Differential Protection

A differential relay responds to vector difference between two or more similar electrical quantities.

Requirements:

(a) It must have at least two actuating quantities, say I_1 and I_2.
(b) The actuating quantities should be similar in nature i.e. current/current or voltage/voltage.
(c) The relay responds to the vector difference between the two quantities, i.e. to (I_1-I_2), which includes magnitude and/or phase angle difference. When this vector difference exceeds a predetermined amount, the relay operates.

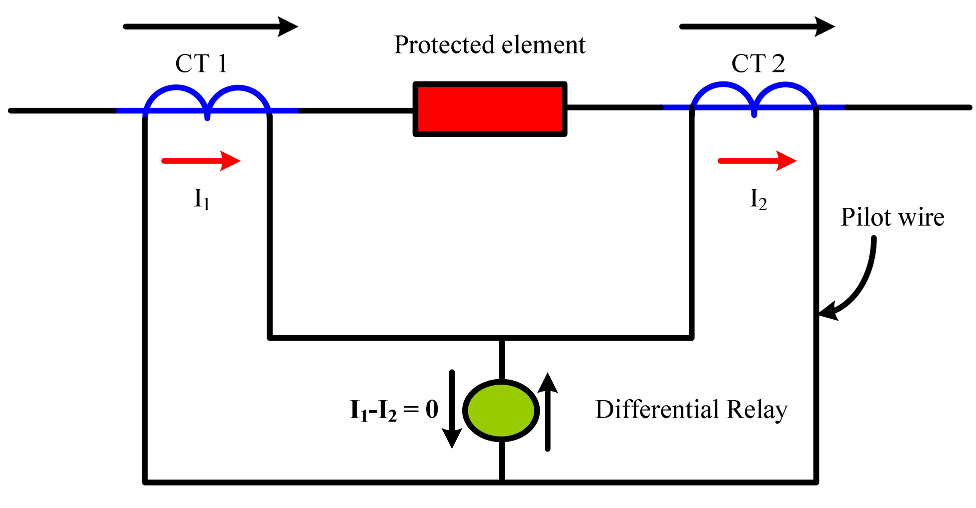
The differential protection is frequently called unit protection. The vector difference is achieved by suitable connection of CT and PT secondary. Most differential relay applications are of the current differential type.

Application:

- Protection of generator and generator-transformer unit.
- Protection of transformer.
- Protection of transmission line by pilot wire current.
- Protection of x-mission line by phase comparison carrier current.
- Protection of large motors.
- Bus zone protection.

Circulating current differential protection (Mertz Price Protection)

A simple example of circulating current differential relay is shown in the following figure,

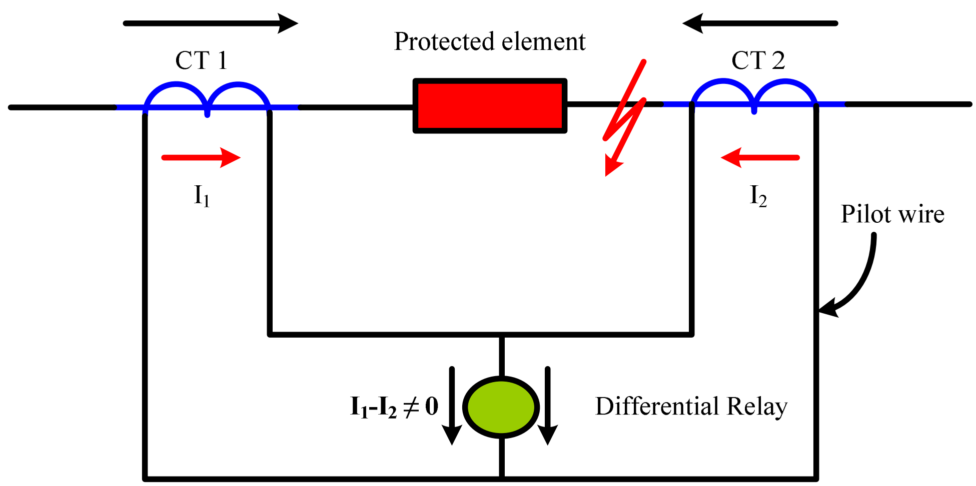


A simple differential relay application

The block represents the system element (transformer, motor, generator, bus etc.) to be protected.

