OVERCURRENT PROTECTION

TIME-CURRENT CHARACTERISTICS

Definite-time Overcurrent Relay

Instantaneous Overcurrent Relay

Inverse-time Overcurrent Relay

Inverse Definite-time Overcurrent Relay

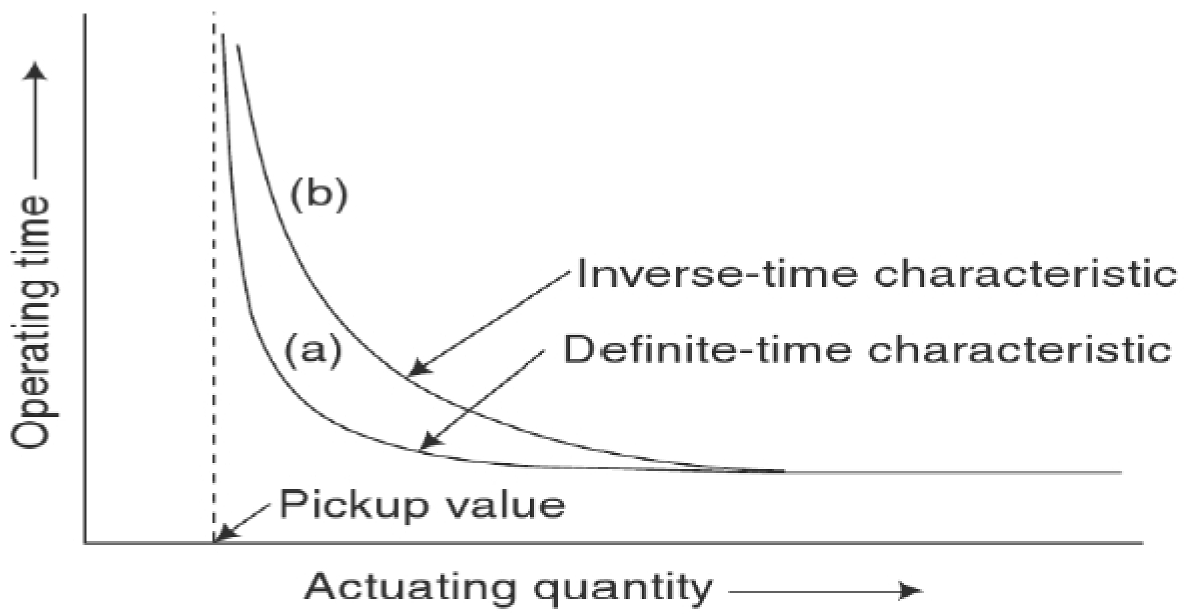
Very Inverse-time Overcurrent Relay

Extremely Inverse-time Overcurrent Relay

Special characteristics

Method of Defining shape of Time-current Characteristics

Technique to Realise Various Time-current Characteristics using Electromechanical Relays



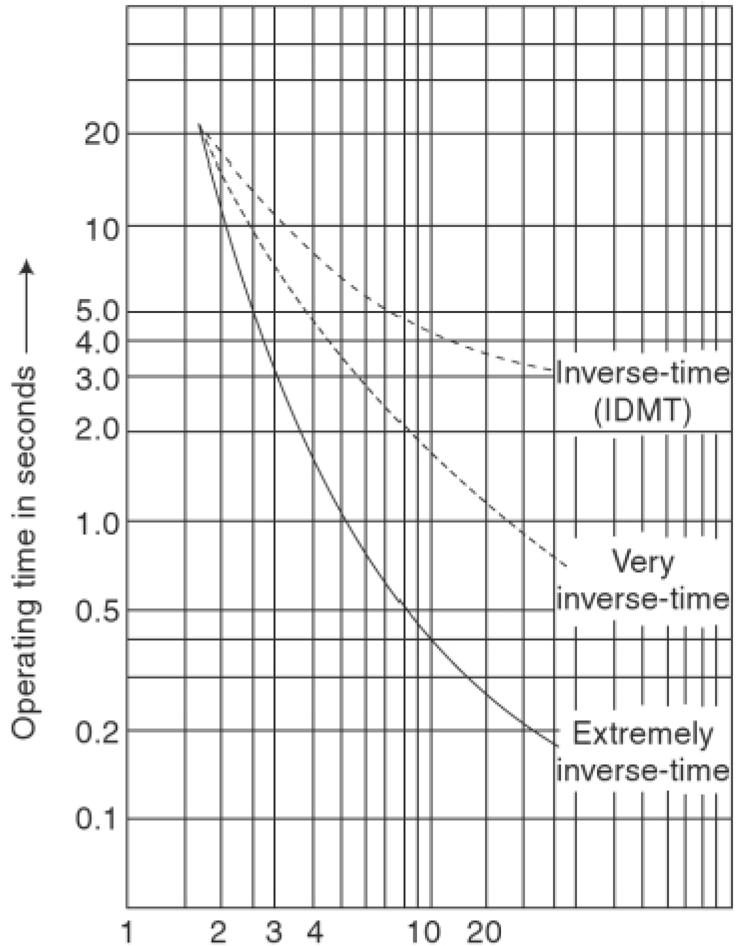
Definite-time and Inverse-time characteristic of Overcurrent relays

Very Inverse-time Overcurrent Relay

$$t = \frac{13.5}{I - 1}$$

$$t = \frac{K}{I^n - 1}$$

Extremely Inverse-time Overcurrent Relay



I.D.M.T., very inverse-time and extremely inverse-time characteristics

Method of defining shape of Time-current characteristics

The general expression for time-current characteristics is given by

$$t = \frac{K}{I^n - 1}$$

The approximate expression is

$$t = \frac{K}{I^n}$$

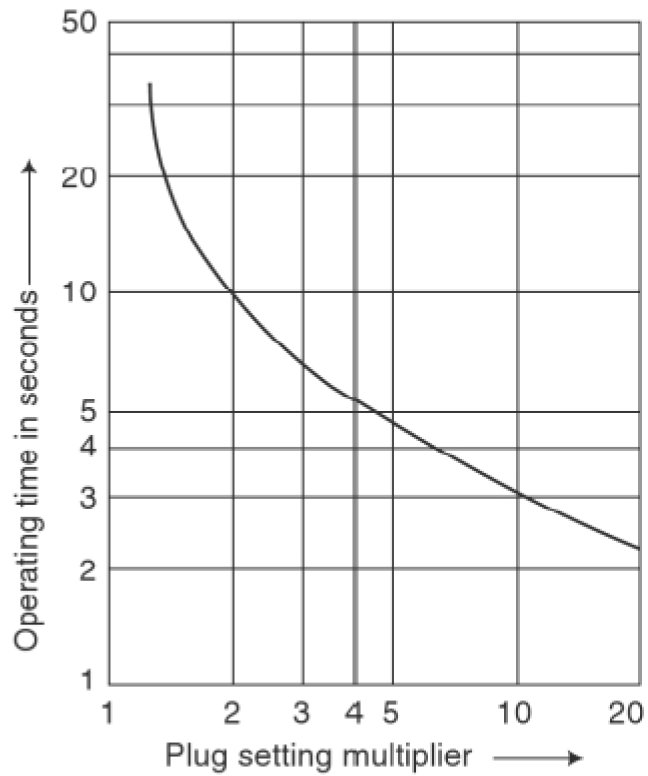
For definite-time characteristic, the value of n is equal to 0. According to the British Standard, the following are the important characteristics of overcurrent relays.

(i) I.D.M.T.: $t = \frac{0.14}{I^{0.02} - 1}$

(ii) Very inverse: $t = \frac{13.5}{I - 1}$

(iii) Extremely inverse: $t = \frac{80}{I^2 - 1}$

Current settings



Standard I.D.M.T ccharacteristic

$$\text{PSM} = \frac{\text{Secondary current}}{\text{Relay current setting}}$$

$$= \frac{\text{Primary current during fault, i.e. fault current}}{\text{Relay current setting} \times \text{CT ratio}}$$

Current in Amperes	*5*	*10*	*20*	*50*
PSM	1	2	4	10
Operating time in seconds	No operation	10	5	3

Current in Amperes	*5*	*10*	*20*	*40*	*100*
PSM	less than 1	1	2	4	10
Operating time in seconds	Relay will not operate	No operation	10	5	3

Example The current rating of an overcurrent relay is 5 A. The relay has a plug setting of 150% and time multiplier setting (TMS) of 0.4. The CT ratio is 400/5. Determine the operating time of the relay for a fault current of 6000 A. At TMS = 1, operating time at various PSM are given in the Table 5.3

