Part V

Power System Protection

Overcurrent Protective Relays

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Power system protection **Dr.Mohammed Tawfeeq**

Overcurrent Protective Relays

Overcurrent relays

Overcurrent relaying is the simplest and cheapest type of protection used for protection of lines, transformers, generators and motor.

Overcurrent relays Types

Based on operating time characteristics, normally defined by the time vs. current curve (or T-I curve), there are three main types of overcurrent relays:

- Instantaneous
- Time-dependent ⇨ Definite time or Inverse time
- Mixed ⇨ Definite time + Inverse time

1. Instantaneous Overcurrent Relays(50,50N)

These relays operate without time delay, so they are called instantaneous units(operating time= 0.1 second). The simplest form of these relays is the magnetic attraction types shown in Fig.1. Solid - State, digital and numerical overcurrent relays also available.

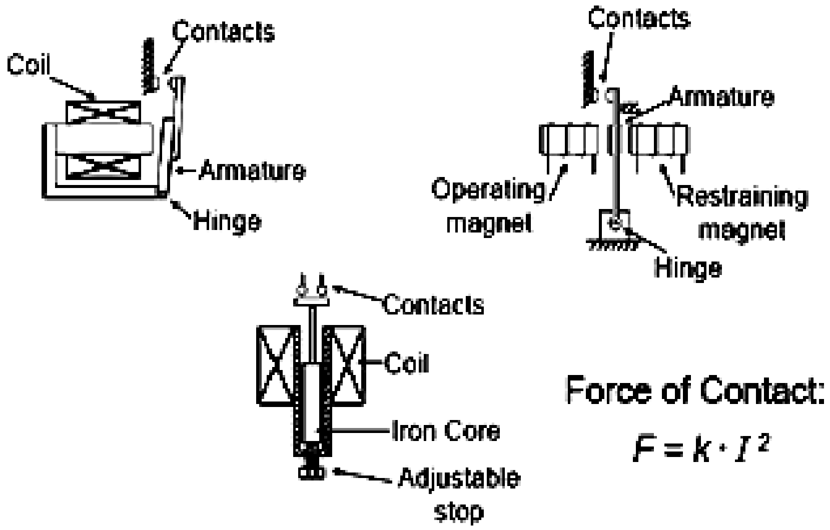


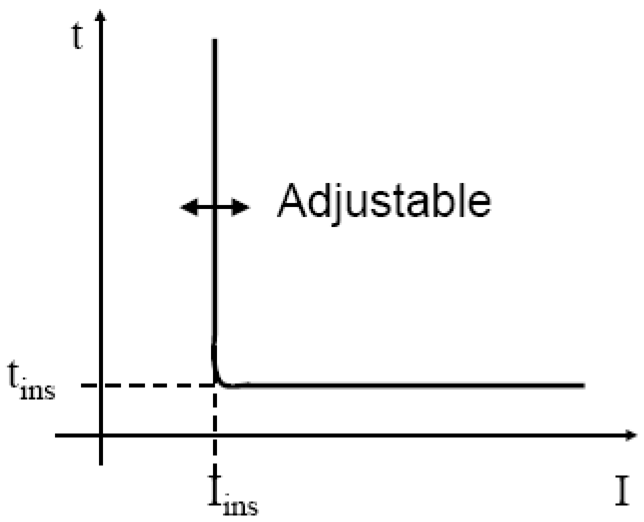
Fig.1

- The pickup current (threshold) is adjustable and the user can choose the setting from a relatively large range.

- **Pickup Current Setting**
  - Taps in the Relay Current Coil
  - Air-Gap Adjustment
  - Spring Adjustment

- **Features of Electromechanical 50 Elements**
  - Suitable for AC and DC Systems
  - Operation Time Less Than 3 Cycles

Instantaneous Curve (50)



50 (ANSI)

Only current is adjustable - Time t_{ins} < 3 Cycles

2. Time Overcurrent Relays

Time overcurrent relays operate with a time delay. The time delay is adjustable. The minimum current at which the relay operates (pick up current) is also adjustable.

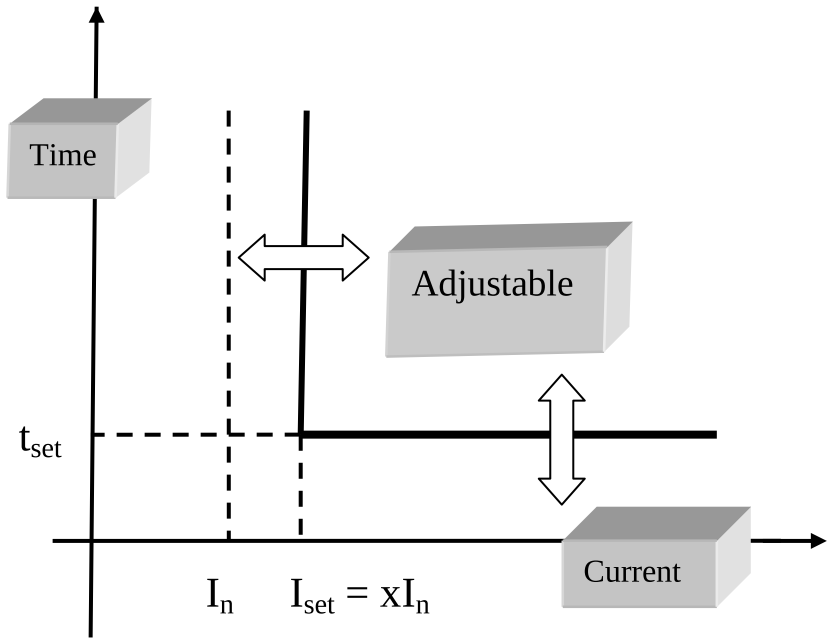
There are five different types of time over-current relays. Their time-current characteristic curves are:

- *Definite time*
- *Inverse-time:*
    - *Moderately inverse*
    - *Inverse (Normal)*
    - *Very inverse*
    - *Extremely inverse*

2.1 Definite-Time Overcurrent Relays

The definite-time relay operates with some delay. This delay is adjustable (as well as the current threshold).

Definite - Time Curve (50)



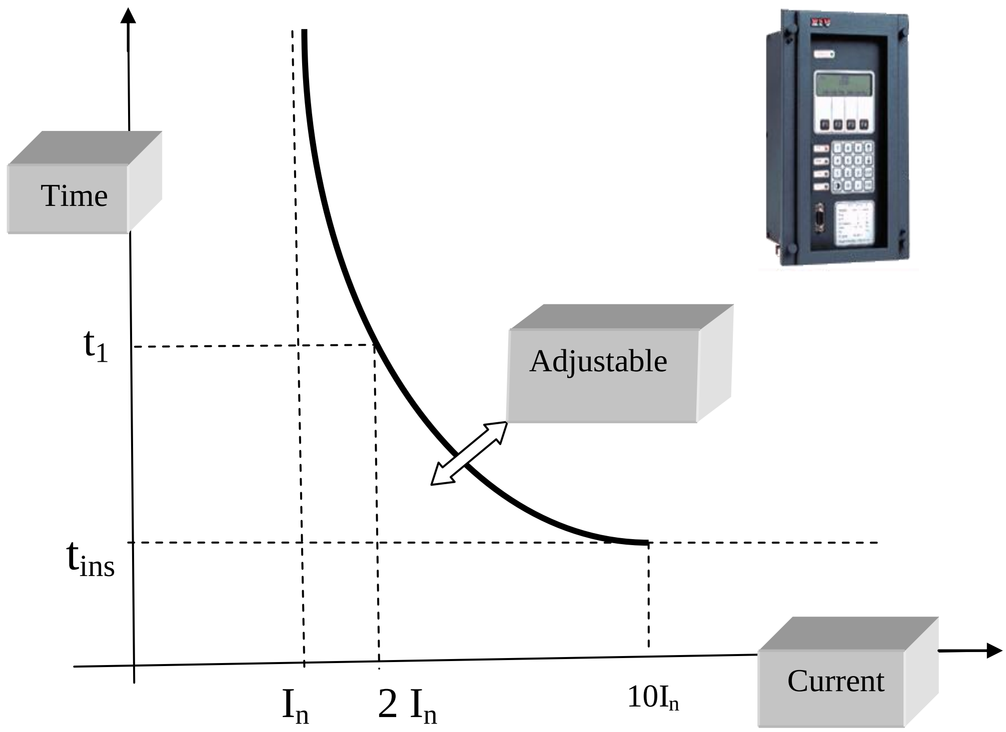
Definite – Time Curve (50).

