MODULE 2

Protective relays

It is a protective device that detects the fault in an electric circuit and initiates the operation of the circuit breaker to isolate the faulty part from the rest of the system.

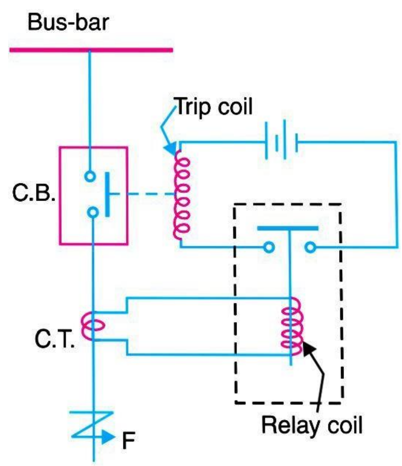


Fig. 21.1

The relay circuit connections can be divided into three parts

1. Primary winding of a current transformer is connected in series with the line to be protected
2. Secondary winding of CT and relay operating coil
3. Tripping circuit consists of source of supply, tripping coil of the circuit breaker and relay stationary contacts

When a fault occurs at a point on the transmission line, the current flowing in the line increases to high value. Current transformer reduces this high current to a value safe for relay. If the current through the relay coil is greater than the pickup value of the relay, coil gets energized and closes the trip circuit of the breaker. As the trip coil gets energized the circuit breaker operating mechanism is actuated and opens the circuit breaker. In this way the faulty section is isolated from the rest of the system.

Basic requirements of protective relays

Selectivity - the railway must select correctly only the faulty section of the power system and isolate the same without disturbing the rest of the system

Sensitivity - it is the ability of the relay system to operate with low value of actual quantity. Smaller the volt ampere input required cause relay operation the most sensitive is the relay. 1VA relay is more sensitive than 3VA relay

Speed - the relay system should disconnect the faulty section as fast as possible for the following reasons

- Electrical apparatus may get damaged if the fault current flows for a long time
- Fault causes dropping system voltage and if the faulty section is not disconnected quickly low voltage may shutdown consumer's motors shutdown and generator may become unstable
- One type of fault may develop into other more severe type

Reliability - the relay must operate correctly under predetermined conditions.
Simplicity - the relay system should be simple so that it can be easily maintained. The simpler the protection scheme the great will be its reliability.
Economy - protective gear should not cost more than 5 % of total cost except for generators and main transmission line

Classification of Relays

Based on Construction and principle of operation

1. **Electromagnetic attraction relays -** attracted armature type, solenoid type, balanced beam type. Search relays are actuated by DC or AC quantities
2. **Electromagnetic induction or simply induction relays -** Which use the principle of the induction motor in their operation. Such relays are actuated by a.c. quantities only.
3. **Electro thermal relays -** These type of relays operate on the principle of thermal effect of the passage of current through the relay element. Such relays are actuated by both A.C. and D.C.
4. **Physio-electric relays -** Buchholz relay is an example of physio-electric relay.
5. **Static relays -** Employing thermionic valves, transistors or magnetic amplifiers to obtain the operating characteristics.
6. **Electro dynamic relays -** Operate on the same principle as the moving coil instrument (moving member consists of a coil free to rotate in an electromagnetic field).

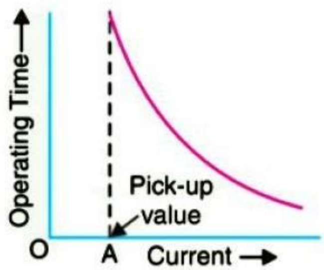
Based on Time of Operation :

1. **Instantaneous relays -** Operation takes place after a negligibly small interval of time from the application of the current or other quantity causing operation
2. **Definite time-lag relays -** The time of operation is quite independent of the magnitude of current or other quantity causing operation.
3. **Inverse time-lag relays -** The time of operation is inversely proportional to the magnitude of current or other quantity which causes operation.
4. **Inverse-definite minimum time lag relays (IDMT relays) -** The time of operation is approximately inversely proportional to the smaller values of current or other quantities which cause operation and tend to a definite minimum time as the value increases without limit

1. <u>Instantaneous relays</u>

An instantaneous relay is one in which no intentional time delay is provided. In this case, the relay contacts are closed immediately after current in the relay coil exceeds the minimum calibrated value. Although there will be a short time interval between the instant of pickup and the closing of relay contacts, no intentional time delay has been added. The instantaneous relays have operating time less than 0·1 second.

2. <u>Inverse-time relay</u>



An inverse-time relay is one in which the operating time is approximately inversely proportional to the magnitude of the fault current. At values of current less than pickup, the relay never operates. At higher values, the time of operation of the relay decreases steadily with the increase of current. The inverse-time delay can be achieved by associating mechanical accessories with relays.

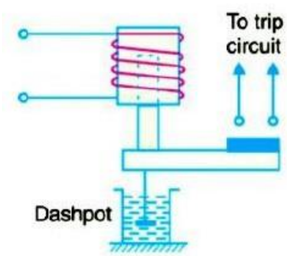


Fig. 21.12

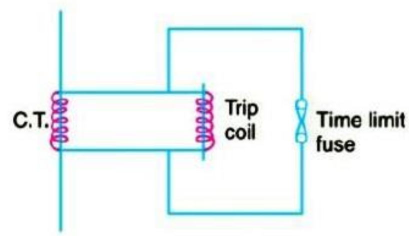


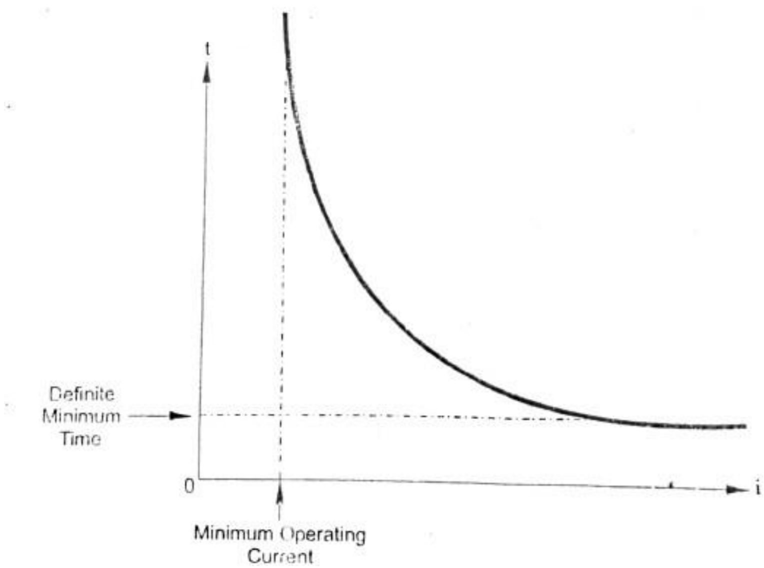
Fig. 21.13

1. Drag magnet - In an induction relay, the inverse-time delay can be achieved by positioning a permanent magnet (known as a **drag magnet**) in such a way that relay disc cuts the flux between the poles of the magnet. When the disc moves, currents set up in it produce a drag on the disc which slows its motion.
2. Oil dashpot - Fig. 21.12 shows an inverse time solenoid relay using **oil dashpot**. The piston in the oil dashpot attached to the moving plunger slows its upward motion. At a current value just equal to the pickup, the plunger moves slowly and time delay is at a maximum. At higher values of relay current, the delay time is shortened due to greater pull on the plunger.
3. Time-limit fuse - Fig. 21.13 shows a Time-limit fuse connected in parallel with the trip coil terminals. The shunt path formed by time-limit fuse is of negligible impedance as compared with the relatively high impedance of the trip coil. Therefore, so long as the fuse remains intact, it will divert practically the whole secondary current of CT from the trip oil. When the secondary current exceeds the current carrying capacity of the fuse, the fuse will blow and the whole current will pass through the trip coil, thus opening the circuit breaker.

3. Definite time lag relay

In this type of relay, there is a definite time lag between the instant of pickup and the closing of relay contacts. This particular time setting is independent of the amount of current through the relay coil, ie. the same for all values of current greater than pickup value. Practically all inverse-time relays are also provided with definite minimum time feature in order that the relay may never become instantaneous in its action for very long overloads.

4. Inverse Definite Minimum Time (IDMT) Over-Current Relay

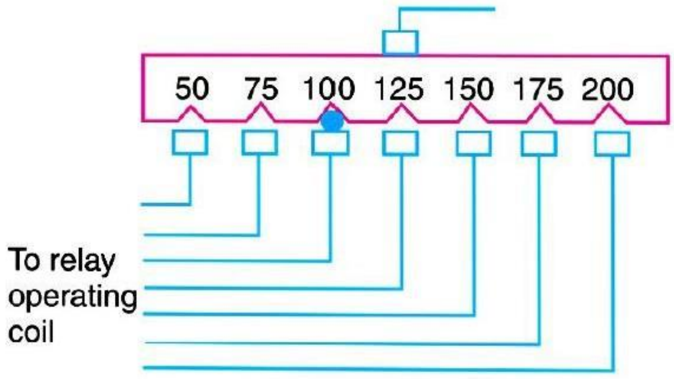


Operating time is approximately inversely proportional to the fault current near pick-up value and then becomes constant above the pick-up value of the relay. The time current characteristics of the relay observe inverse-square law. From the figure it is clear that there is some definite time after which the relay will operate. It is also clear that the time of operation at Pick-up value is nearly very high and as the fault current increases the time of operation decreases maintaining some definite time. The definite minimum time characteristics of the relay are obtained by the use of a saturated upper magnet. This ensures that there is no further increase in flux when the current has reached a certain value and any further increase of current will not affect the relay operation. This results in a flattened current time characteristic and the relay obtains its name as inverse definite minimum time lag (IDMT) relay.