PSM	*2*	*4*	*5*	*8*	*10*	*20*
Operating time in seconds	10	5	4	3	2.8	2.4

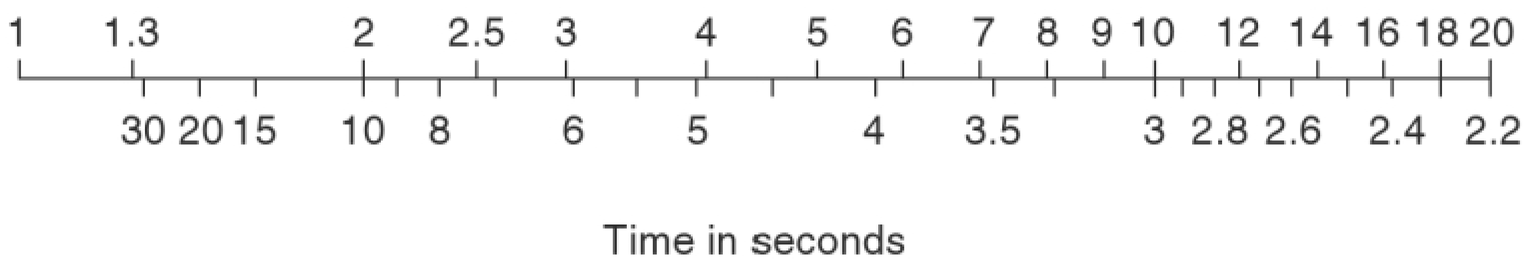


Fig. *Logarithmic scale for I.D.M.T. relay at TMS = 1*

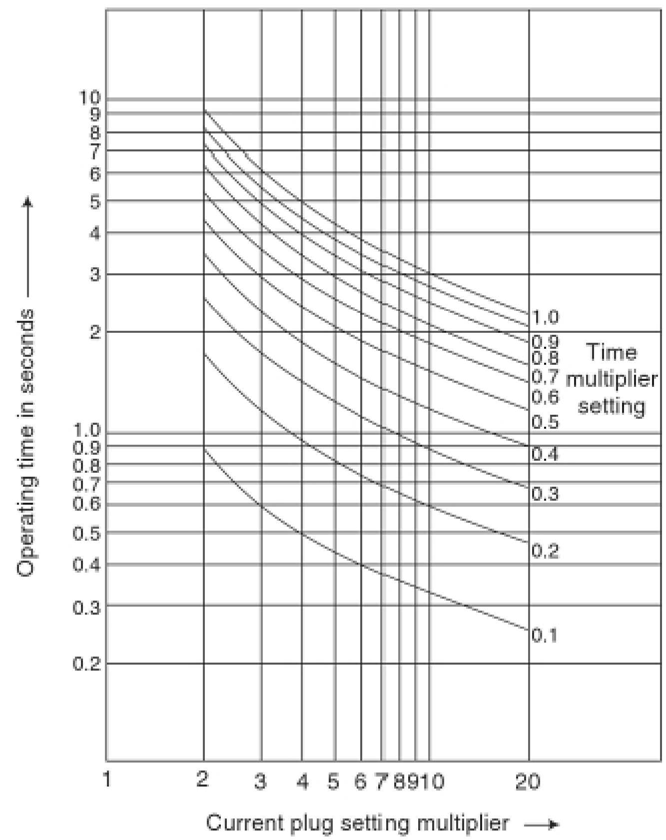


Fig. *Time-current characteristics for different values of TMS*

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Solution: CT ratio = 400/5 = 80

Relay current setting = 150% of 5 A = 1.5 × 5 A = 7.5 A

$$\text{PSM} = \frac{\text{Secondary current}}{\text{Relay current setting}}$$

$$= \frac{\text{Primary current (fault current)}}{\text{Relay current setting} \times \text{CT ratio}}$$

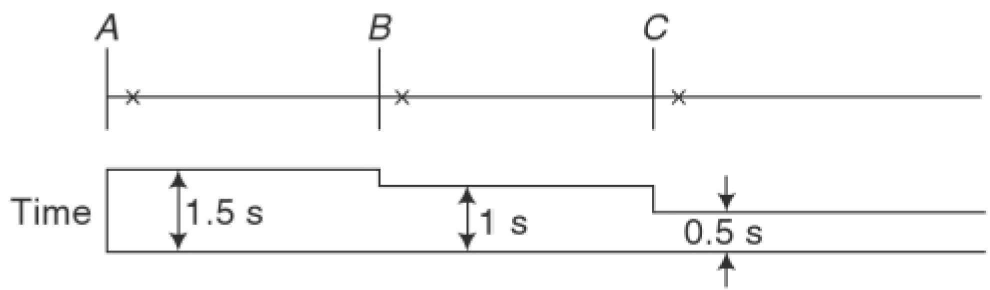
$$= \frac{6000}{7.5 \times 80} = 10$$

The operating time from the given table at PSM of 10 is 2.8 s. This time is for TMS = 1.

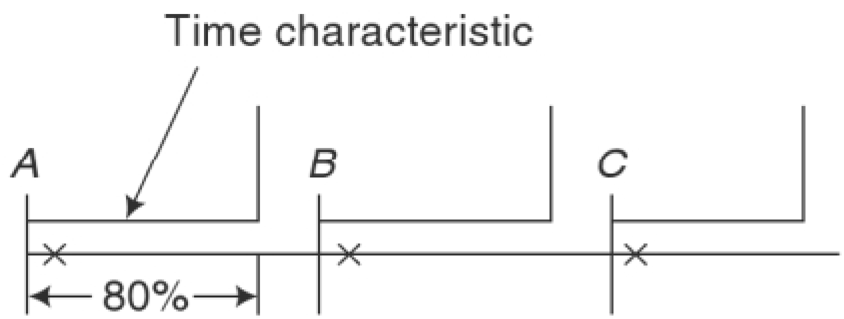
The operating time for TMS of 0.4 will be equal to 2.8 × 0.4 = 1.12 s.

Over current protection schemes

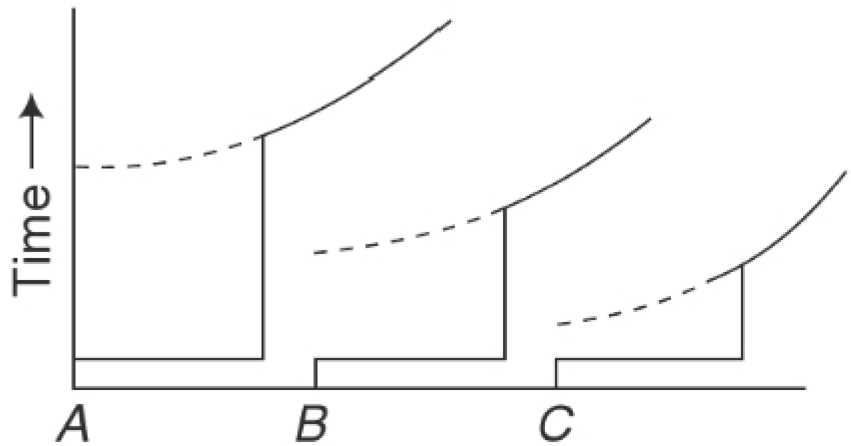
Time-graded system



Current-graded system



A combination of time and current grading



Example | An earth fault develops at point F on the feeder shown in the Fig. 5.8, 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 multiplier setting (TMS) of 0.2. The circuit breakers take 0.20 s to clear the fault, and the relay error in each case is 0.15 s.

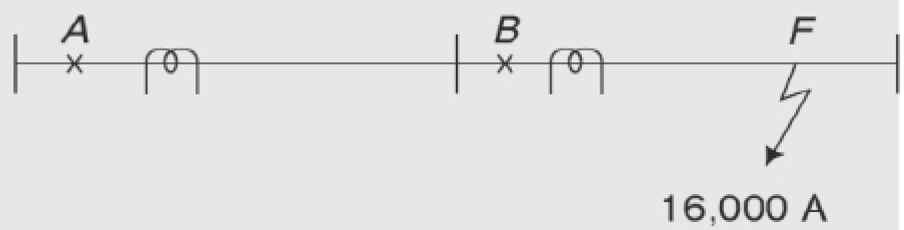


Fig. System for Example

For a plug setting of 200% on the relay A, determine the minimum TMS on that relay for it not to operate before the circuit breaker at B has cleared the fault. A relay operating time curve is same as shown in .

Solution: The primary current in both relays is 16,000 A

$$\text{CT ratio} = 800/5 = 160$$

Thus secondary current

$$= \frac{\text{Primary current}}{\text{CT ratio}}$$

$$= \frac{16{,}000}{160} = 100 \text{ A}$$

For relay at B,

$$\text{Current setting} = 125\% \text{ of } 5 \text{ A} = 1.25 \times 5 \text{ A}$$
$$= 6.25 \text{ A}$$

$$\text{PSM} = \frac{\text{Secondary current}}{\text{Relay current setting}}$$
$$= \frac{100}{6.25} = 16$$

From the curve in Fig. 5.3, the operating time at PSM of 16 for a TMS of 1 = 2.5 s

Since TMS of relay at $B = 0.2$,

$$\text{Operating time of } B = 0.2 \times 2.5 \text{ s} = 0.50 \text{ s}$$

$$\text{Discrimination time} = \text{time for breaker at } B + \text{twice relay error}$$
$$= 0.20 + 2 \times 0.15 = 0.50 \text{ s}$$

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

$$= 0.50 \text{ s} + 0.50 \text{ s} = 1.00 \text{ s}$$

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Secondary current in $A = 100$ A

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

$$= 2 \times 5 \text{ A} = 10 \text{ A}$$

Thus, $$\text{PSM} = \frac{100}{10} = 10$$

From the curve in Fig. 5.3, 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.

