Universal Relay Torque Equation

The universal relay torque equation is given as

$$T = K_1 I^2 + K_2 V^2 + K_3 VI\cos(\theta - \tau) + K$$

By assigning plus & minus signs to some of the terms and letting others be zero and sometimes adding some terms having a combination of voltage and current, the operating characteristics of all types of relays can be obtained.

For example, overcurrent relay has $K_2 = K_3 = 0$ and spring torque will be $-K$, similarly for directional relay $K_1 = K_2 = 0$.

Characteristics Of Distance Relays

Distance relay can be studied with the help of universal torque equation.

Different types of distance relay are (1) Impedance relay
(2) Reactance relay
(3) Mho relay

(1) Impedance Relay

From the universal torque equation putting $K_3 = 0$ and assigning negative sign to the voltage term, the universal torque equation becomes as

$$T = K_1 I^2 - K_2 V^2$$

which means the operating torque is produced by the current coil and the restraining torque is produced by the voltage coil. Hence impedance relay is a voltage restrained over current relay.

For operation of the relay, the operating torque should be greater than the restraining torque i.e.,

$$K_1 I^2 > K_2 V^2$$

$$\Rightarrow K_2 V^2 < K_1 I^2$$

$$\Rightarrow \frac{V^2}{I^2} < \frac{K_1}{K_2}$$

$$\Rightarrow Z^2 < \frac{K_1}{K_2}$$

$$\Rightarrow Z < \sqrt{\frac{K_1}{K_2}} \text{ (design impedance)}$$

This means that the impedance relay will operate only if the impedance seen by the relay is less than a prespecified value (design impedance)

At threshold condition $Z = \sqrt{\frac{K_1}{K_2}}$

The operating characteristics of an impedance relay are shown on an impedance diagram & R-X diagram.

This is clear from the characteristic that if the impedance as seen by the relay lies within the circle will operate otherwise it will not. The position of one value of Z is with angle θ on +R-axis which means that the current lags the voltage by an angle θ.

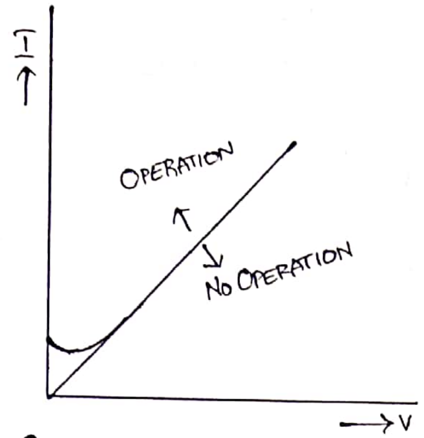


FIG: OPERATING CHARACTERISTICS OF AN IMPEDANCE RELAY ON V-I DIAGRAM

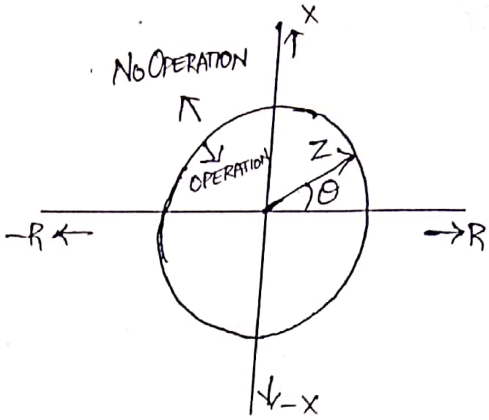


FIG: OPERATING CHARACTERISTICS OF AN IMPEDANCE RELAY ON R-X DIAGRAM

The impedance relays normally used are high speed relays. These relays may use a balance beam structure & an induction cup structure.

