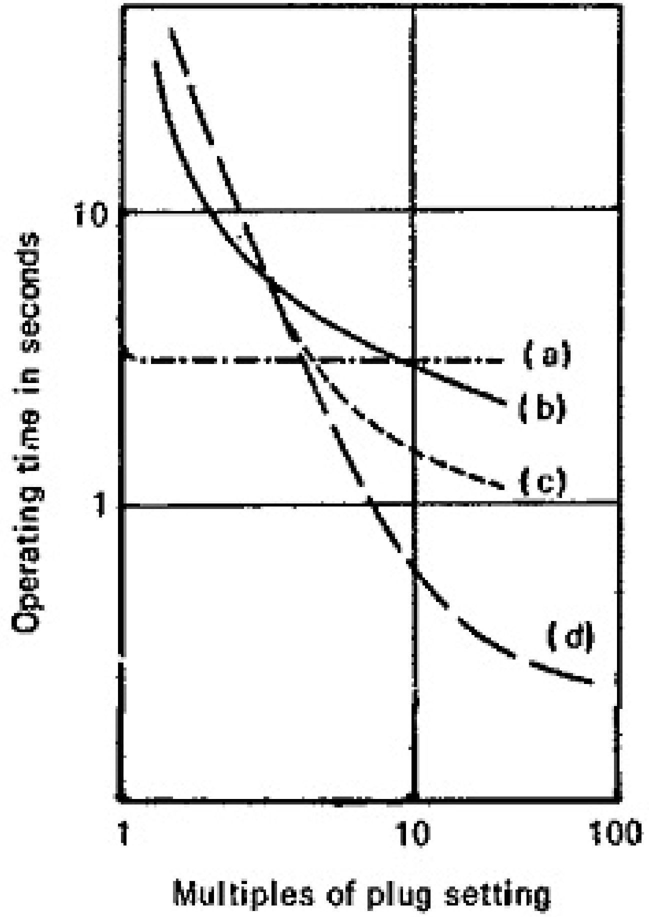
BEE701 Switchgear and Protection

Module 2: **Overcurrent Protection, Microprocessor based Protective Relays**	**Overcurrent Protection:** Introduction, Time current Characteristics, Current Setting, Time Setting. Overcurrent Protective Schemes, Reverse Power or Directional Relay, Protection of Parallel Feeders, Protection of Ring Mains, Earth Fault and Phase Fault Protection, Combined Earth Fault and Phase Fault Protective Scheme, Phase Fault Protective Scheme, Directional Earth Fault Relay, Static Overcurrent Relays, Numerical Overcurrent Relays. **Microprocessor based Protective Relays**: Introduction, Overcurrent relays, Impedance relay

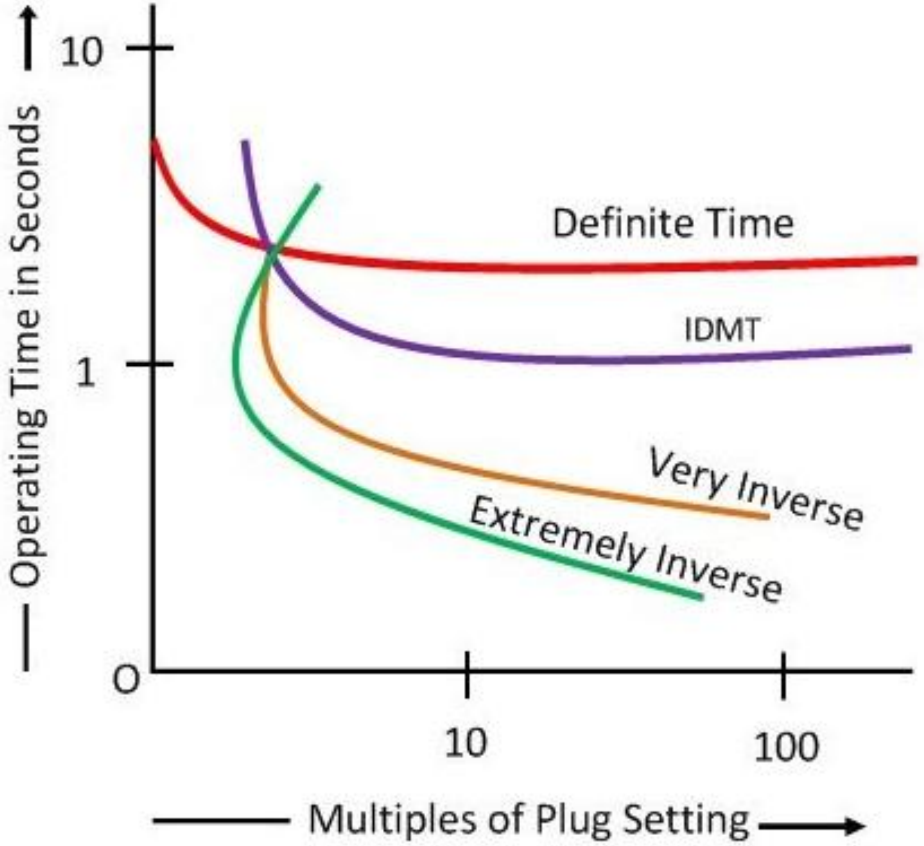
Overcurrent Relays

Time-current Characteristics

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



Characteristics of various overcurrent relays: (a) definite time; (b) IDMT; (c) very inverse; (d) extremely inverse.



Characteristic of Various Overcurrent Relay

Types of Overcurrent Relays

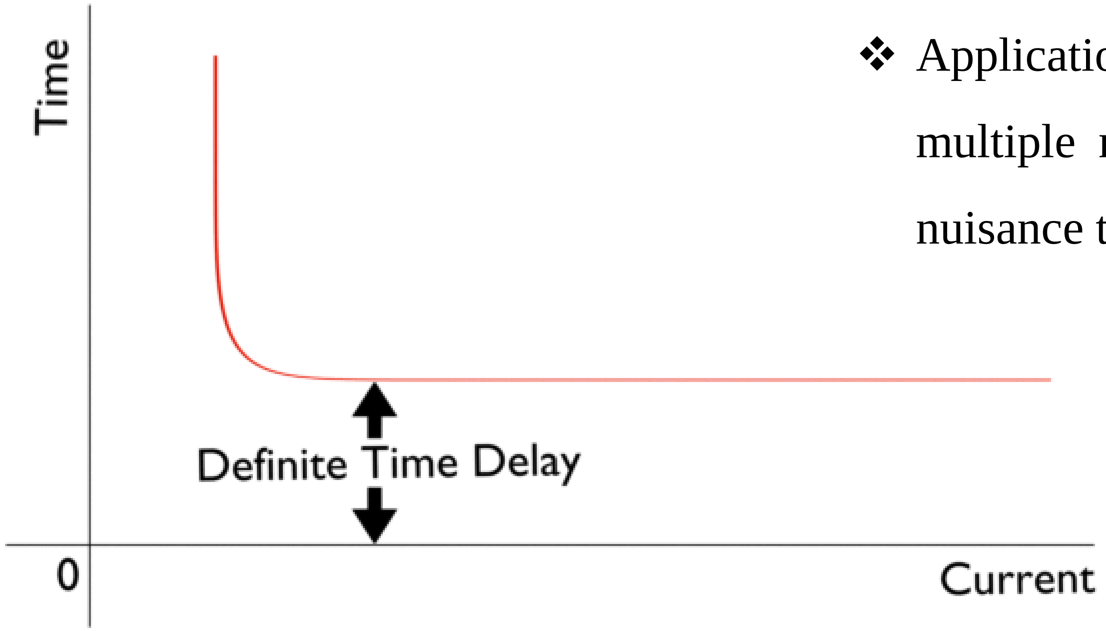
With their time-of-operation classified into Instantaneous, Definite Time, and Inverse Time (including Normal, Very and Extremely Inverse) types

Instantaneous Overcurrent Relay

- An instantaneous relay operates instantly without any intentional time delay when the current exceeds it s pick-up value.
- As the name suggests, this relay operates instantaneously, that is, without an intentional time delay. However, in practice, no relay can operate instantaneously, that is, in zero time. Therefore, a relay that operates within 20 to 40 ms is known as instantaneous relay
- The operating time is constant, irrespective of the magnitude of the current
- There is no intentional time-delay
- It operates in 0.1s or less
- **Application:** Used for high-level short circuits, such as in generators and transformers, where immediate disconnection is critical to prevent damage

Definite-time delay Overcurrent Relay

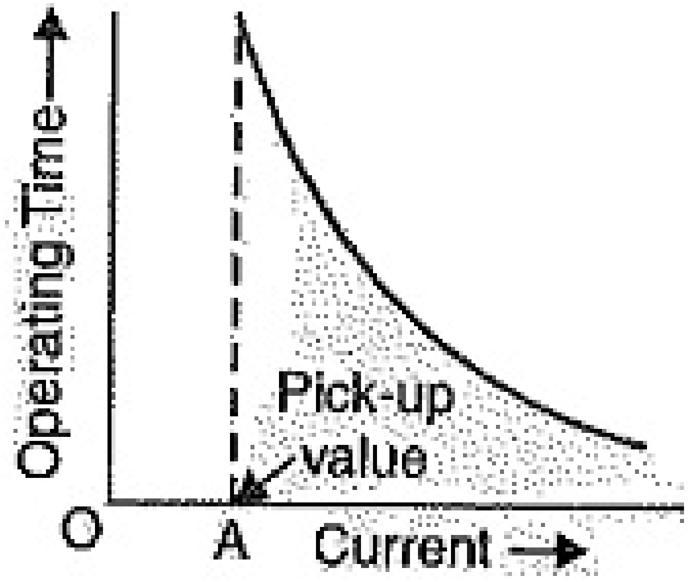
- A definite-time overcurrent relay operates after a after a definite period of time when the current exceeds its pick-up value
- The operating time is constant, irrespective of the magnitude of the current above the pick-up value.
- The desired definite operating time can be set with the help of an intentional time-delay mechanism provided in the relaying unit.

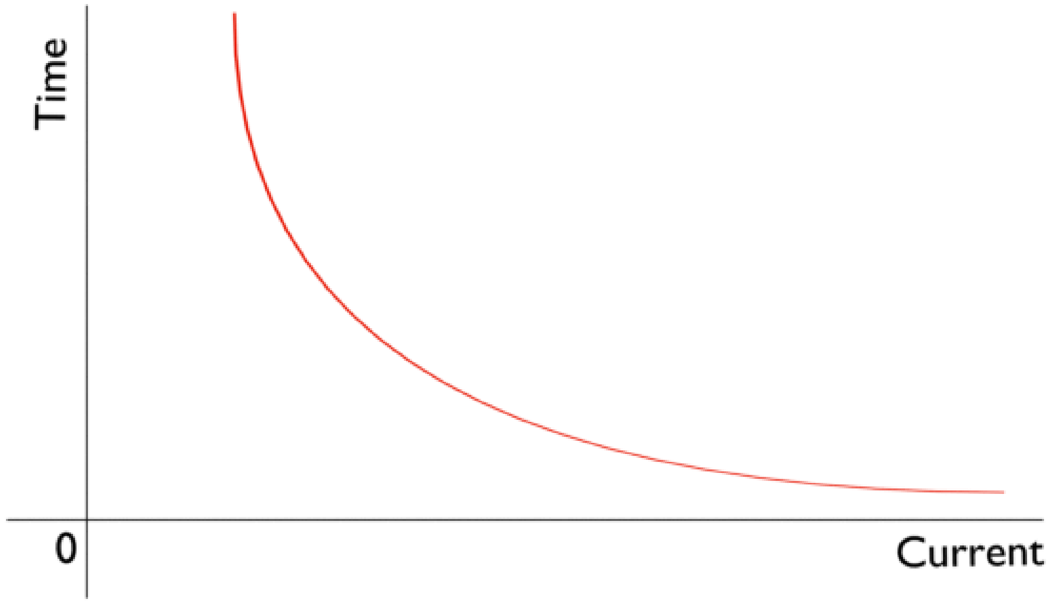


- Application: Essential for coordination in systems with multiple relays, ensuring selective tripping and preventing nuisance trips from temporary overloads.

Normal Inverse-time Overcurrent Relay

- An inverse-time overcurrent relay operates when the current exceeds its pick-up value.
- The operating time depends on the magnitude of the operating current.
- The operating time decreases as the current increases
- **Application: Normal Inverse:** Used in general industrial and utility systems where selective operation is needed.





Inverse Definite Minimum Time Overcurrent (I.D.M.T.) Relay

- This type of a relay gives an inverse-time current characteristic at lower values of the fault current and definite-time characteristic at higher values of the fault current

- Generally, an inverse-time characteristic is obtained if the value of the plug setting multiplier(PSM) is below 10. For values of Plug setting multiplier between 10 and 20, the characteristic tends to become a straight line i.e towards the define time characteristic
- **Applications**
- ID.M.T. relays are widely used for protection of distribution lines. Such relays have a provision for current and time settings
- System Coordination: Their unique operating characteristic is crucial for coordinating with other protection devices in the power system to ensure that faults are cleared in a selective and timely manner.

Very Inverse-time Overcurrent Relay

- A very inverse-time overcurrent relay gives more inverse characteristic (I.e. steeper) than that of a plain inverse relay or the I.D.M.T. relay.
- Its time-current characteristic lies between an I.D.M.T. characteristic and extremely inverse characteristic
- The very inverse characteristic gives better selectivity than the I.D.M.T. characteristic. Hence, it can be used where an I.D.M.T. relay fails to achieve good selectivity

Applications

- Very inverse time-current relays are recommended for the cases where there is a substantial reduction of fault current as the distance from the power source increases. They are particularly effective with ground faults because of their steep characteristic.
- Very/Extremely Inverse: Ideal for protecting motors, cables and other equipment sensitive to overheating from prolonged faults.

Extremely Inverse-time Overcurrent Relay

- An extremely inverse time overcurrent relay gives a time-current characteristic more inverse than that of the very inverse and I.D.M.T. relays.
- i.e. More steeper than Very Inverse relays (Slowest response for the relatively low current levels, but fast actions for extremely higher current)
- When I.D.M.T. and very inverse relays fail in selectivity, extremely inverse relays are employed.
- I.D.M.T. relays are not suitable to be graded with fuses

Enclosed fuses have time-current characteristics according to the law $I^{3.5} * t = K$

The electromagnetic relay which gives the steepest time-current characteristic is an extremely inverse relay.