Two suitable CTs are connected in series as shown in the figure with the help of the pilot wires. The relay operating coil is connected between the mid points (equi-potential points) of the pilot wires. The secondary current of the CTs will circulate through the combined impedance of the pilot wires and CTs. When the operating coil is not connected between the equi-potential points, even though the current through each CT is same, the burden on the two CTs is unequal. This causes heavily loaded CTs to saturate during through faults, thereby causing dissimilarities in the characteristics of two CTs which results in mal-operation of the relay. The relay could be any of the ac type that has been discussed but preferably attracted armature type.

When there is no internal fault, the current entering the protected element is equal in magnitude and phase to current leaving the protected element. The CTs are of such a ratio that during normal operating condition or for external faults (through faults). The secondary current of CTs is equal. These current say$I_1$and I_2 circulate in the pilot wires. The polarities of CTs are such that$I_1$and $I_2$is in the same direction during normal operation through fault condition. The differential current (I_1-I_2) which flow through relay coil is zero. So, the relay does not operate.



Differential current for internal fault

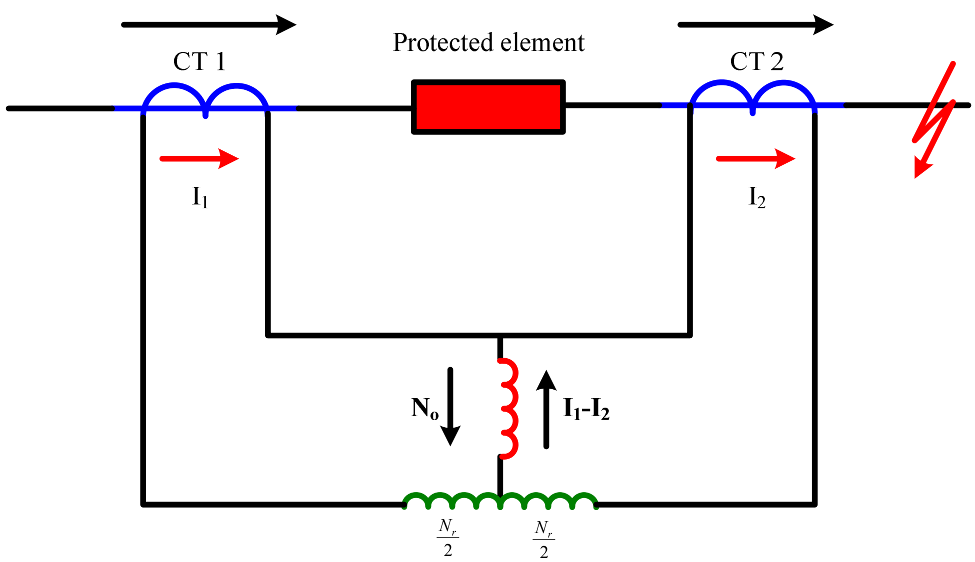
If the fault occurs somewhere in the protected zone, the direction of fault current in the circuit is shown in Fig.2. The differential current, (I_1-I_2), through the relay coil is not equal to zero i.e. (I_1-I_2) $\neq$ 0. If the operating torque due to the differential current exceeds the restraining torque the relay will operate.

Drawbacks:

1) Difference in pilot wire length / solution-adjustable resistor connected in series with the pilot wire.
2) CT ratio error during short circuit.
3) Saturation of CT magnetic circuit during short circuit.
4) Magnetizing inrush current.
5) Tap charging.