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Example 5.3 A 20 MVA transformer, which may be called upon to operate at 25% overload, feeds 11-kV busbars through a circuit breaker; other circuit breakers supply outgoing feeders. The transformer circuit breaker is equipped with 1000/5 A CTs and the feeder circuit breakers with 500/5 A CTs and all sets of CTs feed induction-type overcurrent relays. The relays on the feeder circuit breakers have a 125% plug setting and a 0.4 time setting. If a three phase fault current of 7500 A flows from the transformer to one of the feeders, find the operating time of the feeder relay, the minimum plug setting of the transformer relay, and its time setting assuming a discriminative time margin of 0.5 second. The time-current characteristic of the relays is same as shown in Fig. 5.3.

Solution:

Feeder

$$\text{Secondary current} = 7500 \times \frac{5}{500} = 75 \text{ A}$$

$$\text{Relay current setting} = 125\% \text{ of } 5 \text{ A} = 1.25 \times 5 = 6.25 \text{ A}$$

$$\text{PSM} = \frac{\text{Secondary current}}{\text{Relay current setting}} = \frac{75}{6.25} = 12$$

From the curve in Fig. 5.3, the operating time at PSM of 12 for a TMS of 1 = 2.8 s

Since TMS of the relay = 0.4,

Operating time of the relay = $0.4 \times 2.8 = 1.12$ s

Transformer

$$\text{Overload current} = \frac{(1.25 \times 20) \times 10^3}{\sqrt{3} \times 11} = 1312 \text{ A}$$

$$\text{Secondary current} = 1312 \times \frac{5}{1000} = 6.56 \text{ A}$$

$$\text{Plug Setting Multiplier (PSM)} = \frac{6.56}{\text{PS} \times 5}$$

Where PS means plug setting of the relay.

Since the transformer relay must not operate to overload current, its plug setting multiplier (PSM) must be less than 1, i.e., PS × 5 > 6.56. Thus plug setting (PS) > 6.56/5 > 1.31% or 131%.

The plug settings are restricted to standard values (See section 5.3) in intervals of 25%, so the nearest value is 150%.

$$\text{Secondary fault current} = 7500 \times \frac{5}{1000} = 37.5 \text{ A}$$

Relay current setting = 150% of 5 A = 1.5 × 5 A = 7.5 A

$$\text{PSM} = \frac{\text{Secondary fault current}}{\text{Relay current setting}} = \frac{37.5}{7.5} = 5$$

The operating time from the curve in Fig. 5.3 at PSM of 5 and TMS of 1 = 4.7 seconds

But, actual operating time required

= Operating time of feeder relay + discriminative time margin

= 1.12 sec + 0.50 sec

= 1.62 sec

Hence required time multiplier setting (TMS) = 1.62/4.7 = 0.345

Example 5.4 | Two relays R_1 and R_2 are connected in two sections of a feeder as shown in Fig. 5.9. CTs are of ratio 1000/5 A. The plug setting of relay R_1 is 100% and R_2 is 125%. The operating time characteristics of the relays is same as given in Table 5.3 of Example 5.1.

The time multiplier setting of the relay R_1 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. Find the actual operating times of R_1 and R_2. What is the time multiplier setting (TMS) of R_2.

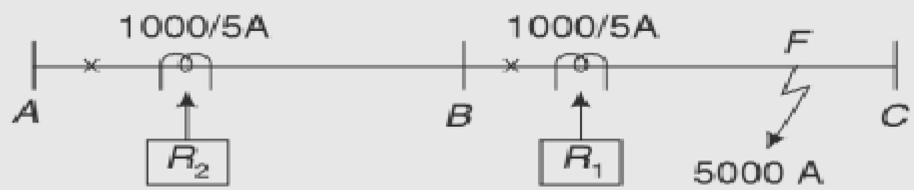

Fig. 5.9 System for Example 5.4

Solution: CT secondary current $= 5000 \times \frac{5}{1000} = 25$ A

Relay R₁

$$\text{Plug setting} = 100\%$$

$$\text{Current setting} = 5 \text{ A}$$

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$$\text{PSM of } R_1 = \frac{\text{Secondary current}}{\text{Relay current setting}} = \frac{25}{5} = 5$$

Operating time of the relay at PSM of 5 and TMS of 1 from the table of Example 5.1 = 4 seconds.

Since TMS of the relay R_1 is 0.3, the actual operating time of the relay = 0.3×4 = $0.3 \times 4 = 1.2$ seconds

Relay R_2

$$\text{Plug setting} = 125\%$$

$$\text{Relay current setting} = 125\% \text{ of } 5 \text{ A} = 1.25 \times 5 = 6.25 \text{ A}$$

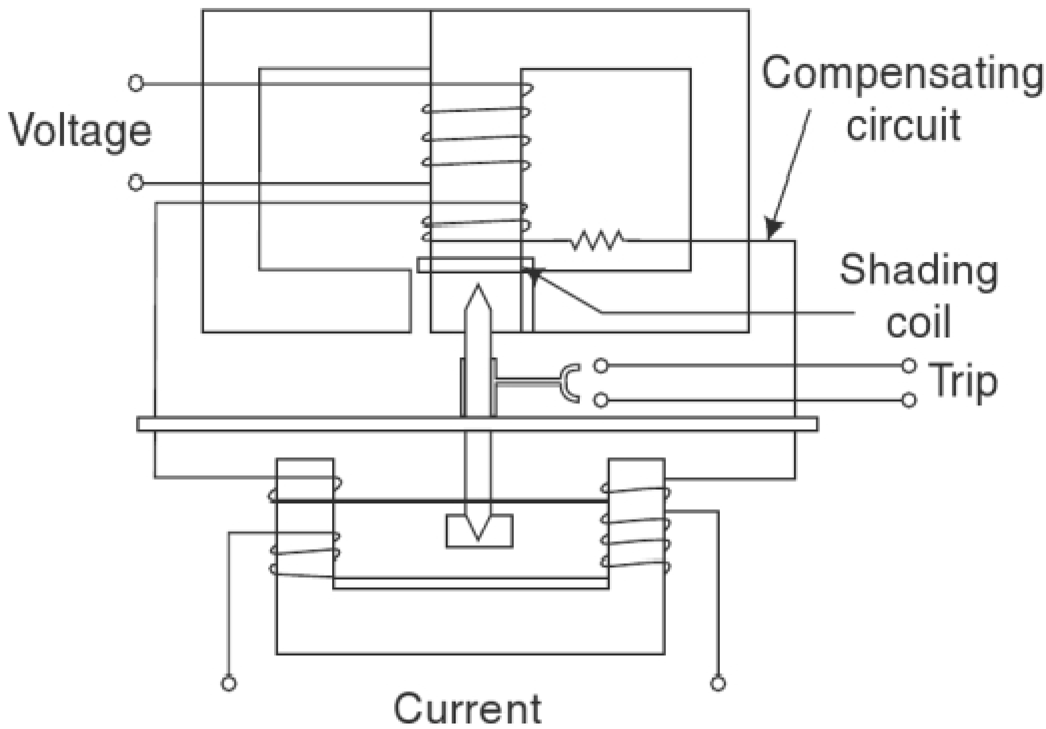
$$\text{PSM} = \frac{\text{Secondary current}}{\text{Relay current setting}} = \frac{25}{6.25} = 4$$

Operating time at PSM of 4 and TMS of 1 from the table of Example 5.1 = 5 seconds

$$\begin{aligned}\text{Actual operating time of } R_2 &= \text{Operating time of } R_1 + \text{time grading margin}\\ &= 1.2 + 0.5\\ &= 1.7 \text{ seconds}\end{aligned}$$