The time-current characteristic of an extremely inverse relay is law $I^2 . t = K$.

its characteristic is not good enough to be graded with fuses. But the best that can be done with electromagnetic relay is to use extremely inverse relays to grade with fuses

An extremely inverse relay is very suitable for the protection of machines against overheating. The heating characteristics of machines and other apparatus is also governed by the law $I^2 . t = K$

Hence, this **type of relays are used for the protection of alternators, power transformers, earthing transformers, expensive cables, railways trolley wires**, etc.

The rotors of large alternators maybe overheated if an unbalanced load or fault remains for a longer period on the system. In such a case, an extremely inverse relay, in conjunction with a negative sequence network is used. By adjusting the time and current settings, a suitable characteristic of the relay is obtained for a particular machine to be protected

A relay should not operate on momentary overloads. But it must operate on sustained short circuit current. For such a situation, it is difficult to set I.D.M.T. relays.

An extremely inverse relay is quite suitable for such a situation. This relay is used for the protection of alternators against overloads and internal faults. It is also used for reclosing distribution circuits after a long outages.

After long outages, when the circuit breaker is reclosed there is a heavy inrush current which is comparable to a fault current. An I.D.M.T. relay is notable to distinguish between the rapidly decaying inrush current of the load and the persistent high current of a fault. Hence, an I.D.M.T. relay trips again after reclosing

But an extremely inverse relay is able to distinguish between a fault current and inrush current due to its steep time-current characteristic. Therefore an extremely inverse relay is quite suitable for the load restoration purpose

Calculation of Tripping Time:

IEC 60255 Tripping Curves

The IEC 60255 standard defines four standard current time characteristics – standard inverse (SI), very inverse (VI), extremely inverse (EI) and long-time inverse.

Each characteristic can be calculated from

Equation for trip time: $$t = \frac{K}{\left(\frac{I}{I_s}\right)^{\alpha} - 1} \times TMS$$

t = tripping time in (S)
I_s is the relay pick-up current setting.
I is the actual current i.e fault (actual) secondary CT current (A)
TMS = time multiplier setting
k and **α** are the curve type constants.

See the table below

For definite-time characteristic, the value of α = 0

Equation constants

Curve type	α	K
Standard Inverse(Normal Inverse(3.0))	0.02	0.14
Normal Inverse(1.3)	0.02	0.061
Normal Inverse(0.6)	0.02	0.028
Very Inverse	1.0	13.5
Extremely Inverse	2.0	80
Long-time Inverse	1.0	120

Calculation of Tripping Time:

IEC 60255 Tripping Curves

Relay Characteristics	Equations (IEC 60255)
Standard inverse (SI)	$t = TMS * \frac{0.14}{(I_r)^{0.02} - 1}$
Very inverse (VI)	$t = TMS * \frac{13.5}{I_r - 1}$
Extremely inverse (EI)	$t = TMS * \frac{80}{I_r^{2} - 1}$
Long time stand by earth fault	$t = TMS * \frac{120}{I_r - 1}$

Where: Ir = I/Is, I= Measured current, Is=Relay setting current, TMS=Time Multiplier Setting

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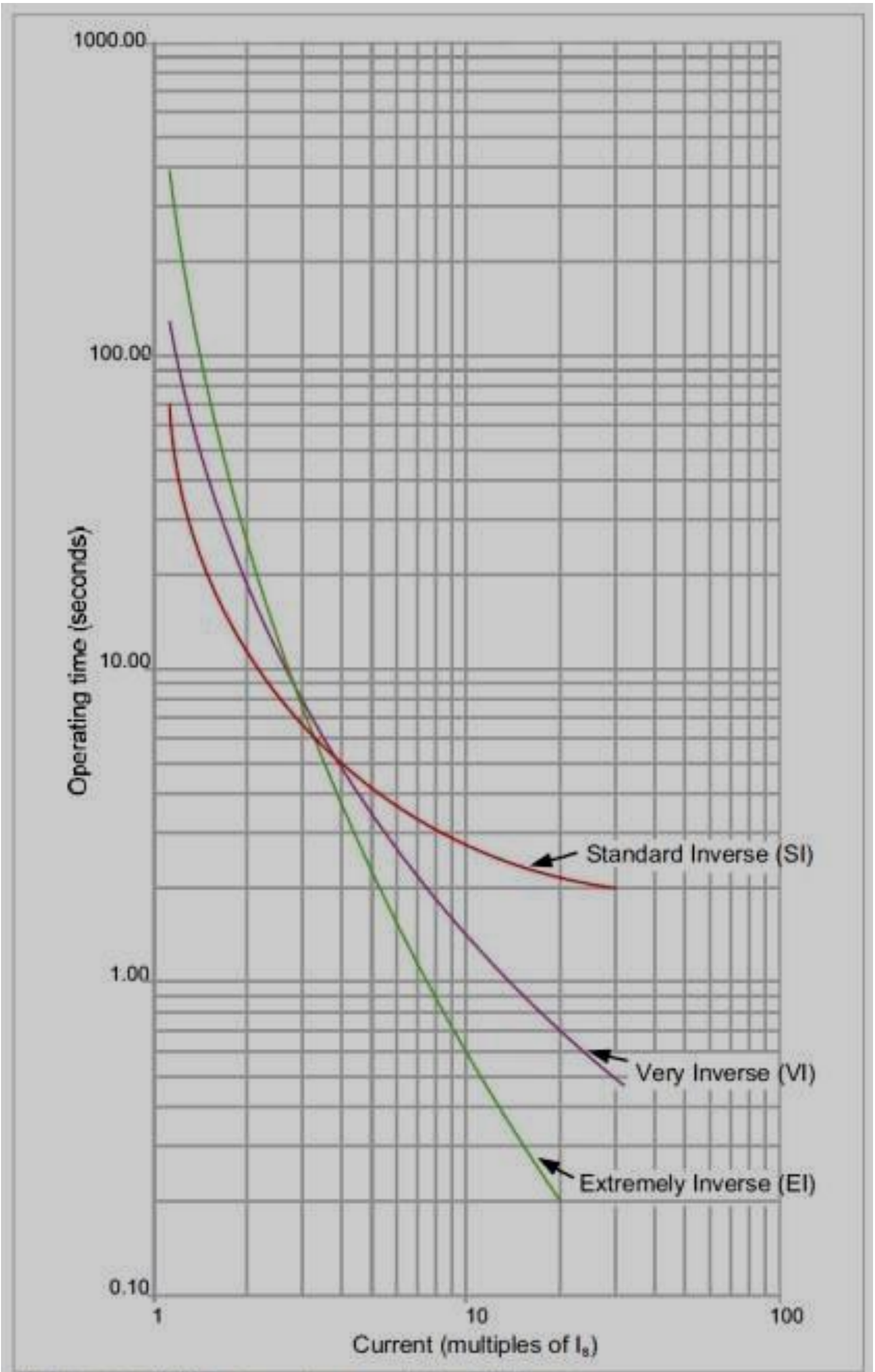
IEC 60255 Tripping Curves



IEC 60255 IDMT relay characteristics; TMS=1.0

Technique to Realise Various Time-current Characteristics Using Electromechanically Relays

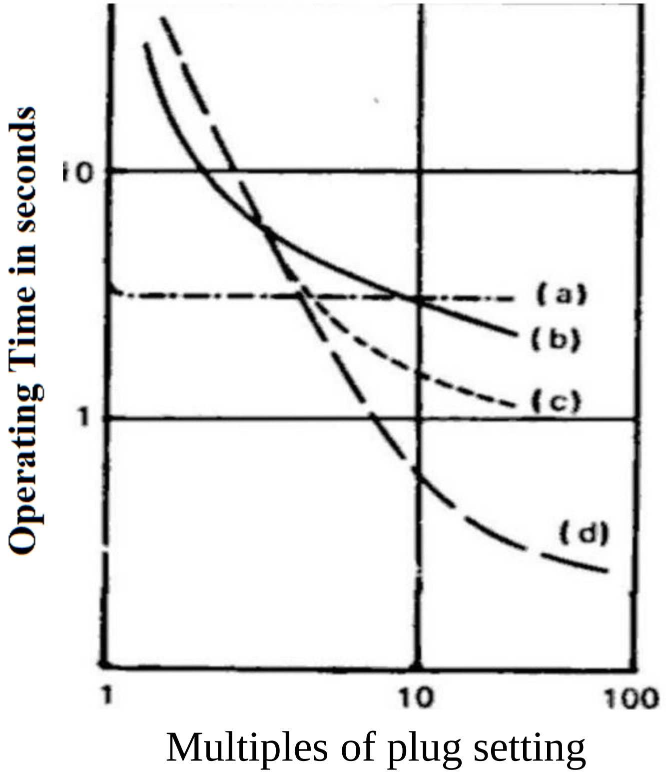
The operating time of all over current relays tends to become asymptotic (Straight Line) to a definite minimum value with increase in the value of current. This is inherent in electromagnetic relays due to saturation of the magnetic circuit. So by varying the point of saturation different characteristics are obtained; these are:

Characteristics of various overcurrent relays:

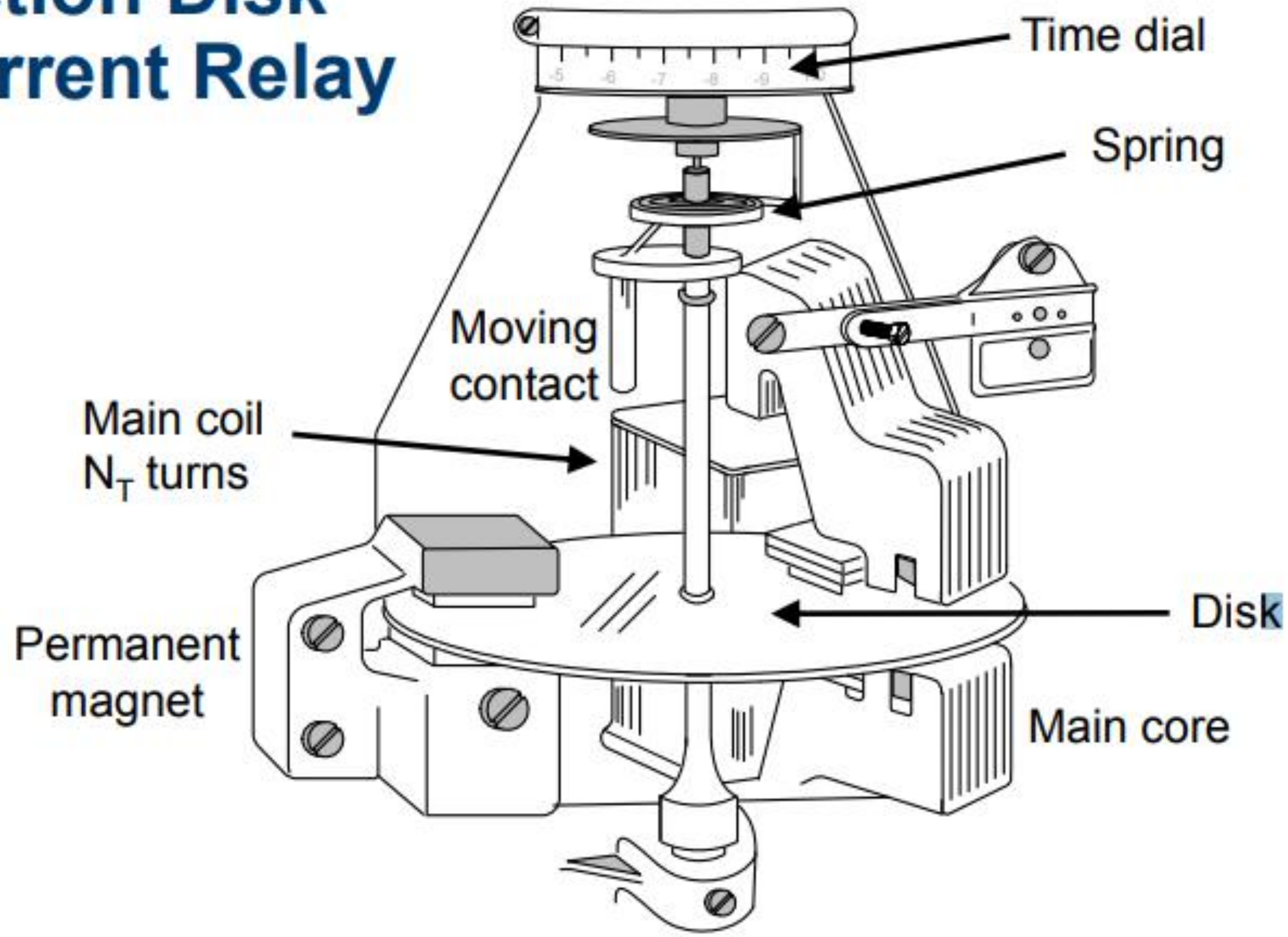
(a) definite time ;(b) Inverse definite minimum time (IDMT).

(c) Very inverse (d) extremely inverse

If the core is designed to saturate at the pick-up value of the current, the relay gives a definite time-characteristic. If the core is designed to saturate at a later stage, an I.D.M.T. characteristic is obtained. If the core saturates at a still later stage, a very inverse characteristic is obtained. If the saturation occurs at a very late stage, the relay gives an extremely inverse characteristic.



