Relay

21.1 Protective Relays

A **protective relay** *is a device that detects the fault and initiates the operation of the circuit breaker to ioslate the defective element from the rest of the system.*

The relays detect the abnormal conditions in the electrical circuits by constantly measuring the electrical quantities which are different under normal and fault conditions. The electrical quantities which may change under fault conditions are voltage, current, frequency and phase angle. Through the changes in one or more of these quantities, the faults signal their presence, type and location to the protective relays. Having detected the fault, the relay operates to close the trip circuit of the breaker. This results in the opening of the breaker and disconnection of the faulty circuit.

A typical relay circuit is shown in Fig. 21.1. This diagram shows one phase of 3-phase system for simplicity. The relay circuit connections can be divided into three parts *viz.*

(*i*) First part is the primary winding of a current transformer (C.T.) which is connected in series with the line to be protected.

(*ii*) Second part consists of secondary winding of C.T. and the relay operating coil.

(*iii*) Third part is the tripping circuit which may be either a.c. or d.c. It consists of a source of supply, the trip coil of the circuit breaker and the relay stationary contacts.

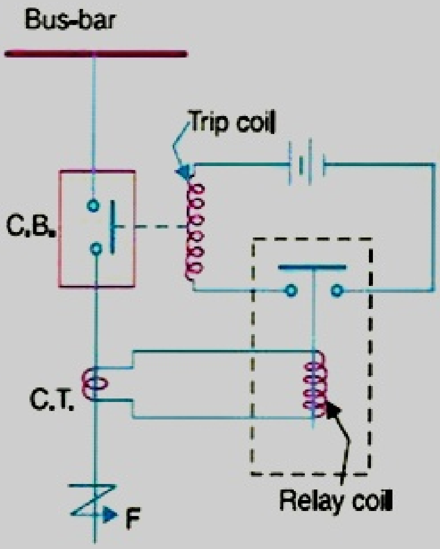


Fig. 21.1

When a short circuit occurs at point *F* on the transmission line, the current flowing in the line increases to an enormous value. This results in a heavy current flow through the relay coil, causing the relay to operate by closing its contacts. This in turn closes the trip circuit of the breaker, making the circuit breaker open and isolating the faulty section from the rest of the system. In this way, the relay ensures the safety of the circuit equipment from damage and normal working of the healthy portion of the system.

1.2 Functions of Protective Relaying

The various functions of protective relaying are :

1. The prompt removal of the component which is behaving abnormally by closing the trip circuit of circuit breaker or to sound an alarm.
2. To disconnect the abnormally operating part so as to avoid the damage or interference within effective operation of the rest of system.
3. To prevent the subsequent faults by disconnecting the abnormally operating part.
4. To disconnect the faulty part as quickly as possible so as to minimise the damage to the faulty part itself. For example, if there is a winding fault in a machine and if it persists for a long time then there is a possibility of the damage of the entire winding. As against this, if it is disconnected quickly then only few coils may get damaged instead of the entire winding.
5. To restrict the spreading of the effect of fault causing least interference to the rest of the healthy system. Thus by disconnecting the faulty part, the fault effects get localised.
6. To improve the system performance, system reliability, system stability and service continuity.

The faults can not be completely avoided but can be minimised. Thus the protective relaying plays an important role in sensing the faults, minimizing the effects of faults and minimizing the damage due to the faults.

21.2 Fundamental Requirements of Protective Relaying

The principal function of protective relaying is to cause the prompt removal from service of any element of the power system when it starts to operate in an abnormal manner or interfere with the effective operation of the rest of the system. In order that protective relay system may perform this function satisfactorily, it should have the following qualities :

(*i*) selectivity (*ii*) speed (*iii*) sensitivity

(*iv*) reliability (*v*) simplicity (*vi*) economy

(*i*) **Selectivity.** *It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system.*

A well designed and efficient relay system should be selective *i.e.* it should be able to detect the point at which the fault occurs and cause the opening of the circuit breakers closest to the fault with minimum or no damage to the system. This can be illustrated by referring to the single line diagram of a portion of a typical power system shown in Fig. 21.2. It may be seen that circuit breakers are located in the connections to each power system element in order to make it possible to disconnect only the faulty section. Thus, if a fault occurs at bus-bars on the last zone, then only breakers nearest to the fault *viz.* 10, 11, 12 and 13 should open. In fact, opening of any other breaker to clear the fault will lead to a greater part of the system being disconnected.