2.2 Inverses-Time Overcurrent Relays

This type of relay have an operating time depending on the value of the current, generally with an inverse characteristic, the operation time of the relay is smaller as the current gets larger.

These relays also have two settings: the pick-up current and the curve level. In early electromechanical relays the curve is set by means of a dial. Thus, the setting is called the "time dial setting - TDS".

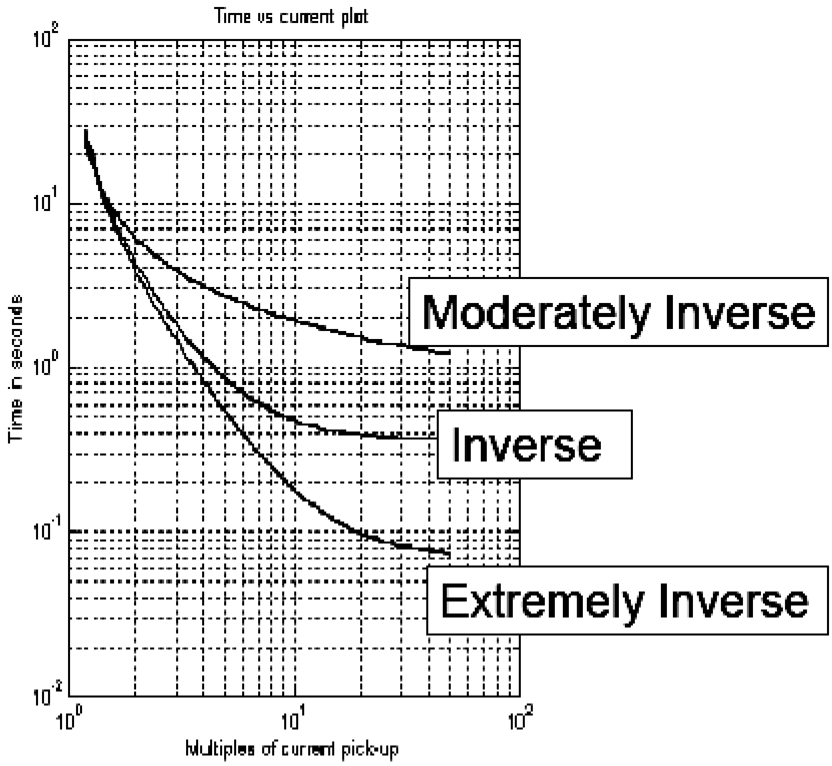
Inverse - Time Curve (51)



Inverse time curve (51)

Degrees of Inverse Curves

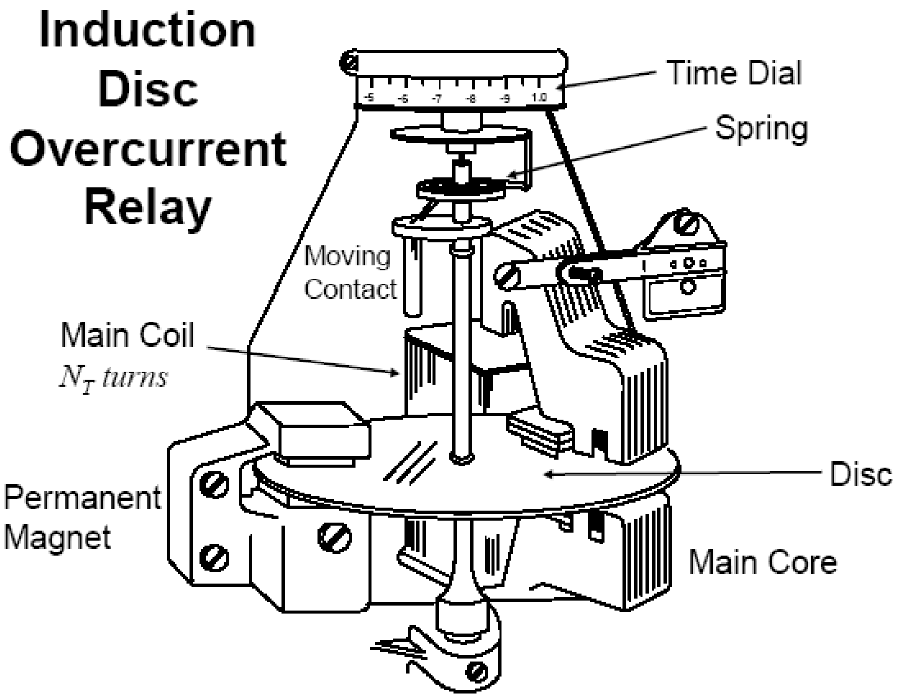
■The most common three types of curves used are, Normal inverse (NI), Very inverse (VI) and Extremely inverse (EI).



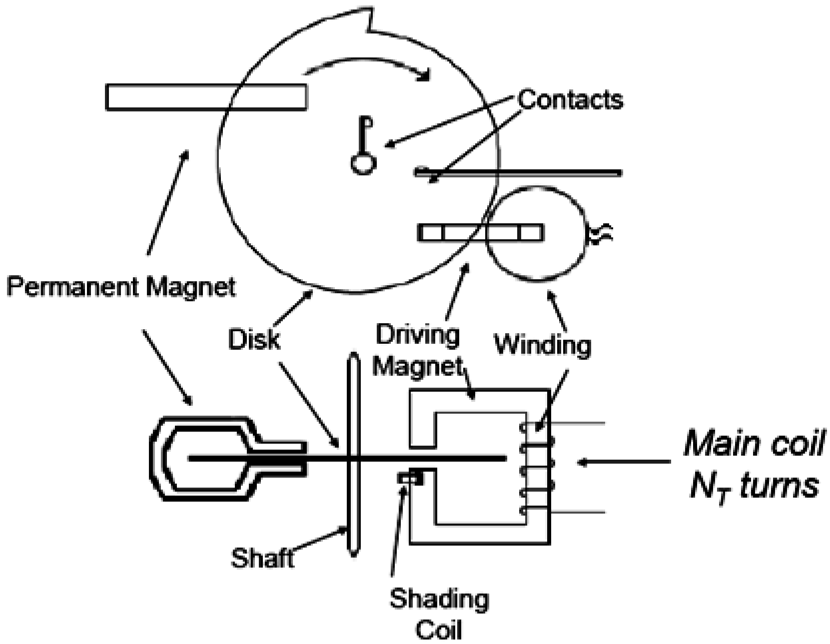
IEEE does not specify coefficients in the standard curve equation. Thus, each manufacturer's curve is similar. But different IEC curves are standardized

Typical Inverse-Time Overcurrent Relay Elements

1. Induction disc overcurrent relay.



2. Shaded-Pole Induction 51 Element



Overcurrent Relay Setting

- 50 Elements: Pickup Setting
- 51 Elements Pickup setting
  - ❖ Time delay setting
  - ❖ definite time: time setting
  - ❖ inverse time: curve selection

Selecting an Overcurrent Relay Time Curve According to American Standrd

Time-overcurrent relays (ANSI 51 relays) have two basic settings:

the pickup current and the time delay settings.