Induction Disk Overcurrent Relay



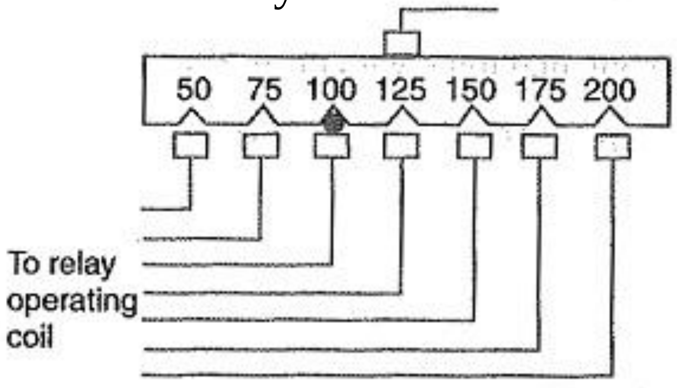
Time-current curve setting – controls initial disk position (time-dial setting)

Pickup current setting – taps in relay current coil

Current (plug) pick-up setting – taps in relay current coil

This adjusts the setting current by means of a plug bridge, which varies the effective turns on the upper electromagnet

Pick-up current: It is the minimum current in the relay coil at which the relay starts to operate



Current setting is usually achieved by the use of tappings on the relay operating coil. The taps are brought out to a plug setting bridge as shown in above Fig.

The plug bridge permits to alter the number of turns on the relay coil. This changes the torque on the disc and hence the time of operation of the Relay Timing Circuit.

The values assigned to each tap are expressed in terms of percentage full-load rating of C.T. with which the relay is associated and represents the value above which the disc commences to rotate and finally closes the trip circuit

For example, suppose that an overcurrent relay having current setting of 125% is connected to a supply circuit through a current transformer of 400/5. The rated secondary current of C.T. is 5 amperes. Therefore, the pick-up value will be 25% more than 5 A i.e. 5 x 1.25 = 6.25 A.

It means that with above current setting, the Relay Timing Circuit will actually operate for a relay coil current equal to or greater than 6.25 A.

An over current relay which is used **For Phase to phase fault protection can be set at 50% to 200% of rated current in steps of 25%. The usual current rating of this relay is 5A**

The relay which is used for the protection against ground fault (Earth Fault relay) settings usually range from and 10% to 80% in steps of 10%. The current rating of an earth-fault relay is usually 1A

Plug-setting multiplier (P.S.M.): It is the ratio of fault current in relay coil to the pick-up current i.e.

Plug-setting multiplier represents the number of times the relay current is in excess of the current setting

$$\text{P.S.M.} = \frac{\text{Fault current in relay coil}}{\text{Pick - up current}}$$

$$= \frac{\text{Fault current in relay coil}}{\text{Rated secondary current of } CT \times \text{Current setting}}$$

PSM = Current injected in relay coil (secondary current of CT) / Relay Current Setting

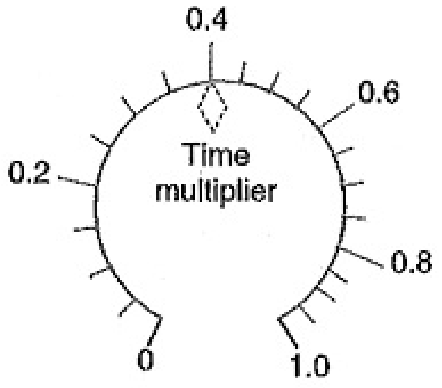
Or

PSM = Primary current during fault i.e. Fault current / (Relay Current Setting * C.T ratio)

Time Setting

Time-current curve setting – controls initial disk position (time-dial setting)

The time multiplier setting: This adjusts the operating time at a given multiple of setting current, by altering by means of the torsion head, the distance that the disk has to travel before contact is made.



A relay is generally provided with control to adjust the time of operation. This adjustment is known as **time-setting multiplier**. The time-setting dial is calibrated from 0 to 1 in steps of 0.05 sec (see Fig.).

These figures are multipliers to be used to convert the time derived from time/P.S.M. curve into the actual operating time. Thus if the time setting is 0.1 and the time obtained from the time/P.S.M. curve is 3 seconds, then actual relay operating time = 3 x 0.1 = 0.3 second.

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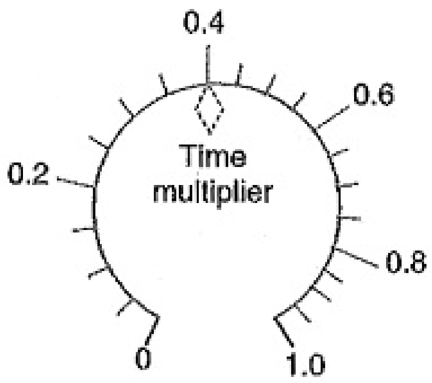
Time Setting



Different TMS is obtained by varying the travel of the disc or cup required to close the contact, The time of operation is controlled by adjusting the amount of travel of the disc (**angular distance travel of the disc**) from its reset position to its pickup position. This is achieved by the adjustment of the position of a movable backstop which controls the travel of the disc and thereby varies the tune in which the relay will close its contacts for given values of fault current. A so-called "time dial" with an evenly divided scale provides this adjustment.

Effect of Time-setting

By reducing the time multiplier, the characteristic is shifted to lower side, indicating that operating time is reduced

Time dial shifts curve up / down (slower / faster)

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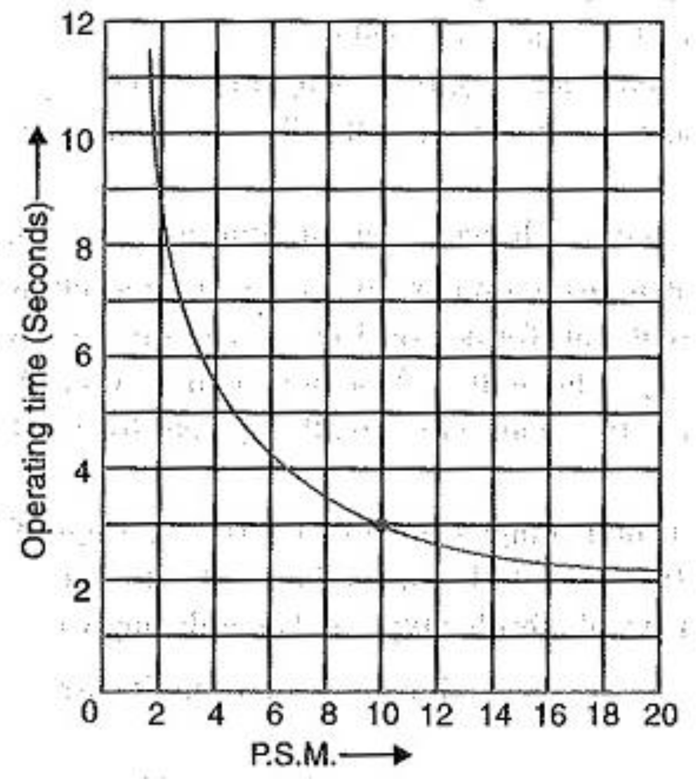
Time/P.S.M. Curve:

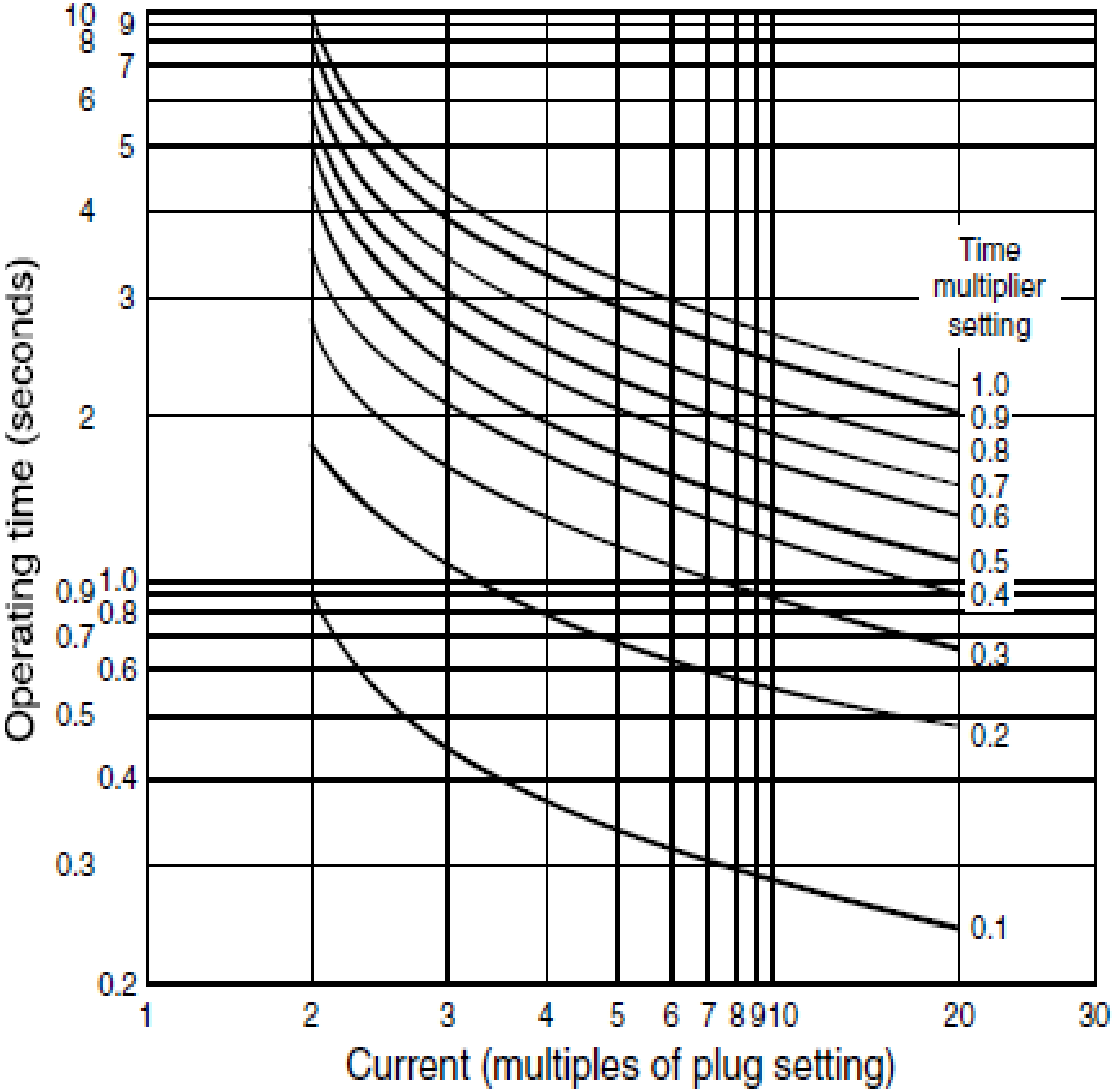
Curve between time of operation and plug setting multiplier of a typical relay

The horizontal scale is marked in terms of plug-setting multiplier and represents the number of times the relay current is in excess of the current setting. The vertical scale is marked in terms of the time required for relay operation.

If the P.S.M. is 10, then the time of operation (from the curve) is 3 seconds. The actual time of operation is obtained by multiplying this time by the time-setting multiplier



Inverse Characteristics of induction disc relay on log scale



Solved Numerical 1

Relay is connected to a 400/5 current transformer and set at 150%. With a primary fault current of 2400 A, be calculated the plug-setting multiplier

$$\text{Pick-up value} = \text{Rated secondary current of } CT \times \text{Current setting}$$

$$\text{Pick-up value} = \text{Rated secondary current of } CT \times \text{Current setting}$$
$$= 5 \times 1{\cdot}5 = 7{\cdot}5 \text{ A}$$

$$\text{Fault current in relay coil} = 2400 \times \frac{5}{400} = 30 \text{ A}$$

$$\text{P.S.M.} = \frac{\text{Fault current in relay coil}}{\text{Pick-up current}}$$

$$= \frac{\text{Fault current in relay coil}}{\text{Rated secondary current of } CT \times \text{Current setting}}$$

$$\text{P.S.M.} = 30/7{\cdot}5 = 4$$

Solved Numerical 2

Solve for the Plug setting multiplier of a 5A, 2.2 sec over current relay having a plug setting PS=200%. The supply CT is rated 400:5A and the fault current is 12000A.

(Note- 2.2 sec operation at 20 time the current plug setting, assuming TMS=1

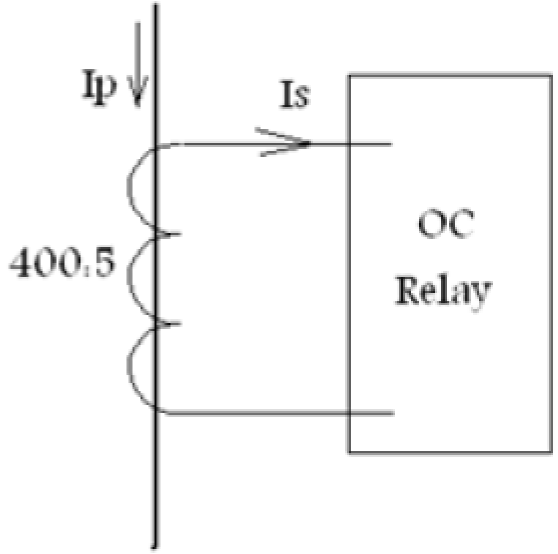
$$I_p = 12000A$$

$$I_s = 12000 \times \frac{5}{400} = 150A$$

On PS of 200%:

$$\text{The relay current} = 5 \times \frac{200}{100} = 10A$$

$$\text{Hence PSM} = \frac{150}{10} = 15$$



Solved Numerical 3

Determine the time of operation of an IDMTL relay rating 5A, 2.2sec and having a plug setting PS= 125% , and TMS=0.6. It is connected to a supply circuit through a C.T of 400/5 ratio. The fault current is 4000A.

