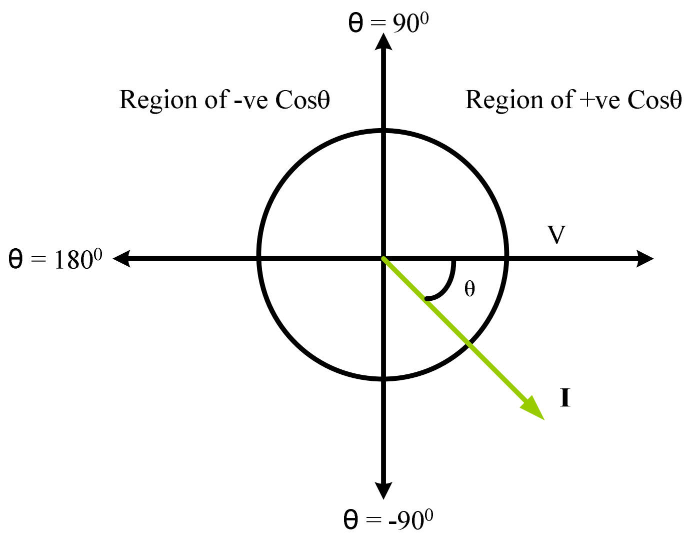
Directional Relay

Active power flowing through a part of an electric circuit is

P=VI cosθ, where θ is an angle between V and I.



From the above vector diagram,

For $\theta < \pm 90°$, cosθ is positive, hence the real power P is positive.

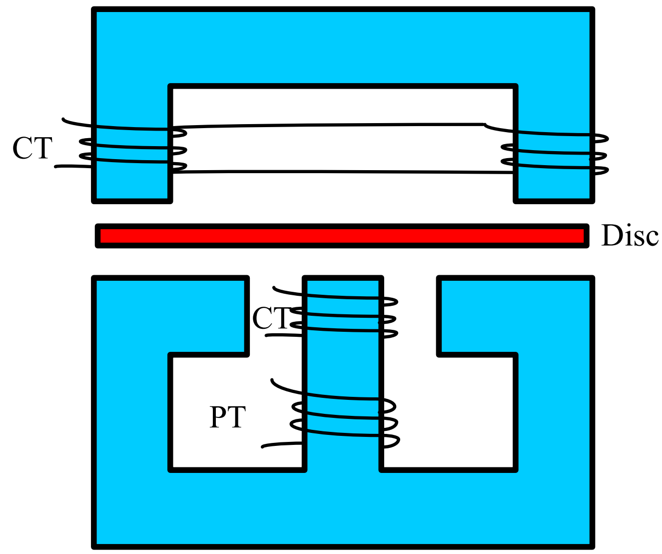
For $\theta = 90°$ & $\theta = 270°$, the real power is zero.

For $\theta > \pm 90°$, then real power P is negative.

The direction of power flow can be sensed by sensing the magnitude and sign of VIcosθ. The directional unit is a four pole induction cup unit. Two opposite poles are fed with voltage and other two poles are fed with current. The voltage is taken as the polarizing quantity. The polarizing quantity is one which produces one of the two fluxes required for production of torque and this quantity is taken as the reference compared with the other quantity which is current here. This means that the phase angle of the polarizing quantity remains more or less fixed while the other quantity suffers wide change in phase angle.

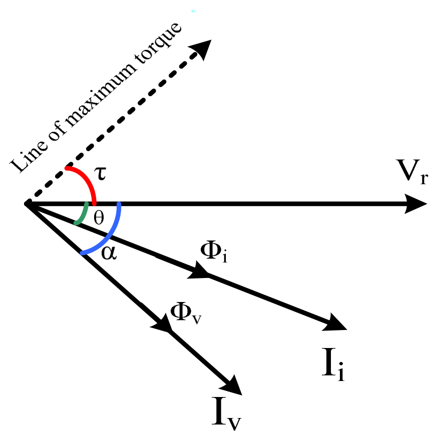
Directional protection responds to the flow of power in a direction with reference to the location of CT's and PT's. Directional relays respond ti the magnitude and sign (direction) of power applied at their terminals.