The process for determining the time delay setting involves:

(1) Calculation of a time delay value in definite-time overcurrent elements

(2) Selection in inverse-time overcurrent elements of a time-current curve from a family of curves.

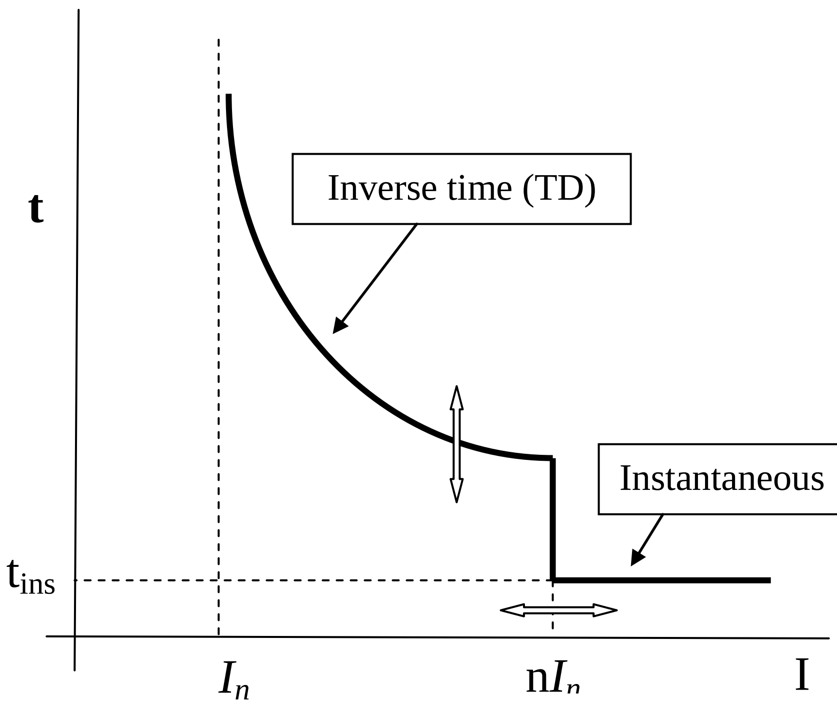
Note: Instantaneous over current (50) elements have only one setting: the pickup current.

2.3 Mixed Curves Overcurrent Relays

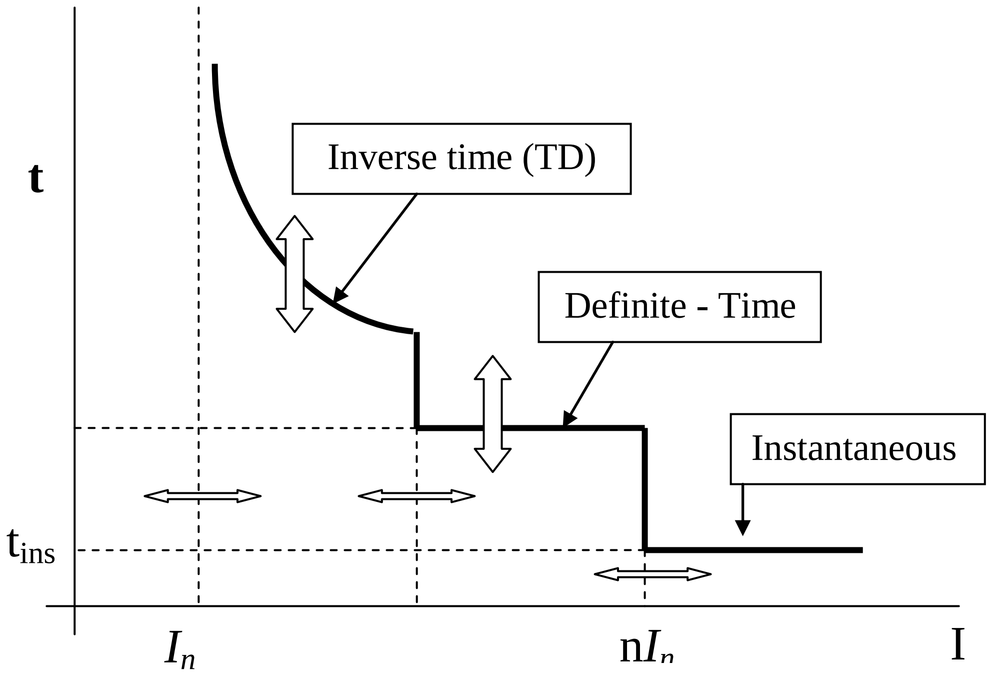
Mixed curves have all the advantages of the different types of overcurrent relays. As the OC elements are built as separate units, we may implement the overcurrent protection principles using:

- a combination of instantaneous and definite-time elements or
- a combination of instantaneous and inverse-time elements.
- a combination of instantaneous, definite-time and inverse-time elements.
- a combination of definite-time and inverse-time elements(IDMT).

2.3.1 Mixed Curves (Inverse-Time + Instantaneous)



2.3.2 Mixed Curves (Inverse-Time +Definite -Time + Instantaneous)

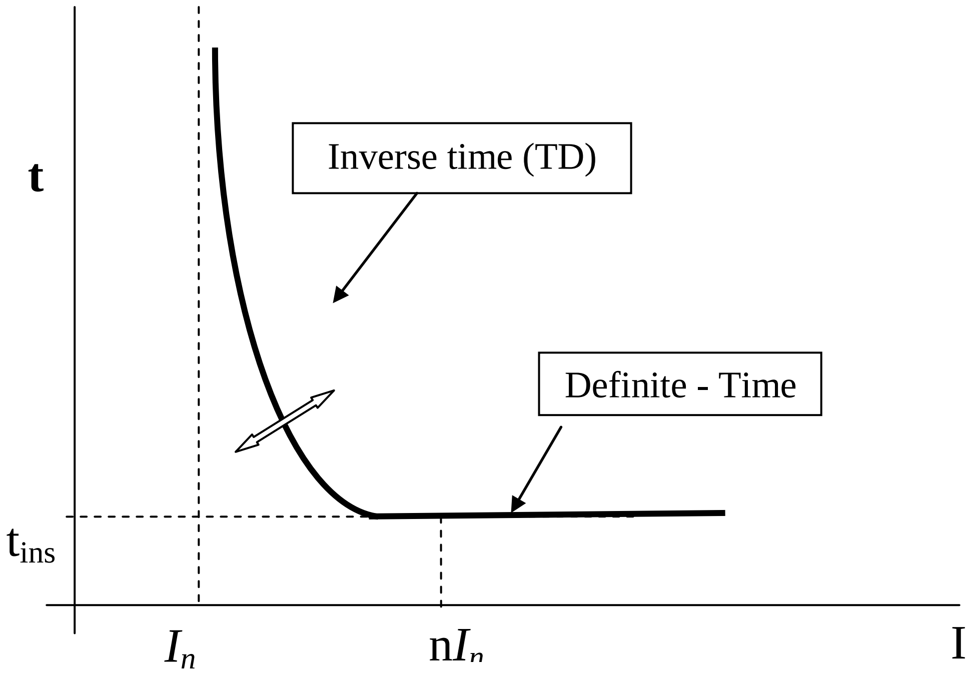


Note: This type of characteristic is mainly used in digital relays.