Drawback of the simple circulating current differential relay

The above form of protection was assumed on the fact that the two CTs used are identical. But in practice it is not true. CT of the type normally used does not transform their currents very accurately under transient condition in particular. This is due to the fact that the short circuit current is offset i.e. it contains dc components. Suppose the two CTs under normal condition differ in their magnetic properties slightly in terms of different amounts of residual magnetism or in terms of unequal burden on two CTs, one of them will saturate earlier during short circuit current flow (having high degree of offset) and thus two CTs will transform their primary current differently even for a through fault condition. This effect is more pronounced especially when the scheme is used for the protection of transformers.
To accommodate these features, Mertz price protection is modified by biasing the relay. This commonly known as biased differential or percentage differential protection as shown in Fig.3



Percentage differential Protection

The relay consists of an operating coil and a restraining coil. The operating coil is connected to the midpoint of the restraining coil. Under through fault condition due to dissimilarities in CTs the differential current in the operating coil is (I_1-I_2) and the equivalent current in the restraining coil is $\frac{(I_1+I_2)}{2}$

The torque developed by the operating coil is proportional to the ampere-turn i.e.

$T_O \propto (I_1 - I_2) \times N_O$, Where N_0 is the number of turns in the operating coil.

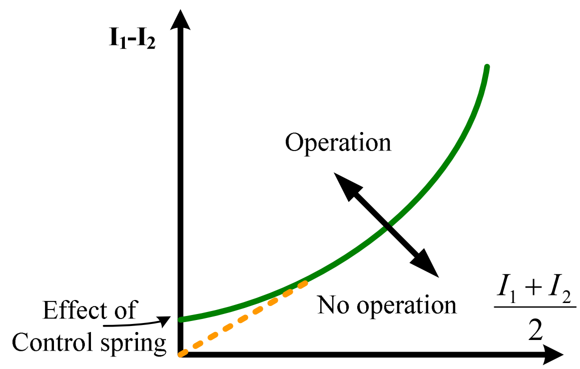
The restraining torque(due to restraining coil) is

$T_r \propto \left(\frac{I_1+I_2}{2}\right) \times N_r$, Where N_r is the number turns in the restraining coil.

At balance, $(I_1 - I_2) \times N_O \propto \left(\frac{I_1+I_2}{2}\right) \times N_r$

$$Or, \frac{(I_1 - I_2)}{\left(\frac{I_1+I_2}{2}\right)} = \frac{N_r}{N_O} = FIXED$$

This means that as the differential current is increased, so do the restraining current. The operating characteristic is shown in figure below.



Operating characteristics of a percentage differential relay

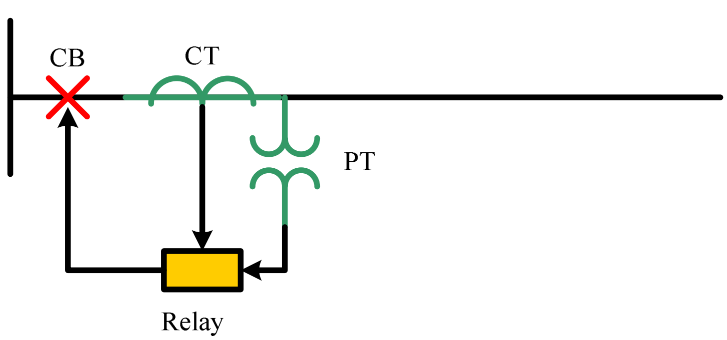
It is clear from the characteristics that except for the effect of the control spring at the low currents, the ratio of the differential operating current to the average retraining current is a fixed percentage. This is why it is called percentage differential relay. The relay described is called current balance relay.

Distance protection

Distance protection is a general term which is given of a group of non-unit protective systems in which relaying devices measure the impedance or reactance of the line, both of which are proportional of the distance between measuring point and the fault.

Actuating quantity: Voltage and current

The torque produced is such that when V/I ratio reducesbelow a set value, the relay operates.



The ratio of V/I is measured at the relay location i.e. at the location of CT and PT.If the fault is nearer to the relay location, the voltage of the relay point is lesser and opposite happens if the fault is farther from the relay location.
Hence each value of V/I measured from the relay location corresponds to distance between relaying point and the fault. Hence such protection is called distance protection.

Application:

-Long high voltage transmission lines-MHO
-Becoming increasingly popular in a modified form, on lines operating at 66KV, 33KV or even 11KV lines.
Motor distance relay can provide very high speed protection and it is simple to apply. It can be used as a primary and back up protection.
A distance protection is one where operation is based on the measurement of the impedance, reactance or admittance between relay location and the fault point.