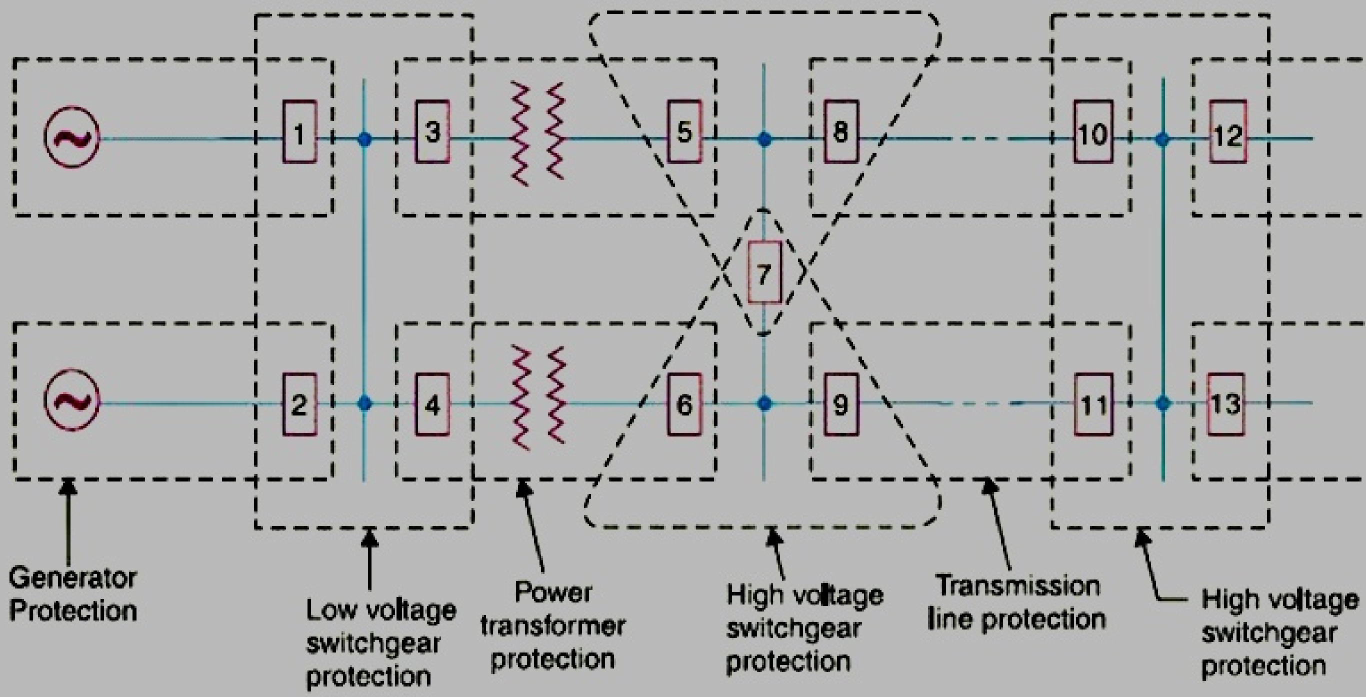


Fig. 21.2

In order to provide selectivity to the system, it is a usual practice to divide the entire system into several protection zones. When a fault occurs in a given zone, then only the circuit breakers within that zone will be opened. This will isolate only the faulty circuit or apparatus, leaving the healthy circuits intact. The system can be divided into the following protection zones :

(*a*) generators (*b*) low-tension switchgear (*c*) transformers

(*d*) high-tension switchgear (*e*) transmission lines

It may be seen in Fig. 21.2 that there is certain amount of overlap between the adjacent protection zones. For a failure within the region where two adjacent zones overlap, more breakers will be opened than the minimum necessary to disconnect the faulty section. But if there were no overlap, a failure in the region between zones would not lie in either region and, therefore, no breaker would be opened. For this reason, a certain amount of overlap* is provided between the adjacent zones.

(ii) **Speed.** The relay system should disconnect the faulty section as fast as possible for the following reasons :

(*a*) Electrical apparatus may be damaged if they are made to carry the fault currents for a long time.

(*b*) A failure on the system leads to a great reduction in the system voltage. If the faulty section is not disconnected quickly, then the low voltage created by the fault may shut down consumers' motors and the generators on the system may become unstable.

(*c*) The high speed relay system decreases the possibility of development of one type of fault into the other more severe type.

