Chapter - 1

INTRODUCTION TO SWITCHGEAR

1.1 WHAT IS SWITCHGEAR?

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

1.2 FEATURES OF SWITCHGEAR

- **Complete Reliability:** With the continued trend of interconnection and the increasing capacity of generating stations, the need for reliable switchgear has become of paramount importance.
- **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.
- **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.
- **Provision for Manual Control:** Switchgear must have provision for manual control. In case the electrical control fails, the necessary operation can be carried out through manual control.

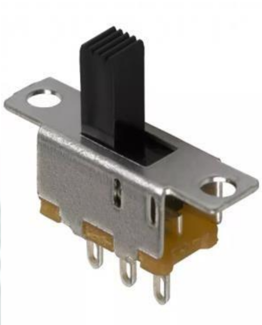
Switchgear covers a wide range of equipments concerned with switching and interrupting currents under both normal and abnormal conditions. Some of them are:

- SWITCHES
- FUSES
- CIRCUIT BREAKERS
- RELAYS

1.2.1 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. It is classified into:

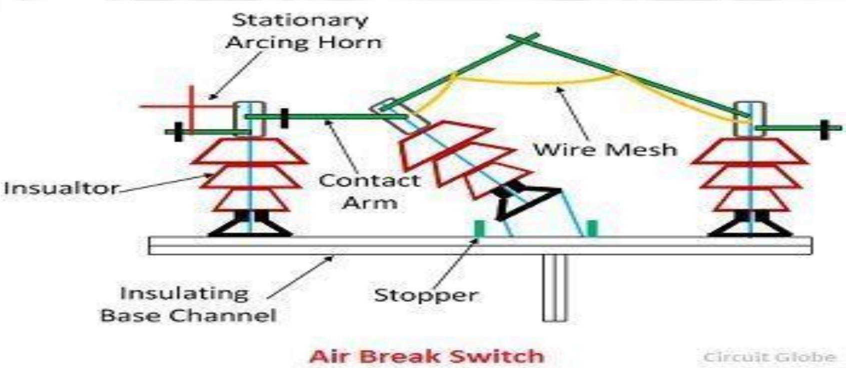
- Air switch
- Isolator switch
- Oil switch



1.2.1.1 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



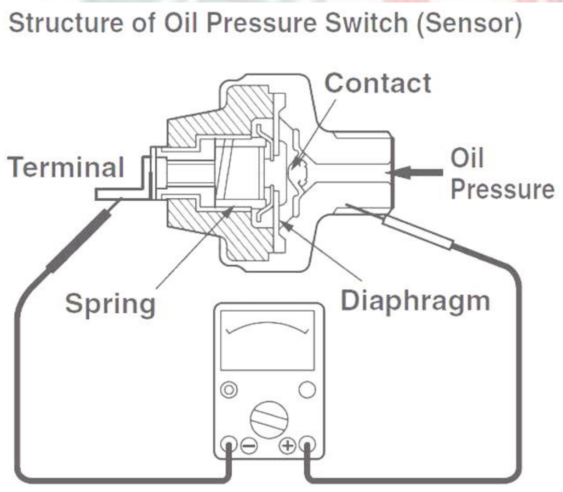
1.2.1.2 ISOLATOR SWITCH

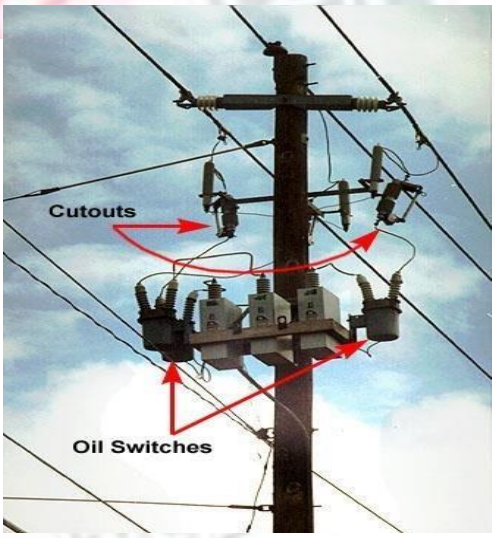
It is designed to open a circuit under no load. Its main purpose is to isolate one portion of the circuit from the other and is not intended to be opened while current is flowing in the line.

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.

1.2.1.3 OIL SWITCH

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.





1.2.2 FUSES

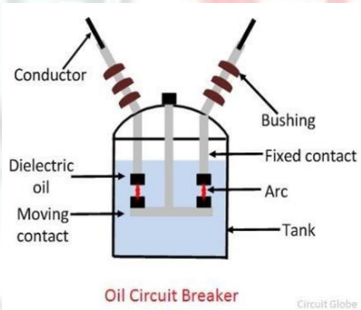
A fuse is a short piece of wire or thin strip which melts when excessive current flows through it for sufficient time. It is inserted in series with the circuit to be protected.

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. A fuse performs both detection and interruption functions.

1.2.3 CIRCUIT BREAKERS

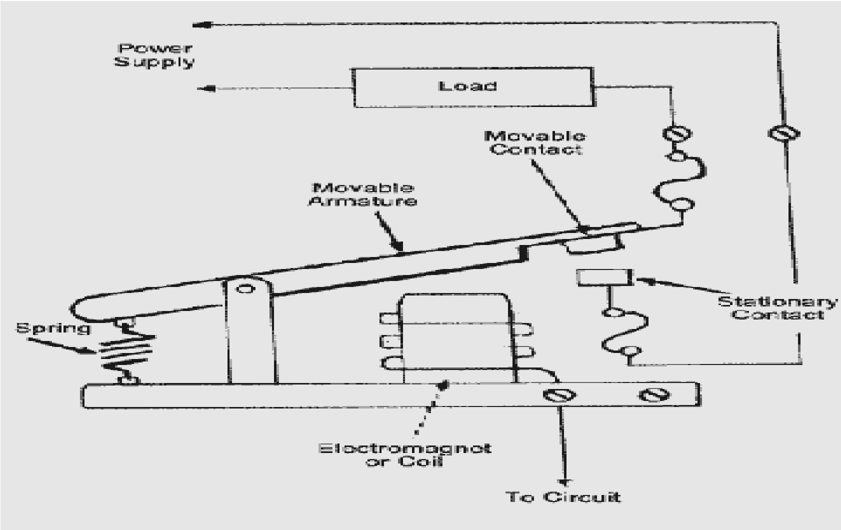
A circuit breaker is an equipment which can open or close a circuit under no load, full load and fault conditions. It is so designed that it can be operated manually (or by remote control) under normal conditions and automatically under fault conditions.

The arc produced during the opening operation is quenched by the oil , air or vaccum.



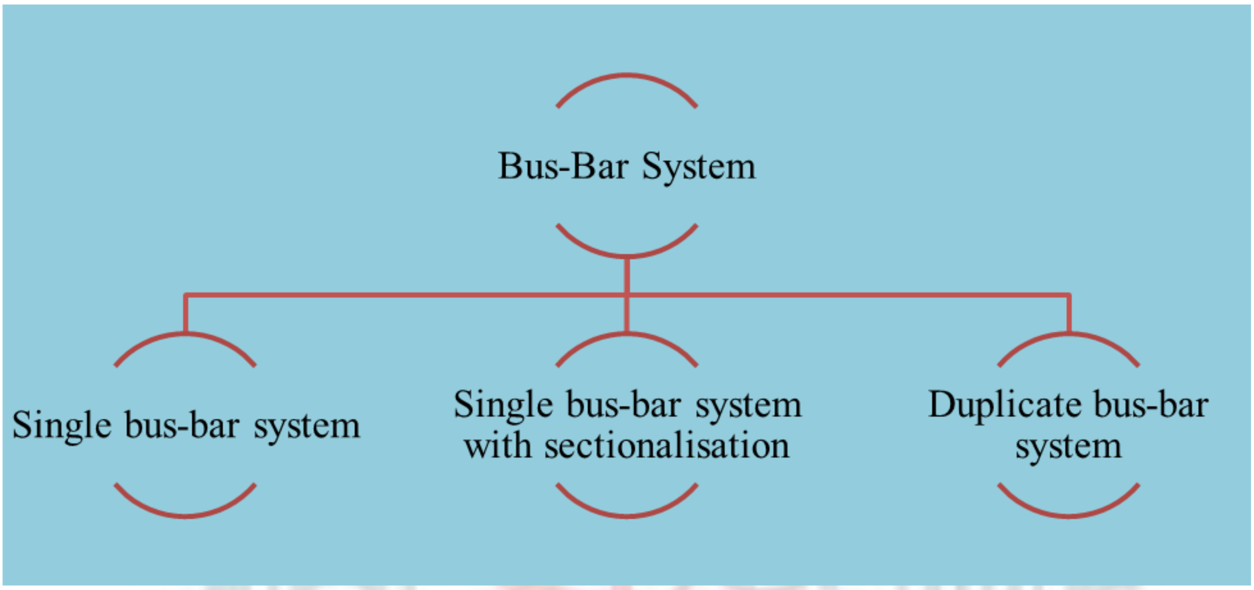
1.2.4 RELAYS

A relay is a device which detects the fault and supplies information to the breaker for circuit interruption.


Power Supply
Load
Movable Contact
Movable Armature
Stationary Contact
Spring
Electromagnet or Coil
To Circuit

1.3 BUS-BAR ARRANGEMENT

- A bus - bar is a conductor or group of conductors and it collects electric energy from incoming feeders and distributes them to outgoing feeders.
- So bus - bar is a junction where all incoming and outgoing currents meet.
- Bus - bar is generally made up of aluminium but not with copper because aluminium has special characters like higher conductivity, lower cost, excellent corrosion resistance.



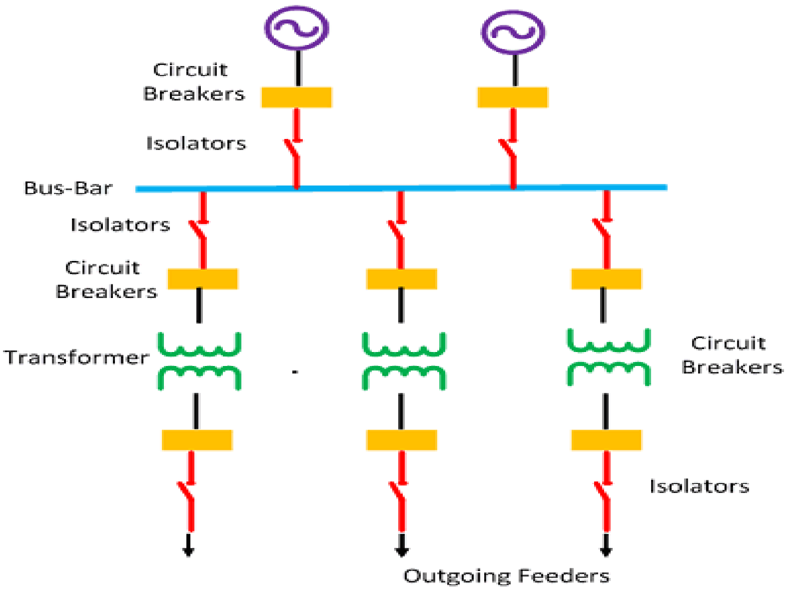
- This single bus - bar arrangement consists of only one bus - bar and all the incoming feeders and outgoing distributors are connected to this bus - bar only. All the fuses, circuit breakers, generators and transformers are connected to it.

ADVANTAGES

- It is easy in operation.
- Initial cost is less.
- Requires less maintenance.

DISADVANTAGES

- When damage occurs then there will be whole interruption of power supply.
- Flexibility and immunity are very less.



Single Bus-Bar Arrangement

1.3.1 Single Bus-Bar System Sectionalisation

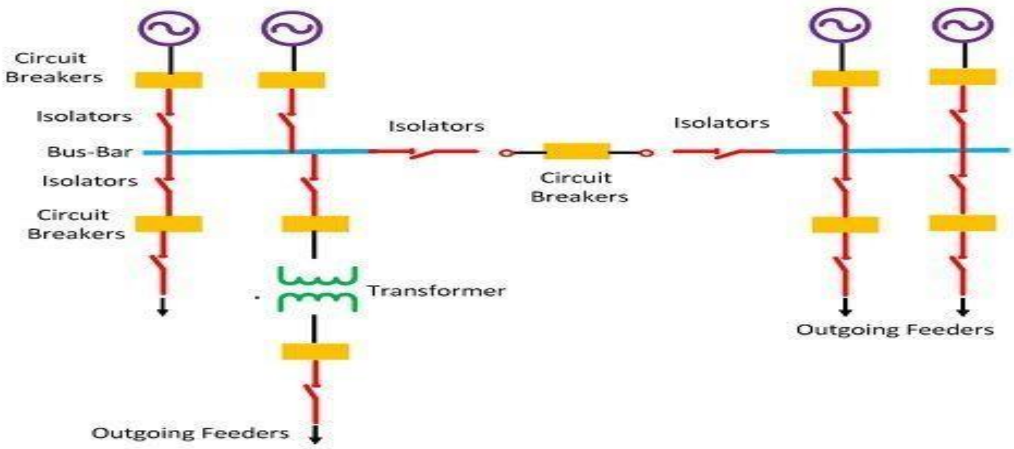
In single bus-bar arrangement with bus sectionalized we divide a single bus - bar into two sections with the help of a circuit breaker and isolator switches and load is distributed equally among both sections.

ADVANTAGES

As we are using circuit breaker to divide a bus - bar into two sections fault on one section will not interrupt power supply on the other section only few loads will have lac of power supply.

DISADVANTAGE

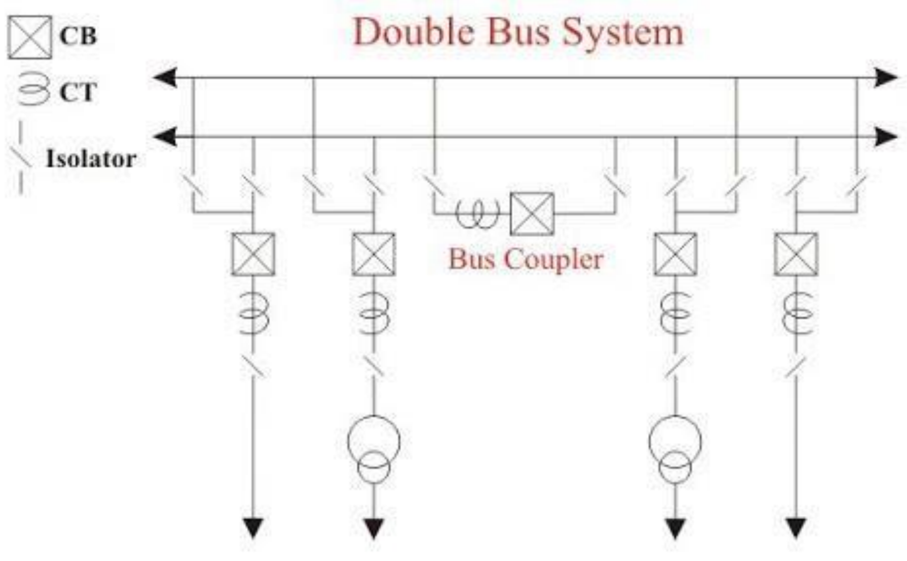
We are using extra isolators and circuit breakers so that the cost will be high.



Sectionalized Single Bus-Bar System

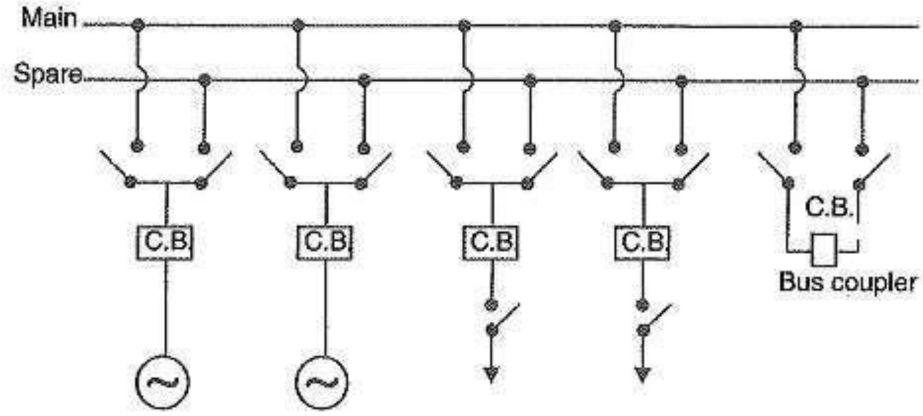
1.3.2 Double Bus-Bar System

* Double bus arrangement has two bus bars and the incoming feeders and outgoing feeders are connected in parallel to both buses with the help of isolators.
* By closing the isolator switch we can connect the feeders either to bus-bar 1 or to bus-bar 2 . We can divide the load among two buses with the help of isolator switches by closing the isolator switch that is connected to bus-bar 1 and feeder the load can be connected to bus-bar 1 and by closing the isolator switch connected to bus-bar 2 and feeder the load gets connected to bus-bar 2.
* We have a bus coupler breaker which is used for bus transfer operation. When we need to transfer load from one bus to other bus we need to close the bus coupler first and then close isolators of the associated bus to which load is to be connected and open the isolator switch coupled to fault bus and then open the bus coupler breaker.



Duplicate bus-bar system: In large stations, it is important that breakdowns and maintenance should interfere as little as possible with continuity of supply. In order to achieve this objective, duplicate Bus Bar Arrangement in Power Station is used in important stations. Such a system consists of two bus-bars, a “main bus-bar” and a “spare” bus-bar (see figure). 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 Main in figure below, 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.



ADVANTAGES

- 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.
- The testing of feeder circuit breakers can be done by putting them on spare bus-bar, thus keeping the main bus-bar undisturbed.
- 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 Arrangement in Power Station.

1.4 SWITCHGEAR ACCOMMODATION

The main components of a switchgear are circuit breakers, switches, bus-bars, instruments and instrument 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:

1. 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.
2. 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.

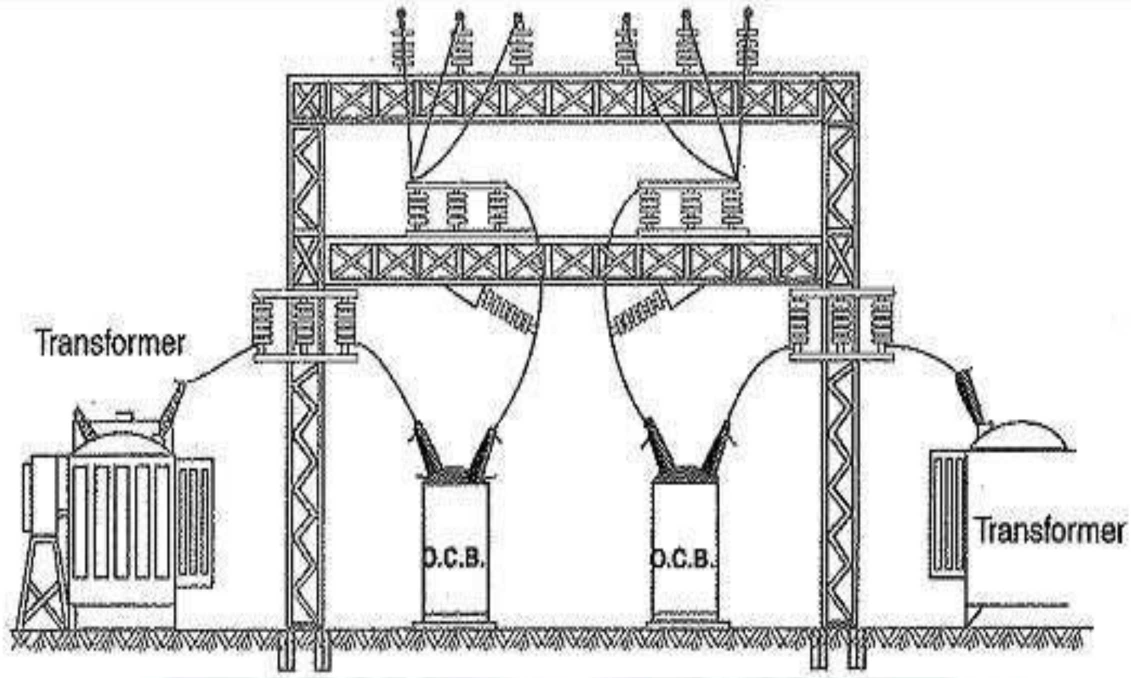


Figure above shows a typical outdoor sub-station with switchgear equipment. The circuit breakers, isolators, transformers and bus-bars occupy considerable space on account of large electrical clearance associated with high voltages.