Important Terms related to relay

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.

Current setting - Current setting is used to adjust the pick-up current to any required value. This is 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.



$\therefore$ Pick-up current = Rated secondary current of C.T. × 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 5A. Therefore, the pick-up value will be 25% more than 5 A i.e. 5 × 1·25 = 6·25 A.

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

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

$$\text{i.e. P. S.M.} = \frac{\text{Fault current in relay coil}}{\text{Rated secondary current of C.T.} \times \text{Current setting}}$$

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 :

Pick-up value = Rated secondary current of CT × Current setting

=5 × 1·5 = 7·5 A

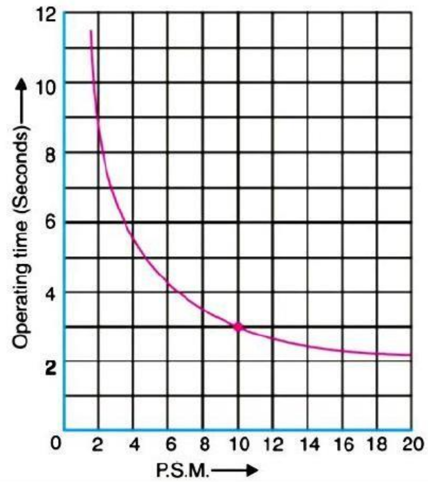
Fault current in relay coil = 2400× 5/ 400 =30 A

$\therefore$ P.S.M. = 30/7·5 = 4

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). The actual time of operation is calculated by multiplying the time setting multiplier with the time obtained from time/P.S.M. curve of the relay.

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 × 0·1 = 0·3 second.

Time/P.S.M. Curve – It is 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.



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 :

1. Convert the fault current into the relay coil current by using the current transformer ratio.
2. Express the relay current as a multiple of current setting i.e. calculate the P.S.M.
3. From the Time/P.S.M. curve of the relay, read off the time of operation for the calculated P.S.M.
4. Determine the actual time of operation by multiplying the above time of the relay by time-setting multiplier in use.

Basic Relays

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 :

1. Electromagnetic attraction
2. Electromagnetic induction

1. Electromagnetic Attraction Relays

In electromagnetic attraction relays an armature is attracted to the poles of an electromagnet or a plunger is drawn into a solenoid. Such relays may be actuated by d.c. or a.c. quantities. The important types of electromagnetic attraction relays are :

(i). Attracted armature type relay

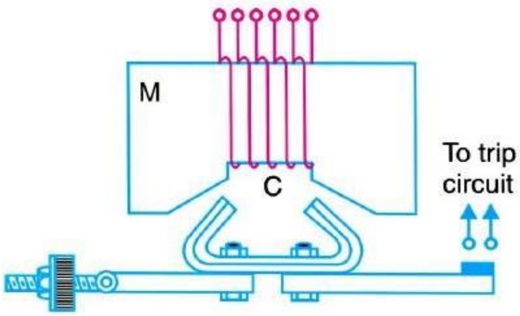


Figure shows the schematic arrangement of an attracted armature type relay. It consists of a laminated electromagnet M carrying a coil C and a pivoted laminated armature. The armature is balanced by a counterweight and carries a pair of spring contact fingers at its free end. Under normal operating conditions, the current through the relay coil C is such that counterweight holds the armature in the position shown. However, when a short circuit occurs, the current through the relay coil increases sufficiently and the relay armature is attracted upwards. The contacts on the relay armature bridge a pair of stationary contacts attached to the relay frame. This completes the trip circuit which results in the opening of the circuit breaker and disconnect the faulty circuit.

(ii). Solenoid type relay.

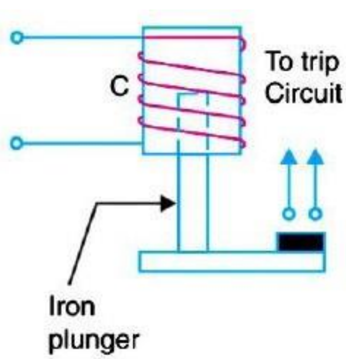
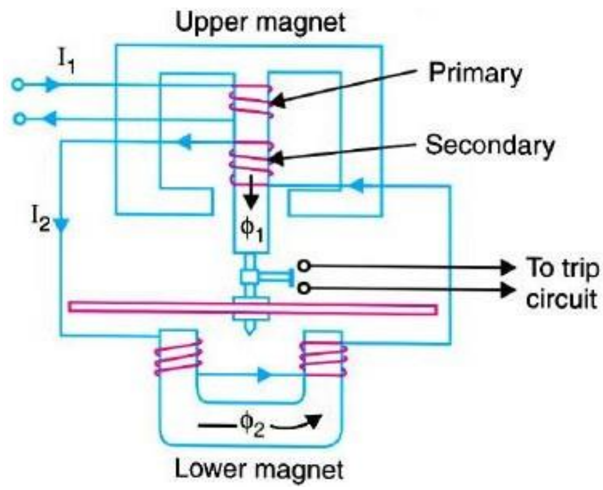


Figure shows the schematic arrangement of a solenoid type relay. It consists of a solenoid and movable iron plunger arranged as shown. Under normal operating conditions, the current through the relay coil C is such that it holds the plunger by gravity or spring in the position shown. However, on the occurrence of a fault, the current through the relay coil becomes more than the pickup value, causing the plunger to be attracted to the solenoid. The upward movement of the plunger closes the trip circuit, thus opening the circuit breaker and disconnecting the faulty circuit.

2. Electromagnetic induction relays



Electromagnetic induction relays operate on the principle of induction. These relays are used on a.c. circuits only due to the principle of operation. The construction is similar to that of Energymeter. It consists of a pivoted aluminium disc arranged to rotate freely between the poles of two electromagnets. The upper electromagnet carries two windings the primary and the secondary. The primary winding carries the relay current $\mathbf{I_1}$ while the secondary winding is connected to the winding of the lower magnet. The primary current $\mathbf{I_1}$ induces e.m.f. in the secondary winding and so circulates a current $\mathbf{I_2}$ in it. $\mathbf{I_1}$ produces flux $\boldsymbol{\phi_1}$ and $\mathbf{I_2}$ produces flux $\boldsymbol{\phi_2}$. The flux $\boldsymbol{\phi_2}$ lag behind flux $\boldsymbol{\phi_1}$ by an angle $\boldsymbol{\alpha}$. The two fluxes $\boldsymbol{\phi_1}$ and $\boldsymbol{\phi_2}$ induces emf in the disc cause the circulation of eddy currents i_1 and i_2 respectively. The interaction of the magnetic fields with the eddy currents induced in the produces a driving torque **T**

$$\mathbf{T \propto \phi_1 \phi_2 \sin \alpha}$$

This torque is opposed by the controlling torque provided by the spring. Under normal operating conditions, controlling torque is greater than the driving torque produced by the relay coil current. Therefore, the aluminium disc remains stationary. When the current exceeds the pick up value, the driving torque becomes greater than the controlling torque. Consequently, the disc rotates and the moving contact bridges the fixed contacts when the disc has rotated through a pre-set angle. The trip circuit operates the circuit breaker which isolates the faulty section

The important types of electromagnetic induction relays are

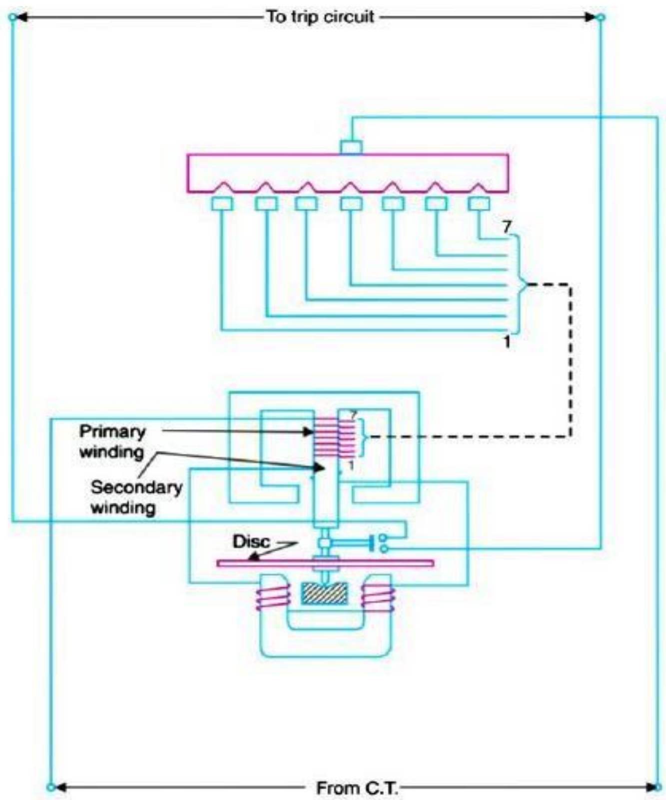
(i) Induction Type *non-directional* Overcurrent Relay

(ii) Induction Type *Directional* Overcurrent Relay

(i) **Induction Type *non-directional* Overcurrent Relay**

This type of relay works on the induction principle. These relays are used on a.c. circuits only and can operate for fault current flow in either direction.