1.3.3 Mixed Curves (Inverse-Time +Definite -Time) IDMT – Characteristics

The most commonly used type of relay is the inverse definite with minimum time lag relay (IDMT) in which inverse characteristic plus definite time characteristic are used.

In this relay, the operating time is approximately inversely proportional to the fault current near pickup value and become substantially constant slightly above the pick up value of the relay. This characteristic is shown in the following figure.



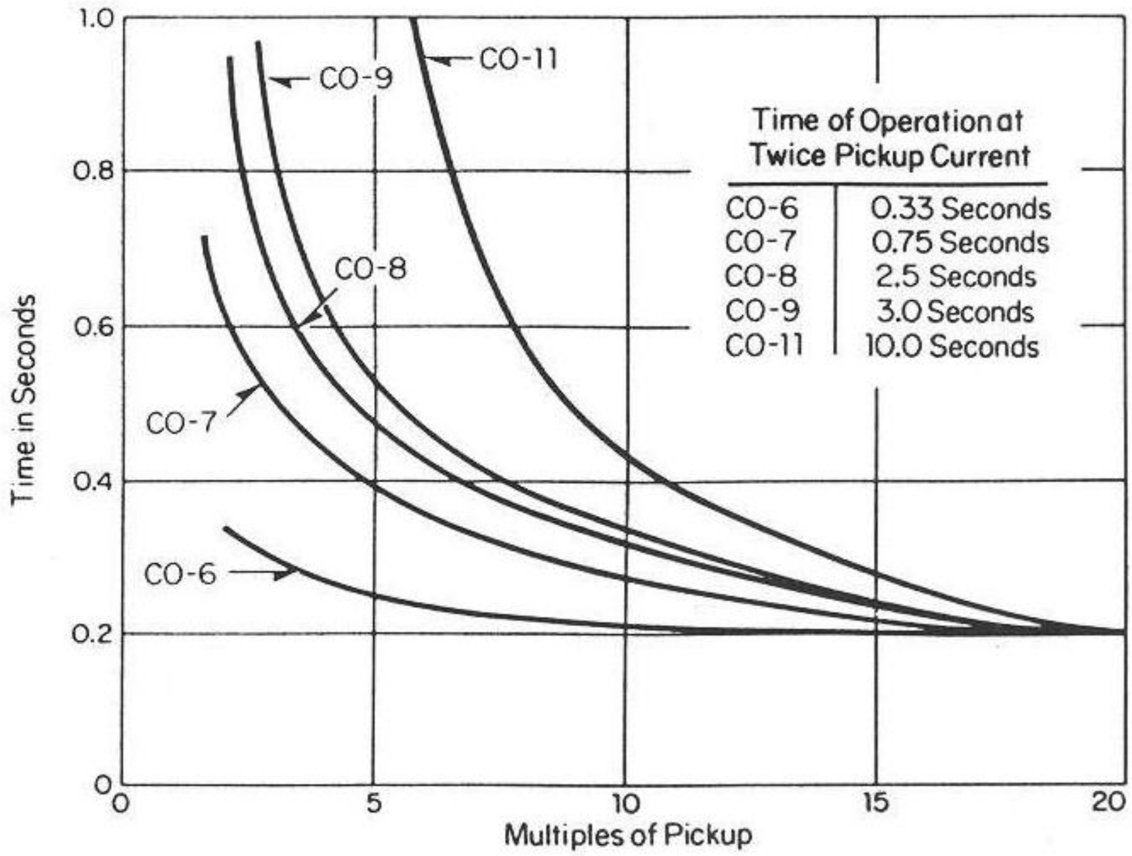
- This characteristic can be achieved using a core of electromagnet which gets saturated for currents slightly greater than the pickup current.
- Wattmetric and shaded pole relays of induction type can be used to obtain this characteristic.

Standard Time and Inverse definite minimum time (IDMT) Relay Characteristics

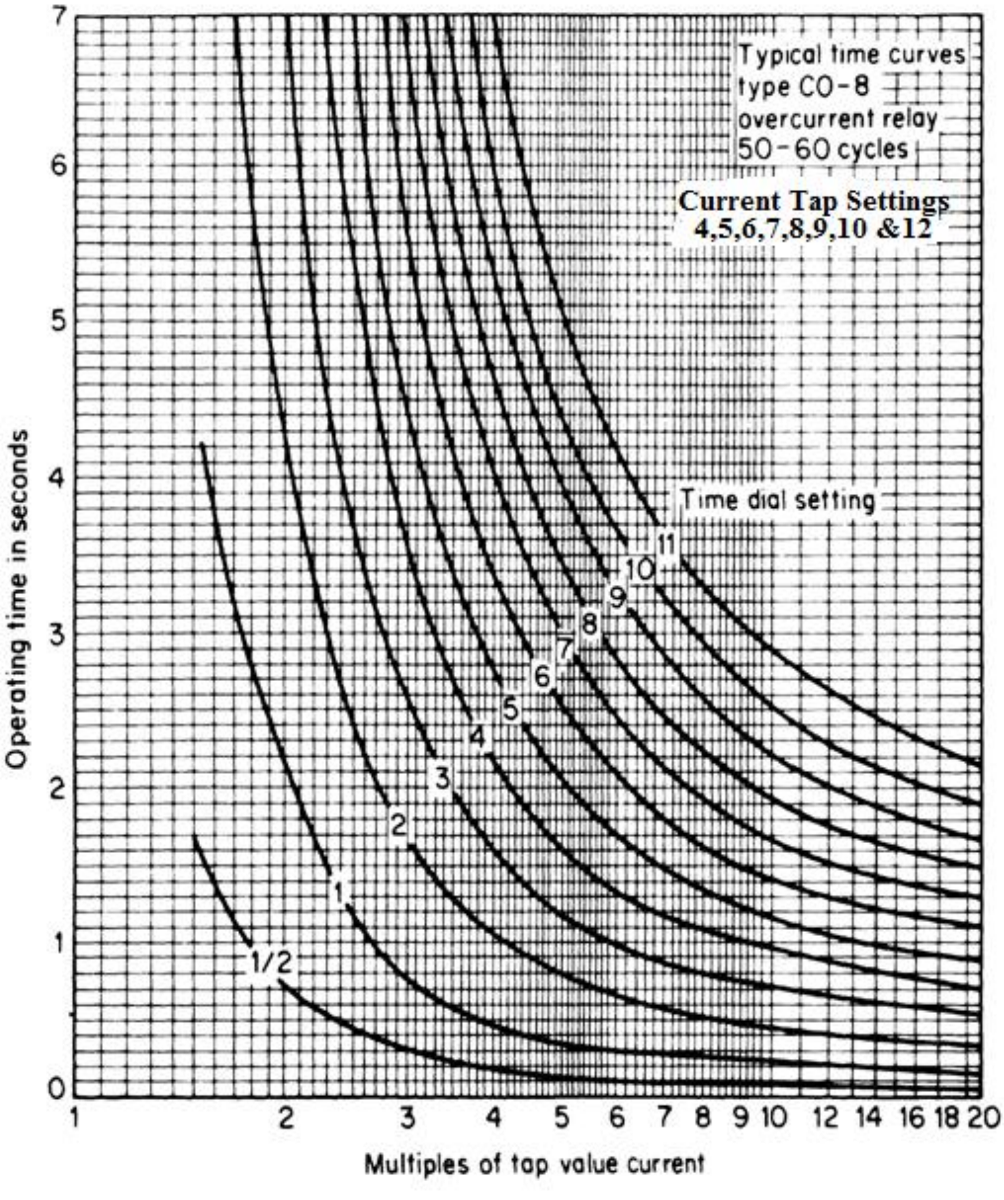
1. American Standard

- In American standard there are five different types of time overcurrent relay. Their time-current characteristic curves are:
  - *Definite minimum, CO-6*
  - *Moderately inverse, CO-7*
  - *Inverse, CO-8*
  - *Very inverse, CO-9*
  - *Extremely inverse, CO-11*