1.5 SHORT CIRCUIT

* A short circuit is simply a low resistance connection between the two conductors supplying electrical power to any circuit.
* This results in excessive current flow in the power source through the 'short,' and may even cause the power source to be destroyed.
* Short circuits can produce very high temperatures due to the high power dissipation in the circuit.

CAUSES

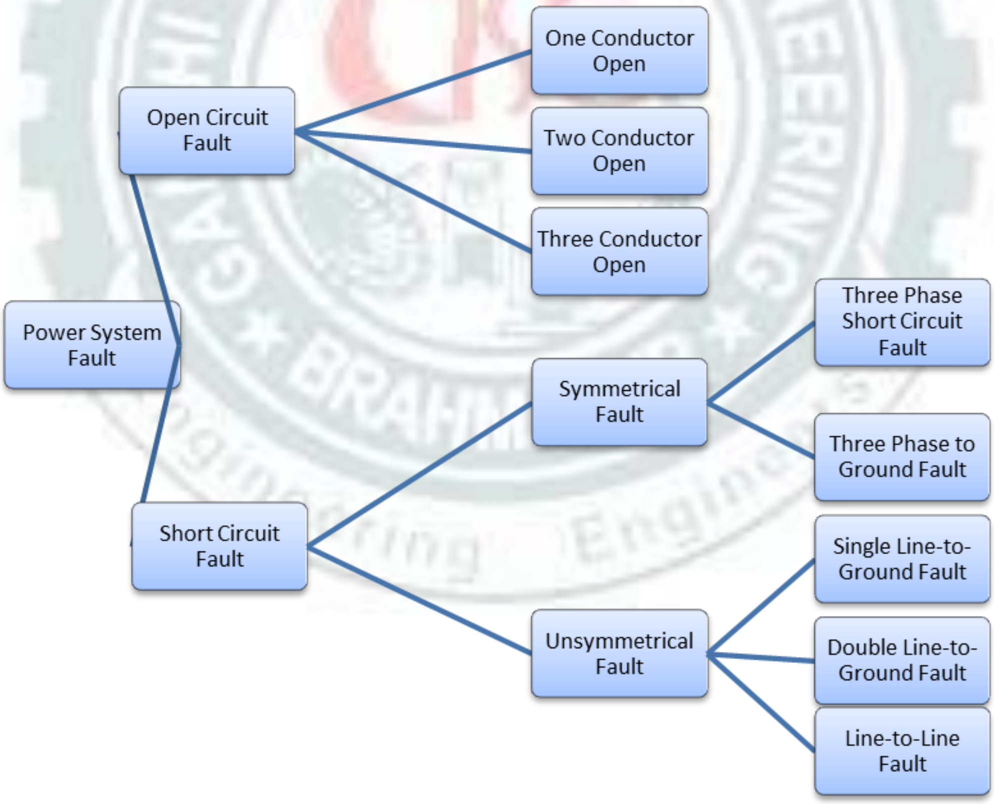
A short circuit in the power system is the result of some kind of abnormal conditions in the system. It may be caused due to internal and or external effects.

* **Internal effects:** These are caused by breakdown of equipment or transmission lines from deterioration of insulation in a generator, transformer etc. Such troubles may be due to ageing of insulation. inadequate design or improper installation.
* **External effects:** These causing short circuit include insulation failure due to lightning surges, overloading of equipment causing excessive heating, mechanical damage by public etc.

Chapter - 2

FAULTS IN POWER SYSTEM

* The fault in the power system is defined as the defect in the power system due to which the current is distracted from the intended path. The fault creates the abnormal condition which reduces the insulation strength between the conductors. The reduction in insulation causes excessive damage to the system
* The faults in the power system may occur because of the number of natural disturbances like lightning, high-speed winds, earthquake, etc. It may also occur because of some accidents like falling off a tree, vehicle colliding, with supporting structure, aeroplane crashing, etc.
* Faults are mainly classified into 2 types
  a) Open circuit fault
  b) Short circuit fault



2.1 TYPES OF FAULTS

2.1.1 Open Circuit Fault

The open circuit fault mainly occurs because of the failure of one or two conductors. The open circuit fault takes place in series with the line, and because of this, it is also called the series fault. Such types of faults affect the reliability of the system. The open circuit fault is categorised as:

- Open Conductor Fault
- Two Conductors Open Fault
- Three Conductors Open Fault.

In this type of fault, the conductors of the different phases come into contact with each other with a power line, power transformer or any other circuit element due to which the large current flow in one or two phases of the system.

2.1.2 Short Circuit Fault

The short-circuit fault is divided into the symmetrical and unsymmetrical fault

SYMMETRICAL FAULT

The faults which involve all the three phases is known as the symmetrical fault. Such types of fault remain balanced even after the fault. The fault on the system may arise on account of the resistance of the arc between the conductors or due to the lower footing resistance.

UNSYMMETRICAL FAULT

The fault gives rise to unsymmetrical current, i.e., current differing in magnitude and phases in the three phases of the power system are known as the unsymmetrical fault. It is also defined as the fault which involves the one or two phases such as L- G, L – L, L – L – G fault. The unsymmetrical makes the system unbalanced.

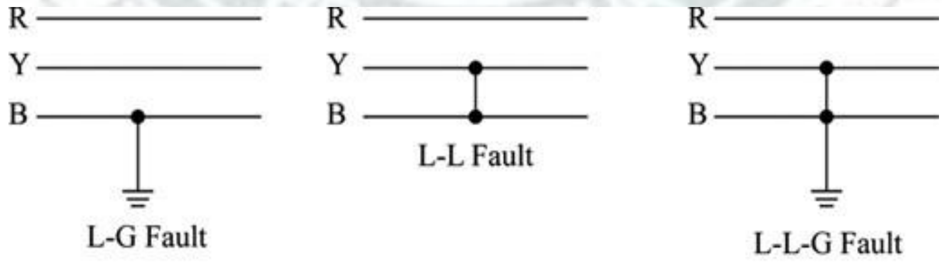
It is mainly classified into three types. They are:

- Single Line-to-ground (L – G) Fault
- Line-to-Line Fault (L – L)
- Double Line-to-ground (L – L – G) Fault

The unsymmetrical fault is the most common types of fault occur in the power system.

The symmetrical fault is sub-categorized into line-to-line-to-line fault and three-phase line-to-ground-fault.

* **Line – Line – Line Fault:** Such types of faults are balanced, i.e., the system remains symmetrical even after the fault. The L – L – L fault occurs rarely, but it is the most severe type of fault which involves the largest current. This large current is used for determining the rating of the circuit breaker.
* **L – L – L – G (Three-Phase Line To The Ground Fault):** The three-phase line to ground fault includes all the three phase of the system. The L – L – L – G fault occurs between the three phases and the ground of the system. The probability of occurrence of such type of fault is nearly 2% to 3%.
* **Single Line-to-Line Ground:** The single line of ground fault occurs when one conductor falls to the ground or contact the neutral conductor. The 70 – 80 percent of the fault in the power system is the single line-to-ground fault.
* **Line – to – Line Fault:** A line-to-line fault occurs when two conductors are short circuited. The major cause of this type of fault is the heavy wind. The heavy wind swinging the line conductors which may touch together and hence cause short-circuit. The percentage of such type of faults is approximately 15 – 20%.
* **Double Line – to – line Ground Fault:** In double line-to-ground fault, the two lines come in contact with each other along with the ground. The probability of such types of faults is nearly 10%.



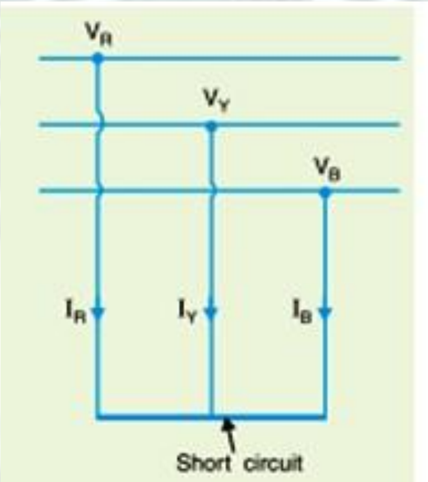
- Single line-to-ground fault (LG).
- Line-to-line fault (LL).
- Double Line-to-ground fault (LLG).
- Three-phase short circuit fault (LLL).
- Three-phase-to-ground fault (LLLG).

2.2 FAULT CALCULATION

SYMMETRICAL FAULTS ON 3-PHASE SYSTEM:

That fault on the power system which gives rise to symmetrical fault currents (i.e. equal fault currents in the lines with 120^o displacement) is called a **symmetrical fault.**

This type of fault gives rise to symmetrical currents *i.e*. equal fault currents with 120^o displacement. Thus referring to figure below fault currents I_R, I_Y and I_B will be equal in magnitude with 120 displacement among them. Because of balanced nature of fault, only one* phase need be considered in calculations since condition in the other two phases will also be similar. The following points may be particularly noted:



The symmetrical fault rarely occurs in practice as majority of the faults are of unsymmetrical nature. How- ever, symmetrical fault calculations are being dis- cussed in this chapter to enable the reader to under- stand the problems that short circuit conditions present to the power system.

That fault on the power system which gives rise to symmetrical fault currents (i.e. equal fault currents in the lines with 120° displacement) is called a symmetrical fault.

The following points may be particularly noted :

1. The symmetrical fault rarely occurs in practice as majority of the faults are of unsymmetrical nature. However, symmetrical fault calculations are being discussed in this chapter to enable the reader to understand the problems that short circuit conditions present to the power system.
2. The symmetrical fault is the most severe and imposes more heavy duty on the circuit breaker.

2.3 PERCENTAGE REACTANCE IN POWER SYSTEM

The Percentage Reactance in Power System of generators, transformers, reactors etc. is usually expressed in percentage reactance to permit rapid short circuit calculations.

The percentage reactance of a circuit is defined as under :

It is the percentage of the total phase-voltage dropped in the circuit when full-load current is flowing.

$$\%X = \frac{I\,X}{V} \times 100$$

where I = full-load current V = phase voltage X = reactance in ohms per phase.

Alternatively, percentage reactance (%X) can also be expressed in terms of kVA and kV as under :

$$\%X = \frac{(\text{kVA})\,X}{10\,(\text{kV})^2}$$

where X is the reactance in ohms.

If X is the only reactance element in the circuit, then short-circuit current is given by ;

$$I_{SC} = \frac{V}{X}$$

$$= I \times \left(\frac{100}{\%X}\right)$$

(by putting the value of x) i.e. short circuit current is obtained by multiplying the full-load current by 100 / % X.

2.3.1 Percentage Reactance and Base KVA

It is clear from exp. (ii) above that percentage reactance of an equipment depends upon its kVA rating. Generally, the various equipments used in the power system have different kVA ratings. Therefore, it is necessary to find the Percentage Reactance in Power System of all the elements on a common kVA rating. This common kVA rating is known as base kVA. The value of this base kVA is quite important and may be :

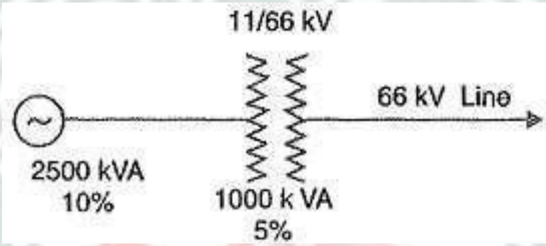
- equal to that of the largest plant
- equal to the total plant capacity
- any arbitrary value

The conversion can be effected by using the following relation :

$$\%\text{ age reactance at base kVA} = \frac{\text{Base kVA}}{\text{Rated kVA}} \times \%\text{ age reactance at rated kVA}$$

Thus, a 1000 kVA transformer with 5% reactance will have a reactance of 10% at 2000 kVA base.

The fact that the value of base kVA does not affect the short circuit current needs illustration. Consider a 3-phase transmission line operating at 66 kV and connected through a 1000 kVA transformer with 5% reactance to a generating station bus-bar. The generator is of 2500 kVA with 10% reactance. The single line diagram of the system is shown in figure below. Suppose a short-circuit fault between three phases occurs at the high voltage terminals of transformer. It will be shown that whatever value of base kVA we may choose, the value of short-circuit current will be the same.



(i) Suppose we choose 2500 kVA as the common base kVA. On this base value, the reactances of the various elements in the system will be :

Reactance of transformer at 2500 kVA base

$$= 5 \times 2500^{*}/1000 = 12{\cdot}5\%$$

Reactance of generator at 2500 kVA base

$$= 10 \times 2500/2500 = 10\%$$

Total percentage reactance on the common base kVA

$$\%X = 12{\cdot}5 + 10 = 22{\cdot}5\%$$

The fullf load current corresponding to 2500 kVA base at 66 kV is given by ;

$$I = \frac{2500 \times 1000}{\sqrt{3} \times 66 \times 1000} = 21{\cdot}87 \text{ A}$$

$$\therefore \quad \text{Short-circuit current, } I_{SC} = I \times \frac{100}{\%X} = 21{\cdot}87 \times \frac{100}{22 \cdot 5} = 97{\cdot}2 \text{ A}$$

(ii) Now, suppose we choose 5000 kVA as the common base value.

Reactance of transformer at 5000 kVA base

$$= 5 \times 5000/1000 = 25\%$$

Reactance of generator at 5000 kVA base

$$= 10 \times 5000/2500 = 20\%$$

Total percentage reactance on the common base kVA

$$\%X = 25 + 20 = 45\%$$

Full-load current corresponding to 5000 kVA at 66 kV is

$$I = \frac{5000 \times 1000}{\sqrt{3} \times 66 \times 1000} = 43{\cdot}74 \text{ A}$$

$$\text{Short-circuit current, } I_{SC} = I \times \frac{100}{\%X} = 43{\cdot}74 \times \frac{100}{45} = 97{\cdot}2 \text{ A}$$

which is the same as in the previous case.

From the above illustration, it is clear that whatever may be the value of base kVA, short-circuit current is the same: However, in the interest of simplicity, numerically convenient value for the base kVA should be chosen.

2.3.2 Short Circuit KVA

Although the potential at the point of fault is zero, it is a normal practice to express the short-circuit current in terms of Short Circuit kVA based on the normal system voltage at the point of fault.

The product of normal system voltage and short-circuit current at the point of fault expressed in kVA is known as Short Circuit kVA.

Let

V = normal phase voltage in volts

I = full-load current in amperes at base kVA

%X = percentage reactance of the system on base kVA upto the fault point

$$\text{Short-circuit current, } I_{SC} = I\left(\frac{100}{\%X}\right)$$

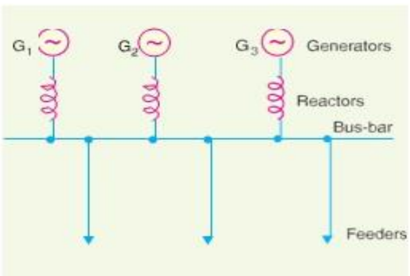
Short-circuit kVA for 3-phase circuit

$$= \frac{3 V I_{SC}}{1000}$$
$$= \frac{3 V I}{1000} \times \frac{100}{\%X}$$
$$= \text{Base kVA} \times \frac{100}{\%X}$$

i.e. Short Circuit kVA is obtained by multiplying the base kVA by 100/% X.

2.3.3 Reactor Control of Short-Circuit Currents

With the fast expanding power system, the fault level (*i.e.* the power available to flow into a fault) is also rising. The circuit breakers connected in the power system must be capable of dealing with maximum possible short-circuit currents that can occur at their points of connection. Generally, the reactance of the system under fault conditions is low and fault currents may rise to a dangerously high value. If no steps are taken to limit the value of these short-circuit currents, not only will the duty required of circuit breakers be excessively heavy, but also damage to lines and other equipment will almost certainly occur.
In order to limit the short-circuit currents to a value which the circuit breakers can handle, addi- tional reactances known as *reactors* are connected in series with the system at suitable points. A reactor is a coil of number of turns designed to have a large inductance as compared to its ohmic resistance. The forces on the turns of these reactors under short-circuit conditions are considerable and, therefore, the windings must be solidly braced. It may be added that due to very small resistance of reactors, there is very little change in the efficiency of the system.



ADVANTAGES

- Reactors limit the flow of short-circuit current and thus protect the equipment from over- heating as well as from failure due to destructive mechanical forces.
- Troubles are localised or isolated at the point where they originate without communicating their disturbing effects to other parts of the power system. This increases the chances of continuity of supply. They permit the installation of circuit breakers of lower rating

DISADVANTAGES

- There is a constant voltage drop and power loss in the reactors even during normal operation.
- If a bus-bar or feeder fault occurs close to the bus-bar, the voltage at the bus-bar will be reduced to a low value, thereby causing the generators to fall out of step. If a fault occurs on any feeder, the continuity of supply to other is likely to be affected.

Per Unit Change of MVA Base

- Parameters for equipment are often given using power rating of equipment as the MVA base
- To analyze a system all per unit data must be on a common power base

$$Z_{pu}^{OriginalBase} \rightarrow Z_{actual} \rightarrow Z_{pu}^{NewBase}$$

$$\text{Hence} \quad Z_{pu}^{OriginalBase} \times \frac{V_{base}^2}{S_{Base}^{OriginalBase}} / \frac{V_{base}^2}{S_{Base}^{NewBase}} = Z_{pu}^{NewBase}$$

$$Z_{pu}^{OriginalBase} \times \frac{S_{Base}^{NewBase}}{S_{Base}^{OriginalBase}} = Z_{pu}^{NewBase}$$

Per Unit Change of Base Example

A 54 MVA transformer has a leakage reactance of 3.69% (on its own MVA base).

- What is the reactance on a 100 MVA base?

$$X_e = 0.0369 \times \frac{100}{54} = 0.0683 \text{ p.u.}$$

2.3.4 Transformer Reactance

- Transformer reactance is often specified as a percentage, say 10%. This is a per unit value expressed as a percentage on the power base of the transformer.
- Example: A 350 MVA, 230/20 kV transformer has leakage reactance of 10%. What is p.u. value on 100 MVA base? What is value in ohms (230 kV)?

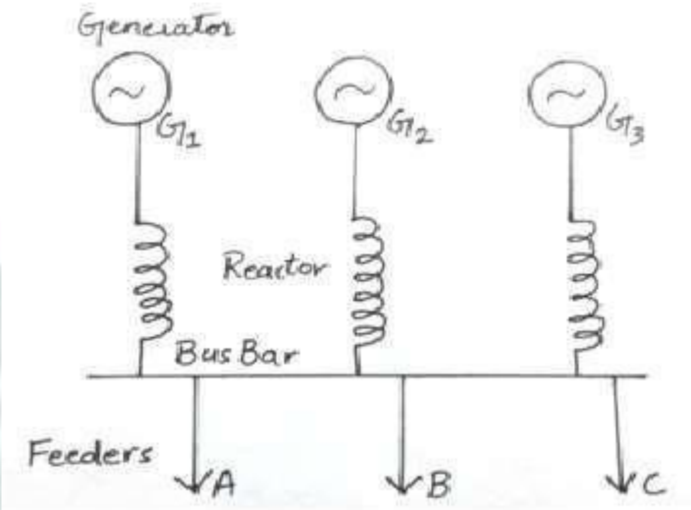
$$X_e = 0.10 \times \frac{100}{350} = 0.0286 \text{ p.u.}$$

$$0.0286 \times \frac{230^2}{100} = 15.1\,\Omega$$

2.5 LOCATION OF REACTORS IN POWER SYSTEM

1. Generator Reactors:

When reactor is connected between bus bar and generator, it is called a generator reactor. This reactor can also be connected in series with the generator. When a new generator is connected with an old generator, a reactor is added in series with the old generator to provide protection. The value of this reactor depends on the impedance of that generator. Its pu value should be 0.05 or 0.06. See the following figure:

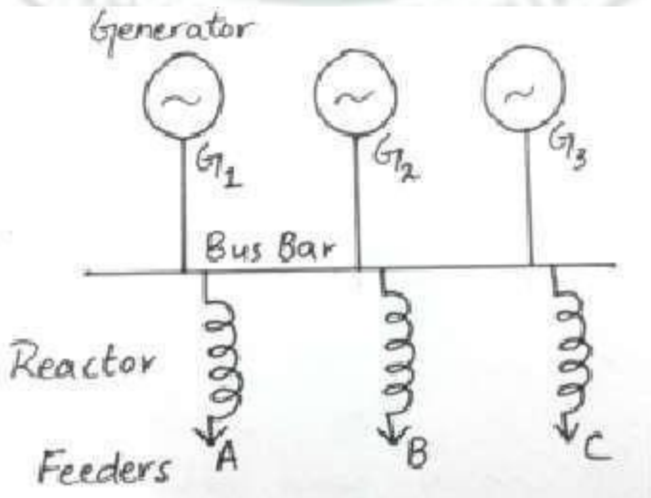


Disadvantages:

- The fault on a feeder disconnects the supply of other feeders also.
- After removing the faulty feeder, the generator has to be synchronized again.
- During normal operation, full load current passes through the reactor which causes continuous power loss.