Directional power relays, directional O/C relays, directional earth fault relays come under the group "directional relays". The construction feature of the directional relay is shown in Fig 2.



The torque of the induction relay is proportional to the product of two fluxes and sine of the angle between them i.e. T α $\varphi_1\varphi_2$ sinθ. Maximum torque will occur when θ=90°.

The phasor diagram of the directional relay is shown below in Fig 3.



Here φ_v is the flux due to the voltage coil and lags behind the voltage by about almost 60° to 70° (α). And φ_i is the flux due to the current coil. The net torque is produced due to the interaction of φ_v and φ_i. the torque is maximum when the two fluxes are displaced by 90°. Here the dotted line in the phasor diagram represents the desired position of φ_i for maximum torque. Since $V_r$is the reference or polarizing quantity and φ_v has fixed position with respect to $V_r$for a particular design, the angle between the dotted line and the polarizing quantity V_r is known as the maximum torque angle and is normally denoted by τ, maximum torque is produced. By changing the internal angle α of the relay, the characteristic of the directional relay could be varied.

The torque developed by a directional unit is given by-

T=$\varphi_v \varphi_i$Sin (α-θ)-K……. (1)

Where, V_r is the voltage applied to the voltage coil.

I_v is the current in the voltage coil

I_i is the current in the current coil

φ_v is the flux due to I_v

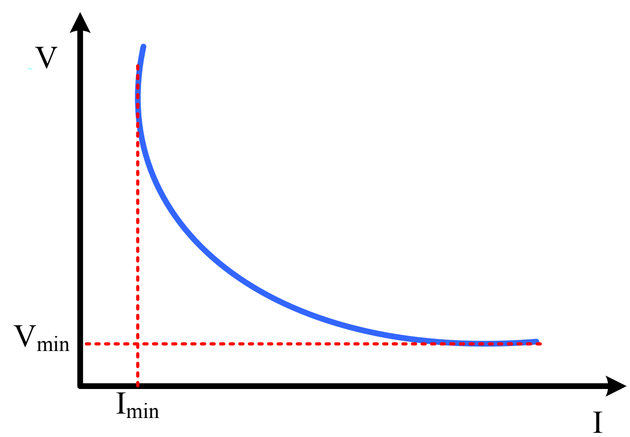
φ_i is the flux due to I_i

θ is the angle between V_r and I_i

K is the restraining force including spring and friction.

The sign of the torque depends upon the sign of Sin (α-θ). Sin (α-θ) is positive when the angle (α-θ) lies between 0-180° and negative when lies between 180°-360°. For a particular installation Sin (α-θ) is constant, K1 then torque-

T=$K_1 V_r I_i - K$ … …. . (2)
Under threshold condition,
T= 0 = K_1VI - K
Or, VI=K/K_1=constant……… (3)
The equation can be represented by a rectangular hyperbola shown in Fig 4.