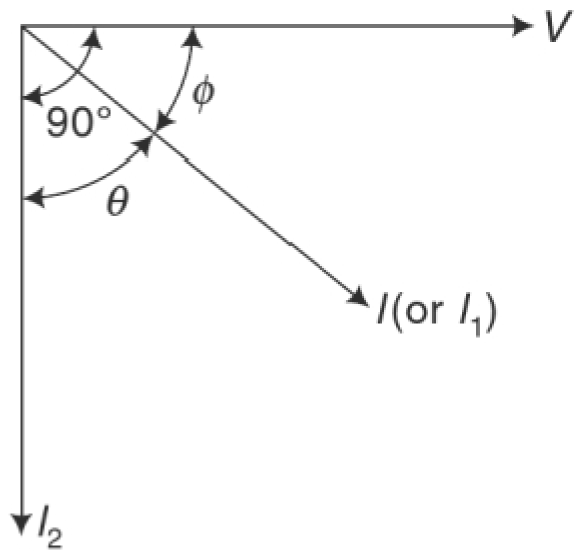
Hence, $\text{TMS} = 1.7/5 = 0.34$

Reverse power or Directional Relay

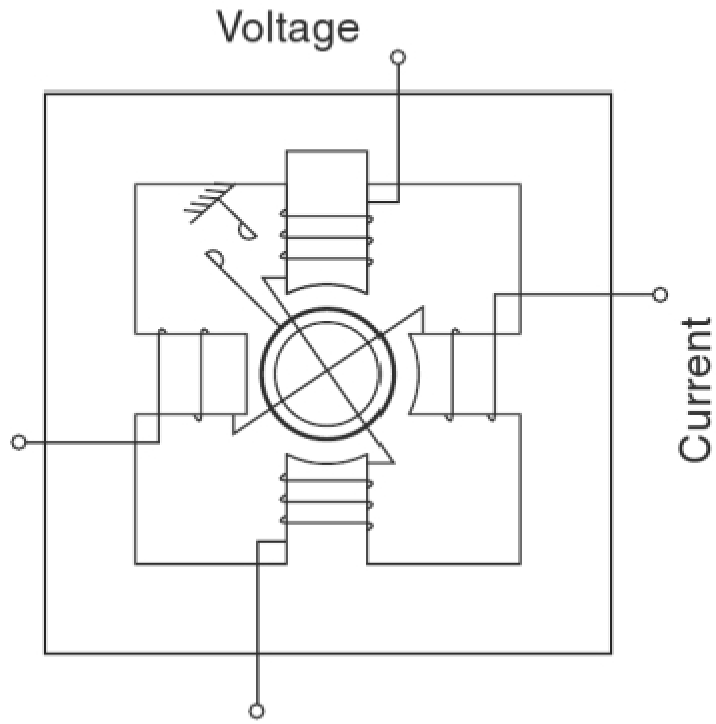


(a) Construction

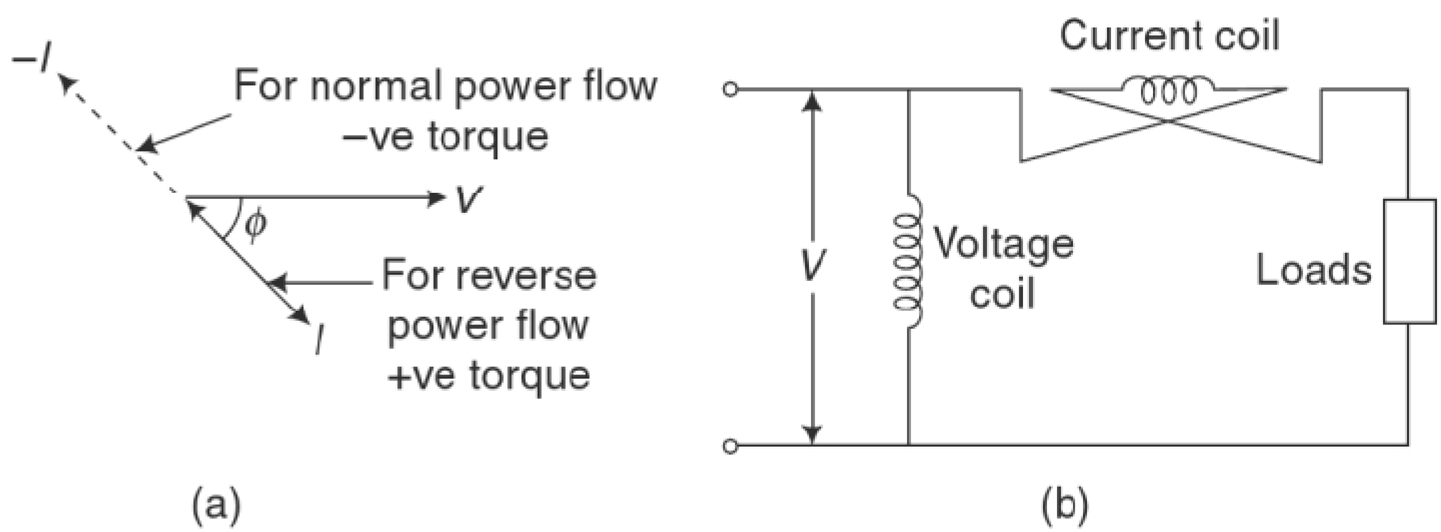
Induction disc type directional relay



(b) Phasor diagram

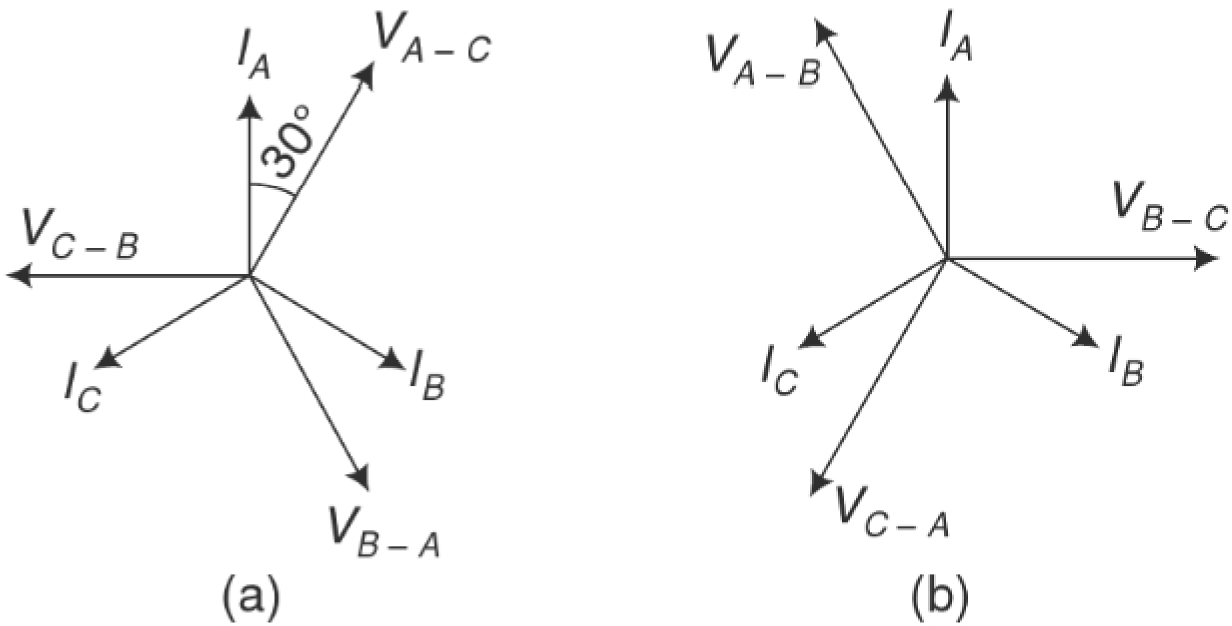


Induction cup type directional relay



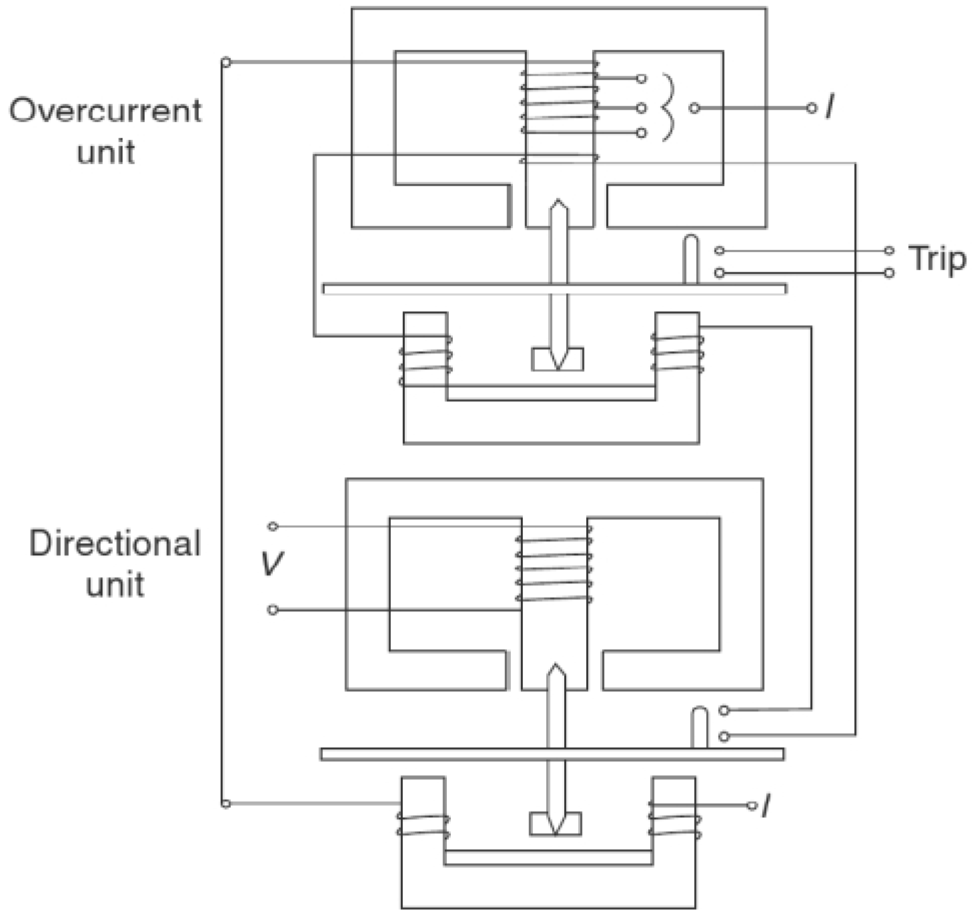
(a) Phasor diagram for directional relay
(b) Connection of current coil for reverse power relay