2. Feeder reactors:

It is when a reactor is connected in series with a feeder as shown in the figure:



Usually short circuits occur on feeders therefore, feeder reactors are very important. In the absence of feeder reactors, if a fault occurs on the nearest generating station, the bus bar voltage will be reduced to zero and the connected generators will lose their synchronism.

Advantages:

- The voltage drop across a reactor during faulty conditions will not affect the voltage of bus bar, therefore, there are less chances of losing synchronism.
- A fault on a feeder will not affect any other feeder.

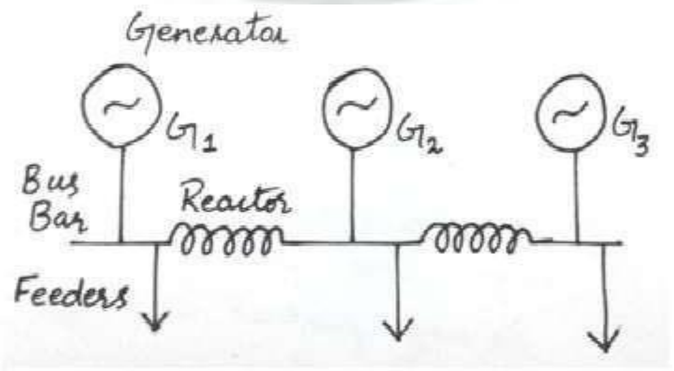
Disadvantages:

- Every feeder needs a reactor hence the number or reactors increases.
- If the number of generators increases, then the size of the reactor should also be increased.
- During normal operation, full load current passes through the reactor which causes continuous power loss.
- Reactors should be connected according to the power factor of the feeders to regulate proper voltages. Feeder reactance should be about 0.05 to 0.12 pu.

3. Bus bar reactors:

These reactors are connected with bus bars. Bus bar reactors divide the bus bar in smaller sections. If the voltage level is same, no current passes through these reactors and every section act as an independent bus bar.

If a fault occurs on a section of bus bar, the reactor prevents the fault from reaching to other sections and only the fault section is affected. Hence a bus bar should be large enough to protect the system but it should not disturb the synchronism of the system. A reactor which drops the voltage about 30 to 50% at full current is suitable. However the reactance of a sinlge bus bar reactor should be about 0.3 to 0.5 pu.



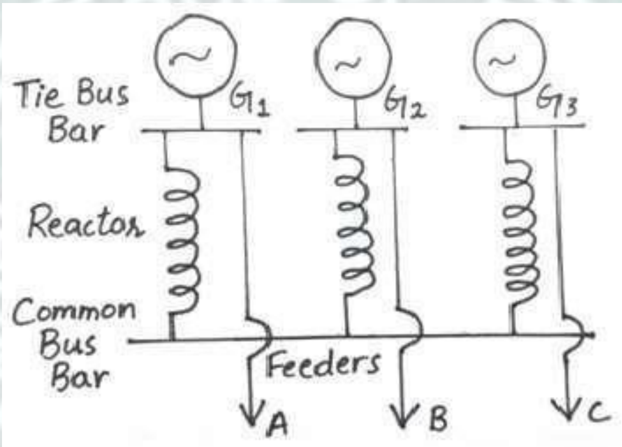
The following methods describe how to decrease the continuous voltage drop and power losses in case of feeder and generator reactors:

A. Ring system:

In this system, a bus bar is divided into different sections and these sections are connected together through a reactor. Each feeder is fed by a separate generator and during normal operation each generator supplies power to its respective load due to which very less power loss occurs in the reactors.

B. Tie bar system:

In this system, the generators are connected to a common bus bar through the reactors and feeders are fed through the generator side of the reactors. This system is very efficient in case of larger systems. The reactance of the reactors in this case is half as compared to the ring system reactance.



Advantages:

This system is more flexible. By increasing the number of sections, the switch gears work efficiently without any modifications in the system.

Disadvantages:

This system is complex and requires an additional bus i.e., tie bar

Chapter -3

FUSE

3.1 INTRODUCTION

* A fuse is an electrical safety device that operates to provide overcurrent protection of an electrical circuit.
* Its essential component is a metal wire or strip that melts when too much current flows through it, thereby interrupting the current.
* It is a sacrificial device; once a fuse has operated it is an open circuit, and it must be replaced or rewired, depending on type.

3.2 OPERATION

* A fuse is a short length of wire designed to melt and separate in the case of excessive current.
* Fuses are always connected in series with the components to be protected from overcurrent, so that when the fuse blows, it will open the entire circuit and stop current through the component. A fuse connected in one branch of a parallel circuit, would not affect current through any of the other branches

Normally, the thin piece of fuse wire is contained within a safety sheath to minimize hazards of arc blast if the wire burns open with violent force, as can happen in the case of severe over current

3.3 CHARACTERISTICS OF FUSE

A fuse is a safety device consisting of a strip of wire that melts and breaks an Electric circuit if the current exceeds the safe value.

Characteristics of a fuse are:-

* It should have low melting point.
* It should have high conductivity (or low resistivity).
* It should be economical

3.4 FUSE ELEMENTS

METAL	MELTING POINT IN (°C)	SPECIFIC RESISTANCE (μΩ-mm)	VALUE OF FUSE CONSTANT k for d in mm
SILVER	980	160	-
TIN	240	112	12.8
ZINC	419	60	-
LEAD	328	210	10.8
COPPER	1090	17	80
ALUMINIUM	665	28	59

FUSE ELEMENTS MATERIALS

- The materials commonly used for fuse elements are tin, lead, silver, copper, zinc, aluminium, and alloys of lead and tin.
- An alloy of lead and tin (lead 37% and tin 63%) is used for fuses with a current rating below 15 A.
- For current exceeding 15A copper wire fuses are employed.

The present trend is to use silver as fuse element material despite its higher cost owing to the following advantages:

* It does not get oxidized and is oxide is unstable.
* The conductivity of silver is not deteriorated with oxidation.
* High conductivity.

IMPORTANT TERMS

* MINIMUM FUSING CURRENT : It is minimum value of current due to which fuse melts.
* CURRENT RATING OF FUSE : It is maximum value of current due to which fuse does not get melt.
* FUSING FACTOR : This is the ratio of minimum fusing current and current rating of fuse.

$$* \text{ fusing factor} = \frac{\text{minimum fusing current}}{\text{current rating of fuse}}$$

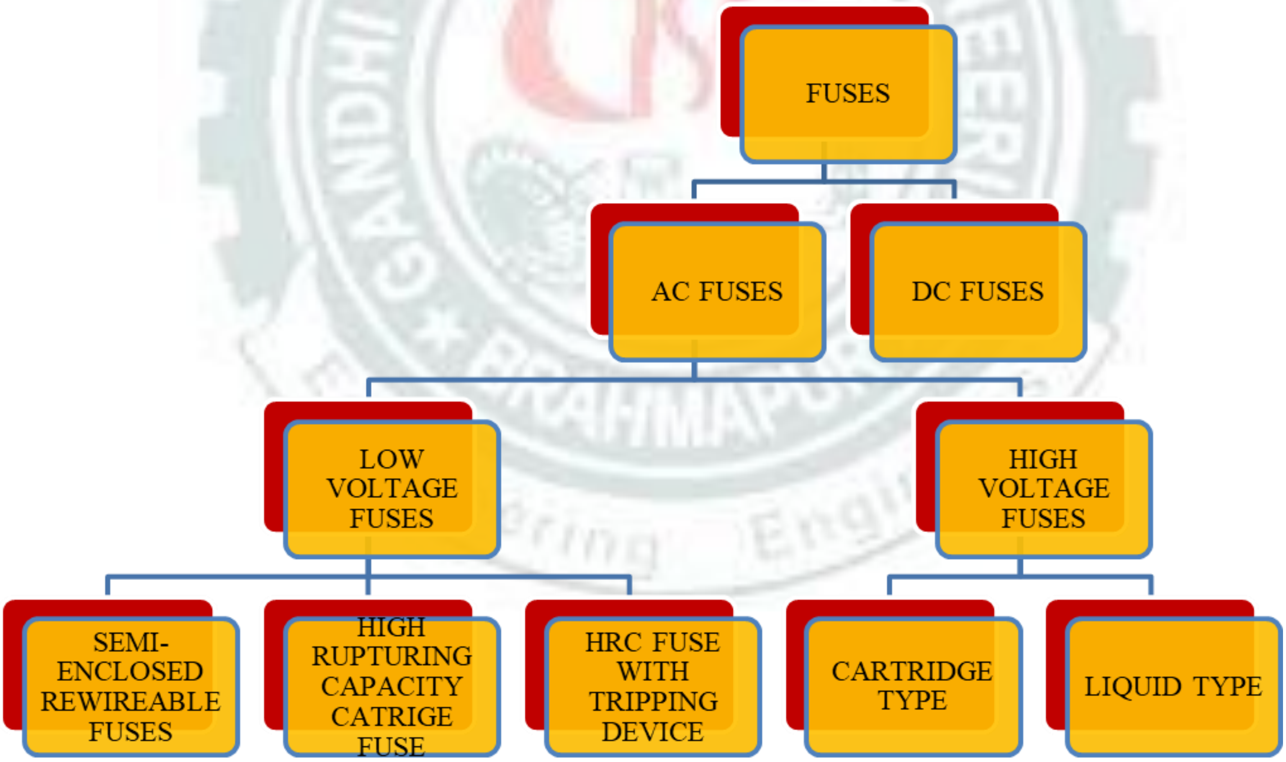
* PROSPECTIVE CURRENT : The prospective current is defined as the value of current which would flow through the fuse immediately after a short circuit occurs in the network.

* **PRE-ARCING TIME OF FUSE :** This is the time taken by an fuse wire to be broken by melting. It is counted from the instant, the over current starts to flow through fuse, to the instant when fuse wire is just broken by melting.
* **ARCING TIME OF FUSE :** The time accounted from the instant of arc initiated to the instant of arc being extinguished is known as arcing time of fuse.
* **OPERATING TIME OF FUSE :** The operating time of fuse is the time gap between the instant when the over rated current just starts to flow through the fuse and the instant when the arc in fuse finally extinguished.

3.5 TYPES OF FUSES

LOW VOLTAGE FUSES

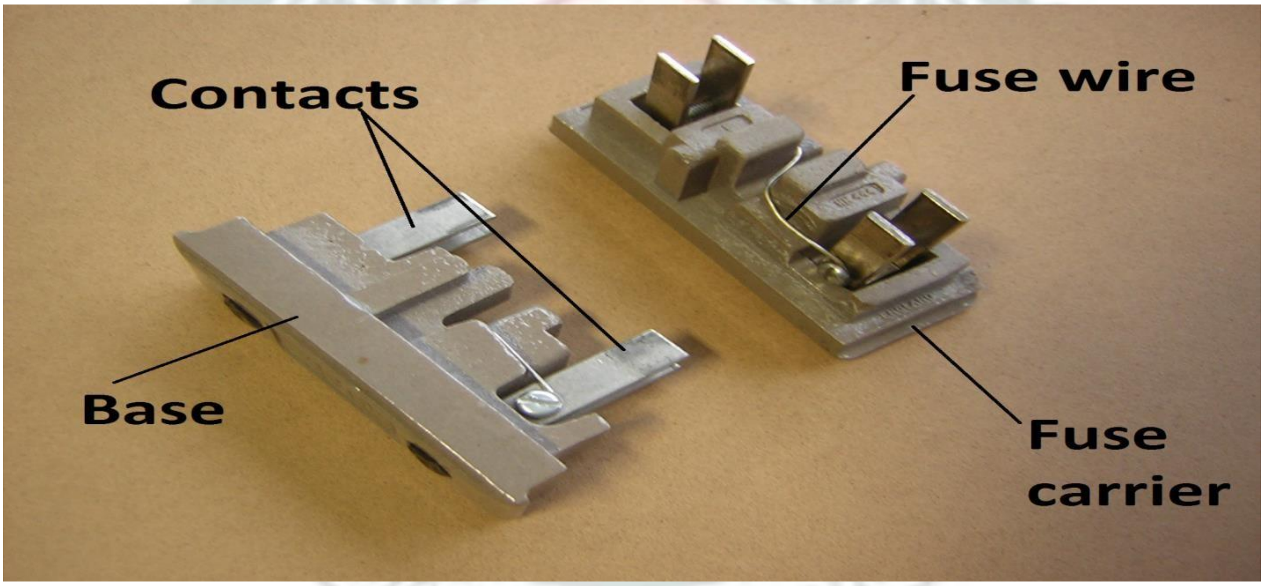
HIGH VOLTAGE FUSES



3.5.1 Low Voltage Fuses

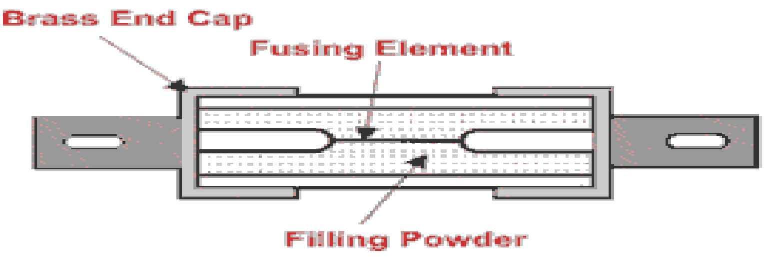
3.5.1.1 Semi-Enclosed Rewireable Fuses

* It is also called as kit-kat fuse.
* It mainly consists of two parts:
  a) Base
  b) Carrier
* Base is made of porcelain which holds the wires.
* The fuse element is located inside the carrier that is also made of porcelain.
* Fuse carrier can be remove without a risk of electrical shock.
* When there is a fault, the fuse element is blown out and the circuit is interrupted.
* The fuse carrier is then taken out and the blown out wire is replaced with new one and re-inserted to base to restore supply.



3.5.1.3 High Rupturing Capacity Cartridge Fuses

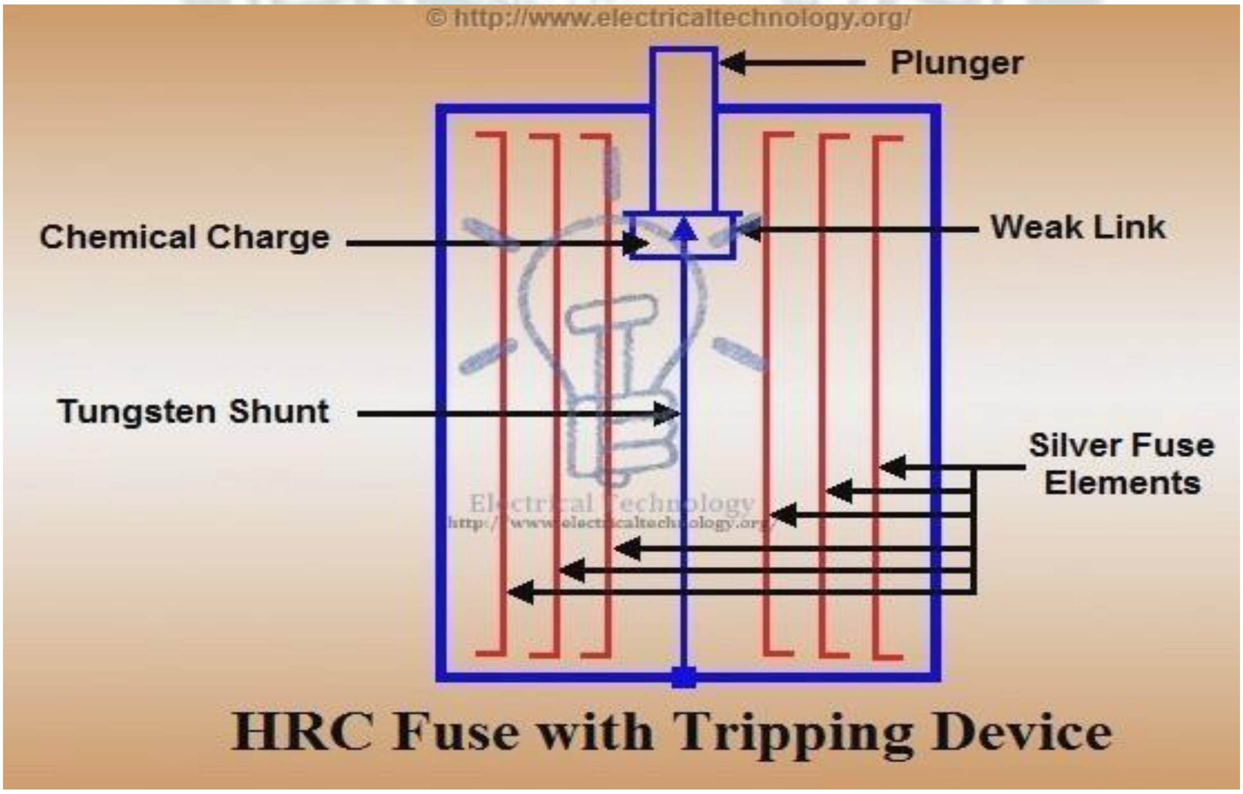
* It consists of a heat resisting ceramic body having metal end-caps to which a silver current carrying element is welded.
* The space within the body surrounding the element is completely packed with a filling, which could be either chalk, plaster of paris, quartz or marble dust to quench arc.
* When a fault occurs, the current increases which melts the fuse element. The heat produced in the process vapourises the silver element which after reacting with filling helps in quenching the arc.



Construction of HRC Fuse

3.5.1.3 High Rupturing Capacity (HRC) Fuse with Tripping Device

- In this type of fuse a HRC cartridge fuse is provided with tripping device.
- Its body is of ceramic material with a metallic cap rigidly fixed at each end. These are connected by a number of silver fuse elements.
- Plunger is attached at one end which hits the tripping mechanism of the fuse under fault conditions. Its is connected to the other end of cap through a weal link, chemical charge and tungsten wire.
- When the fault occurs, the fuse element blows out and current is transferred o the tungsten wire. The weak link in series with the wire gets fused and chemical charge detonates. This forces the plunger outward and breaks the circuit.



HRC Fuse with Tripping Device

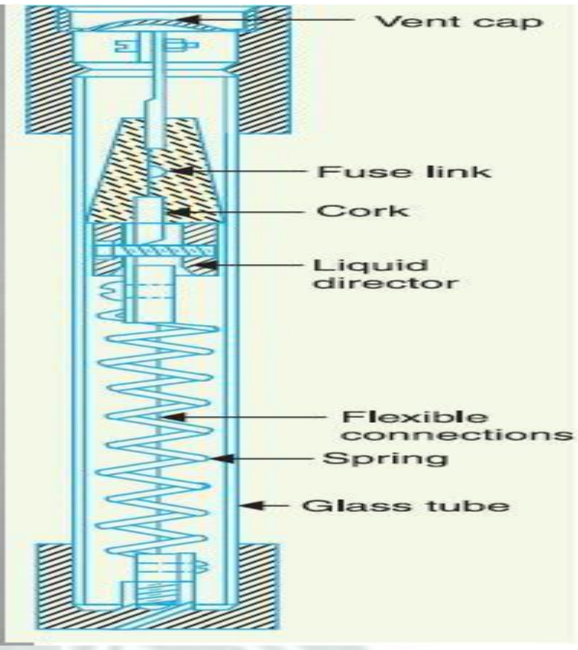
3.5.2 High Voltage Fuses

3.5.2.1 Cartridge Type

* This type of fuses are similar in general construction to low voltage cartridge type except some special design features.
* There are two fuse elements are incorporated in parallel:
  a) Low resistance wire (silver wire)
  b) High resistance wire (tungsten wire)
* When a fault occurs, the low resistance element is blown out and high resistance element reduces the short circuit current and finally breaks the circuit.
* These type of fuses are used up to 33kV with breaking capacity of about 8700A at that voltage.