(iii) **Sensitivity.** *It is the ability of the relay system to operate with low value of actuating quantity.*

Sensitivity of a relay is a function of the volt-amperes input to the coil of the relay necessary to cause its operation. The smaller the volt-ampere input required to cause relay operation, the more sensitive is the relay. Thus, a 1 VA relay is more sensitive than a 3 VA relay. It is desirable that relay system should be sensitive so that it operates with low values of volt-ampere input.

(iv) **Reliability.** It is the ability of the relay system to operate under the pre-determined conditions. Without reliability, the protection would be rendered largely ineffective and could even become a liability.

(v) **Simplicity.** The relaying system should be simple so that it can be easily maintained. Reliability is closely related to simplicity. The simpler the protection scheme, the greater will be its reliability.

(vi) **Economy.** The most important factor in the choice of a particular protection scheme is the economic aspect. Sometimes it is economically unjustified to use an ideal scheme of protection and a compromise method has to be adopted. As a rule, the protective gear should not cost more than 5% of total cost. However, when the apparatus to be protected is of utmost importance (*e.g.* generator, main transmission line etc.), economic considerations are often subordinated to reliability.

21.21 Types of Protection

When a fault occurs on any part of electric power system, it must be cleared quickly in order to avoid damage and/or interference with the rest of the system. It is a usual practice to divide the protection scheme into two classes *viz.* primary protection and back-up protection.

(*i*) **Primary Protection.** It is the protection scheme which is designed to protect the component parts of the power system. Thus referring to Fig. 21.29, each line has an overcurrent relay that protects the line. If a fault occurs on any line, it will be cleared by its relay and circuit breaker. This forms the primary or main protection and serves as the first line of defence. The service record of primary relaying is very high with well over ninety percent of all operations being correct. However, sometimes faults are not cleared by primary relay system because of trouble within the relay, wiring system or breaker. Under such conditions, back-up protection does the required job.

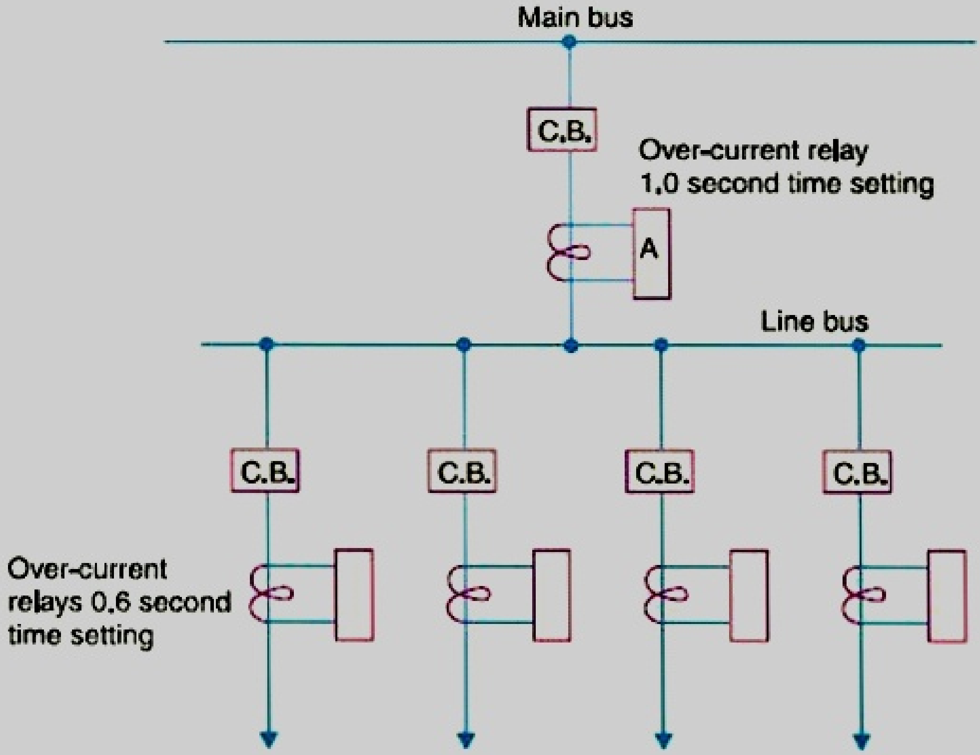


Fig. 21.29

(*ii*) **Back-up protection.** It is the second line of defence in case of failure of the primary protection. It is designed to operate with sufficient time delay so that primary relaying will be given enough time to function if it is able to. Thus referring to Fig. 21.29, relay *A* provides back-up protection for each of the four lines. If a line fault is not cleared by its relay and breaker, the relay *A* on the group breaker will operate after a definite time delay and clear the entire group of lines. It is evident that when back-up relaying functions, a larger part is disconnected than when primary relaying functions correctly. Therefore, greater emphasis should be placed on the better maintenance of primary relaying.