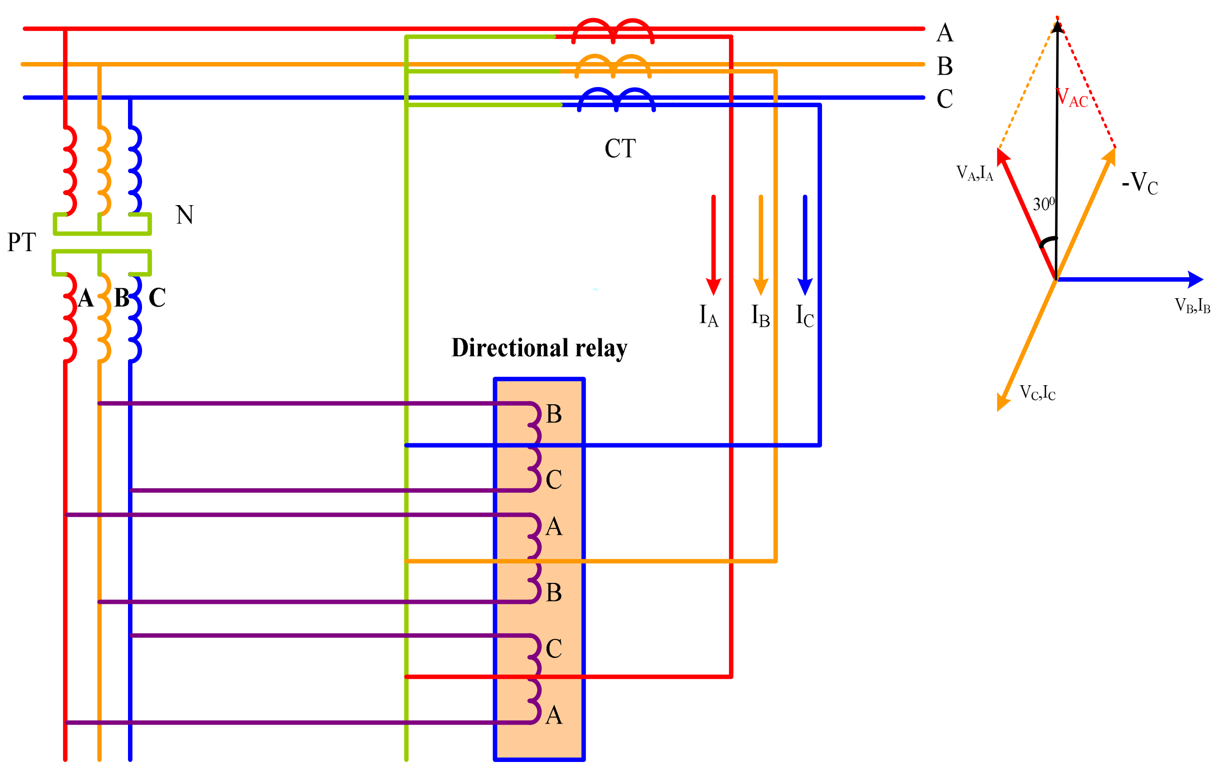
For the operation of the relay, the product of V and I should give a minimum torque which exceeds the friction and spring torque. From the characteristic it is clear that it is not enough to have the product greater than K, but there is minimum value of voltage and a minimum value of current required for the torque to be developed. For a close up fault the voltage at the relay point may collapse, so under that condition the relay will not operate. The maximum distance up to which the voltage is less than the minimum voltage required is known as the dead zone of the directional relay.

For satisfactory results the directional element in each relay must respond quickly and decisively; in a forward direction when the operation of the over current element is required and in reverse direction, to restrain, when it is not. To achieve this for all types of faults the relay cannot be connected to operate on true wattmeter type since the torque would not be sufficient when the voltage is small as occurs, for example, with close up faults. To overcome this, and thus to ensure that sufficient torque is always available; each relay is supplied with current from its respective phase and voltage from two phases.

One of the two methods of connection is normally used.