Construction



It consists of a metallic (aluminium) disc which is free to rotate in between the poles of two electromagnets. The upper electromagnet has a primary and a secondary winding. The primary is connected to the secondary of a C.T. in the line to be protected and is tapped at intervals. The tappings are connected to a plug-setting bridge by which the number of active turns on the relay operating coil can be varied, thereby giving the desired current setting. The secondary winding is energised by induction from primary and is connected in series with the winding on the lower magnet. The controlling torque is provided by a spiral spring. The spindle of the disc carries a moving contact which bridges two fixed contacts (connected to trip circuit) when the disc rotates through a pre-set angle. This angle can be adjusted to any value between 0° and 360°. By adjusting this angle, the travel of the moving contact can be adjusted and hence the relay can be given any desired time setting.

Operation

The primary winding carries the relay current $\mathbf{I_1}$ while the secondary winding is connected to the winding of the lower magnet. The primary current $\mathbf{I_1}$ induces e.m.f. in the secondary winding and so circulates a current $\mathbf{I_2}$ in it. $\mathbf{I_1}$ produces flux ϕ_1 and $\mathbf{I_2}$ produces flux ϕ_2. The flux ϕ_2 lag behind flux $\phi$by an angle α. The two fluxes ϕ_1 and ϕ_2 induces emf in the disc cause the circulation of eddy currents

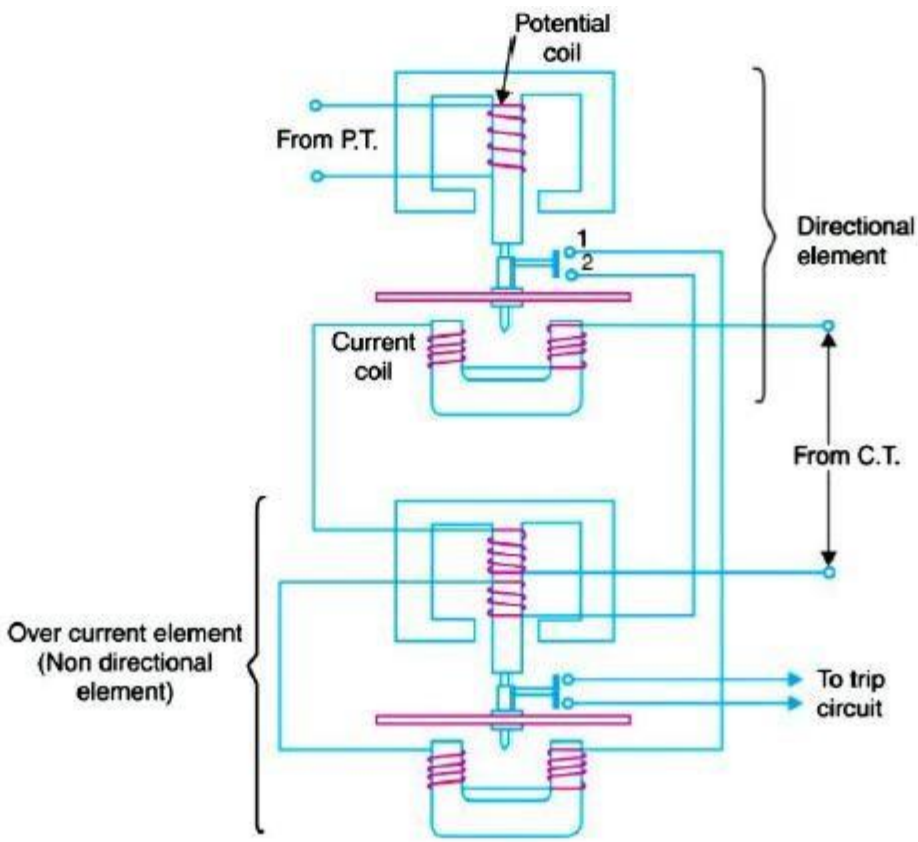
i_1 and i_2 respectively. The interaction of the magnetic fields with the eddy currents induced in the produces a driving torque **T**

$$T \propto \phi_1 \phi_2 \sin \alpha$$

This torque is opposed by the restraining torque provided by the spring. Under normal operating conditions, restraining torque is greater than the driving torque produced by the relay coil current. Therefore, the aluminium disc remains stationary. However, if the current in the protected circuit exceeds the pre-set value, the driving torque becomes greater than the restraining torque. Consequently, the disc rotates and the moving contact bridges the fixed contacts when the disc has rotated through a pre-set angle. The trip circuit operates the circuit breaker which isolates the faulty section.

(ii) Induction Type *Directional* Overcurrent Relay

Directional Overcurrent relay operates when the fault current in the circuit flows in a specified direction. This relay is designed in such a way that the reversal of current in the circuit reverses the direction of driving torque on the disc.



Construction

It consists of two relay elements mounted on a common case ie. (1) Directional element (2) Non-directional element (overcurrent element).

1. **Directional element**

   It is essentially a directional power relay which operates only when power flows in a specific direction. The potential coil of this element is connected through a potential transformer (P.T.) to the system voltage. The current coil of the element is connected to C.T. This winding is carried over the upper magnet of the non-directional element. The trip contacts (1 and 2) of the directional element are connected in series with the secondary circuit of the Non-directional element.

2. **Non-directional element.**

   It is an overcurrent element similar to a non-directional overcurrent relay. It consists of a metallic (aluminium) disc which is free to rotate in between the poles of two electromagnets. The upper electromagnet has a primary and a secondary winding. The primary is connected to the secondary of a C.T. in the line to be protected and is tapped at intervals. The tappings are connected to a plug-setting bridge by which the number of active turns on the relay operating coil can be varied, thereby giving the desired current setting (not shown in figure). The secondary winding is energised by induction from primary and is connected in series with the winding on the lower magnet.

   The trip contacts (1 and 2) of the directional element are connected in series with the secondary circuit of the Non-directional element. The directional element must operate first (i.e. contacts 1 and 2 should close) in order to operate the Non-directional element**.** The spindle of the disc of this element carries a moving contact which closes the fixed contacts (trip circuit contacts) after the operation of directional element.

   Operation

   Under normal operating conditions, power flows in the normal direction in the circuit protected by the relay. Therefore, directional power relay (upper element) does not operate, thereby keeping the overcurrent element (lower element) unenergised.

   When a short-circuit occurs, there is a tendency for the current or power to flow in the reverse direction. The disc of the Directional element rotates to bridge the fixed contacts 1 and 2. This completes the circuit for overcurrent element, disc of this element rotates and the moving contact attached to it closes the trip circuit. This operates the circuit breaker which isolates the faulty section.

Distance Relay (or Impedance Relay)

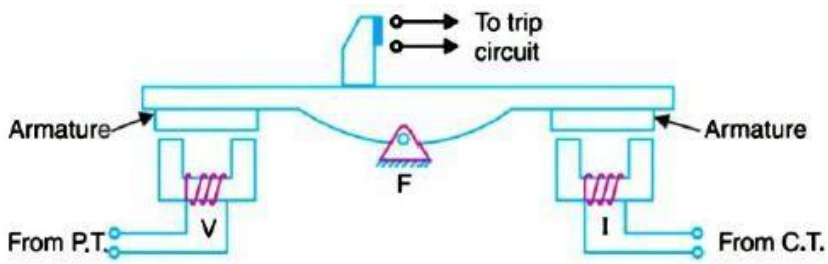
Distance protection is very commonly used in protection of transmission lines. A distance relay operates only when the impedance (Z= V/I) of the protected zone falls below a pre-determined value.

Distance relays differ in principle from other types of relays and its operation does not depend on the magnitude of current or voltage in the protected circuit but rather on the ratio of these two quantities. Distance relay is actually a double actuating quantity relay with one coil energized by voltage and the other coil by current. The current element produces a positive or pick-up torque while the voltage element produces a negative or reset torque. When a fault occurs in the protected zone, the impedance (Z= V/I) between the relay and fault point will be less than Z_L (impedance of the protected zone) and hence the relay operates. There are two types of distance relays

(i) Definite-distance relay - operates instantaneously for fault upto a pre-determined distance from the relay.

(ii) Time-distance relay - time of operation is proportional to the distance of fault from the relay point. If the fault is near to relay its operating time decreases.

(i) <u>Definite – Distance Impedance Relay</u>



Construction

This relay operates instantaneously for fault upto a pre-determined distance from the relay. Figure shows the schematic arrangement of a definite-distance type impedance relay. It consists of a pivoted beam F and two electromagnets energised respectively by a current and voltage transformer in the protected circuit. The armatures of the two electromagnets are mechanically coupled to the beam as shown in figure. The beam is provided with a bridging piece for the trip contacts. The relay is so designed that the torques produced by the two electromagnets are in the opposite direction.

Operation

Under normal operating conditions, the pull due to the voltage element is greater than that of the current element. Therefore, the relay contacts remain open. However, when a fault occurs in the protected zone, the applied voltage to the relay decreases whereas the current increases. Hence the ratio of voltage to current (i.e. impedance) falls below the pre-determined value. Therefore, the pull of the current element will exceed the pull due to the voltage element and this causes the beam to tilt in a direction to close the trip contacts. The pull of the current element is proportional to I^2 and that of voltage element to V^2. Consequently, the relay will operate when

$$k_1 V^2 < k_2 I^2$$

$$\frac{V^2}{I^2} < \frac{k_2}{k_1}$$

$$\frac{V}{I} < \sqrt{\frac{k_2}{k_1}}$$

$$Z < \sqrt{\frac{k_2}{k_1}}$$

The value of the constants k_1 and k_2 depends upon the ampere-turns of the two electromagnets.