Since Ps =125% = 1.25

Then the operating current of the relay: 5×1.25=6.25A

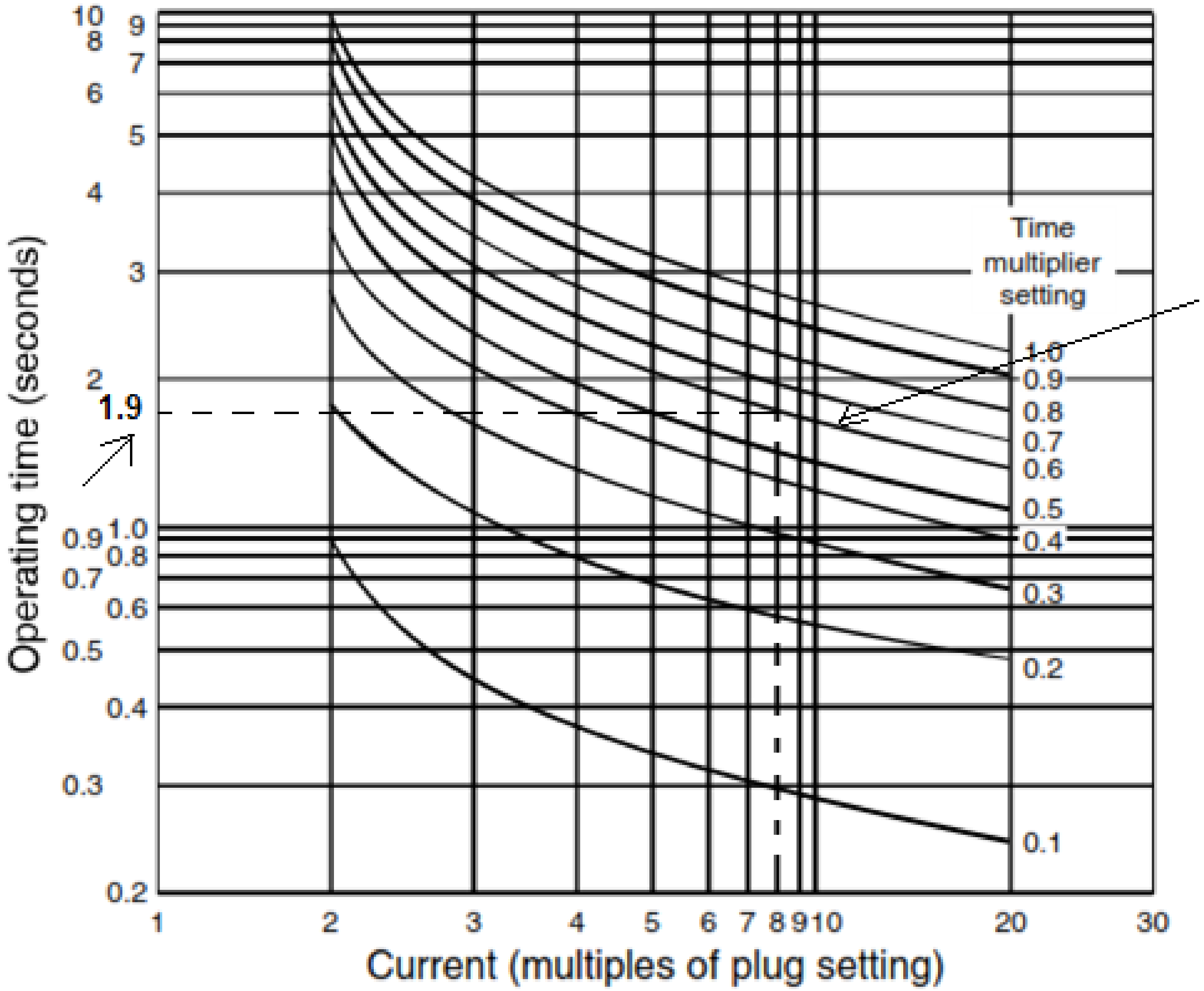
$$I_p = 4000A$$

$$I_s = 4000 \times \frac{5}{400} = 50A$$

$$PSM = \frac{secondary \cdot current}{relay.operating.current} = \frac{50}{6.25} = 8$$

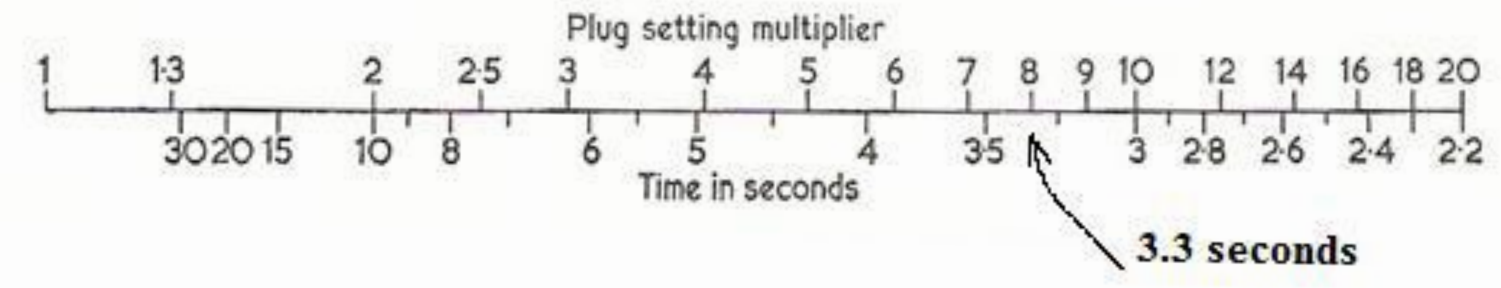
Now we can find the operating time of the relay in following methods

Directly from characteristics of the relay as shown in Fig



The operating time of the relay top from figure: top= 1.9secs (approx.) for TMS=0.6 & PSM=8

When TMS=1



For PSM = 8 , the operating Time of relay is = 3.3 sec at T.M.S = 1

The operating time of the relay for PSM=8 and TMS =0.6 is

= ((operating time for TMS = 1) * 0.6 TMS)

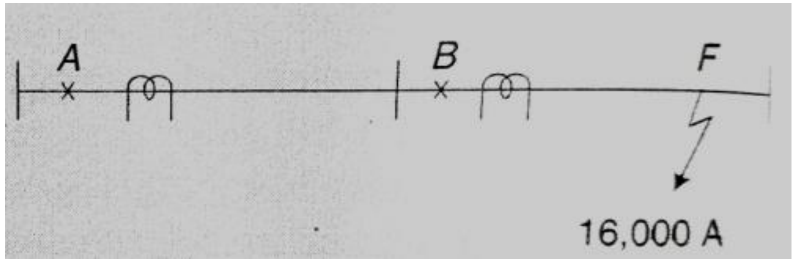
= 3.3Sec*0.6

= 1.9 secs

Solved Numerical 4

An earth fault develops at point F on the feeder and the fault current is 16000 A. The IDMT relays at points A and B are fed via 800/5 A CTs: The relay at B has a plug setting of 125% and time to multiplier setting (TMS) of 0.2. The circuit breakers take 0.20s to clear the fault, and the relay error in each case is 0.15s. For a plug setting of 200% on the relay A, Examine the minimum TMS on that relay for it not to operate before the circuit breaker at B has cleared the fault. The relay operating time characteristics of relay at various PSM are given in the below Table.

PSM	2	4	5	8	10	12	16	20
Operating time in seconds	10	5	4	3.4	3	2.8	2.5	2.2



The primary current in both relays is 16,000 A

CT ratio = 800/5 = 160

Thus secondary current = Primary current / CT ratio

= 16,00/160 = 100 A

For relay at B,

Current setting = 125% of 5 A = 1.25 x 5 A= 6.25 A

PSM = Secondary current/ Relay current setting

= 100/6.25 = 16

From the above table operating time at PSM of 16 for a TMS of 1 = 2.5 secs

Since TMS of relay at B = 0.2

Operating time of B = 0.2 x 2.5 s = 0.50 s

Discrimination time for breaker at B + twice relay error

= 0.20 + 2 x 0.15 = 0.50 s

This is because one relay may run rapidly while the second runs slowly. moreover, the relay at A does not reset until the breaker at B has interrupted the fault current. Any overshoot of the relay A has been neglected.

Hence time for relay at A = operating time for B + discrimination time

= 0.50 s + 0.50 s = 1.00 S

Secondary current in A = 100 A

For relay at A, current setting = 200% of 5 A

= 2 x 5 A = 10 A

Thus, PSM = 100/10 = 10

From the Table, the operating time at PSM of 10 for a TMS of 1 =3.0 s.

But actual time required = 1.00 s

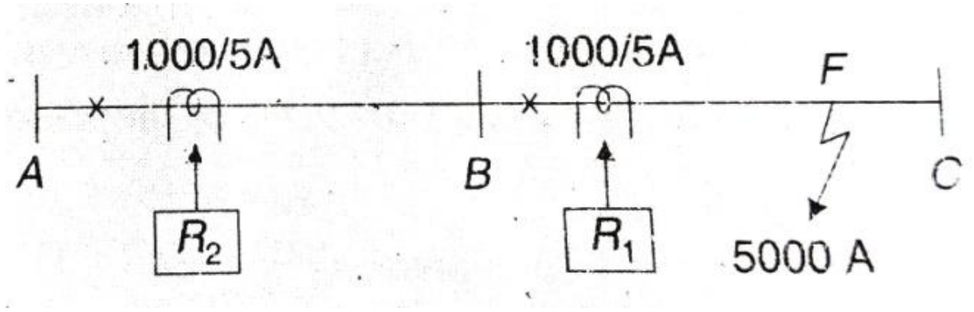
Hence required TMS for relay at A = 1.00/3.0= 0.33

i.e., the minimum value of TMS of relay at A must be 0.33.

Solved Numerical 5

Two relays R1 and R2 are connected in two sections of a feeder as shown in below Fig. CTs are of ratio 1000/5 A. The plug setting of relay R1 is 100% and R2 is 125%. The time multiplier setting of the relay R1 is 0.3. The time grading scheme has a discriminative time margin of 0.5 s between the relays. A three-phase short circuit at F results in a fault current of 5000 A. Examine the actual operating times of R1 and R2. Examine the time multiplier setting (TMS) of R2. The relay operating time characteristics of relay at various PSM are given in the below Table

PSM	2	4	5	8	10	12	16	20
Operating time in seconds For T.M.S = 1	10	5	4	3.4	3	2.8	2.5	2.2



CT secondary current =5000 x (5 / 1000)= 25 A

Relay R1

Plug setting = 100%

Current setting = 5 A

PSM = Secondary current / Relay current setting = 25/5

Operating time of the relay at PSM of 5 and TMS of 1 from the table is = 4 seconds.

Since TMS of the relay R1 is 0.3, the actual operating time of the relay = 0.3 x 4 = 0.3 x 4 = 1.2 seconds

Relay R2

Plug setting = 125%

Relay current setting = 125% of 5 A = 1.25 x 5 = 6.25 A

PSM = Secondary current / Relay current setting = 25/6.25 =4

Operating time at PSM of 4 and TMS of 1 from the table is 5 seconds

Actual operating time of R2 = Operating time of R1 + time grading margin

= 1.2 + 0.5

= 1.7 seconds

Hence, TMS = 1.7/5 = 0.34

OVERCURRENT PROTECTIVE SCHEMES

Overcurrent protective schemes are widely used for the protection of distribution lines. A radial feeder may be sectionalized and two or more overcurrent may be used, one relay for the protection of each section of the feeder, as shown in below fig.

Protection of Radial Feeder

In radial feeder, the power flows in one direction only, which is from source to load. This type of feeders can easily be protected by using either definite time relays or inverse time relays

Overcurrent relays have to play dual roles of both primary and backup protection. For example, in a radial distribution system, there may be more feeders downstream. If the downstream fuse or relay R1or circuit breaker fails to detect the fault and/or isolate the equipment, upstream relays/CBs R2 have to be opened.

For proper selectivity of the relays, one of the following schemes can be employed, depending on the system conditions.

(i) Time-graded system

(ii) Current-graded system

(iii) A combination of time and current grading

Overcurrent Protective Schemes

Time-Graded Systems:

- In this scheme, definite-time delay overcurrent relays are used.
- The operating time of the relays is adjusted in increasing order from the far end of the feeder

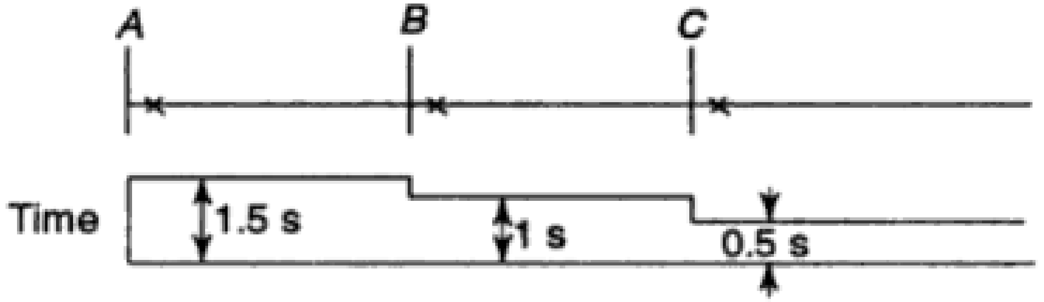


FIGURE Time-graded overcurrent protection of a feeder

Current-Graded Systems:

- In a current-graded scheme, the relays are set to pick-up at progressively higher values of current towards the source.
- The relays employed in this scheme are high set (high speed) instantaneous overcurrent relays.
- The operating time is kept the same for all relays used to protect different sections of the feeder

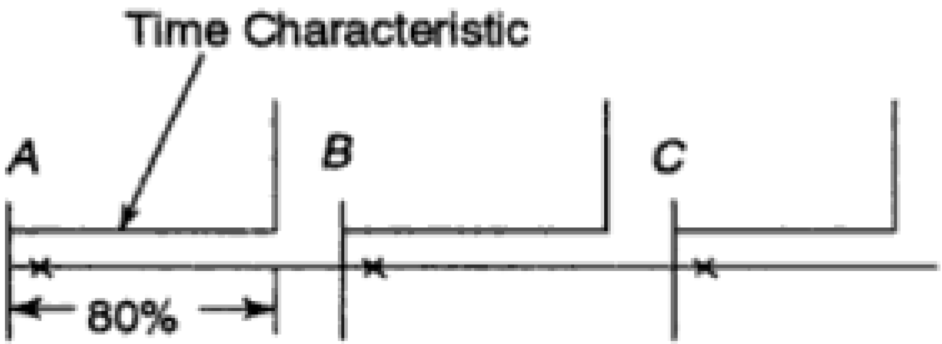


FIGURE Instantaneous overcurrent protection of a feeder

Consequently, to obtain proper discrimination relay are set to protect only a part of the feeder, usually about 80% , since above scheme cannot protect the entire feeder, it is not used alone, it may be used in conjunction with I.D.M.T. relays,

Combination of Time And Current Grading Systems:

- This scheme is widely used for the protection of distribution lines. ID.M.T. relays are employed in this scheme.
- They have the combined features of current and time-grading.
- I.D.M.T. relays have current as well as time setting arrangements.
- The current setting of the relay is made according to the fault current level of the particular section to be protected.
- The relays are set to pickup progressively at higher current levels, towards the source.
- Time setting is also done in a progressively increasing order towards the source.
- The difference in operating times of two adjacent-relays is kept 0.5s.

