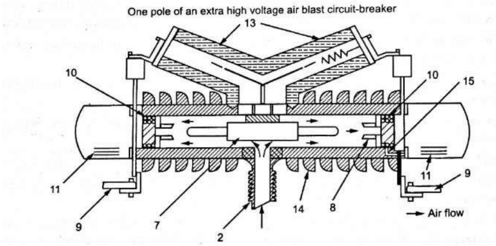
While the above description relates to the worst possible conditions, it is obvious that if the gap breakdown strength does not increase rapidly enough, successive re-strikes can build up a dangerous voltage in the open circuit's line. However due to leakage and corona loss, the maximum voltage on the line in such cases is limited to 5Vgmax

- Fast operations, suitability for repeated operation, auto reclosure, unit type multi break constructions, simple assembly, and modest maintenance are some of the main features of air blast circuit breakers.
- A compressors plant necessary to maintain high air pressure in the air receiver. The air blast circuit breakers are especially suitable for railways and arc furnaces, where the breaker operates repeatedly.
- Air blast circuit breakers is used for interconnected lines and important lines where rapid operation is desired.
- High pressure air at a pressure between 20 to 30 kg/ cm^2 stored in the air reservoir. Air is taken from the compressed air system.
- Three hollow insulator columns are mounted on the reservoir with valves at their basis. The double arc extinguished chambers are mounted on the top of the hollow insulator chambers.
- The current carrying parts connect the three arc extinction chambers to each other in series and the pole to the neighboring equipment.
- Since there exists a very high voltage between the conductor and the air reservoir, the entire arc extinction chambers assembly is mounted on insulators.



Construction:

One pole of an extra high voltage air blast circuit-breaker



Details of double arc extinction chamber

Operation:

Since there are three double arc extinction poles in series, there are six breaks per pole. Each arc extinction chamber consists of one twin fixed contact. There are two moving contacts. The moving can move axially so as to open or close. Its position open or close depends on air pressure and spring pressure.

The operating mechanism operates the rod when it gets a pneumatic or electrical signal. The valves open so as to send the high pressure air in the hollow of the insulator. The high pressure air rapidly enters the double arc extinction chamber. As the air enters into the arc extinction the pressure on the moving contacts becomes more than spring pressure and contacts open.

The contacts travel through a short distance against the spring pressure. At the end of the contact travel the port for outgoing air is closed by the moving and the entire arc extinction chamber is filled with high pressure air as the air is not allowed to go out. However, during the arcing period the air goes out through the openings and takes away the ionized air of the arc.

While closing, the valve is turned so as to close connection between the hollow of the insulator the reservoir. The valve lets the air from the hollow insulator to the atmosphere. As a result of the pressure of air in the arc extinction chamber is dropped down to the atmospheric pressure and the moving contacts close over the fixed contacts by virtue of the spring pressure.

The opening is fast because the air takes a negligible time to travel from the reservoir to the moving contact. The arc is extinguished within a cycle.
Therefore, air blast circuit breaker is very fast in breaking the current.

Closing is also fast because the pressure in the arc extinction chamber drops immediately as the valve operates and the contacts close by virtue of the spring pressure.

Advantages

- There is no chance of fire hazard caused by oil.
- The breaking speed of circuit breaker is much higher during **operation of air blast circuitbreaker.**
- Arc quenching is much faster during **operation of air blast circuit breaker.**
- The duration of arc is same for all values of small as well as high currents interruptions.
- As the duration of arc is smaller, so lesser amount of heat realized from arc to current carrying contacts hence the service life of the contacts becomes longer.
- The stability of the system can be well maintained as it depends on the speed of operation of circuit breaker.
- Requires much less maintenance compared to oil circuit breaker.