(ii) <u>Time-Distance Impedance Relay</u>

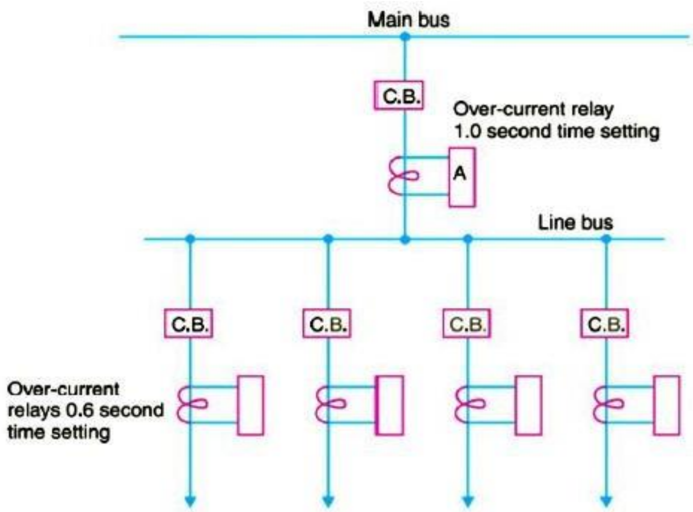
A time-distance impedance relay is one which automatically adjusts its operating time according to the distance of the relay from the fault point *i.e.*

$$\text{Operating time,} \quad T \propto V/I$$
$$\propto Z$$
$$\propto \text{distance}$$

As the distance between relay and fault increases, its operating time also increases.

Types of Protection (Primary & Back up)

When a fault occurs on any part of electric power system, it must be cleared quickly in order to avoid damage of the rest of the system. It is a usual practice to divide the protection scheme into two classes. (1) primary protection and (2) back-up protection.



Primary Protection - It is the protection scheme which is designed to protect the component parts of the power system. In figure, 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 90% 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.

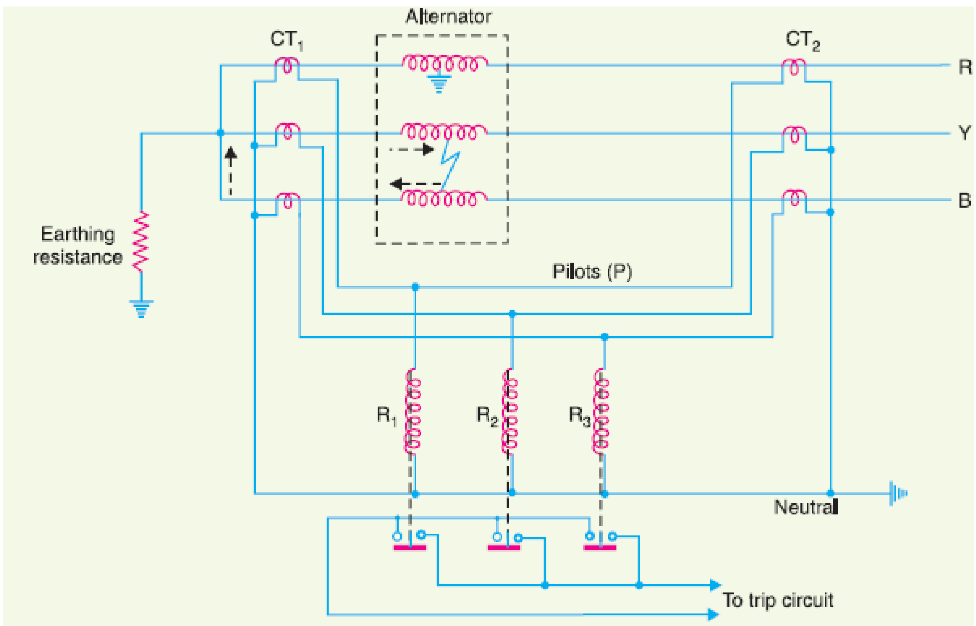
Back-up protection - It is the second line of defence in case of failure of the primary protection. It is designed to operate with sufficient time delay so that primary relaying will be given enough time to function if it is able to. In figure, relay A provides back-up protection for each of the four lines. If a line fault is not cleared by its relay and breaker, the relay A will operate after a definite time delay (0.4sec in fig) and clear the entire group of lines. 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.

Protection of Alternators

Main protection schemes used for alternators are,

1. Differential Protection (Merz-Price circulating current scheme)
2. Balanced Earth-fault Protection

1. <u>Differential Protection (Merz-Price circulating current scheme)</u>



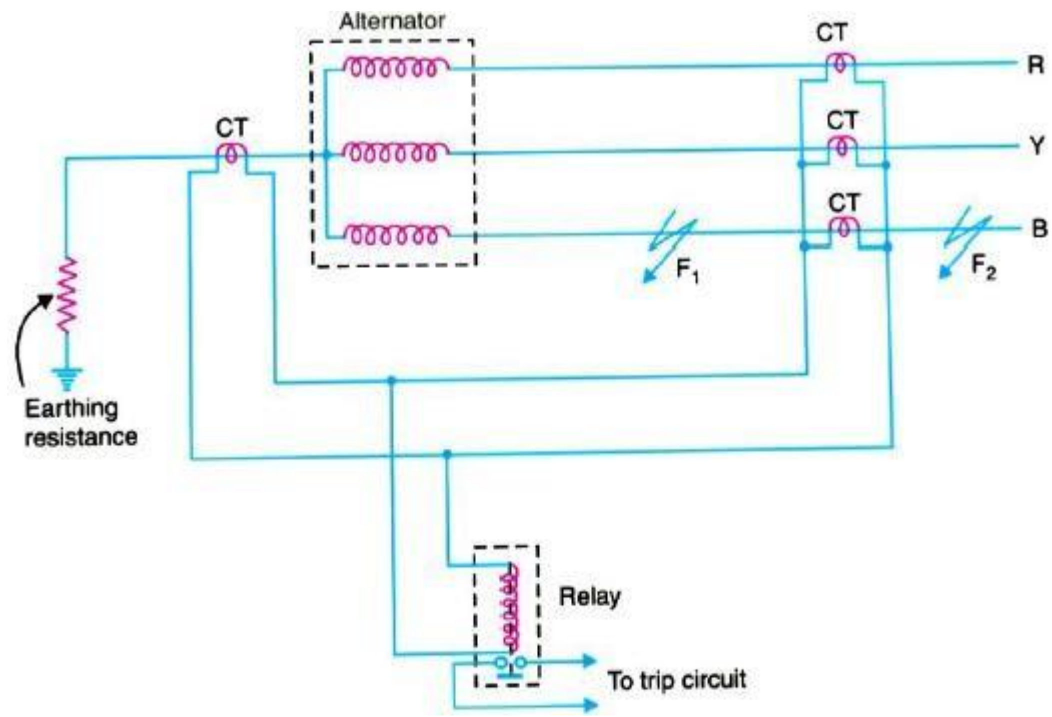
In **Differential protection**, currents at the two ends of the protected section are compared. Under normal operating conditions, these currents are equal but may become unequal on the occurrence of a fault in the protected section. The difference of the currents under fault conditions is arranged to pass through the operating coil of the relay. The relay causes tripping of CB and disconnects the alternator from the system.

Identical current transformers CT_1 and CT_2 are placed on either side of stator windings. The secondaries of current transformers are connected in star; and the two CTs are connected together by means of a four-core pilot cable. The relay coils are connected in star. Relay coils are connected between common neutral of CTs and three pilot wires.

Operation - Under normal operating conditions, the current at both ends of each winding will be equal and hence the currents in the secondaries of two CTs connected in any phase will also be equal. Therefore, there is balanced circulating current in the pilot wires and no current flows through the operating coils (R1, R2 and R3) of the relays. When an earth-fault or phase-to-phase fault occurs, this condition no longer holds good and the differential current flowing through the relay circuit operates the relay to trip the circuit breaker.

Suppose a short-circuit fault occurs between the phases Y and B as shown in Fig. 22.2. The short-circuit current circulates via the neutral end connection through the two windings and through the fault as shown by the dotted arrows. The currents in the secondaries of CTs connected in Y and B phase will become unequal and the differential current will flow through the operating coils of the relays (i.e. R2 and R3) connected in these phases. Consequently, the relay operates to trip the circuit breaker.

2. Balanced Earth-fault Protection



This scheme provides protection against earth-faults only (in small-size alternators where Differential protection is not possible to apply). It provides no protection against phase-to-phase faults, unless and until they develop into earth-faults.

It consists of three line current transformers, one mounted in each phase, and a single current transformer in the conductor joining the star point of the alternator to earth. Secondaries of all the CTs are connected in parallel. A relay is connected across the secondaries of CT. The protection against earth faults is limited to the region between the neutral and the line current transformers.

Operation

Under normal operating conditions, the currents flowing in the alternator leads and hence the currents flowing in secondaries of the line current transformers add to zero and no current flows through the relay. Also under these conditions, the current in the neutral wire is zero and the secondary of neutral current transformer supplies no current to the relay. If an earth-fault develops at F_2 external to the protected zone, the sum of the currents at the terminals of the alternator is exactly equal to the current in the neutral connection and hence no current flows through the relay. When an earth-fault occurs at F_1 or within the protected zone, these currents will not be equal and the differential current flows through the operating coil of the relay. The relay then closes its contacts and trip the circuit breaker.

Protection of transformers

Transformers are static devices, totally enclosed and generally oil immersed. Therefore, chances of faults occurring on them are very rare. However, the consequences of even a rare fault may be very serious unless the transformer is quickly disconnected from the system. Small distribution transformers are usually connected to the supply system through series fuses instead of circuit breakers. Consequently, no automatic protective relay equipment is required.

Common transformer faults.

(i) Open circuits
(ii) Overheating
(iii) Winding short circuits (e.g. earth faults, phase-to-phase faults and inter-turn faults).