Distance relay can be classified as

1. Non-directional:
   - -Impedance relay
   - -Reactance relay

2. Directional:
   - -Mho relay

Impedance relay:

The ratio of voltage and current across a branch gives the impedance of the branch.

$$\frac{V}{I} = Z = R + JX$$

The current gives the operating torque and the voltage gives the restraining torque.
The general torque equation of an impedance relay is

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

Where
T = net torque
K_1I^2= operating torque
K_2V^2= restraining torque
K_3=effect of control spring

At threshold, T= 0

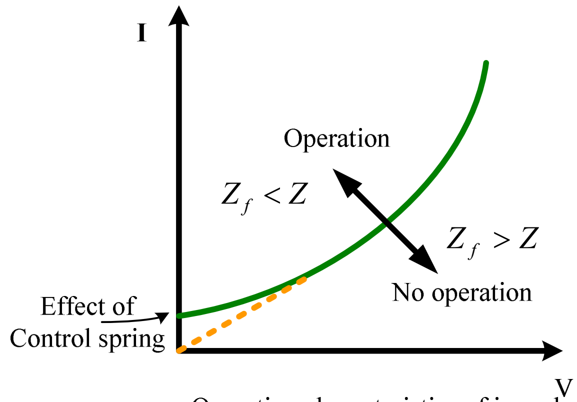
$$K_2V^2 = K_1I^2 - K_3$$

$$\text{Or, } \frac{V^2}{I^2} = \frac{K_1}{K_2} - \frac{K_3}{K_2 I^2}$$

If the effect of control spring be neglected i.e. K_3=0

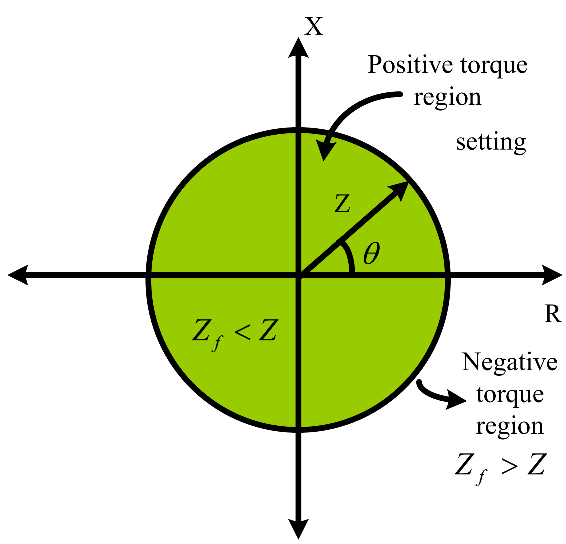
$$\frac{V}{I} = \sqrt{\frac{K_1}{K_2}} = \text{Constant}$$

Therefore the relay will operate if the fault impedance Z_f(i.e. $\frac{Vf}{If}$) is less than a certain value of Z given by $\sqrt{\frac{K_1}{K_2}}$. If Z_f is greater than Z then the relay will not operate.
The characteristics in term of V and I is shown below:



Operating characteristics of impedance relay

By adjustment of the slope of the operating characteristic can be changed so that the relay will respond to all values of impedance less than any desired upper limit.
A much more useful way of showing the operating characteristic of impedance relay is by means of impedance diagram or R-X diagram is shown below. Since the relay operates for certain value, less than the set value of Z, the operating characteristic is a circle of radius Z.



R-X diagram of an impedance relay

If Z_f<Z the relay will operate; and if Z_f> Z the relay will not operate. This a rule regardless of phase angle between V and I.
At very low current where the operating characteristics of figure 1 departs from a straight line because of the control spring. The effect of figure 2 is to make the radius of the circle smaller.