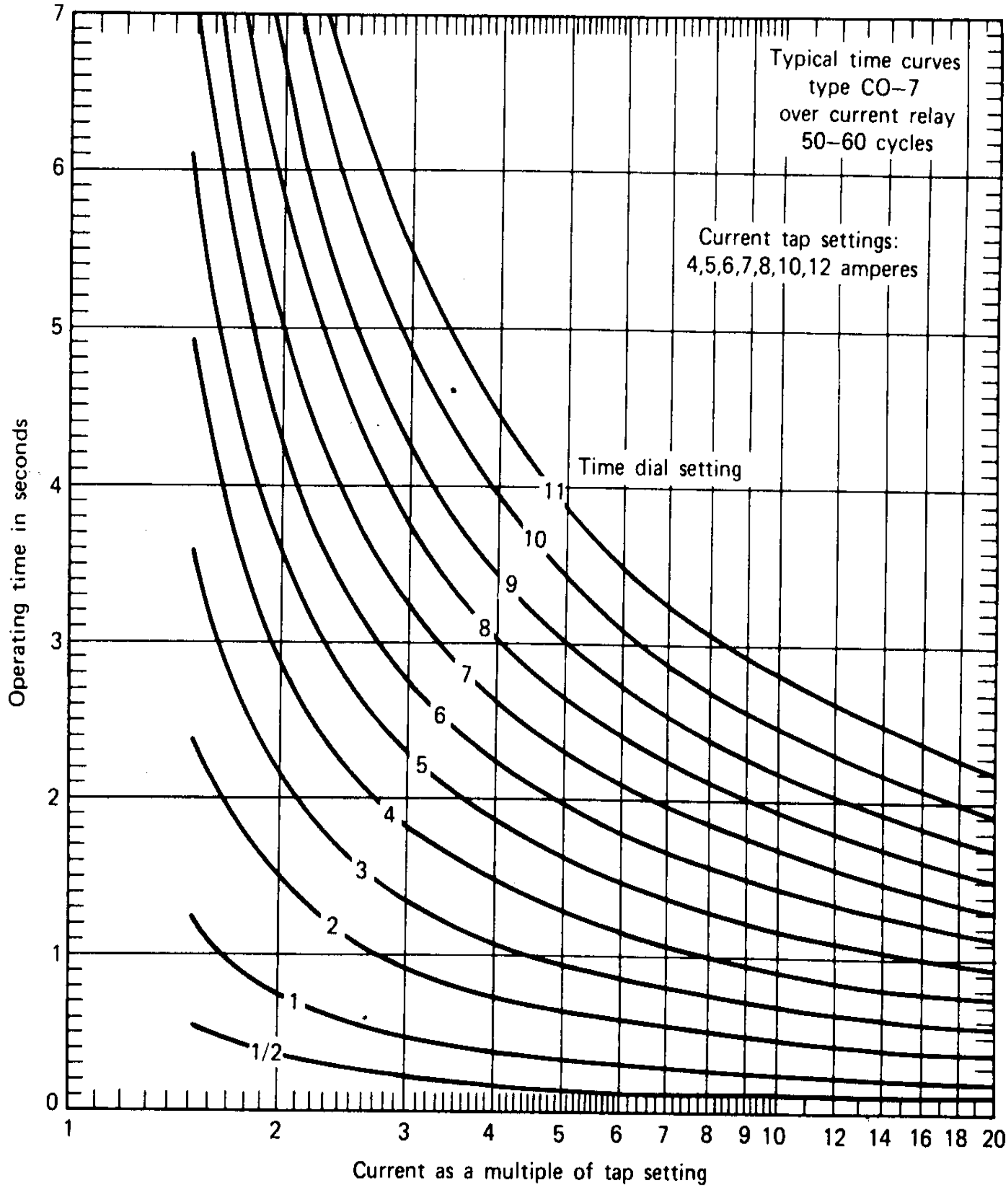
These time-current characteristics are compared in Figure below. *The time lever settings are selected so that all relays operate in 0.2 sec at 20 times the tap setting.*



Typical time curves for CO-8 American overcurrent relay (normal inverse).



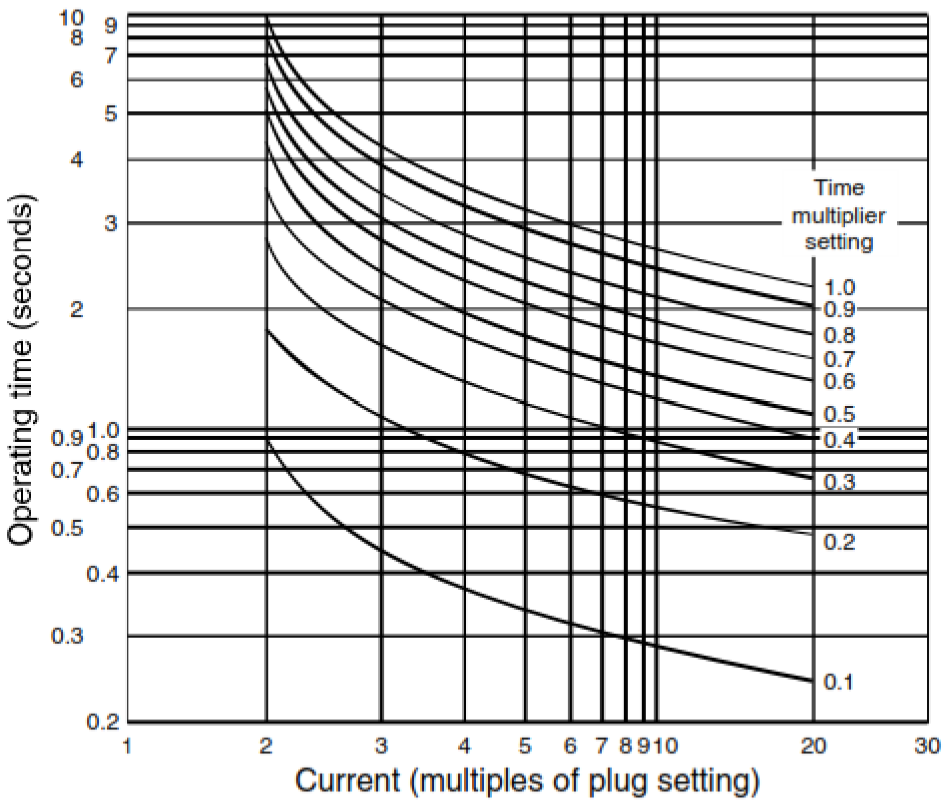
Typical time curves for CO-7 American overcurrent relay (moderate inverse).



2. IEC and British Standards

In IEC and BS Standards, we have three curves that one can use:

(a) The typical time curves for standard British Standard (BS142) and IEC Standard overcurrent relay (normal inverse). For: TMS= 0.1- to -1.0. shown below:



(b) The typical time curves for standard BS and IEC overcurrent relay(normal inverse).TMS=1.