1. 30° connection.
2. 90° connection

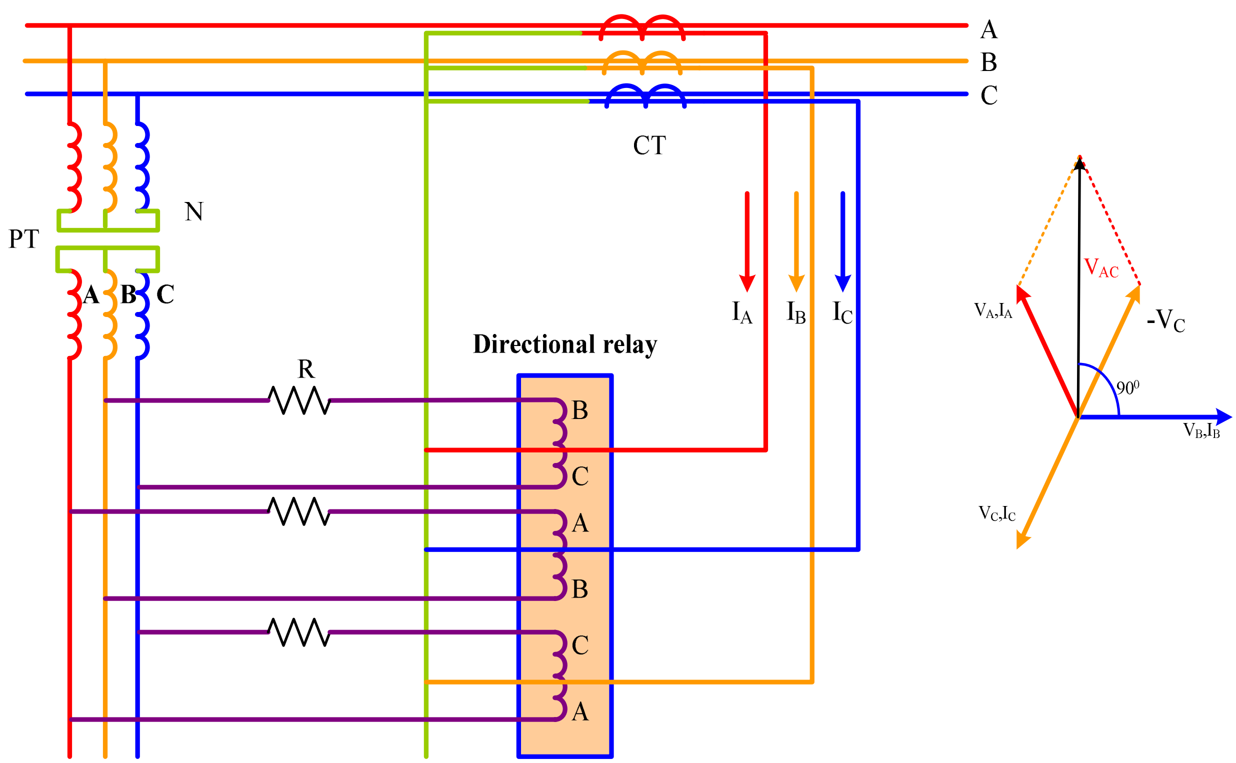
The first type employs a relay with a unity power factor characteristic i.e. where maximum torque occurs with the applied current and voltage in phase. The phase A relay is supplied with A phase current and A-C voltage, the B phase relay with B phase current and B-A voltage, and the C phase relay with C phase current and C-B voltage.



30^0 Connection

30° connection and its vector diagram are shown in Fig. 5. Since the relay is uncompensated for phase angle the maximum torque will occur when the primary power factor is $\cos 30^0 = 0.866$ leading.

The second type of connection (90° connection) gives a better performance with high torque. This requires a relay which has internal compensation so that maximum torque occurs when the relay current leads the voltage by 45°. For 90° connection the A phase current is combined with the B-C voltage in the A phase relay. In the B phase, the B phase current and A-C voltage are applied; and in the C phase, the C phase current and B-A voltage are applied. The connection and the vector diagram are shown in Figure.



90^0 Connection with internal compensation, R is applied for compensation to provide 45^0 lead of the flux from voltage coil

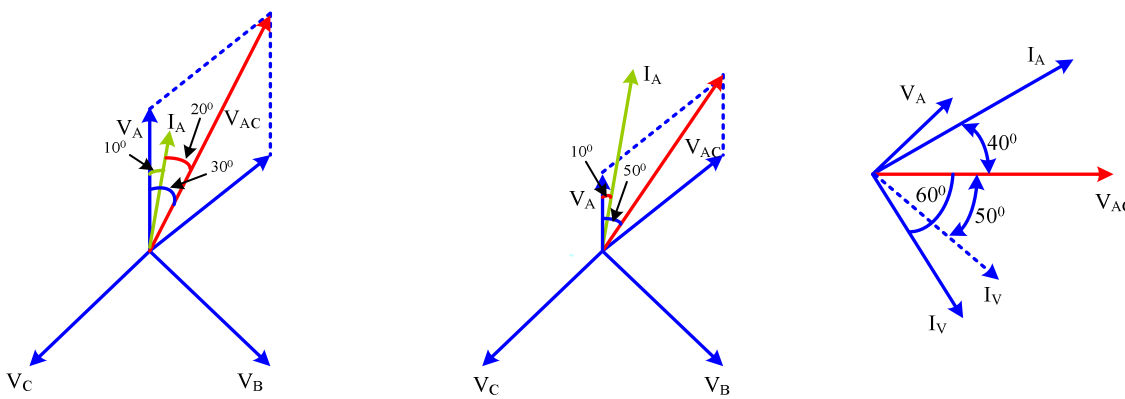
With these connection whatever the type of fault i.e. line to ground, line to line double line to ground or three phase faults, the phase angle between the current and voltage will always be well below 90°. The connection configuration of current coil and voltage coil for relays in 3 phases for both 30° and 90° connection are shown in the following table:

30° connection			90° connection		
Relay	I_r	V_r	Relay	I_r	V_r
I	I_A	V_{AC}	I	I_A	V_{AC}
II	I_B	V_{BA}	II	I_B	V_{BA}
III	I_C	V_{CB}	III	I_C	V_{CB}

Problem: A circuit with an impedance angle of 10° is to be protected by directional O/C relays. Use 30° connection for the directional element. The relay potential coil has an impedance of $1000\angle 60°\Omega$. What modification should be made and also find the quantitative value if it is desired that the relay will develop maximum torque under a close up fault condition on phase 'a'. The angle between V_a and V_{ac} at relay location becomes 50° under above mentioned fault condition.

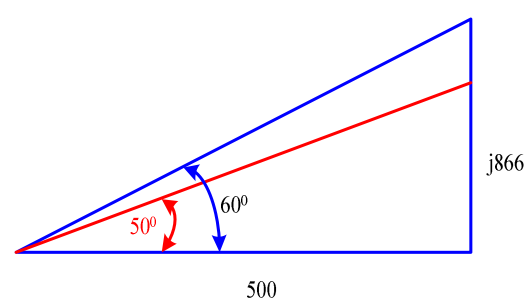
Solution:

For the cable, the impedance angle under operating condition is 10°. With 30° connection the phase angle between V_a and V_{ac} is 30°. V_{ac} Lags V_a by 30° and therefore I_a leads V_{ac} by 20°. The relay quantitates are current proportional to I_a and voltage proportional to V_{ac} for a fault on phase 'a'. In case of fault on phase 'a' the voltages of this phase up to the relay point becomes quiet small and say the phase angle between V_a and V_{ac} becomes 50° instead of 30°, thereby the angle between I_a and V_{ac} becomes 40°. The phasor diagram is shown in the figure:



Voltage V_{ac} is applied to the potential coil which has an impedance angle of 60° and the position of the current Iv is shown in the phasor diagram. The torque to be maximum, the angle between I_a and I_v should be 90°; therefore a capacitor of suitable value should be connected such that the impedance angle becomes 50° rather than 60° as shown by a dotted phasor in the phasor diagram.

$1000\angle 60°$= (500+j866)
For angle to be 50°, tan-1(X/R) = 50
Or, tan 50= X/R.
Or, X= 596,
but we have inductive reactance of 866 Ω
Therefore, capacitive reactance required
= 866-596= 270Ω
X_c = 1/(2πfC), or C = 1/(315*270) = 11.8 μf



Protection of ring mains by directional over current relay

Directional relays are more commonly applied to ring mains. The co-ordination of directional O/C relays for the protection of a ring main are shown and explained here**.**