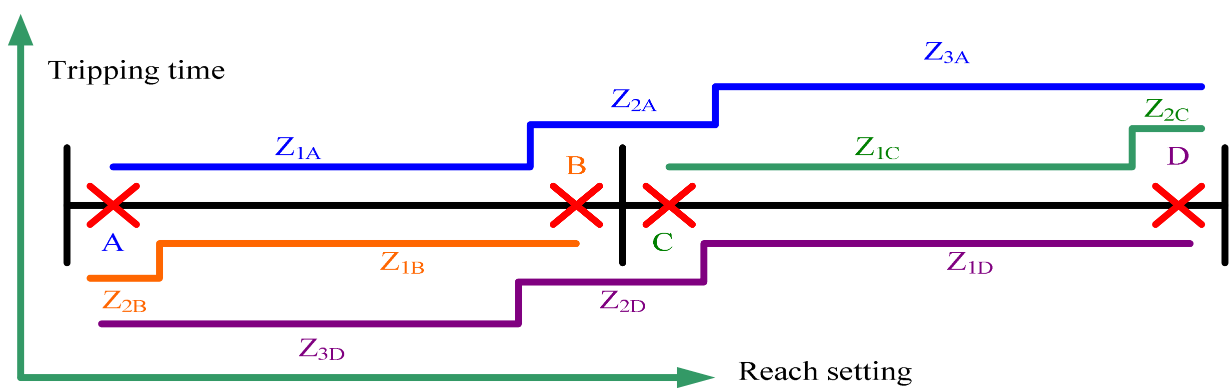
Disadvantage of impedance relay:

1. It is non directional; it will see fault both in front of and behind the relaying point and therefore requires a directional element to give correct discrimination.
2. It is affected by are resistance in the fault path.
3. It is very highly sensitive to power swings because of the larger area covered by the impedance circle.

To make impedance relay directional, a directional unit is incorporated with the impedance relay.

#Describe how correct co-ordination the distance relays is obtained for three zone distance protection.

Correct co ordination between distance relay on a power system is obtained by controlling the reach settings and tripping times of the various zones of measurements. A conventional distance protection will comprise an instantaneous directional zone-1 protection and one or more time delayed zones. Typical three zone distance protection scheme is shown in the figure which consists of two line sections AB and CD.



The protection scheme is divided in three zones. Say for relay at A, the three zones are Z_{1A}, Z_{2A} and Z_{3A}. The Z_{1A} represents the reach setting of relay at A for the instantaneous zone-1 protection and corresponds to approximately 80% impedance(length) of the line AB. No intentional time lag is provided for this zone. The ordinate shown corresponding to Z_{1A} gives the operating time when the fault takes place in this zone. It is to be noted here that the first zone is extended only up to 80% and not 100% length of the line AB as the relay impedance measurement will not be very accurate towards the end of the line especially when the current is offset.

Second zone, Z_{2A} for relay at A covers remaining 20% length of the line AB and 20% of the adjoining line i.e. line CD. In case of a fault in this section relay at A will operate when the time elapsed corresponds to the ordinate Z_{2A}. The main idea of the second zone is to provide protection for the remaining 20% section of the line AB. In case of an arcing fault in the section AB which adds to the impedance of the line as seen by the relay at A, The adjustment is such that the relay at A will see that impedance in second zone and will operate. This is why the

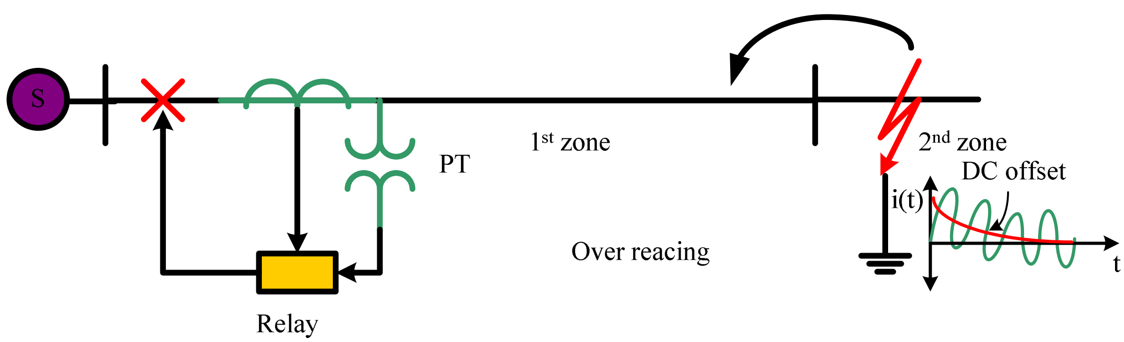
second zone is extended into the adjoining line. The operating time of the second zone is normally about 0.2 to 0.5 seconds.
The 3rd zone unit at relay A provides back up protection for faults in the line CD. That means if there is a fault in line CD and if for some reasons the relay at C fails to operate then relay at A will provide backup protection. The delay time for the 3rd zoneis usually 0.4 to 1.0 second.
In case the feeder is being fed from both the ends and say the fault takes place in the second zone of the line AB (20% of the line AB), the relay at B will operate instantaneously (because it lies in the first zone BA) whereas the fault lies in the second zone of the relay at A. This is undesirable from stability point of view and it is desirable to avoid this delay. This is made possible when the relay at B gives an inter trip signal to the relay at A in order to trip the breaker quickly rather than waiting for zone 2 tripping.