3.5.2.2 Liquid Type

* These fuses are filled with carbon tetrachloride solution and have the widest range of application to high voltage systems.
* It consists glass tube filled with the solution and sealed with brass caps. The fuse wire is sealed at one end of the tube and the other end of the wire is held by a strong spiral spring fixed at the other end.
* When the fault occurs the fuse wire blows out. As the fuse melts, the spring retracts part of it through a liquid director and draws it well into the liquid.
* A small quantity of gas is generated at the point of fusion which forces some part of the liquid into the passage and extinguishes the arc.



3.6 CURRENT CARRYING CAPACITY OF FUSE ELEMENT

* The current carrying capacity of a fuse element mainly depends on the cross-sectional area, length, the state of surface and the surroundings of fuse.
* When the fuse element attains steady temperature,

Heat produced per sec = Heat lost per second by convection , radiation and conduction

$$I^2 R$$

or $$I^2\left(\rho \frac{l}{a}\right) = \text{Constant} \times \text{Effective surface area}$$

or $$= \text{constant} \times d \times l$$

where d = diameter of fuse element
l = length of fuse element

$$\therefore \quad I^2 \frac{\rho l}{(\pi/4)d^2} = \text{constant} \times d \times l$$

or $$I^2 = \text{constant} \times d^3$$

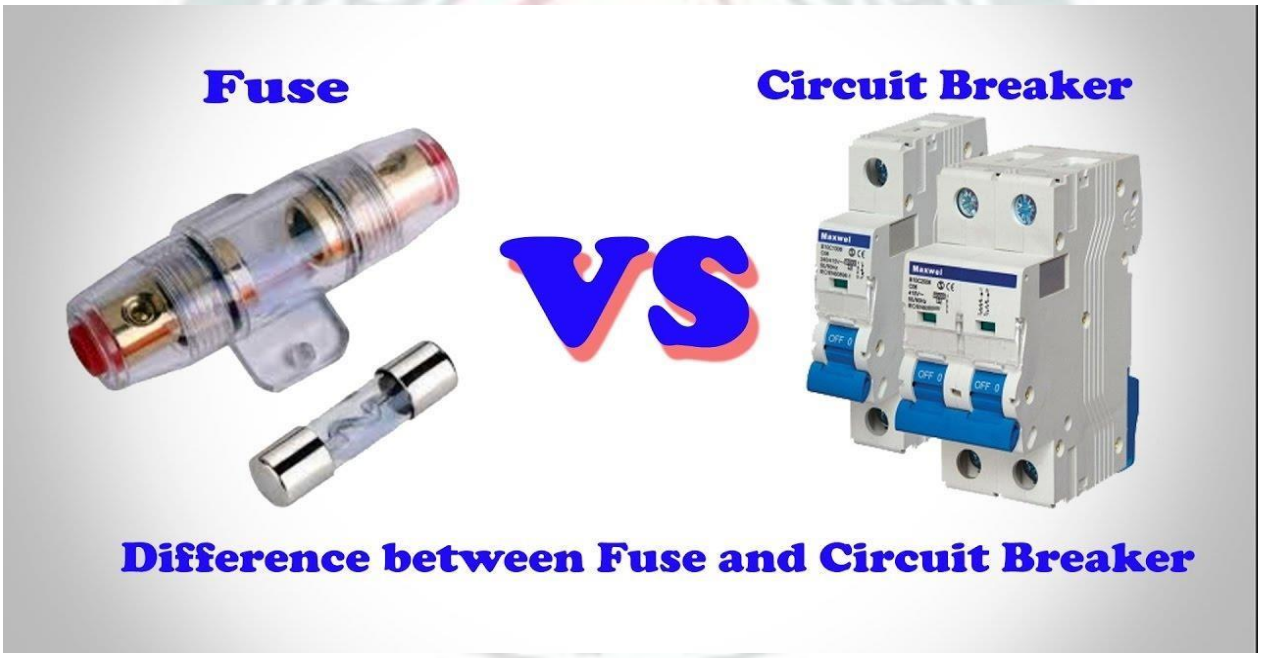
$$I^2 \propto d^3$$

or

Its is known as ordinary fuse law.

3.7 DIFFERENCE BETWEEN A FUSE AND CIRCUIT BREAKER

S. No.	PARTICULAR	FUSE	CIRCUIT BREAKER
1.	**Function**	It performs both detection and interruption functions.	It performs interruption function only. The detection of fault is made by relay system.
2.	**Operation**	Inherently completely automatic.	Requires elaborate equipment for automatic action.
3.	**Breaking capacity**	Small	Very large
4.	**Operating time**	Very small	Comparatively large
5.	**Replacement**	Requires replacement after every operation.	No replacement after operation.



Chapter - 4

CIRCUIT BREAKER

4.1 INTRODUCTION

* A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by over current, typically resulting from an overload or short circuit. Its basic function is to interrupt current flow after a fault is detected. Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation.
* Circuit Breakers are quite unique devices in the sense that they are mechanical devices connected to electrical system. Since the time when first electrical systems were utilized, there is always a need for a mechanism or a device that can initiate and interrupt the flow of electric current.
* In power system, it is often necessary to switch on or off various electrical devices and circuits like generating plants, transmission line, distribution systems, etc. either in normal operating conditions or under abnormal situations. Originally, this task is performed by a switch and a fuse connected in series with the electrical circuit.
* The main disadvantage of such a setup is that if a fuse is blown, it is often time consuming to replace one and restore the power supply. The other and main disadvantage is that a fuse cannot interrupt heavy fault currents.
* These limitations restricted the usage of switch and fuse combination to small voltage and small capacity circuits. But in case of high voltage and large current system, a more dependable way than using a switch and fuse is desired.

4.2 OPERATION MECHANISM

- Circuit Breaker consists of two contacts:
  - Fixed contact
  - Moving contact
- Moving contact is used to make and break the circuit using stored energies in the form of spring or compressed air.
- Spring, pneumatic or oil damping is used to arrest the speed mc while closing.
- Fc contains a spring which holds the mc after closing.

- Circuit breaker consists of two coils:
- Closing coil - Used to close the circuit.
- Tripping coil- Used to trip the circuit.
- These coils activate the stored energy and direct the mc to open or close.
- DC batteries are used to energize these coils.
- Solenoids are used to close or trip it.
- CBs are usually arranged with pilot devices to sense a fault current and to operate the trip opening mechanism.

4.3 ARC PHENOMENONA

During the separation of contacts, due to large fault current and high current density at the contact region the surrounding medium ionizes and thus a conducting medium is formed. This is called as the ARC and this phenomenon is called as the ARC phenomenon.

Factors responsible for arc:

* Potential difference between the contacts.
* Ionized particles between the contacts.

PRINCIPLE OF ARC EXTINCTION

Arc extinction methods are:

There are basically 2 methods:

- High Resistance method.
- Low resistance method.

High Resistance Method: In this method, arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc.

Consequently, the current is interrupted or the arc is extinguished.

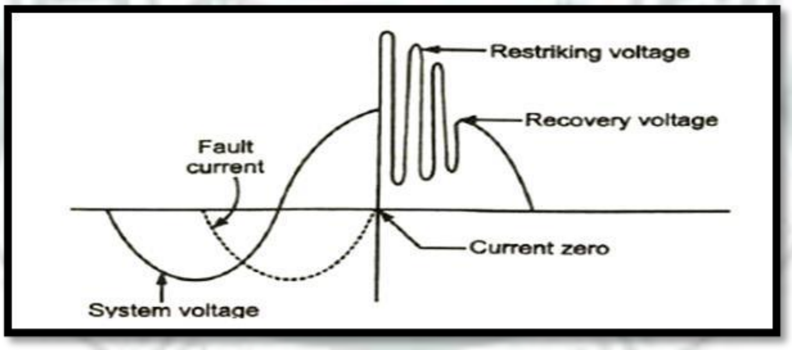
- Methods of increasing arc resistance-
  a. Lengthening of arc.
  b. Cooling of arc.
  c. Reducing cross section area of arc.

Low Resistance Method: In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally and is prevented from restriking in spite of the rising voltage across the contacts.

The ionized particles between the contacts tend to maintain the arc. If the arc path is deionized, the arc extinction is facilitated. This may be achieved by cooling the arc or by bodily removing the ionized particles from the space between the contacts.

IMPORTANT TERMS

- **ARC Voltage:** As soon as the contacts of the circuit breaker separate, an arc is formed. The voltage that appears across the contacts during arcing period is called the arc voltage. Its value is low except for the period the fault current is at or near zero current point.
- **Re-striking Voltage:** It is the transient voltage that appears across the contacts at or near current zero during arcing period. At current zero, a high-frequency transient voltage appears across the contacts and is caused by the rapid distribution of energy between the magnetic and electric fields associated with the plant and **transmission lines of the system. The current interruption in the circuit depends upon this voltage**
- **Recovery voltage:** It is the normal frequency rms voltage that appears across the contacts of the circuit breaker after complete interruption of the arc (i.e after the transient oscillation dies out).



4.4 CLASSIFICATION OF CIRCUIT BREAKERS

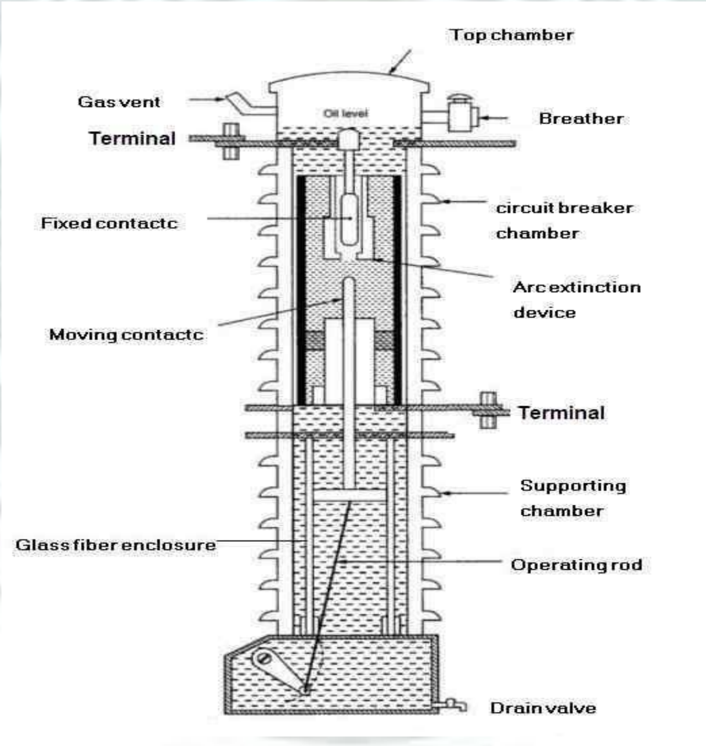
The type of the circuit breaker is usually identified according to the medium of arc extinction. The classification of the circuit breakers based on the medium of arc extinction is as follows:

- Oil Circuit Breaker
- Air-break circuit breaker
- Air blast circuit breaker
- Sulphur hexafluoride circuit breaker
- Vacuum circuit breaker

4.4.1 Oil Circuit Breaker

Oil circuit breaker is such type of circuit breaker which used oil as a dielectric or insulating medium for arc extinction. In oil circuit breaker the contacts of the breaker are made to separate within an insulating oil. When the fault occurs in the system the contacts of the circuit breaker are open under the insulating oil, and an arc is developed between them and the heat of the arc is evaporated in the surrounding oil

- It is designed for 11kV – 765kV.
- These are of two types
  - BOCB (BULK Oil Circuit Breaker)
  - MOCB (Minimum Oil Circuit Breaker)
- The contacts are immersed in oil.
- Oil provides cooling by hydrogen created by arc.
- It acts as a good dielectric medium and quenches the arc.

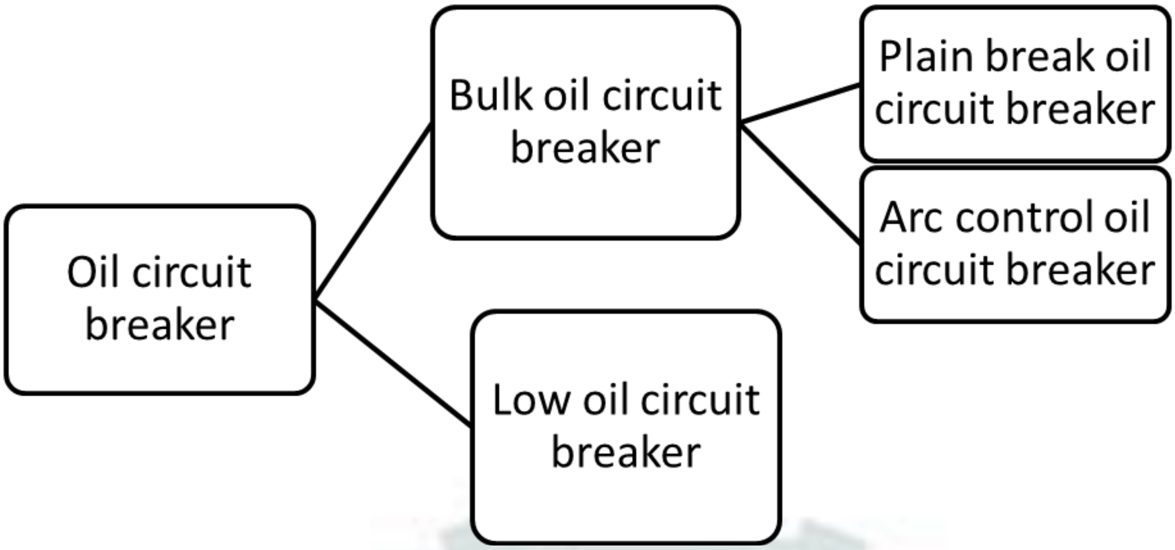


ADVANTAGES

- Oil has good dielectric strength.
- It has wide range of breaking capability.

DISADVANTAGES

- Slower operation, takes about 20 cycles for arc quenching.
- It is highly inflammable, so high risk of fire.
- High maintenance cost



PLAIN BREAK OIL CIRCUIT BREAKER

A plain-break oil circuit breaker is a bulk oil circuit breaker which involves the simple process of separating the contacts under the whole of the oil in the tank. There is no special system for arc control other than the increase in length caused by the separation of contacts. The arc extinction occurs when a certain critical gap between the contacts is reached.

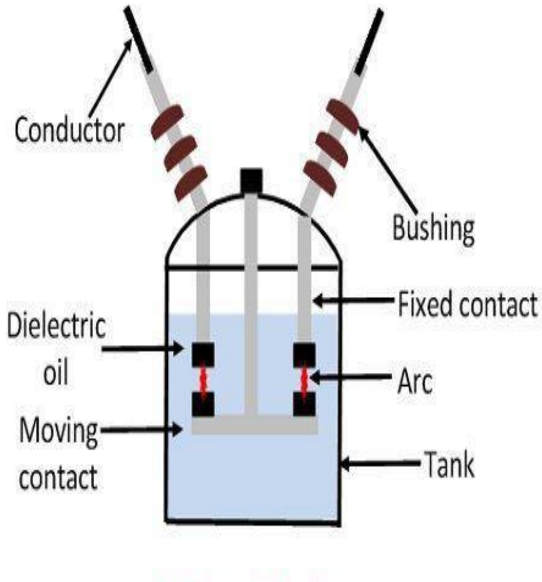
The plain-break oil circuit breaker is the earliest type from which all other circuit breakers have developed

ARC CONTROL OIL CIRCUIT BREAKER

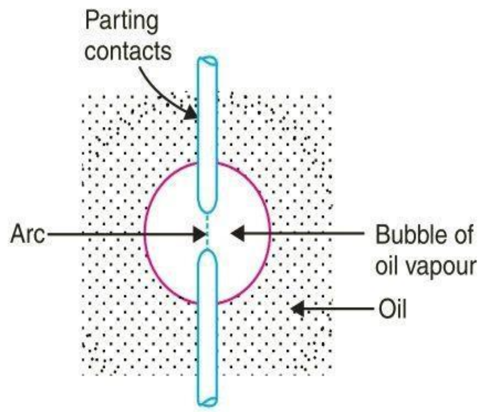
In case of plain-break oil circuit breaker, there is very little artificial control over the arc. Therefore, comparatively long arc length is essential in order that turbulence in the oil caused by the gas may assist in quenching it. However, it is necessary and desirable that final arc extinction should occur while the contact gap is still short. For this purpose, some arc control is incorporated and the breakers are then called arc control circuit breakers.

There are two types of such breakers:

- Self-blast oil circuit breakers: In which arc control is provided by internal means i.e. the arc itself is employed for its own extinction efficiently.
- Forced-blast oil circuit breakers: In which arc control is provided by mechanical means external to the circuit breaker.



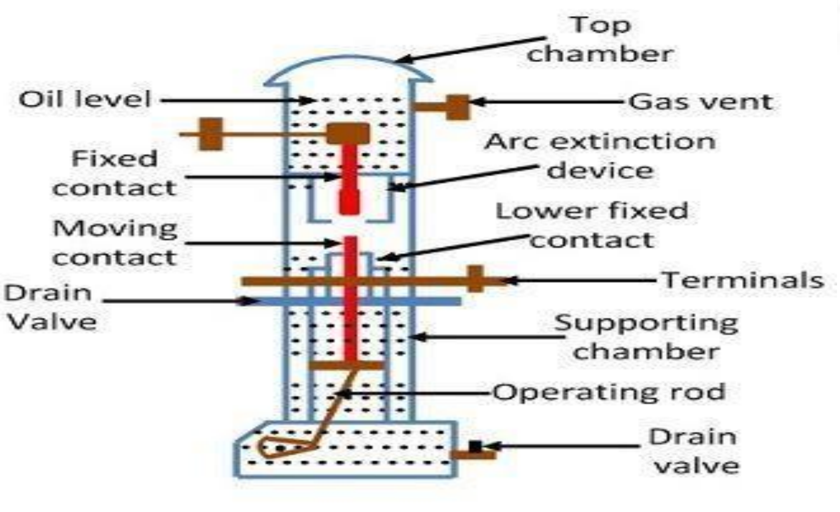
Oil Circuit Breaker



LOW OIL CIRCUIT BREAKER

In the bulk oil circuit breakers discussed so far, the oil has to perform two functions. Firstly, it acts as an arc quenching medium and secondly, it insulates the live parts from earth. It has been found that only a small percentage of oil is actually used for arc extinction while the major part is utilized for insulation purposes.

For this reason, the quantity of oil in bulk oil circuit breakers reaches a very high figure as the system voltage increases. This not only increases the expenses, tank size and weight of the breaker but it also increases the fire risk and maintenance problems



Minimum Oil Circuit Breaker

MAINTENANCE OF OIL CIRCUIT BREAKER

After a circuit breaker has interrupted by short-circuit current, sometimes their contacts may get burnt due to arcing. Also, the dielectric oil gets carbonized in the area of the contacts, thereby losing its dielectric strength. This results in the reduced breaking capacity of the breaker. Therefore, the maintenance of oil circuit breaker is essential for checking and replacement of oil and contacts.

4.4.2 Air Blast Circuit Breaker

- This operates using high velocity blast of air which quenches the arc.
- It consists of blast valve, blast tube & contacts.
- Blast valve contains high air pressure.
- Blast tube carries the air at high pressure and opens the moving contact attached to spring.
- Air should be kept clean and dry to operate it properly.