(2) REACTANCE RELAY

In this relay the operating torque is obtained by the current and the restraining torque is obtained by the current - voltage directional element. This means a reactance relay is an overcurrent relay with directional restraint. The direction element is so designed that its maximum torque angle is 90° i.e., $\tau = 90°$ in the universal torque equation.

$$T = K_1 I^2 - K_3 VI\cos(\theta - \tau)$$

$$\Rightarrow T = K_1 I^2 - K_3 VI\cos(\theta - 90)$$

$$\Rightarrow T = K_1 I^2 - K_3 VI\sin\theta$$

For operating the relay, the operating torque should be greater than the restraining torque i.e.,

$$K_1 I^2 > K_3 VI\sin\theta$$

$$\Rightarrow K_3 VI\sin\theta < K_1 I^2$$

$$\Rightarrow \frac{VI\sin\theta}{I^2} < \frac{K_1}{K_3}$$

$$\Rightarrow Z\sin\theta < \frac{K_1}{K_3}$$

$$\Rightarrow X < \frac{K_1}{K_3}.$$

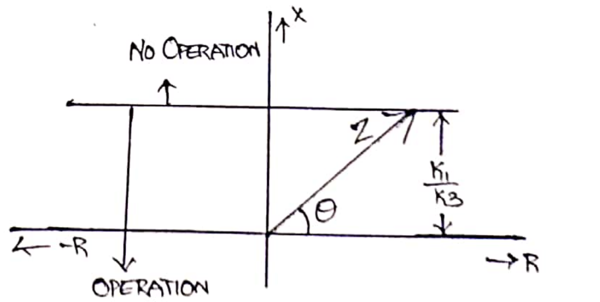


FIG: CHARACTERISTICS OF A REACTANCE RELAY

This means for the operation of the relay the reactance seen by the relay should be smaller than the reactance for which the relay has been designed.

This means if the impedance relay vector head lies on the parallel lines this will have a constant X component. The impotant about this characteristic is that the resistance component of the impedance has no effect on the operation of the relay. It reponds only to the reactance component of the impedance. The relay will operate for all impedances whose heads lie below the operating characteristics whether below & above R axis.

(3) MHO RELAY

In this relay the operating torque is obtained by the V-I element and restraining torque due to the voltage element. This means a mho relay is a voltage restrained directional relay. From the universal torque equation

$$T = K_3 VI \cos(\theta - \tau) - K_2 V^2$$

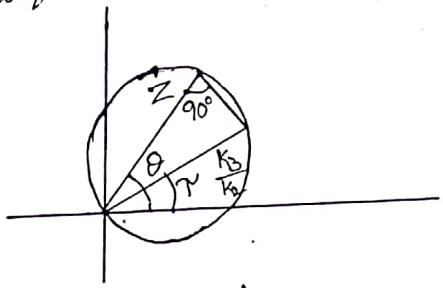
For the relay to operate, the operating torque should be higher than the restraining torque i.e.,

$$K_3 VI \cos(\theta - \tau) > K_2 V^2$$

$$\Rightarrow K_2 V^2 < K_3 VI \cos(\theta - \tau)$$

$$\Rightarrow \frac{V^2}{VI} < \frac{K_3}{K_2} \cos(\theta - \tau)$$

$$\Rightarrow Z < \frac{K_3}{K_2} \cos(\theta - \tau)$$



This characteristics when drawn on an admittance diagram is a straight line passing through the origin and if drawn on an impedance diagram is a circle passing through the origin.

The relay operates when the impedance seen by the relay falls within this circle. The relay is inherently directional so that it needs only one pair of contacts which makes it fast tripping for fault clearance and reduces VA burden on current transformers.

CHARACTERISTICS OF OVER CURRENT RELAYS

Depending up on the time of operation, the overcurrent relays are classified as follows. They are (1) Instantaneous over current relay

(2) Inverse time - current relay

(3) Inverse Definite Minimum Time (IDMT) overcurrent relay

(4) Very Inverse relay

(5) Extremely Inverse relay

(1) INSTANTANEOUS OVER CURRENT RELAY

This relay is the one in which no intentional time delay is provided for the operation. The time of operation of such relays is approximately 0.1 sec. This characteristic can be achieved by using hinged armature relays. The instantaneous relay is more effective where the impedance Z_s between the source and the relay is small when compared with the impedance Z_l of the section to be provided.