Reach of distance relay:

A distance relay is set to operate up to a particular value of impedance, for an impedance greater than this set value the relay should not operate. This setting is known as the reach of the relay.

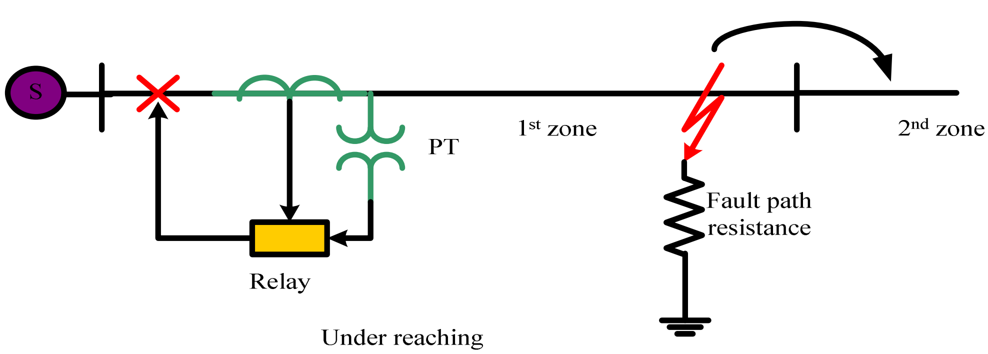
Over reach:

A distance relay is said over reach when the impedance presented to it is less than the apparent impedance to the fault. An important reason for over reach is the presence of dc offset in the fault current wave, as the offset current has a higher phase value than that of a symmetrical wave for which the relay is set. The over-reaching tendency is more as the impedance is more inductive.



Under reach:

A distance relay is said to be under reach when the impedance presented to it is greater than the apparent impedance to the fault. A distance relay may under reach because of the introduction of fault path resistance.



Reactance relay:

In this relay the operating torque is proportional to the square of the current and the restraining torque is proportional to the product of the voltage and current and the line of the angle between them. The reactance type distance relay has reactance measuring unit. The reactance measuring unit has an over current element developing positive torque and a directional element (VIsinΘ) which either gives a positive or negative torque. Hence the reactance relay is an over current relay with directional restraint. The directional element is so designed that its maximum torque angle is 90^0i.e. $\tau = 90^0$ in the torque equation.

$T = K_1I^2 - K_2VIcos(\Theta-\tau) - V_3$

Where, T= net torque
I = current to relay coil
V= voltage to relay coil
Θ=phase angle between V & I