Disadvantages

- In order to have frequent operations, it is necessary to have sufficiently high capacity air compressor.
- Frequent maintenance of compressor, associated air pipes and automatic control equipment's is also required.
- Due to high speed current interruption there is always a chance of high rate of rise of re-striking voltage and current chopping.
- There also a chance of air pressure leakage from air pipes junctions.
- As we said earlier that there are mainly two types of ACB, plain air circuit breaker and air blast circuit breaker. But the later can be sub divided further into three different categories.
    - Axial Blast ACB.
    - Axial Blast ACB with side moving contact.
    - Cross Blast ACB.

- Bulk oil circuit breakers are enclosed in metal-grounded weatherproof tanks that are referred to as dead tanks. The original design of bulk OCBs was very simple and inexpensive.
- Example of such a breaker, called plain break oil circuit breaker, the arc was drawn directly inside of the container tank without any additional arc extinguishing but the one provided by the gas bubble surrounding the arc.
- Plain break breakers were superseded by arc controlled oil breakers. The arc controlled oil breakers have an arc

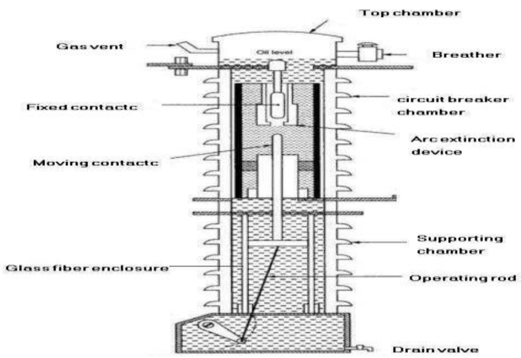
control device surrounding the breaker contacts. The purpose of the arc control devices is to improve operating capacity, speed up the extinction of arc, and decrease pressure on the tank.

➢ The arc control devices can be classified into two groups: cross-blast and axial blast interrupters. In an oil circuit breaker with simple interruption under oil, the duration of arcing is 0.02-0.05 sec. To extinguish the arc more efficiently, arc- quenching chambers are used.

➢ In a longitudinal blast chamber the vapors and gases evolved travel upward along the arc, thus cooling it.

➢ In addition, the arc is in contact with the cold oil that fills the annular slots of the chamber, which also accelerates cooling of the arc. In a transverse blast chamber a drastic pressure increase within the gas bubble causes a stream of oil and gases to flow across the arc, thus accelerating the cooling process.

Construction:



Operation:

➢ In terms of design, a distinction is made between tank-type oil circuit breakers and oil-minimum, or low-oil-capacity, circuit breakers. In the first type, the main contacts and the arc-quenching devices are located in a grounded metal tank; in the second type they are in an insulating or ungrounded metal enclosure filled with oil.

➢ Tank-type oil circuit breakers are inferior to other types of high-voltage breakers in many regards. However, their low cost and high reliability have led to their continued use in the USSR, the USA, and Canada.

➢ In the USSR, tank-type oil circuit breakers are manufactured for voltages from 6 to 220 kilovolts (kV); maximum rated current, 3.2 kilo-amperes (kA); breaking current, 50 kA. For voltages of 10 kV or less and breaking currents of 15 kA or less, all three poles of the oil circuit breaker are located in the same tank.

➢ For higher voltages and breaking currents, each pole is located in a separate tank. Oil-minimum circuit breakers are used in the USSR, the Federal Republic of Germany, and France.

➢ They are manufactured for 3 to 420 kV; since the late 1960’s they have also been manufactured for higher voltages.

Advantages

A low oil circuit breaker has following advantages compared to bulk oil circuit breaker

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

Disadvantages

A low oil circuit breaker has following disadvantages compared to bulk oil circuit breaker

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

Also, the gas in the arc chamber escapes to the gas expansion chamber, so that a type of heat dissipation by convection is created, thus the rate at which heat is dissipating is increasing.

Near current zero, the thermal power generated by the current (in the arc) approaches zero. If the heat dissipation outwards is sufficiently large, the temperature in the arc zone can be reduced in such a manner that the arc would lose conductivity and extinguish.