(2) INVERSE TIME CURRENT RELAY

This relay is the one in which the operating time reduces as the actuating quantity increases in magnitude. They are normally more inverse near the pick up value of the actuating quantity and becomes less inverse as it is in[illegible]. This characteristic can be obtained with induction type of relays by using a suitable core which does not saturate for a large value of fault current. If the saturation occurs at a very early stage, the time of operation remain same over the working range. The characteristics are shown by curve (a) in the below figure and is known as definite time characteristics.

(3) INVERSE DEFINITE MINIMUM TIME (IDMT) CURRENT RELAY

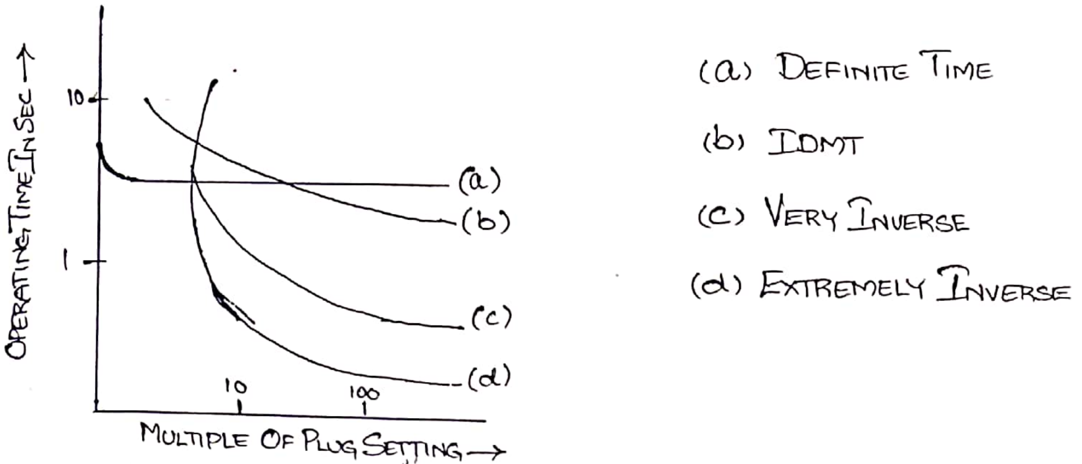


FIG: CHARACTERISTICS OF VARIOUS OVERCURRENT RELAYS

This relay is the one in which the operating time is approximately inversely proportional to the fault current near pick up value and becomes substantially constant slightly above the pick up value of the relay as shown in the curve (b). This is achieved by using a core of the electromagnetic which gets saturated for the currents slightly greater than the pick up current.

(4) VERY INVERSE RELAY

This relay is the one in which the saturation of the core occurs at a later stage, the characteristics assume the shape as shown in curve (c) and is known as very inverse characteristic. The time current characteristic is inverse over a greater range and after saturation tends to definite time.

(5) EXTREMELY INVERSE RELAY

This relay is the one in which the saturation of the core occurs at a still later stage. The equation describing the curve (d) is approximately of the form $I^2t = K$, where I is the operating current and t is the operating time.

CHARACTERISTICS OF DIRECTIONAL OVER CURRENT RELAYS

The relay consists of two units namely

(i) Directional unit

(ii) Non directional & inverse time current unit.

The directional unit is a four pole induction cup unit. Two opposite poles are fed with voltage while the other two opposite poles are fed with current. The voltage is taken as the polarizing quantity which produces one of the two fluxes required for production of the torque and this quantity is taken as reference compared with the other quantity which is current here. This means that the phase angle of the polarizing quantity must remain more & less fixed when the other quantity suffers wide changes in the phase angle.

In a circuit at a point current can flow in one direction at a particular instant. Consider this direction as the normal direction of flow of current. Under this condition the directional unit will develop negative torque and the relay will be restrained to operate. Now if due to certain changes in the circuit condition, the current flows in opposite direction, the relay develops positive torque and will operate.

For a directional over current unit, unless the directional unit contacts are closed, the overcurrent unit is not energized because the operating coil of the over current unit completes its circuit through the directional unit contacts or if the over current unit has shading coil on its poles for production of lagging flux then the shading coil completes its circuit through the directional unit contacts as shown in the below figure.