Though I.D.M.T. relays are widely used for the protection of distribution systems and some other applications, in certain situations very inverse and extremely inverse relays are used instead of I.D.M.T. relays, has already discussed

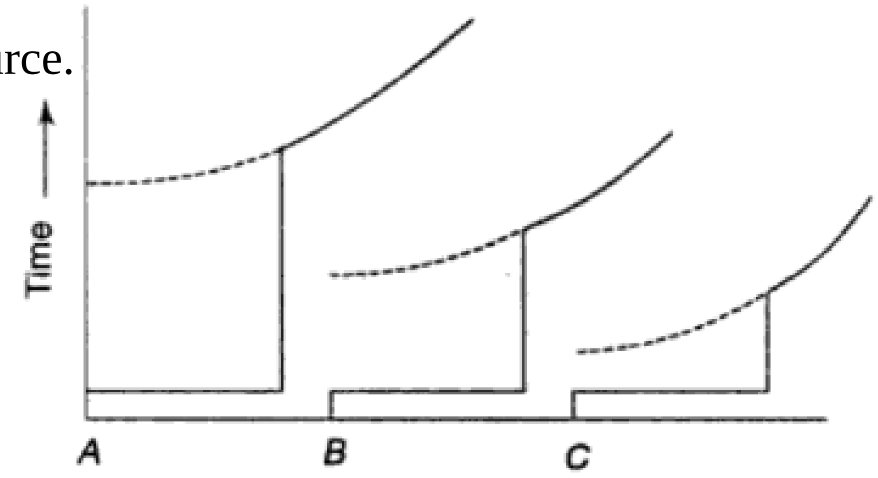
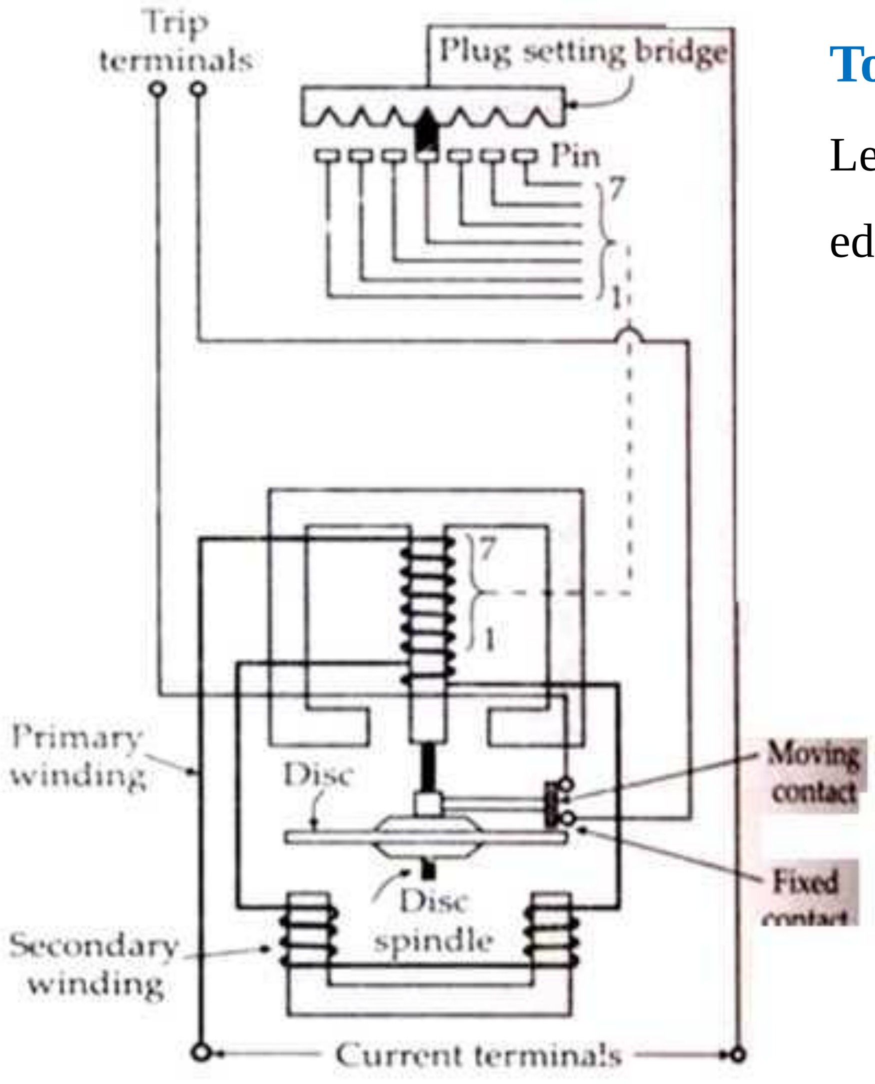


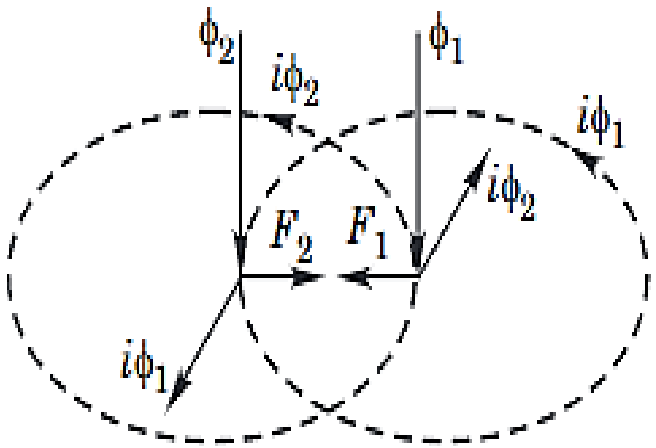
FIGURE Combined instantaneous and I.D.M.T. protection

NON-DIRECTIONAL OVER-CURRENT OR EARTH-LEAKAGE (INDUCTION TYPE) RELAY



Torque Equation of an Induction Disc Relay

Let and ϕ1 and ϕ2 be the two fluxes at a phase difference of θ and which produce eddy currents iϕ1 and iϕ2 in the disc.



$$\phi_1 = \phi \sin \omega t$$

$$\phi_2 = \phi \sin (\omega t + \theta)$$

$$i\phi_1 = \frac{d\phi_1}{dt} \propto \phi \cos \omega t$$

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

$$F = (F_2 - F_1) \propto \phi_2 \, i\phi_1 - \phi_1 \, i\phi_2$$

where F is net force due to interaction between ϕ2 and ϕ1 . F1 is force due to interaction between ϕ1 and ϕ2 .

$$F \propto \phi_1 \phi_2 [\sin (\omega t + \theta) \cos \omega t - \sin \omega t \cos (\omega t + \theta)]$$

$$\propto \phi_1 \phi_2 \sin \theta.$$

Reverse Power or Directional Relay

Reverse power protection is applicable when generators run in parallel with the grid to ensure uninterrupted power to essential loads and to protect against the failure of the prime mover. Should this fail then, the generator would motor by taking power from the system and could aggravate the failure of the mechanical drive

The basic protection employed in such systems are use of reverse power relays, which are used basically, to protect the grid from the faulty generators operating as motors.

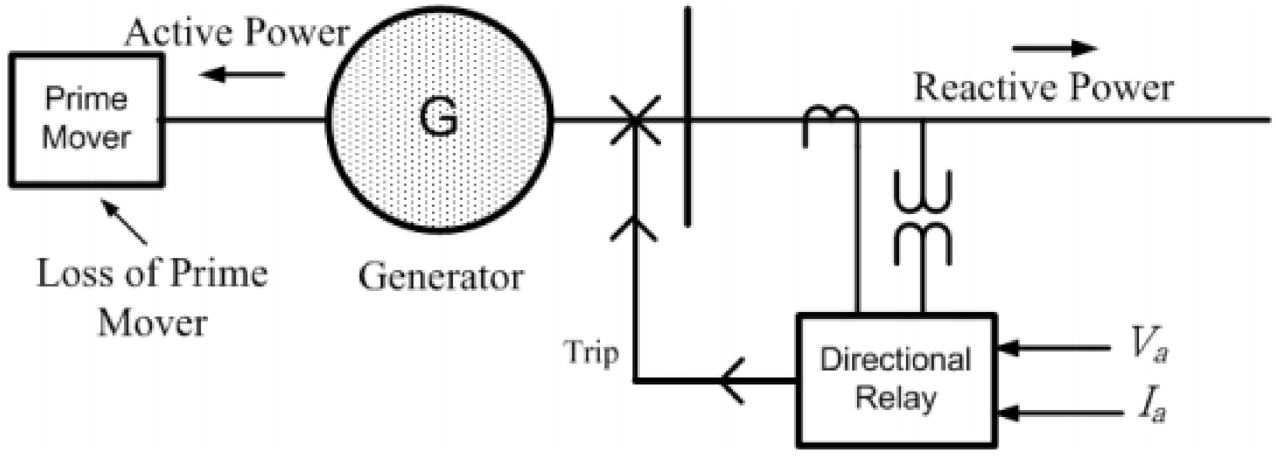


Figure . Reverse Power Relay in Power System

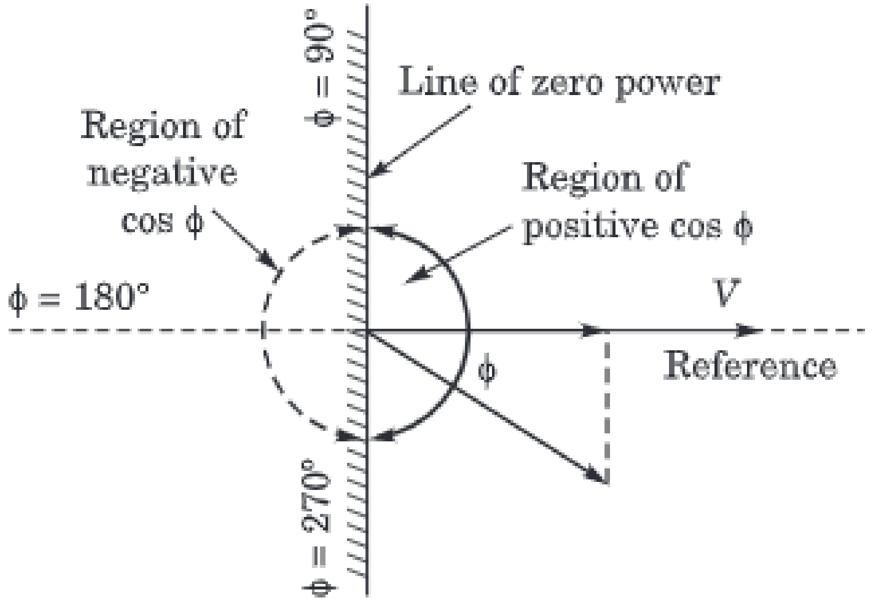


Fig. (a) Vector diagram of power.

'Ø' is the angle between current and voltage, then under normal direction of load flow $-90° < Ø < 90°$

And in case of reversed power flow **$+90° < Ø < 270°$**

Reverse Power or Directional Relay

Principle of Measurements

Active-power flowing through a part of an electric circuit is given by P= VI CosØ, where Ø is a phase angle between I and V

The reactive power is given by VI sin Ø **Referring to Fig**

For 270° < Ø < +90°, Cos Ø is positive, hence real power P is Positive. i.e. Normal direction of load flow -90° < *Ø* < *90°*

For Ø = 90° and 180°, real power P is zero.

For + 90° <Ø < + 270° real power P is negative

i.e. case of reversed power flow +90° **< Ø < + 270°**

Therefore the power flow can be sensed by sensing the magnitude and sign of VI CosØ.

The voltage coil of the directional relay is supplied from secondary of voltage transformer. The current coil is supplied from the secondary of current transformer

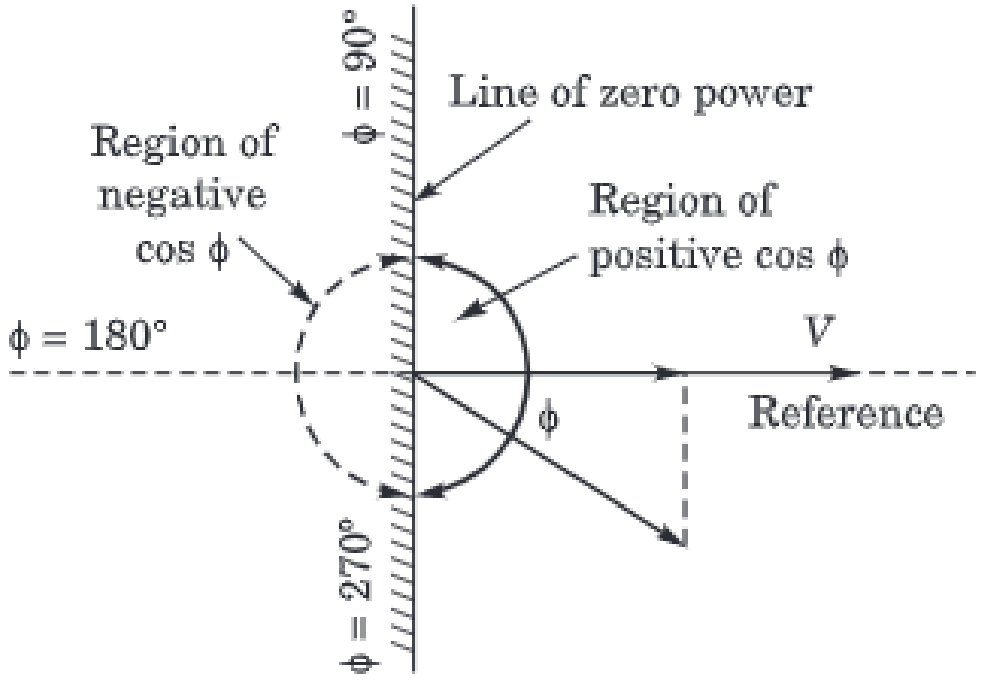


Fig. (*a*) Vector diagram of power.