The principal relays and systems used for transformer protection are :

1. Buchholz devices - protection against all kinds of incipient faults i.e. slow-developing faults such as insulation failure of windings, core heating, fall of oil level due to leaky joints etc.
2. Differential system (Merz-Price Protection Scheme or circulating-current system) - protection against both earth and phase faults.
3. Earth-fault relays -protection against earth-faults only.
4. Overcorrect relays - protection mainly against phase-to-phase faults and overloading.

1. Buchholz Relay

Buchholz relay is a gas-actuated relay installed in oil immersed transformers for protection against all kinds of faults. It is used to

1. give an alarm in case of incipient (i.e. slow-developing) faults in the transformer and to
2. disconnect (trip) the transformer from the supply in the event of severe internal faults.

It is usually installed in the pipe connecting the conservator to the main tank as shown in Fig 1. It is a universal practice to use Buchholz relays on all such oil immersed transformer having ratings more than 750 kVA.

Construction - Fig 2 shows the constructional details of a Buchholz relay. It takes the form of a domed vessel placed in the connecting pipe between the main tank and the conservator. The device has two elements. The upper element consists of a mercury type switch attached to a float. The lower element contains a mercury switch mounted on a hinged type flap located in the direct path of the flow of oil from the transformer to the conservator. The upper element closes an alarm circuit during incipient faults whereas the lower element is arranged to trip the circuit breaker in case of severe internal faults.

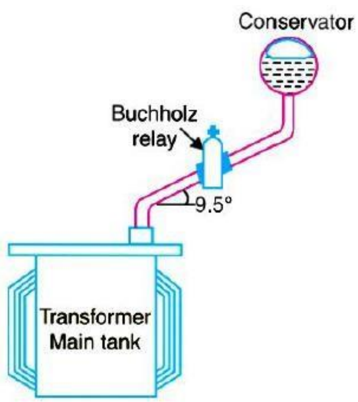


Fig. 1

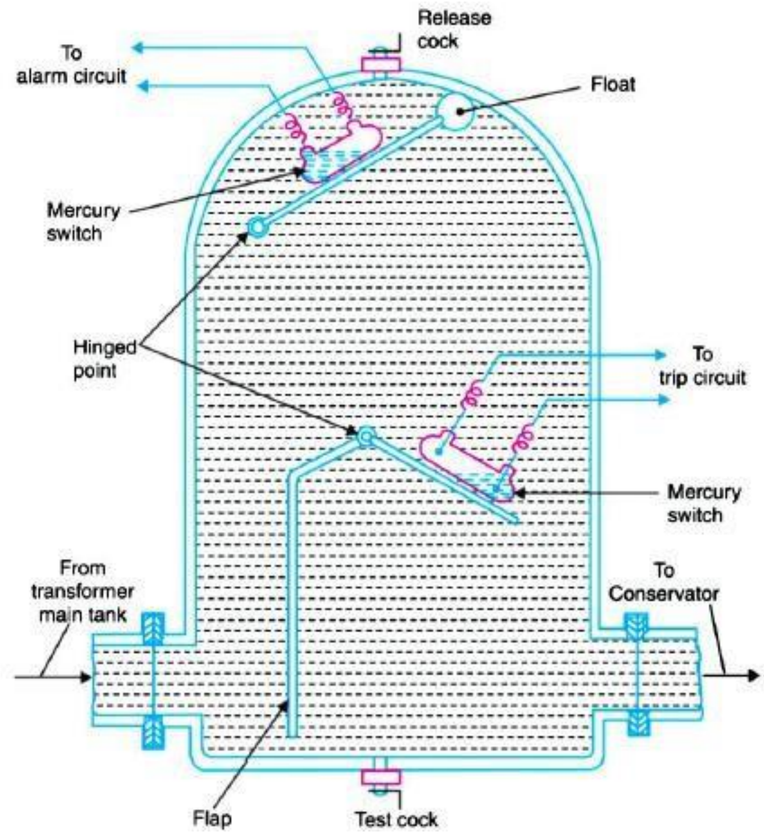


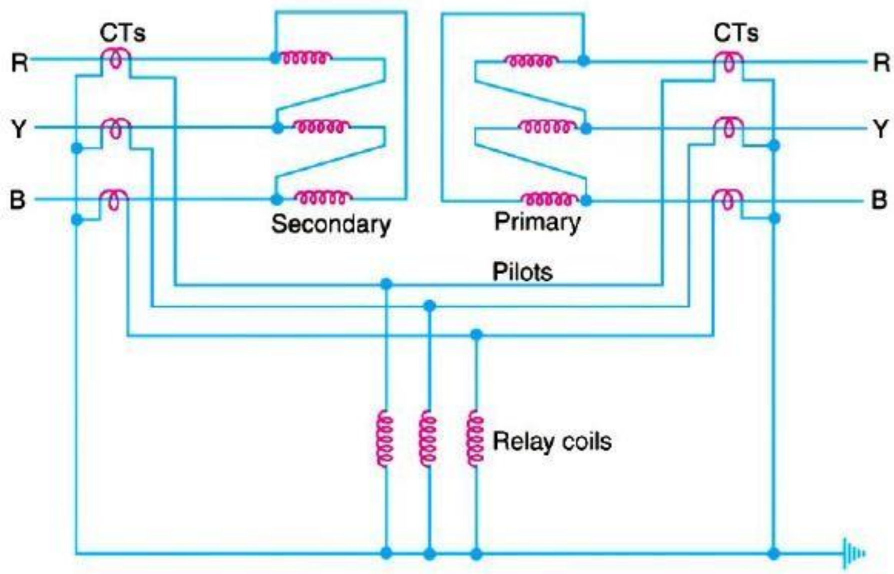
Fig. 2

Operation - The operation of Buchholz relay is as follows:

(i) In case of incipient faults within the transformer, the heat due to fault causes the decomposition of some transformer oil in the main tank. The products of decomposition contain more than 70% of hydrogen gas. The hydrogen gas being light tries to go into the conservator and in the process gets entrapped in the upper part of relay chamber. When a predetermined amount of gas gets accumulated, it exerts sufficient pressure on the float to cause it to tilt and close the contacts of mercury switch attached to it. This completes the alarm circuit to sound an alarm.

(ii) If a serious fault occurs in the transformer, an enormous amount of gas is generated in the main tank. The oil in the main tank rushes towards the conservator via the Buchholz relay and in doing so tilts the flap to close the contacts of mercury switch. This completes the trip circuit to open the circuit breaker controlling the transformer.

2. Differential system (Merz-Price circulating current scheme)



Merz-Price circulating -current principle is commonly used for the protection of power transformers against earth and phase faults. While applying circulating current principle for protection of transformers, below precautions are necessary in order to avoid inadvertent relay operation

(i) In a power transformer, currents in the primary and secondary are usually different; therefore, a differential current flows through the relay even under no fault conditions. This is compensated by different turn ratios of CTs. If T is the turn-ratio of power transformer, then turn ratio of CTs on the LV side is made T times that of the CTs on the HV side.

(ii) There is usually a phase difference between the primary and secondary currents of a 3-phase power transformer. To correct this, for a delta/star power transformer, the CTs on the delta side must be connected in star and those on the star side in delta.

(iii) Tap changing will cause differential current to flow through the relay even under normal operating conditions. The above difficulty is overcome by adjusting the turn-ratio of CTs on the side of the power transformer provided with taps.

Working:

In the figure CTs on the two sides of the Delta/Delta transformer are connected in star to compensates for the phase difference between the transformer primary and secondary. The CTs on the two sides are connected by pilot wires and one relay is used for each pair of CTs. During normal operating conditions, the secondaries of CTs carry identical currents. Therefore, the currents entering and leaving the pilot wires at both ends are the same and no current flows through the relays. If a ground or phase-to-phase fault occurs, the currents in the secondaries of CTs will not be the same and the differential current flowing through the relay circuit will trip the breaker on both sides of the transformer. The-protected zone is limited to the region between CTs on the high-voltage side and the CTs on the low-voltage side of the power transformer.

Bus bar Protection

Busbars in the generating stations and sub-stations form important link between the incoming and outgoing circuits. The two most commonly used schemes for busbar protection are

1. Differential protection
2. Fault bus protection

1. <u>Differential protection</u>

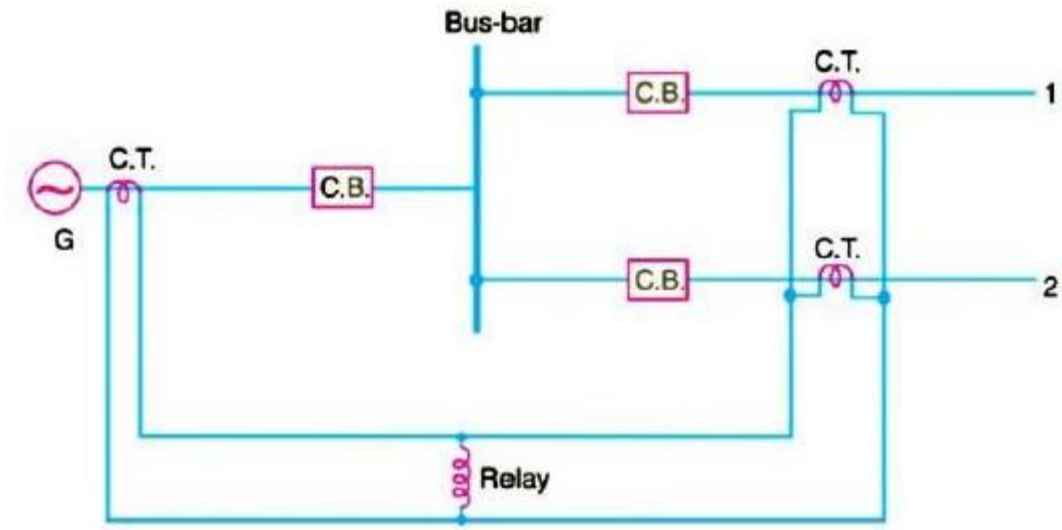


Fig.1

Fig.1 shows the single line diagram of current differential scheme for a station busbar. The busbar is fed by a generator and supplies load to two lines. The secondaries of current transformers in the generator lead, in line 1 and in line 2 are all connected in parallel. The protective relay is connected across this parallel connection. All CTs must be of the same ratio in the scheme regardless of the capacities of the various circuits.