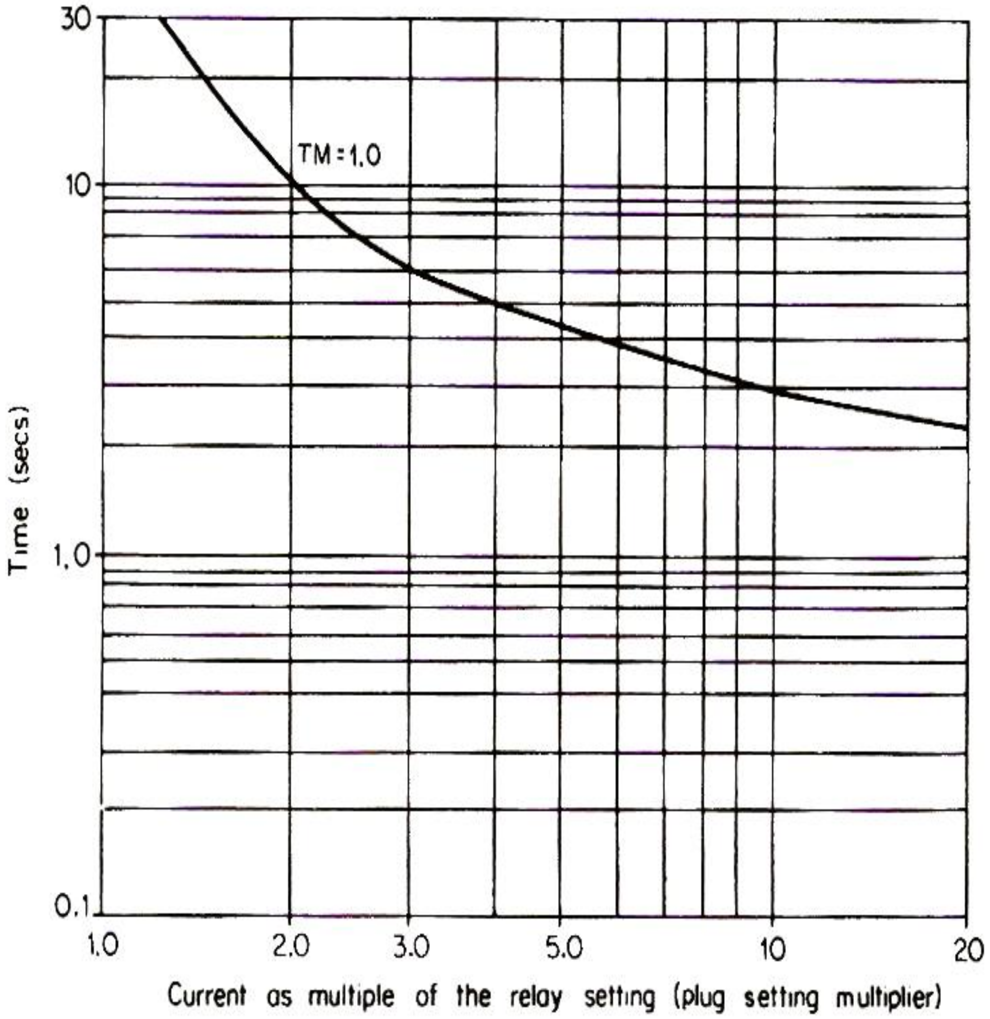


Figure- 1A

(c) OR the above figure can be given as:

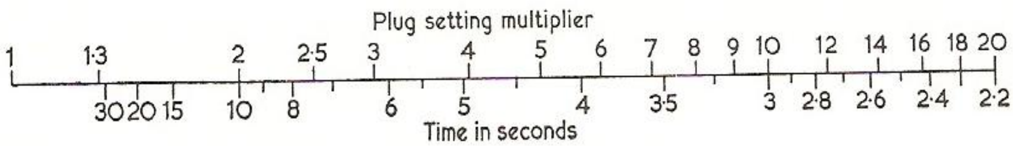


Figure – 1B

Curve Equations

1. The typical time curves for CO-8 American overcurrent relay(normal inverse) characteristics can be approximated by the following equation.

$$t_{relay} = TD\left[\frac{5.95}{M^2-1} + 0.18\right]$$

Where TD = Time delay

$$M = \frac{I_{relay}}{I_{pickup}}$$

t_{relay} = operating time of the relay

I_{relay} = Relay current = $I_{secondary}$

I_{pickup} = Relay pick up current

2. The typical time curves for IEC and BS standards overcurrent relay(normal inverse) characteristics can be approximated by the following equation.

$$t_{relay} = \frac{0.14 \times TMS}{\left(\frac{I_F}{CTR \times PS}\right)^{0.02} - 1}$$

Where : TMS = Time multiplier setting

CTR = Current transformer ratio

PS = Plug setting

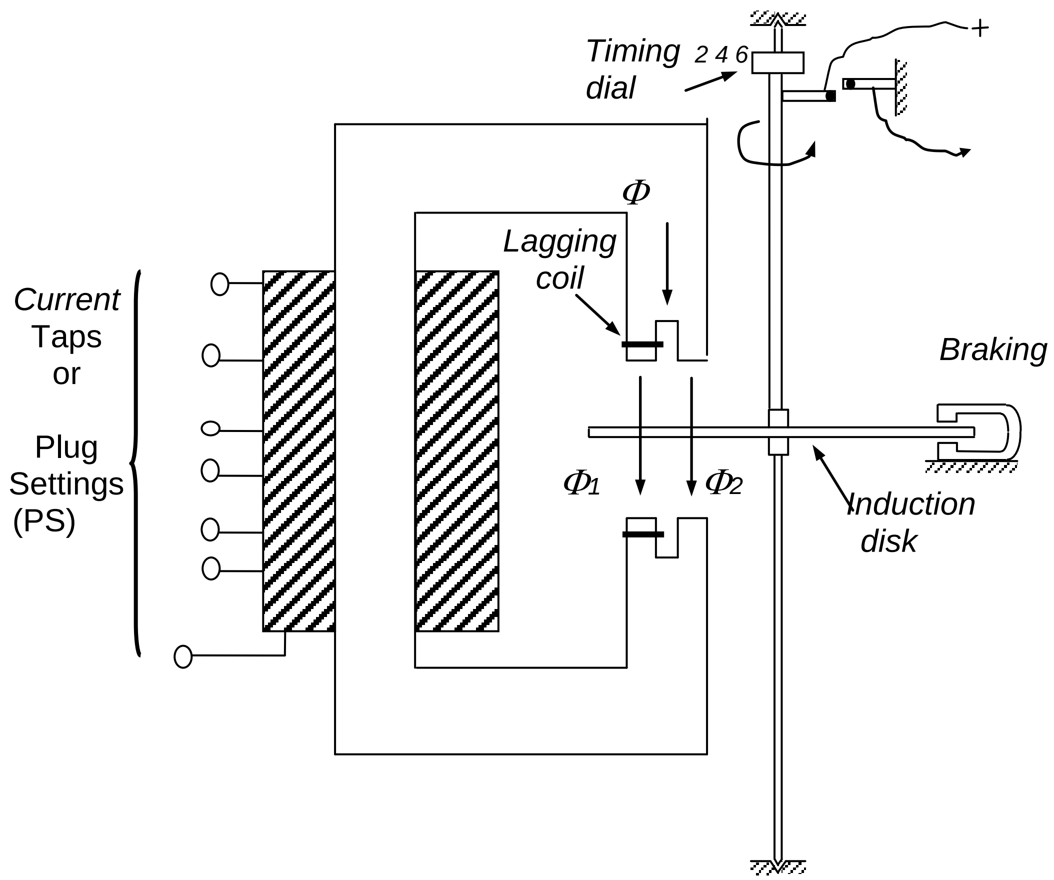
I_F = Fault primary current

Notes on IEC and BS Standards

- **Meaning of the Plug Setting (PS) and Time multiplier Setting (TMS) in Overcurrent Relays.**

The working principle of an inverse time overcurrent relay is depicted in figure below.