21.10 Functional Relay Types

Most of the relays in service on power system today operate on the principle of electromagnetic attraction or electromagnetic induction. Regardless of the principle involved, relays are generally classified according to the function they are called upon to perform in the protection of elelctric power circuits. For example, a relay which recognises overcurrent in a circuit (*i.e.* current greater than that which can be tolerated) and initiates corrective measures would be termed as an *overcurrent relay* irrespective of the relay design. Similarly an *overvoltage relay* is one which recognises over-voltage in a circuit and initiates the corrective measures. Although there are several types of special-function relays, only the following important types will be discussed in this chapter :

(*i*) Induction type overcurrent relays
(*ii*) Induction type reverse power relays
(*iii*) Distance relays
(*iv*) Differential relays
(*v*) Translay scheme

Types of Relay:

Types of protection relays are mainly based on their characteristic, logic, on actuating parameter and operation mechanism.

Electromagnetic Attraction Type Relays

1. Solenoid Type
2. Attracted Armature Type
3. Balanced Beam Type

Induction Type Relays

1. Induction Disc Type
2. Induction Cup Type

Directional Type Relays

1. Reverse Current Type
2. Reverse Power Type

Timing Based Relay

1. Instantaneous Type
2. Definite Time Lag Type
3. Inverse Time Lag Type

Distance Type Relays

1. Impedance Type
2. Reactance Type
3. Admittance Type

Differential Type Relays

1. Current Differential Type
2. Voltage Differential Type

Other Types Of Relays

1. Under Voltage, Current, Power Relay
2. Over Voltage, Current, Power Relay
3. Thermal Relay
4. Rectifier Relay

5. Permanent Magnet Moving Coil Relay
6. Static Relay
7. Gas Operated Relay

Some examples of Mechanical Relay are

1. Thermal
   - (a) OT Trip (Oil Temperature Trip)
   - (b) WT Trip (Winding Temperature Trip)
   - (C) Bearing Temp Trip etc.
2. Float Type
   - (a) Buchholz
   - (b) OSR
   - (c) PRV
   - (d) Water level Controls etc.
3. Pressure Switches.
4. Mechanical Interlocks.
5. Pole discrepancy Relay.

21.3 Basic Relays

Most of the relays used in the power system operate by virtue of the current and/or voltage supplied by current and voltage transformers connected in various combinations to the system element that is to be protected. Through the individual or relative changes in these two quantities, faults signal their presence, type and location to the protective relays. Having detected the fault, the relay operates the trip circuit which results in the opening of the circuit breaker and hence in the disconnection of the faulty circuit.

Most of the relays in service on electric power system today are of electro-mechanical type. They work on the following two main operating principles :

(*i*) Electromagnetic attraction
(*ii*) Electromagnetic induction

1.9 Terminologies used in Protective Relaying

The various terminologies used in the protective relaying are,

1. **Protective Relay :** It is an electrical relay, which closes its contacts when an actuating quantity reaches a certain preset value. Due to closing of contacts, relay initiates a trip circuit of circuit breaker or an alarm circuit.
2. **Relay Time :** It is the time between the instant of fault occurrence and the instant of closure of relay contacts.
3. **Breaker Time :** It is the time between the instant at circuit breaker operates and opens the contacts, to the instant of extinguishing the arc completely.
4. **Fault Clearing Time :** The total time required between the instant of fault and the instant of final arc interruption in the circuit breaker is fault clearing time. It is sum of the relay time and circuit breaker time.
5. **Pickup :** A relay is said to be picked up when it moves from the 'OFF' position to 'ON' position. Thus when relay operates it is said that relay has picked up.
6. **Pickup Value :** It is the minimum value of an actuating quantity at which relay starts operating. In most of the relays actuating quantity is current in the relay coil and pickup value of current is indicated along with the relay.
7. **Dropout or Reset :** A relay is said to dropout or reset when it comes back to original position i.e. when relay contacts open from its closed position. The value of an actuating quantity current or voltage below which the relay resets is called **reset value** of that relay.
8. **Time Delay :** The time taken by relay to operate after it has sensed the fault is called time delay of relay. Some relays are instantaneous while in some relays intentionally a time delay is provided.

