Lecture Note

SWITCH GEAR AND PROTECTIVE DEVICES

DEPARTMENT OF ELECTRICAL ENGINEERING

CH-1

A great demand for electrical energy is a notable feature of modern civilisation. Most of this energy is needed for light-
ing, heating, domestic appliances, industrial elec-trical machinery and electric traction. The im-portance of electric supply in everyday life has reached such a stage that it is desirable to protect the power system from harm during fault condi-tions and to ensure maximum continuity of sup-ply. For this purpose, means must be provided to switch on or off generators, transmission lines, distributors and other equipment under both nor-mal and abnormal conditions. This is achieved by an apparatus called switchgear. A switchgear essentially consists of switching and protecting devices such as switches, fuses, circuit breakers, relays etc.

section from the system. In this way, switchgear protects the system from the damage and ensures continuity of supply. In this chapter, we shall present the elementary introduction to switchgear.

Switchgear

The apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as switchgear.

The switchgear equipment is essentially concerned with switching and interrupting currents either under normal or abnormal operating conditions. The tumbler switch with ordinary fuse is the simplest form of switchgear and is used to control and protect lights and other equipment in homes, offices etc. For circuits of higher rating, a high-rupturing capacity (H.R.C.) fuse in conjuction with a switch may serve the purpose of controlling and protecting the circuit. However, such a switchgear cannot be used profitably on high voltage system (3·3 kV) for two reasons. Firstly, when a fuse blows, it takes sometime to replace it and consequently there is interruption of service to the custom-ers. Secondly, the fuse cannot successfully interrupt large fault currents that result from the faults on high voltage system.

With the advancement of power system, lines and other equipments operate at high voltages and carry large currents. When a short circuit occurs on the system, heavy current flowing through the equipment may cause considerable damage. In order to interrupt such heavy fault currents, auto-matic circuit breakers (or simply circuit breakers) are used. A circuit breaker is a switchgear which can open or close an electrical circuit under both normal and abnormal conditions. Even in instances where a fuse is adequate, as regards to breaking capacity, a circuit breaker may be preferable. It is because a circuit breaker can close circuits, as well as break them without replacement and thus has wider range of use altogether than a fuse.

Essential Features of Switchgear

The essential features of switchgear are :

(i) Complete reliability. With the continued trend of interconnection and the increasing capacity of generating stations, the need for a reliable switchgear has become of paramount impor-tance. This is not surprising because switchgear is added to the power system to improve the reliabil-ity. When fault occurs on any part of the power system, the switchgear must operate to isolate the faulty section from the remainder circuit.

(ii) Absolutely certain discrimination. When fault occurs on any section of the power system, the switchgear must be able to discriminate between the faulty section and the healthy section. It should isolate the faulty section from the system without affecting the healthy section. This will ensure continuity of supply.

(iii) Quick operation. When fault occurs on any part of the power system, the switchgear must operate quickly so that no damage is done to generators, transformers and other equipment by the short-circuit currents. If fault is not cleared by switchgear quickly, it is likely to spread into healthy parts, thus endangering complete shut down of the system.

(iv) Provision for manual control. A switchgear must have provision for manual control. In case the electrical (or electronics) control fails, the necessary operation can be carried out through manual control.

(v) Provision for instruments. There must be provision for instruments which may be required. These may be in the form of ammeter or voltmeter on the unit itself or the necessary current and voltage transformers for connecting to the main switchboard or a separate instrument panel.

Switchgear Equipment

Switchgear covers a wide range of equipment concerned with switching and interrupting currents under both normal and abnormal conditions. It includes switches, fuses, circuit breakers, relays and other equipment. A brief account of these devices is given below. However, the reader may find the detailed discussion on them in the subsequent chapters.

Switches. A switch is a device which is used to open or close an electrical circuit in a convenient way. It can be used under full-load or no-load conditions but it cannot interrupt the fault currents. When the contacts of a switch are opened, an *arc is produced in the air between the contacts. This is particularly true for circuits of high voltage and large current capacity. The switches may be classified into (i) air switches (ii) oil switches. The contacts of the former are opened in air and that of the latter are opened in oil.

(i) Air-break switch. It is an air switch and is designed to open a circuit under load. In order to quench the arc that occurs on opening such a switch, special arcing horns are provided. Arcing horns are pieces of metals between which arc is formed during opening operation. As the switch opens, these horns are spread farther and farther apart. Consequently, the arc is lengthened, cooled and interrupted. Air-break switches are generally used outdoor for circuits of medium capacity such as lines supplying an industrial load from a main transmission line or feeder.

(ii) Isolator or disconnecting switch. It is essentially a knife switch and is designed to open a circuit under no load. Its main purpose is to isolate one portion of the circuit from the other and is not intended to be opened while current is flowing in the line. Such switches are generally used on both sides of circuit breakers in order that repairs and replacement of circuit breakers can be made without any danger. They should never be opened until the circuit breaker in the same circuit has been opened and should always be closed before the circuit breaker is closed.

(iii) Oil switches. As the name implies, the contacts of such switches are opened under oil, usually transformer oil. The effect of oil is to cool and quench the arc that tends to form when the circuit is opened. These switches are used for circuits of high voltage and large current carrying capacities.

[0].Fuses. A fuse is a short piece of wire or thin strip which melts when excessive current flows through it for sufficient time. It is inserted in series with the circuit to be protected. Under normal operating conditions, the fuse element it at a temperature below its melting point. Therefore, it carries the normal load current without overheating. However, when a short circuit or overload occurs, the current through the fuse element increases beyond its rated capacity. This raises the temperature and the fuse element melts (or blows out), disconnecting the circuit protected by it. In this way, a fuse protects the machines and equipment from damage due to excessive currents. It is worthwhile to note that a fuse performs both detection and interruption functions.

[1].Circuit breakers. A circuit breaker is an equipment which can open or close a circuit under all conditions viz. no load, full load and fault conditions. It is so designed that it can be operated manually (or by remote control) under normal conditions and automatically under fault conditions. For the latter operation, a relay circuit is used with a circuit breaker. Fig. 16.1 (i) shows the parts of a typical oil circuit breaker whereas Fig. 16.1 (ii) shows its control by a relay circuit. The circuit

breaker essentially consists of moving and fixed contacts enclosed in strong metal tank and immersed in oil, known as transformer oil.

Under normal operating conditions, the contacts remain closed and the circuit breaker carries the full-load current continuously. In this condition, the e.m.f. in the secondary winding of current transformer (C.T.) is insufficient to operate the trip coil of the breaker but the contacts can be opened (and hence the circuit can be opened) by manual or remote control. When a fault occurs, the resulting overcurrent in the C.T. primary winding increases the secondary e.m.f. This energises the trip coil of the breaker and moving contacts are pulled down, thus opening the contacts and hence the circuit. The arc produced during the opening operation is quenched by the oil. It is interesting to note that relay performs the function of detecting a fault whereas the circuit breaker does the actual circuit interruption.

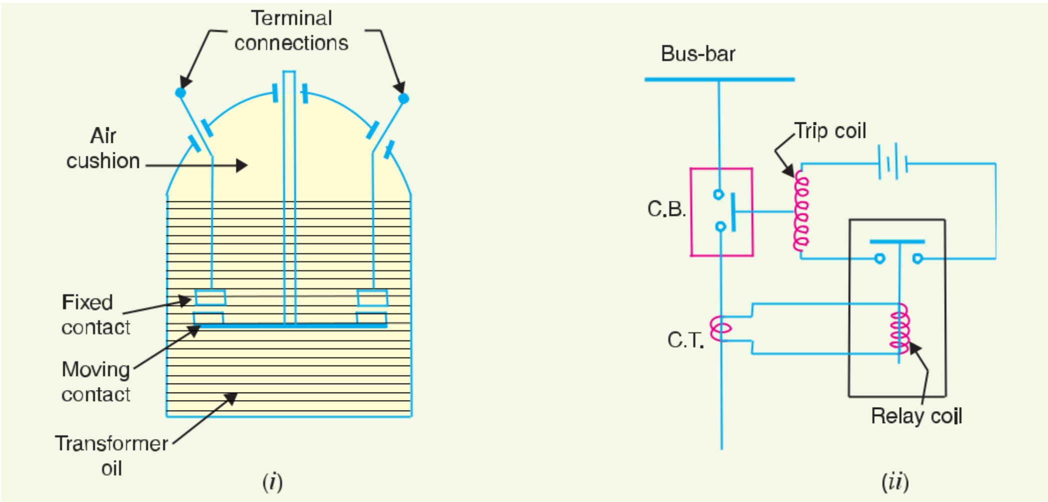


Fig. 16.1

[2]. Relays. A relay is a device which detects the fault and supplies information to the breaker for circuit interruption. Fig. 16.1 (ii) shows a typical relay circuit. It can be divided into three parts viz.

(i) The primary winding of a *current transformer (C.T.) which is connected in series with the circuit to be protected. The primary winding often consists of the main conductor itself.

(ii) The second circuit is the secondary winding of C.T. connected to the relay operating coil.

(iii) The third circuit is the tripping circuit which consists of a source of supply, trip coil of circuit breaker and the relay stationary contacts.

Under normal load conditions, the e.m.f. of the secondary winding of C.T. is small and the current flowing in the relay operating coil is insufficient to close the relay contacts. This keeps the trip coil of the circuit breaker unenergised. Consequently, the contacts of the circuit breaker remain closed and it carries the normal load current. When a fault occurs, a large current flows through the

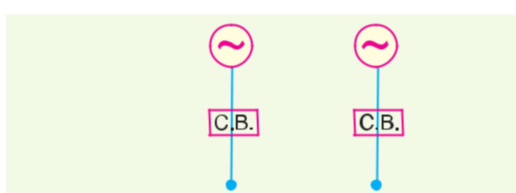
primary of C.T. This increases the secondary e.m.f. and hence the current through the relay operating coil. The relay contacts are closed and the trip coil of the circuit breaker is energised to open the contacts of the circuit breaker.

16.4 Bus-Bar Arrangements

When a number of generators or feeders operating at the same voltage have to be directly connected electrically, bus-bars are used as the common electrical component. *Bus-bars are copper rods or thin walled tubes and operate at constant voltage. We shall discuss some important bus-bars arrange-ments used for power stations and sub-stations. All the diagrams refer to 3-phase arrangement but are shown in single-phase for simplicity.

[3]. Single Bus-bar System. The single bus-bar system has the simplest design and is used for

power stations. It is also used in small outdoor stations having relatively few outgoing or incom-



ing feeders and lines. Fig. 16.2 shows the single bus-bar system for a typical power station.The generators, outgoing lines and transformers are connected to the bus-bar. Each generator and feeder is controlled by a circuit breaker. The isolators permit to isolate generators, feeders and circuit breakers from the bus-bar for maintenance. The chief advantages of this type of arrangement are low initial cost, less maintenance and simple operation.

Disadvantages. Single bus-bar system has the following three principal disadvantages :

(i) The bus-bar cannot be cleaned, repaired or tested without de-energising the whole system.

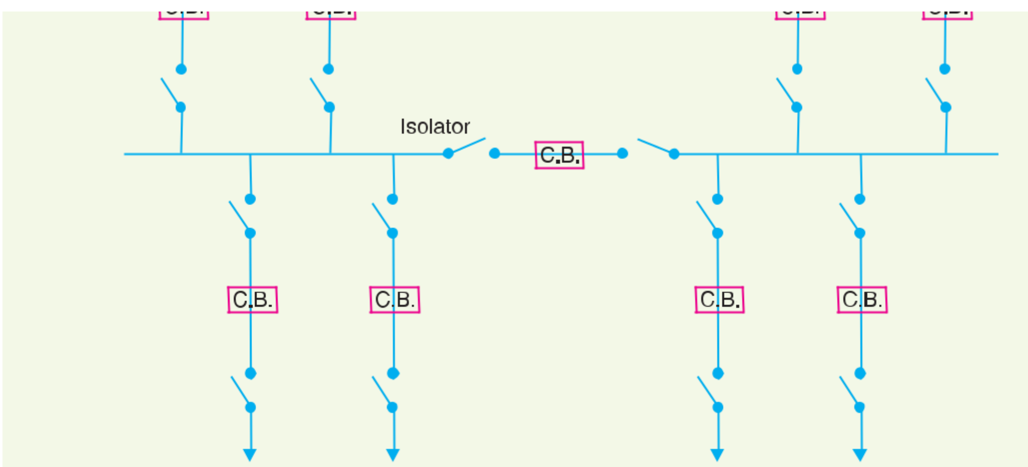
(ii) If a fault occurs on the bus-bar itself, there is complete interruption of supply.

(iii) Any fault on the system is fed by all the generating capacity, resulting in very large fault currents.

Single bus-bar system with Sectionalisation. In large generating stations where several units are installed, it is a common practice to sectionalise the bus so that fault on any section of the bus-bar will not cause complete shut down. This is illustrated in Fig. 16.3 which shows the bus-bar divided into two sections connected by a circuit breaker and isolators. Three principal advantages are claimed for this arrangement. Firstly, if a fault occurs on any section

of the bus-bar, that section can be isolated without affecting the supply to other sections. Secondly, if a fault occurs on any feeder, the fault current is much **lower than with unsectionalised bus-bar. This permits the use of circuit breakers of lower capacity in the feeders. Thirdly, repairs and maintenance of any section of the bus-bar can be carried out by de-energising that section only, eliminating the possibility of com-plete shut-down.

It is worthwhile to keep in mind that a circuit breaker should be used as the sectionalising switch so that uncoupling of the bus-bars may be carried out safely during load transfer. Moreover, the circuit breaker itself should be provided with isolators on both sides so that its maintenance can be done while the bus-bars are alive.



[4].Duplicate bus-bar system. In large stations, it is important that breakdowns and mainte-nance should interfere as little as possible with continuity of supply. In order to achieve this objec-tive, duplicate bus-bar system is used in important stations. Such a system consists of two bus-bars, a

"main bus-bar'' and a "spare" bus-bar (see Fig. 16.4). Each generator and feeder may be connected to either bus-bar with the help of bus coupler which consists of a circuit breaker and isolators.

In the scheme shown in Fig. 16.4, service is interrupted during switch over from one bus to another. However, if it were desired to switch a circuit from one to another without interruption of service, there would have to be two circuit breakers per circuit. Such an arrangement will be too expensive.

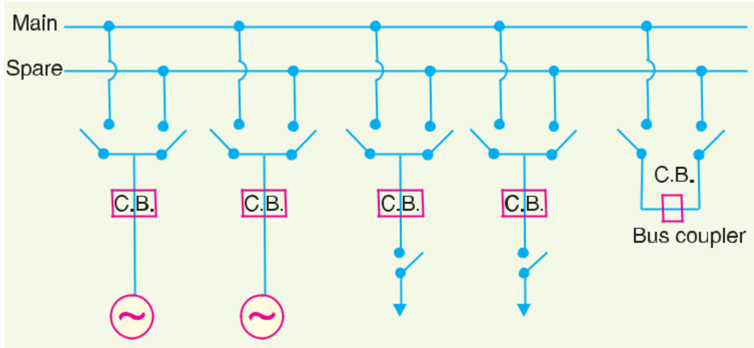


Fig. 16.4

Advantages

(i) If repair and maintenance it to be carried on the main bus, the supply need not be interrupted as the entire load can be transferred to the spare bus.

(ii) The testing of feeder circuit breakers can be done by putting them on spare bus-bar, thus keeping the main bus-bar undisturbed.

(iii) If a fault occurs on the bus-bar, the continuity of supply to the circuit can be maintained by transferring it to the other bus-bar.

Switchgear Accommodation

The main components of a switchgear are circuit breakers, switches, bus-bars, instruments and instru-ment transformers. It is necessary to house the switchgear in power stations and sub-stations in such a way so as to safeguard personnel during operation and maintenance and to ensure that the effects of fault on any section of the gear are confined to a limited region. Depending upon the voltage to be handled, switchgear may be broadly classified into (i) outdoor type (ii) indoor type.

(i) Outdoor type. For voltages beyond 66 kV, switchgear equipment is installed outdoor. It is because for such voltages, the clearances between conductors and the space required for switches, circuit breakers, transformers and others equipment become so great that it is not economical to install all such equipment indoor.

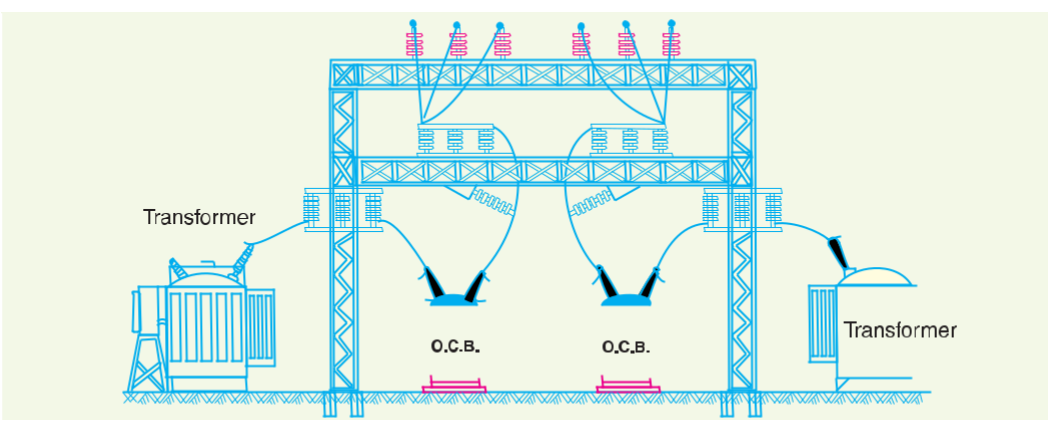


Fig. 16.5 shows a typical outdoor sub-station with switchgear equipment. The circuit breakers, isolators, transformers and bus-bars occupy considerable space on account of large electrical clear-ance associated with high voltages.

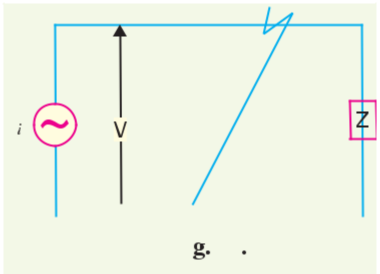
(ii) Indoor type. For voltages below 66 kV, switchgear is generally installed indoor because of economic considerations. The indoor switchgear is generally of metal-clad type. In this type of construction, all live parts are completely enclosed in an earthed metal casing. The primary object of this practice is the definite localisation and restriction of any fault to its place of origin.

Short-Circuit

Whenever a fault occurs on a network such that a large current flows in one or more phases, a short-circuit is said to have occurred.

When a short circuit occurs, a heavy current called short circuit current flows through the circuit. This can be beautifully illustrated by referring to Fig. 16.6 where a single phase generator of voltage

[5].and internal impedance Zi is supplying to a load Z. Under normal conditions, the current in the circuit is limited by *load impedance Z. However, if the load terminals get shorted due to any reason, the circuit impedance is reduced to a very low value ; being Zi in



this case. As Zi is very small, therefore, a large current flows through the circuit. This is called short-circuit current. It is worth-while to make a distinction between a **short-circuit and an z overload. When a short-circuit occurs, the voltage at fault point is reduced to zero and current of abnormally high magnitude flows through the network to the point of fault. On the other hand, an overload means that loads greater than the designed values have Fi 16 6 been imposed on the system. Under such conditions, the voltage at the overload point may be low, but not zero. The undervoltage conditions may extend for some distance beyond the overload point into the remainder of the system. The currents in the overloaded equipment are high but are substantially lower than that in the case of a short-circuit.

Causes of short-circuit. A short circuit in the power system is the result of some kind of abnor-mal conditions in the system. It may be caused due to internal and/or external effects.

(i) Internal effects are caused by breakdown of equipment or transmission lines, from deterio-ration of insulation in a generator, transformer etc. Such troubles may be due to ageing of insulation, inadequate design or improper installation.

(ii) External effects causing short circuit include insulation failure due to lightning surges, over-loading of equipment causing excessive heating; mechanical damage by public etc.

Effects of short-circuit. When a short-circuit occurs, the current in the system increases to an abnormally high value while the system voltage decreases to a low value.

(i) The heavy current due to short-circuit causes excessive heating which may result in fire or explosion. Sometimes short-circuit takes the form of an arc and causes considerable damage to the system. For example, an arc on a transmission line not cleared quickly will burn the conductor severely causing it to break, resulting in a long time interruption of the line.

(ii) The low voltage created by the fault has a very harmful effect on the service rendered by the power system. If the voltage remains low for even a few seconds, the consumers' motors may be shut down and generators on the power system may become unstable.

Due to above deterimental effects of short-circuit, it is desirable and necessary to disconnect the faulty section and restore normal voltage and current conditions as quickly as possible.

Short-Circuit Currents

Most of the failures on the power system lead to short-circuit fault and cause heavy current to flow in the system. The calculations of these short-circuit currents are important for the following reasons :

(i) A short-circuit on the power system is cleared by a circuit breaker or a fuse. It is necessary, therefore, to know the maximum possible values of short-circuit current so that switchgear of suitable rating may be installed to interrupt them.

(ii) The magnitude of short-circuit current determines the setting and sometimes the types and location of protective system.

(iii) The magnitude of short-circuit current determines the size of the protective reactors which must be inserted in the system so that the circuit breaker is able to withstand the fault current.

(iv) The calculation of short-circuit currents enables us to make proper selection of the associ-ated apparatus (e.g. bus-bars, current transformers etc.) so that they can withstand the forces that arise due to the occurrence of short circuits.

Faults in a Power System

A fault occurs when two or more conductors that normally operate with a potential difference come in contact with each other. These faults may be caused by sudden failure of a piece of equipment, accidental damage or short-circuit to overhead lines or by insulation failure resulting from lightning surges. Irrespective of the causes, the faults in a 3-phase system can be classified into two main categories viz.

(i) Symmetrical faults (ii) Unsymmetrical faults

(i) Symmetrical faults. That fault which gives rise to symmetrical fault currents (i.e. equal faults currents with 120o displacement) is called a symmetrical fault. The most common example of symmetrical fault is when all the three conductors of a 3-phase line are brought together simulta-neously into a short-circuit condition. The method of calculating fault currents for symmetrical faults is discussed in chapter 17.

(ii) Unsymmetrical faults. Those faults which give rise to unsymmetrical currents (i.e. un-equal line currents with unequal displacement) are called unsymmetrical faults. The unsymmetrical faults may take one of the following forms :

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Fault

INTRODUCTION ABOUT FAULT ANALYSIS –

Type of Faults

There are two types of faults which can occur on any transmission lines; balanced faults and unbalanced faults also known as symmetrical and asymmetrical faults respectively. Most of the faults that occur on power systems are not the balanced three-phase faults, but the unbalances faults. In addition, faults can be categorized as the shunt faults, series faults and simultaneous faults.

Series Faults

Series faults represent open conductor and take place when unbalanced series impedance conditions of the lines are present. Two examples of series fault are when the system holds one or two broken lines . Series faults are characterized by increase of voltage and frequency and fall in current in the faulted phases.

Shunt Faults

The shunt faults are the most common type of fault taking place in the field. They involve power conductors or conductor-to-ground or short circuits between conductors. One of the most important characteristics of shunt faults is the increment the current suffers and fall in voltage and frequency. Shunt faults cab be classified into four categories .

[6]. **Line-to-ground fault**: this type of fault exists when one phase of any transmission lines establishes a connection with the ground either by ice, wind, falling tree or any other incident. 70% of all transmission lines faults are classified under this category.

[7]. **Line-to-line fault**: as a result of high winds, one phase could touch anther phase & line-to-line fault takes place. 15% of all transmission lines faults are considered line-to-line faults

[8]. **Double line-to-ground**: falling tree where two phases become in contact with the ground

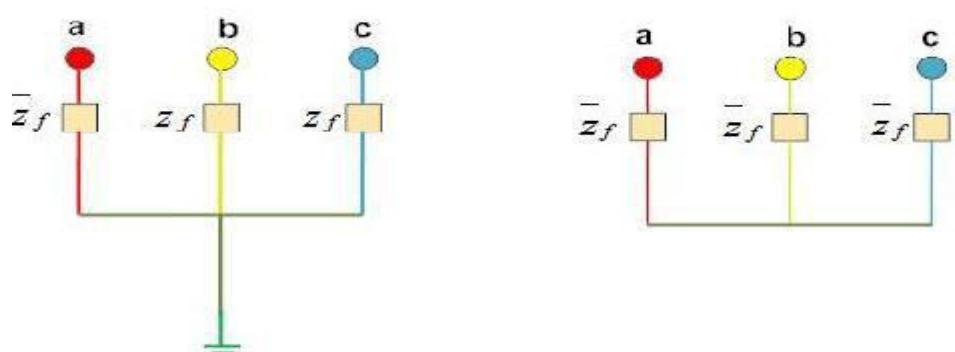
could lead to this type of fault. In addition, two phases will be involved instead of one at the line-to-ground faults scenarios. 10% of all transmission lines faults are under this type of faults

- **Three phase fault**: in this case, falling tower, failure of equipment or even a line breaking and touching the remaining phases can cause three phase faults. In reality, this type of fault not often exists which can be seen from its share of 5% of all transmission lines faults

The first three of these faults are known as asymmetrical faults. Electrical fault is the deviation of voltages and currents from nominal values or states. Under normal operating conditions, power system equipment or lines carry normal voltages and currents which results in a safer operation of the system. But when fault occurs, it causes excessively high currents to flow which causes the damage to equipments and devices. Fault detection and analysis is necessary to select or design suitable switchgear equipments, electromechanical relays, circuit breakers and other protection devices.

1.Symmetrical faults

These are very severe faults and occur infrequently in the power systems. These are also called as balanced faults and are of two types namely line to line to line to ground (L-L-L-G) and line to line to line (L-L-L).



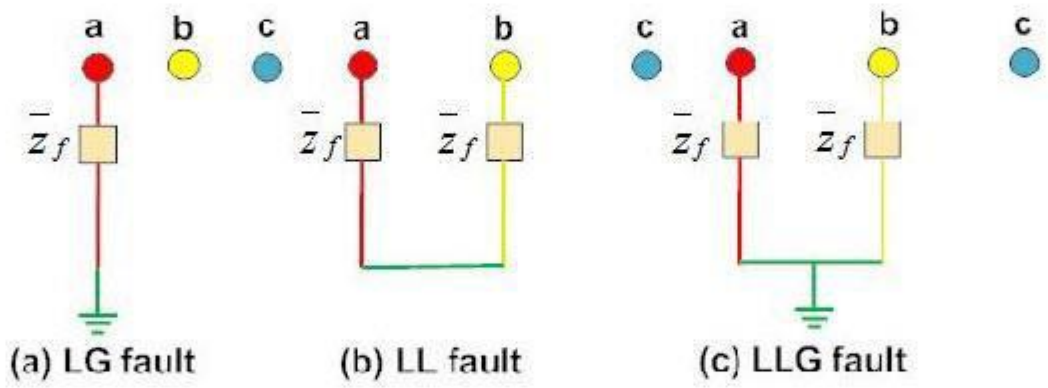
(a) LLLG fault (b) LLL fault

Only 2-5 percent of system faults are symmetrical faults. If these faults occur, system remains balanced but results in severe damage to the electrical power system equipments.