Directional relay connections

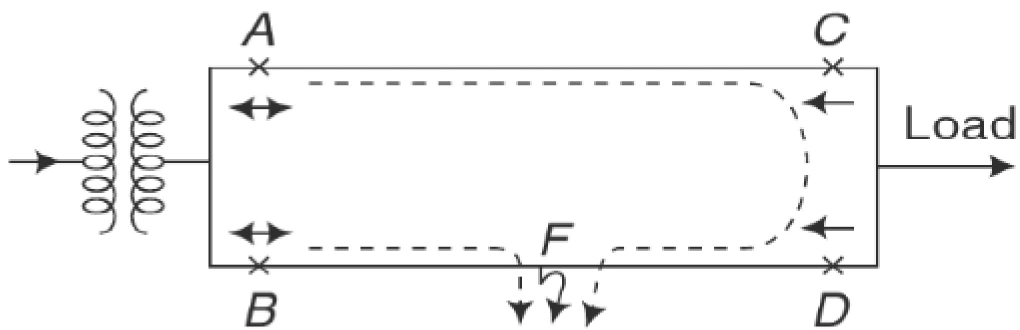


Phasor diagram for directional relay connections:
(a) For 30° connection (b) For 90° connection

Directional over current relay

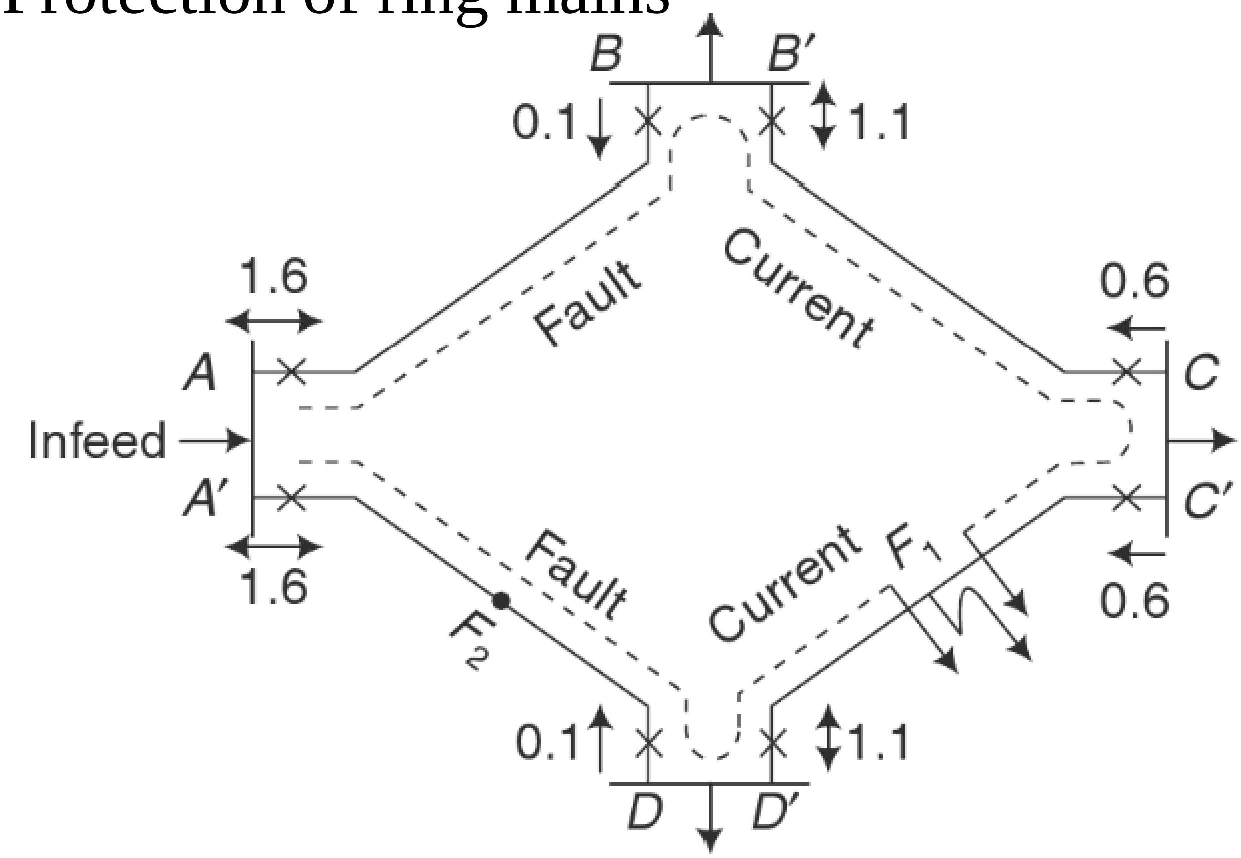


Protection of parallel feeders

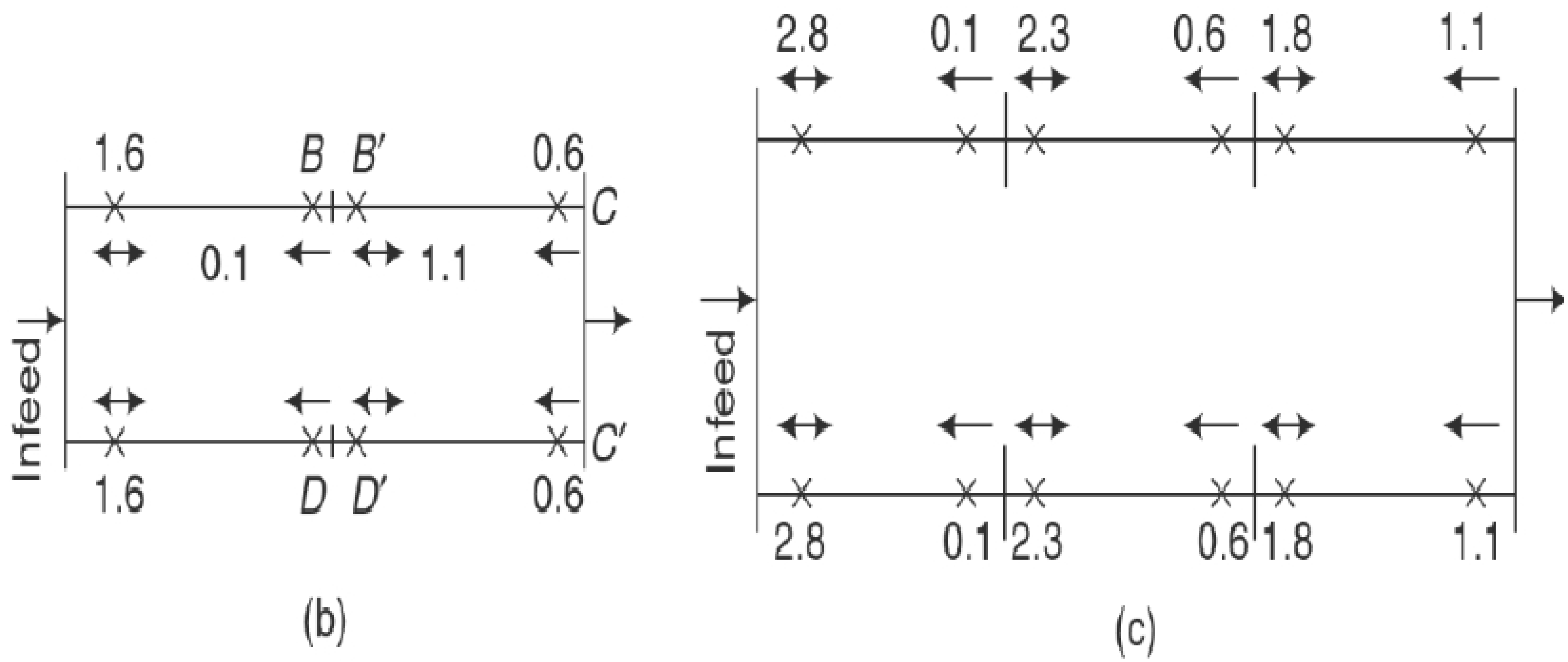


Protective scheme for parallel feeder

Protection of ring mains



(a)