14. **Trip Circuit :** The opening operation of circuit breaker is controlled by a circuit which consists of trip coil, relay contacts, auxiliary switch, battery supply etc. which is called trip circuit.

15. **Earth Fault :** The fault involving earth is called earth fault. The examples of earth fault are single line to ground fault, double line to ground fault etc.

16. **Phase Fault :** The fault which does not involve earth is called phase fault. The example is line to line fault.

17. **Protective Scheme :** The combination of various protective systems covering a particular protective zone for a particular equipment is called protective scheme. For example a generator may be provided with protective systems like overcurrent, differential, earth fault etc. The combination of all these systems is called generator protective scheme.

18. **Protective System :** The combination of circuit breakers, trip circuits, C.T. and other protective relaying equipments is called protective system.

(*i*) **Pick-up current.** It is the minimum current in the relay coil at which the relay starts to operate. So long as the current in the relay is less than the pick-up value, the relay does not operate and the breaker controlled by it remains in the closed position. However, when the relay coil current is equal to or greater than the pickup value, the relay operates to energise the trip coil which opens the circuit breaker.

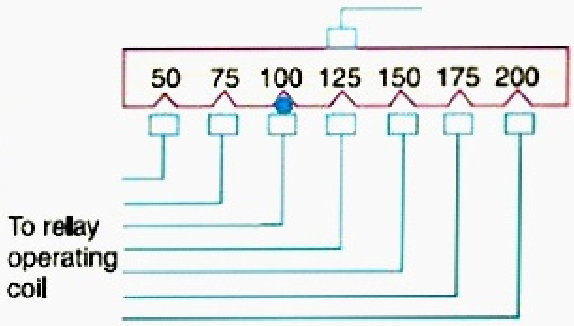


Fig. 21.14

(*ii*) **Current setting.** It is often desirable to adjust the pick-up current to any required value. This is known as current setting and is usually achieved by the use of tappings on the relay operating coil. The taps are brought out to a plug bridge as shown in Fig. 21.14. 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. 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.

$$\therefore \quad \text{Pick-up current} = \text{Rated secondary current of C.T.} \times \text{Current setting}$$

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.* $5 \times 1{\cdot}25 = 6{\cdot}25$ A. It means that with above current setting, the relay will actually operate for a relay coil current equal to or greater than 6·25 A.

The current plug settings usually range from 50% to 200% in steps of 25% for overcurrent relays and 10% to 70% in steps of 10% for earth leakage relays. The desired current setting is obtained by inserting a plug between the jaws of a bridge type socket at the tap value required.

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

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

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

For example, suppose that a relay is connected to a 400/5 current transformer and set at 150%. With a primary fault current of 2400 A, the plug-setting multiplier can be calculated as under :

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

$$= 5 \times 1{\cdot}5 = 7{\cdot}5 \text{ A}$$

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

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

(iv) Time-setting multiplier. 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. 21.15). 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 $= 3 \times 0{\cdot}1 = 0{\cdot}3$ second. For instance, in an induction relay, the time of operation is controlled by adjusting the amount of 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 time 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. The acutal time of operation is calculated by multiplying the time setting multiplier with the time obtained from time/P.S.M. curve of the relay.

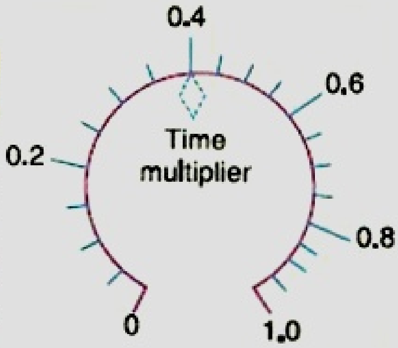


Fig. 21.15

21.8 Time/P.S.M. Curve

Fig. 21.16 shows the 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.