τ = angle of the maximum torque

According to the design of the reactance relay

$Cos(\Theta-\tau) = Cos(\Theta-90^0) = Sin\Theta$

So, Net torque, $T = K_1I^2 - K_2VIsin\Theta$

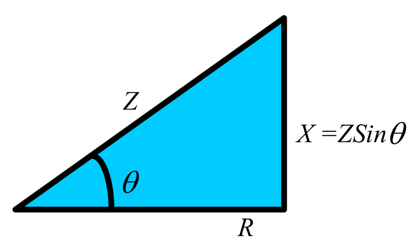
On the verge if relay operation T=0

$\gg K_1I^2 = K_2VIsin\Theta$

$\gg (\frac{V}{I})\ sin\Theta = \frac{K_1}{K_2}$

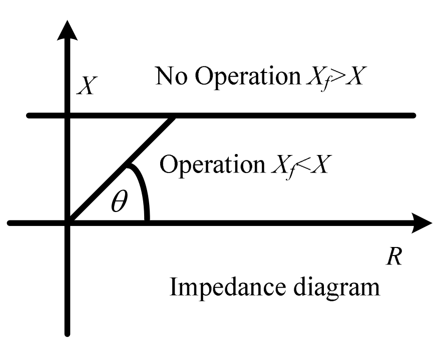
or $Zsin\Theta = \frac{K_1}{K_2}$

Hence $X = \frac{K_1}{K_2}$,this is the equation of the reactance relay



For the operation of the relay,$X_f < \frac{K_1}{K_2}$,

This means for the operation of the relay the reactance seen by relay should be smaller than the reactance for which the relay has been set. The characteristics of the relay is shown below-



The important point about these characteristics is that the resistive component of the impedance has no effect on the operation of the relay. It responds only to the reactance component of the impedance. We can also say that the setting of the reactance relay does not vary in the presence of arc resistance, because it is designed to measure only the reactive component of the line. The relay will operate for all impedances whose heads lies below operating characteristic whether below or above the R-axis. This relay, as can be seen from the characteristic, is a non directional relay.

Ground fault protection (Earth fault protection):

When the fault current flows through earth return path the fault is called earth fault (E/F). The other faults which do not involve ground are called phase faults. Since earth results are relatively frequent, E/F protection is necessary in most cases. When separate E/F protection is not economical, the phase relays sense the E/F currents. However, such protection lacks sensitivity. More sensitivity protection against E/F can be obtained by using a relay which responds only to the residual current of the system, since the residual component exists only when the fault current flows to the earth. The E/F current relay is, therefore, completely unaffected by the load currents whether balanced or not.

Low current setting is permissible to increase the relay sensitivity for the E/F's. But this low current setting may be limited in magnitude by neutral earthing impedance or by earth contact resistance.

Residual connection of CTs to E/F relay

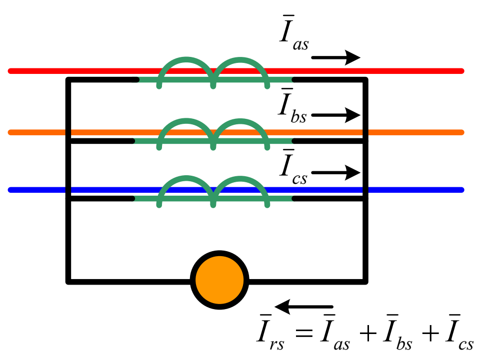


Fig. (a) : E/F relay connected in residual circuit.

In the absence of E/F, the vector sum of three line currents is zero. Therefore, the vector sum of three secondary currents is also zero.

$\bar{I}_{as} + \bar{I}_{bs} + \bar{I}_{cs} = 0 = \bar{I}_{rs}$ (This is called residual current)

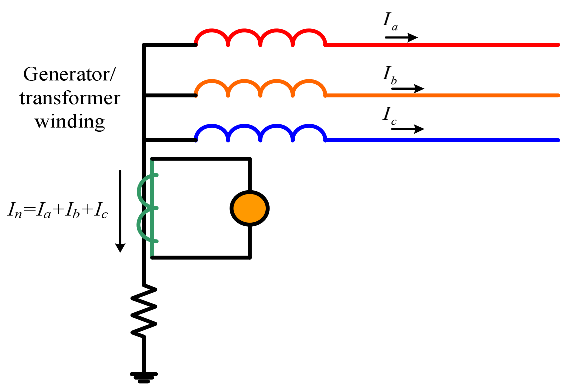
The E/F relay is connected in such a way that $\bar{I}_{rs}$ flows through it as shown in the Fig. (a). So in the absence of earth fault the relay will not operate. However, in the presence of earth fault

$\bar{I}_{as} + \bar{I}_{bs} + \bar{I}_{cs} \neq 0 = \bar{I}_{rs}$

and if the residual current is above the pick up value, the E/F relay will operate. In this scheme E/F at any location near or away from the CTs location can cause the residual current to flow.

Hence the protected zone is not defined. Such protection is called unrestricted E/F protection. For selectivity directional E/F protection is necessary.