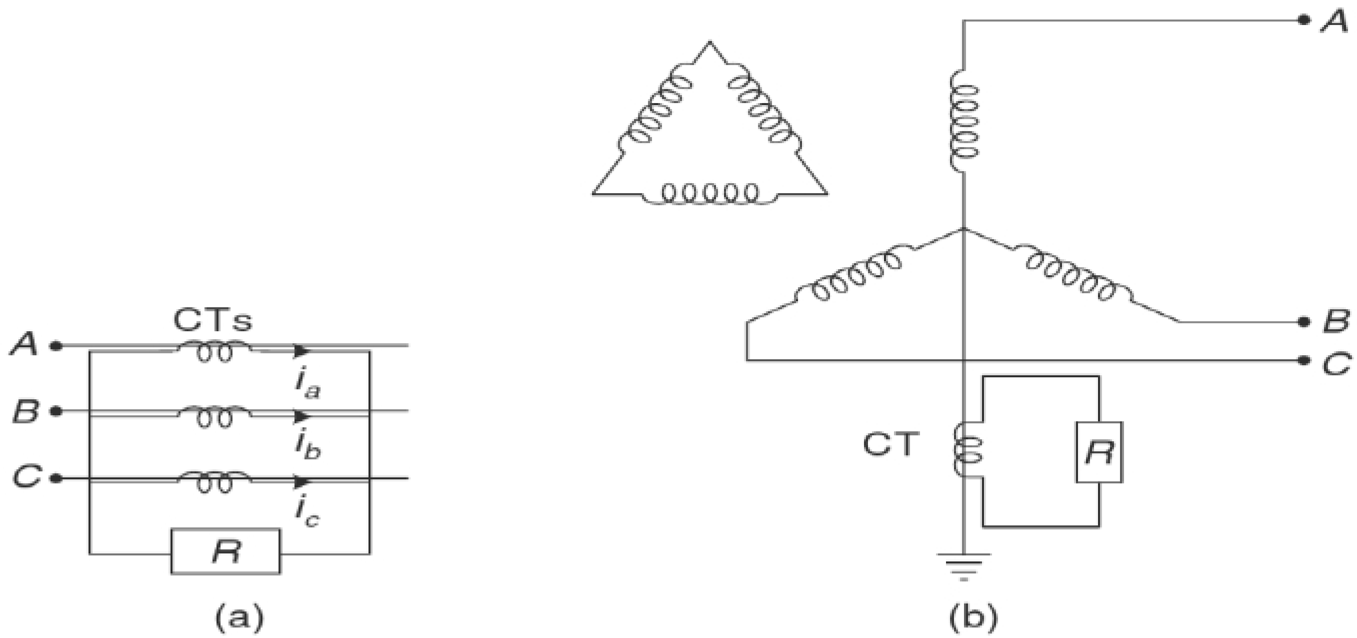


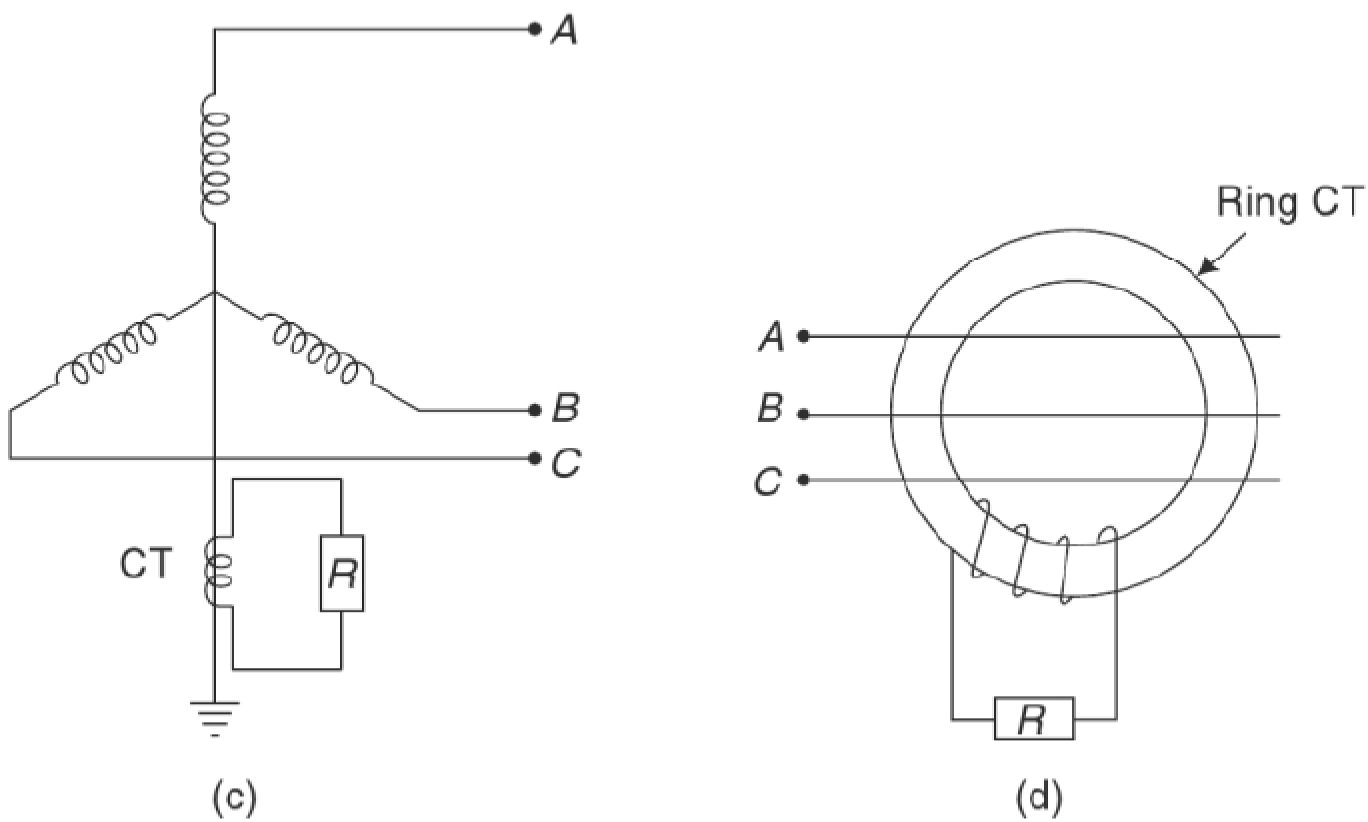
Protection of ring feeder

EARTH FAULT AND PHASE FAULT PROTECTION

Earth fault relay and over current relay

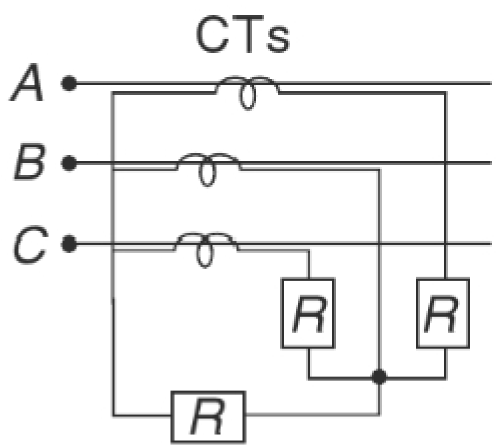
Earth fault Protective schemes



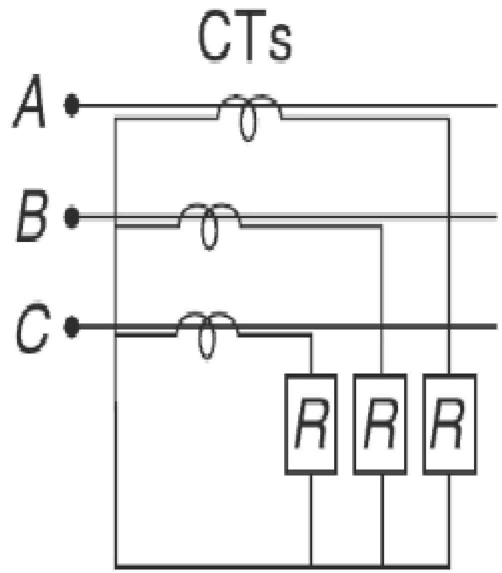


Various earth fault protective schemes

Combined Earth Fault and Phase fault protective scheme

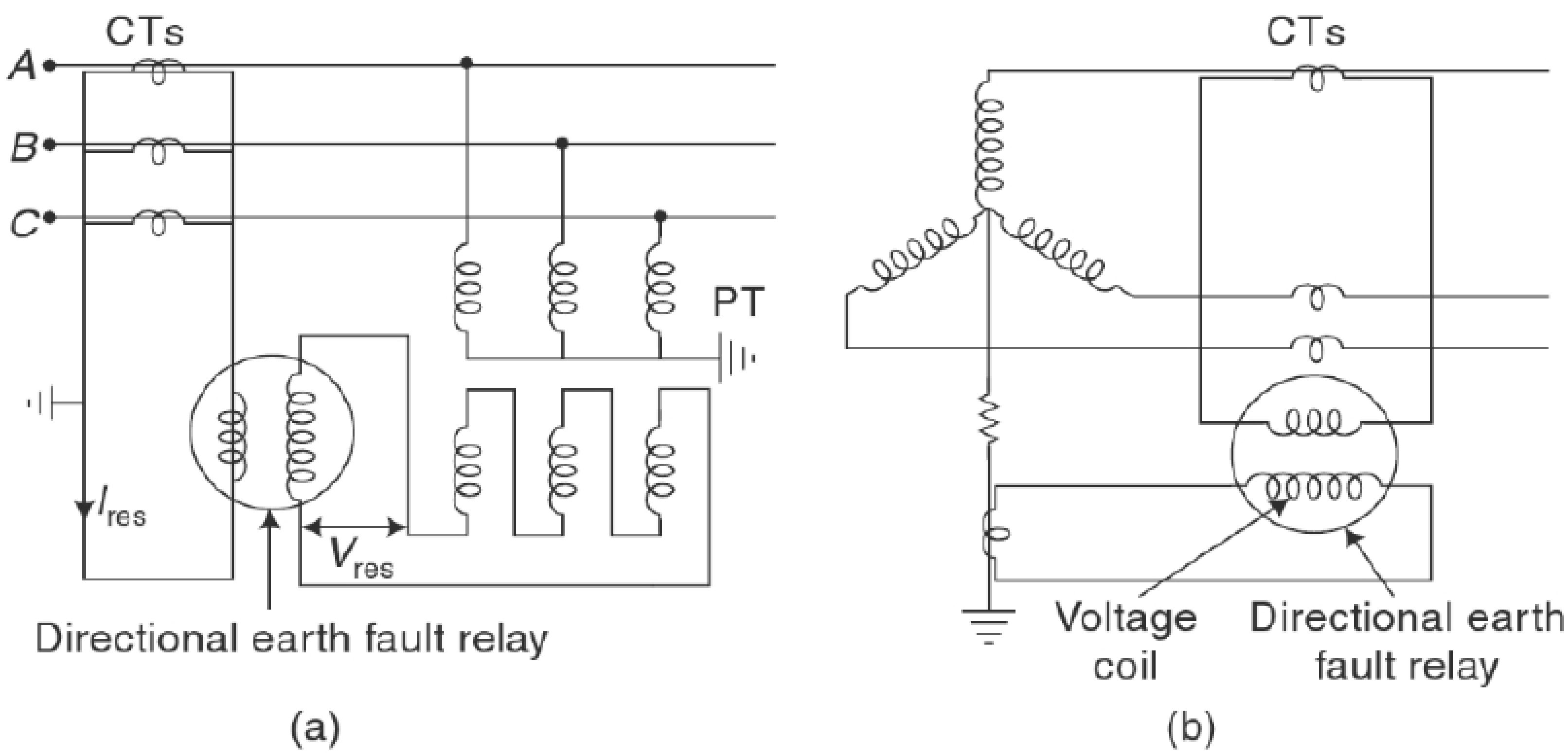


Two over current and one earth fault relay

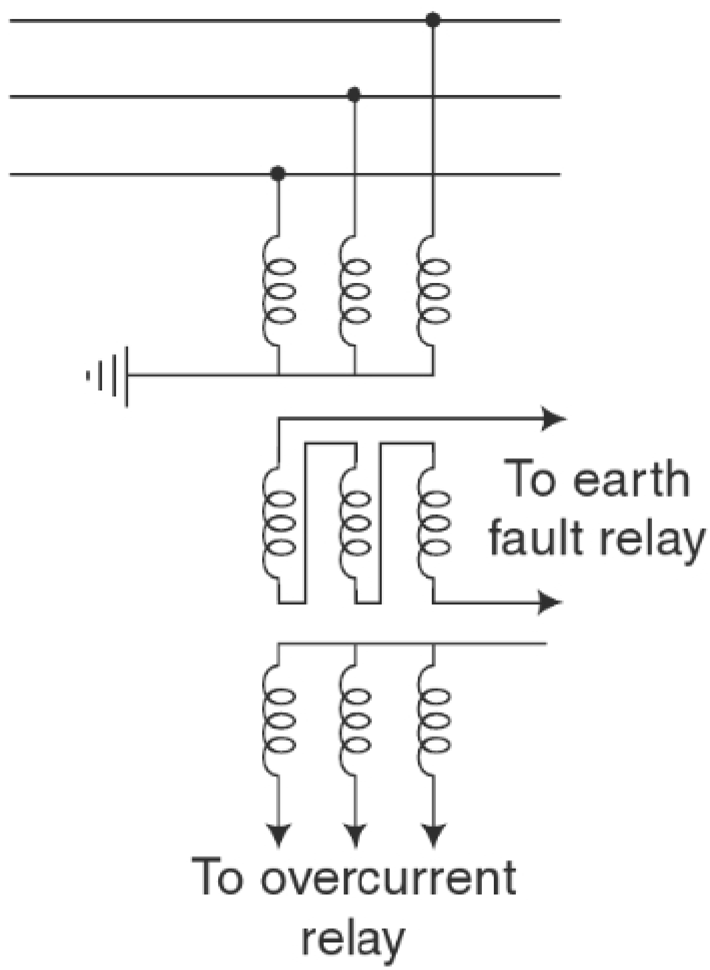


Two over current and one earth fault relay

Directional earth fault relay



Connection of a directional earth fault relay

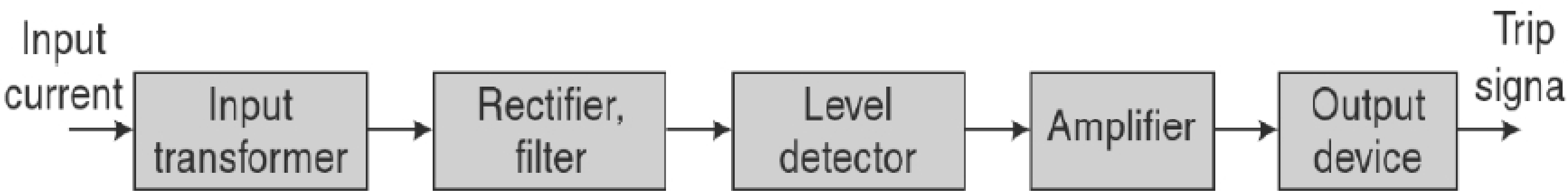


Five limb VT

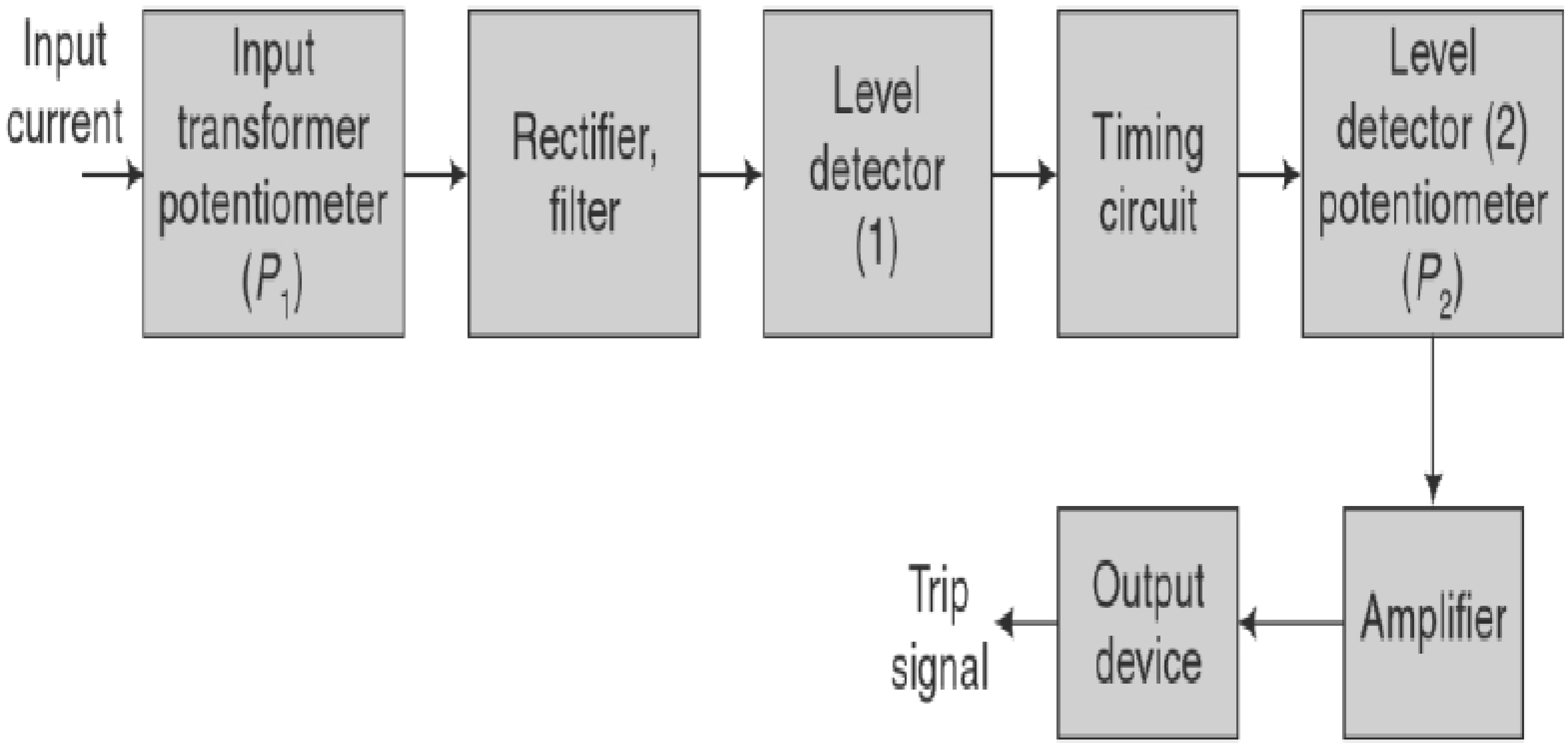
Static over current relay

$$t = \frac{K}{I^n - 1}$$

Instantaneous over current relay



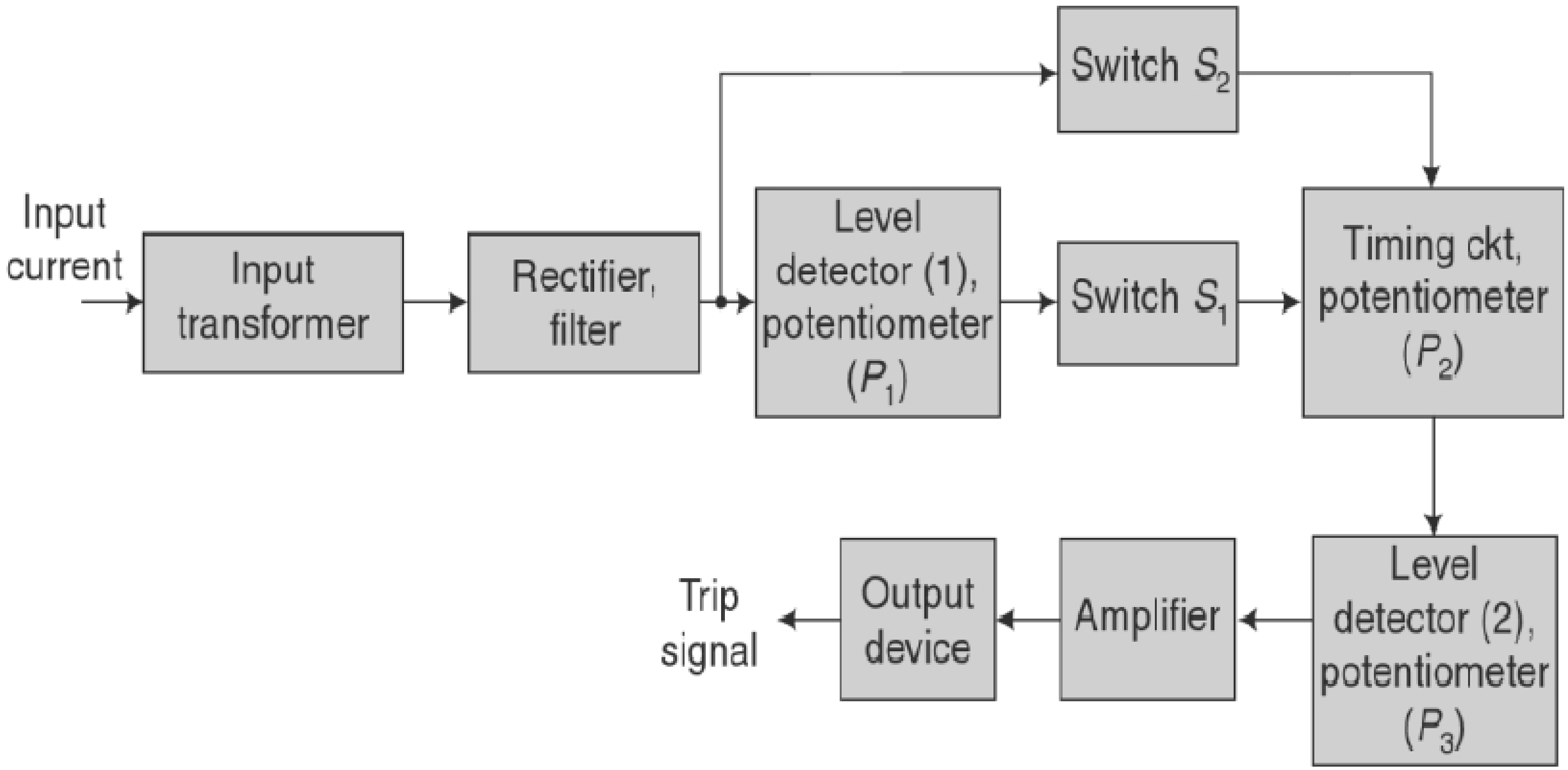
Definite Time over current relay



Block diagram of Definite Time over current relay

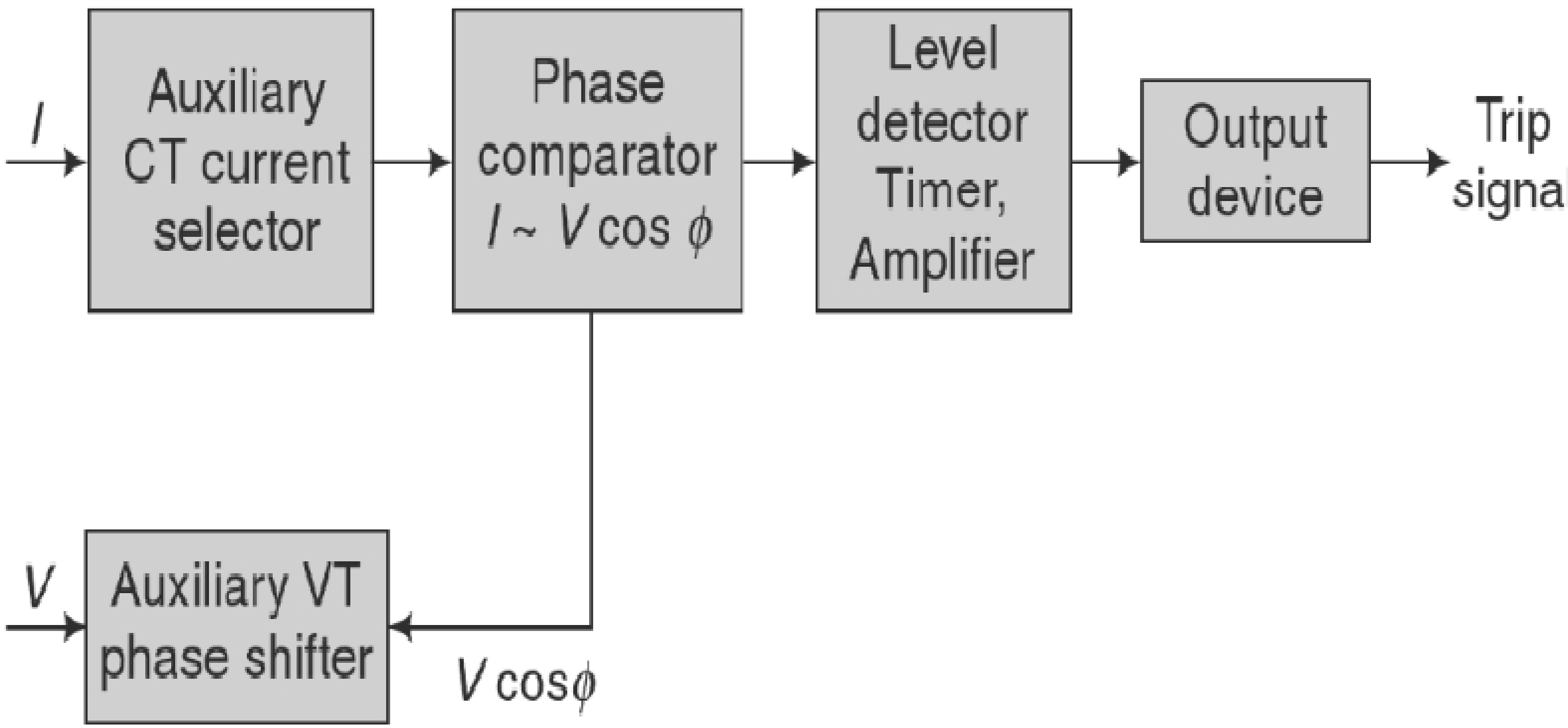
$$T_C = RC \log_e \left[\frac{V}{V - V_T} \right]$$

Inverse-time over current relay



Block diagram of Inverse-time over current relay

Directional over current relay



Block diagram of Directional over current relay

Numerical over current relay