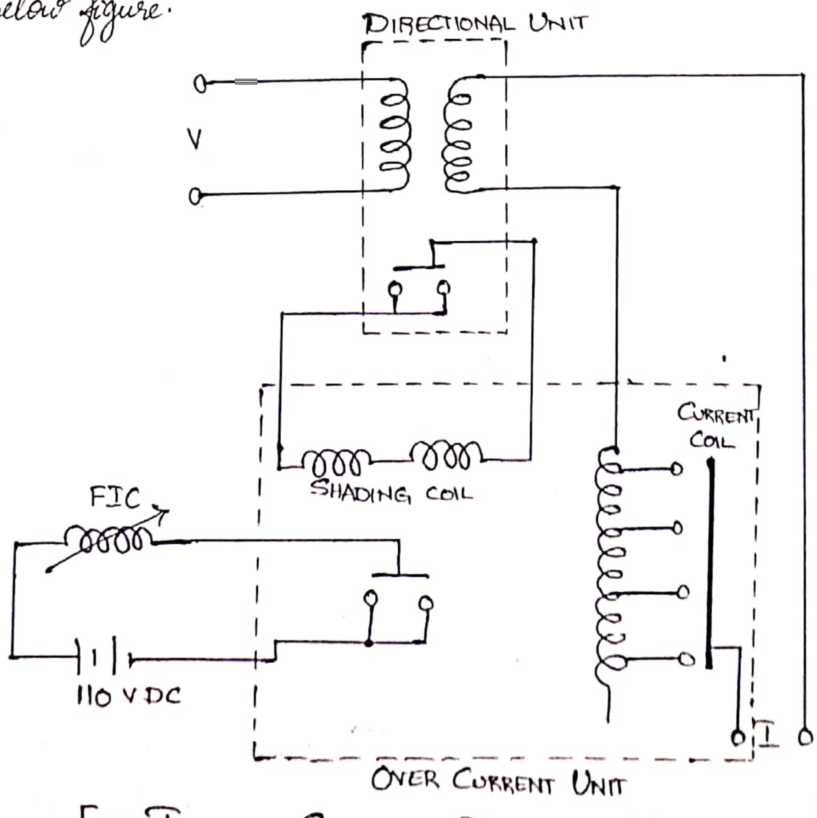


FIG: INTERNAL CONNECTION DIAGRAM OF DIRECTIONAL OVER CURRENT RELAY

The contacts of the directional unit can be easily removed if maintainance is required the whole unit can be easily dismantled and re-assembled without altering its characteristics.

The torque developed by a directional unit is given by

$$T = VI\cos(\theta - \tau) - K$$

where V is rms magnitude of voltage fed to the voltage coil circuit

I is rms magnitude of current in current coil.

θ is angle between I and V

τ is maximum torque angle

K is restraining torque including spring and friction

For a particular installation $(\theta-\tau)$ = constant K_1; then the torque equation becomes as

$$T = K_1 VI - K$$

Under threshold condition when the relay is about to start,

$$T = K_1 VI - K = 0$$

$$\Rightarrow VI = \frac{K}{K_1} = K' = \text{constant}$$

This characteristic is known as constant product characteristic and is of the form of rectangular hyperbola as shown in the figure.

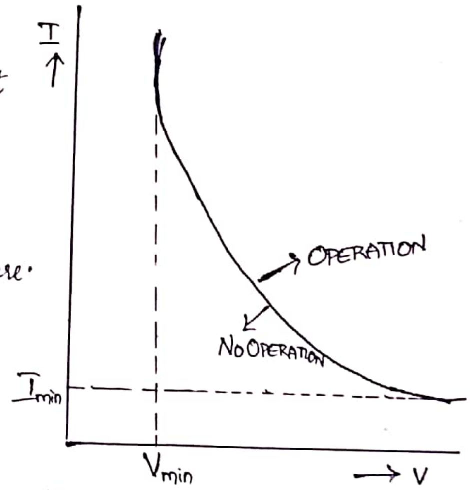


FIG: CONSTANT PRODUCT CHARACTERISTIC OF DIRECTIONAL RELAY

For the operation of 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 minimum value of current required for the torque to be developed. The product of any value of voltage and any value of current to exceed K' is not enough. Let A be the location of directional relay as shown in the below figure.