Above figure shows two types of three phase symmetrical faults. Analysis of these fault is easy and usually carried by per phase basis. Three phase fault analysis or information is required for selecting set-phase relays, rupturing capacity of the circuit breakers and rating of the protective switchgear.

2.Unsymmetrical faults

These are very common and less severe than symmetrical faults. There are mainly three types namely line to ground (L-G), line to line (L-L) and double line to ground (LL-G) faults.



Line to ground fault (L-G) is most common fault and 65-70 percent of faults are of this type.

It causes the conductor to make contact with earth or ground. 15 to 20 percent of faults are double line to ground and causes the two conductors to make contact with ground. Line to line faults occur when two conductors make contact with each other mainly while swinging of lines due to winds and 5- 10 percent of the faults are of this type.

These are also called unbalanced faults since their occurrence causes unbalance in the system. Unbalance of the system means that that impedance values are different in each phase causing unbalance current to flow in the phases.

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Fuse

A fuse is a device that protects a circuit from an over current condition only. It has a fusible link directly heated and destroyed by the current passing through it. A fuse contains a current-carrying element sized so that the heat generated by the flow of normal current through it does not cause it to melt the element; however, when an over current or short-circuit current flows through the fuse, the fusible link will melt and open the circuit.

A device that protects a circuit by fusing opens its current-responsive element when an over-current passes through it. An over-current is either due to an overload or a short circuit condition.

Fuse Construction:

The typical fuse consists of an element which is surrounded by filler and enclosed by the fuse body. The element is welded or soldered to the fuse contacts (blades or ferrules).

The element is a calibrated conductor. Its configuration, mass and the materials employed are selected to achieve the desired electrical and thermal characteristics.

The element provides the current path through the fuse. It generates heat at a rate dependent on its resistance and the load current.

The heat generated by the element is absorbed by the filler and passed through the fuse body to the surrounding air. The filler material, such as quartz sand, provides effective heat transfer and allows for the small element cross-section typical in modern fuses.

The effective heat transfer allows the fuse to carry harmless overloads .The small element cross section melts quickly under short-circuit conditions. The filler also aids fuse performance by absorbing arc energy when the fuse clears an overload or short circuit.

When a sustained overload occurs, the element will generate heat at a faster rate than the heat can be passed to the filler. If the overload persists, the element will reach its melting point and open. Increasing the applied current will heat the element faster and cause the fuse to open sooner. Thus, fuses have an inverse time current characteristic: that is, the greater the over current, the less time required for the fuse to open the circuit.

This characteristic is desirable because it parallels the characteristics of conductors, motors, transformers, and other electrical apparatus. These components can carry low-level overloads for relatively long periods without damage. However, under high-current conditions, damage can occur quickly. Because of its inverse time current characteristic, a properly applied fuse can provide effective protection over a broad current range, from low-level overloads to high-level short circuits.

Type of Fuse:

A fuse unit essentially consists of a metal fuse element or link, a set of contacts between which it is fixed and a body to support and isolate them. Many types of fuses also have some means for extinguishing the arc which appears when the fuse element melts. In general, there are two categories of fuses.

Low voltage fuses.

High voltage fuses.

Usually isolating switches are provided in series with fuses where it is necessary to permit fuses to be replaced or rewired with safety.

In absence of such isolation means, the fuses must be so shielded as to protect the user against accidental contact with the live metal when the fuse is being inserted or removed.

LOW VOLTAGE FUSES

Low voltage fuses can be further divided into two classes namely
Semi-enclosed or Rewire able type.
Totally enclosed or Cartridge type.

(1) Re Wire able Fuse:

The most commonly used fuse in 'house wiring' and small current circuit is the semi-enclosed or rewire able fuse. (also sometime known as KIT-KAT type fuse). It consist of a **porcelain base** carrying the fixed contacts to which the incoming and outgoing live or phase wires are connected and a **porcelain fuse carrier** holding the fuse element, consisting of one or more strands of fuse wire, stretched between its terminals.

The fuse carrier is a separate part and can be taken out or inserted in the base without risk, even without opening the main switch. If fuse holder or carrier gets damaged during use, it may be replaced without replacing the complete unit.

The fuse wire may be of lead, tinned copper, aluminum or an alloy of tin lead.

The actual fusing current will be about twice the rated current. When two or more fuse wire are used, the wires should be kept apart and a de rating factor of 0.7 to 0.8 should be employed to arrive at the total fuse rating.

The specification for re wire able fuses are covered by IS: 2086-1963. Standard ratings are 6, 16, 32, 63, and 100A.

A fuse wire of any rating not exceeding the rating of the fuse may be used in it that is a 80 A fuse wire can be used in a 100 A fuse, but not in the 63 A fuse. On occurrence of a fault, the fuse element blows off and the circuit is interrupted. The fuse carrier is pulled out, the blown out fuse element is replaced by new one and the supply can is resorted by re-inserting the fuse carrier in the base.

Though such fuses have the advantage of easy removal or replacement without any danger of coming into the contact with a lie part and negligible replacement cost but suffers from following disadvantages:

Unreliable Operations.
Lack of Discrimination.
Small time lag.
Low rupturing capacity.
No current limiting feature.
Slow speed of operations.

(2) Totally Enclosed Or Cartridges Type Fuse:

B) Link type Cartridge or High Rupturing Capacity (HRC)

Where large numbers of concentrations of powers are concerned, as in the modern distribution system, it is essential that fuses should have a definite known breaking capacity and also this breaking capacity should have a high value. High rupturing capacity cartridge fuse, commonly called HRC cartridge fuses, have been designed and developed after intensive research by manufactures and supply engineers in his direction.

The usual fusing factor for the link fuses is 1.45. the fuses for special applications may have as low as a fusing factor as 1.2.

The specification for medium voltage HRC link fuses are covered under IS: 2202-1962.

Fuse Selection Guide

The fuse must carry the normal load current of the circuit without nuisance openings. However, when an over current occurs the fuse must interrupt the over current, limit the energy let-through, and withstand the voltage across the fuse during arcing. To properly select a fuse the followings must be considered:

Normal operating current (The current rating of a fuse is typically de rated 25% for operation at 25C to avoid nuisance blowing. For example, a fuse with a current rating of 10A is not usually recommended for operation at more than 7.5A in a 25C ambient.)

Overload current and time interval in which the fuse must open.

Application voltage (AC or DC Voltage).

Inrush currents, surge currents, pulses, start-up currents characteristics.

Ambient temperature.

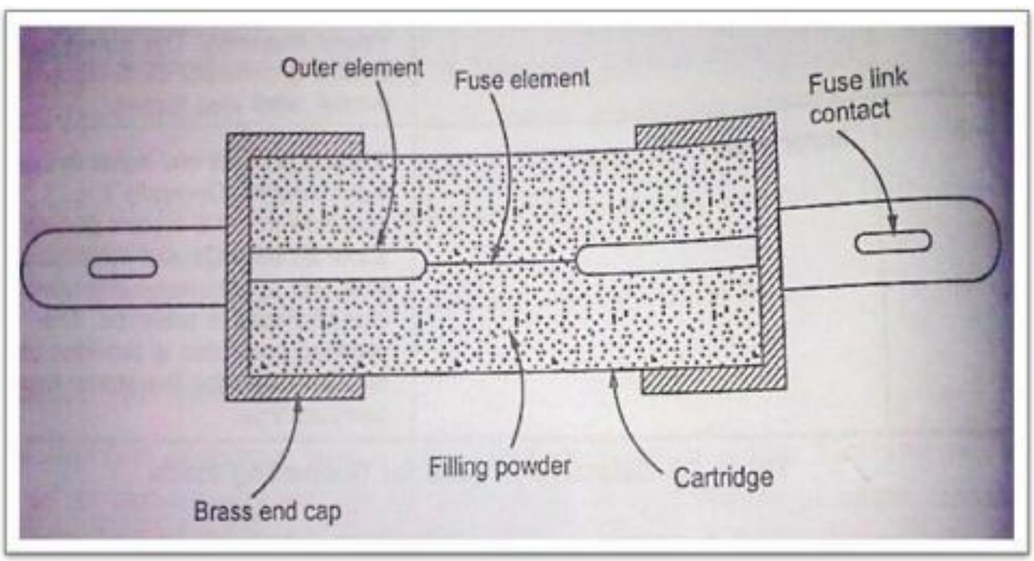
Applicable standards agency required, such as UL, CSA, and VDE.

Considerations: Reduce installation cost, ease of removal, mounting type/form factor, etc

HRC Fuse

It is a high rupturing capacity cartridge type of fuse. It is one of the simplest form of fuse which is used for distribution purposes. The low and uncertain breaking capacity of semi closed fuses is overcome in HRC Fuses.

Construction: The body of this fuse is of heat resisting ceramic with metal end caps and is of cylindrical shape. Between end caps, the fixed elements are mounted, which are welded to the end caps. The fuse element is generally silver, attached between the fixed elements. The body space surrounding the fuse is completely filled with quartz sand, plaster of paris or marble dust. The filling powder material is selected such that its chemical reaction with silver vapour forms very high resistance substance.



Operation

The various steps in the operation of the HRC Fuse are

Occurrence of fault or short circuit

Increase in current through fuse element to high value

Melting of silver element

Vaporization of the silver element

Fusion of the silver vapour and formation of high resistance substance

Extinction of arc

The electrical phenomena associated with the operation of the HRC Fuse are

Operation

The various steps in the operation of the HRC Fuse are

Occurrence of fault or short circuit

Increase in current through fuse element to high value

Melting of silver element

Vaporization of the silver element

Fusion of the silver vapour and formation of high resistance substance

Extinction of arc

The electrical phenomena associated with the operation of the HRC Fuse are

Applications of HRC fuse

The main applications of HRC Fuse are to protect the low voltage distribution system against the overload and short circuit conditions. For the back up protection to circuit breakers. Protection of meshed feeders with the steady load.

CH-5

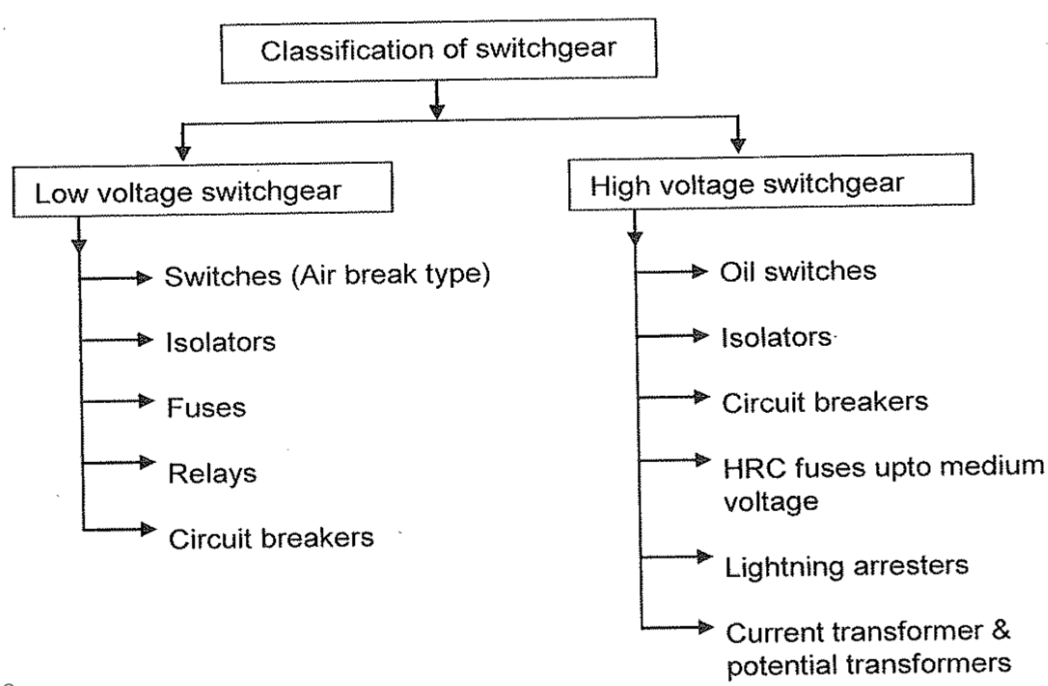
1.1 Fundamentals of Power System Protection

The purpose of an Electric Power System is to generate and supply electrical energy to consumers. The power system should be designed and managed to deliver this energy to the utilization points with both reliability and economically

The capital investment involved in power system for the generation, transmission and distribution is so great that the proper precautions must be taken to ensure that the equipment not only operates as nearly as possible to peak efficiency, but also must be protected from accidents

The normal path of the electric current is from the power source through copper (or aluminium) conductors in generators, transformers and transmission lines to the load and it is confined to this path by insulation. The insulation, however, may break down, either by the effect of temperature and age or by a physical accident, so that the current then follows an abnormal path generally known as Short Circuit or Fault

- Any abnormal operating state of a power system is known as *FAULT*. Faults in general consist of short circuits as well as open circuits. Open circuit faults are less frequent than short circuit faults, and often they are transformed in to short circuits by subsequent events.



1.2 Consequences of occurrence of Faults

Faults are of two type

- Short circuit fault- current
- Open circuit fault- voltage

In terms of seriousness of consequences of a fault , short circuits are of far greater concern than open circuits, although some open circuits present some potential hazards to personnel

Classification of short circuited Faults

- Three phase faults (with or without earth connection)
- Two phase faults (with or without earth connection)
- Single phase to earth faults

Classification of Open Circuit Faults

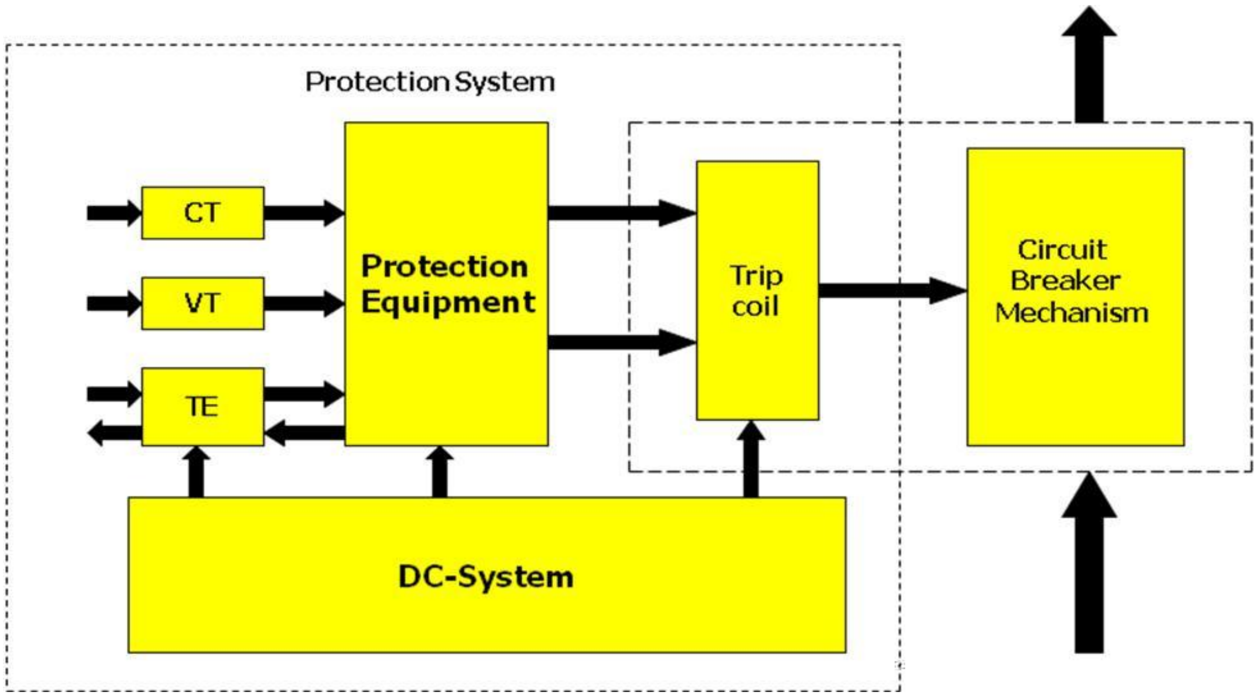
- Single Phase open Circuit
- Two phase open circuit
- Three phase open circuit

Consequences

- Damage to the equipment due to abnormally large and unbalanced currents and low voltages produced by the short circuits
- Explosions may occur in the equipments which have insulating oil, particularly during short circuits. This may result in fire and hazardous conditions to personnel and equipments
- Individual generators with reduced voltage in a power station or a group of generators operating at low voltage may lead to loss of synchronism, subsequently resulting in islanding.

- Risk of synchronous motors in large industrial premises falling out of step and tripping out.

The general layout of a protection system may be viewed as given in the following figure



1.3 Zones and types of Protection system

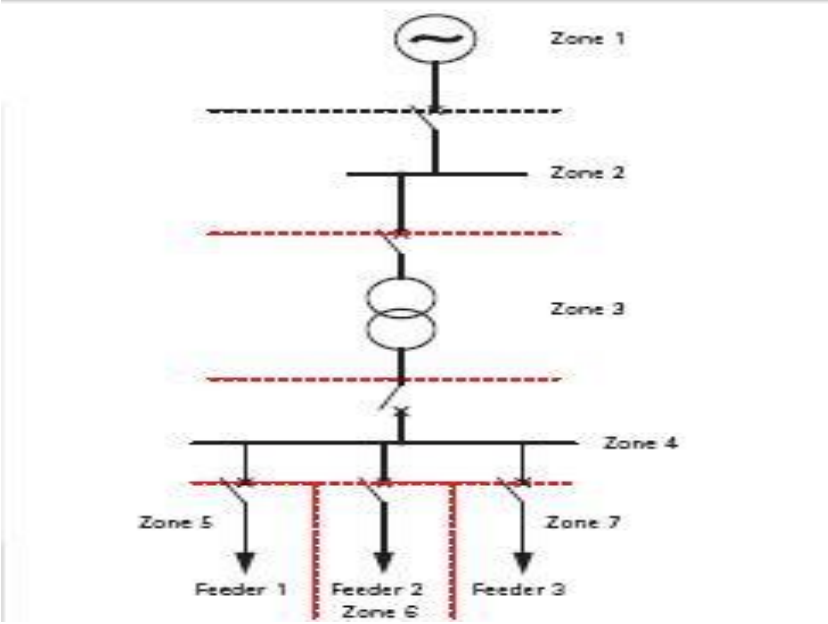
1.3.1 Zones of Protection system

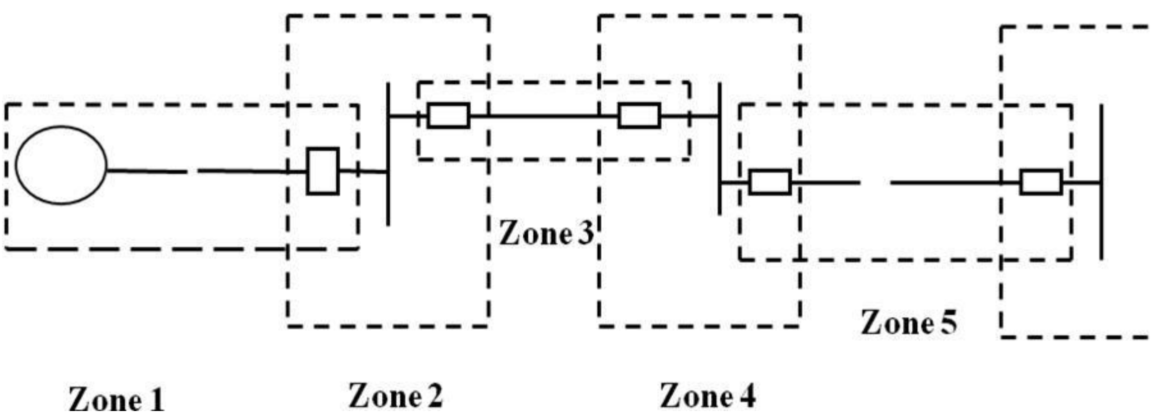
- An electric power system is divided into several zones of protection. Each zone of protection, contains one or more components of a power system in addition to two circuit breakers.

- When a fault occurs within the boundary of a particular zone, then the protection system responsible for the protection of the zone acts to isolate (by tripping the Circuit Breakers) every equipment within that zone from the rest of the system.

- The circuit Breakers are inserted between the component of the zone and the rest of the power system. Thus, the location of the circuit breaker helps to define the boundaries of the zones of protection.

- Different neighbouring zones of protection are made to overlap each other, which ensure that no part of the power system remains without protection. However, occurrence of the fault with in the overlapped region will initiate a tripping sequence of different circuit breakers so that the minimum necessary to disconnect the faulty element





1.3.2 Types of Protection (Primary and Back-up Protection)

1.3.2.1 Primary Protection

– The primary protection scheme ensures fast and selective clearing of any fault within the boundaries of the circuit element, that the zone is required to protect. Primary Protection as a rule is provided for each section of an electrical installation.

However, the primary protection may fail. The primary cause of failure of the Primary Protection system are enumerated below.

1. Current or voltage supply to the relay.
2. D.C. tripping voltage supply
3. Protective relays
4. Tripping circuit
5. Circuit Breaker

1.3.2.2 Back-up Protection

Back-up protection is the name given to a protection which backs the primary protection whenever the later fails in operation. The back-up protection by definition is slower than the primary protection system. The design of the back-up protection needs to be coordinated with the design of the primary protection and essentially it is the second line of defence after the primary protection system.

1.4 Protection System Requirements and some basic terminologies used

- The fundamental requirements for a protection system are as follows:

1.4.1 *Reliability*: It is the ability of the protection system to operate correctly. The reliability feature has two basic elements, which are *dependability* and *security*. The dependability feature demands the certainty of a correct operation of the designed system, on occurrence of any fault. Similarly, the security feature can be defined as the ability of the designed system to avoid incorrect operation during faults. A comprehensive statistical method based reliability study is required before the protection system may be commissioned. The factors which affect this feature of any protection system depends on some of the following few factors.

a) Quality of Component used

b) Maintenance schedule

c) The supply and availability of spare parts and stocks

d) The design principle

e) Electrical and mechanical stress to which the protected part of the system is subjected to.

1.4.2 *Speed*: Minimum operating time to clear a fault in order to avoid damage to equipment. The speed of the protection system consists primarily of two time intervals of interest.

a) *The Relay Time* : This is the time between the instant of occurrence of the fault to the instant at which the relay contacts open.

b) *The Breaker Time:* This is the time between the instant of closing of relay contacts to the instant of final arc extinction inside the medium and removal of the fault.

1.4.3 *Selectivity*: This feature aims at maintaining the continuity of supply system by disconnecting the minimum section of the network necessary to isolate the fault. The property of selective tripping is also known as “discrimination”. This is the reason for which the entire system is divided into several protective zones so that minimum protion of network is isolated with accuracy. Two examples of utilization of this feature in a relaying scheme are as follows

a) Time graded systems

b) Unit systems

1.4.4. Sensitivity: The sensitivity of a relay refers to the smallest value of the actuating quantity at which the relay operates detecting any abnormal condition. In case of an overcurrent relay, mathematically this can be defined as the ratio between the short circuit fault current (I_S) and the relay operating current (I_O). The value of I_O , should not be too small or large so that the relay is either too sensitive or slow in responding.

1.4.5 Stability: It is the quality of any protection system to remain stable within a set of defined operating scenarios and procedures. For example the biased differential scheme of differential protection is more stable towards switching transients compared to the more simple and basic Merz Price scheme in differential protection

1.4.6 Adequacy: It is economically unviable to have a 100% protection of the entire system in concern. Therefore, the cost of the designed protection system varies with the criticality and importance of the protected zone. The protection system for more critical portions

is generally costly, as all the features of a good protection system is maximized here. But a small motor can be protected by a simple thermally operated relay, which is simple and cheap. Therefore, the cost of the protection system should be adequate in its cost.

1.4.7 Some basic terminologies used in protection system

Some basic terminologies commonly used in the protection system are enlisted below.

i) Measuring Relay ii) Fault Clearing Time iii) Auxilliary relay iv) Relay Time v) Pick up value vi) Reset Value vii) Drop out viii) Reach (under and over reaches) ix) Relay Burden x) Unit/ Non unit protection xi) All or Nothing relay

1.5 Classification and construction of relays

1.5.1 Classification

Protection relays can be primarily classified in accordance with their construction, the actuating signal and application and function

1.5.1.1 According to the Construction principle

Depending upon the principle of construction, the following four brad categories are found.

- Electromechanical
- Solid State
- Microprocessor
- Numerical

1.5.1.2 According to the actuating signals

The actuating signal may be any of the following signals including a numbers of different combinations of these signals depending upon whether the designed relay require a single or multiple inputs for its realization.

- Current
- Voltage
- Power
- Frequency
- Temperature
- Pressure
- Speed
- Others

1.5.1.3 Function

The functions for which the protection system is designed classify the relays in the following few categories.

- Directional Over current
- Distance

- Over voltage
- Differential
- Reverse Power
- Others

It is important to notice that the same set of input actuating signals may be utilized to design to relays having different function or application. For example, the voltage and current input relays can be designed both as a *Distance* and/ or a *Reverse Power* relay.

Electromechanical relays

These relays are constructed with electrical, magnetic & mechanical components & have an operating coil & various contacts,& are very robust & reliable. Based on the construction, characteristics, these are classified in three groups.