- **The current to be controlled feeds a coil with multiple taps which allow the pick up current setting - Plug setting (PS).**
- **The generated magnetic field makes the disc rotate with a speed proportional to the current.**
- **A timing dial allows the adjustment between contacts and hence sets the operating time –Time dial setting.**
- **The braking magnet lessens the rotating speed and acts as an opposing force to the rotation. Varying the magnetization, different tripping curves can be achieved.**



The following Table gives the equivalent names for overcurrent relay setting in both IEC and American Standards

IEC & BS standard	American Standard
Plug Setting (PS)	**Current Tap Setting (CTS)**
Time Multiplier Setting (TMS)	**Time Dial Setting (TDS)**

***Example*:** Calculate the plug setting and time multiplier setting for an IDMTL relay on the following network so that it will trip in 2.4 s (see Figure 1).The relay characteristic is shown in Figure2.The C.T. setting is 100/5 A and the fault current is 1000 A.

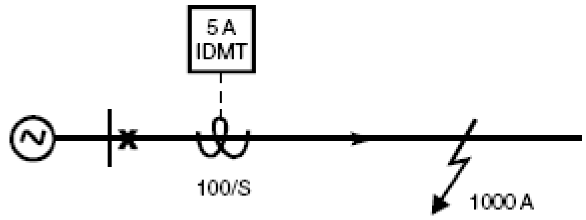


Figure 1

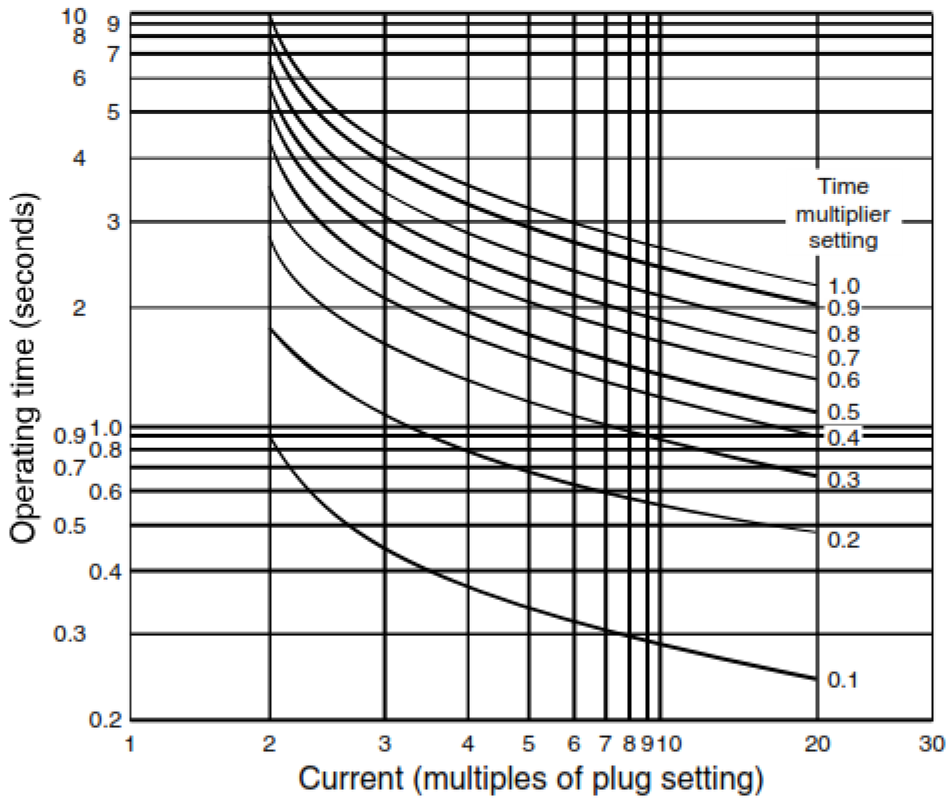


Figure 2 (Figure – 1A given previously)

Answer:

Fault current = 1000 A

CT ratio = 100/5 A

Hence expected current into relay under fault conditions,

$$Ir = (1000 \times 5/100) = 50 \text{ A}$$

Choose plug setting of 5 A (100%). Therefore, current into relay as a multiple of plug setting during fault: 50 / 5 = 10

- We require the relay to operate after 2.4 s as soon as this much current starts flowing in the circuit. Referring to characteristic curves given in Figure 2 above, read time multiplier setting where 10 times plug setting current and 2.4 s cross, which is about 0.8. Accordingly, relay settings = current plug tap 5 A (100%) and time multiplier 0.8.
- Alternatively, if the current plug setting is chosen as 125% (6.25 A), the fault current through the relay will be 50/6.25 = 8 A. The graph shows that eight times plug setting to operate in 2.4 s, the time multiplier should be about 0.7. This technique is fine if the required setting falls exactly on the TM curve. However, if the desired setting falls between the curves, it is not easy to estimate the intermediate setting accurately as the scales of the graph are log/log. The following procedure is therefore recommended (see Figure 3).
- Go to the multiple of plug setting current and read the second value corresponding to the 1.0 time multiplier curve. Then divide the desired time setting by this figure. This will give the exact time multiplier setting:
- Second value at 10 times = 3
- (at 8 times it is about 3.3s)

  Desired setting = 2.4s.

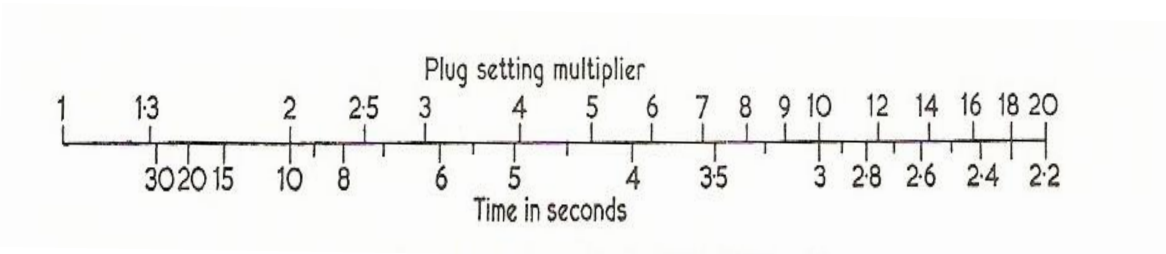
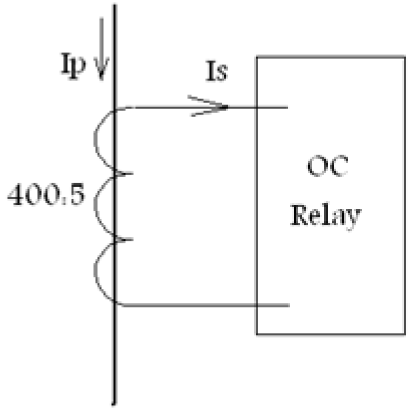


Figure 3
(Figure – 1B previously)

Logarithmic scale for I.D.M.T. relay

Examples :

Example1: Determine the PSM (plug setting multiplier) of a 5A, 2.2 sec over current relay having a plug setting P_s=200%. The supply CT is rated 400:5A and the fault current is 12000A.



Solution:

$$I_p = 12000A$$

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

On PS of 200%:

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

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

Example 2: 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.