FIG: DIRECTIONAL RELAY USED ON A LINE

In case the fault is close to the relay, the voltage to be fed to the relay may be less than the minimum voltage required. The maximum distance upto which the voltage is less than the minimum voltage required is known as the dead zone of the directional relay i.e., if the fault takes place within this zone the relay will not operate.

The phasor diagram is shown in the below figure. ϕ_V is the flux due to the voltage coil and lags behind the voltage by about 60° to 70°. ϕ_I is the flux due to the current coil. The net torque is produced due to interaction of ϕ_V and ϕ_I.

The torque is maximum when two fluxes are displaced by 90°. Here dotted line in the phasor diagram represents the desired position of ϕ_I for maximum torque and since V is the reference & polarizing quantity and ϕ_V has fixed position with respect to V for a particular design. The angle between the dotted line and the polarizing quantity V is known as maximum torque angle τ. This means when the relay current leads the voltage by an angle τ, maximum torque is produced.

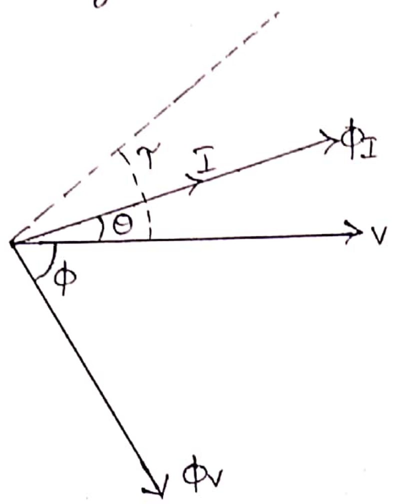


Fig: Phasor Diagram Of A Directional Relay

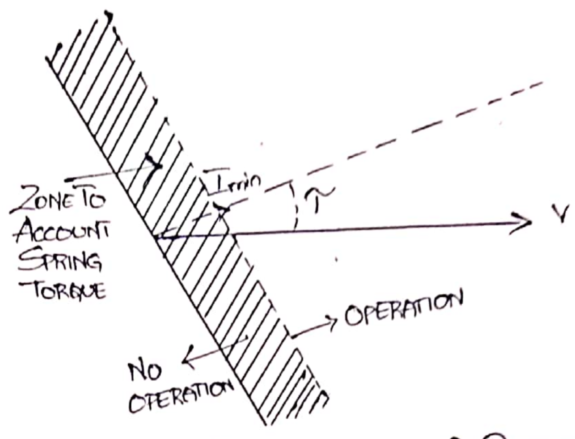


Fig: Polar Characteristic Of Directional Relay

Referring the torque equation, if V is fixed and under operating condition K is negligible then

$$I\cos(\theta-\tau)=0$$

Since I cannot be zero for torque production

$$\cos(\theta-\tau)=0$$

$$\Rightarrow \theta-\tau=\pm\frac{\pi}{2}$$

$$\Rightarrow \theta=\tau\pm\frac{\pi}{2}$$

This is the equation used for describing the polar characteristics of the directional relay as shown in the above figure.

The zone between the dotted line and the line parallel to it corresponds to the spring torque. If the current vector lies within these lines, the torque developed is less than the spring torque and hence the relay ~~ope~~ does not operate. If the current crosses the dotted line the spring torque is less than the operating torque and hence the relay operates.

Static Relays

Static relays are the relays that contain electronic circuitry which may include transistors, IC's, diodes and other electronic components. There is a comparator circuit in the relay, which compares two or more currents or voltage and gives an output which is applied to either a slave relay or a thyristor circuit. The slave relay is an electromagnetic relay which closes the contact. A static relay consisting of slave relay is a semistatic relay where as the static relay consisting of thyristor circuit or electronic circuit is complete static relay.

ADVANTAGES OF STATIC RELAYS

Advantages of static relays over electromechanical relays are as follows.

(i) Low burden on CT's and PT's.