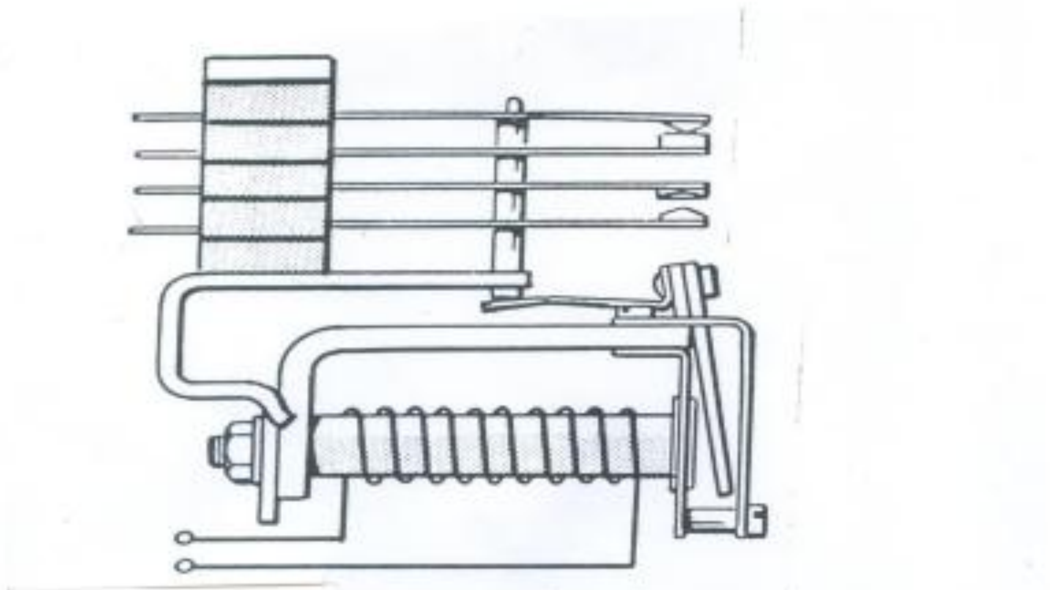
Attraction relays

Attraction relays can be AC & DC and operate by the movement of a piece of iron when it is attracted by the magnetic field produced by a coil. There are two main types of relays:

1. The attracted armature type
2. Solenoid type relay

Attracted armature relays

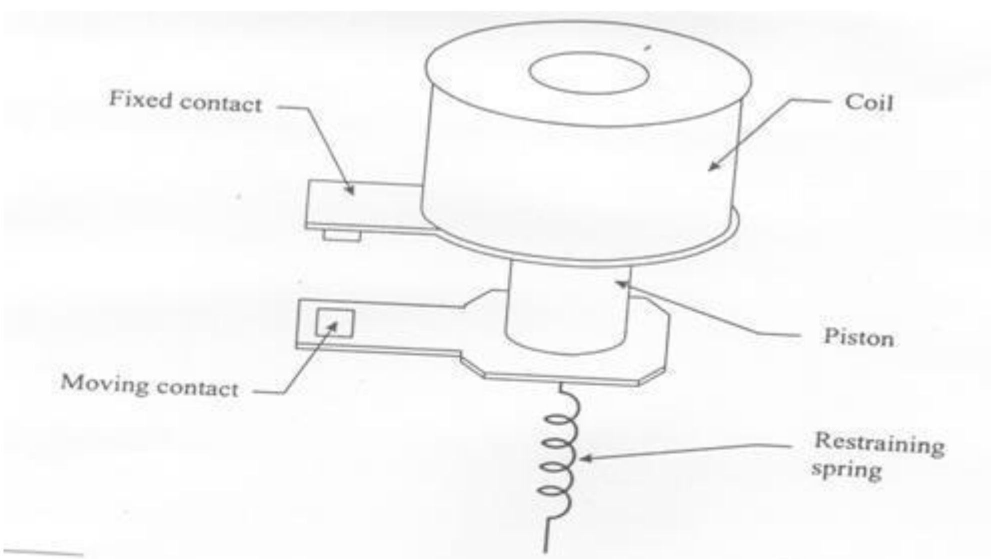
- Consists of a bar or plate (made of iron) that pivots when it is attracted towards the coil.
- The armature carries the moving part of the contact ,which is closed or opened, according to the design, when the armature is attracted to the coil.



Hinged armature relay

Solenoid type relays

In this a plunger or a piston is attracted axially within the field of the solenoid. In this case, the piston carries the moving contacts.



Solenoid-type relay

The force of attraction = $K_1 I^2 - K_2$

Where, K_1 depends on

- The number of turns of the coil
- The air gap
- The effective area
- The reluctance of the magnetic circuit

K_2 is the restraining force, usually produced by spring

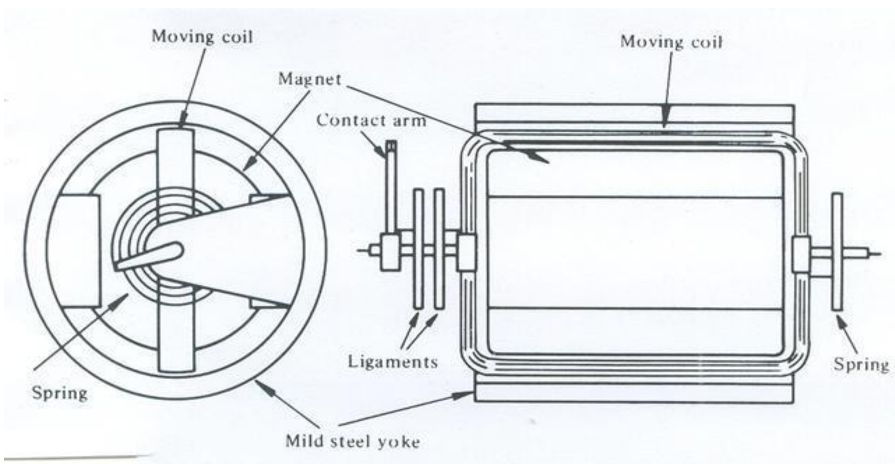
For threshold or balanced condition, the resultant force is zero.

$$K_1 I^2 = K_2 \qquad I = \sqrt{\left(\frac{K_1}{K_2}\right)}$$

In order to control the value of current at which relay operates, the parameters K_1 and K_2 may adjusted. Attraction relays effectively have no time delay and are widely used when instantaneous operation is required.

Relays with movable coils

This type of relay consists of a rotating movement with a small coil suspended or pivoted with the freedom to rotate between the poles of a permanent magnet. The coil is restrained by two special springs which also serve as connections to carry the current to the coil.



Moving-coil relay for protection schemes

The torque produced in the coil is

$$T = BlaNi$$

Where, T= Torque

B= flux density

l= length of the coil

a= distance between the two sides of the coil

i=current flowing through the coil

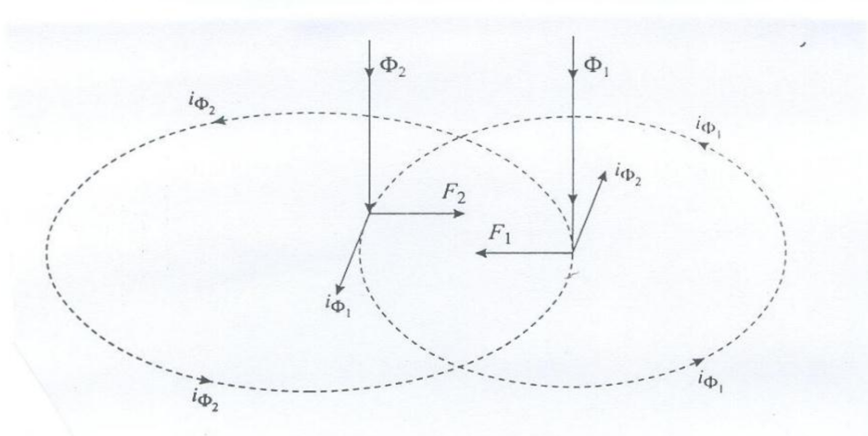
N=number of turns in the coil

- The relay has inverse type characteristic

Induction relays

- An induction relay works only with AC
- It consists of an electromagnetic system Which operates on a moving conductor, generally in the form of a DISC or CUP

Production of actuating torque



Electromagnetic forces in induction relays

Various quantities are shown at instant when

- Both fluxes are directed downward
- Are increasing in

  magnitude Let

  $\phi_1(t) = \phi_{m1} \sin(\omega t)$

  $\phi_2(t) = \phi_{m2} \sin(\omega t + \theta)$

  It may be assumed with negligible error that the paths in which rotor current flow have negligible self inductance.

$$F = F_2 - F_1$$

$$= \alpha\, \phi_2(t)\, i_{\phi 1}(t) - \phi_1(t)\, i_{\phi 2}(t)$$

$$= \alpha\, \phi_{m1}\phi_{m2}[\sin(\omega t + \theta)\cos(\omega t) - \sin(\omega t)\cos(\omega t + \theta)]$$

$$= \alpha\, \phi_{m1}\phi_{m2} \sin\theta$$

Since sinusoidal flux waves are assumed, we may substitute the rms values of the fluxes for the crest values in the above equation.

$$F \alpha \phi_{m1}\phi_{m2} \sin\theta$$

- It may be noted that the net force is same at every instant.
- The net force is directed from the point where the leading flux process the rotor towards the point where the lagging flux pierces the rotor.
- Actuating force is produced in the presence of out of phase fluxes.

- Maximum force is produced when $\theta=90^{o}$

Classification of induction relays

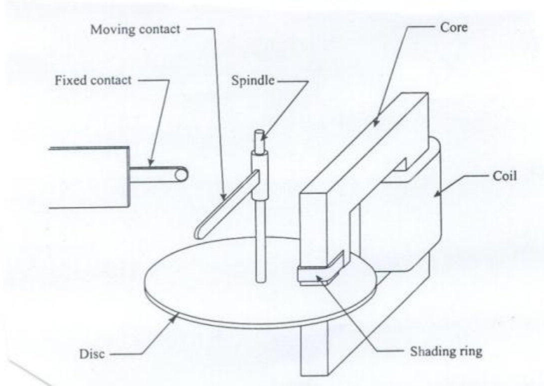
1. Shaded pole relay

2. Watthour- meter type relay

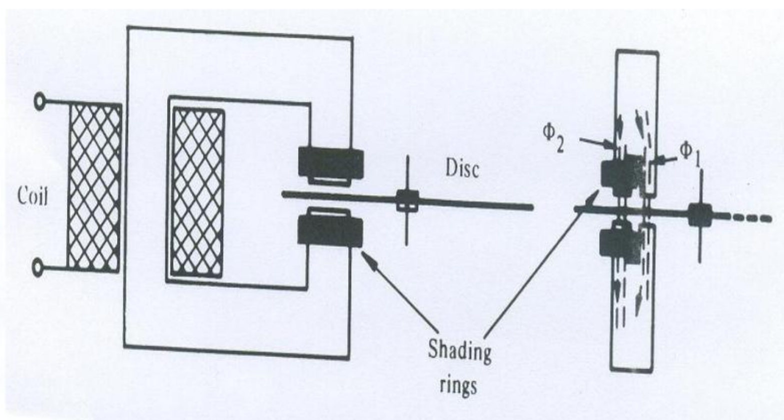
3. Cup type relay

The air gap flux produced by the current flowing in a single coil is split into two out of phase components by a so called „Shading Ring" generally of copper, that encircles part of the pole face of each pole at the air gap.

- The shading ring may be replaced by coils if control of operation of the shaded pole relay is desired.
- The inertia of the disc provides the time delay characteristics.



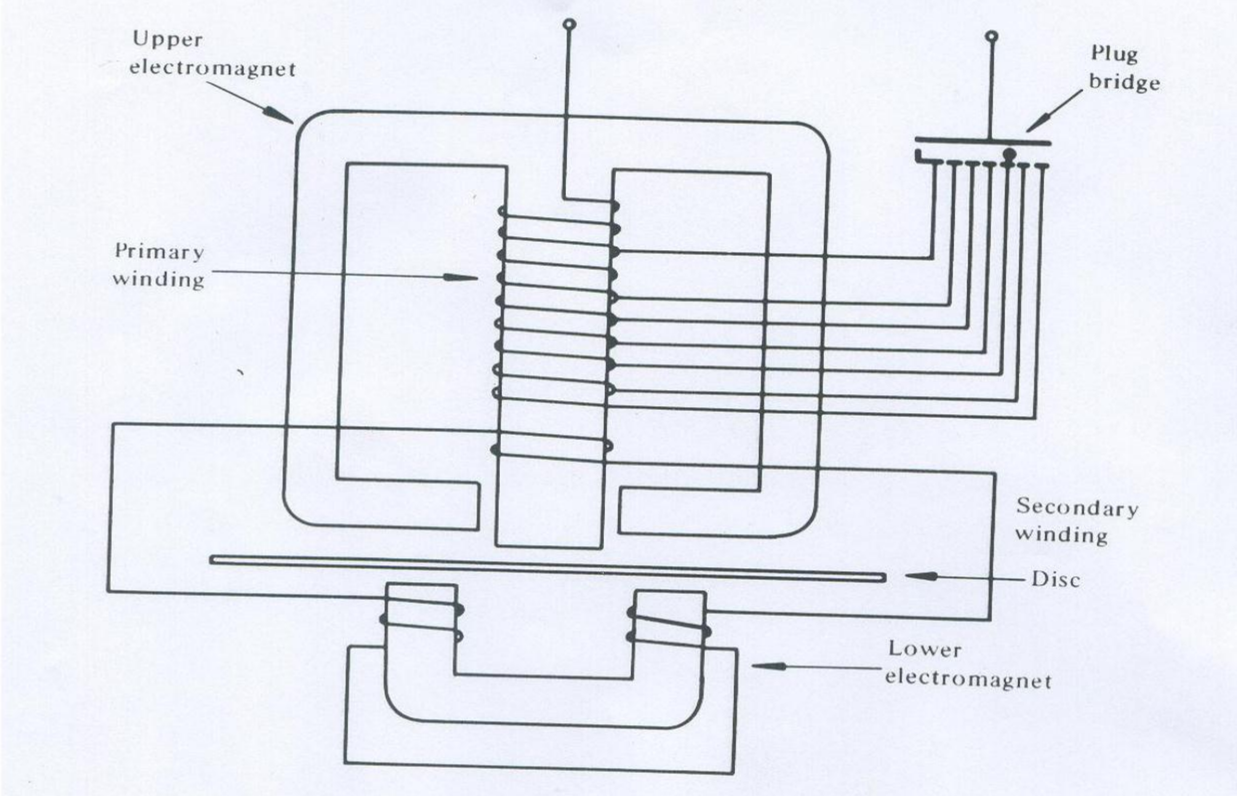
Shaded-pole relay



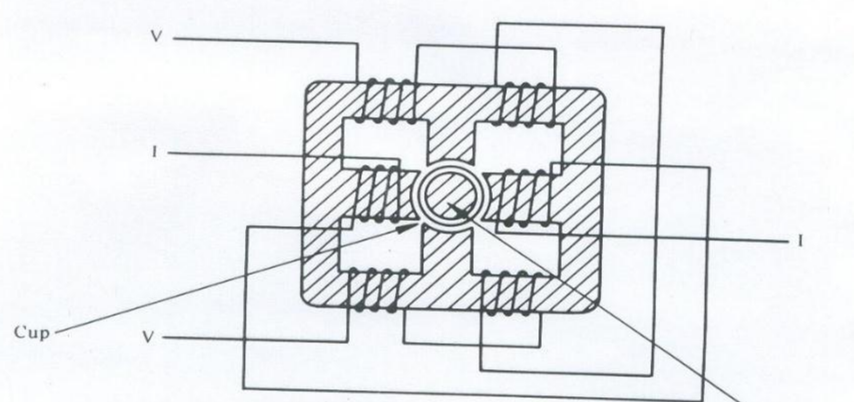
Shaded-pole induction-disc relay

Watt hour –meter structure

- This structure gets its name from the fact that it is used in watt hour meters.
- As shown in the top figure below, it contains two separate coils on two different magnetic circuit, each of which produces one of two necessary fluxes for driving the rotor, which is also a disc



Winding arrangement



Four pole cup relay

Induction-cup

- This type of relay has a cylinder similar to a cup which can rotate in the annular air gap between the poles & the fixed central core. The figure is shown above.
- The operation of this relay is similar to that of an induction motor with salient poles for the windings of the stator.
- The movement of the cup is limited to a small amount by the contact & the stops.
- A special spring provides restraining torque.
- The cup type of relay has a small inertia & is therefore principally used when high speed operation is required, for example in instantaneous units.

General Torque equation of Relay

Before understanding about different other relays, it is first necessary to know the general torque equation that defines any relay. The following equation defines torque in general.

$$T = K_1 I^2 + K_2 V^2 + K_3 VI \, Cos(\theta - \tau) + K_4$$

Where, θ is the power factor angle and τ is the angle of maximum torque.

As seen from the equation, the component of torques may be proportional to current, voltage, power and combination of the three quantities. The constant K_4 is meant for the spring constant of the relay. Depending upon the type of relay, the one or several of the four constants K_1–K_4 are either zero or non zero. In the subsequent discussions this will be elaborated when different types of relays are discussed.

1.6 Overcurrent Relays

- Protection against excess current was naturally the earliest protection systems to evolve
- From this basic principle has been evolved the graded over current system, a discriminate fault protection.
- “over current” protection is different from “over load protection”.

- Overload protection makes use of relays that operate in a time related in some degree to the thermal capability of the plant to be protected.
- Over current protection, on the other hand, is directed entirely to the clearance of the faults, although with the settings usually adopted some measure of overload protection is obtained.
- In terms of the general torque equation the over current relay has both constants K_2 and K_3 equal to zero. Therefore, the equation becomes

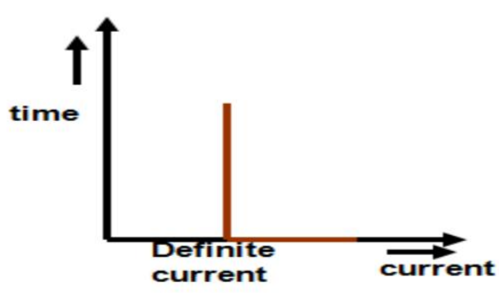
$$T = K_1 I^2 + K_4$$

1.6.1 Types of over current relays

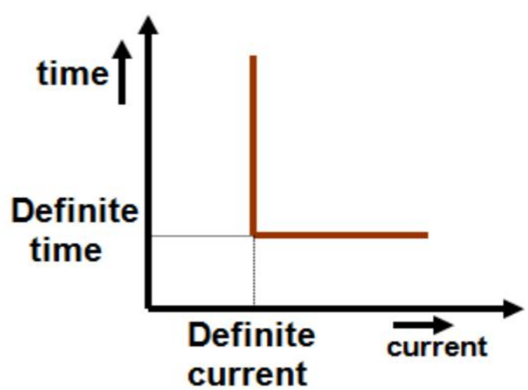
- Based on the relay operating characteristics , overcurrent relays can be classified into three groups
  - Definite current or instantaneous
  - Definite time
  - Inverse time

DEFINITE-CURRENT RELAYS

- This type of relay operates instantaneously when the current reaches a predetermined value.



DEFINITE TIME CURRENT RELAYS



- This type of relay operates after a definite time when the current reaches a pre-determined value.

1.7 Directional Over Current Relays

1. When fault current can flow in both the directions through the relay, at its location. Therefore, it is necessary to make the relay respond for a particular defined direction, so that proper discrimination is possible. This can be achieved by introduction of directional control elements.

2. These are basically power measuring devices in which the system voltage is used as a reference for establishing the relative phase of the fault current.

Basically, an AC directional relay can recognize certain difference in phase angle between two quantities, just as a D.C. directional relay recognize difference in polarity

1.7.1The polarizing quantity of a directional relay

1. It is the reference against which the phase angle of the other quantity is compared. Consequently the phase angle of the polarizing quantity must remain fixed when other quantity suffers wide change in phase angle.

2. The voltage is chosen as the “polarizing” quantity in the current-voltage induction type directional relay.

3. Four pole induction cup construction is normally used.

1.8 Distance relay

Distance relay is used for the protection of transmission line & feeders

In a distance relay, instead of comparing the local line current with the current at far end of line, the relay compares the local current with the local voltage in the corresponding phase or suitable components of them

1.8.1Principle of operation of distance relay

1. The basic principle of measurement involves the comparison of fault current seen by the relay with the voltage at relaying point; by comparing these two quantities.

2. It is possible to determine whether the impedance of the line up to the point of fault is greater than or less than the predetermined reach point impedance

There are two types of torques

1. Restraining torque

$$T_r \alpha V_F^2$$

2. Operating torque

$$T_0 \alpha I^2_F$$

The relay trips when T_0 greater than T_r

$$KI_F^2 > V_F^2$$

$$\frac{V_F}{I_F} < \sqrt{K}$$

The constant K depends on the design of the electromagnets.

1.8.2 Types of distance relay

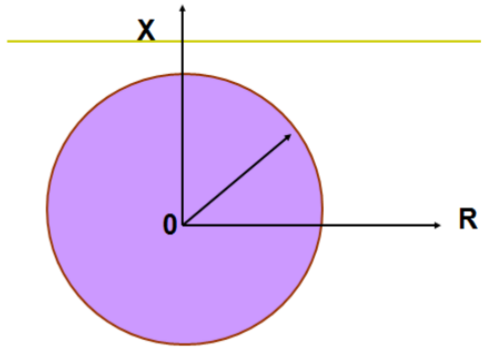
Distance relays are classified depending on their operating characteristic in the R-X plane

- Impedance Relay
- Mho Relay
- Reactance Relay

IMPEDANCE RELAY:

The torque equation T, for such a relay the current actuates the operating torque and the voltage actuates the restraining torque, with the usual spring constant K_4.

$$T = K_1I^2 + K_2V^2 + K_4$$



Considering K_2 to be negative (as it produces the restraining torque) and neglecting the torque component due to spring, the equation represents a circle in the R-X plane.

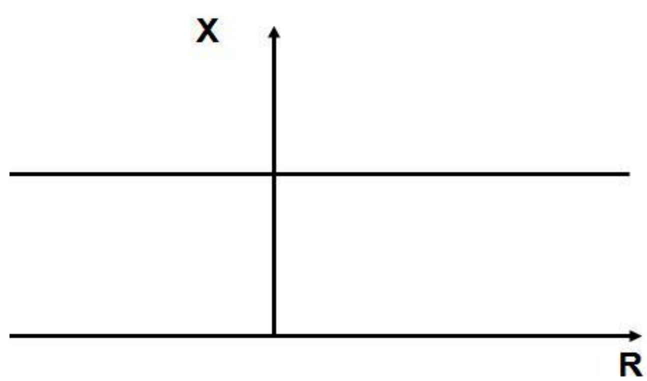
DISADVANTAGE OF IMPEDANCE RELAY

1. It is not directional.
2. It is affected by the Arc resistance
3. It is highly sensitive to oscillations on the power system, due to large area covered by its circular characteristic

REACTANCE RELAY

The reactance relay is basically a directional restrained overcurrent relay. Therefore, the actuating quantity is current and the equation becomes as follows, where the constant K_2 is zero.

$$T = K_1 I^2 + K_3 VI \, Cos(\theta - \tau) + K_4$$



In the above equation, constant K_1 is positive as the current produces operating torque and K_3 is negative as the power direction produces restraining torque. In the above equation the angle τ is considered as 90^0. So the equation derives to

$$T = K_1 I^2 - K_3 VI \, Cos(\theta - 90) + K_4 \geq 0$$

Simplified to

$\frac{V}{I} Sin\theta \leq \frac{K_1}{K_3}$, which gives $ZSin\theta = X \leq \frac{K_1}{K_3}$ in the R-X plane. The characteristics resembles a horizontal line parallel to the R-axis with constant X value. The portion below the line gives the operating zone of the relay.

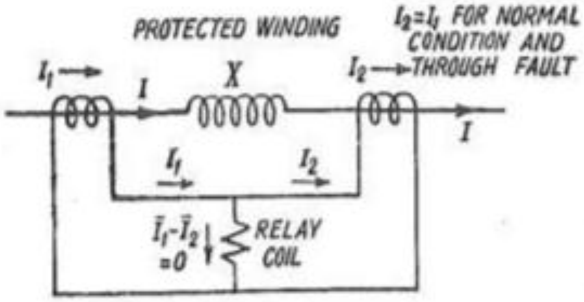
1. The reactance relay is designed to measure only reactive component of the line reactance.
2. The fault resistance has no affect on the reactance relay

1.9 Differential Relay

One of the most prevalent and successful method of protecting a circuit is to arrange relays to compare the currents entering and leaving it, which should be the same under normal conditions and during an external fault. Any difference current must be flowing in to a fault within the protected circuit

1.9.1Principle of circulating current differential (MERZ-PRIZE) protection

The figure below illustrates the principle of differential protection of generator and transformer, X is the winding of the protected machine. Where there is no internal fault, the current entering in X is equal in phase and magnitude to current leaving X. The CT's have such a ratio that during the normal conditions or for external faults (Through Faults) the secondary current of CT's are equal. These current say I_1 and I_2 circulate in the pilot wire. The polarity connections are such the current I_1 and I_2 are in the same direction of pilot wire during normal condition or external faults. Relay operation coil is connected at the middle of pilot wires. Relay unit is of over current type.



For Through Fault

Fig. 1 (*a*). Principle of circulating current relay of generators, transformers.

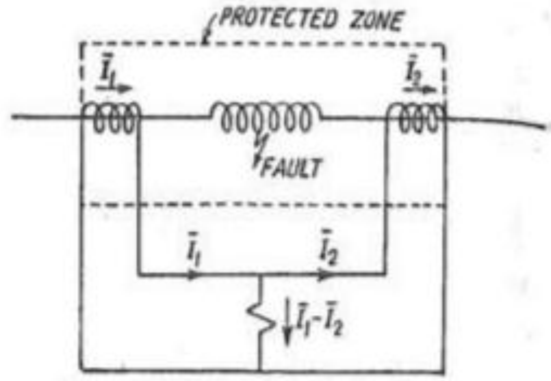


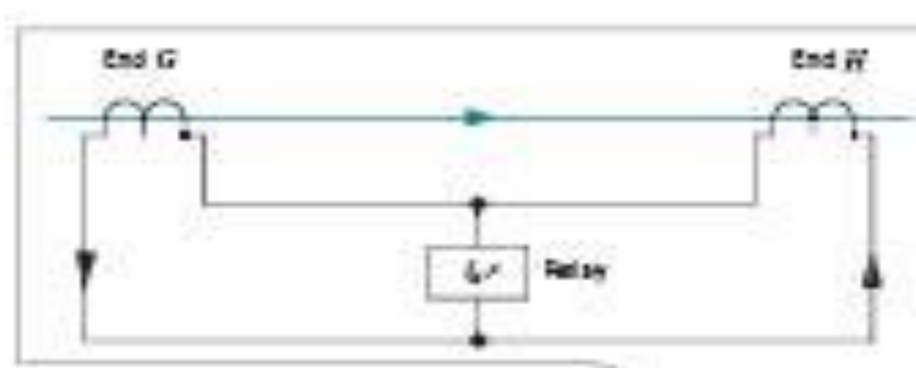
Fig. 1 (*b*). Internal Fault : $I_1 - I_2 \neq 0$.

During normal condition and external fault the protection system is balanced and the CT's ratios are such that secondary currents are equal. These current circulate in pilot wires. The vector differential current I_1- I_2 which flow through the relay coil is zero.

I_1-I_2 = 0 (normal condition or external faults)

This balance is disturbed for internal faults. When fault occurs in the protected zone, the current entering the protected winding is no more equal to the leaving the winding because some current flows to the fault. The differential I_1-I_2 flows through the relay operating coil and the relay operates if the operating torque is more than the restraining torque.

The current I_1 and I_2 circulate in the secondary circuit. Hence CT's does not get damaged. Polarities of CT's should be proper, otherwise the currents I_1 and I_2 would add up even for normal condition and mal operate the relay.



1.9.2 Differential Protection current balance

- When this system is applied to electrical equipment (Generator stator windings, Transformer, Bus bars etc.) it is called differential current protection.
- When it is applied to lines and cables it is called pilot differential protection because pilot wires or an equivalent link or channel is required to bring the current to the relay from the remote end of the line.

The CTs at both ends of the protected circuit connected so that for through load or through fault conditions current circulates between the interconnected CTs. The over-current relay is normally connected across equipotential points and therefore doesn‟t operate.

- Circulating current balance methods are widely used for apparatus protection where CTs are within the same substation area and interconnecting leads between CTs are short (e.g. generator stator windings, Transformer, Bus bars etc.)
- The circulating current balance method is also called longitudinal differential protection or Merz-Price differential protection system.
- The current in the differential relay would be proportional to the phasor difference between the currents that enter and leave the protected circuit. If the current through the relay exceeds the pick-up value, then the relay will operate.