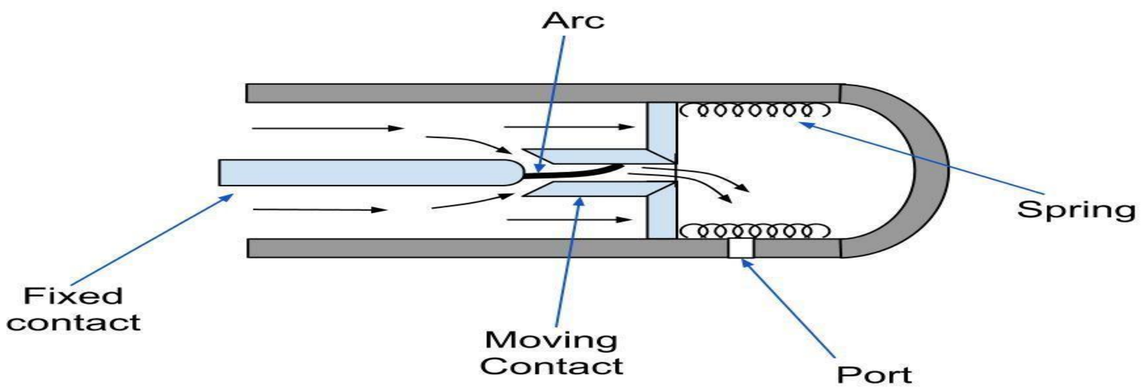
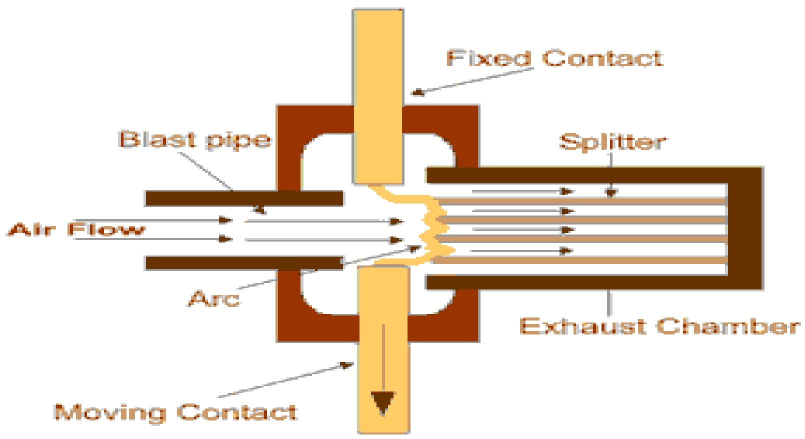
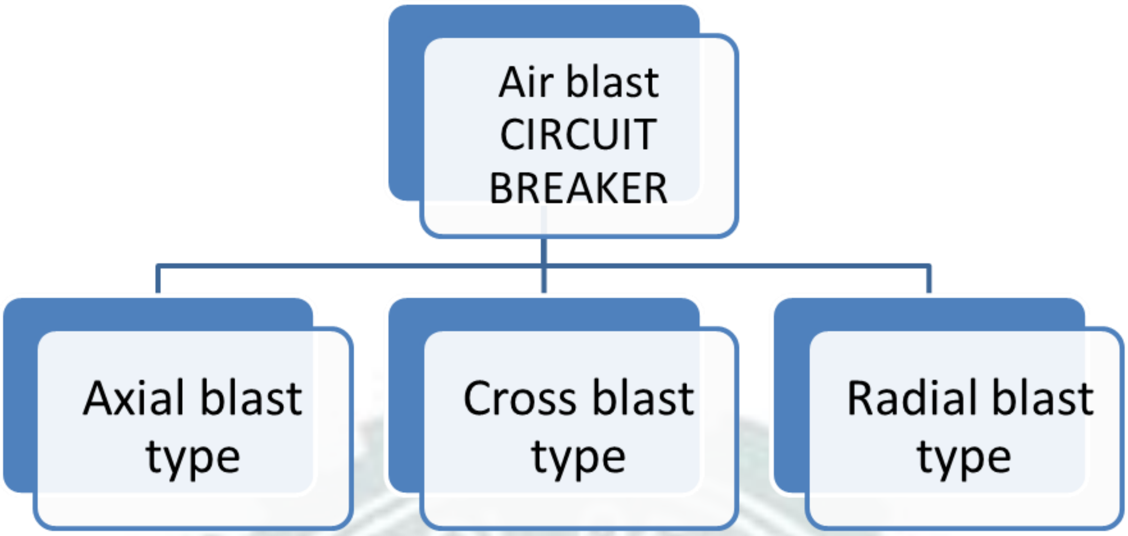


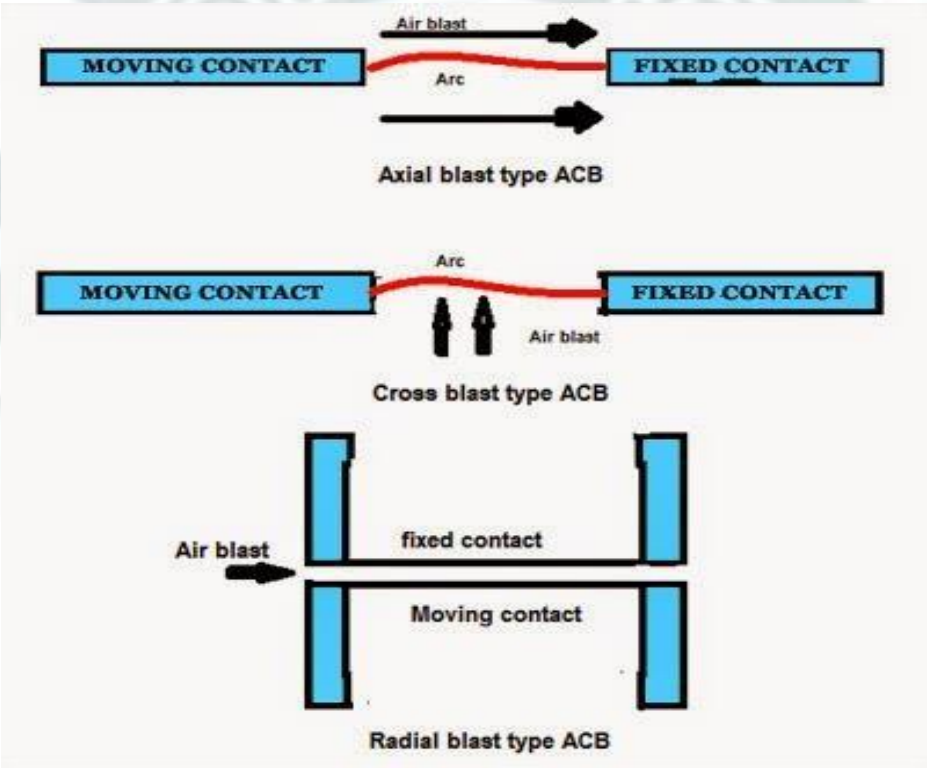
Fig-A: Sketch Illustrating Working of Air Blast Circuit Breaker



Principle of Cross Blast Air Circuit Breaker

CLASSIFICATION OF AIR BLAST CB

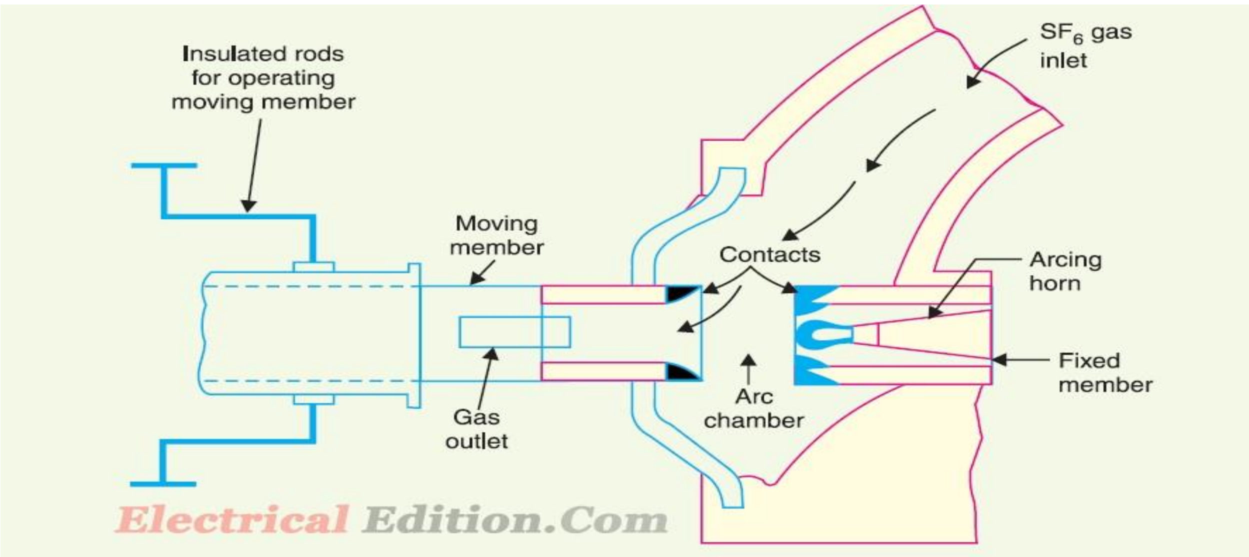




1. Axial Blast Type - air blast is directed along the arc path.
2. Cross Blast Type - air blast is directed at right angles to the arc path.
3. Radial Blast Type - air blast is directed radially.

4.4.3 Sulphur Hexafloride (SF_6) Circuit Breaker

- It contains an arc interruption chamber containing SF_6 gas.
- In closed position the contacts remain surrounded by SF_6 gas at a pressure of 2.8Kg/cm^2.
- During opening high pressure SF_6 gas at 14Kg/cm^2 from its reservoir flows towards the chamber by valve mechanism.
- SF_6 rapidly absorbs the free electrons in the arc path to form immobile negative ions to build up high dielectric strength.



- It also cools the arc and extinguishes it.
- After the operation the valve is closed by the action of a set of springs
- Absorbent materials are used to absorb the by-products and moisture.

ADVANTAGES

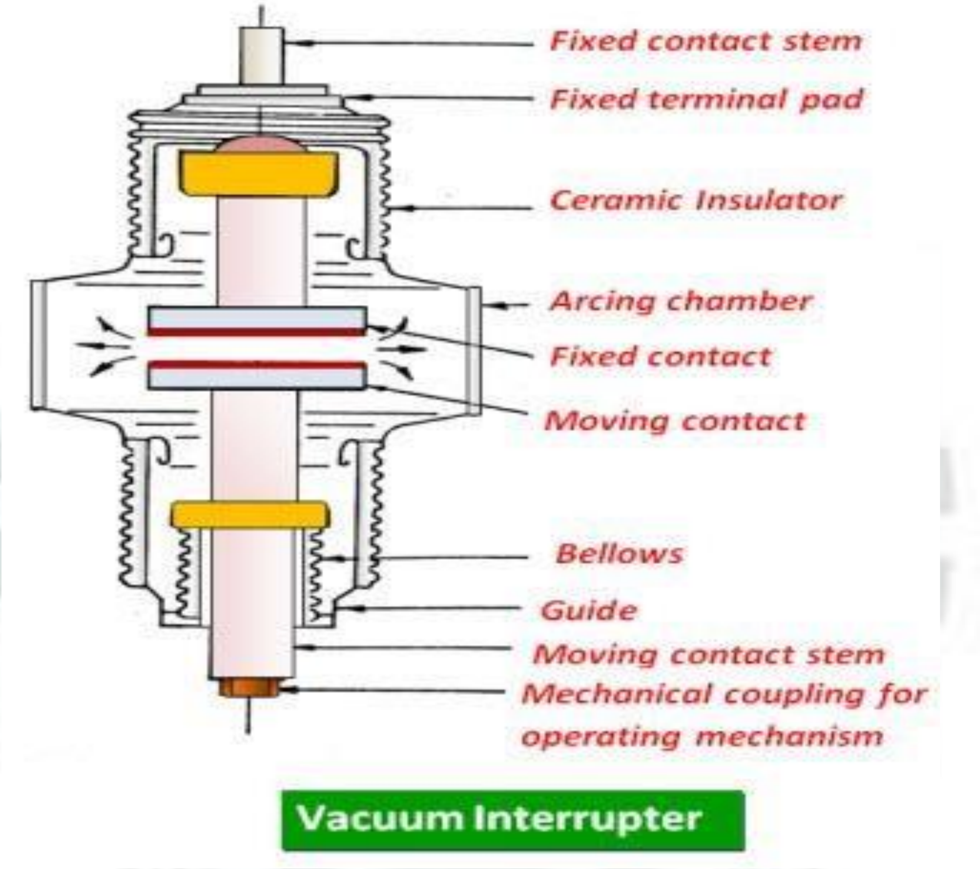
- No risk of fire.
- Low maintenance, light foundation.
- No over voltage problem.
- Can interrupt much larger currents as compared to other breakers

DISADVANTAGES

- SF_6 breakers are costly due to high cost of SF_6.
- SF_6 gas has to be reconditioned after every operation of the breaker, additional equipment is required for this purpose.

4.4.4 Vacuum Circuit Breaker

- It is designed for medium voltage range (3.3 – 33kV).
- This consists of vacuum of pressure ($1x10^{-6}$) inside arc extinction chamber.
- The arc burns in metal vapour when the contacts are disconnected.
- At high voltage, it's rate of dielectric strength recovery is very high.
- Due to vacuum arc extinction is very fast.
- The contacts loose metals gradually due to formation of metal vapours.



ADVANTAGES

- Free from arc and fire hazards.
- Low cost for maintenance & simpler mechanism.
- Low arcing time & high contact life.
- Silent & less vibrational operation.

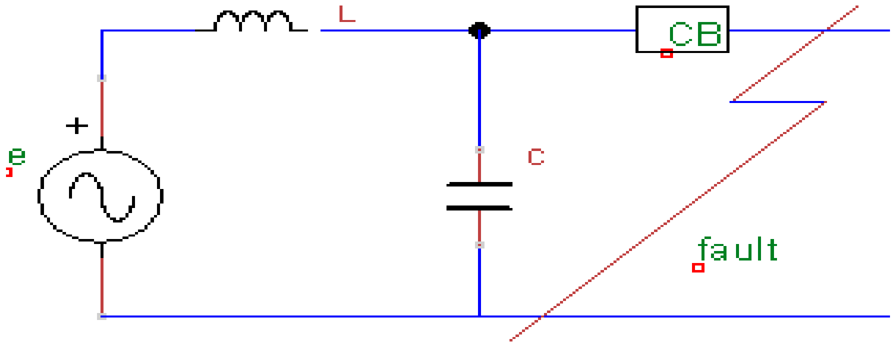
DISADVANTAGES

- High initial cost due to creation of vacuum.
- Surface of contacts are depleted due to metal vapours.
- High cost & size required for high voltage breakers.

4.5 PROBLEMS OF CIRCUIT INTERRUPTION

Rate of rise in restriking voltage:

- Every line has some inductance L in series and some capacitance C in parallel to a generator.
- When fault occurs, the current from generator has 2 paths. One through capacitor C and other through fault. The fault always offers very low resistance so all the current flows through fault and no current flow through C.



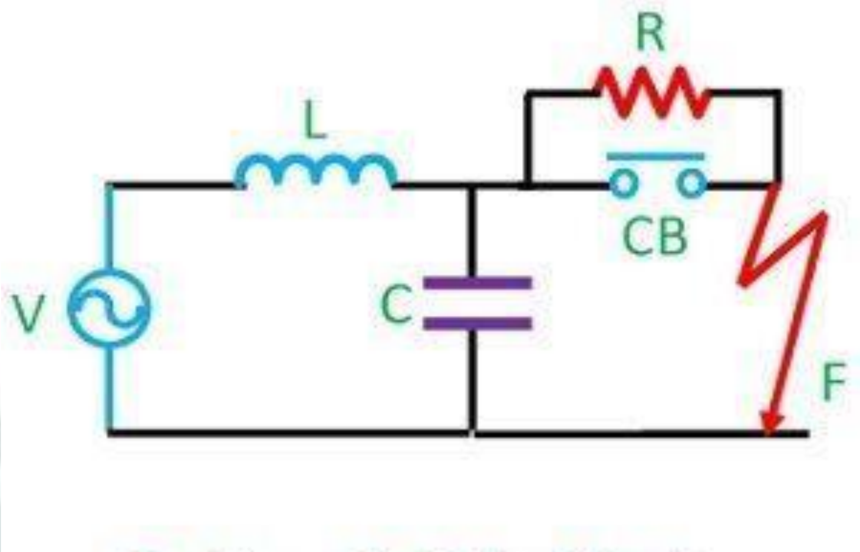
* As there is only one element in the circuit, the full voltage e will be given to L only.
* Therefore, The current I lags e by 90 ° (as the element in inductive).
* But when CB starts opening its contacts (moving contact and fixed contact are now separating) and arc is quenched then this circuit becomes series L-C circuit.
* Whenever L-C series circuit is form, a voltage is form which is called as Restriking voltage.
* This Restriking voltage helps the arc to produce again. i.e. after quenching of arc this Restriking voltage produces arc again.
* If Rate of Rising this Restriking voltage is more (RRRV is more) then arc forms again and again.

Current chopping:

* In circuit breaker, the AC current is interrupted when it is crossing zero. (i.e. SF_6, Air etc is flow on arc at zero point because it is easy to quench arc at zero point).
* This problem of current chopping mainly occurs in Air-Blast circuit breaker, when some low current is (stopped or) interrupted.
* Current chopping is the process in which, when current is interrupted (stopped) before zero point then some very high voltage is develop between fixed contact and moving contact.

4.7 RESISTANCE SWITCHING

A fixed connection of resistance in parallel with the contact space or arc is called the resistance switching. Resistance switching is employed in circuit breakers having a high post zero resistance of contact space. The resistance switching is mainly used for reducing the restriking voltage and the transient voltage surge.



Resistance Switching Circuit

4.8 CIRCUIT BREAKER RATING

- The rating of the circuit breaker is given on the duties that are performed by it. For complete specification standard ratings and various tests of switches and circuit breakers may be consulted.
- Apart from the normal working of circuit breakers, the circuit breaker is required to perform following three major duties under short circuit conditions:
- It is capable of breaking the faulty section of the system. This is described as the breaking capacity of the circuit breaker.
- The circuit breaker must be capable of making the circuit in the greatest asymmetrical current in the current wave. This refers to making the capacity of the circuit breaker.
- It must be capable of carrying fault safely for a short time while the other breaker is clearing the fault. This refers to the short-time capacity of a circuit breaker.

Chapter - 5

RELAY

5.1 INTRODUCTION

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

5.2 FUNDAMENTAL REQUIREMENTS OF RELAYING

Relay must have following requirements to perform desired function:

- **SELECTIVITY:** It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system.
  In order to provide selectivity entire system is divided in following protection zones:
  1. Generators
  2. Low voltage switchgear
  3. Transformers
  4. High voltage switchgear
  5. Transmission lines
- **SPEED:** The relay system should disconnect the faulty section as fast as possible to protect the system from being unstable.
- **SENSITIVITY:** It is the ability of the relay system to operate with low value of actuating quantity.
- **RELIABILITY:** It is the ability of the relay system to operate under the pre-determined conditions.
- **SIMPLICITY:** The relaying system should be simple so that it can be easily maintained.

5.3 BASIC RELAYS

- Most of the relays used in the power system operates by virtue of current or voltage supplied connected in various combinations to the system element that is to be protected.
- Most of the relays today are of electro-mechanical type. They work on the following two main operating principles:

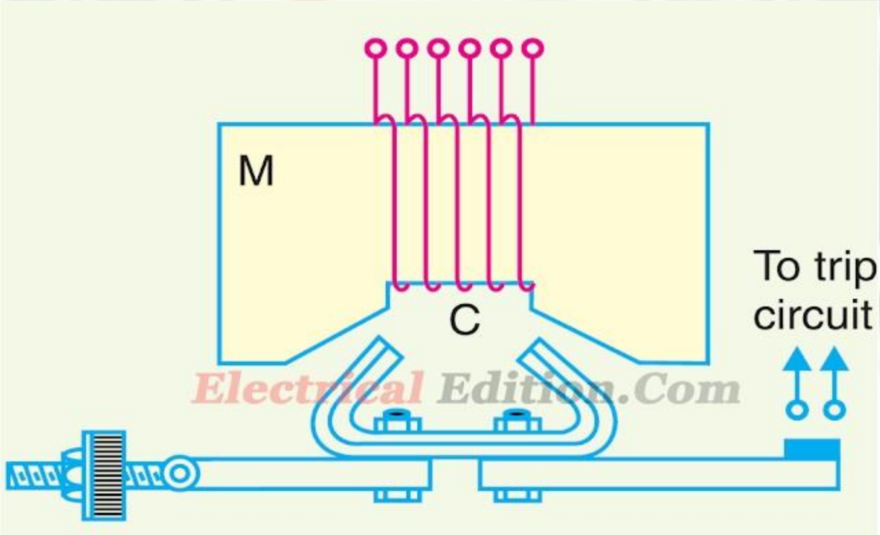
i. Electromagnetic attraction
ii. Electromagnetic induction

5.3.1 Electromagnetic Attraction Relay

Electromagnetic attraction relays operate by virtue of an armature being attracted to the poles of an electromagnet or a plunger being drawn into a solenoid. Such relays may be actuated by DC or AC quantities.