The Directional Element (67) receives Reference voltage Vref from the VT on the bus, Current is measured by the CT in the protected Line, in normal operation the phase angle of the current may be upto say 20deg Lag, but if the direction of the current flow reverses, then the phase angle will change by 180deg, this very large difference is easy to relay to detect and activate the directional element

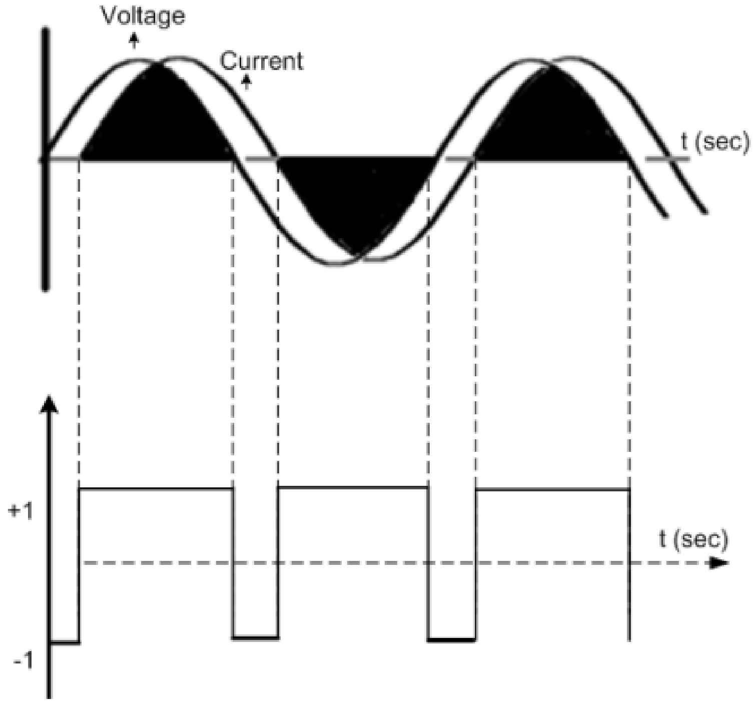
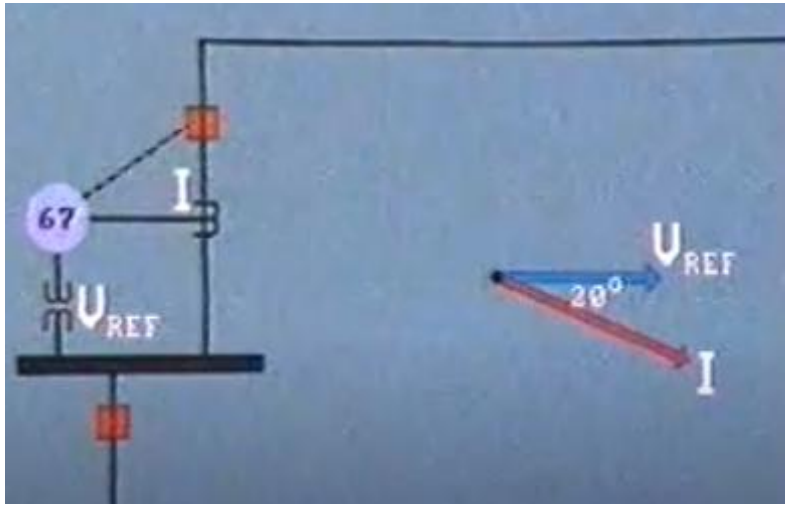
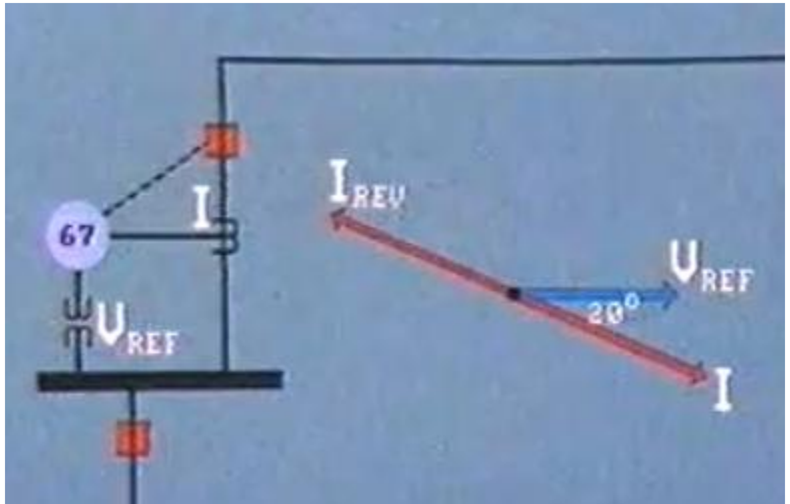


Figure a. Angle between Voltage and Current Waveforms under Normal Conditions





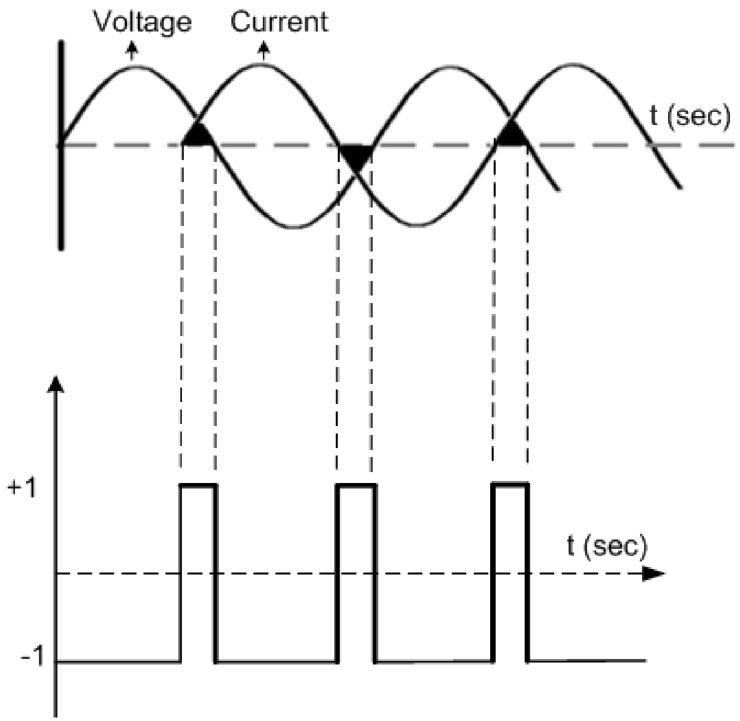
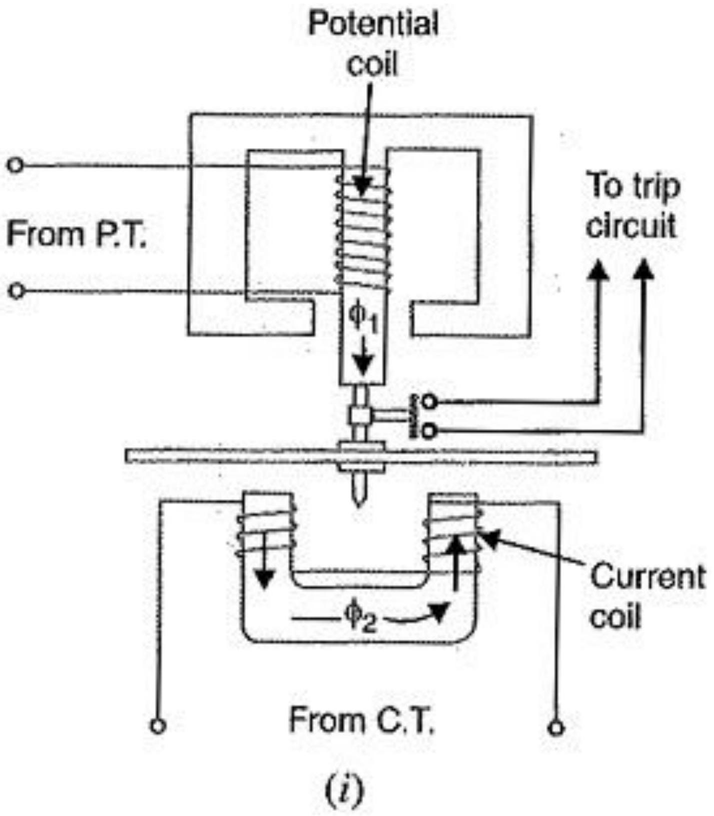
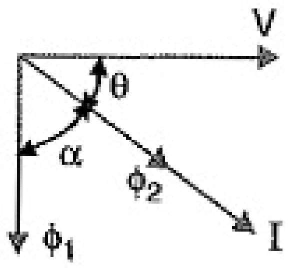


Figure b. Angle between Voltage and Current Waveforms under Fault Conditions

Induction Type Directional Power Relay

Construction & Working





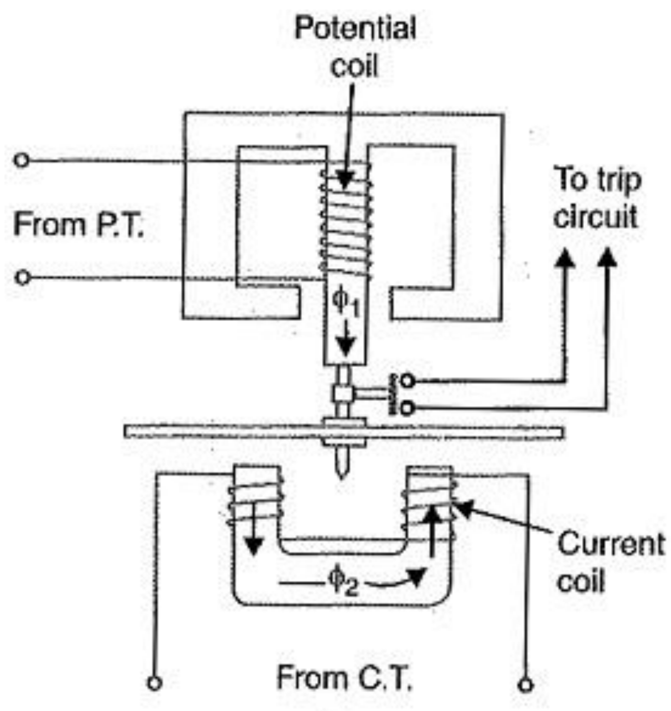
Directional protection responds to flow of power in a definite direction with reference to the location of CT's and PT's, Directional relays respond to the magnitude and sign (DIRECTION) of power applied at their terminal, directional relay are used in protective system as a element which judge the directional of power flow

The operating torque is produced by the interaction of fields given by both voltage and current sources of the circuit it protects. The relay operates when the current exceeds a predetermined set value in a specified direction.

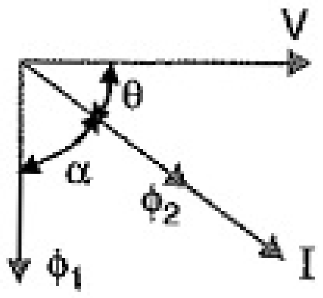
Construction

The lower electromagnet has a separate winding (called current coil) connected to the secondary of C.T. in the line to be protected. The current coil is provided with a number of tappings connected to the plug-setting bridge (not shown for clarity). This permits to have any desired current setting. The restraining torque is provided by a spiral spring. The spindle of the disc carries a moving contact which bridges two fixed contacts when the disc has rotated through a pre-set angle. By adjusting this angle, the travel of the moving disc can be adjusted and hence any desired time-setting can be given to the relay

Induction Type Directional Power Relay



(i)



Working

The two fluxes are produced by the two quantities for the production of torque. Let the two fluxes be Φ_1 and Φ_2. The current in the potential coil lags behind the applied voltage V nearly by 90°. Hence the flux Φ_1 produced by the potential coil also lags behind the applied voltage. While the flux Φ_2 produced by the current coil will be in phase with the line current. The torque produced on the disc is due to the interaction of eddy currents with the flux imposed by the potential and current coils and it is called driving torque. The driving torque is given by,

$$T \propto \Phi_1 \Phi_2 \sin \alpha$$

$$\text{Since, } \Phi_1 \propto V, \Phi_2 \propto I \text{ and } \alpha = 90° - \theta$$

$$T \propto V I \sin (90° - \theta)$$

$$T \propto V I \cos \theta \text{ (power in the circuit)}$$

It is clear that the direction of driving torque on the disc depends upon the direction of power flow in the circuit to which the relay is associated. When the power in the circuit flows in the normal direction, the driving torque and the restraining torque (due to spring) help each other to turn away the moving contact from the fixed contacts. Consequently, the relay remains inoperative. However, the reversal of current in the circuit reverses the direction of driving torque on the disc. When the reversed driving torque is large enough, the disc rotates in the reverse direction and the moving contact closes the trip circuit. This causes the operation of the circuit breaker which disconnects the faulty section.