1.9.3 Demerits of a Differential Relay(Merz Price Scheme)

1. **Unmatched characteristics of C.T.s** : Though the saturation is avoided, there exist difference in the C.T. characteristics due to ratio error at high values of short circuit currents. This causes an appreciable difference in the secondary currents which can operate the relay. So the relay operates for through external faults.

This difficulty is overcome by using percentage differential relay. In this relay, the difference in current due to the ratio error exists and flows through relay coil. But at the same time the average current ($I_1 + I_2/2$) flows through the restraining coil which produces enough restraining torque. Hence relay becomes inoperative for the through faults.

2. **Ratio change due to tap change**: To alter the voltage and current ratios between high voltage and low voltage sides of a power transformer, a tap changing equipment is used. This is an important feature of a power transformer. This equipment effectively alters the turns ratio. This causes unbalance on both sides. To compensate for this effect, the tapping can be provided on C.T.s also which are to be varied similar to the main power transformer. But this method is not practicable.

The percentage differential relays ensure relays ensure the stability with respect to the amount of unbalance occurring at the extremities of the tap change range.

3. **Difference in lengths of pilot wires**: Due to the difference in lengths of the pilot wires on both sides, the unbalance condition may result. The difficulty is overcome by connecting the adjustable resistors in pilot wires on both sides. These are called balancing resistors. With the help of these resistors, equipotential points on the pilot wires can be adjusted. In percentage differential relays the taps are provided on the operating coil and restraining coil to achieve an accurate balance.

4. **Magnetizing current inrush**: When the transformer is energized, the condition initially is of zero induced E.m.f. A transient inflow of magnetizing current occurs in to the transformer. This current is called magnetizing inrush current. This current may be as great as 10 times the full load current of the transformer. This decays very slowly and is bound to operate differential protection of the transformer falsely, because of the temporary difference in magnitude of the primary and secondary currents.

The factors which affect the magnitude and direction of the magnetizing inrush current can be one of the following reasons.

a. Size of the transformer.

b. Size of the power system

c. Type of magnetic material used for the core.

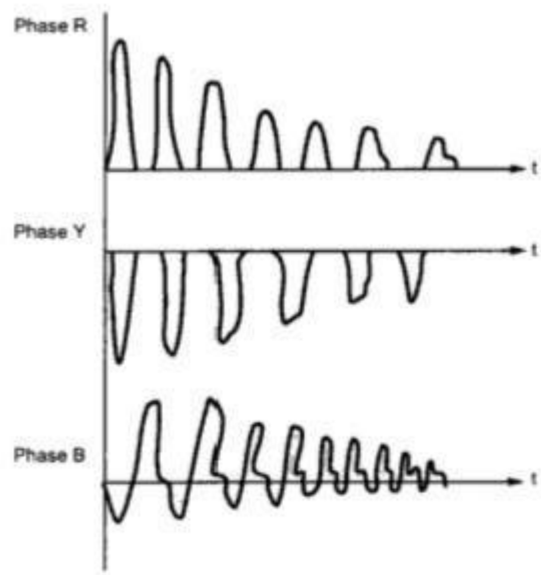
d. The amount of residual flux existing before energizing the transformer.

e. The method by which transformer is energized.

If the transformer is energized when the voltage wave is passing through zero, the magnetizing current inrush is maximum. At this instant, the current and flux should be maximum in highly inductive circuit. And in a half wave flux reversal must take place to attain maximum value in the other half cycles. If the residual flux exists, the required flux may be in same or opposite direction. Due to this magnetizing current inrush is less or more. If it is more, it is responsible to saturate the core which further increases its component.

This current decays rapidly for first few cycles and then decays slowly. The time constant L/R of the circuit is variable as inductance of circuit varies due to the change in permeability of the core. The losses in the circuit damp the inrush currents. Depending on the size of the transformer, the time constant of inrush current varies from 0.2 sec to 1 sec.

The waveforms of magnetizing inrush current in three phases are shown in the figure below.



1.9.4 Biased or per cent Differential Relay

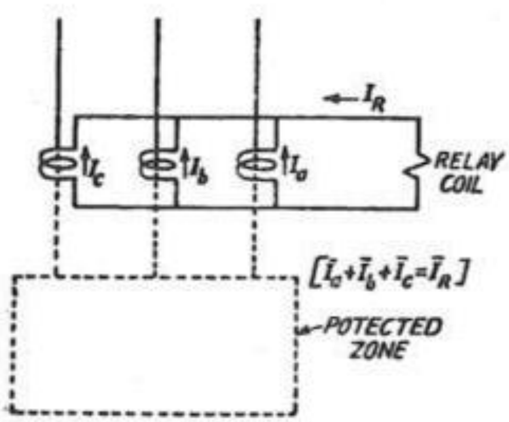
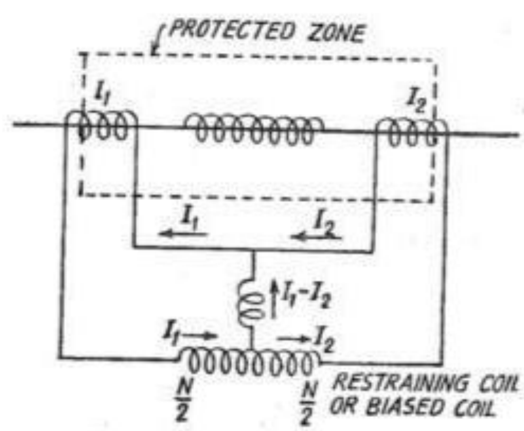


Fig. 2. Differential Protection of 3-phase circuit.



$$\text{A.T.} = \left(\frac{I_1 + I_2}{2}\right)N$$

Fig. 3. Per cent Differential Relay. (Biased Differential Relay.)

The reason for using this modification in the circulating current scheme, is to overcome the trouble arising out of differences in CT ratios for high values of external short circuit currents. The percentage differential relay has an additional restraining coil connected in the pilot wire as shown in the above figure.

In this relay the operating coil is connected to the mid-point of the restraining coil. The restraining torque therefore is proportional to the sum of ampere turns in its two halves, i.e $(I_1N/2) + (I_2N/2)$ which gives the average restraining current of $(I_1 + I_2)/2$ in N turns. For external faults both I_1 and I_2 increase and thereby the restraining torque increases which prevents the mal-operation. The operating characteristic of the relay is given in the figure below.

The ratio of differential operating current to average restraining current is a fixed percentage and the value of which decides the nature of the characteristics. Therefore, the relay is also called *'percentage differential relay'*. The relay is also called *'Biased differential relay*' because the restraining coil (bias coil) biases the main flux by some additional flux.

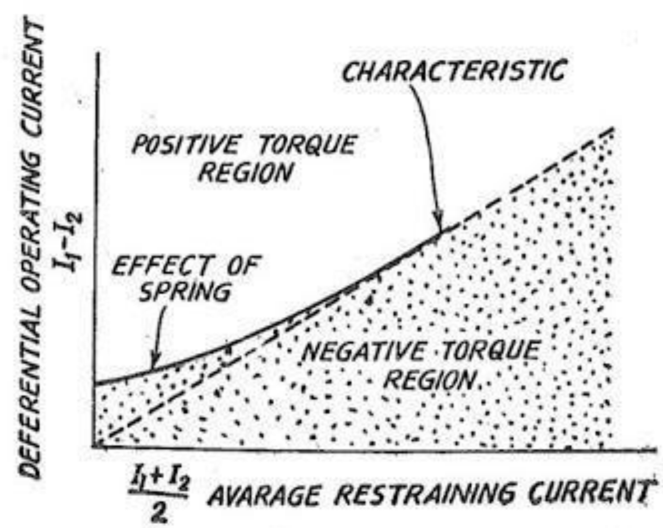


Fig. 4. Operating characteristic of differential relay.

The percentage of biased differential relay has a rising single pick up characteristic. As the magnitude of through current increases, the restraining current decreases.

1.9.5 Setting of differential relay:

The circulating current differential relay has tow principle settings namely,

- Setting of operating coil circuit.
- Setting of restraining coil circuit.

Setting of operating coil circuit (Basic setting). The percentage setting of (Basic setting) of operating coil circuit is defined as the ratio:

$$\%\text{Basic Setting} = \frac{\text{Smallest current in oprerating coil to cause operation}}{\text{Rated current of the operating coil}} \times 100$$

(when the current in restraining coil is zero)

Setting of restraining coil circuit (pick up value). It is defined as the ratio :

$$= \frac{\text{Current in operating coil for causing operation}}{\text{Current in restraining coil}} \times 100$$

$$\%\text{Pick-up Value} = \frac{I_1 - I_2}{(I_1 + I_2)/2} \times 100$$

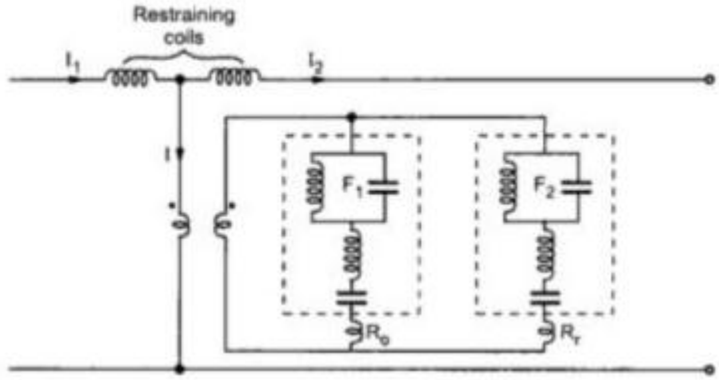
While determining this setting the factors which needs to be considered include

- CT Errors -Tap-changing
- Resistance of pilot wires - Stability of through faults

In case of power transformers, percentage basic setting is of the order of 20 % and percentage pick-up value of the order of 25%.

1.9.6 Harmonic restraint Feature in Differential Relay

Thus more the harmonic contents in the inrush current, more is the restraining torque and the relay does not operate. So use of percentage differential protection rather than simple differential protection is preferred. The circuit used to compensate the effect of magnetizing current using harmonic restraint method is shown in the figure below.


Restraining coils
I_1
I_2
I
F_1
F_2
R_o
R_r

CH-6

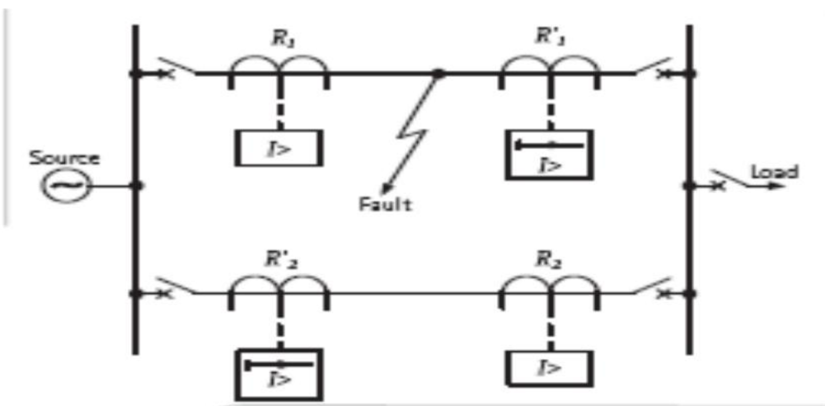
PROTECTION OF FEEDERS

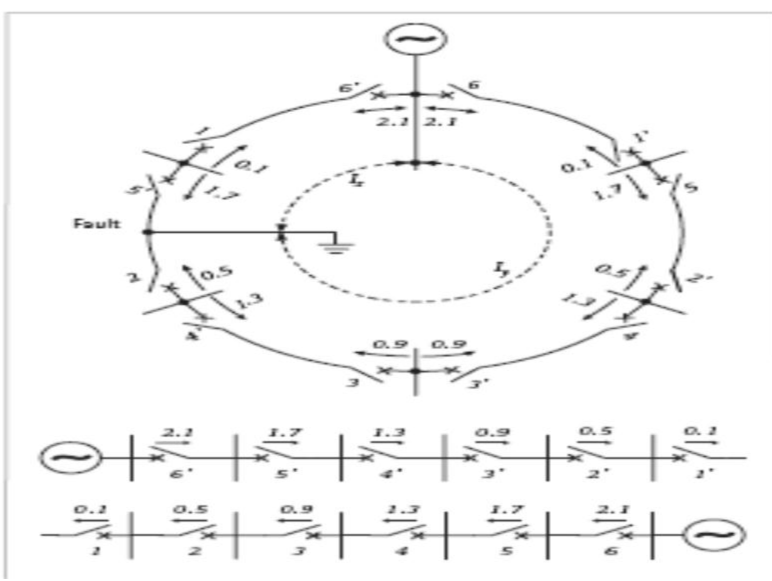
2.1 Over current and earth fault protection

It is customary to have two elements of over current and one element of earth fault protection system in the most elementary form of protection of three phase feeders. Different types of feeders employ the over current protection along with the directional relay so that proper discrimination of an internal fault is possible. Some examples are illustrated below.

2.1.1Application of directional relays to parallel feeders

It may be seen from the below given parallel feeders that the relays placed at the load side of both the lines use directional element which respond to a direction away from the bus bars. Similarly, the relays placed at the source side do not require any directional element.

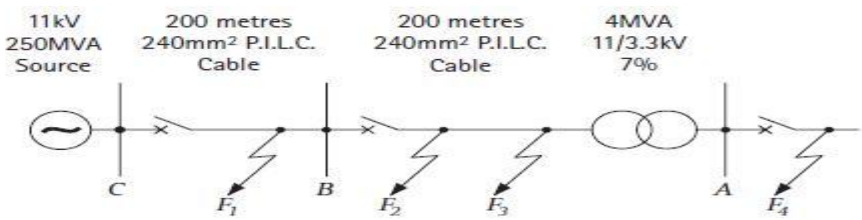




2.1.2Application of directional relays to ring mains

A similar concept of discrimination is also utilized in the below given ring main feeder and a feeder fed from both the sides. It can be observed that relays placed near the bus connecting the sources, don not have any directional feature, where as the rest of the buses, respond to a direction always away from the source. It is good practice to locate a fault any where among different sections of the feeders and check whether that particular section only is isolated without disrupting the power flow in other sections.

2.1.3Over current protection radial system



2.2 Pilot wire schemes for feeder protection

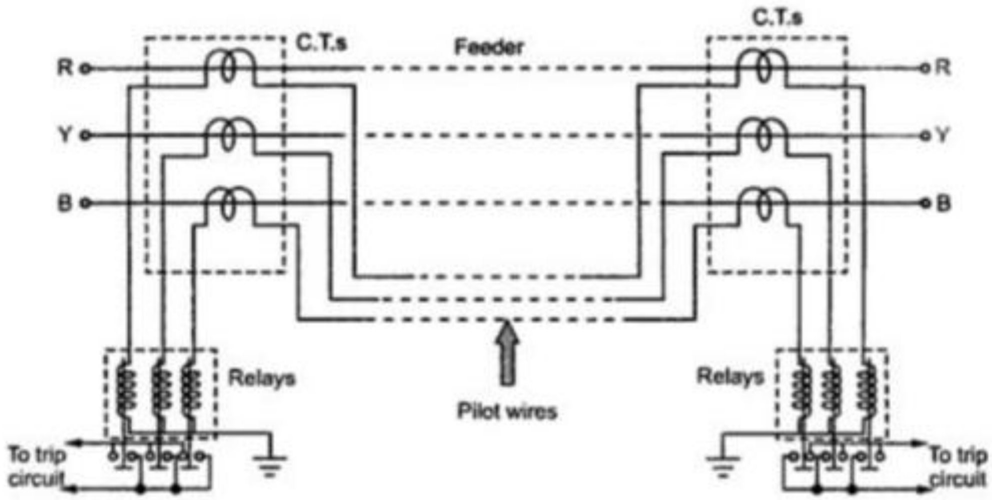
In differential protection scheme, the current entering at one end of the line and leaving from other end of the line is compared. The pilot wires are used to connect the relays. Under normal working condition, the two currents at both ends are equal and pilot wires do not carry any current, keeping relays inoperative. Under an internal fault condition, the two currents at both the ends are no longer same, this causes circulating current flow through pilot wires and makes the relay to trip.

The various schemes used with this method of protection are,

1. Merz-Price Voltage Balance System
2. Translay Scheme

2.2.1 *Merz-Price Voltage Balance System*

The figure below shows Merz-Price voltage balance system used for the three phase feeders.



Under normal condition, current entering the line at one end is equal to current leaving from the other end. Therefore, equal and opposite voltages are induced in the secondaries of C.T.s. at the two ends resulting in no current flow, through the relay.

Under fault condition, two currents at the two ends are different. Thus the secondary voltages of both the end C.T.s differ from each other. This circulates a circulating current through the pilot wires and the relays. Thus the relays trip the circuit breakers to isolate the faulty section.

The **advantages** of this method are as follows

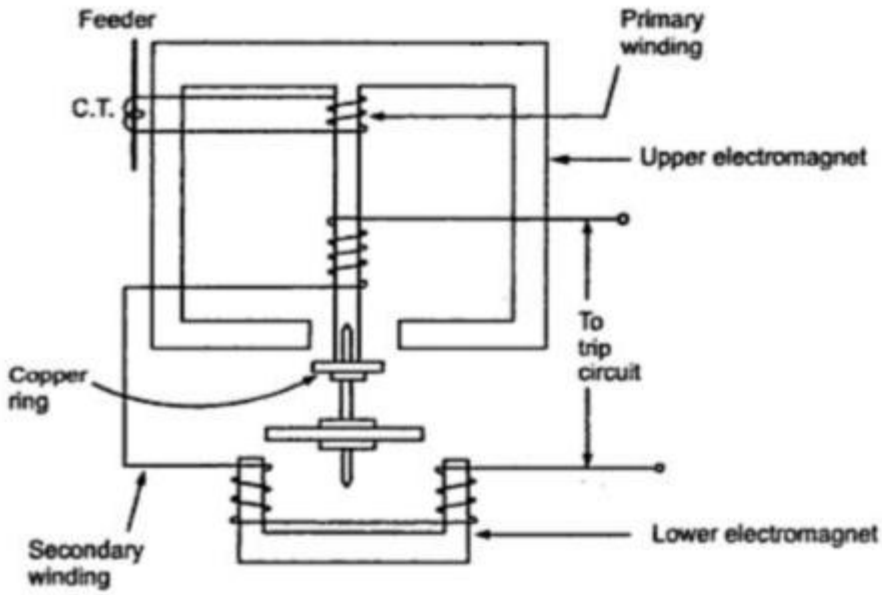
1. It can be used for parallel as well as ring main system.
2. It provides instantaneous protection to ground faults.

The **limitations** of this method are as follows

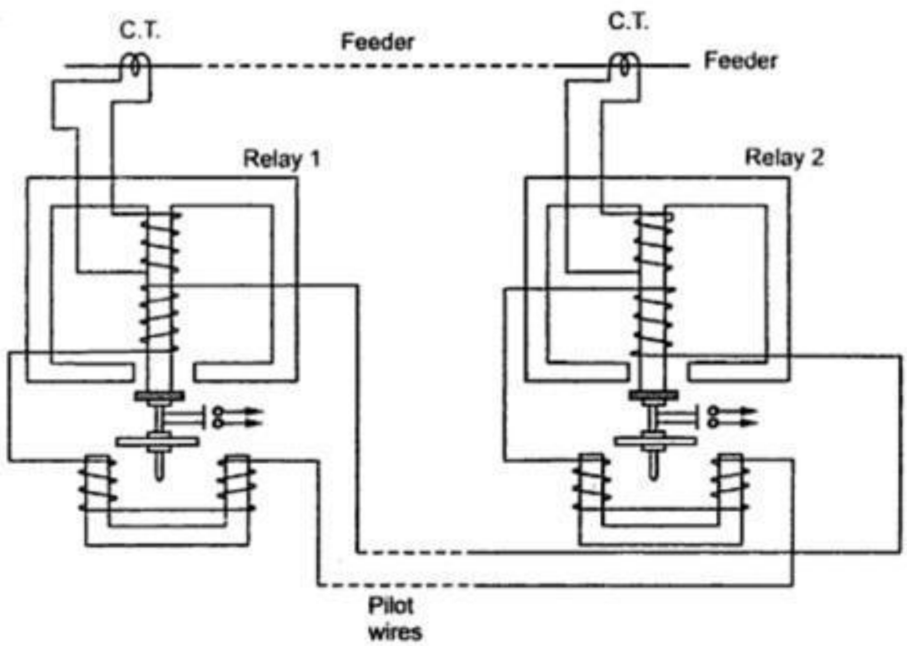
1. The C.T.s used must match accurately.
2. The pilot wires must be healthy without discontinuity.
3. Economically not suitable as the cost is high due to long pilot wires.
4. Due to long pilot wires, capacitive effects adversely bias the operation of the relays.
5. The large voltage drop in the pilot wires requiring better insulation.

2.2.2 *Translay Scheme*

The translay relay is another type of differential relay. The arrangement is similar to overcurrent relay but the secondary winding is not closed on itself. Additionally copper ring or copper shading bands are provided on the central limb as shown in the figure below.



In this scheme, two such relays are employed at the two ends of feeder as shown in the figure below.



The secondaries of the two relays are connected to each other using pilot wires. The connection is such that the voltages induced in the two secondaries oppose each other. The copper coils are used to compensate the effect of pilot wire capacitance currents and unbalance between two currents transformers.

Under normal operating conditions, the current at the two ends of the feeder is same. The primaries of the two relays carry the same currents inducing the same voltage in the secondaries. As these two voltages are in opposition, no current flows through the two secondaries circuits and no torque is exerted on the discs of both the relays.

When the fault occurs, the currents at the two ends of the feeder are different. Hence unequal voltages are induced in the secondaries. Hence the circulating current flows in the secondary circuit causing torque to be exerted on the disc of each relay. But as the secondaries are in opposition, hence torque in one relay operates so as to close the trip circuit while in other relay the torque restricts the operation. Care must be taken so that, at least one relay operates under the fault condition.

Role of copper ring: Mainly relays may operate because of unbalance in the current transformers. The copper rings are so adjusted that the torque due to current induced in the copper ring due to primary winding of relay is restraining and do not allow the disc to rotate. It is adjusted just to neutralize the effect of unbalance existing between the current transformers. The copper rings also neutralize the effect of pilot capacitive currents. Though the feeder current is same at two ends, a capacitive current may flow in the pilots. This current leads the secondary voltage by 90^{o}. The copper rings are adjusted such that no torque is exerted on the disc, due to such capacitive pilot currents. Therefore in this scheme the demerits of pilot relaying scheme is somewhat taken care of.

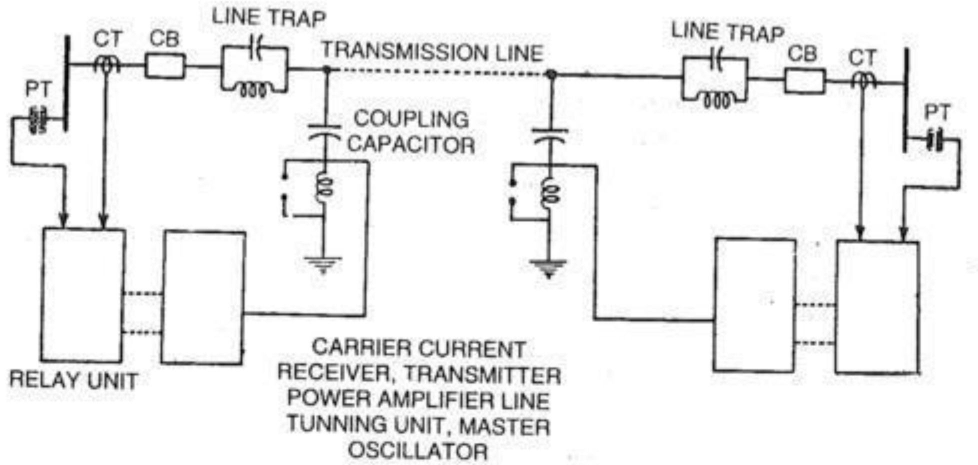
The **advantages** of this scheme are,

1. Only two pilot wires are required.
2. The cost is very low.
3. The current transformers with normal design can be employed.
4. The capacitive effects of pilot wire currents do not affect the operation of the relays.

2.3 Carrier Current unit protection system

2.3.1The basic block diagram and various components

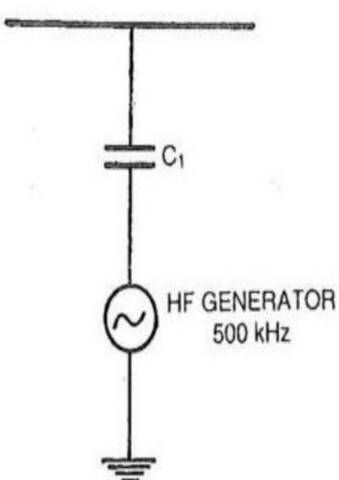
The



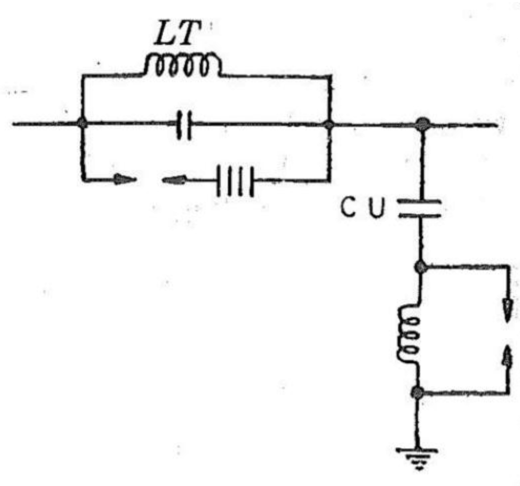
Schematic diagram of the carrier current scheme is shown below. Different basic components of the same are discussed below.

The Coupling capacitor

These coupling capacitors (CU) which offer low reactance to the higher frequency carrier signal and high reactance to the power frequency signal. Therefore, it filters out the low (power) frequency and allows the high frequency carrier waves to the carrier current equipments. A low inductance is connected to the CU, to form a resonant circuit.



$$Z = \frac{1}{\omega C_1}$$
$= 1.5$ mega ohms for 50 Hz.
$= 150$ ohms for 500 kHz.



Wave Traps

The Wave traps (also known as Line Trap) are inserted between the busbar and the connection of the CU. These traps are L and C elements connected in parallel, and they are tuned in such a manner that they offer low reactance to the power frequency signals and high reactance to the carrier waves. They ensure that neither of these different frequency signals get mixed up before being received at the bus bar.

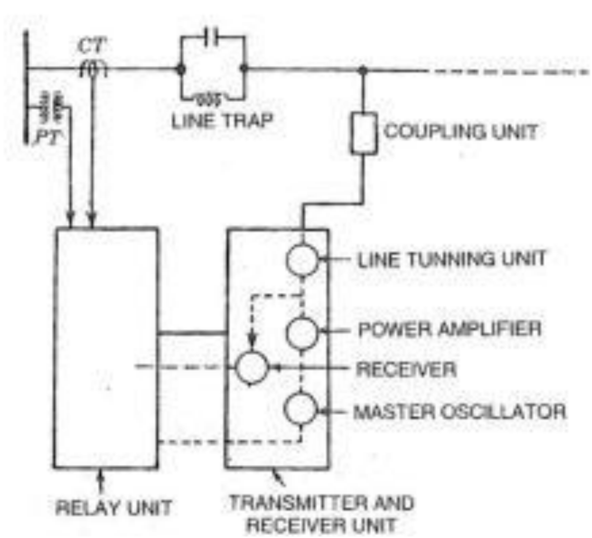
Both the CU and the Wave traps are protected from switching and lightening surges, with the help suitably designed *Spark Gaps* or *Varistors*.