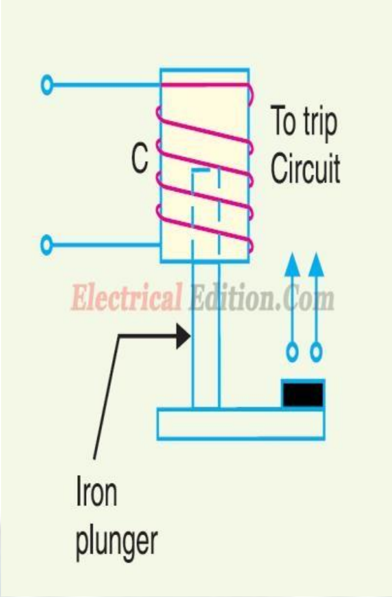
The important types of electromagnetic attraction relays are:

Attracted armature type relay: It consists of a electromagnet carrying a coil and an armature. When a short-circuit occurs, the current through the relay coil increases sufficiently and the relay armature is attracted upwards. This completes the trip circuit which results in opening of circuit breaker. The minimum current at which the relay armature is attracted to close the trip circuit is called pickup current.



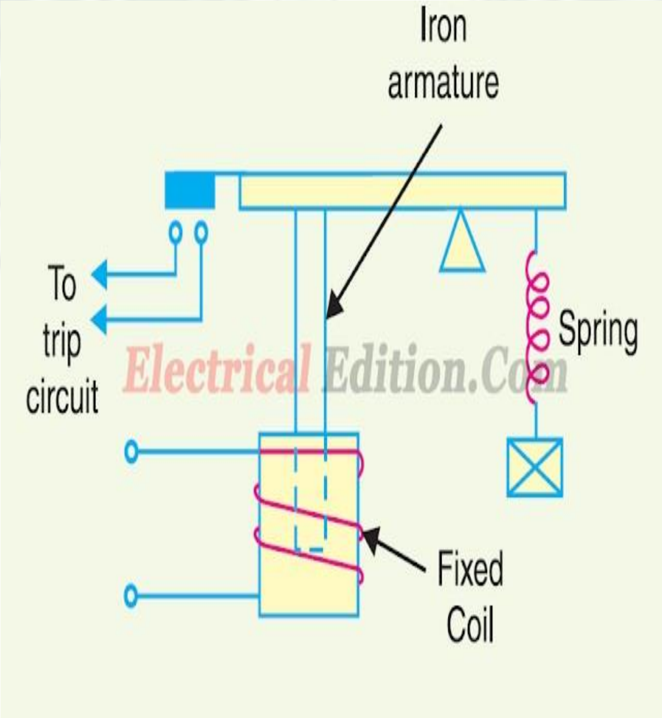
Solenoid type relay: It consists of a solenoid and movable iron plunger arranged as shown. Under normal operating conditions, the current through the relay coil C is such that it holds the plunger by gravity or spring in the position shown.

However, on the occurrence of a fault, the current through the relay coil becomes more than the pickup value, causing the plunger to be attracted to the solenoid. The upward movement of the plunger closes the trip circuit, thus opening the circuit breaker and disconnecting the faulty circuit.



Balanced beam type relay: It consists of an iron armature fastened to a balance beam. Under normal operating conditions, the current through the relay coil is such that the beam is held in the horizontal position by the spring.

When a fault occurs, the current through the relay coil becomes greater than the pickup value and the beam is attracted to close the trip circuit. This causes the opening of the circuit breaker to isolate the faulty circuit.



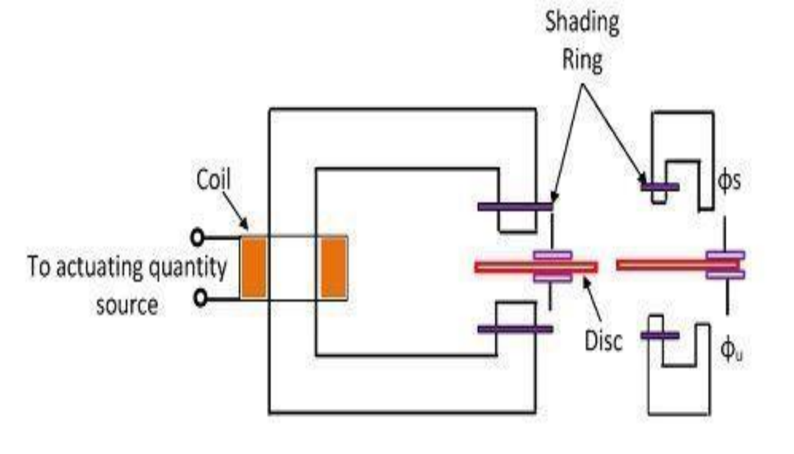
5.3.2 Electromagnetic Induction Relays

Electromagnetic-induction relays use the principle of the induction motor where torque is developed by induction in a rotor; this operating principle applies only to relays actuated by Alternating Current, and called Induction Type relays

The different type of structure has been used for obtaining the phase difference in the fluxes. These structures are

- **Shaded pole structure :** This coil is usually energised by current flowing in the single coil wound on a magnetic structure containing an air gap. The air-gap fluxes produce by the initializing current is split into two flux displace in time-space and by a shaded ring. The shaded ring is made up of the copper ring that encircles the part of the pole face of each pole.

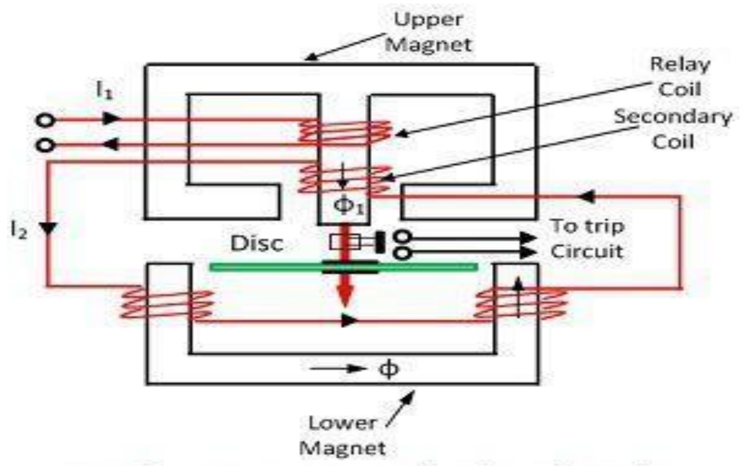
  The disc is made up of aluminium. The inertia of the aluminium disc is very less. Hence they need less deflecting torque for its movement. The two rings have the current induced in them by the alternating flux of the electromagnetic. The magnetic field develops from the current produces the flux in the portion of the iron ring surrounded by the ring to lag in phase by 40° to 50° behind the flux in the unshaded portion of the pole.



Shaded Pole Construction of Induction Disc Relay

- **Watt-hour Meter Structure:** The E-shaped electromagnet carries the two windings the primary and the secondary. The primary current was carrying the relay current I1 while the secondary winding is connected to the windings of the U-shaped electromagnet.

  The primary winding carries relay current I1 while the secondary current induces the emf in the secondary and so circulate the current I2 in it. The flux φ1 induces in the E shed magnet, and the flux φ induces in the U-shaped magnet. These fluxes induced in the upper and lower magnetic differs in phase by angle θ which will develop a driving torque on the disc proportional to $\varphi 1 \varphi \sin\theta$.

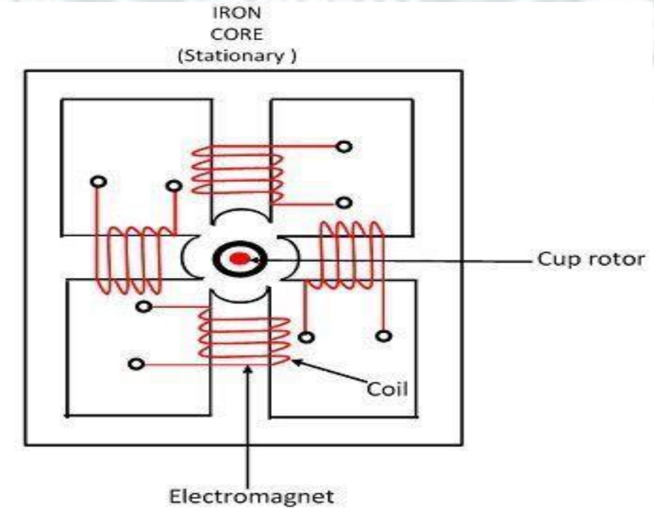


Watt-hour Meter Type Induction Disc Relay

- **Induction Cup Relay :** The relay which works on the principle of electromagnetic induction is known as the induction cup relay. The relay has two or more electromagnet which is energized by the relay coil. The static iron core is placed between the electromagnet.

The coil which is wound on the electromagnet generates the rotating magnetic field. Because of the rotating magnetic field, the current induces inside the cup. Thus, the cup starts rotating. The direction of rotation of the cup is same as that of the current.

The more torque is produced in the induction cup relay as compared to the shaded and watt meter type relay. The relay is fast in operation and their operating time is very less approximately 0.01 sec.



Induction Cup Relay

IMPORTANT TERMS

- PICK-UP CURRENT: It is the minimum current in the relay coil at which the relay starts to operate.
- CURRENT SETTING: It is the required value to which the pick-up current is adjusted.

  Pick-up Current = Rated Secondary Current Of C.T. X Current Setting
- PLUG-SETTING MULTIPLIER(P.S.M.): It is the ratio of fault current in relay coil to the pick-up current,

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

Or, $$\text{P.S.M}=\frac{\textit{Fault current in relay}}{\textit{Rated secondary current of C.T.xCurrent setting}}$$

- **TIME-SETTING MULTIPLIER:** A relay is generally provided with control to adjust the time of operation. This adjustment is known as time-setting multiplier.

5.4 CLASSIFICATION OF FUNCTIONAL RELAY

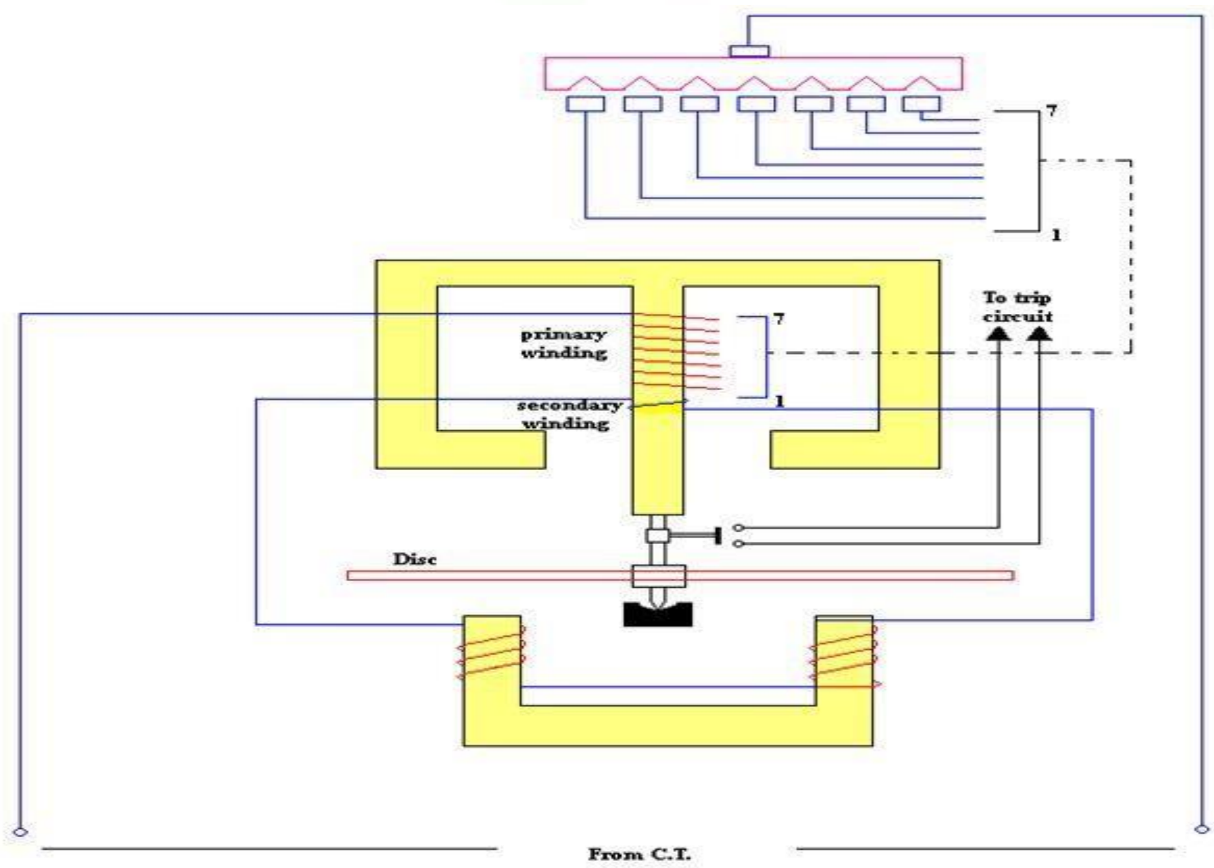
- Relays are generally classified according to the function they are called upon to perform in the protection of electric power circuits.
- Some important types of functional relays are:
  - i. Induction type over current relays
  - ii. Induction type reverse power relays
  - iii. Distance relays
  - iv. Differential relays
  - v. Translay scheme

5.4.1 Induction Type Overcurrent Relay (Non-Directional

- This relay is also called earth leakage induction type relay. The overcurrent relay operates when the current in the circuit exceeds a certain preset value.
- The upper is E shaped while the lower is U shaped. The aluminium disc is free to rotate between the two magnets. The spindle of the disc carries moving contacts and when the disc rotates the moving contacts come in contact with fixed contacts which are the terminals of a trip circuit. The upper magnet has two windings, primary and secondary.
- The primary is connected to the secondary of C.T on the line to be protected his winding is tapped at intervals. The tappings are connected to plug setting bridge. With the help of this bridge, the

number of turns of the primary winding can be adjusted. Thus the desired current setting for the Non-directional Induction Overcurrent Relay can be obtained.

- The torque is produced due to induction principle, as explained in non-directional Induction Type Overcurrent Relay. This torque is opposed by restraining force produced by spiral springs. Under normal conditions, the restraining force is more than driving force hence disc remains stationary. Under fault conditions when the current becomes high, the disc rotates through the preset angle and makes contact with the fixed contacts of the trip circuit. The trip circuit opens the circuit breaker, isolating the faulty part from rest of the healthy system.



5.4.2 Induction Type Directional Over Current Relay

- This type of relay is designed to over come the difficulty of insufficient torque by being almost independent of system voltage and power factor.
- It consists of both directional and non-directional element.
- Directional element will operate when power flows in a specific direction. After the operation of directional element the spindle of the disc of non directional element carries a moving contact which closes the fixed contacts.

When a short circuit occurs the disc of the upper element rotates to bridge the fixed contacts. This completes the circuit for overcurrent element. The disc of this element rotates and the moving contact attached to it closes the trip circuit. This operates the circuit breaker

5.4.3 Differential Relay

- A differential relay is defined as the relay that operates when the phase difference of two or more identical electrical quantities exceeds a predetermined amount. The differential relay works on the principle of comparison between the phase angle and magnitude of two or more similar electrical quantities.
- There are two fundamental systems of differential protection:
  - Current balance protection
  - Voltage balance protection

5.4.3.1 Current Differential Relay

- In current differential relay two current transformers are fitted on the either side of the equipment to be protected. The secondary circuits of CTs are connected in series in such a way that they carry secondary CT current in same direction.
- The operating coil of the relaying element is connected across the CT's secondary circuit. Under normal operating conditions, the protected equipment carries normal current. In this situation, say the secondary current of CT_1 is I_1 and secondary current of CT_2 is I_2. The current passing through the relay coil is I_1-I_2. The current transformer's ratio and polarity are so chosen, $I_1 = I_2$, hence there will be no current flowing through the relay coil
- If any fault occurs in the external to the zone covered by the CTs, faulty current passes through primary of the both current transformers and thereby secondary currents of both current transformers remain same as in the case of normal operating conditions. Therefore at that situation the relay will not be operated. But if any ground fault occurred inside the protected equipment as shown, two secondary currents will be no longer equal. At that case the differential relay is being operated to isolate the faulty equipment from the system.

5.4.3.2 Voltage Differential Relay

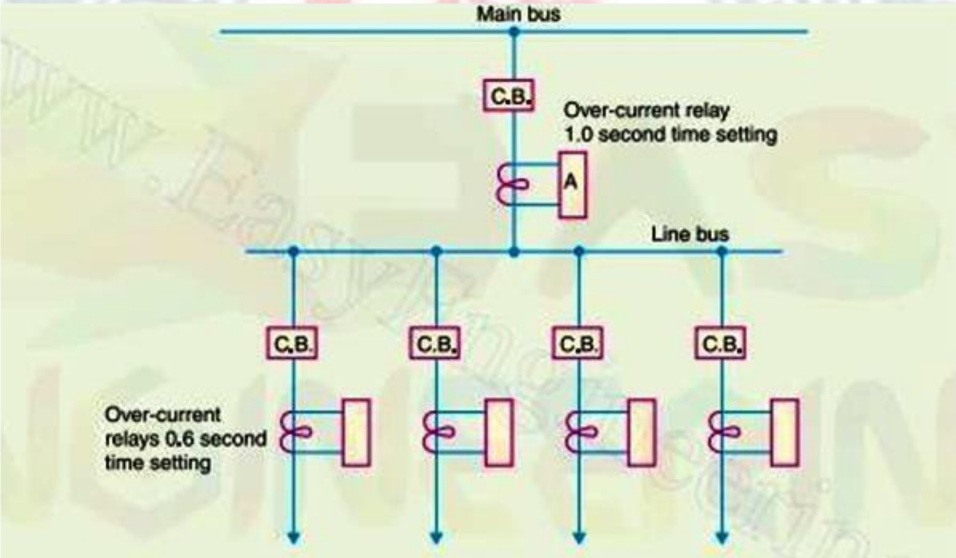
- The voltage differential relay uses two similar current transformer places across the protective zone with the help of pilot wire.

- The relays are connected in series with the secondary of the current transformer. The relays are connected in such a way that no current flows through it in the normal operating condition. The voltage balance differential relay uses the air core CTs in which the voltages induces regarding current.

When the fault occurs in the protection zone, the current in the CTs become unbalance because of which the voltage in the secondary of the CTs disturbs. The current starts flowing through the operating coil. Thus, the relay starts operating and gives the command to the circuit breaker to operates

5.5 TYPES OF PROTECTION

- **PRIMARY PROTECTION:** It is a protection scheme which is designed to protect the components parts of the power system. Each line has an overcurrent relay that protects the line. This forms the primary protection and serves as the first line of defence. However, sometimes faults are not cleared by primary relay system. Under such conditions, back-up protection does the required job



- **BACK-UP PROTECTION:** It is the second line of defence in case of failure of primary defence. It is designed to operate with sufficient time delay so that primary relaying will get enough time to function. There is a single relay for protection of all lines. If fault occurs and primary defence fails then this relay will disconnect the supply from all lines

Chapter - 6

PROTECTION OF ELECTRICAL POWER EQUIPMENT AND LINES

6.1 PROTECTION OF ALTERNATORS

The generating units, especially the larger ones, are relatively few in number and higher in individual cost than most other equipment's. Therefore, it is desirable and necessary to provide Protection of Alternators to cover the wide range of faults which may occur in the modern generating plant.

Some of the important faults which may occur on an alternator are :

1. Failure of Prime-Mover:

When input to the prime-mover fails, the alternator runs as a synchronous motor and draws some current from the supply system. This motoring conditions is known as "inverted running".

- In case of turbo-alternator sets, failure of steam supply may cause inverted running. If the steam supply is gradually restored, the alternator will pick up load without disturbing the system. If the steam failure is likely to be prolonged, the machine can be safely isolated by the control room attendant since this condition is relatively harmless. Therefore, automatic protection is not required.
- In case of hydro-generator sets, Protection of Alternators against inverted running is achieved by providing mechanical devices on the water-wheel. When the water flow drops to an insufficient rate to maintain the electrical output, the alternator is disconnected from the Therefore, in this case also electrical protection is not necessary.
- Diesel engine driven alternators, when running inverted, draw a considerable amount of power from the supply system and it is a usual practice to provide Protection of Alternators against motoring in order to avoid damage due to possible mechanical seizure. This is achieved by applying reverse power relays to the alternators which *isolate the latter during their motoring action. It is essential that the reverse power relays have time-delay in operation in order to prevent inadvertent tripping during system disturbances caused by faulty synchronizing and phase swinging.