Induction cup type directional Relay

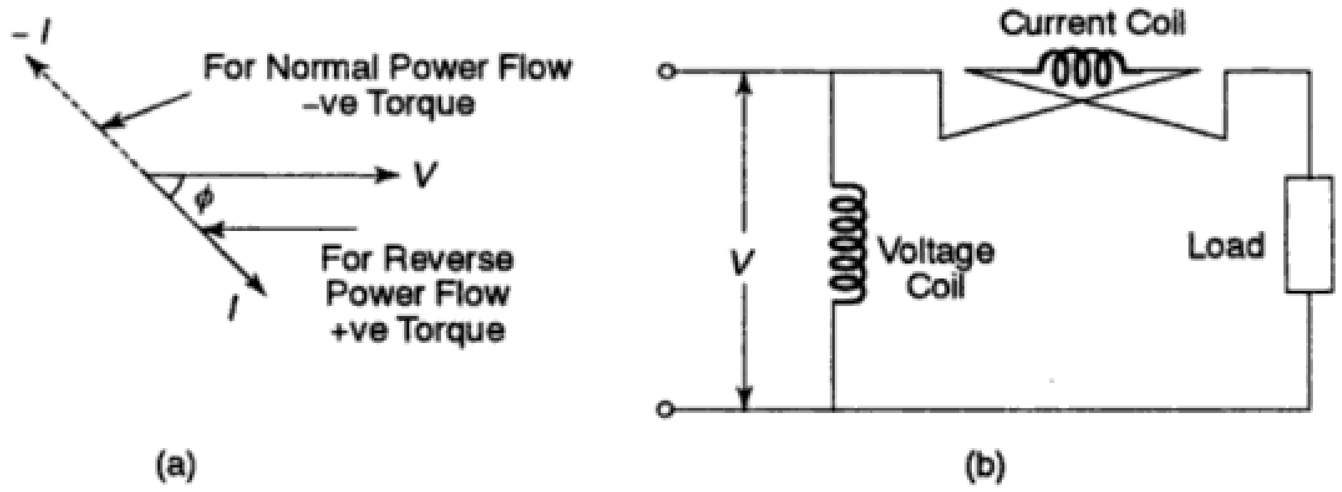


FIGURE (a) Phasor diagram for directional relay
(b) Connection of current coil for reverse power relay

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DIRECTIONAL RELAY CONNECTIONS

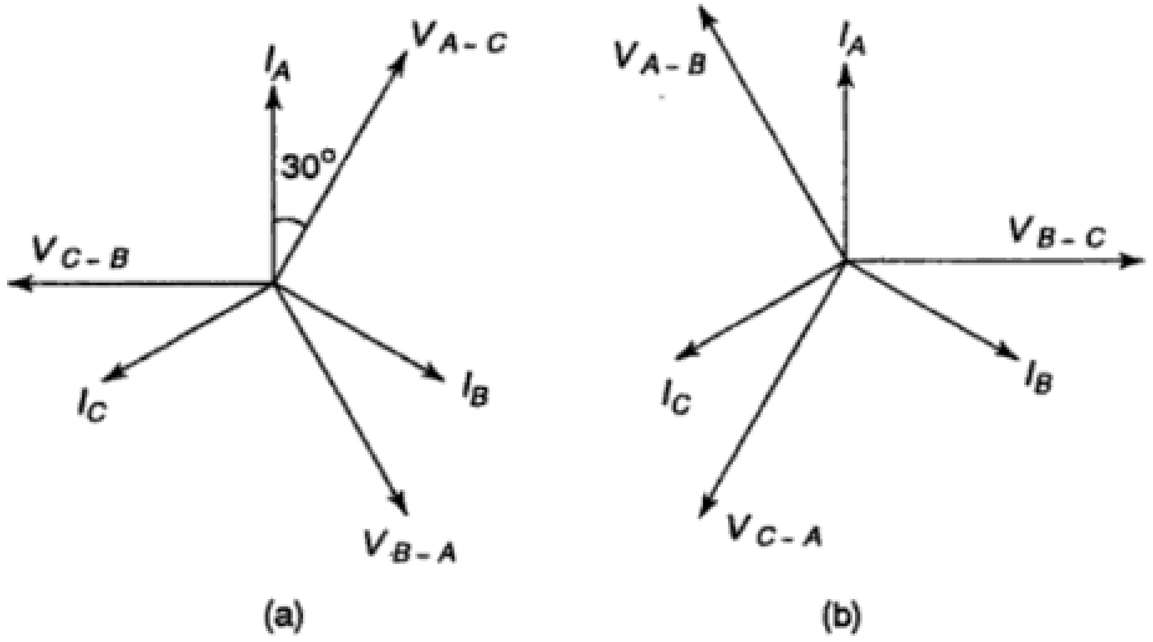
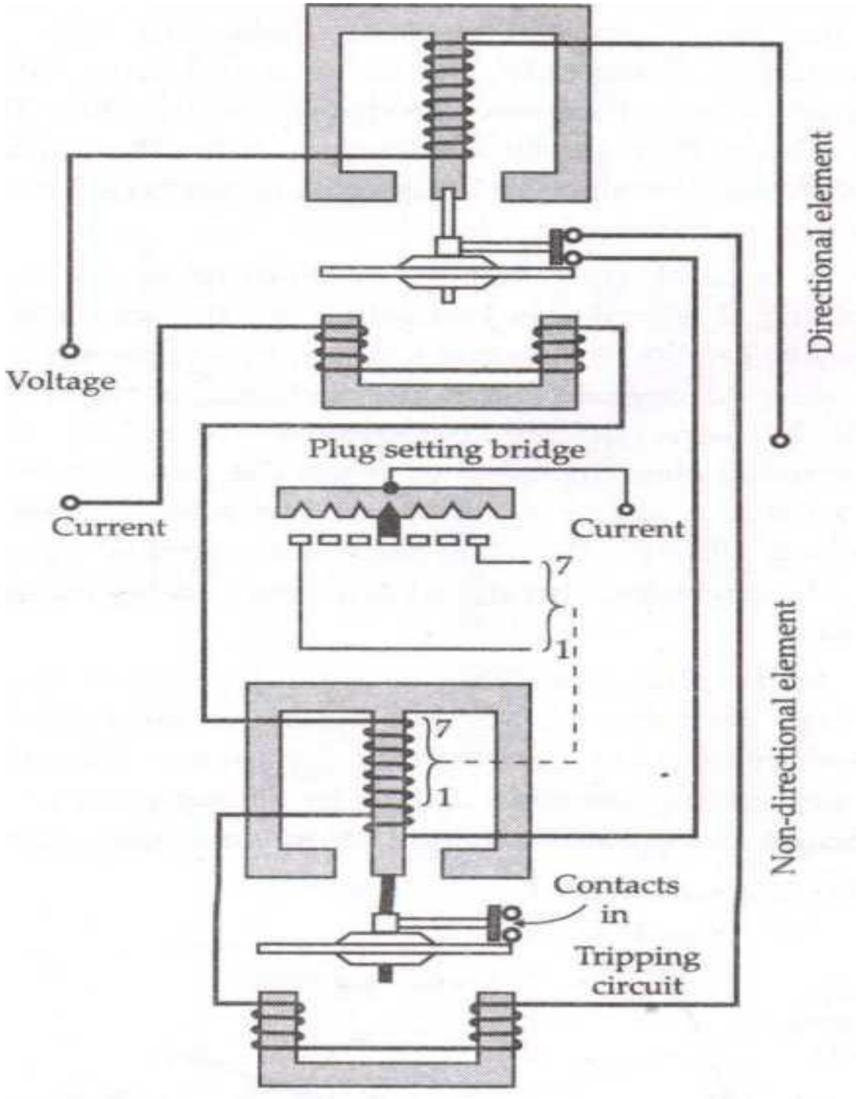
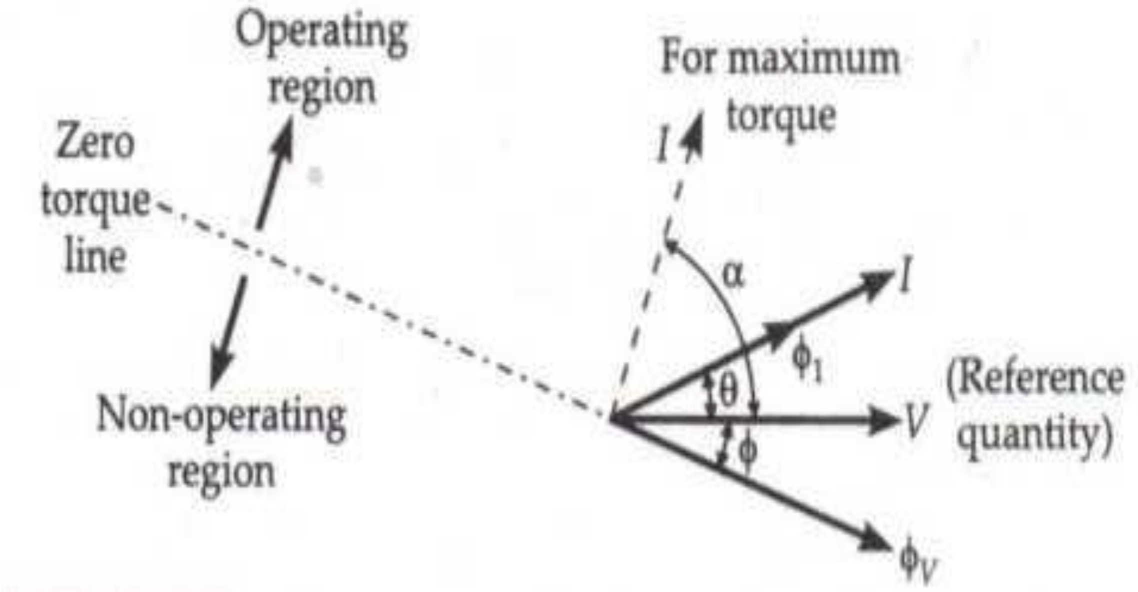


FIGURE Phasor diagram for directional relay connections
(a) For 30° connection (b) For 90° connection

DIRECTIONAL OVERCURRENT RELAY





T α V*I***Sin (Φ+θ),**

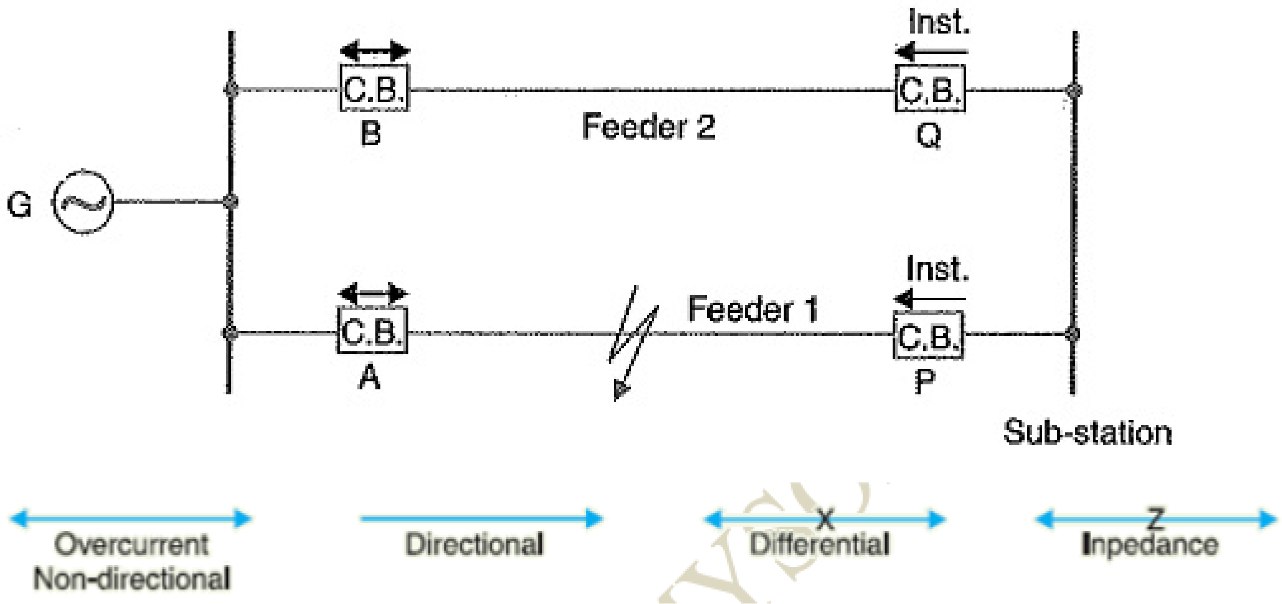
Maximum torque occurs when **Sin(θ+Φ)** is a maximum i.e., when (θ+Φ) =90°, the condition shown by the dotted line in above Fig.

Zero torque will occur when sin(θ+Φ)= 0 i.e., (θ+Φ)= 0 or 180° this being satisfied when the relay current phasor lies along the chain dotted line which is at right angles to the maximum torque line

Protection of Parallel feeders

Where continuity of supply is particularly necessary, two parallel feeders may be installed. If a fault occurs on one feeder, it can be disconnected from the system and continuity of supply can be maintained from the other feeder.

The parallel feeders cannot be protected by non-directional overcurrent relays only. It is necessary to use directional relays also and to grade the time setting of relays for selective tripping



Symbols indicating the various type of relays

Protection of Parallel feeders

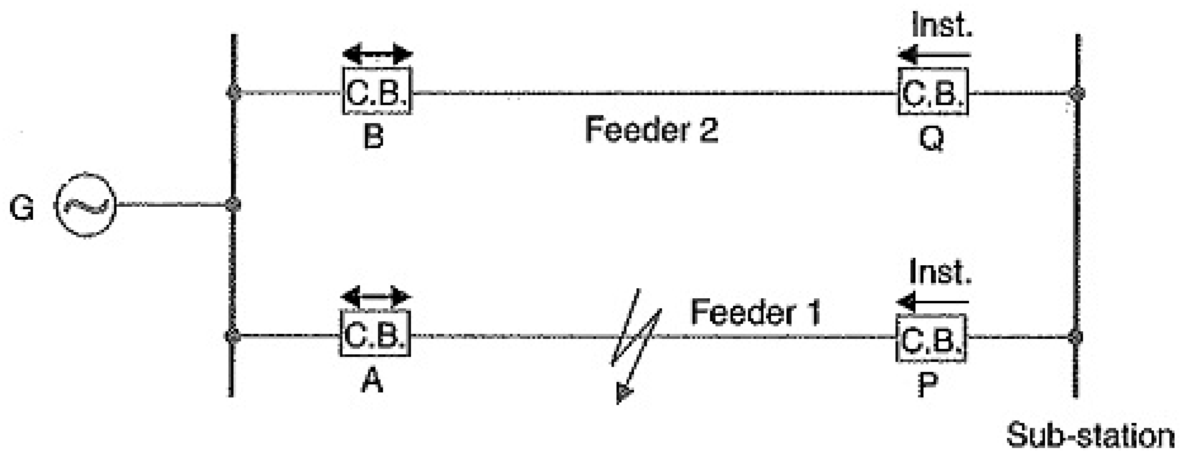
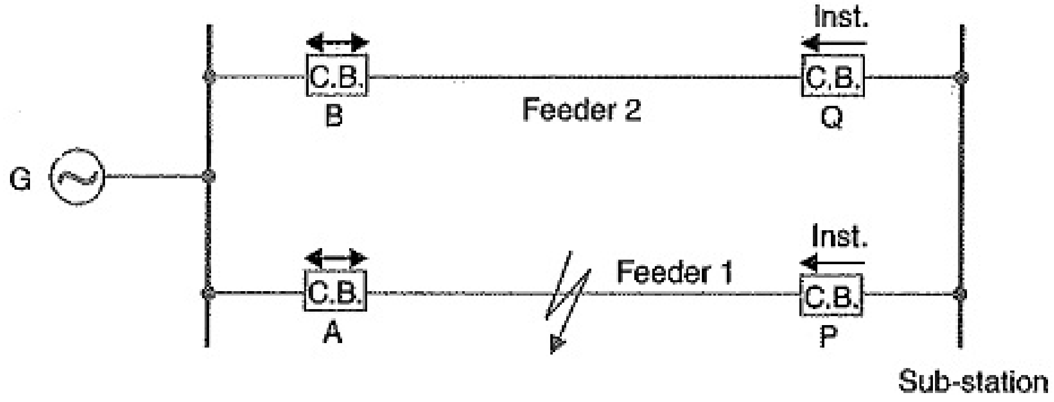


Fig. shows the system where two feeders are connected in parallel between the generating station and the sub-station. The protection of this system requires that

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

(ii) Each feeder has a reverse power or directional relay at the sub-station end. These relays should be instantaneous type and operate only when power flows in the reverse direction i.e. in the direction of arrow at P and Q.