Frequency spacing

Different frequencies are used in adjacent lines and the wave traps ensure that carrier signals of other lines do not enter a particular line section. Therefore, proper choice of frequency bands for different lines are adopted.

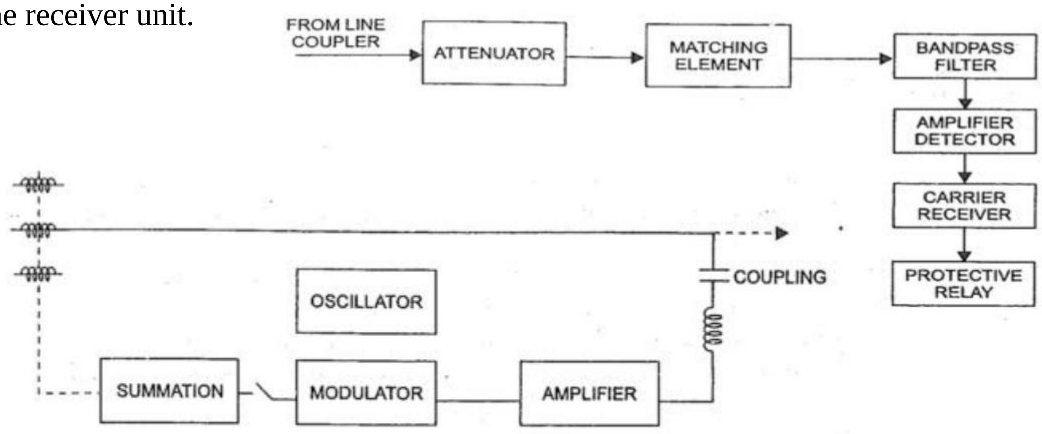
Transmitter Unit

In a Transmitter unit, the carrier frequency in the range of 50 to 500 KHz of constant magnitude is generated in the oscillator, which is fed to an amplifier. Amplification is required to overcome any loss in the coupling equipments, weather conditions, Tee connections in the lines of different size and length. The amplifier and the oscillators are constantly energized and a connection is made between the two with the help of a control unit.

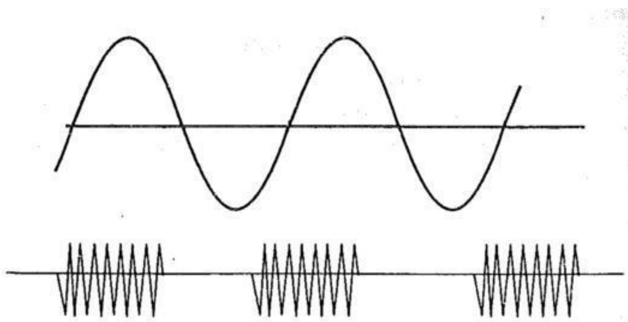


Receiver Unit

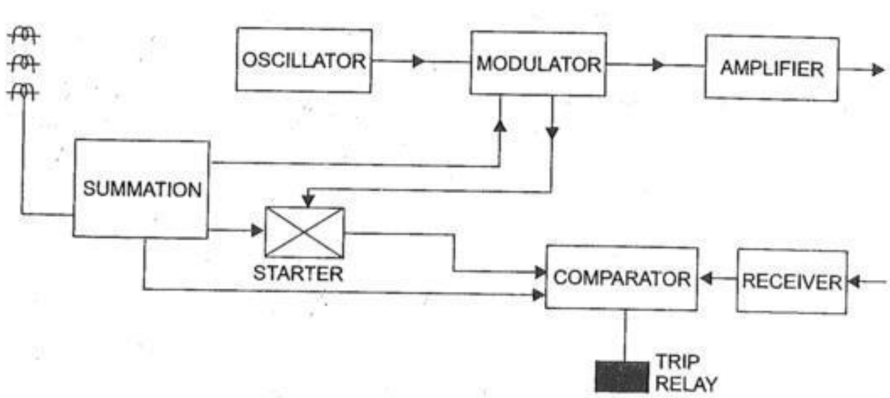
The Receiver unit consists of an attenuator and a Band pass filter, which restricts the acceptance of any unwanted signals. The unit also has matching transformer to match the line impedance and that of the receiver unit.



MODULATOR

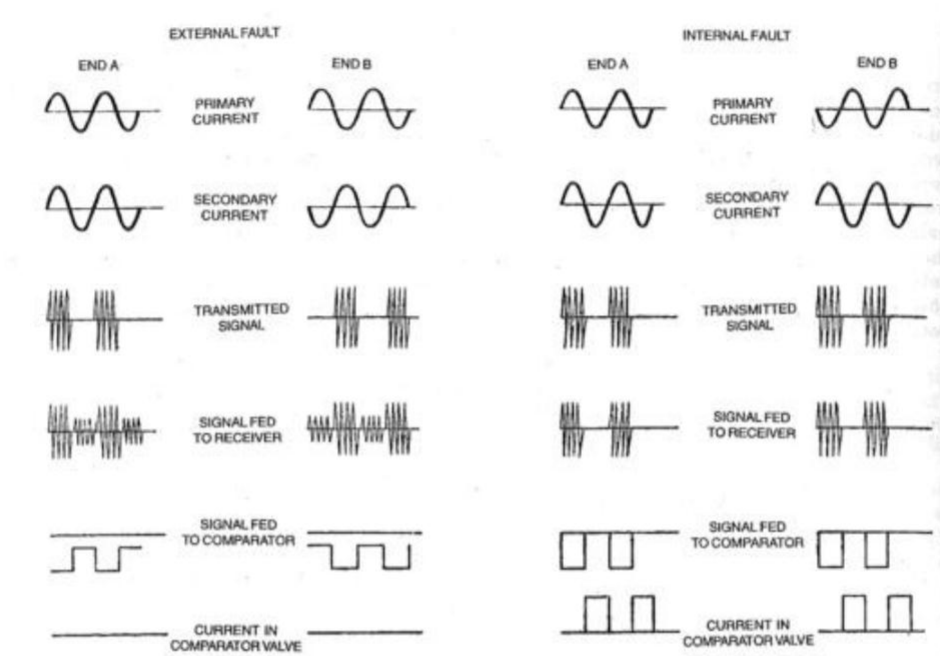


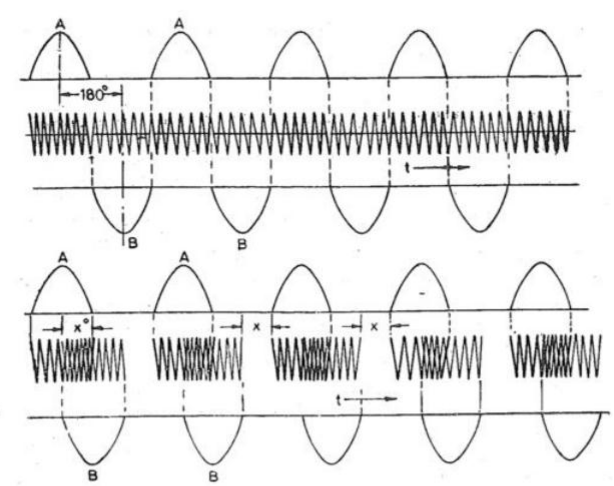
The Modulator modulates, the 50 Hz power signals with high frequency carrier waves and the modulated signal is fed to an amplifier. The amplifier output is transmitted via a CU. It takes half a cycle of power signal to produce requisite *Blocks of carrier* as shown above.



The Schematic of CCE

The CTs connected to the transmission line feed the Summation block which consist of Network sequence filters. It transforms the CT output to a single phase voltage signal that is representative of the fault condition. The voltage signal is used to control the output from the local transmitter unit, through the starting relay known as *Starte*r. It therefore initiates comparison between the local transmitter output and the signal received from the remote receiver in the comparator. The comparator output condition then initiates the *Trip relay*.





The principle of *Phase Comparison* is one of the methods that involve decision of tripping. As shown above, the presence of blocks of carrier signals abort any tripping and its absence initiates the tripping. Therefore, in a section of transmission line, where CTs at both end buses are connected 180 degree out of phase, an absence of carrier signal can only be possible if an internal fault has occurred. However, it can be seen that such absencve of carrier blocks is not possible for an external fault.

2.3.2 Application advantages and multiple roles of CCE

Pilot channel such are carrier current over the power line provides simultaneous tripping of circuit-breakers at both the ends of the line in one to three cycles. Thereby high speed fault clearing is obtained, which improves the stability of the power system. Besides there are several other merits of carrier current relaying. There are :

1. Fast, simultaneous operating of circuit-breakers at both ends.
2. Auto-reclosing simultaneous reclosing signal is sent thereby simultaneous (1 to 3 cycles) reclosing of circuit breaker is obtained.
3. Fast clearing prevents shocks to systems.
4. Tripping due to synchronizing power surges does not occur, yet during internal fault clearing is obtained.
5. For simultaneous faults, carrier current protection provides easy discrimination.
6. Fast (2 cycle) and auto-reclosing circuit breakers such as air blast circuit breaker require faster relaying. Hence, the carrier current relaying is best suited for fast relaying in conjunction with modern fast circuit breaker.
7. The carrier current equipment is used for several other application besides protection. They are as follows

(a) Station to station communication. In power station, receiving stations and sub-stations telephones are provided. These are connected to carrier current equipment and conversion can be carried out by means of "Current Carrier Communication".

(b) Control. Remote control of power station equipment by carrier signals.

(c) Telemetering.

2.3.4 Media used for protection signaling

- Power - line - carrier circuits
- Pilot wires

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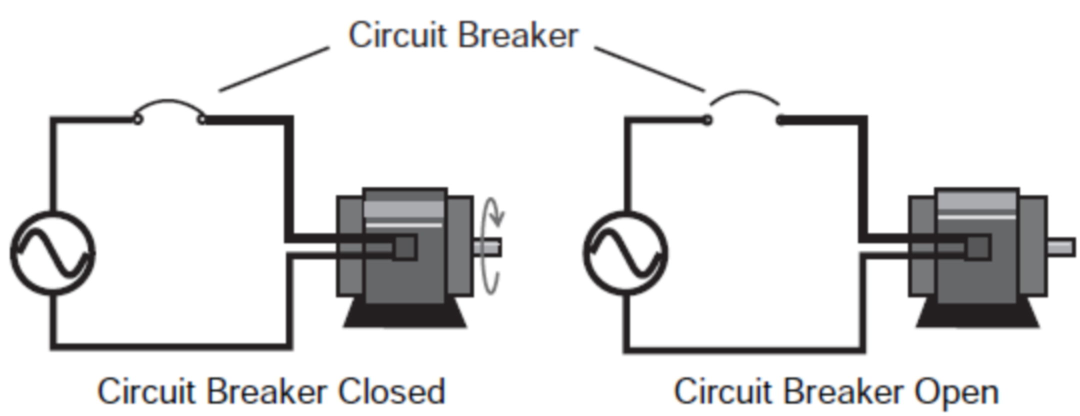
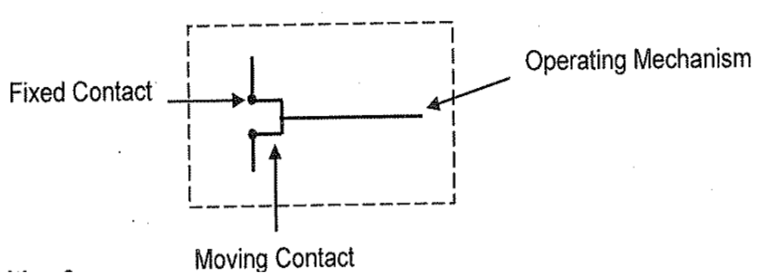
3.1 Circuit Breaker

Circuit breakers provide a manual means of energizing and de-energizing a circuit. Unlike fuses, which must be replaced when they open, a circuit breaker can be reset once the overcurrent condition has been corrected. Pushing the handle to the “OFF” position then back to the “ON” position restores the circuit. If a circuit reopens upon reset to the “ON” position, the circuit should be checked by a qualified electrician.

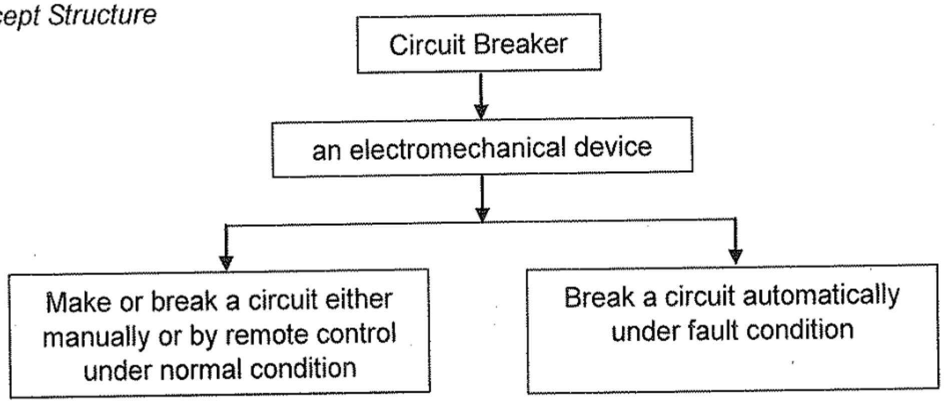
3.1.1 The fundamental of Circuit breaker operation

In the following illustration, an AC motor is connected through a circuit breaker to a voltage source. When the circuit breaker is closed, a complete path for current exists between the voltage source and the motor allowing the motor to run. Opening the circuit breaker breaks the path of current flow and the motor stops. The circuit breaker automatically opens when it senses a fault. After the fault has been cleared, the breaker can be closed, allowing the motor to operate.





Concept Structure



3.2 Formation of arc during circuit breaking

3.2.1 The phenomena of Arc

During opening of current carrying contacts in a circuit breaker the medium in between opening contacts become highly ionized through which the interrupting current gets low resistive path and continues to flow through this path even after the contacts are physically separated. During the flowing of current from one contact to other the path becomes so heated that it glows in the form of an arc.

3.2.2 Arc in circuit breaker

Whenever, the contacts of circuit breaker open while carrying load there is an arc in the medium between the separating contacts of the circuit breaker. As long as this arc is sustained in between the contacts, the current through the circuit breaker will not be interrupted totally. For total interruption of current, the arc needs to be quenched as quickly as possible. The main designing criteria of a circuit breaker is to provide appropriate technology of arc quenching in circuit breaker to fulfill quick and safe current interruption. So before going through different arc quenching techniques employed in circuit breaker, it is first necessary to understand the phenomena of arc in circuit breaker.

THERMAL IONIZATION OF GAS

There are numbers of free electrons and ions present in the medium separating the two contacts of the circuit breaker. These free electrons and ions are so few in number that they are insufficient to sustain conduction of electricity. The gas molecules move randomly at room temperature. It is found an air molecule at a temperature of 300°K (Room temperature) moves randomly with an approximate average velocity of 500 meters/second and collides other molecules at a rate of 10^{10} times/second. These randomly moving molecules collide each other in very frequent manner but the kinetic energy of the molecules is not sufficient to extract an electron from atoms of the molecules. If the temperature is increased the air will be heated up and consequently the velocity on the molecules increased. Higher velocity means higher impact during inter molecular collision. During this situation some of the molecules are disassociated in to atoms. If temperature of the air is further increased many atoms are deprived of valence electrons and make the gas ionized. Then this ionized gas can conduct electricity because of sufficient free electrons. This condition of any gas or air is called plasma. This phenomenon is called thermal ionization of gas.

IONIZATION DUE TO ELECTRIC FILED

As we discussed that there are always some free electrons and ions presents in the air or gas but they are insufficient to conduct electricity. Whenever these free electrons come across a strong electric field, these are attracted by the field and acquire sufficiently high velocity. In other words, the electrons are accelerated along the direction of the electric field due to high potential gradient. During their travel these electrons collide with other atoms and molecules of the air or gas and extract valance electrons from their orbits. After extracted from parent atoms, the electrons will also run along the direction of the same electric field due to potential gradient. These electrons will similarly collide with other atoms and create more free electrons which will also be directed along the electric field. Due to this conjugative action the numbers of free electrons in the gas will become so high that the gas starts conducting electricity. This phenomenon is known as ionization of gas due to electron collision.

DEIONIZATION OF GAS

If all the causes of ionization of gas are removed from an ionized gas it rapidly come back to its neutral state by recombination of the positive and negative charges. The process of recombination of positive and negative charges is known as deionization process. In deionization by diffusion, the negative ions or electrons and positive ions move to the walls under the influence of concentration gradients and thus completing the process of recombination.

3.2.3 Role of arc in circuit breaker

When two current carrying contacts open, an arc bridges the contact gap through which the current gets a low resistive path to flow so there will not be any sudden interruption of current. As there is no sudden and abrupt change in current during opening of the contacts, there will not be any abnormal switching over voltage in the system. Let i is the current flowing through the contacts just before they open and L is the system inductance, switching over voltage during opening of contacts, may be expressed as $V = L.(di/dt)$ where di/dt rate of change of current with respect to time during opening of the contacts. In the case of alternating current arc is momentarily extinguished at every current zero. After crossing every current zero the medium between separated contacts gets ionized again during next cycle of current and the arc in circuit breaker is reestablished. To make the interruption complete and successful, this re-ionization in between separated contacts to be prevented after a current zero.

If arc in circuit breaker is absence during opening of current carrying contacts, there would be sudden and abrupt interruption of current which will cause a huge switching overvoltage sufficient to severely stress the insulation of the system. On the other hand, the arc provides a gradual but quick, transition from the current carrying to the current breaking states of the contacts.

3.3 Arc Interruption or Arc Quenching or Arc Extinction Theory

3.3.1 Arc column characteristics

At high temperature the charged particles in a gas move rapidly and randomly, but in absence of electric field, no net motion occurs. Whenever an electric field is applied in the gas, the charged particles gain drift velocity superimposed on their random thermal motion. The drift velocity is proportional to the voltage gradient of the field and particle mobility. The particle mobility depends upon the mass of the particle, heavier particles, lower the mobility. The mobility also depends upon mean free paths available in the gas for random movement of the particles. Since every time a particle collides, it loses its directed velocity and has to be re-accelerated in the direction of electric field again. Hence net mobility of the particles is reduced. If the medium has high pressure, it becomes denser and hence, the gas molecules come closer to each other, therefore collision occurs more frequently which lowers the mobility particles. The total current by charged particles is directly proportional to their mobility. Therefore the mobility of charged particles depends upon the temperature, pressure of the gas and as well as nature of the gas. Again the mobility of gas particles determines the degree ionization of gas.

So from above explanation we can say that ionization process of gas depends upon nature of gas (heavier or lighter gas particles), pressure of gas and temperature of gas. As we said earlier the intensity of arc column depend up on the presence of ionized media between separated electrical contacts, hence, special attention should be given in reducing ionization or increasing deionization of media between contacts. That is why the main designing feature of circuit breaker is to provide different pressure control methods, cooling methods for different arc media in between circuit breaker contacts.

HEAT LOSS FROM ARC

Heat loss from an arc in circuit breaker takes place through conduction, convection as well as radiation. In circuit breaker with plain break arc in oil, arc in chutes or narrow slots nearly all the heat loss due to conduction. In air blast circuit breaker or in breaker where a gas flow is present between the electrical contacts, the heat loss of arc plasma occurs due to convection process. At normal pressure the radiation is not a significant factor but at higher pressure the radiation may become a very important factor of heat dissipation from arc plasma. During opening of electrical contacts, the arc in circuit breaker is produced and it is extinguished at every zero crossing, getting established again during the next cycle. The final arc extinction or arc quenching in circuit breaker can be achieved by rapid increase of the dielectric strength in the medium between the contacts so that the arc gets quenched after the first zero crossing. This rapid increase of dielectric strength in between circuit breaker contacts is achieved either by deionization of gas in the arc media or by replacing ionized gas by cool and fresh gas.

There are various deionization processes applied for arc extinction in circuit breaker, let us discussed in brief.

DEIONIZATION OF GAS DUE TO INCREASING PRESSURE

If pressure of the arc path increases, the density of the ionized gas is increased which means, the particles in the gas come closer to each other and as a result the mean free path of the particles is reduced. This increases the collision rate and as we discussed earlier at every collision the charged particles loss their directed velocity along electric field and again they are re-accelerated towards field. It can be said that over all mobility of the charged particles is reduced so the voltage required to maintain the arc is increased. Another effect of the increased density of particles is a higher rate of deionization of gas due to the recombination of oppositely charged particles.

The rate of ionization of gas depends upon the intensity of impact during collision of gas particles. The intensity of impact during collision of particles again depends upon velocity of random motions of the particles. This random motion of a particle and its velocity increases with increase of temperature of the gas. Hence it can be concluded like that if temperature of a gas is increased; its ionization process is increased and opposite statement is also true that is if the temperature is decreased the rate of ionization of gas is decreased means deionization of gas is increased. Therefore more voltage required to maintain arc plasma with a decreased temperature. Finally it can be said that the cooling effectively increases the resistance of the arc.

The insulating material (may be fluid or air) used in circuit breaker should serve two important functions as follows:

1. It should provide sufficient insulation between the contacts when circuit breaker opens.
2. It should extinguish the arc occurring between the contacts when circuit breaker opens.

3.3.2 Methods of arc interruption

There are two methods by which interruption is done.

1. High resistance method.
2. Low resistance method or zero interruption method.

In high interruption method we can increase the electrical resistance many times to such a high value that it forces the current to reach to zero and thus restricting the possibility of arc to be struck again. Proper steps must be taken in order to ensure that the rate at which the resistance is increased or decreased is not abnormal because it may lead to generation of harmful induced voltages in the system. The arc resistance can be increased by various methods like lengthening or cooling of the arc etc.

Limitations of high resistance method: Arc discharge has a resistive nature due to this most of the energy is received by circuit breaker itself hence proper care should be taken during the manufacturing of circuit breaker like mechanical strength etc. Therefore this method is applied in dc power circuit breaker, low and medium ac power circuit breaker.

Low resistance method is applicable only for ac circuit and it is possible there because of presence of natural zero of current. The arc gets extinguished at the natural zero of the ac wave and is prevented from restricting again by rapid building of dielectric strength of the contact space.

There are two theories which explains the phenomenon of arc extinction:

1. Energy balance theory,
2. Voltage race theory.

Before going in details about these theories, we should know the following terms.

- *Restriking voltage*: It may be defined as the voltage that appears across the breaking contact at the instant of arc extinction.
- *Recovery voltage* **:** It may be defined as the voltage that appears across the breaker contact after the complete removal of transient oscillations and final extinction of arc has resulted in all the poles.
- *Active recovery voltage :* It may be defined as the instantaneous recovery voltage at the instant of arc extinction.
- *Arc voltage :* It may be defined as the voltage that appears across the contact during the arcing period, when the current flow is maintained in the form of an arc. It assumes low value except for the point at which the voltage rise rapidly to a peak value and current reaches to zero.

1. *Energy Balance Theory*: When the contact of circuit breaker are about to open, re striking voltage is zero, hence generated heat would be zero and when the contacts are fully open there is infinite resistance, therefore no production of heat again. We can conclude from this that the maximum generated heat is lying between these two cases and can be approximated, now this theory is based on the fact that, if the rate of generation of heat between the contacts of circuit breaker is lower than the rate at which heat between the contact is dissipated, then the established arc shall be extinguished successfully. Thus if it is possible to remove the generated heat by cooling, lengthening and splitting the arc at a high rate the generation, arc can be extinguished.

2. *Voltage Race Theory*: The arc is due to the ionization of the gap between the contact of the circuit breaker. Thus the resistance at the initial stage is very small i.e. when the contact are closed and as the contact separates the resistance starts increasing. If we remove ions at the

initial stage either by recombining them into neutral molecules or inserting insulation at a rate faster than the rate of ionization, the arc can be interrupted. The ionization at zero current depends on the restriking voltage. The theory states that if the rate of rise of restriking voltage is lesser than the rate at which the dielectric strength of the medium increases, then the arc will be successfully extinguished.

Let us define an expression for restriking voltage. For loss-less or ideal system we have, Here *V* = restriking voltage.

V = value of voltage at the instant of interruption.

L and C are series inductor and shunt capacitance up to fault point.

Thus from above equation we can see that lower the value of product of L and C, higher the value of restriking voltage.