2. Failure of field:

The chances of field failure of alternators are undoubtedly very rare. Even if it does occur, no immediate damage will be caused by permitting the alternator to run without a field for a short- period. It is sufficient to rely on the control room attendant to disconnect the faulty alternator manually from the system bus-bars. Therefore, it is a universal practice not to provide automatic protection against this contingency.

3. Overcurrent:

It occurs mainly due to partial breakdown of winding insulation or due to overload on the supply system. Overcurrent protection for alternators is considered unnecessary because of the following reasons:

- The modern tendency is to design alternators with very high values of internal impedance so that they will stand a complete short-circuit at their terminals for sufficient time without serious overheating. On the occurrence of an overload, the alternators can be disconnected manually.
- The disadvantage of using overload Protection of Alternators is that such a protection might disconnect the alternators from the power plant bus on account of some momentary troubles outside the plant and, therefore, interfere with the continuity of electric service.

4. Over speed:

The chief cause of over speed is the sudden loss of all or the major part of load on the alternator. Modern alternators are usually provided with mechanical centrifugal devices mounted on their driving shafts to trip the main valve of the prime-mover when a dangerous over speed occurs.

5. Over-voltage:

The field excitation system of modern alternators is so designed that over-voltage conditions at normal running speeds cannot occur. However, over voltage in an alternator occurs when speed of the prime-mover increases due to sudden loss of the alternator load.

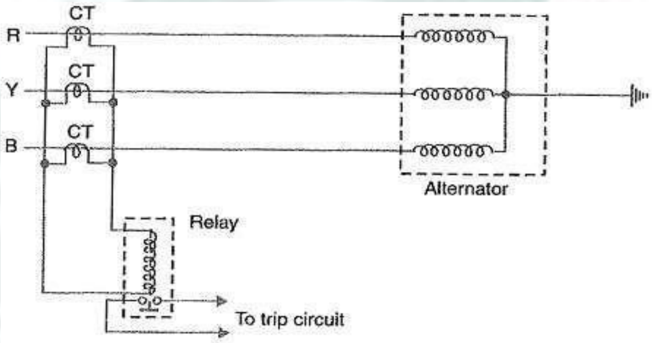
In case of steam-turbine driven alternators, the control governors are very sensitive to speed variations. They exercise a continuous check on over speed and thus prevent the occurrence of over- voltage on the generating unit. Therefore, over-voltage protection is not provided on turbo-alternator sets.

In case of hydro-generator, the control governors are much less sensitive and an appreciable time may elapse before the rise in speed due to loss of load is checked. The over-voltage during this time may reach a value which would over-stress the stator windings and insulation breakdown may occur. It is, therefore, a usual practice to provide over-voltage protection on hydro-generator units. The over- voltage relays are operated from a voltage supply derived from the generator terminals. The relays are so arranged that when the generated voltage rises 20% above the normal value, they operate to

- trip the main circuit breaker to disconnect the faulty alternator from the system
- disconnect the alternator field circuit

6. Unbalanced loading:

Unbalanced loading means that there are different phase currents in the alternator. Unbalanced loading arises from faults to earth or faults between phases on the circuit external to the alternator. The unbalanced currents, if allowed to persist, may either severely burn the mechanical fixings of the rotor core or damage the field winding.



Above figure shows the schematic arrangement for the Protection of Alternators against unbalanced loading. The scheme comprises three line current transformers, one mounted in each phase, having their secondaries connected in parallel. A relay is connected in parallel across the transformer secondaries. Under normal operating conditions, equal currents flow through the different phases of the alternator and their algebraic sum is zero. Therefore, the sum of the currents flowing in the secondaries is also zero and no current flows through the operating coil of the relay. However, if unbalancing occurs, the currents induced in in the secondaries will be different and the resultant of these currents will flow through the relay. The operation of the relay will trip the circuit breaker to disconnect the alternator from the system.

7. Stator winding faults:

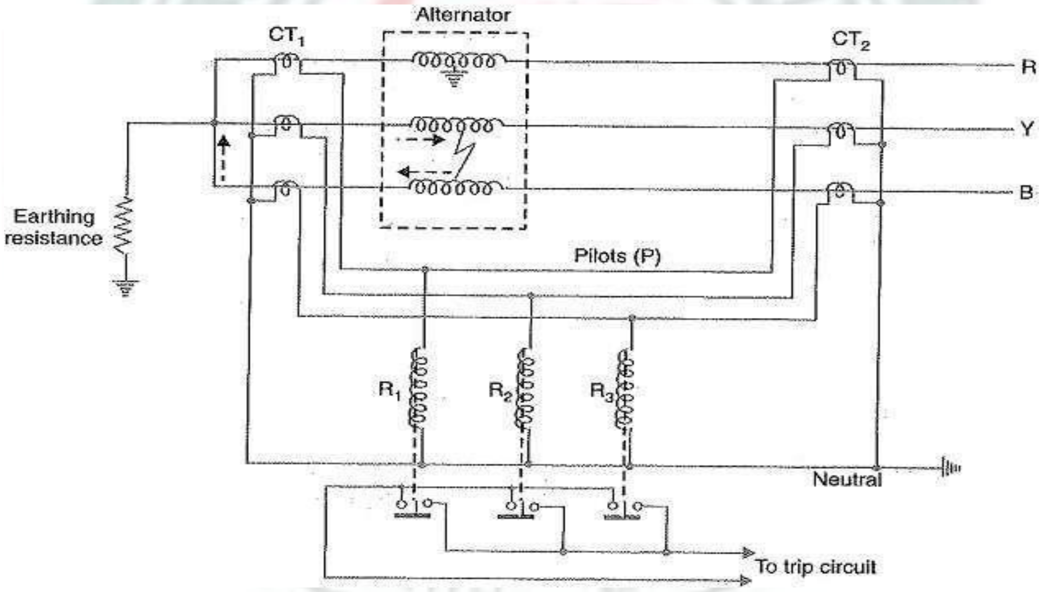
These faults occur mainly due to the insulation failure of the stator windings. The main types of stator winding faults, in order of importance are :

- fault between phase and ground
- fault between phases
- inter-turn fault involving turns of the same phase winding

The stator winding faults are the most dangerous and are likely to cause considerable damage to the expensive machinery. Therefore, automatic protection is absolutely necessary to clear such faults in the quickest possible time in order to minimize the extent of damage. For Protection of Alternators against such faults, differential method of protection (also knows as Merz-Price system) is most commonly employed due to its greater sensitivity and reliability.

6.1.1 Differential Protection of Alternators

The most common system used for the protection of stator winding faults employs circulating-current principle. In this scheme of Differential Protection of Alternators, currents at the two ends of the protected section are compared. Under normal operating conditions, these currents are equal but may become unequal on the occurrence of a fault in the protected section. The difference of the currents under fault conditions is arranged to pass through the operating coil of the relay. The relay then closes its contacts to isolate protected section from the system. This form of protection is also known as Merz-Price Circulating Current Scheme.



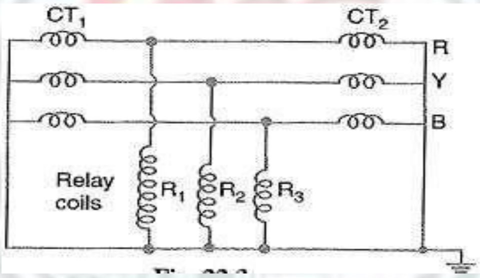
Schematic arrangement:

Above figure shows the schematic arrangement of Differential Protection of Alternators for a 3-phase alternator. Identical current transformer pairs CT1 and CT2 are placed on either side of each phase of the stator windings. The secondaries of each set of current transformers are connected in star ; the two neutral points and the corresponding terminals of the two star groups being connected together by means of a four-core pilot cable. Thus there is an independent path for the currents circulating in each pair of current transformers and the corresponding pilot P.

The relay coils are connected in star, the neutral point being connected to the current-transformer common neutral and the outer ends one to each of the other three pilots. In order that burden on each current transformer is the same, the relays are connected across equipotential points of the three pilot wires and these equipotential points would naturally be located at the middle of the pilot wires. The relays are generally of electromagnetic type and are arranged for instantaneous action since fault should be cleared as quickly as possible.

Operation:

Referring to above figure it is clear that the relays are connected in shunt across each circulating path. Therefore, the circuit of Fig. can be shown in a simpler form in Fig. Under normal operating conditions, the current at both ends of each winding will be equal and hence the currents in the secondaries of two CTs connected in any phase will also be equal. Therefore, there is balanced circulating current in the pilot wires and no current flows through the operating coils (R_1, R_2 and R_3) of the relays. When an earth-fault or phase-to-phase fault occurs, this condition no longer holds good and the differential current flowing through the relay circuit operates the relay to trip the circuit breaker.



(i) Suppose an earth fault occurs on phase R due to breakdown of its insulation to earth as shown in above figure. The current in the affected phase winding will flow through the core and frame of the machine to earth, the circuit being completed through the neutral earthing resistance. The currents in the secondaries of the two CTs in phase R will become unequal and the difference of the two currents will flow through the corresponding relay coil (i.e. R_1), returning via the neutral pilot. Consequently, the relay operates to trip the circuit breaker.

(ii) Imagine that now a short-circuit fault occurs between the phases Y and B as shown in above figure. The short-circuit current circulates via the neutral end connection through the two windings and through the fault as shown by the dotted arrows. The currents in the secondaries of two CTs in each affected phase will become unequal and the differential current will flow through the operating coils of the relays (i.e. R_2 and R_3) connected in these phases. The relay then closes its contacts to trip the circuit breaker. It may be noted that the relay circuit is so arranged that its energizing causes (i) opening of the breaker connecting the alternator to the bus-bars and (ii) opening of the field circuit of the alternator.

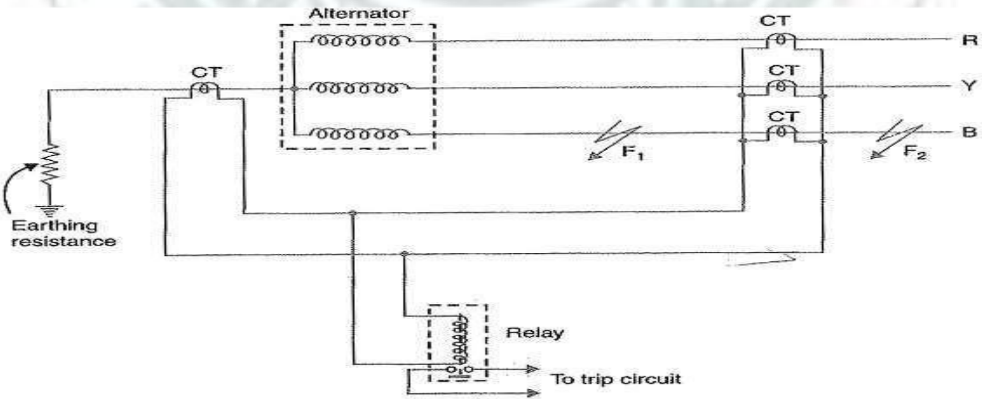
Limitations:

The two circuits for alternator protection shown above have their own limitations. It is a general practice to use neutral earthing resistance in order to limit the destructive effects of earth-fault currents. In such a situation, it is impossible to protect whole of the stator windings of a star- connected alternator during earth-faults. When an earth-fault occurs near the neutral point, there may be insufficient voltage across the short-circuited portion to drive the necessary current round the fault circuit to operate the relay. The magnitude of unprotected zone depends upon the value of earthing resistance and relay setting.

Makers of protective gear speak of “protecting 80% of the winding” which means that faults in the 20% of the winding near the neutral point cannot cause tripping i.e. this portion is unprotected. It is a usual practice to protect only 85% of the winding because the chances of an earth fault occurring near the neutral point are very rare due to the uniform insulation of the winding throughout.

6.1.2 Balanced Earth Fault Protection

In small-size alternators, the neutral ends of the three-phase windings are often connected internally to a single terminal. Therefore, it is not possible to use Merz-Price circulating current principle described above because there are no facilities for accommodating the necessary current transformers in the neutral connection of each phase winding. Under these circumstances, it is considered sufficient to provide protection against earth-faults only by the use of Balanced Earth Fault Protection scheme. This scheme provides no protection against phase- to-phase faults, unless and until they develop into earth- faults, as most of them will.



Schematic arrangement

Above figure shows the schematic arrangement of a Balanced Earth Fault Protection for a 3-phase alternator. It consists of three line current transformers, one mounted in each phase, having their secondaries connected in parallel with that of a single current transformer in the conductor joining the star point of the alternator to earth. A relay is connected across the transformers secondaries. The protection against earth faults is limited to the region between the neutral and the line current transformers.

Operation:

Under normal operating conditions of Balanced Earth Fault Protection, the currents flowing in the alternator leads and hence the currents flowing in secondaries of the line current transformers add to zero and no current flows through the relay. Also under these conditions, the current in the neutral wire is zero and the secondary of neutral current transformer supplies no current to the relay.

If an earth-fault develops at F2 external to the protected zone, the sum of the currents at the terminals of the alternator is exactly equal to the current in the neutral connection and hence no current flows through the relay. When an earth-fault occurs at F1 or within the protected zone, these currents are no longer equal and the differential current flows through the operating coil of the relay. The relay then closes its contacts to disconnect the alternator from the system.

6.2 PROTECTION OF TRANSFORMERS

Transformers are static devices, totally enclosed and generally oil immersed. Therefore, chances of faults occurring on them are very rare. However, the consequences of even a rare fault may be very serious unless the transformer is quickly disconnected from the system. This necessitates to provide adequate automatic Protection of Transformers against possible faults.

Small distribution transformers are usually connected to the supply system through series fuses instead of circuit breakers. Consequently, no automatic protective relay equipment is required. However, the probability of faults on power transformers is undoubtedly more and hence automatic protection is absolutely necessary.

Common transformer faults: As compared with generators, in which many abnormal conditions may arise, power transformers may suffer only from :

- open circuits
- overheating
- Winding short-circuits g. earth-faults, phase-to-phase faults and inter-turn faults.

An open circuit in one phase of a 3-phase transformer may cause undesirable heating. In practice, relay protection is not provided against open circuits because this condition is relatively harmless. On the occurrence of such a fault, the transformer can be disconnected manually from the system. Overheating of the transformer is usually caused by sustained overloads or short-circuits and very occasionally by the failure of the cooling system. The relay protection is also not provided against this contingency and thermal accessories are generally used to sound an alarm or control the banks of fans.

Winding short-circuits (also called internal faults) on the transformer arise from deterioration of winding insulation due to overheating or mechanical injury. When an internal fault occurs, the transformer must be disconnected quickly from the system because a prolonged arc in the transformer may cause oil fire. Therefore, relay protection is absolutely necessary for internal faults.

6.2.1 Protection Systems for Transformers

For protection of generators, Merz-Price circulating-current system is unquestionably the most satisfactory. Though this is largely true of Protection of Transformers, there are cases where circulating current system offers no particular advantage over other systems or impracticable on account of the troublesome conditions imposed by the wide variety of voltages, currents and earthing conditions invariably associated with power transformers. Under such circumstances, alternative protective systems are used which in many cases are as effective as the circulating-current system. The principal relays and systems used for Protection of Transformers are :

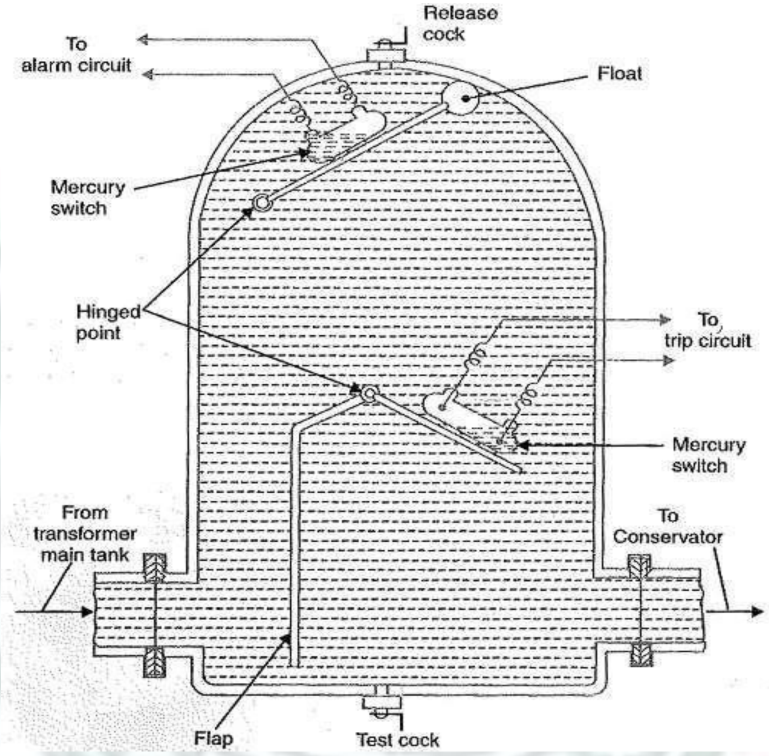
- Buchholz devices providing protection against all kinds of incipient faults i.e. slow-developing faults such as insulation failure of windings, core heating, fall of oil level due to leaky joints etc.
- Earth fault relays providing protection against earth-faults only.
- Overcurrent relays providing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

The complete Protection of Transformers usually requires the combination of these systems. Choice of a particular combination of systems may depend upon several factors such as

- Size of the transformer
- Type of cooling
- Location of transformer in the network
- Nature of load supplied and
- Importance of service for which transformer is required.

6.2.2 Buchholz Relay

Buchholz Relay is a gas-actuated relay installed in oil immersed transformers for protection against all kinds of faults. Named after its inventor, Buchholz, it is used to give an alarm in case of incipient (i.e. slow-developing) faults in the transformer and to disconnect the transformer from the supply in the event of severe internal faults. It is usually installed in the pipe connecting the conservator to the main tank as shown in Fig. It is a universal practice to use Buchholz relays on all such oil immersed transformers having ratings in excess of 750 kVA.



Buchholz relay

Construction:

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

Operation:

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

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

Advantages of Buchholz Relay:

- It is the simplest form of transformer protection.
- It detects the incipient faults at a stage much earlier than is possible with other forms of protection. Disadvantages of Buchholz Relay:
- It can only be used with oil immersed transformers equipped with conservator tanks.
- The device can detect only faults below oil level in the transformer. Therefore, separate protection is needed for connecting cables.

6.3 BUSBAR PROTECTION

Busbars and lines are important elements of electric power system and require the immediate attention of protection engineers for safeguards against the possible faults occurring on them. The methods used for the protection of generators and transformers can also be employed, with slight modifications, for the busbars and lines. The modifications are necessary to cope with the protection problems wising out of greater length of lines and a large number of circuits connected to a Busbar Protection. Although differential protection can be used it becomes too expensive for longer lines due to the greater length of pilot wires required. Fortunately, less expensive methods are available which are reasonably effective in providing protection for the busbars and lines. In this chapter, we shall focus our attention on the various methods of protection of bus bars and lines.

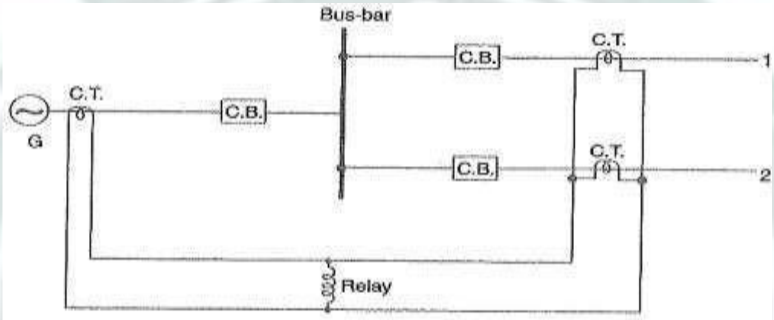
Busbar Protection in the generating stations and sub-stations form important link between the incoming and outgoing circuits. If a fault occurs on a busbar, considerable damage and disruption of supply will occur unless some form of quick-acting automatic protection is provided to isolate the faulty busbar. The busbar zone, for the purpose of protection, includes not only the busbars themselves but also the isolating switches, circuit breakers and the associated connections. In the event of fault on any section of the busbar, all the circuit equipment connected to that section must be tripped out to give complete isolation.