Under normal load conditions or external fault conditions, the sum of the currents entering the bus is equal to those leaving it and no current flows through the relay.

If a fault occurs within the protected zone, the currents entering the bus will not be equal to the current leaving the bus. The difference of these currents will flow through the relay and cause the opening of circuit breakers connected at the end of protected zone

2. <u>Fault Bus protection</u>

Fault bus is an earthed metal barrier that surrounds each conductor throughout its entire length in the bus structure. With this arrangement, every fault on the system can be converted into earth fault.

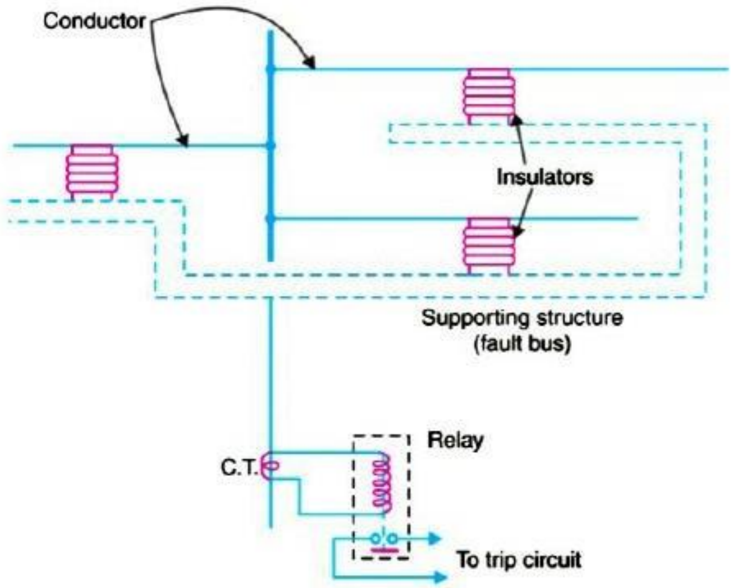


Figure shows the schematic arrangement of fault bus protection. The metal supporting structure or fault bus is earthed through a current transformer. A relay is connected across the secondary of this CT. Under normal operating conditions, there is no current flow from fault bus to ground and the relay does not operate. When a fault occur on the bus bar, a connection between a conductor and earthed supporting structure (fault bus) will result in current flow to ground through the fault bus, causing the relay to operate. The operation of relay will trip all breakers connecting equipment to the bus.

Protection of Lines

The probability of faults occurring on the lines is much more due to their greater length and exposure to atmospheric conditions. While differential protection is ideal method for lines, it is much more expensive to use. The two ends of a line may be several kilometres apart and to compare the two currents, a costly pilot-wire circuit is required.

The requirements of line protection are:

(i) In the event of a short-circuit, the circuit breaker closest to the fault should open, all other circuit breakers remaining in a closed position.

(ii) In case the nearest breaker to the fault fails to open, back-up protection should be provided by the adjacent circuit breakers.

(iii) The relay operating time should be just as short as possible in order to preserve system stability, without unnecessary tripping of circuits.

The common methods of line protection are

1. **Time-graded overcurrent protection**
2. **Differential protection**
3. **Distance protection**

1. Time-Graded Overcurrent Protection

In this scheme of overcurrent protection, time discrimination is incorporated. In other words, the time setting of relays is so graded that in the event of fault, the smallest possible part of the system is isolated. Let us consider a radial feeder. The main characteristic of a radial system is that power can flow only in one direction, from generator or supply end to the load. Time-graded protection of a radial feeder can be achieved by using (i) definite time relays and (ii) inverse time relays.

(i) Definite time relays

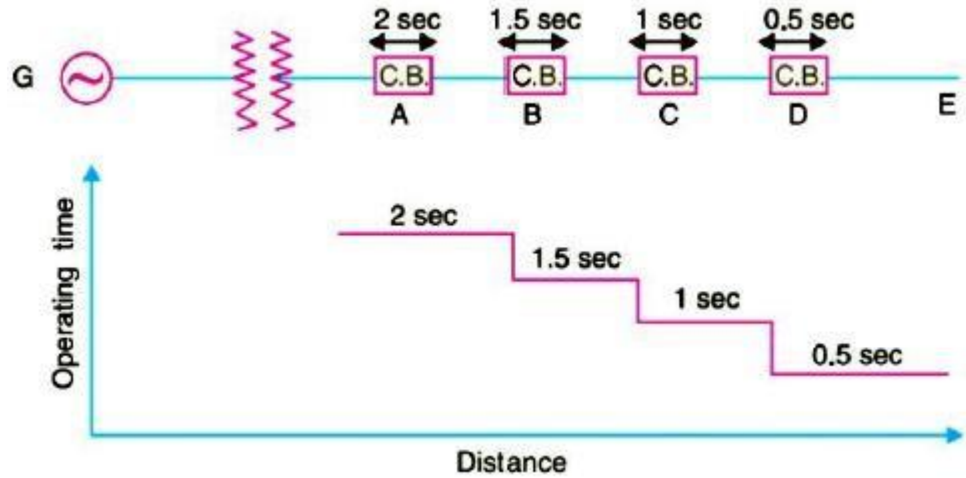


Fig shows the over current protection of a radial feeder by definite time relays. The time of operation of each relay is fixed and is independent of the operating current. Thus relay D has an operating time of 0·5 second and for other relays C, B, A, time delay is successively increased by 0·5 second. If a fault occurs in the section DE, it will be cleared in 0·5 second by the relay and circuit breaker at D because all other relays have higher operating time. In this way only section DE of the system will be isolated. If the relay at D fails to trip, the relay at C will operate after a time delay of 0·5 second i.e. after 1 second from the occurrence of fault.

Disadvantage of this system is that if there are a number of feeders in series, the tripping time for faults near the supply end becomes high (2 seconds in this case). This disadvantage can be overcome to a reasonable extent by using inverse-time relays.

(ii) Inverse time relays

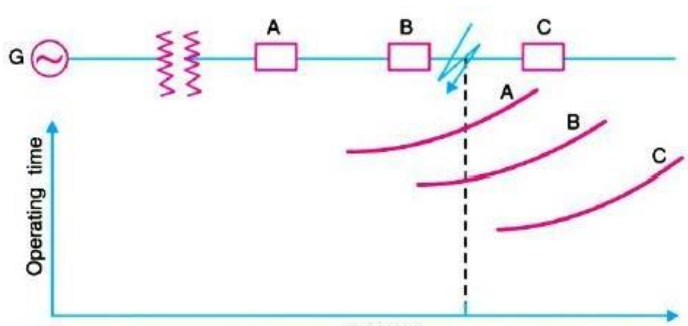


Fig shows overcurrent protection of a radial feeder using inverse time relays in which operating time is inversely proportional to the operating current. In this arrangement, as the distance of the circuit breaker from the generating station increases, the relay operating time decreases. When fault occurs in section BC, breaker at B will trip. If the relay at B fails to trip, the relay at A will operate after a time delay. Thus relay B act as primary protection and relay A act as back up protection of the line section BC.

2. Differential protection (Merz-Price voltage balance system)

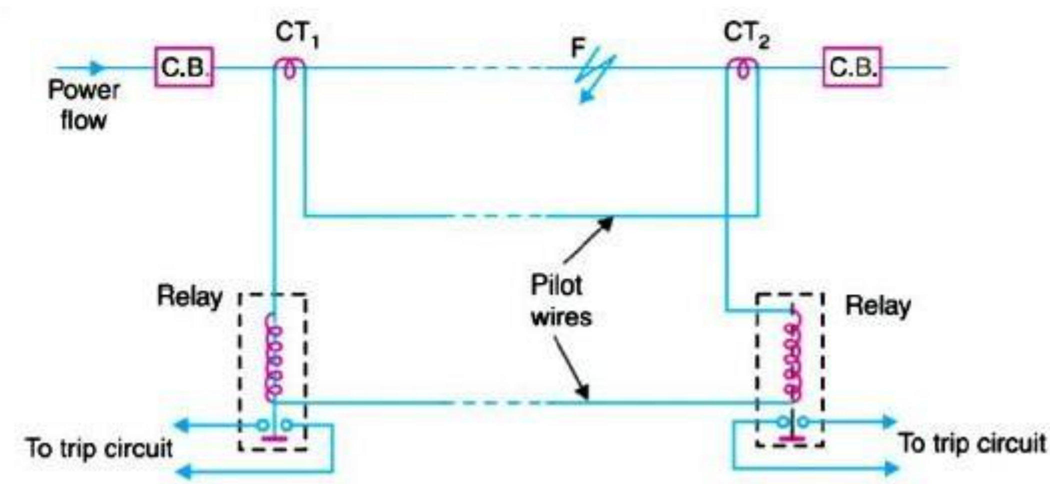


Fig. 23.8 shows the single line diagram of Merz Price voltage balance system for the protection of a 3-phase line. Identical current transformers are placed in each phase at both ends of the line.