Recovery process

$$L\frac{di}{dt} + \frac{1}{C}\int idt = V_m \cos \omega t$$

Transient Recovery Voltage (TRV)

$$LC\frac{d^2 v_{TRV}}{dt} + v_{TRV} = V_m u(t)$$

$$v_{TRV} = V_m (1 - \cos\frac{t}{\sqrt{LC}})$$

At $t = \pi\sqrt{LC}$, v_{TRV} doubles, arc initiates again sustain for longer time.

$$RRRV = \frac{d}{dt}(v_{TRV}) = \text{rate of rise of recovery voltage}$$

The value of RRRV w.r.t. the rate of rise of dielectric strength of medium will decide whether arc is restruck or ignited or sustained for longer time.

$$v_{TRV} = V_m (1 - \cos\frac{t}{\sqrt{LC}})$$

$$\frac{d}{dt}(v_{TRV}) = RRRV = \frac{V_m}{\sqrt{LC}} \sin\frac{t}{\sqrt{LC}}$$

At $t = \pi\sqrt{LC}$ v_{TRV} is maximum

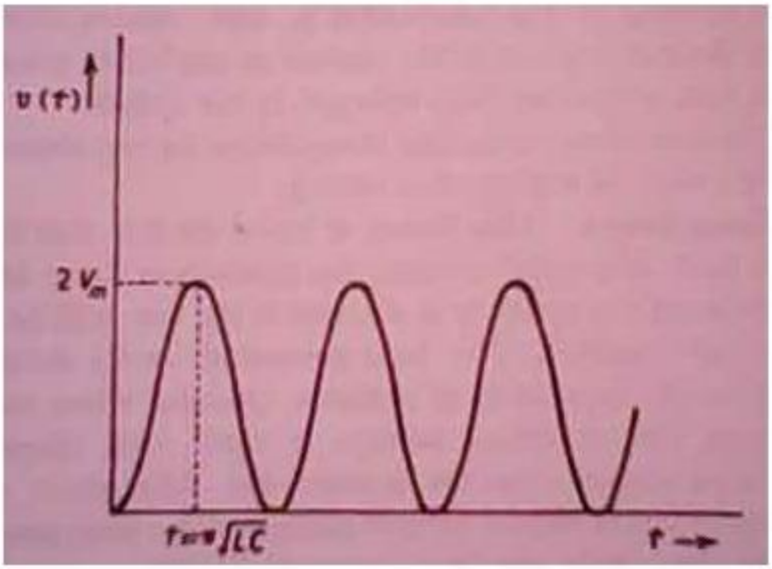
$TRV_{max} = 2\ V_m$

$$RRRV_{avg} = \frac{2V_m}{\pi\sqrt{LC}}$$

$$RRRV_{max} = \frac{V_m}{\sqrt{LC}}$$

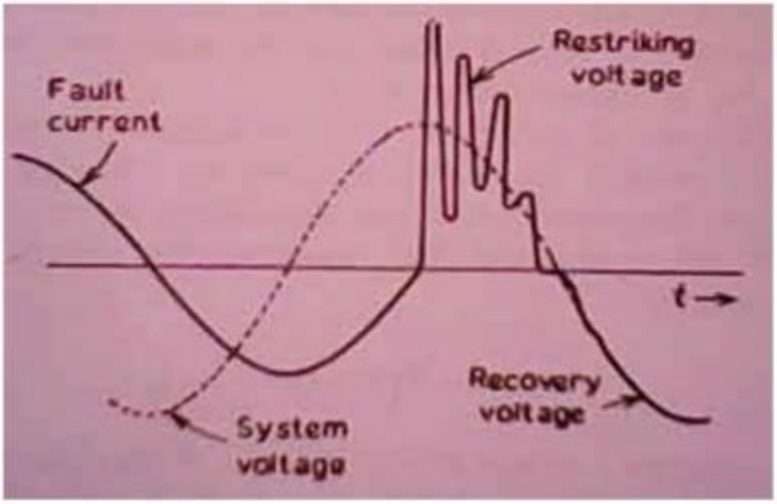
t at which $RRRV_{max}$ occurs $= \frac{\pi}{2}\sqrt{LC}$

The variation of *V* versus time is plotted below:

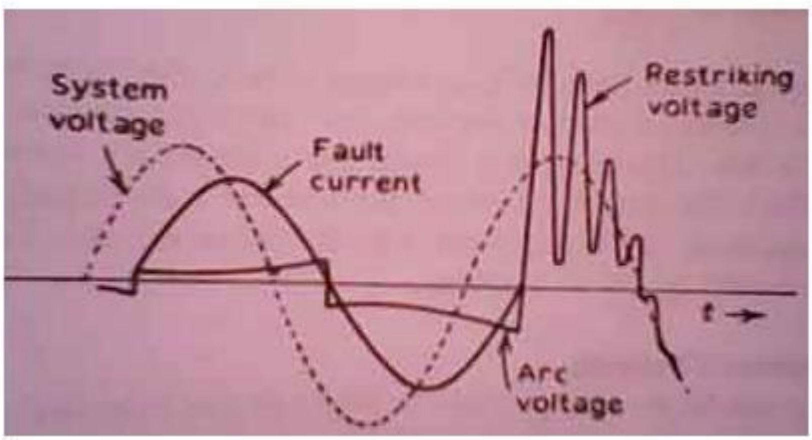


Restriking voltage across breaker contacts

Now let us consider a practical system, or assume there finite loss in the system. As shown in the figure below in this case the restriking voltage is damped out due to the presence of some finite resistance. Here it is assumed that the current lags behind the voltage by an angle (measured in degrees) of 90. However in practical situation angle may vary depending upon time in cycle at which the fault occurrs.



Let us consider the effect of arc voltage, if arc voltage is included in the system, there is an increment in the restriking voltage. However this is offset by another effect of an arc voltage which opposes the current flow and making change in the phase of current, thus bringing it more into phase with the applied voltage. Hence the current is not at its peak value when voltage passes through zero value.



Rate of Rise of Restriking Voltage (RRRV): It is defined as the ratio of peak value of restriking voltage to time taken to reach to peak value. It is one of the most important parameter as if the rate at which the dielectric strength developed between the contacts is greater than RRRV, then the arc will be extinguishes.

Factor affecting TRV

1. Natural frequency of oscillation which depends on X_S of generator and the capacitance value of the breaker zone.

2. If the high power factor (p.f) of current load is delivered, then the severity is less.

3. Reactance drop i.e L affects frequency and voltage.
4. Armature reaction reduces TRV
5. Phase factor (more severe for first pole that is opened)

Re-ignition

If the C.B contact space breaks down within $1/4^{th}$ of natural frequency or if it takes more time or above $1/4^{th}$ of a cycle, it is restriking.

$V_r = K_1 K_2 K_3 V_{max} \sin\phi$

K_1 = factor of demagnetization

K_2 = phase factor, 1.5 for first pole or 1 for other poles

K_3 = line or phase value, $\sqrt{3}$ or 1.

Arc extinction

1. Recombination
2. Diffusion: help in reducing ionisation
3. Drift: depends on density of the medium.

   Arc current depends on external circuit condition. It does not depends on pole voltage from where it arises.

3.4 Rating of Circuit Breaker

The **rating of a circuit breaker** includes,

1) Rated short circuit breaking current.

2) Rated short circuit making current.

3) Rated operating sequence of circuit breaker.

4) Rated short time current.

3.4.1 Short circuit breaking current of circuit breaker

This is the maximum short circuit current which a circuit breaker can withstand before it. Finally cleared by opening its contacts. When a short circuit flows through a circuit breaker,

there would be thermal and mechanical stresses in the current carrying parts of the breaker. If the contact area and cross-section of the conducting parts of the circuit breaker are not sufficiently large, there may be a chance of permanent damage in insulation as well as conducting parts of the CB.

The short circuit current has a certain value at the instant of contact separation. The breaking current refers to value of current at the instant of the contact separation. The rated values of transient recovery voltage are specified for various rated voltage of circuit breakers. For specified conditions of rated TRV and rated power frequency recovery voltage, a circuit breaker has a certain limit of breaking current. This limit is determined by conducting short circuit type tests on the circuit breaker. The waveforms of short circuit current are obtained during the breaking test. The evaluation of the breaking current is explained in Fig. 3. The breaking current is expressed by two values. The *r.m.s* values of *a.c.* components are expressed in KA. the standard values being 8, 10, 12.5, 16, 20, 25, 31.5, 40, 45, 63, 80 and 100KA.

The earlier practice was to express the rated breaking capacity of a circuit breaker in terms of MVA given as follows

Rated Breaking MVA capacity = $\sqrt{3}$ x KV x KA

Where MVA = Breaking capacity of a circuit breaker

kV KV = Rated voltage

KA = Rated breaking current

This practice of specifying the breaking capacity in terms of MVA is convenient while calculating the fault levels. However, as per the revised standards, the breaking capacity is expressed in KA for specified conditions of TRV and this method takes into account both breaking current and TRV. The breaking capacity can be both symmetrical and asymmetrical in nature. In asymmetrical breaking capacity the DC component of the current is added.

While selecting the circuit breaker for a particular location in the power system the fault level at that location is determined. The rated breaking current can then be selected from standard range.

3.4.2 Rated short circuit making capacity

The short circuit making capacity of circuit breaker is expressed in peak value not in rms value like breaking capacity.It may so happen that circuit breaker may close on an existing fault. In such cases the current increase to the maximum value at the peak of first current loop. The circuit breaker should be able to close without hesitation as contact touch. The circuit breaker should be able to withstand the high mechanical forces during such a closure. These capabilities are proved by carrying out making current test. The rated short circuit making current of a circuit breaker is the peak value of first current loop of short circuit current (*I* pk)Which the circuit breaker is capable of making at its rated voltage.

The rated short circuit making current should be least 2.5 times the r.m.s. value of a.c. component of rated breaking current .

Rated making current = 1.8 x √2 x Rated short circuit breaking =

2.5 x Rated short circuit breaking current

In the above equation the factor √2 convert the r.m.s value to peak value. Factor 1.8 takes into account the doubling effect of short circuit current with consideration to slight drop in current during the first quarter cycle .

3.4.3 Rated operating sequence or duty cycle of circuit breaker

This is mechanical duty requirement of circuit breaker operating mechanism. The sequence of rated operating duty of a circuit breaker has been specified as O – t – CO – t‟ – CO

Where *O* indicates opening operation of the CB. *CO* represents closing operation immediately followed by an opening operation without any intentional time delay. t‟ is time between two operations which is necessary to restore the initial conditions and / or to prevent undue heating of conducting parts of circuit breaker. t = 0.3 sec for circuit breaker intended for first auto re closing duty, if not otherwise specified.

Suppose rated duty circle of a circuit breaker is 0 – 0.3 sec – CO – 3 min – CO.

This means, an opening operation of circuit breaker is followed by a closing operation after a time interval of 0.3 sec, then the circuit breaker again opens without any intentional time delay. After this opening operation the CB is again closed after 3 minutes and then instantly trips without any intentional time delay.

3.4.4 Rated short time current

This is the current limit which a circuit breaker can carry safely for certain specific time without any damage.

The circuit breakers do not clear the short circuit current as soon as any fault occurs in the system. There always some intentional and an intentional time delays present between the instant of occurrence of fault and instant of clearing the fault by CB. This delay is present because of time of operation of protection relays, time of operation of circuit breaker and also there may be some intentional time delay imposed in relay for proper coordination of power system protection. Hence, after fault, a circuit breaker has to carry the short circuit for certain time. The summation of all time delays should not be more than 3 seconds, hence a circuit breaker should be capable of carrying a maximum fault current for at least this short period of time.

The short circuit current may have two major affects inside a circuit breaker.

1. Because of the high electric current, there may be high thermal stress in the insulation and conducting parts of CB.
2. The high short circuit current, produces significant mechanical stresses in differentcurrent carrying parts of the circuit breaker.

A circuit breaker is designed to withstand these stresses. But no circuit breaker has to carry a short circuit current not more than a short period depending upon the coordination of protection. So it is sufficient to make CB capable of withstanding affects of short circuit current for a specified short period.

The rated short time current of a circuit breaker is at least equal to rated short circuit breaking current of the circuit breaker.

3.4.5 Rated voltage of circuit breaker

Rated voltage of circuit breaker depends upon its insulation system. For below 400 KV system, the circuit breaker is designed to withstand 10% above the normal system voltage. For above or equal 400 KV system the insulation of circuit breaker should be capable of withstanding 5% above the normal system voltage. That means, rated voltage of circuit breaker corresponds to the highest system voltage. This is because during no load or small load condition the voltage level of power system is allowed rise up to highest voltage rating of the system.

A circuit breaker is also subject to two other high voltage condition.

1) Sudden disconnection of huge load for any other cause, the voltage imposed on the CB and also between the contacts when the CB is open, may be very high compared to higher system

voltage. This voltage may be of power frequency but does not stay for very long period as this high voltage situation must be cleared by protective switchgear.

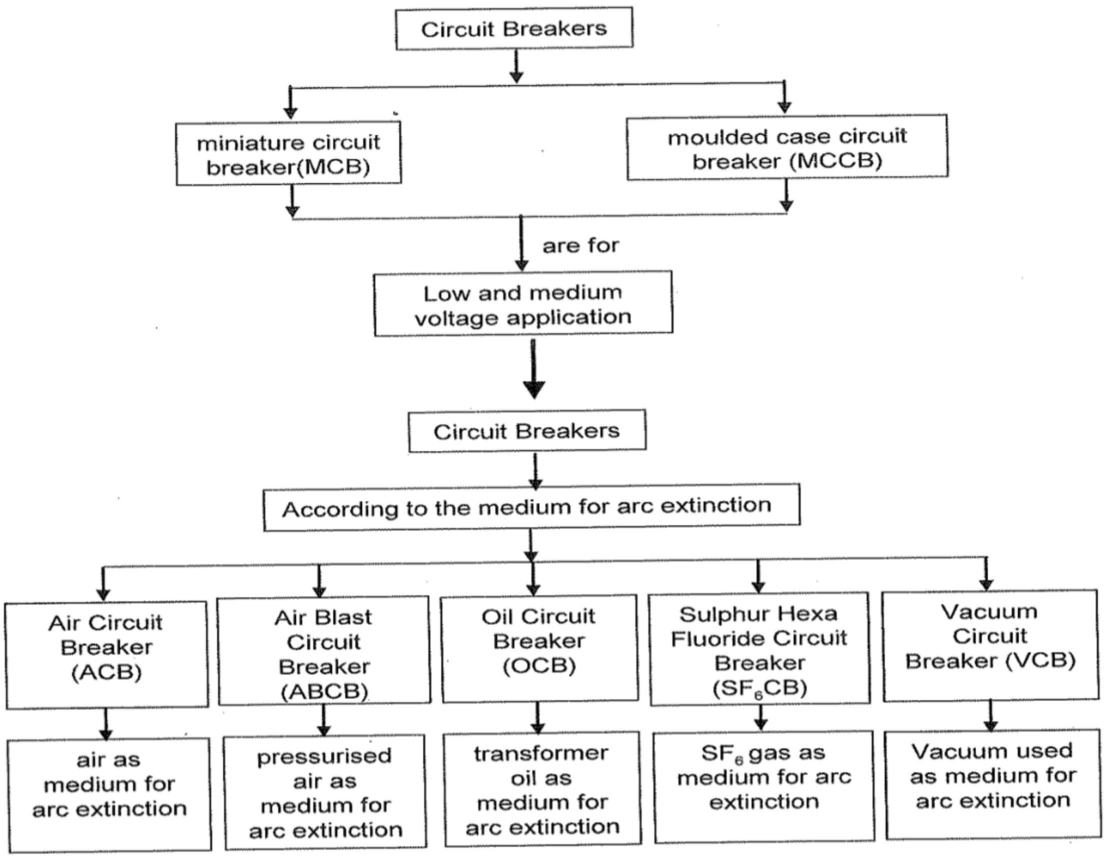
But a circuit breaker may have to withstand this power frequency over voltage, during its normal life span.

The Circuit Breaker must be rated for power frequencies withstand voltage for a specific time only. Generally the time is 60 seconds. Making power frequency withstand capacity, more than 60 second is not economical and not practically desired as all the abnormal situations of electrical power system are definitely cleared within much smaller period than 60 seconds.

2) Like other apparatuses connected to power system, a circuit breaker may have also to face lightening impulse and switching impulses during its life span.

The insulation system of CB has to withstand these impulse voltage waveform. So a circuit breaker is designed to withstand this impulse peaky voltage for microsecond range only.

NOMINAL SYSTEM VOLTAGE	HIGHEST SYSTEM VOLTAGE	POWER FREQUENCY WITHSTAND VOLTAGE	IMPULSE VOLTAGE LEVEL
11 KV	12 KV	–	–
33 KV	36 KV	70 KV	170 KV
132 KV	145 KV	275 KV	650 KV
220 KV	245 KV	460 KV	1050 KV
400 KV	420 KV	–	–



3.5 Air Circuit Breaker and Air Blast Circuit Breaker

This type of circuit breakers, is those kind of circuit breaker which operates in air at atmospheric pressure. After development of oil circuit breaker, the medium voltage air circuit breaker (ACB) is replaced completely by oil circuit breaker in different countries. But in countries like France and Italy, ACBs are still preferable choice up to voltage 15 KV. It is also good choice to avoid the risk of oil fire, in case of oil circuit breaker. In America ACBs were exclusively used for the system up to 15 KV until the development of new vacuum and SF_6 circuit breakers.

3.5.1 *Working principle of air circuit breaker(ACB)*

The working principle of this breaker is rather different from those in any other types of circuit breakers. The main aim of all kind of circuit breaker is to prevent the reestablishment of arcing after current zero by creating a situation where in the contact gap will withstand the system recovery voltage. The air circuit breaker does the same but in different manner. For interrupting arc it creates an arc voltage in excess of the supply voltage. Arc voltage is defined as the minimum voltage required maintaining the arc. This circuit breaker increases the arc voltage by mainly three different ways,

1. It may increase the arc voltage by cooling the arc plasma. As the temperature of arc plasma is decreased, the mobility of the particle in arc plasma is reduced, hence more voltage gradient is required to maintain the arc.
2. It may increase the arc voltage by lengthening the arc path. As the length of arc path is increased, the resistance of the path is increased, and hence to maintain the same arc current more voltage is required to be applied across the arc path. That means arc voltage is increased.

3. Splitting up the arc into a number of series arcs also increases the arc voltage.

The *first objective* is usually achieved by forcing the arc into contact with as large an area as possible of insulating material. Every air circuit breaker is fitted with a chamber surrounding the contact. This chamber is called „arc chute". The arc is driven into it. If inside of the arc chute is suitably shaped, and if the arc can conform to the shape, the arc chute wall will help to achieve cooling. This type of arc chute should be made from some kind of refractory material. High temperature plastics reinforced with glass fiber and ceramics are preferable materials for making arc chute.

The *second objective* that is lengthening the arc path is achieved concurrently with the first objective. If the inner walls of the arc chute is shaped in such a way that the arc is not only forced into close proximity with it but also driven into a serpentine channel projected on the arc chute wall. The lengthening of the arc path increases the arc resistance.

The *third objective* is achieved by using metal arc slitter inside the arc chute. The main arc chute is divided into numbers of small compartments by using metallic separation plates. These metallic separation plates are actually the arc splitters and each of the small compartments behaves as individual mini arc chute. In this system the initial arc is split into a number of series arcs, each of which will have its own mini arc chute. So, each of the arc splits has its own cooling and lengthening effect. This collectively, increases the overall arc voltage and helps in quenching.

AIR BLAST CIRCUIT BREAKER

These types of air circuit breaker were used for the system voltage of 245 KV, 420 KV and even more, especially where faster breaker operation was required. Air blast circuit breaker has some specific *advantages* over oil circuit breaker which are listed as follows,

1. There is no chance of fire hazard caused by oil.
2. The breaking speed of circuit breaker is much higher during its operation**.**
3. Arc quenching is much faster.
4. The duration of arc is same for all values of small as well as high currents interruptions.
5. As the duration of arc is smaller, so lesser amount of heat is generated, which ensures longer service life of the contacts.
6. The stability of the system can be well maintained as it depends on the speed of operation.
7. Requires much less maintenance compared to oil circuit breaker.

Some of the *disadvantages* of using ABCB are as follows

1. In order to have frequent operations, it is necessary to have sufficiently high capacity air compressor.

2. Frequent maintenance of compressor, associated air pipes and automatic control equipments is also required.

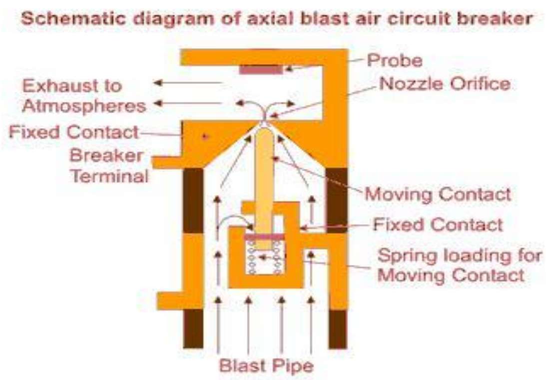
3. Due to high speed current interruption there is always a chance of high rate of rise of re-striking voltage and current chopping.

4. There also a chance of air pressure leakage from air pipes junctions.

As we said earlier that there are mainly two types of ACB, plain air circuit breaker and air blast circuit breaker. But the later can be sub divided further into three different categories.

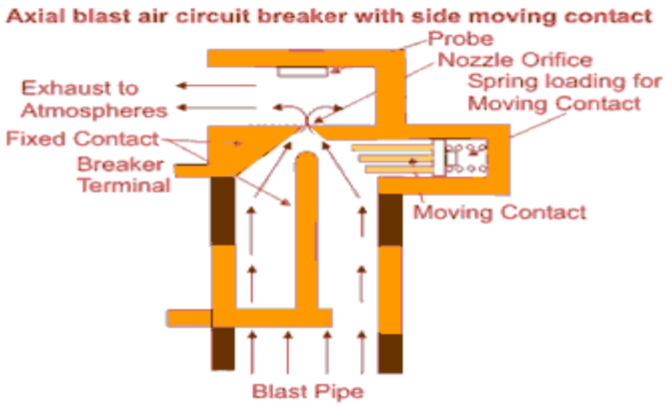
1. Axial Blast ACB.
2. Axial Blast ACB with side moving contact.
3. Cross Blast ACB.

1.*AXIAL BLAST AIR CIRCUIT BREAKER*



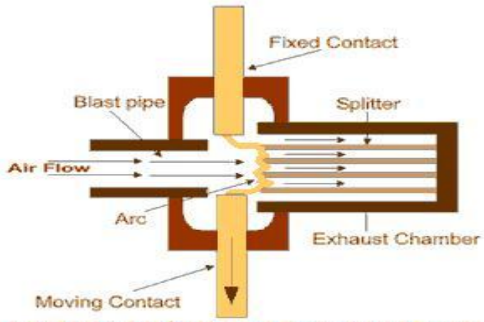
In axial blast ACB the moving contact is in contact with fixed contact with the help of a spring pressure as shown in the figure above. There is a nozzle orifice in the fixed contact which is blocked by tip of the moving contact at normal closed condition of the breaker. When fault occurs, the high pressure air is introduced into the arcing chamber. The air pressure will counter the spring pressure and deforms the spring hence the moving contact is withdrawn from the fixed contact and nozzle hole becomes open. At the same time the high pressure air starts flowing along the arc through the fixed contact nozzle orifice. This axial flow of air along the arc through the nozzle orifice will make the arc lengthen and colder hence arc voltage become much higher than system voltage that means system voltage is insufficient to sustain the arc consequently the arc is quenched.

2. AXIAL BLAST ACB WITH SIDE MOVING CONTACT



In this type of axial blast air circuit breaker, the moving contact is fitted over a piston supported over a spring. In order to open the circuit breaker the air is admitted into the arcing chamber when pressure reaches to a predetermined value, it presses down the moving contact. An arc is drawn between the fixed and moving contacts. The air blast immediately transfers the arc to the arcing electrode and is consequently quenched by the axial flow of air.

3 .CROSS BLAST AIR CIRCUIT BREAKER



Principle of Cross Blast Air Circuit Breaker

The working principle of cross blast air circuit breaker is quite simple. In this system, a pipe is fixed in perpendicular to the movement of moving contact in the arcing chamber and on the opposite side of the arcing chamber one exhaust chamber is also fitted at the same alignment of blast pipe, so that the air comes from blast pipe can straightly enter into exhaust chamber through the contact gap of the breaker. The exhaust chamber is split with arc splitters. When moving contact is withdrawn from fixed contact, an arc is established in between the contact, and at the same time high pressure air coming from blast pipe will pass through the contact gap radially, and the high pressure air blast will forcefully take the arc into exhaust chamber where the arc is split with the help of arc splitters and ultimately arc is quenched.

3.6 Oil Circuit Breaker

Oil Circuit Breakers are generally of two types and they are

i) Bulk Oil type or the Dead tank type (OCB)

ii) Minimum Oil Circuit Breaker(MOCB)

3.6.1. ***Bulk Oil type or the Dead tank type (OCB)***

The bulk oil circuit breakers are those which use large volumes of oil for two specific purposes. These oils need large tanks which solve the purpose of arc quenching chamber. The oil is used for

a) Providing insulation from the live current carrying contacts

b) Serving as a medium of arc quenching.

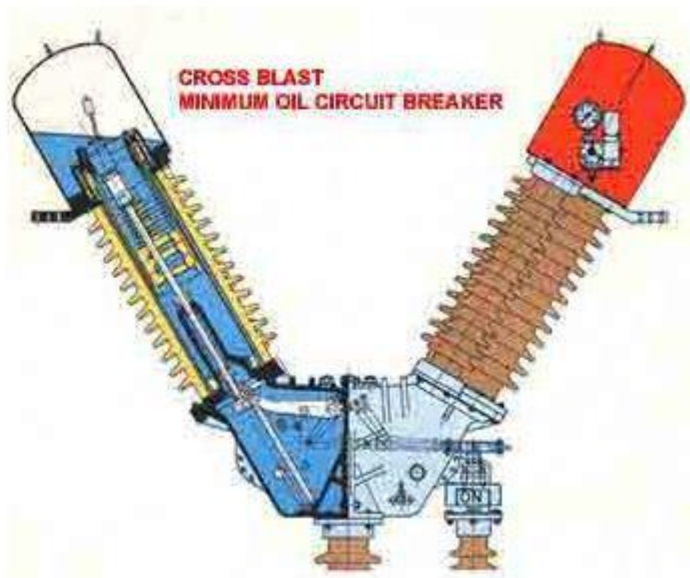
The tank, that houses the current carrying contacts, is at ground potential. When the moving contacts open to initiate the circuit breaking process, an arc is struck inside the oil medium. Due to oil heating, it vapourizes to produce hydrogen and other hydrocarbon gases. These gases generate high pressure in the vicinity of the arc and cool it. Subsequently, the arc can‟t sustain itself and gets quenched.

3.6.2. ***Minimum Oil Circuit Breaker (MOCB)***

These types of circuit breakers utilize oil as the interrupting media. However, unlike bulk oil circuit breaker, a minimum oil circuit breaker places the interrupting unit in insulating chamber at live potential. The insulating oil is available only in interrupting chamber. The features of designing MOCB is to reduce requirement of oil, and hence these breaker are called minimum oil circuit breaker.

As the volume of the oil in bulk oil circuit breaker is huge, the chances of fire hazard in bulk oil system are more. For avoiding unwanted fire hazard in the system, one important development in the design of oil circuit breaker has been introduced where use of oil in the circuit breaker is much less than that of bulk oil circuit breaker. It has been decided that the oil in the circuit breaker should be used only as arc quenching medium, not as an insulating media. In this type of circuit breaker the arc interrupting device is enclosed in a tank of insulating material which as a whole is at live potential of system. This chamber is called arcing chamber or interrupting pot. The gas pressure developed in the arcing chamber depends upon the current to be interrupted. Higher the current to be interrupted causes larger the gas pressure developed inside the chamber, hence better the arc quenching. But this puts a limit on the design of the arc chamber for mechanical stresses. With use of better insulating materials for the arcing chambers such as glass fiber, reinforced synthetic resin etc, the minimum oil circuit breaker are able to meet easily the increased fault levels of the system.

Working principle or arc quenching in minimum oil circuit breaker



Working Principle of minimum oil circuit breaker is described below. In a minimum oil circuit breaker**,** the arc is drawn across the current carrying contacts is contained inside the arcing chamber. Hence the hydrogen bubble formed by the vaporized oil is trapped inside the chamber. As the contacts continue to move, after its certain travel an exit vent becomes available for exhausting the trapped hydrogen gas. There are two different types of arcing chambers, available in terms of *venting*. One is axial venting and other is radial venting. In axial venting, gases (mostly Hydrogen), produced due to vaporization of oil and decomposition of oil during arc, will sweep the arc in axial or longitudinal direction.

Let‟s have a look on working principle Minimum Oil Circuit Breaker with axial venting arc chamber. The moving contact has just been separated and arc is initiated in MOCB.

The ionized gas around the arc sweeps away through upper vent and cold oil enters into the arcing chamber through the lower vent in axial direction as soon as the moving contact tip crosses the lower vent opening and final arc quenching in minimum oil circuit breaker occurs

The cold oil occupies the gap between fixed contact and moving contact and the minimum oil circuit breaker finally comes into open position.

Whereas in case of radial venting or cross blast, the gases sweeps the arc in radial or transverse direction.The axial venting generates high gas pressure and hence has high dielectric strength, so it is mainly used for interrupting low current at high voltage.