Protection of Parallel feeders



Suppose an earth fault occurs on feeder 1 as shown in Fig. It is desired that only circuit breakers at A and P should open to clear the fault, whereas feeder-2 should remain intact to maintain the continuity of supply.

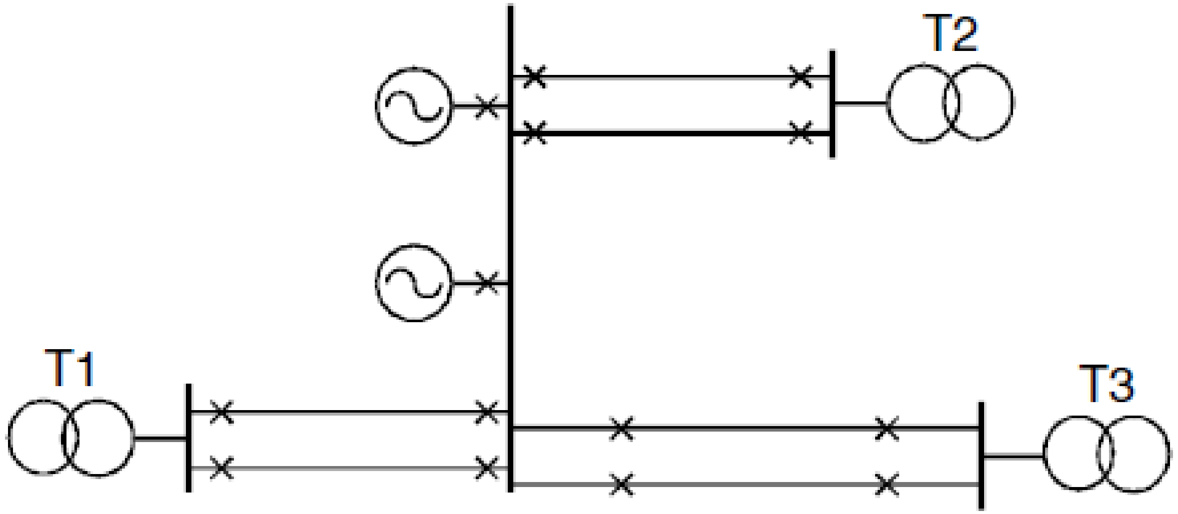
The above arrangement accomplishes this job. The shown fault is fed via two routes, viz.

(a) Directly from feeder 1 via the relay A

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

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

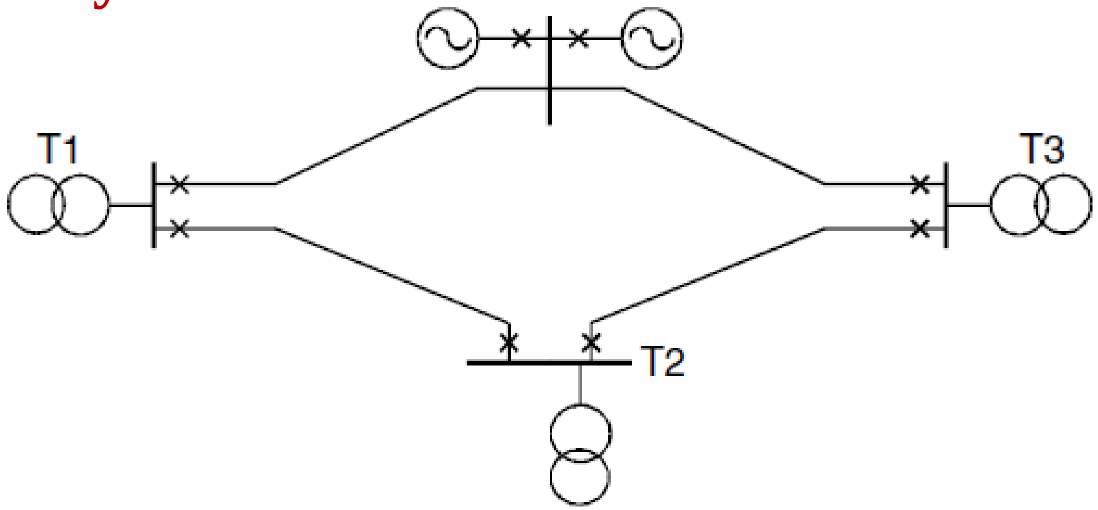
However, this requires more cabling and is not always economical. The fault current also tends to increase due to use of two cables



Radial distribution system with parallel feeders

A Ring main distribution system

The Ring main system, which is the most favored, then came into being, Here each consumer has two feeders but connected in different paths to ensure continuity of power, in case of conductor failure in any section



Advantages

Essentially, meets the requirements of two alternative feeds to give 100% continuity of supply, whilst saving in cabling/copper compared to parallel feeders.

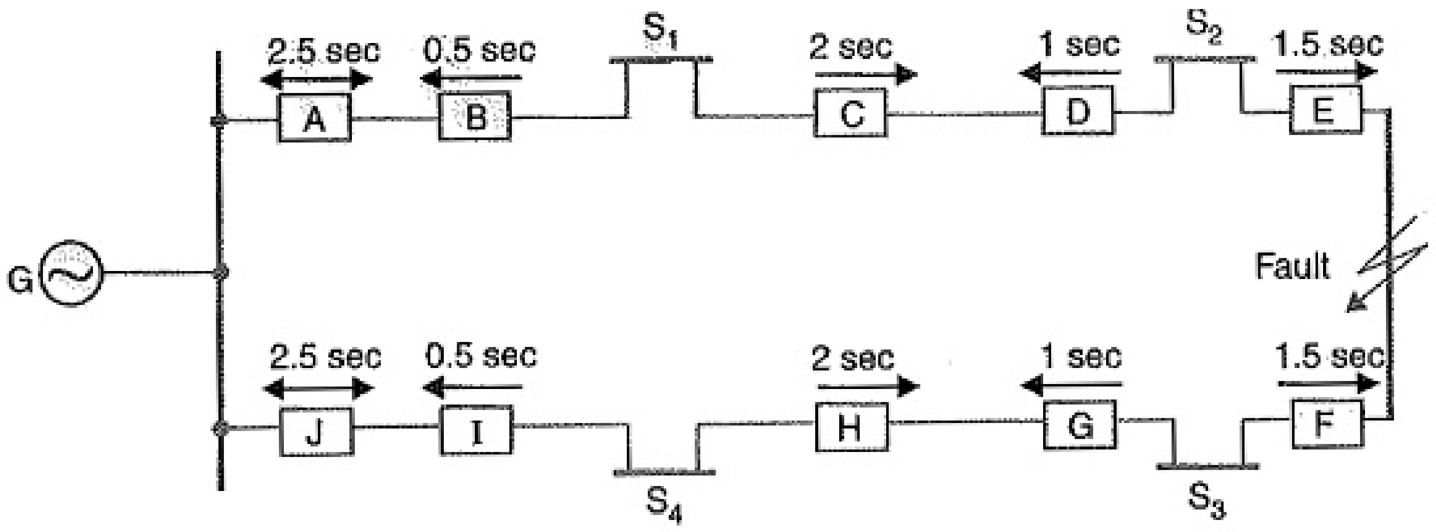
Disadvantages

For faults at T1, fault current is fed into fault via two parallel paths effectively reducing the impedance from the source to the fault location, and hence the fault current is much higher compared to a radial path. The fault currents in particular could vary depending on the exact location of the fault.

Protection must therefore be fast and discriminate correctly, so that other consumers are not interrupted. The above case basically covers feeder failure, since cable tend to be the most vulnerable component in the network.

Protection of Ring main system

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



Above Fig. shows the single line diagram of a typical ring main system consisting of one generator G supplying four sub-stations S1, S2, S3 and S4. In this arrangement, power can flow in both directions under fault conditions. Therefore, it is necessary to grade in both directions round the ring and also to use directional relays.

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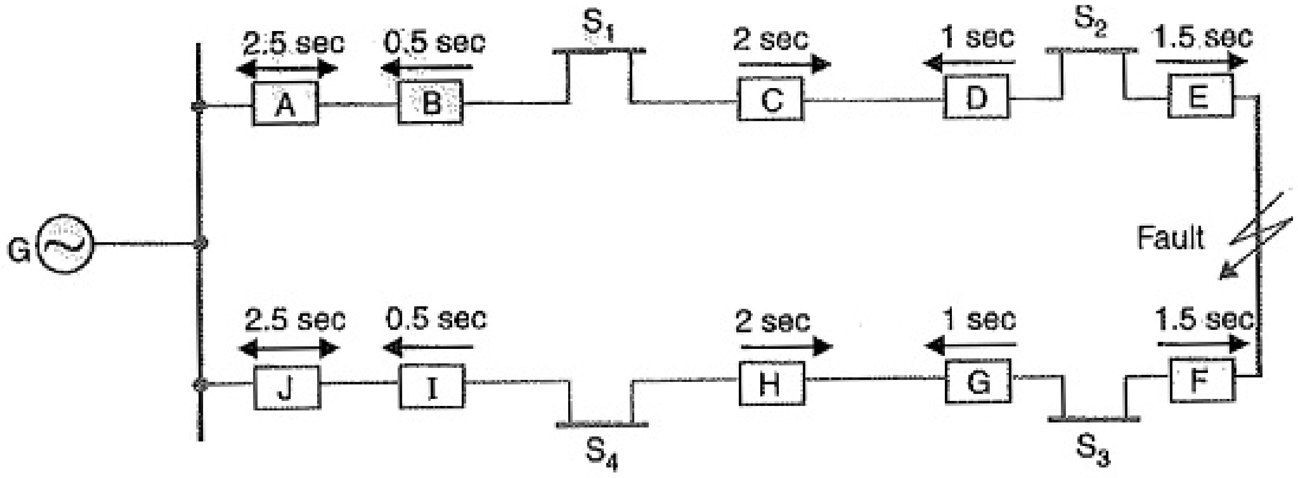
Protection of Ring main system



In order that only faulty section of the ring is isolated under fault conditions, the types of relays and their time settings should be as follows :

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

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

There should be proper relative time-setting of the relays. As an example, going round the loop GS1 S2 S3 S4G ; the outgoing relays (viz at A, C, E, G and I) are set with decreasing time limits e.g. A = 2·5 sec, C = 2 sec, E = 1·5 sec G = 1 sec and I = 0·5 sec

Similarly, going round the loop in the opposite direction (i.e. along G S4 S3 S2 S1 G), the outgoing relays (J, H, F, D and B) are also set with a decreasing time limit e.g. J = 2·5 sec, H = 2 sec, F = 1·5 sec, D = 1 sec, B = 0·5 sec.

What is a Circuit Breaker?

A circuit breaker is basically a switch to interrupt the flow of current.

- It opens on relay command.
- It has to handle large voltages and currents.
- The inductive nature of power system results in arcing between the terminals of a CB.
- CBs are categorized based on the interrupting medium used.

- A Circuit Breaker (CB) is basically a switch used to interrupt the flow of current. It opens on relay command. The relay command initiates mechanical separation of the contacts. It is a complex element because it has to handle large voltages (few to hundreds of kV's) and currents (in kA's). Interrupting capacity of the circuit breaker is therefore expressed in MVA

Power systems under fault behave more like inductive circuits. X/R ratio of lines is usually much greater than unity. For 400 kV lines, it can be higher than 10 and it increases with voltage rating. From the fundamentals of circuit analysis, we know that current in an inductive circuit (with finite resistance) cannot change instantaneously. The abrupt change in current, if it happens due to switch opening, will result in infinite di/dt and hence will induce infinite voltage. Even with finite di/dt, the induced voltages will be quite high. The high induced voltage developed across the CB will ionize the dielectric between its terminals. This results in arcing. When the current in CB goes through the natural zero, the arc can be extinguished (quenched). However, if the interrupting medium has not regained its dielectric properties then the arc can be restruck. The arcing currents reduce with passage of time and after a few cycles the current is finally interrupted.

Usually CB opening time lies in the 2-6 cycles range. CBs are categorized by the interrupting medium used. Minimum oil, air blast, vacuum arc and SF_6 CBs are some of the common examples. CB opening mechanism requires much larger power input than what logical element relay can provide. Hence, when relay issues a trip command, it closes a switch that energizes the CB opening mechanism powered by a separate dc source (station battery). The arc struck in a CB produces large amount of heat which also has to be dissipated.