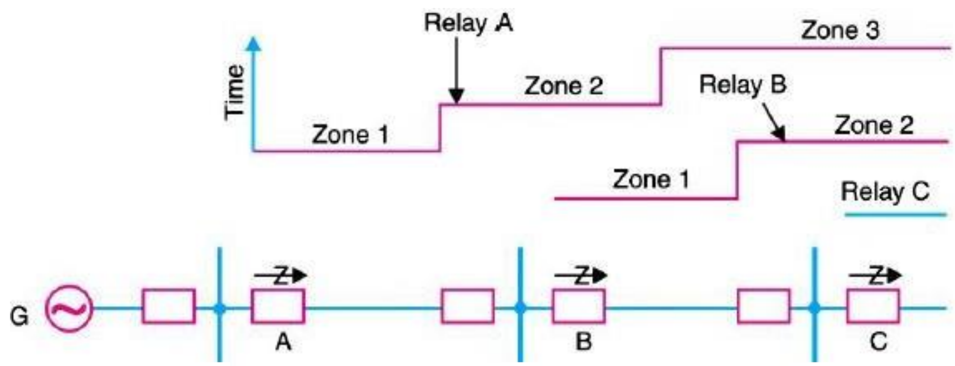
Under healthy conditions, current entering the line at one-end is equal to that leaving it at the other end. Therefore, equal and opposite voltages are induced in the secondaries of the CTs at the two ends of the line. The result is that no current flows through the relays.

Suppose a fault occurs at point F on the line as shown in Fig. 23.8. This will cause a greater current to flow through CT_1 than through CT_2. Consequently, their secondary voltages become unequal and circulating current flows through the pilot wires and relays. The circuit breakers at both ends of the line will trip out and the faulty line will be isolated.

3. Distance protection

Both time-graded and Differential protection are not suitable for *very long* high voltage transmission lines. Time-graded protection gives an unduly long time delay in fault clearance at the generating station end when there are more than four or five sections. Pilot-wire system becomes too expensive due to the greater length of pilot wires required.
Therefore, for *very long* high voltage transmission lines **Distance protection** is used. Operating time of Distance relay depends upon the distance (or impedance) of the relay from the fault point.

$$\text{Operating time, } T \propto V/I \propto Z \propto \text{distance}$$



A B C

Figure shows a 'three-zone' distance protection. In this scheme of protection, three distance relays A, B, C are used. Operating area of Relay A is divided into 3 zones named as Zone 1, Zone 2, Zone 3.

- Zone 1 covers first 90% of the protected line AB and is arranged to trip instantaneously for faults in this portion.
- Zone 2 covers remaining 10% of the protected line AB + 50% of the adjacent line BC , but a time delay is added if the fault is in the adjacent line BC ie, Relay A acts as backup protection for the adjacent line.
  Total Distance covered by Zone 2 - Z_{AB} + 50% of Z_{BC}
- Zone 3 covers remaining 50% of the adjacent line BC + 20% more
  Total Distance covered by Zone 3 - Z_{AB} + Z_{BC} +20% more
  The Zone3 element provides back-up protection in the event a fault in the next section is not cleared by its breaker.

Zone	Total Distance covered
Zone 1	90% of Z_{AB}
Zone 2	Z_{AB} + 50% of Z_{BC}
Zone 3	Z_{AB} + Z_{BC} +20% more

Zone	Total Distance covered	Operating time	Type of protection
Zone 1	90% of protected line AB	Instantaneous(T)	Provides primary protection to 90% of line AB
Zone 2	100% of protected line AB + 50% of adjoining line BC	T_1= T+ time delay	• Provides primary protection to remaining 10% of AB • Back up protection to 100% of AB • Back up protection to 50% of BC
Zone 3	100% of protected line AB + 50% of adjoining line BC + 20% more	T_2= T_1+ time delay	Back up protection to 100% of AB Back up protection to 100% of BC

Protection against Over voltage

A sudden rise in voltage for a very short duration on the power system is known as a voltage surge or transient voltage. Transients or surges are of temporary nature and exist for a very short duration (a few hundred μ*s*) but they cause over voltages on the power system

Surges are caused due to Switching, Insulation failure, Arcing ground, Resonance and lightning. Among these, lightning causes severe overvoltages which results in flash over of the line insulators (near the point where lightning has struck) and damage the nearby transformers, generators or other equipment connected to the line if the equipment is not suitably protected.

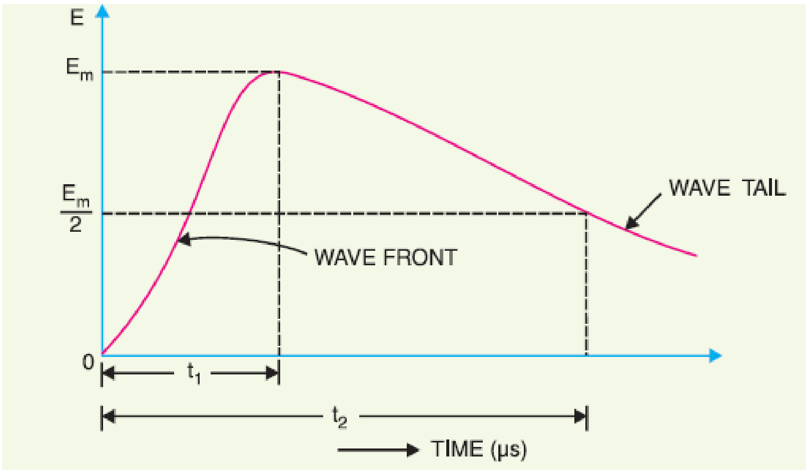


Fig. 24.1

Fig 24.1 shows the wave-form of a typical lightning surge. The voltage build-up is taken along *y*-axis and the time along *x*-axis. From the diagram it is clear that lightning introduces a steep-fronted voltage wave.

Voltage surges are generally specified as t_1/ t_2 μs

- t_1 is the rise time (t_1 varies from 1 μs to 10 μs)
- t_2 is the time taken by the wave to decay to half of the peak value(t_2 varies from 10 μs to 100 μs)

Causes of Overvoltage

The overvoltage on a power system may be broadly divided into two main categories *viz*.

1. **Internal causes**
   1) Switching surges
   2) Insulation failure
   3) Arcing ground
   4) Resonance
2. **External causes –** lightning

Internal Causes of Overvoltage

When circuit conditions are changed suddenly (normal switching operation such as opening of a circuit breaker or fault condition such as grounding of a line conductor) oscillations are setup on the power system. These oscillations develop over voltages (twice the normal voltage) that are not severe as lightning surges. Only normal system insulation is needed for protection against over voltages due to internal causes.

1) **Switching Surges -** The over voltages produced on the power system due to switching operations (opening and closing of a line using CB) are known as switching surges.
2) **Insulation failure -** The most common case of insulation failure in a power system is the grounding of conductor (*i.e.* insulation failure between line and earth) which may cause over voltages in the system.
3) **Arcing ground -** The phenomenon of intermittent arc taking place in line-to-ground fault of a 3φ system with an ungrounded neutral is known as arcing ground. The arcing ground produces severe oscillations (transients) of three to four times the normal voltage. The transients produced due to arcing ground may damage the equipment in the power system by causing breakdown of insulation. Arcing ground can be prevented by earthing the neutral.
4) **Resonance -** Resonance occurs when inductive reactance of the circuit becomes equal to capacitive reactance. Under resonance, the impedance of the circuit is equal to resistance of the circuit and the p.f. becomes unity. Resonance causes high voltages in the electrical system.

Lightning

Lightning is a huge spark or electric discharge that takes place when clouds are charged to such a high potential (+ve or −ve) and the dielectric strength of medium (air) is destroyed. Lightning may occur between clouds, between cloud and earth, or between the charge centres of the same cloud.

How the clouds acquire charge

When warm moist air from earth rises up, the friction between the air and the tiny particles of water causes the building up of charges. When drops of water are formed, the larger drops become positively charged and the smaller drops become negatively charged. When the drops of water accumulate, they form clouds, and hence cloud may possess either a positive or a negative charge. When the charge on a cloud become so great that it will discharge to another cloud or to earth and this discharge is called lightning.

The following points may be noted about lightning discharge:

- 87% of all lightning strokes result from negatively charged clouds and only 13% originate from positively charged clouds.
- Throughout the world, there occur about 100 lightning strokes per second.
- Voltage of Lightning – 10MV to 100MW

- Current in Lightning discharge - 10 kA to 90 kA.
- Energy in Lightning stroke -250kWh (approx.)