On the other hand radial venting produces relatively low gas pressure and hence low dielectric strength so it can be used for low voltage and high current interruption. Many times the combination of both is used in minimum oil circuit breaker so that the chamber is equally efficient to interrupt low current as well as high current. These types of circuit breaker are available up to 8000 MVA at 245 KV.

3.7 Vacuum Circuit Breaker or VCB

A vacuum circuit breaker is such kind of circuit breaker where the arc quenching takes place in vacuum. The technology is suitable for mainly medium voltage application. For higher voltage vacuum technology has been developed but not commercially viable. The operation of opening and closing of current carrying contacts and associated arc interruption take place in a vacuum chamber in the breaker which is called vacuum interrupter. The vacuum interrupter consists of a steel arc chamber in the centre symmetrically arranged ceramic insulators. The vacuum pressure inside a vacuum interrupter is normally maintained at 10^{-6} bar.

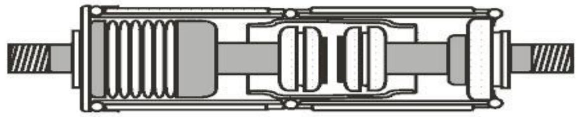
The material used for current carrying contacts plays an important role in the performance of the **V**acuum circuit breaker. Cu-Cr is the most ideal material to make VCB contacts. Vacuum interrupter technology was first introduced in the year of 1960. But still it is a developing technology. As time goes on, the size of the vacuum interrupter is being reduced from its early 1960‟s size due to different technical developments in this field of engineering. The contact geometry is also improving with time, from butt contact of early days it gradually changes to spiral shape, cup shape and axial magnetic field contact. The vacuum circuit breaker is today recognized as most reliable current interruption technology for medium voltage switchgear. It requires minimum maintenance compared to other circuit breaker technologies.

3.7.1. ***Advantages of vacuum circuit breaker or VCB***

Service life of vacuum circuit breaker is much longer than other types of circuit breakers. There is no chance of fire hazard as oil circuit breaker. It is much environment friendly than SF_6 Circuit breaker. Besides, the contraction of VCB is much user friendly. Replacement of vacuum interrupter (VI) is much convenient.

3.7.2 ***Operation of vacuum circuit breaker***

The main aim of any circuit breaker is to quench arc during current zero crossing, by establishing high dielectric strength in between the contacts so that reestablishment of arc after current zero becomes impossible. The dielectric strength of vacuum is eight times greater than that of air and four times greater than that of SF_6 gas. This high dielectric strength makes it possible to quench a vacuum arc within very small contact gap. For short contact gap, low contact mass and no compression of medium the drive energy required in vacuum circuit breaker is minimum. When two face to face contact areas are just being separated to each other, they are not done so instantly. Instead, as the contact area on the contact face is being reduced and ultimately comes to a point and then they are finally de-touched. This happens in a fraction of micro second. At this instant of de-touching of contacts in a vacuum, the current through the contacts concentrated on that last contact point on the contact surface and makes a hot spot there. As the medium is vacuum, the metal on the contact surface gets easily vaporized due to that hot spot and create a conducting media for arc path. Therefore, the material constituting the arc is very small and thus a feeble arc is established even with high current interruption. The arc will be initiated and continues until the onset of next current zero. Th figure below shows the cross section assembly of a VCB.



Cross section of Vacuum Interrupter

At current zero this vacuum arc is extinguished and the conducting metal vapor is re-condensed on the contact surface. At this point, the contacts are already separated hence there is no question of re-vaporization of contact surface, for next cycle of current. That means, the arc cannot be reestablished again. In this way vacuum circuit breaker prevents the reestablishment of arc by producing high dielectric strength in the contact gap after current zero.

There are two types of arc shapes. For interrupting current up to 10 kA, the arc remains diffused and the form of vapor discharge and cover the entire contact surface. Above 10 kA the diffused arc is constricted considerably by its own magnetic field and the contracts. The phenomenon gives rise to over heating of contacts at its center. In order to prevent this, the design of the contacts should be such that the arc does not remain stationary but keeps travelling by its own magnetic field. Specially designed contact shape of vacuum circuit breaker makes the constricted stationary arc travel along the surface of the contacts, thereby causing minimum and uniform contact erosion.

3.8 SF_6 Circuit Breaker

A circuit breaker in which the current carrying contacts operate in sulphur hexafluoride or SF_6 gas is known as an *SF_6 circuit breaker*. SF_6 has excellent insulating property and it has a high electro-negativity. Therefore, it has high affinity of absorbing free electrons. Whenever a free electron collides with the SF_6 gas molecule, it is absorbed by that gas molecule and forms a negative ion with the following processes.

$$SF_6 + e = SF_6^-$$
$$SF_6 + e = SF_5^- + F$$

These negative ions are much heavier than a free electron and therefore the over all mobility of the negatively charged particle in the medium is considerably reduced compared to other gases. As the mobility of charged particle is reduced, therefore the severity of arcing shall also be affected and reduced.

Hence, for heavier and less mobile charged particles in SF_6 gas, it acquires very high dielectric strength. Not only the gas has a good dielectric strength but also it has the unique property of fast recombination after the process of arcing is completed. The gas also has a very good heat transfer property. Due to its low gaseous viscosity (because of less molecular mobility) SF_6 gas can efficiently transfer heat by convection. So due to its high dielectric strength and high cooling effect SF_6 gas is approximately 100 times more effective arc quenching medium compared to air. Due to these unique properties of this gas, SF_6 circuit breaker is used in complete range of medium voltage and high voltage electrical power system. These circuit breakers are available for the voltage ranges from 33KV to 800KV and even more.

3.8.1 Disadvantages of SF_6 CB

The SF_6 gas is identified as a greenhouse gas, safety regulation are being introduced in many countries in order to prevent its release into atmosphere.

Puffer type design of SF_6 CB needs a high mechanical energy which is almost five times greater than that of oil circuit breaker.

3.8.2 Types of sf_6 circuit breaker

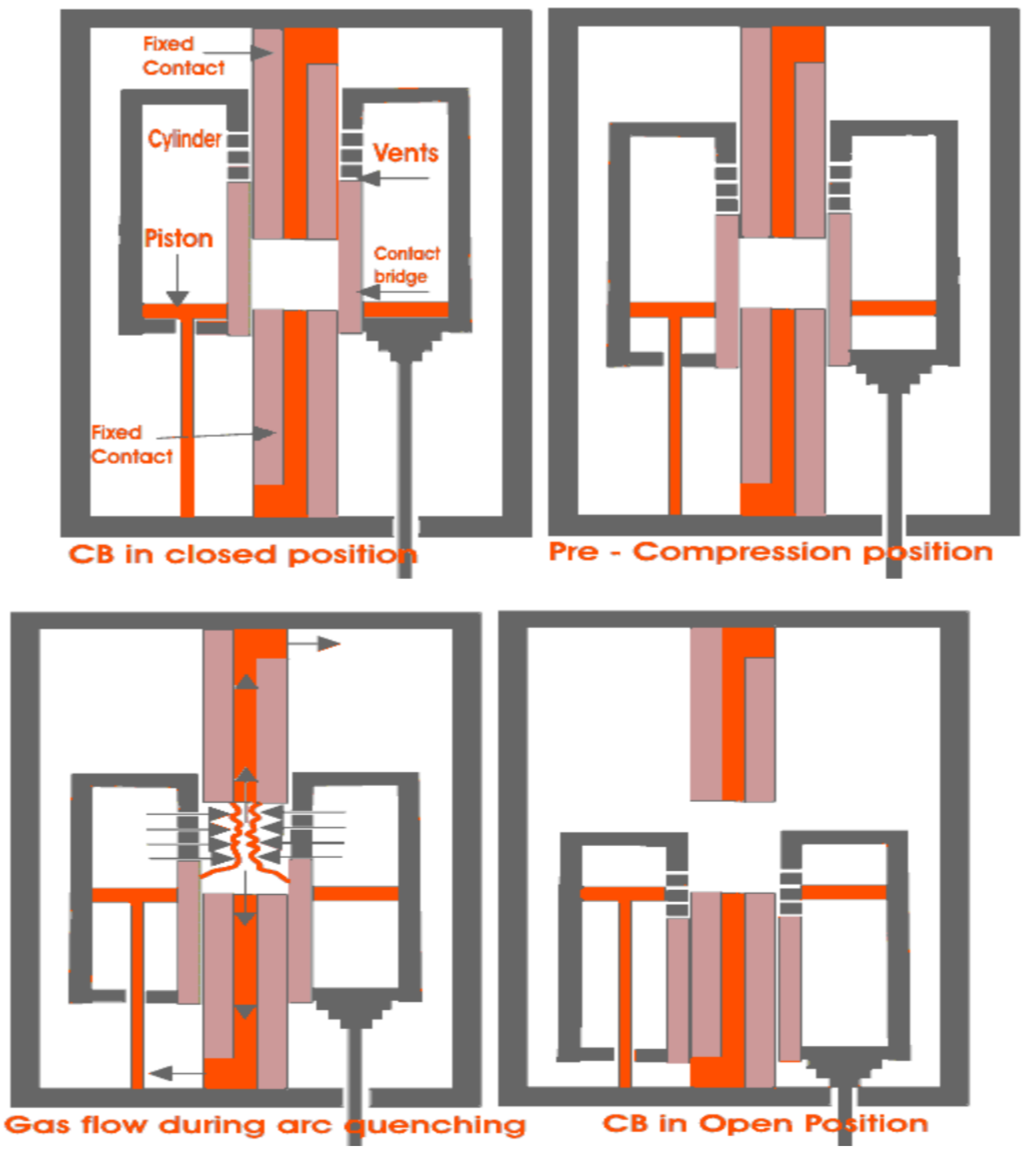
There are mainly three types of SF_6 CB depending upon the voltage level of application-

1. Single interrupter SF_6 CB applied for up to 245 KV(220 KV) system.
2. Two interrupter SF_6 CB applied for up to 420 KV(400 KV) system.

3. Four interrupter SF_6 CB applied for up to 800 KV(715 KV) system.

3.8.3 Working of SF_6 circuit breaker

The working of SF_6 CB of first generation was quite simple it is some extent similar to air blast circuit breaker. Here SF_6 gas was compressed and stored in a high pressure reservoir. During operation of SF_6 circuit breaker this highly compressed gas is released through the arc in breaker and collected to relatively low pressure reservoir and then it pumped back to the high pressure reservoir for re utilize.



The working of SF_6 circuit breaker is little bit different in modern time. Innovation of

Puffer type design makes operation of SF_6 CB much easier. In *Puffer* type design, the arc energy is utilized to develop pressure in the arcing chamber for arc quenching.

Here the breaker is filled with SF_6 gas at rated pressure. There are two fixed contact fitted with a specific contact gap. A sliding cylinder bridges these to fixed contacts. The cylinder can axially slide upward and downward along the contacts. There is one stationary piston inside the cylinder which is fixed with other stationary parts of the SF_6 circuit breaker, in such a way that it cannot change its position during the movement of the cylinder. As the piston is fixed and cylinder is movable or sliding, the internal volume of the cylinder changes when the cylinder slides.

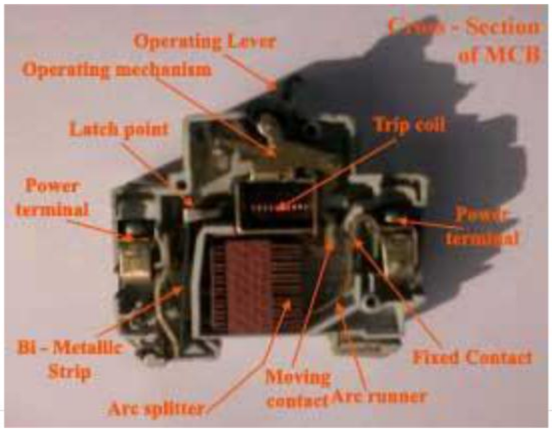
During opening of the breaker the cylinder moves downwards against position of the fixed piston hence the volume inside the cylinder is reduced which produces compressed SF_6 gas inside the cylinder. The cylinder has numbers of side vents which were blocked by upper fixed contact body during closed position. As the cylinder move further downwards, these vent openings cross the upper fixed contact, and become unblocked and then compressed SF_6 gas inside the cylinder will come out through this vents in high speed towards the arc and passes through the axial hole of the both fixed contacts. The arc is quenched during this flow of SF_6 gas.

During closing of the circuit breaker, the sliding cylinder moves upwards and as the position of piston remains at fixed height, the volume of the cylinder increases which introduces low pressure inside the cylinder compared to the surrounding. Due to this pressure difference SF_6 gas from surrounding will try to enter in the cylinder. The higher pressure gas will come through the axial hole of both fixed contact and enters into cylinder via vent and during this flow; the gas will quench the arc.

The TRIP Unit of the MCB

The trip unit is the main part, responsible for proper working of miniature circuit breaker**.** Two main types of trip mechanism are provided in MCB. A bimetal provides protection against over load current and an electromagnet provides protection against short-circuit current.

OPERATION OF MINIATURE CIRCUIT BREAKER



There are three mechanisms provided in a single miniature circuit breaker to make it switched off. If we carefully observe the picture beside, we will find there are mainly one bi – metallic strip, one trip coil and one hand operated on – off lever. Electric current carrying path of a miniature circuit breaker shown in the picture is like follows. First left hand side power terminal – then bimetallic strip – then current coil or trip coil – then moving contact – then fixed contact and – lastly right had side power terminal. All are arranged in series. Miniature Circuit Breaker

If circuit is overloaded for long time, the bi – metallic strip becomes over heated and deformed. This deformation of bi metallic strip causes, displacement of latch point. The moving contact of the MCB is so arranged by means of spring pressure, with this latch point, that a little displacement of latch causes, release of spring and makes the moving contact to move for opening the MCB. The current coil or trip coil is placed such a manner that during short circuit fault the *mmf* of that coil causes its plunger to hit the same latch point and make the latch to be displaced. Hence the MCB will open in same manner. Again when operating lever of the miniature circuit breaker is operated by hand, that means when we make the MCB at off position manually, the same latch point is displaced as a result moving contact separated from fixed contact in same manner. So, whatever may be the operating mechanism from either of the three possibilities, such as deformation of bi – metallic strip, increased *mmf* of trip coil and/or manual operation, the same latch point is displaced and the deformed spring is released, which ultimately responsible for movement of the moving contact. When the moving contact separated from fixed contact, there may be a high chance of arc. This arc then goes up through the arc runner and enters into arc splitters and is finally quenched. When we switch on an MCB, we actually reset the displaced operating latch to its previous on position and make the MCB ready for another switch off or trip operation.

3.10 HRC Fuse or High Rupturing Capacity Fuse

HRC fuse or high rupturing capacity fuse is a type of fuse whose wire or element can carry short circuit heavy current for a known time period. During this time if the fault is removed, then it does not blow off otherwise it blows off or melts.

The enclosure of HRC fuse is either of glass or some other chemical compound. This enclosure is fully air tight to avoid the effect of atmosphere on the fuse materials. The ceramic enclosure having metal end cap at both heads, to which fusible silver wire is welded. The space within the enclosure, surrounding the fuse wire or fuse element is completely packed with a filling powder. This type of fuse is reliable and has inverse time characteristic, that means if the fault current is high then rupture time is less and if fault current is not so high then rupture time is long.

3.10.1 Operation of HRC fuse

When the over rated current flows through the fuse element of high rupturing capacity fuse the element is melted and vaporized. The filling powder is of such a quantity that the chemical reaction between the silver vapour and the filling powder forms a high electrical resistance substance which very much help in quenching the arc.

CH-7

Causes of Overvoltages

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

1. Internal causes

(i) Switching surges (ii) Insulation failure

(iii) Arcing ground (iv) Resonance

External causes i.e. lightning

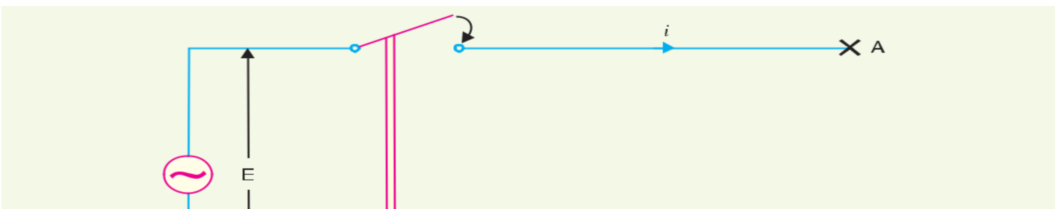
Internal causes do not produce surges of large magnitude. Experience shows that surges due to internal causes hardly increase the system voltage to twice the normal value. Generally, surges due to internal causes are taken care of by providing proper insulation to the equipment in the power system. However, surges due to lightning are very severe and may increase the system voltage to several times the normal value. If the equipment in the power system is not protected against lightning surges, these surges may cause considerable damage. In fact, in a power system, the protective devices provided against overvoltages mainly take care of lightning surges.

Internal Causes of Overvoltages

Internal causes of overvoltages on the power system are primarily due to oscillations set up by the sudden changes in the circuit conditions. This circuit change may be a normal switching operation such as opening of a circuit breaker, or it may be the fault condition such as grounding of a line conductor. In practice, the normal system insulation is suitably designed to withstand such surges. We shall briefly discuss the internal causes of overvoltages.

Switching Surges. The overvoltages produced on the power system due to switching operations are known as switching surges. A few cases will be discussed by way of illustration :

(i) Case of an open line. During switching operations of an unloaded line, travelling waves are set up which produce overvoltages on the line. As an illustration, consider an unloaded line being connected to a voltage source as shown in Fig. 24.2.



When the unloaded line is connected to the voltage source, a voltage wave is set up which travels along the line. On reaching the terminal point A , it is reflected back to the supply end without change of sign. This causes voltage doubling i.e. voltage on the line becomes twice the normal value. If $E_{r.m.s.}$ is the supply voltage, then instantaneous voltage which the line will have to withstand will be $2\sqrt{2}\,E$. This overvoltage is of temporary nature. It is because the line losses attenuate the wave and

in a very short time, the line settles down to its normal supply voltage E. Similarly, if an unloaded line is switched off, the line will attain a voltage of $2\sqrt{2}\,E$ for a moment before settling down to the normal value.

(ii) Case of a loaded line. Overvoltages will also be produced during the switching operations of a loaded line. Suppose a loaded line is suddenly interrupted. This will set up a voltage of $2 Z_n i$ across the break (i.e. switch) where i is the instantaneous value of current at the time of opening of line and $*Z_n$ is the natural impedance of the line. For example, suppose the line having Z_n = 1000 Ω carries a current of 100 A (r.m.s.) and the break occurs at the moment when current is maximum. The

voltage across the breaker (i.e. switch) = $2\sqrt{2} \times 100 \times 1000/1000$ = 282·8 kV. If V_m is the peak value of voltage in kV, the maximum voltage to which the line may be subjected is = (V_m + 282·8) kV.

(iii) Current chopping. Current chopping results in the production of high voltage transients across the contacts of the air blast circuit breaker as detailed in chapter 19. It is briefly discussed here. Unlike oil circuit breakers, which are independent for the effectiveness on the magnitude of the

current being interrupted, air-blast circuit breakers retain the same extinguishing power irrespective of the magnitude of this current. When breaking low currents (e.g. transformer magnetising current) with air-blast breaker, the powerful de-ionising effect of air-blast causes the current to fall abruptly to zero well before the natural current zero is reached. This phenomenon is called current chopping and produces high transient voltage across the breaker contacts. Overvoltages due to current chopping are prevented by resistance switching (See Chapter 19).

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 overvoltages in the system. This is illustrated in Fig. 24.3.

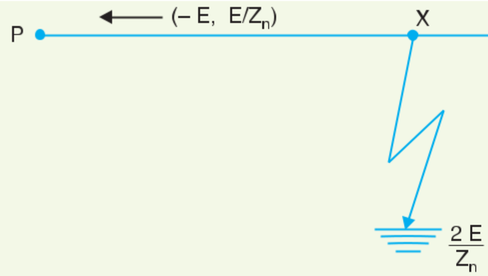


Fig. 24.3

Suppose a line at potential E is earthed at point X . The earthing of the line causes two equal voltages of −E to travel along X Q and XP containing currents −E/Zn and +E/Zn respectively. Both these currents pass through X to earth so that current to earth is 2 E/Zn.

Arcing ground. In the early days of transmission, the neutral of three phase lines was not earthed to gain two advantages. Firstly, in case of line-to-ground fault, the line is not put out of action. Secondly, the zero sequence currents are eliminated, resulting in the decrease of interference with communication lines. Insulated neutrals give no problem with short lines and comparatively low voltages. However, when the lines are long and operate at high voltages, serious problem called arcing ground is often witnessed. The arcing ground produces severe oscillations of three to four times the normal voltage.

The phenomenon of intermittent arc taking place in line-to-ground fault of a 3φ system with consequent production of transients is known as arcing ground.

The transients produced due to arcing ground are cumulative and may cause serious damage to the equipment in the power system by causing breakdown of insulation. Arcing ground can be pre-vented by earthing the neutral.

Resonance. Resonance in an electrical system occurs when inductive reactance of the cir-cuit becomes equal to capacitive reactance. Under resonance, the impedance of the circuit is equal to resistance of the circuit and the p.f. is unity. Resonance causes high voltages in the electrical system. In the usual transmission lines, the capacitance is very small so that resonance rarely occurs at the fundamental supply frequency. However, if generator e.m.f. wave is distorted, the trouble of reso-nance may occur due to 5th or higher harmonics and in case of underground cables too.

Lightning

An electric discharge between cloud and earth, between clouds or between the charge centres of the same cloud is known as lightning.

Lightning is a huge spark and takes place when clouds are charged to such a high potential (+ve or −ve) with respect to earth or a neighbouring cloud that the dielectric strength of neighbouring medium (air) is destroyed. There are several theories which exist to explain how the clouds acquire charge. The most accepted one is that during the uprush of warm moist air from earth, 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, depending upon the charge of drops of water they contain. The charge on a cloud may become so great that it may discharge to another cloud or to earth and we call this discharge as lightning. The thunder which accompanies lightning is due to the fact that lightning suddenly heats up the air, thereby causing it to expand. The surrounding air pushes the expanded air back and forth causing the wave motion of air which we recognise as thunder 24.5 Mechanism of Lightning Discharge

Let us now discuss the manner in which a lightning discharge occurs. When a charged cloud passes over the earth, it induces equal and opposite charge on the earth below. Fig. 24.4 shows a negatively charged cloud inducing a positive charge on the earth below it. As the charge acquired by the cloud increases, the potential between cloud and earth increases and, therefore, gradient in the air increases. When the potential gradient is sufficient (5 kV*/cm to 10 kV/cm) to break down the surrounding air, the lightning stroke starts. The stroke mechanism is as under :

(i) As soon as the air near the cloud breaks down, a streamer called leader streamer or pilot streamer starts from the cloud towards the earth and carries charge with it as shown in Fig. 24.4 (i). The leader streamer will continue its journey towards earth as long as the cloud, from which it originates feeds enough charge to it to maintain gradient at the tip of leader streamer above the strength of air. If this gradient is not maintained, the leader streamer stops and the charge is dissipated without the formation of a complete stroke. In other words, the leader streamer will not reach the earth. Fig. 24.4 (i) shows the leader streamer being unable to reach the earth as gradient at its end cloud not be maintained above the strength of air. It may be noted that current in the leader streamer is low (<100 A) and its velocity of propagation is about 0·05% that of velocity of light. Moreover, the luminosity of leader is also very low.

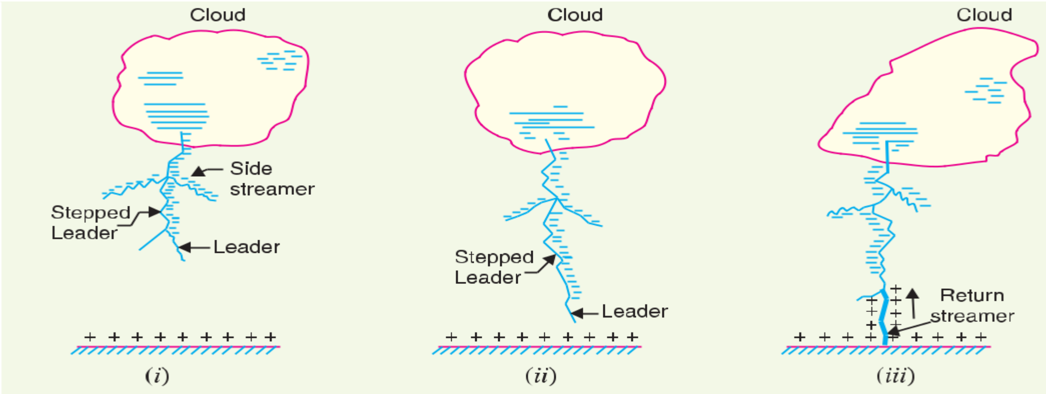


Fig. 24.4

(ii) In many cases, the leader streamer continues its journey towards earth [See Fig. 24.4 (ii)] until it makes contact with earth or some object on the earth. As the leader streamer moves towards earth, it is accompanied by points of luminescence which travel in jumps giving rise to stepped leaders. The velocity of stepped leader exceeds one-sixth of that of light and distance travelled in one step is about 50 m. It may be noted that stepped leaders have sufficient luminosity and give rise to first visual phenomenon of discharge.

(iii) The path of leader streamer is a path of ionisation and, therefore, of complete breakdown of insulation. As the leader streamer reaches near the earth, a return streamer shoots up from the earth [See Fig. 24.4 (iii)] to the cloud, following the same path as the main channel of the downward leader. The action can be compared with the closing of a switch between the positive and negative terminals; the downward leader having negative charge and re-turn streamer the positive charge. This phenomenon causes a sudden spark which we call lightning. With the resulting neutralisation of much of the negative charge on the cloud, any further discharge from the cloud may have to originate from some other portion of it.

The following points may be noted about lightning discharge :

(a) A lightning discharge which usually appears to the eye as a single flash is in reality made up of a number of separate strokes that travel down the same path. The interval between them varies from 0·0005 to 0·5 second. Each separate stroke starts as a downward leader from the cloud.

(b) It has been found that 87% of all lightning strokes result from negatively charged clouds and only 13% originate from positively charged clouds.

(c) It has been estimated that throughout the world, there occur about 100 lightning strokes per second.

(d) Lightning discharge may have currents in the range of 10 kA to 90 kA.

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.), namely;

1. Direct stroke 2. Indirect stroke

Direct stroke. In the direct stroke, the lightning discharge (i.e. current path) is directly from the cloud to the subject equipment e.g. an overhead line. From the line, the current path may be over the insulators down the pole to the ground. The overvoltages set up due to the stroke may be large enough to flashover this path directly to the ground. The direct strokes can be of two types viz. (i) Stroke A and (ii) stroke B.