Solution:

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 3 methods:

1) Directly from characteristics of the relay as shown in Fig. EX2-1(if available)

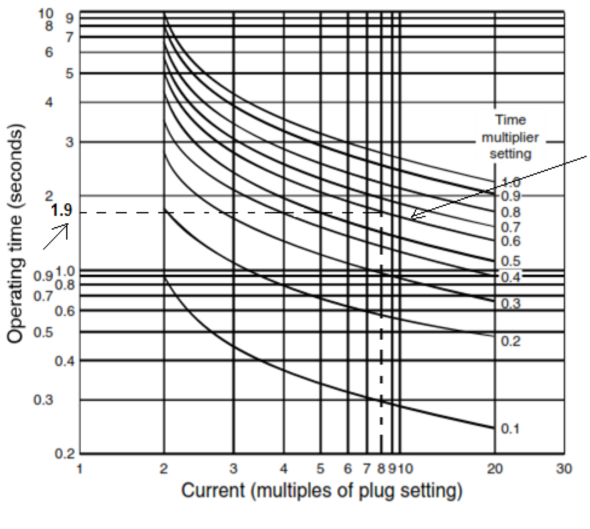


Fig. EX2-1

The operating time of the relay top from figure:

top= 1.9 (approx.)

2) From the curve of TMS=1(Fig. EX.2-2) , the operating time t_{op} for PSM=8 is 3.3sec (TMS=1) and for TMS=0.6 is 1.92sec $(\frac{0.6}{1.0}\times 3.3.)$

This comes from:

TMS	t_{op}
1	3.3
0.6	?

$$?=\frac{0.6}{1.0}\times 3.3.=1.92 \text{ sec}$$

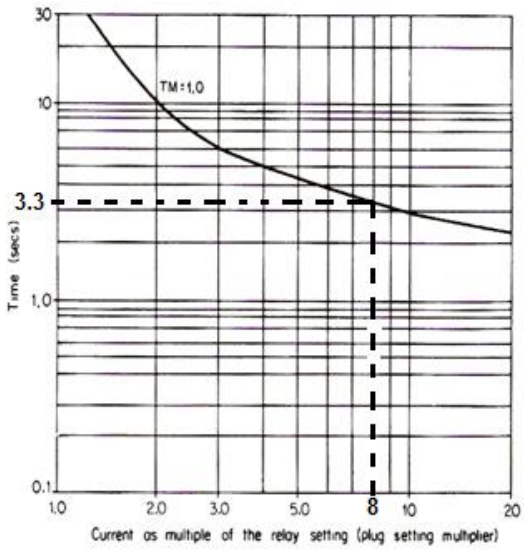


Fig. EX.2-2

3) Or from Fig. EX.2-3

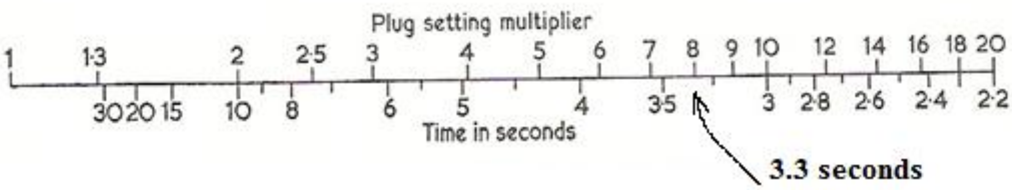


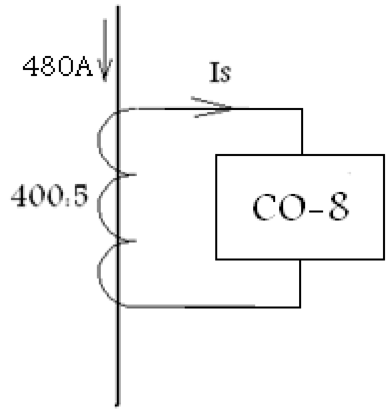
Fig. EX.2-3

For PSM = 8 , top = 3.3 sec. for TMS =1. Now convert top to TMS =0.6 as above:

TMS	top
1	3.3
0.6	?

$$?=\frac{0.6}{1.0}\times 3.3.=1.92 \text{ sec}$$

Example3: If the rated current (pick up current) of a relay is 3A, and the time dial setting is 1. (a) How long does it take the relay to trip if the supply C.T is rated at 400:5 A, and the fault current is 480A? The type of the OC relay is CO-8.
(b) Solve using the standard curve equation and compare the results.



Solution:

(a) $I_p = 480A$

$$I_s = 480 \times \frac{5}{400} = 6A$$

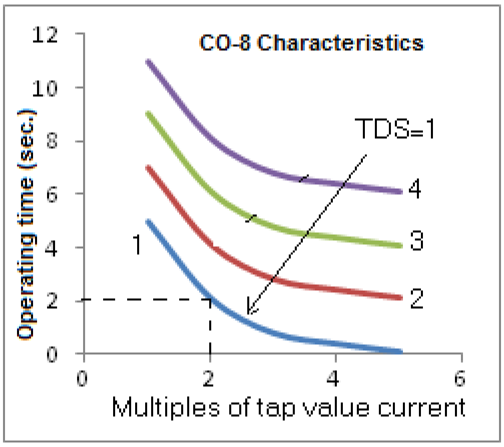
Tap value of current=3A

∴ Multiple of tap value current

$$= \frac{I_s}{I_{tap}} = \frac{6}{3} = 2$$

From the CO-8 characteristic curves (see Figure below) :

Operating time=2.1 sec.



(b) Using the curve equation:

$$t_{relay} = TD\left[\frac{5.95}{M^2 - 1} + 0.18\right]$$

$TD = 1 \Rightarrow TDS$

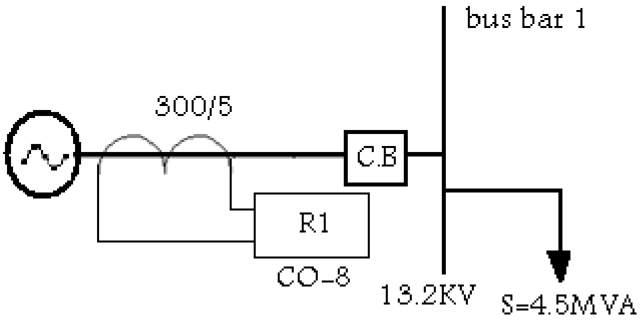
$$M = \frac{I_s}{I_{pickup}} = \frac{I_s}{I_{tap}} = \frac{6}{3} = 2$$

$$\therefore \quad t_{relay} = 1 \times \left[\frac{5.95}{(2)^2 - 1} + 0.18\right]$$

$$= 2.16 \sec$$

(Same result)

Example4: For the relay R_1 in the system shown determine the current tap setting CTS. If the maximum three-phase fault current is 2400A and the TDS=2.0 find the operating time if the relay type is CO-8 (inverse type).



<u>Solution:</u>

- Load current at the busbar1

$$I_{L1} = \frac{S}{\sqrt{3}V} = \frac{4.5\times10^6}{\sqrt{3}\times13.2\times10^3} = 196.82A$$

The relay current $I_R = 196.82\times\frac{5}{300} = 3.28A$

Since the current tap setting (CTS) of CO-8 relay available are 4,5,6,7,8,10 and 12

Hence we choose CTS=4

- Fault current $I_f = 2400A$

$\therefore$ Relay current during fault $= 2400\times\frac{5}{300} = 40A$

As multiple of selected CTS $= \frac{40}{4} = 10$

From the CO-8 ch/s curve:

Operating time $\cong 0.3105\text{sec}$