An arc in hydrogen has a short thermal time constant, so that the conditions are favorable for quenching. There are two other situations that may occur under certain conditions: thermal Restriping of Arc, resignation.

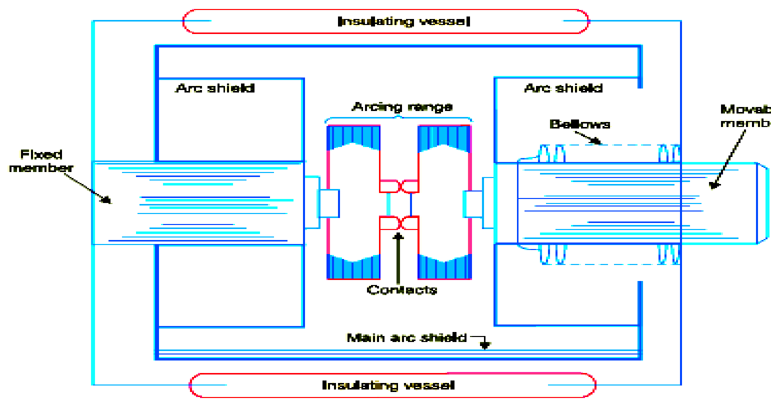
Thermal restriping is when the post-arc current rises again and passes into the next half cycle of SCC, as the arc plasma heats up due to the insufficiency of heat dissipation to make conductance of the arc zone equal to zero.

Resignation happens when there striking voltage of the system causes a renewed formation of the arc, (after completion of the first interruption) and continuation of flow of current.

The arcing chamber designs are either of the axial or radial venting type. Often, a combination of both is used in the design of minimum oil, MV CB's. The axial venting process generates high gas pressures and has high dielectric strength. This is used mainly for interruption of low currents. The radial venting is used for high current interruptions, as the gas pressures developed are low and the dielectric strength is low.

Vaccum CB:

Construction:



In this breaker, vacuum is being used as the arc quenching medium. Vacuum offers highest insulating strength, it has far superior arc quenching properties than any other medium.

When contacts of a breaker are opened in vacuum, the interruption occurs at first current zero with dielectric strength between the contacts building up at a rate thousands of times that obtained with other circuit breakers.

Principle of operation:

When the contacts of the breaker are opened in vacuum (10 -7 to 10 -5 tore), an arc is produced between the contacts by the ionization of metal vapours of contacts.

The arc is quickly extinguished because the metallic vapours, electrons, and ions produced during arc condense quickly on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength.

As soon as the arc is produced in vacuum, it is quickly extinguished due to the fast rate of recovery of dielectric strength in vacuum. It consists of fixed contact, moving contact and arc shield mounted inside a vacuum chamber. The movable member is connected to the control mechanism by stainless steel bellows. This enables the permanent sealing of the vacuum chamber so as to eliminate the possibility of leak.

A glass vessel or ceramic vessel is used as the outer insulating body.

The arc shield prevents the deterioration of the internal dielectric strength by preventing metallic vapours falling on the inside surface of the outer insulating cover.

Working:

When the breaker operates the moving contacts separates from the fixed contacts and an arc is struck between the contacts. The production of arc is due to the ionization of metal ions and depends very much upon the material of contacts.

The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in short time and seized by the surfaces of moving and fixed members and shields. Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker occurs with a short contact separation.

Advantages:

a. They are compact, reliable and have longer life.

b. There are no fire hazards

c. There is no generation of gas during and after operation

d. They can interrupt any fault current. The outstanding feature of a VCB is that it can break any heavy-fault current perfectly just before the contacts reach the definite open position.

e. They require little maintenance and are quiet in operation

f. Can withstand lightning surges

g. Low arc energy

h. Low inertia and hence require smaller power for control mechanism.

Applications:

For outdoor applications ranging from 22 kV to 66 kV.Suitable for majority of applications in rural area