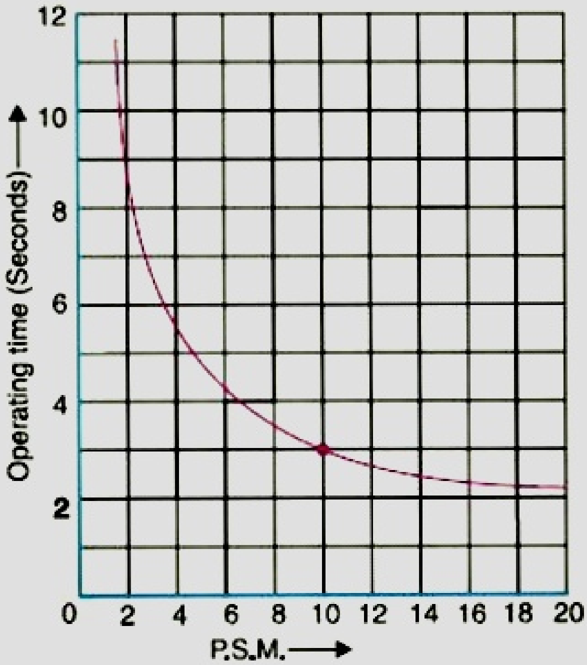


Fig. 21.16

It is evident from Fig. 21.16 that for lower values of overcurrent, time of operation varies inversely with the current but as the current approaches 20 times full-load value, the operating time of relay tends to become constant. This feature is necessary in order to ensure discrimination on very heavy fault currents flowing through sound feeders.

21.9 Calculation of Relay Operating Time

In order to calculate the actual relay operating time, the following things must be known :

(*a*) Time/P.S.M. curve

(*b*) Current setting

(*c*) Time setting

(*d*) Fault current

(*e*) Current transformer ratio

The procedure for calculating the actual relay operating time is as follows :

(*i*) Convert the fault current into the relay coil current by using the current transformer ratio.

(*ii*) Express the relay current as a multiple of current setting *i.e.* calculate the P.S.M.

(*iii*) From the Time/P.S.M. curve of the relay, read off the time of operation for the calculated P.S.M.

(*iv*) Determine the actual time of operation by multiplying the above time of the relay by time-setting multiplier in use.

Example 21.1. *Determine the time of operation of a 5-ampere, 3-second overcurrent relay having a current setting of 125% and a time setting multiplier of 0·6 connected to supply circuit through a 400/5 current transformer when the circuit carries a fault current of 4000 A. Use the curve shown in Fig. 21.16.*

Solution.

$$\text{Rated secondary current of C.T.} = 5 \text{ A}$$

$$\text{Pickup current} = 5 \times 1{\cdot}25 = 6{\cdot}25 \text{ A}$$

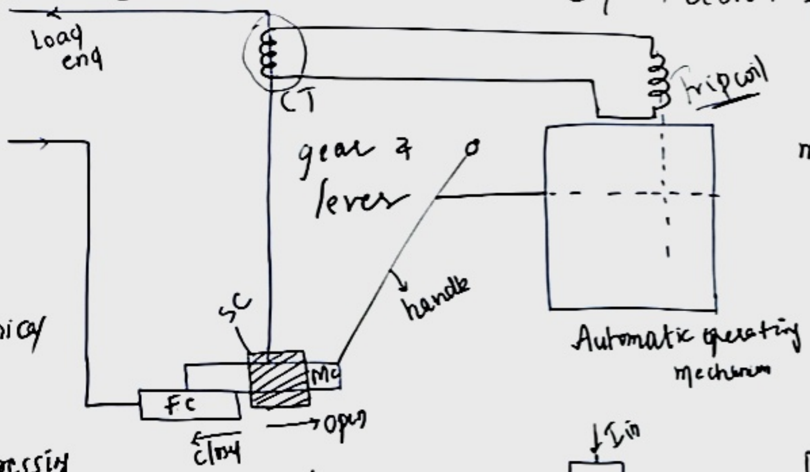
$$\text{Fault current in relay coil} = 4000 \times \frac{5}{400} = 50 \text{ A}$$

$$\therefore \quad \text{Plug-setting multiplier (P.S.M.)} = \frac{50}{6{\cdot}25} = 8$$

Corresponding to the plug-setting multiplier of 8 (See Fig. 21.16), the time of operation is 3.5 seconds.

$$\therefore \quad \text{Actual relay operating time} = 3{\cdot}5 \times \text{Time-setting} = 3{\cdot}5 \times 0{\cdot}6 = \mathbf{2{\cdot}1 \text{ seconds}}$$

Circuit Breaker Operation & its Types



spring charging
compressing air
mechanically stored

P.E → deforming metal spring
→ Compressed air
→ Hydraulic pressure

operating coils

Arc quenching media
1) Air Blast
2) Oil CB
3) SF6 CB
4) Vacuum CB

1) Mechanical pressure

1) Compressing
↓
accelerates
2) Cooling
3) Fresh gases

manually | automatically
↓ control | ↓ protect

P.N | E.E

↑ dielectric strength