(ii) Less power consumption

(iii) Fast response

(iv) Long life

(v) High resistance to shock and vibration

(vi) Less maintanance due to absence of moving parts and bearings

(vii) Frequent operations cause no deteriration.

(viii) Quick resetting and absence of overshoot

(ix) Compact size

(x) Greater sensitivity as amplification can be provided easily

(xi) Complex relaying characteristics can be easily obtained

(xii) Logic circuits can be used for complex protective schemes

DISADVANTAGES OF STATIC RELAYS

Disadvantages of static relays are as follows

(i) Static relays are temperature sensitive. Their characteristics may vary with the variation of temperature. Temperature compensation can be made by using thermistors and by using digital techniques for measurements etc.

(ii) Static relays are sensitive to voltage transients. The semiconductor components may get damaged due to voltage spikes. Filters and shielding can be used for their protection ~~and~~ against voltage spikes.

(iii) Static relays need an auxilary supply. This can however be easily supplied by a battery & a stabilized power supply.

COMPARATORS

When faults occur on a system, the magnitude of voltage and current and phase angle between voltage and current may change. These quantities during faulty condition are different from those under healthy condition. The static relay circuitry is designed to recognize the changes and to distinguish between healthy and faulty conditions. Either the magnitudes of voltage/current are compared & phase angle between voltage and current are measured by the static relay circuitry and sends a trip signal to the circuit breaker as and when the fault occurs. The part of circuitry which compares the actuating quantities either in amplitude & phase is known as the comparator. There are two types of comparators namely (i) amplitude comparator and (ii) phase comparator.

(1) AMPLITUDE COMPARATOR

An amplitude comparator is a comparator which compares the magnitudes of two input quantities irrespective of the angle between them. One of the input quantity is an operating quantity and the other a restraining quantity. When the amplitude of the operating quantity exceeds the amplitude of restraining quantity the relay sends a tripping signal.

(2) PHASE COMPARATOR

A phase comparator is a comparator which compares the phase angle of two input quantities irrespective of their magnitudes and operates if the phase angle between them is $\leq 90°$.

INSTANTANEOUS STATIC OVER CURRENT RELAY

The current derived from main CT is fed to the input transformer which gives proportional output voltage. The input transformer has an air gap in the iron core to give linearity in the current/voltage relationship up to the highest value of current expected and is provided with tappings on secondary winding to obtain different current settings.

The output voltage of the transformer is rectified through a rectifier and then filtered at a single stage to avoid undesirable time delay in filtering so as to ensure high speed of operation.

A limiter made of zener diode is also incorporated into the circuit to limit the rectified voltages to safe values even when the input current is very high under fault conditions. A fixed portion of the rectified and filtered voltage is compared against a preset pick up value by a level detector and if it exceeds the pick value, a signal through an amplifier is given to the output device which issues the trip signal. The output device may either be a static thyristor circuit or an electromagnetic slave relay.

FIG: BLOCK DIAGRAM OF INSTANTANEOUS STATIC OVER CURRENT RELAY

DEFINITE TIME STATIC OVER CURRENT RELAY

The operating time of a definite time overcurrent relay is constant, irrespective of the level of the fault current. In this case, an intentional time delay is introduced through a timing circuit. The input current signal derived from main CT is converted to a proportional voltage signal by the input transformer and then rectified, filtered and compared with the preset threshold value of level detector 1. If the voltage exceeds the preset threshold value, the level detector gives an output voltage there by the charging of the capacitor C of the RC timing circuit starts. As soon as the voltage across the capacitor exceeds the preset threshold value (V_T) of level detector 2, a signal through the amplifier is given to the output device which issues the trip signal.