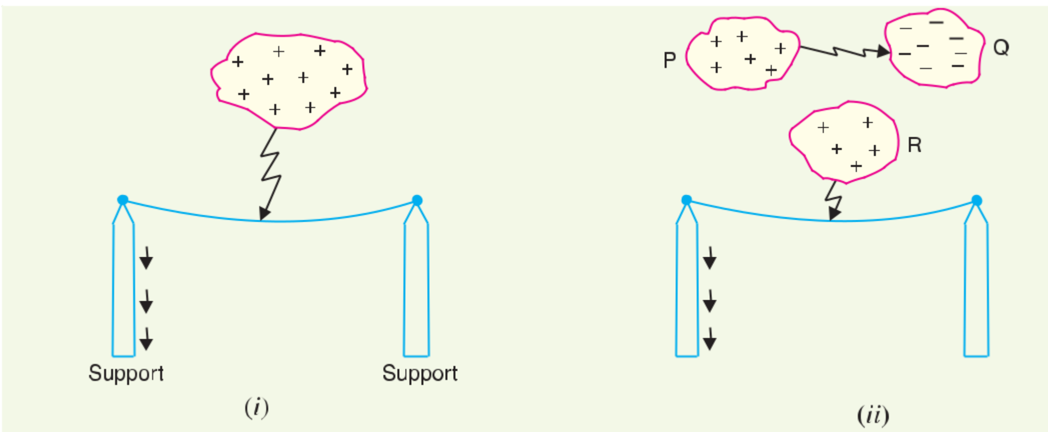


Fig. 24.5

(i) In stroke A , the lightning discharge is from the cloud to the subject equipment i.e. an overhead line in this case as shown in Fig. 24.5 (i). 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) In stroke B, the lightning discharge occurs on the overhead line as a result of stroke A between the clouds as shown in Fig. 24.5 (ii). 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.

Two points are worth noting about direct strokes. Firstly, direct strokes on the power system are very rare. Secondly, stroke A will always occur on tall objects and hence protection can be provided against it. However, stroke B completely ignores the height of the object and can even strike the ground. Therefore, it is not possible to provide protection against stroke B.

Indirect stroke. Indirect strokes result from the electrostatically induced charges on the conductors due to the presence of charged clouds. This is illustrated in 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, however, 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. The result is that negative charge rushes along the line is both directions in the form of travelling waves. It may be worthwhile to mention here that majority of the surges in a transmission line are caused by indirect lightning strokes.

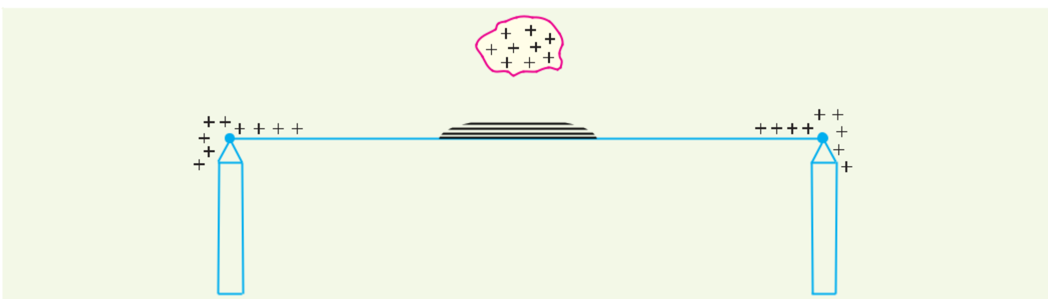


Fig. 24.6

Harmful Effects of Lightning

A direct or indirect lightning stroke on a transmission line produces a steep-fronted voltage wave on the line. The voltage of this wave may rise from zero to peak value (perhaps 2000 kV) in about 1 μs and decay to half the peak value in about 5μs. Such a steep-fronted voltage wave will initiate travel-ling waves along the line in both directions with the velocity dependent upon the L and C parameters of the line.

(i) The travelling waves produced due to lightning surges will shatter the insulators and may even wreck poles.

(ii) If the travelling waves produced due to lightning hit the windings of a transformer or gen-erator, it may cause considerable damage. The inductance of the windings opposes any sudden passage of electric charge through it. Therefore, the electric charges "piles up" against the transformer (or generator). This induces such an excessive pressure between the windings that insulation may breakdown, resulting in the production of arc. While the normal voltage between the turns is never enough to start an arc, once the insulation has
broken down and an arc has been started by a momentary overvoltage, the line voltage is usually sufficient to maintain the arc long enough to severely damage the machine.

(iii) If the arc is initiated in any part of the power system by the lightning stroke, this arc will set up very disturbing oscillations in the line. This may damage other equipment connected to the line.

Protection Against Lightning

Transients or surges on the power system may originate from switching and from other causes but the most important and dangerous surges are those caused by lightning. The lightning surges may cause serious damage to the expensive equipment in the power system (e.g. generators, transformers etc.) either by direct strokes on the equipment or by strokes on the transmission lines that reach the equip-ment as travelling waves. It is necessary to provide protection against both kinds of surges. The most commonly used devices for protection against lightning surges are :

(i) Earthing screen

(ii) Overhead ground wires

(iii) Lightning arresters or surge diverters

Earthing screen provides protection to power stations and sub-stations against direct strokes whereas overhead ground wires protect the transmission lines against direct lightning strokes. How-ever, lightning arresters or surge diverters protect the station apparatus against both direct strokes and the strokes that come into the apparatus as travelling waves. We shall briefly discuss these methods of protection.

The Earthing Screen

The power stations and sub-stations generally house expensive equipment. These stations can be protected against direct lightning strokes by providing earthing screen. It consists of a network of copper conductors (generally called shield or screen) mounted all over the electrical equipment in the sub-station or power station. The shield is properly connected to earth on atleast two points through a low impedance. On the occurrence of direct stroke on the station, screen provides a low resistance path by which lightning surges are conducted to ground. In this way, station equipment is protected against damage. The limitation of this method is that it does not provide protection against the travelling waves which may reach the equipment in the station.

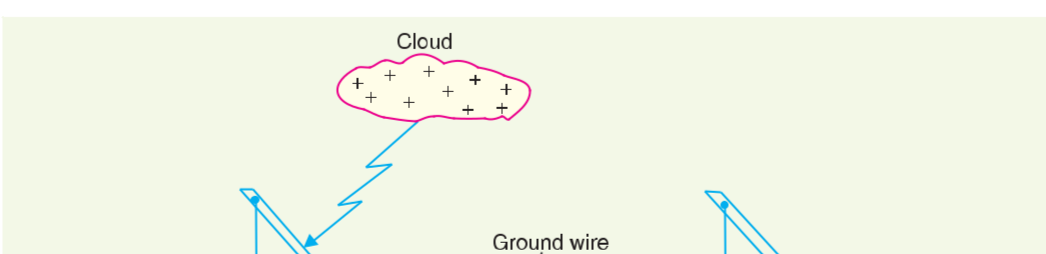
Overhead Ground Wires

The most effective method of providing protection to transmission lines against direct lightning strokes is by the use of overhead ground wires as shown in Fig. 24.7. For simplicity, one ground wire and one line conductor are shown. The ground wires are placed above the line conductors at such positions that practically all lightning strokes are intercepted by them (i.e. ground wires). The ground wires are grounded at each tower or pole through as low resistance as possible. Due to their proper location, the *ground wires will take up all the lightning strokes instead of allowing them to line conductors.

When the direct lightning stroke occurs on the transmission line, it will be taken up by the ground wires. 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. It may be mentioned here that the degree of protection provided by the ground wires depends upon the footing resistance of the tower. Suppose, for example, 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_t given by ;

$$V_t = I_1R_1$$

Since V_t ($= I_1R_1$) is the approximate voltage between tower and line conductor, this is also the voltage that will appear across the string of insulators. If the value of V_t is less than that required to cause insulator flashover, no trouble results. On the other hand, if V_t is excessive, the insulator flashover may occur. Since the value of V_t depends upon tower-footing resistance R_1, the value of this resistance must be kept as low as possible to avoid insulator flashover.



Advantages

(i) It provides considerable protection against direct lightning strokes on transmission lines.

(ii) A grounding wire provides damping effect on any disturbance travelling along the line as it acts as a short-circuited secondary.

(iii) It provides a certain amount of electrostatic shielding against external fields. Thus it reduces the voltages induced in the line conductors due to the discharge of a neighbouring cloud.

Disadvantages

(i) It requires additional cost.

(ii) There is a possibility of its breaking and falling across the line conductors, thereby causing a short-circuit fault. This objection has been greatly eliminated by using galvanised stranded steel conductors as ground wires. This provides sufficient strength to the ground wires.

Lightning Arresters

The earthing screen and ground wires can well protect the electrical system against direct lightning strokes but they fail to provide protection against travelling waves which may reach the terminal apparatus. The lightning arresters or surge diverters provide protection against such surges.

lightning arrester or a surge diverter is a protective device which conducts the high voltage surges on the power system to the ground.
Fig. 24.8 (i) shows the basic form of a surge diverter. It consists of a spark gap in series with a non-linear resistor. One end of the diverter is connected to the terminal of the equipment to be protected and the other end is effectively grounded. The length of the gap is so set that normal line voltage is not enough to cause an arc across the gap but a dangerously high voltage will break down the air insulation and form an arc. The property of the non-linear resistance is that its resistance decreases as the voltage (or current) increases and vice-versa. This is clear from the *volt/amp characteristic of the resistor shown in Fig. 24.8 (ii).

Action. The action of the lightning arrester or surge diverter is as under :

(i) Under normal operation, the lightning arrester is off the line i.e. it conducts **no current to earth or the gap is non-conducting.

(ii) On the occurrence of overvoltage, the air insulation across the gap breaks down and an arc is formed, providing a low resistance path for the surge to the ground. In this way, the excess charge on the line due to the surge is harmlessly conducted through the arrester to the ground instead of being sent back over the line.

(iii) It is worthwhile to mention the function of non-linear resistor in the operation of arrester. As the gap sparks over due to overvoltage, the arc would be a short-circuit on the power system and may cause power-follow current in the arrester. Since the characteristic of the resistor is to offer high resistance to high voltage (or current), it prevents the effect of a short-circuit. After the surge is over, the resistor offers high resistance to make the gap non-conducting.

Two things must be taken care of in the design of a lightning arrester. Firstly, when the surge is over, the arc in gap should cease. If the arc does not go out, the current would continue to flow through the resistor and both resistor and gap may be destroyed. Secondly, I R drop (where I is the surge current) across the arrester when carrying surge current should not exceed the breakdown strength of the insulation of the equipment to be protected.

Types of Lightning Arresters

There are several types of lightning arresters in general use. They differ only in constructional details
but operate on the same principle viz. providing low resistance path for the surges to the ground. We shall discuss the following types of lightning arresters :

1. Rod gap arrester	**2.**	**Horn gap arrester**
3. Multigap arrester	**4.**	**Expulsion type lightning arrester**

Valve type lightning arrester

1. Rod Gap Arrester. It is a very simple type of diverter and consists of two 1·5 cm rods which are bent at right angles with a gap inbetween as shown in Fig. 24.9. One rod is connected to the line circuit and the other rod is connected to earth. The distance between gap and insulator (i.e. distance P) must not be less than one-third of the gap length so that the arc may not reach the insulator and damage it. Generally, the gap length is so adjusted that breakdown should occur at 80% of spark- over voltage in order to avoid cascading of very steep wave fronts across the insulators. The string of insulators for an overhead line on the bushing of transformer has frequently a rod gap across it. Fig. 24.9 shows the rod gap across the bushing of a transformer.

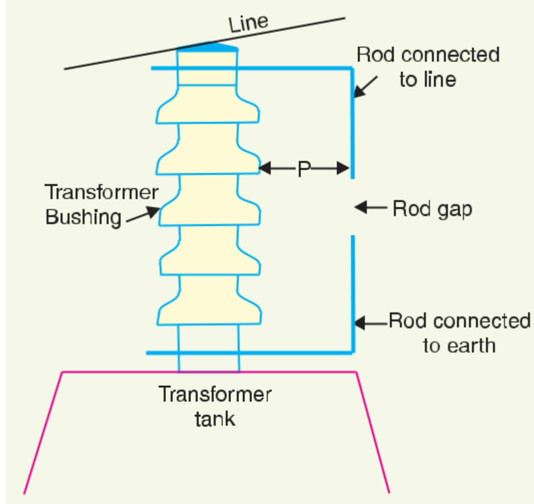


Fig. 24.9

Under normal operating conditions, the gap remains non-conducting. On the occurrence of a high voltage surge on the line, the gap sparks over and the surge current is conducted to earth. In this way, excess charge on the line due to the surge is harmlessly conducted to earth.

Limitations

(i) After the surge is over, the arc in the gap is maintained by the †normal supply voltage, leading to a short-circuit on the system.

(ii) The rods may melt or get damaged due to excessive heat produced by the arc.

(iii) The climatic conditions (e.g. rain, humidity, temperature etc.) affect the performance of rod gap arrester.

(iv) The polarity of the surge also affects the performance of this arrester.

Due to the above limitations, the rod gap arrester is only used as a 'back-up' protection in case of main arresters.

Horn Gap Arrester. Fig. 24.10 shows the horn gap arrester. It consists of two horn shaped metal rods A and B separated by a small air gap. The horns are so constructed that distance between them gradually increases towards the top as shown. 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 is so designed that it 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. The gap between the horns is so adjusted that normal supply voltage is not enough to cause an arc across the gap.

Multigap arrester. Fig. 24.11 shows the multigap arrester. It consists of a series of metallic (generally alloy of zinc) cylinders insulated from one another and separated by small intervals of air gaps. The first cylinder (i.e. A) in the series is connected to the line and the other to the ground through a series resistance. The series resistance limits the power arc. By the inclusion of series resistance, the degree of protection against travelling waves is reduced. In order to overcome this difficulty, some of the gaps (B to C in Fig. 24.11) are shunted by a resistance.
Expulsion type arrester. This type of arrester is also called 'protector tube' and is com-monly used on system operating at voltages upto 33 kV. Fig. 24.12 (i) shows the essential parts of an expulsion type lightning arrester. It essentially consists of a rod gap A A′ in series with a second gap enclosed within the fibre tube. The gap in the fibre tube is formed by two electrodes. The upper electrode is connected to rod gap and the lower electrode to the earth. One expulsion arrester is placed under each line conductor. Fig. 24.12 (ii) shows the installation of expulsion arrester on an overhead line.

Valve type arrester. Valve type arresters incorporate non-linear resistors and are exten-sively used on systems operating at high voltages. Fig. 24.13 (i) shows the various parts of a valve type arrester. It consists of two assemblies (i) series spark gaps and (ii) non-linear resistor discs (made of material such as thyrite or metrosil) in series. The non-linear elements are connected in series with the spark gaps. Both the assemblies are accommodated in tight porcelain container.

(i) The spark gap is a multiple assembly consisting of a number of identical spark gaps in series. Each gap consists of two electrodes with a fixed gap spacing. The voltage distribu-tion across the gaps is linearised by means of additional resistance elements (called grading resistors) across the gaps. The spacing of the series gaps is such that it will withstand the normal circuit voltage. However, an overvoltage will cause the gap to breakdown, causing the surge current to ground via the non-linear resistors.

(ii) The non-linear resistor discs are made of an inorganic compound such as Thyrite or Metrosil. These discs are connected in series. The non-linear resistors have the property of offering a high resistance to current flow when normal system voltage is applied, but a low resis-tance to the flow of high-surge currents. In other words, the resistance of these non-linear elements decreases with the increase in current through them and vice-versa.

Surge Absorber

The travelling waves set up on the transmission lines by the surges may reach the terminals apparatus and cause damage to it. The amount of damage caused not only depends upon the amplitude of the surge but also upon the steepness of its wave front. The steeper the wave front of the surge, the more the damage caused to the equipment. In order to reduce the steepness of the wave front of a surge, we generally use surge ab-sorber.

A surge absorber is a protective device which reduces the steepness of wave front of a surge by ab-sorbing surge energy.

Although both surge diverter and surge absorber eliminate the surge, the manner in which it is done is different in the two devices.

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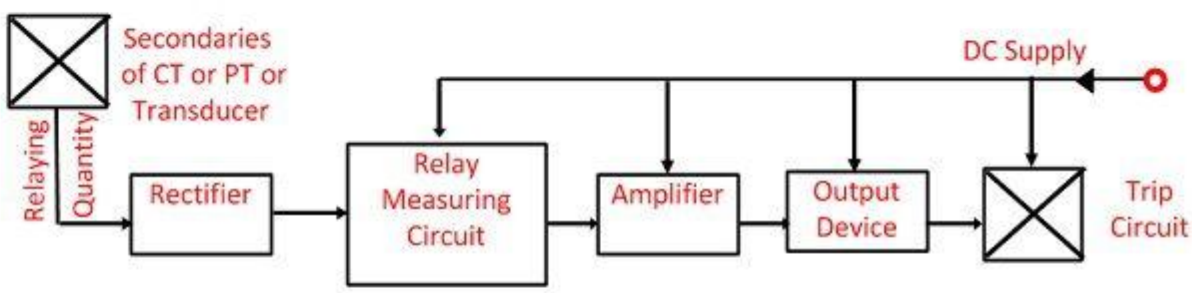
Static Relay

Definition: The relay which does not contain any moving parts is known as the static relay. In such type of relays, the output is obtained by the static components like magnetic and electronic circuit etc. The relay which consists static and electromagnetic relay is also called static relay because the static units obtain the response and the electromagnetic relay is only used for switching operation.

The component of the static relay is shown in the figure below. The input of the current transformer is connected to the transmission line, and their output is given to the rectifier. The rectifier was rectifying the input signal and pass it to the relaying measuring unit.



Block Diagram of Static Relay

The rectifying measuring unit has the comparators, level detector and the logic circuit. The output signal from relaying unit obtains only when the signal reaches the threshold value. The output of the relaying measuring unit acts as an input to the amplifier.

The amplifier amplifies the signal and gives the output to the output devices. The output device activates the trip coil only when the relay operates. The output is obtained from the output devices only when the measurand has the well-defined value. The output device is activated and gives the tripping command to the trip circuit.

The static relay only gives the response to the electrical signal. The other physical quantities like heat temperature etc. is first converted into the analogue and digital electrical signal and then act as an input for the relay.

Advantages of Static Relay

The following are the benefits of static relays.

The static relay consumes very less power because of which the burden on the measuring instruments decreases and their accuracy increases.

The static relay gives the quick response, long life, high reliability and accuracy and it is shockproof.

The reset time of the relay is very less.
It does not have any thermal storage problems.
The relay amplifies the input signal which increases their sensitivity.
The chance of unwanted tripping is less in this relay.
The static relay can easily operate in earthquake-prone areas because they have high resistance to shock.

Limitations of Static Relay

The components used by the static relay are very sensitive to the electrostatic discharges. The electrostatic discharges mean sudden flows of electrons between the charged objects. Thus special maintenance is provided to the components so that it does not affect by the electrostatic discharges.
The relay is easily affected by the high voltage surges. Thus, precaution should be taken for avoiding the damages through voltage spikes.
The working of the relay depends on the electrical components.
The relay has less overloading capacity.
The static relay is more costly as compared to the electromagnetic relay.
The construction of the relay is easily affected by the surrounding interference.

Overcurrent Relay

Definition: The overcurrent relay is defined as the relay, which operates only when the value of the current is greater than the relay setting time. It protects the equipment of the power system from the fault current.
Depending on the time of operation the overcurrent relay is categorized into following types.
Instantaneous Overcurrent relay
Inverse time Overcurrent Relay
Definite Time Overcurrent Relay
Inverse Definite Time Overcurrent Relay
Very Inverse Definite Time Overcurrent Relay
Extremely Inverse Definite Time Overcurrent Relay
Instantaneous Overcurrent relay
Instantaneous Over Current Relay
Construction and working principle of **instantaneous over current relay** is quite simple. Here generally a magnetic core is wound by a current coil. A piece of iron is so fitted by hinge support and restraining spring in the relay, that when there is not sufficient current in the coil, the NO contacts remain open. When the current in the coil crosses a preset value, the attractive force becomes enough to pull the iron piece towards the magnetic core, and consequently, the no contacts get closed.

We refer the pre-set value of current in the relay coil as pickup setting current. This relay is referred as instantaneous **over current relay**, as ideally, the relay operates as soon as the current in the coil gets higher than pick upsetting current. There is no intentional time delay applied. But there is always an inherent time delay which we cannot avoid practically. In practice, the operating time of an instantaneous relay is of the order of a few milliseconds.
Basic on Inverse Definite Minimum Time Over-current Relay (IDMT Relay)

Working Principle of an Over-current Relay:

In an over current relay or o/c relay the actuating quantity is only current.
There is only one current operated element in the relay, no voltage coil etc.

are required to construct this protective relay.

In an over current relay, there would be essentially a current coil. When normal current flows through this coil, the magnetic effect generated by the coil is not sufficient to move the moving element of the relay, as in this condition the restraining force is greater than deflecting force. But when the current through the coil increased, the magnetic effect increases, and after certain level of current, the deflecting force generated by the magnetic effect of the coil, crosses the restraining force, as a result, the moving element starts moving to change the contact position in the relay.

Although there are different types of over current relays but basic working principle of over current relay is more or less same for all.

Types of Over Current Relay

Depending upon time of operation, there are various types of OC relays, such as,

Instantaneous over current relay.
Definite time over current relay.

Inverse time over current relay.

Inverse time over current relay or simply inverse OC relay is again subdivided as inverse definite minimum time (IDMT), very inverse time, extremely inverse time over current relay or OC relay

Instantaneous Over Current Relay:

Construction and working principle of instantaneous over current relay quite simple.

Here generally a magnetic core is wound by current coil. A piece of iron is so fitted by hinge support and restraining spring in the relay, that when there is not sufficient current in the coil, the NO contacts remain open. When current in the coil crosses a present value, the attractive force becomes sufficient to pull the iron piece towards the magnetic core and consequently the No contacts are closed.

The preset value of current in the relay coil is referred as pick up setting current. This relay is referred as instantaneous over current relay, as ideally, the relay operates as soon as the current in the coil gets higher than pick up setting current. There is no intentional time delay applied. But there is always an inherent time delay which cannot be avoided practically. In practice the operating time of an instantaneous relay is of the order of a few
milliseconds.

Inverse Definite Minimum Time Over Current Relay or IDMT O/C Relay:

Ideal inverse time characteristics cannot be achieved, in an over current relay. As the current in the system increases, the secondary current of the current transformer is increased proportionally. The secondary current is fed to the relay current coil. But when the CT becomes saturated, there would not be further proportional increase of CT secondary current with increased system current.

From this phenomenon it is clear that from trick value to certain range of faulty level, an inverse time relay shows exact inverse characteristic. But after this level of fault, the CT becomes saturated and relay current does not increase further with increasing faulty level of the system. As the relay current is not increased further, there would not be any further reduction in time of operation in the relay. This time is referred as minimum time of operation. Hence, the characteristic is inverse in the initial part, which tends to a definite minimum operating time as the current becomes very high. That is why the relay is referred as inverse definite minimum time over current relay or simply IDMT relay.In this type of relays, the time of operation depends upon the magnitude of

actuating quantity. If the magnitude of actuating quantity is very high, the relay operation is very fast. In other words, the relay operating time that is time delay in the relay is inversely proportional to the magnitude of actuating quantity. The general characteristics of an inverse time relay is shown in figure below.

Here, in the graph it is clear that, when, actuating quantity is OA, the operating time of the relay is OA', when actuating quantity is OB, the relay operating time is OB' and when actuating quantity is OC, the relay operating quantity is OC'.

In the graph above, it is also observed that, when actuating quantity is less than OA, the relay operating time becomes infinity, that means for actuating quantity less than OA, the relay does not at all actuate. This minimum value of actuating quantity for which a relay initiates its operation is known as pick up value of actuating quantity. Here it is denoted as OA.

It is also seen from the graph that, when actuating quantity approaches to infinity along x axis the operating time does not approach to zero. The curve approaches to an approximately constant operating time. This is approximately minimum time required to operate the relay.

The inverse time relay, where the actuating quantity is current, is known as inverse current relay. In this type of relay, the inverse time is achieved by attaching some mechanical accessories in the relay. Inverse time delay is achieved in induction disc relay by providing a permanent magnet in such a way, that, when disc rotates, it cuts the flux of permanent magnet. Due to
this, current is induced in the disc which slows down the movement of the disc. A solenoid relay can be made inverse time relay, by providing a piston and a oil dash-pot. A piston, attached to the moving iron plunger, is immersed in oil in a dash-pot. When the solenoid relay is actuated, the piston moves upwards along with iron plunger. Viscosity of oil slows the upward movement of plunger. The speed of this upward movement against gravity also depends upon how strongly the solenoid attracts the iron plunger. This attraction force of the solenoid depends upon the magnitude of actuating current. Hence, time of operation of relay is inversely proportional to actuating current.

Pick Up Current | Current Setting | Plug Setting Multiplier and Time Setting

Multiplier of Relay:

During study of electrical protective relays, some special terms are frequently used. For proper understanding, the functions of different protective relays, the definition of such terms must be understood properly. Such terms are,

Pick up current.

Current setting.

Plug setting multiplier (PSM).

Time setting multiplier (TSM).

Pick Up Current of Relay

In all electrical relays, the moving contacts are not free to move. All the contacts remain in their respective normal position by some force applied on them continuously. This force is called controlling force of the relay. This controlling force may be gravitational force, may be spring force, may be magnetic force.

The force applied on the relay's moving parts for changing the normal position of the contacts, is called deflecting force. This deflecting force is always in opposition of controlling force and presents always in the relay. Although the deflecting force always presents in the relay directly connected to live line, but as the magnitude of this force is less than controlling force in normal condition, the relay does not operate. If the actuating current in the relay coil increases gradually, the deflecting force in electro mechanical relay, is also increased. Once, the deflecting force crosses the controlling force, the moving parts of the relay initiate to move to change the position of the contacts in the relay. The current for which the relay initiates it operation is called pick up current of relay.

Current Setting of Relay

he minimum pick up value of the deflecting force of an electrical relay is constant. Again the deflecting force of the coil is proportional to its number of turns and current flowing through the coil.

Now, if we can change the number of active turns of any coil, the required current to reach at minimum pick value of the deflecting force, in the coil also changes. That means if active turns of the relay coil is reduced, then proportionately more current is required to produce desired relay actuating force. Similarly if active turn of the relay coil is increased, then proportionately reduced current is required to produce same desired deflecting force.

Practically same model relays may be used in different systems. As per these systems requirement the pickup current of relay is adjusted. This is known as current setting of relay. This is achieved by providing required number of tapping in the coil. These taps are brought out to a plug bridge. The number of active turns in the coil can be changed by inserting plug in different points in the bridge. The current setting of relay is expressed in percentage ratio of relay pick up current to rated secondary current of CT. That means, For example, suppose, you want that, an over current relay should operate when the system current just crosses 125% of rated current. If the relay is rated with 1 A, the normal pick up current of the relay is 1 A and it should be equal to secondary rated current of current transformer connected to the relay.

Then, the relay will be operated when the current of CT secondary becomes more than or equal 1.25 A. As per definition,
The current setting is sometimes referred as current plug setting.

The current setting of over current relay is generally ranged from 50 % to 200 %, in steps of 25 %. For earth fault relay it is from 10% to 70% in steps of 10%.

Plug Setting Multiplier of RelayPlug setting multiplier of relay is referred as ratio of fault current in the relay to its pick up current.