- Microprocessor-based over current relay
- Microcontroller-based over current relay
- Digital Signal Processor (DSP)-based relays
- Field Programming Gate Arrays (FPGA)-based over current relays.
- Artificial Neural Network (ANN) based numerical relays

REVIEW QUESTIONS

1. What are the various types of overcurrent relays? Discuss their area of applications.
2. Explain current setting and time setting.

   The current rating of an overcurrent relay is 5 A. PSM = 2, TMS = 0.3, CT ratio = 400/5, Fault current = 4000 A. Determine the operating time of the relay. At TMS = 1, operating time at various PSM are:

PSM	*2*	*4*	*5*	*8*	*10*	*20*
Operating time in seconds	10	5	4	3	2.8	2.4

3. An overcurrent relay of current rating 5 A and setting 150% is connected to the secondary of CT of ratio 400/5. Calculate the current in lines for which the relay picks up. (**Ans.** 600 A)
4. An earth-fault starting relay has a setting of 30%, and a current rating of 5 A. It is connected to a CT of ratio 500/5. Calculate pick-up current in primary for which the earth fault relay operates (**Ans.** 150 A)

Contd....

5. The time-current (PSM) characteristic of an overcurrent relay for TMS of 1 is given in the Table 5.4.

Table 5.4

PSM	2	3	5	7	10	13	15	18	20
Operating time in seconds	10	6.8	4.4	3.4	2.8	2.5	2.4	2.3	2.2

If the current plug setting is adjusted to 50% and the time multiplier is adjusted to, 0.75, calculate the time of operation of the relay when the fault current is 3000 A and the relay is connected to a CT ratio 400/5. **(Ans.** 1.8 sec.)

6. Under what circumstances are overcurrent relays having very inverse and extremely inverse characteristics used?
7. Compare the time-current characteristics of inverse, very inverse and extremely inverse overcurrent relays. Discuss their area of applications.
8. Describe the techniques used to realise various time-current characteristics using electromechanical relays.
9. Can a relay, having a time-current characteristic steeper than extermely inverse relay, be realised using electromechanical construction?
10. What are the various overcurrent protective schemes? Discuss their merits, demerits and field of applications.
11. Two relays R_1 and R_2 are connected in two sections fo a feeder as shown in Fig. 5.26.

    Relay R_1 : CT ratio = 300/5, plug setting = 50%, TMS = 0.3

    Relay R_2 : CT ratio = 500/5, plug setting = 75%.

    A fault at F results in a fault current of 3000 A. Find TMS of R_2 to give time-grading margin of 0.5 sec between the relays.