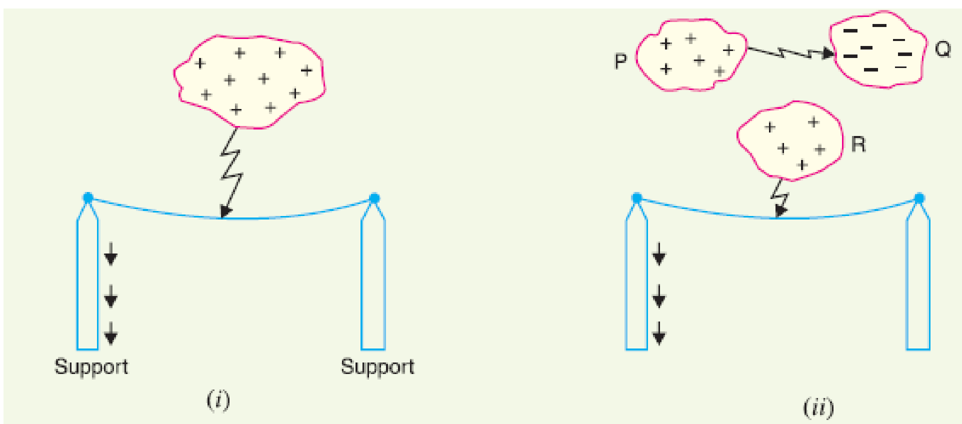
Types of Lightning Strokes

There are two main ways in which a lightning may strike the power system (e.g. overhead lines, towers, sub-stations etc.),

1. Direct stroke
2. Indirect stroke

1. Direct stroke - In the direct stroke, the lightning discharge (*i.e.* current path) is directly from the cloud to the object on earth (*e.g.* an overhead line). From the line, the current path may be over the insulators down the pole to the ground. The over voltage set up due to the stroke may cause flashover of insulators and break the poles that support the line and discharge directly to ground. The direct strokes can be of two types,

(i) Stroke A **(ii) Stroke B**



(i) Stroke A - The cloud will induce a charge of opposite sign on the tall object (*e.g.* an overhead line in this case). When the potential between the cloud and line exceeds the breakdown value of air, the lightning discharge occurs between the cloud and the line.

(ii) Stroke B - There are three clouds *P*, *Q* and *R* having positive, negative and positive charges respectively. The charge on the cloud *Q* is bound by the cloud *R*. If the cloud *P* shifts too near the cloud *Q*, then lightning discharge will occur between them and charges on both these clouds disappear quickly. The result is that charge on cloud *R* suddenly becomes free and it then discharges rapidly to earth, ignoring tall objects.

- ✓ **Direct strokes** on the power system are very rare.
- ✓ **Stroke A** will always occur on tall objects and hence protection can be provided against it.
- ✓ **Stroke B** completely ignores the height of the object and can even strike the round. Therefore, it is not possible to provide protection against stroke *B*.

2. **Indirect stroke.** Indirect strokes are due to the electrostatically induced charges on the transmission line due to the presence of charged clouds.

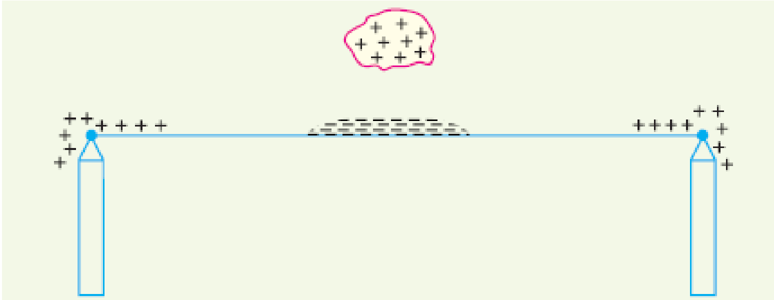


Fig. 24.6

A positively charged cloud is above the line and induces a negative charge on the line by electrostatic induction. This negative charge will be only on that portion of the line right under the cloud and the portions of the line away from it will be positively charged as shown in Fig. 24.6. The induced positive charge leaks slowly to earth *via* the insulators. When the cloud discharges to earth or to another cloud, the negative charge on the wire is isolated as it cannot flow quickly to earth over the insulators. Negative charge rushes along the line in both directions in the form of travelling waves.

- ✓ The majority of the surges in a transmission line are caused by indirect lightning strokes

Protection Against Lightning

The most commonly used devices for protection against lightning surges are :

1. Earthing screen
2. Overhead ground wires
3. Lightning arresters (or surge diverters)
4. Surge absorber

1. Overhead Ground Wires

The ground wires are placed over the transmission tower above the line conductors. When direct lightning strokes occur, ground wires will take up all the lightning strokes instead of allowing them to line conductors. The ground wires are grounded at each tower through a low resistance. The heavy lightning current (10 kA to 50 kA) from the ground wire flows to the ground, thus protecting the line from the harmful effects of lightning.

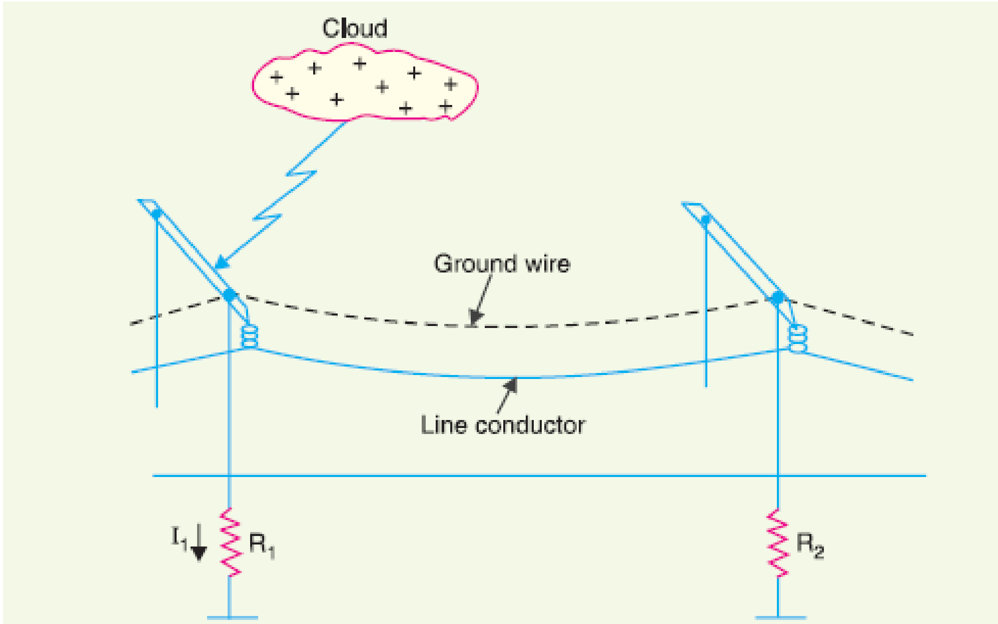


Fig. 24.7

Let the tower-footing resistance is R_1 ohms and that the lightning current from tower to ground is I_1 amperes. Then the tower rises to a potential V_1 given by

$$V_1 = I_1 R_1$$

This voltage will appear across the strings of insulators. If V_1 is very high, the insulator flashover may occur. Since the value of V_1 depends upon tower-footing resistance *R*1, the value of this resistance must be kept as low as possible to avoid insulator flashover.

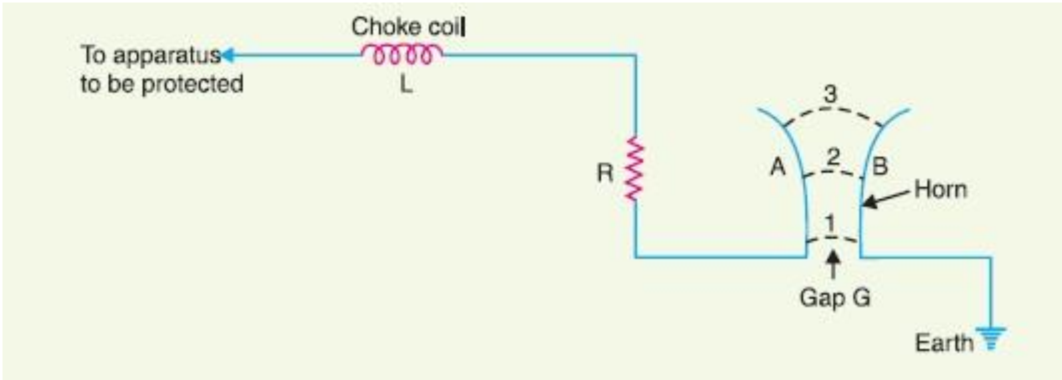
2. Lightning Arresters

It is a protective device which conducts the high voltage surges (due to both direct and indirect stroke) on the power system to the ground and protects the equipments connected to it.

Types of lightning arresters :

1. Rod gap arrester
2. Horn gap arrester
3. Multigap arrester
4. Expulsion type lightning arrester
5. Valve type lightning arrester
6. Thyrite type lightning arrester

1. Horn Gap Arrester



Construction: It consists of two horn shaped metal rods A and B separated by a small air gap. The distance between them gradually increases towards the top as shown. The gap between the horns is so adjusted that normal supply voltage is not enough to cause an arc across the gap. The horns are mounted on porcelain insulators. One end of horn is connected to the line through a resistance *R* and choke coil *L* while the other end is effectively grounded. The resistance *R* helps in limiting the follow current to a small value. The choke coil offers small reactance at normal power frequency but a very high reactance at transient frequency. Thus the choke does not allow the transients to enter the apparatus to be protected.

Working: Under normal conditions, the horn gap does not conduct (*i.e*. normal supply voltage is insufficient to initiate the arc between the gap). When an overvoltage occurs, spark-over takes place across the small gap *G*. The heated air around the arc and the magnetic effect of the arc cause the arc to travel up the gap. The arc moves progressively into positions 1, 2 and 3. At position 3, the distance may be too great for the voltage to maintain the arc. Consequently, the arc is extinguished. The excess charge on the line is thus conducted through the arrester to the ground.

Advantages

- The arc is self-clearing. Therefore, this type of arrester does not cause short-circuiting of
- the system after the surge is over as in the case of rod gap.
- Series resistance helps in limiting the follow current to a small value.

Limitations

- The bridging of gap by some external agency (*e.g*. birds) will create a short circuit.
- Corrosion or pitting will adversely affects the performance of the arrester.
- The time of operation is comparatively long (about 3 seconds) when compared to modern lightning arresters..

Due to the above limitations, this type of arrester is not reliable and can only be used as ‘back-up’ protection with main arresters.