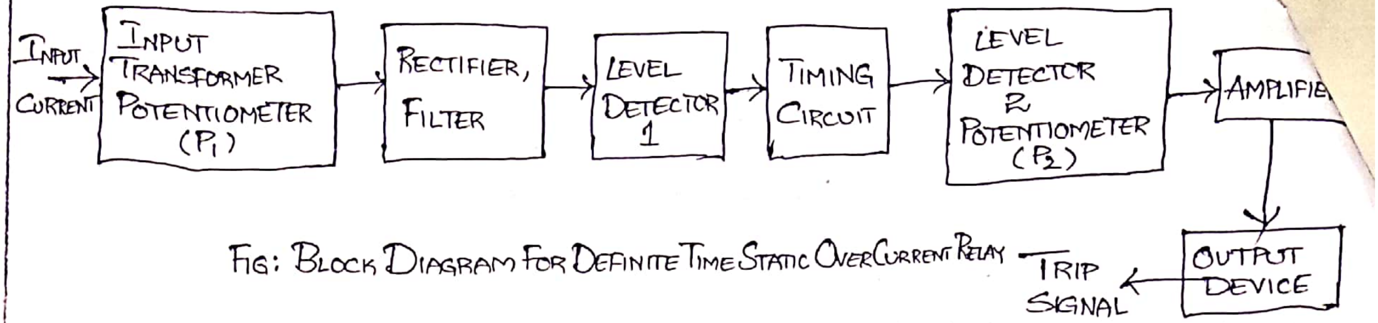


Fig: Block Diagram For Definite Time Static Over Current Relay

If V_T is the threshold value of the level detector, the time T_C required to reach this voltage depends upon the charging time of the capacitor C of the RC timing circuit given by

$$T_C = RC \log_e \left[\frac{V}{V - V_T}\right]$$ where V is voltage applied to the capacitor

If V, R and C are constant, the charging time for a given value of V_T will be constant. The time T_C can be varied by varying R-C combinations and V_T.

Inverse Time Static Over Current Relay

The operating time of the inverse time overcurrent relay decreases with increasing fault current. For this relay with inverse-time characteristics, the charging of the capacitor of timing circuit takes place from a voltage proportional to the current.

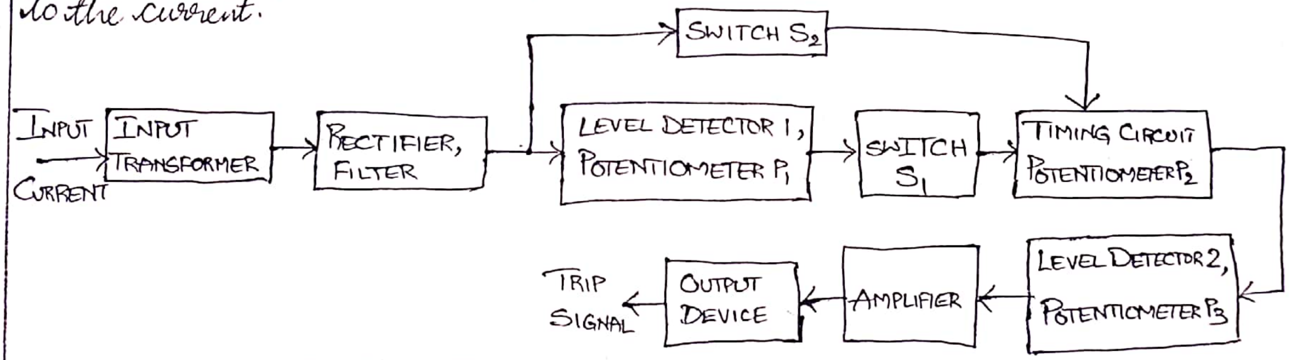


Fig: Block Diagram Of Inverse Time Static Over Current Relay

The current signal is converted to a proportional voltage signal by the input transformer and then rectified, filtered and compared with a reference voltage of the level detector 1 set by the potentiometer P_1. Under normal operating conditions i.e., when the input current is low then switch S_1 is ON, short circuiting the capacitor C of RC timing circuit and switch S_2 is OFF. As soon as the input ~~current~~ voltage exceeds the preset reference voltage of the level detector 1, switch S_1 is switched OFF and switch S_2 is switched ON and also the charging of capacitor C of the timing circuit starts from a voltage proportional to the current. Switches S_1 & S_2 are made of static components. When the voltage across the capacitor C of timing circuit exceeds the reference voltage of level detector 2 as set by the potentiometer P_3, a signal is given to the output device through an amplifier. Finally, the output device issues the trip signal.