E/F relay connected in neutral to earth circuit (Fig. (b))



$I_n = I_a + I_b + I_c$, The magnitude of E/F current is dependent on the type of earthing (resistance, reactance or solid) and the location of fault.

In this type of protection, the zone of the protection cannot be accurately defined. The protected area is not restricted to the transformer /generator winding alone. The relay senses the E/Fs beyond the transformer/generator winding. Hence such protection is called unrestricted E/F protection.

Combined E/F and phase fault protection:

It is convenient to incorporate phase fault relays and E/F relay in a combined phase and earth fault protection.

Three phase fault O/C relays are provided on three phases and the E/F relay is residually connected as shown in fig. (c)

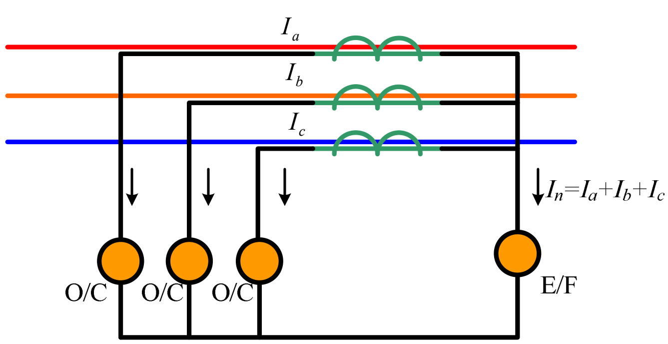


Figure: c

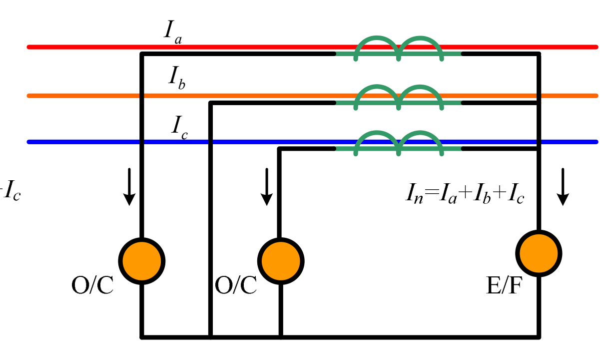


Figure: d

Instead of using three O/C relay for three phases, very often phase fault O/C relay are provided on only two phases since these will detect any interphase fault; the connection to the E/F relay are unaffected by this consideration. The arrangement is illustrated in fig. (d).

Restricted E/F protection:

A simple O/C and E/F system will not give good protection cover for a star connected primary winding, particularly if the neutral is earthed through impedance. The degree of protection is very much improved by the application of a unit differential E/F system or restricted E/F protection as shown in fig. (e)

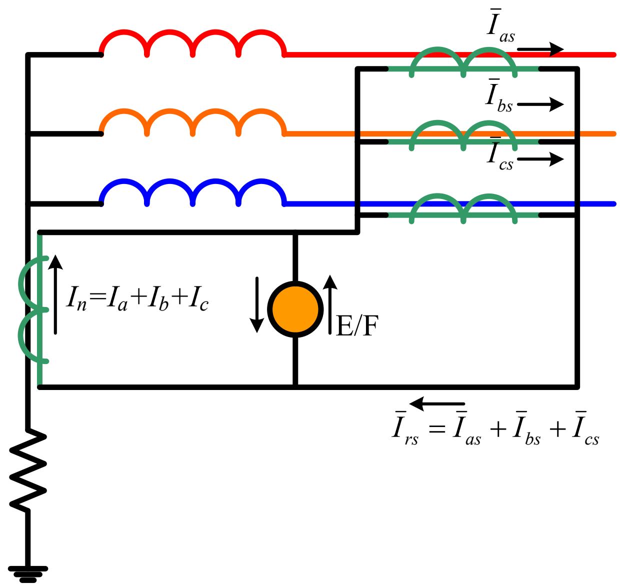


Figure (e): Restricted E/F protection of a star winding.

The system is operative for faults within the region between the CTs that is, for faults in the star winding in question. The system will remain stable for all faults outside this zone.