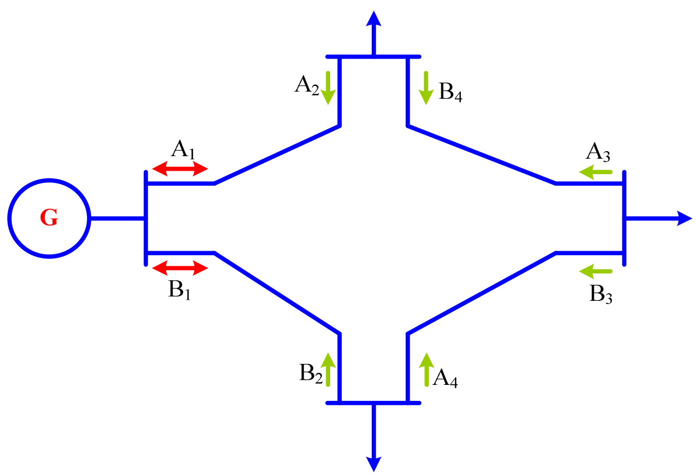


Figure: 1(a) : Ring main to be protected

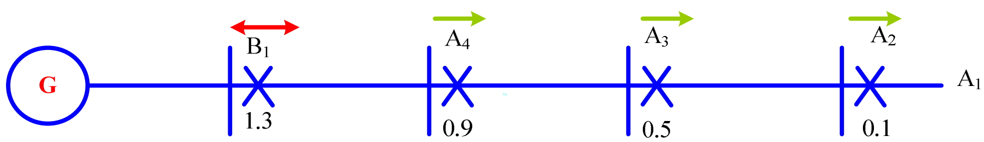


Figure 1(b)

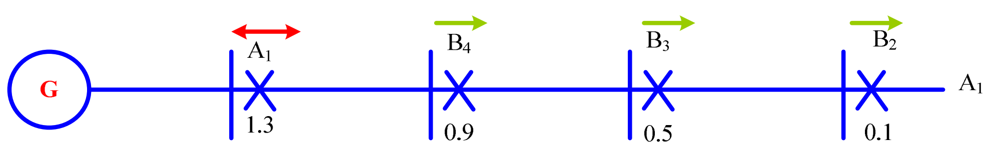


Figure 1(c)

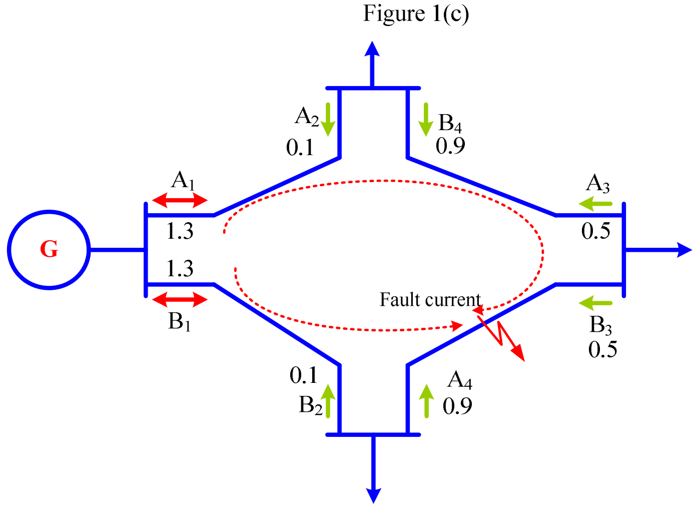


Figure: 1(d)

As shown in Fig. 1(a), four substations are interconnected and fed through one source. The relays A_1 and B_1 at the supply end are non-directional relays and the rest are directional relays. The usual procedure for grading the relays in an interconnected system is to open the ring at the supply point A_1 and considering the system as a radial feeder connected to one source as shown in Fig. 1(b). The relays (directional) are arranged to operate in the sequence A_2 in 0.1 sec, A_3 in 0.5 sec and A_4 in 0.9 sec and B_1 (Non-directional) in 1.3 sec.

Next open the ring at B_1 and the directional relay grading are performed in the sequence B_2 in 0.1 sec, B_3 in 0.5 sec, B_4 in 0.9 sec and the non-directional relay A_1 in 1.3 sec as shown in Fig. 1(b). Total protection scheme is shown in Fig. 1(d).

Consider a fault as shown in fig. 1(d), the fault will be as shown by the dotted line with arrow. The relays A_1, B_4, B_3, and B_1 and A_4 will start moving. The relays B_3 will operate first as this has minimum operating time out of these relays; therefore after a time 0.5 sec the relays B_4 and A_1 will reset as the fault current ceases to flow through these relays. In another fault path, A_4 will operate earlier than B_1 as the operating time of the former is less than that of the latter. Hence the faulty feeder between the relays B_3 and A_4 is isolated from the source. Discrimination of the faulty feeder is carried out according to time and fault current direction.

When two or more power sources feed into the ring main, time graded O/C protection is difficult to apply and full discrimination may not be possible.