The standard of construction for Busbar Protection has been very high, with the result that bus faults are extremely rare. However, the possibility of damage and service interruption from even a rare bus fault is so great that more attention is now given to this form of protection. Improved relaying methods have been developed, reducing the possibility of incorrect operation.

The two most commonly used schemes for busbar protection are :

1. Differential Protection:

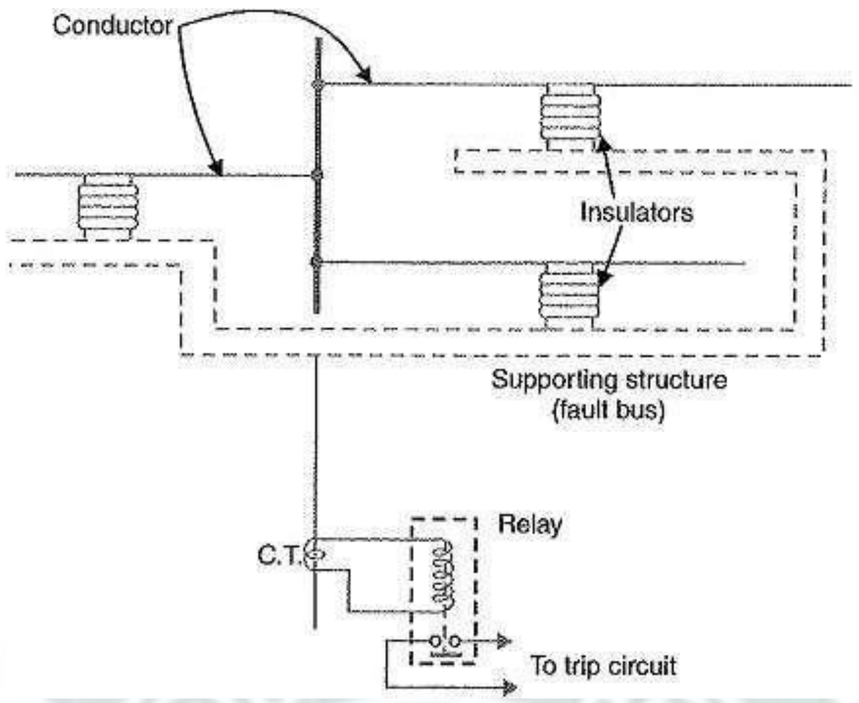
The basic method for busbar protection is the differential scheme in which currents entering and leaving the bus are totalised. During normal load condition, the sum of these currents is equal to zero. When a fault occurs, the fault current upsets the balance and produces a differential current to operate a rela



Above figure shows the single line diagram of current differential scheme for a station busbar. The Busbar Protection is fed by a generator and supplies load to two lines. The secondaries of current transformers in the generator lead, in line 1 and in line 2 are all connected in parallel. The protective relay is connected across this parallel connection. All CTs must be of the same ratio in the scheme regardless of the capacities of the various circuits. Under normal load conditions or external fault conditions, the sum of the currents entering the bus is equal to those leaving it and no current flows through the relay. If a fault occurs within the protected zone, the currents entering the bus will no longer be equal to those leaving it. The difference of these currents will flow through the relay and cause the opening of the generator, circuit breaker and each of the line circuit breakers.

2. Fault Bus Protection:

It is possible to design a station so that the faults that develop are mostly earth-faults. This can be achieved by providing earthed metal barrier (known as fault bus) surrounding each conductor throughout its entire length in the bus structure. With this arrangement, every fault that might occur must involve a connection between a conductor and an earthed metal By directing the flow of earth-fault current, it is possible to detect the faults and determine their location. This type of protection is known as fault bus protection.



Above figure show the schematic arrangement of fault bus protection. The metal supporting structure or fault bus is earthed through a current transformer. A relay is connected across the secondary of this CT. Under normal operating conditions, there is no current flow from fault bus to ground and the relay remains inoperative. A fault involving a connection between a conductor and earthed supporting structure will result in current flow to ground through the fault bus, causing the relay to operate. The operation of relay will trip all breakers connecting equipment to the bus.

6.4 PROTECTION OF LINES

The probability of faults occurring on the lines is much more due to their greater length and exposure to atmospheric conditions. This has called for many protective schemes which have no application to the comparatively simple cases of alternators and transformers. The requirements of line protection are :

- In the event of a short-circuit, the circuit breaker closest to the fault should open, all other circuit breakers remaining in a closed position.
- In case the nearest breaker to the fault fails to open, back-up protection should be provided by the adjacent circuit breakers.
- The relay operating time should be just as short as possible in order to preserve system stability, without unnecessary tripping of circuits.

The protection of lines presents a problem quite different from the protection of station apparatus such as generators, transformers and Busbar Protection. While differential protection is ideal method for lines, it is much more expensive to use. The two ends of a line may be several kilometers apart and to compare the two currents, a costly pilot-wire circuit is required. This expense may be justified but in general less costly methods are used. The common methods of line protection are :

- Time-graded overcurrent protection
- Differential protection
- Distance protection

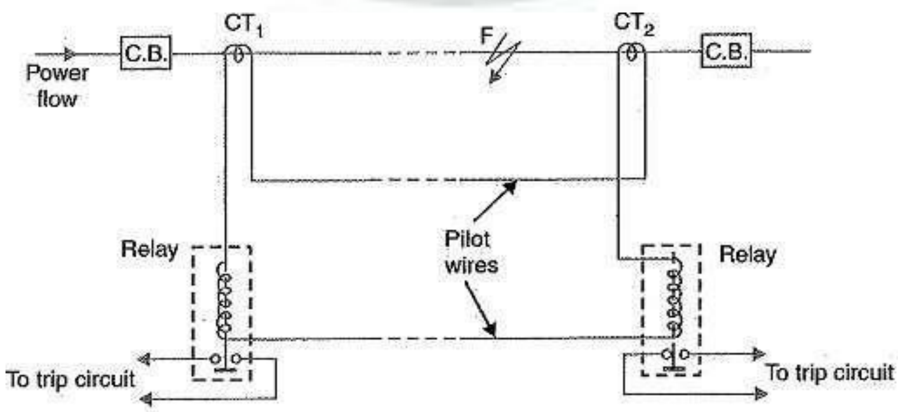
Shows the symbols indicating the various types of relay

6.4.1 Differential Pilot Wire Protection

The Differential Pilot Wire Protection is based on the principle that under normal conditions, the current entering one end of a line is equal to that leaving the other end. As soon as a fault occurs between the two ends, this condition no longer holds and the difference of incoming and outgoing currents is arranged to flow through a relay which operates the circuit breaker to isolate the faulty line. There are several Differential Pilot Wire Protection schemes in use for the lines. However, only the following two schemes will be discussed

6.4.1.1 Men-Price Voltage Balance System

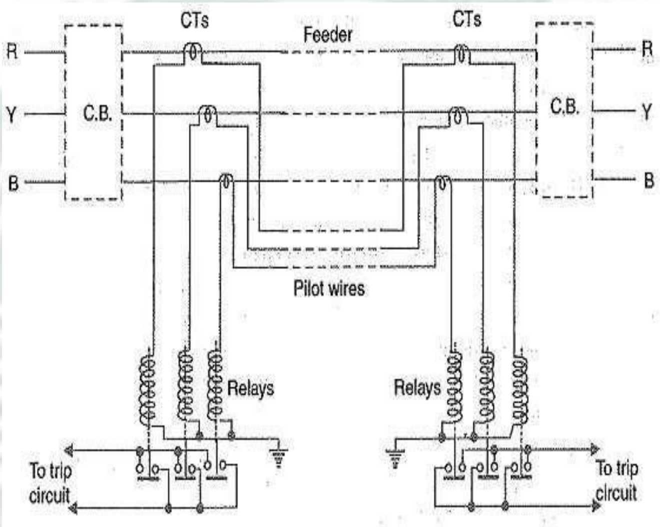
Figure shows the single line diagram of MerzPrice voltage balance system for the protection of a 3-phase line. Identical current transformers are placed in each phase at both ends of the line. The pair of CTs in each line is connected in series with a relay in such a way that under, normal conditions, their secondary voltages are equal and in opposi- tion i.e. they balance each other.



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

Suppose a fault occurs at point F on the line as shown in Fig. This will cause a greater current to flow through CT1 than through CT2. Consequently, their secondary voltages become unequal and circulating current flows through the pilot wires and relays. The circuit breakers at both ends of the line will trip out and the faulty line will be isolated.

Figure shows the connections of Merz-Price voltage balance scheme for all the three phases of the line.



Advantages of Differential Pilot Wire Protection:

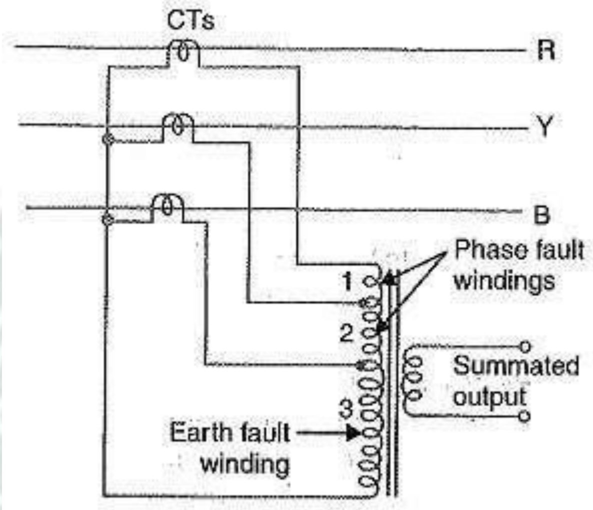
- This system can be used for ring mains as well as parallel feeders,
- This system provides instantaneous protection for ground faults. This decreases the possibility of these faults involving other phases.
- This system provides instantaneous relaying which reduces the amount of damage to overhead conductors resulting from arcing faults.

Disadvantages of Differential Pilot Wire Protection:

- Accurate matching of current transformers is very essential.
- If there is a break in the pilot-wire circuit, the system will not operate.
- This system is very expensive owing to the greater length of pilot wires required.
- In case of long lines, charging current due to pilot-wire capacitance effects may be sufficient to cause relay operation even under normal conditions.
- This system cannot be used for line voltages beyond 33 kV because of constructional difficulties in matching the current transformers.

6.4.1.2 Translay scheme

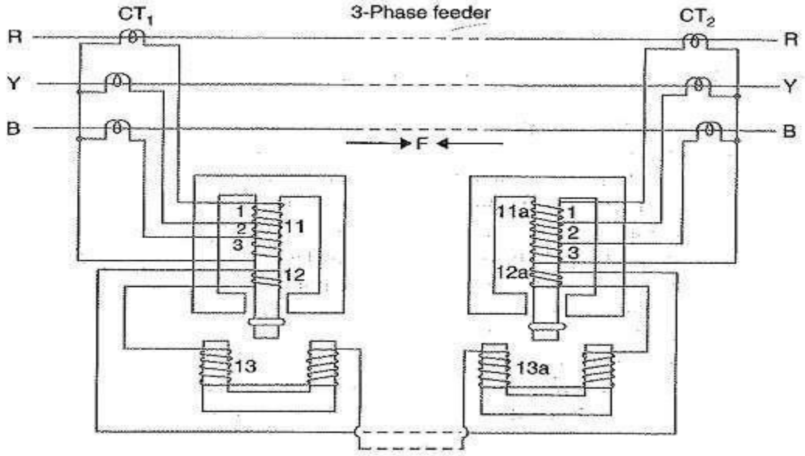
This system is similar to voltage balance system except that here balance or opposition is between the voltages induced in the secondary windings wound on the relay magnets and not between the secondary voltages of the line current transformers. This permits to use current transformers of normal design and eliminates one of the most serious limitations of original voltage balance system, namely ; its limitation to the system operating at voltages not exceeding 33 kV.



The application of Translay scheme for a single phase line has already been discussed. This can be extended to 3-phase system by applying one relay at each end of each phase of the 3-phase line. However, it is possible to make fur her simplification by combining currents derived from all phases in a single relay at each end, using he principle of summation transformer (See figure). A summation transformer is a device that reproduces the poly phase line currents as a single-phase quantity. The three lines CTs are connected to the tapped primary of summation transformer. Each line. CT energizes a different number of turns (from line to neutral) with a resulting single phase output. The use of summation transformer permits two advantages viz (i) primary windings 1 and 2 can be used for phase faults whereas winding 3 can be used for earth fault (ii) the number of pilot wires required is only two.

Schematic Arrangement:

The Translay scheme for the protection of a 3-phase line is shown in figure. The relays used in the scheme are essentially over current induction type relays. Each relay has two electromagnetic elements. The upper element carries a winding (11 or 11 a) which is energized as a summation transformer from the secondaries of the line CTs connected in the phases of the line to be protected. The upper element also carries a secondary winding (12 or 12 a) which is connected is series with the operating winding (13 or 13 a) on the lower magnet. The secondary windings 12, 12 a and operating windings 13, 13 a are connected in series in such a way that voltages induced in them oppose each other.. Note that relay discs and tripping circuits have been omitted in the diagram for clarity.



Operation:

When the feeder is sound, the currents at its two ends are equal so that the secondary currents in both sets of CTs are equal. Consequently, the currents flowing in the relay primary winding 11 and 11 a will be equal and they will induce equal voltages in the secondary windings 12 and 12a. Since these windings are connected in opposition, no current flows in them or in the operating windings 13 and 13a. In the event of a fault on the protected line, the line current at one end must carry a greater current than that at the other end. The result is that voltages induced in the secondary windings 12 and 12 a will be different and the current will flow through the operating coils 13, 13a and the pilot circuit. Under these conditions, both upper and lower elements of each relay are energised and a forward torque acts on the each relay disc. The operation of the relays will open the circuit breakers at both ends of the line.

- Suppose a fault F occurs between phases R and Y and is fed from both sides as shown in Fig. 11. This will energise only section 1 of primary windings 11 and 11a and induce voltages in the secondary windings 12 and 12a. As these voltages are now additive, therefore, current will circulate through operating coils 13, 13a and the pilot circuit. This will cause the relay contacts to close and open the circuit breakers at both ends. A fault between phases Y and B energises section 2 of primary windings 11 and 11a whereas that between R and B will energise the sections 1 and 2.
- Now imagine that an earth fault occurs on phase R. This will energize sections 1, 2 and 3 of the primary windings 11 and 11a. Again if fault is fed from both ends, the voltages induced in the secondary windings 12 and 12a are additive and cause a current to flow through the operating coils 13, 13a. The relays, therefore, operate to open the circuit breakers at both ends of the line. In the event of earth fault on phase Y, sections 2 and 3 of primary winding 11 and 11a will be energised and cause the relays to operate. An earth fault on phase B will energise only section 3 of relay primary windings 11 and 11a.

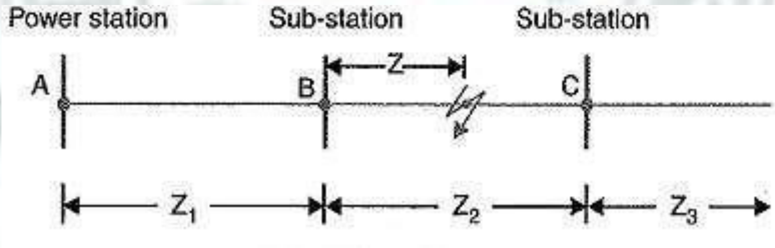
Advantages

- The system is economical as only two pilot wires are required for the protection of a 3-phase line.
- Current transformers of normal design can be used.
- The pilot wire capacitance currents do not affect the operation of relays.

6.4.2 Distance Protection

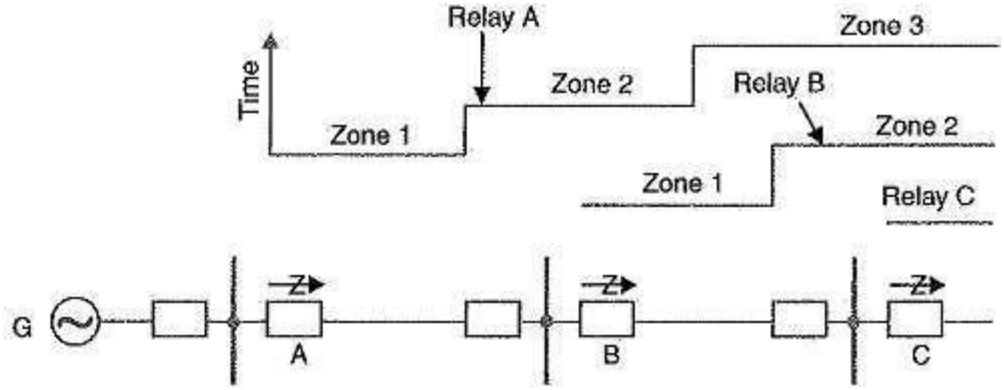
Both time-graded and pilot-wire system are not suitable for the protection of very long high voltage transmission lines. The former gives an unduly long time delay in fault clearance at the generating station end when there are more than four or five sections and the pilot-wire system becomes too expensive owing to the greater length of pilot wires required. This has led to the development of Distance Protection in which the action of relay depends upon the distance (or impedance) between the point where the relay is installed and the point of fault. This system provides discrimination protection without employing pilot wires.

The principle and operation of Distance Protection relays have already been discussed here. We shall now consider its application for the protection of transmission lines. Figure shows a simple system consisting of lines in series such that power can flow only from left to right.



The relays at A, B and C are set to operate for impedance less than Z_1 , Z_2 and Z_3 respectively. Suppose a fault occurs between sub-stations B and C, the fault impedance at power station and sub-station A and B will be $Z_1 + Z$ and Z respectively. It is clear that for the portion shown, only relay at B will operate. Similarly, if a fault occurs within section AB, then only relay at A will operate. In this manner, instantaneous protection can be obtained for all conditions of operation.

In actual practice, it is not possible to obtain instantaneous protection for complete length of the line due to inaccuracies in the relay elements and instrument transformers. Thus the relay at A [See Figure)] would not be very reliable in distinguishing between a fault at 99% of the distance AB and the one at 101% of distance AB. This difficulty is overcome by using 'three-zone'. Distance Protection shown in figure.



In this scheme of Distance Protection, three distance elements are used at each terminal. The zone 1 element covers first 90% of the line and is arranged to trip instantaneously for faults in this portion. The zone 2 element trips for faults in the remaining 10% of the line and for faults in the next line section, but a time delay is introduced to prevent the line from being tripped if the fault is in the next section. The zone 3 element provides back-up protection in the event a fault in the next section is not cleared by its breaker.

6.4.3 Time Graded Overcurrent Protection

In this scheme of Time Graded Overcurrent Protection, time discrimination is incorporated. In other words, the time setting of relays is so graded that in the event of fault, the smallest possible part of the system is isolated. We shall discuss a few important cases.

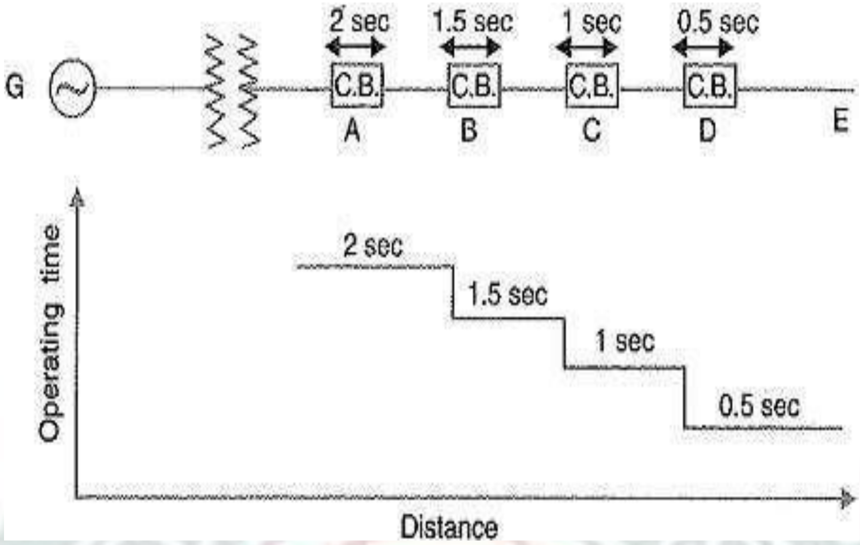
6.4.3.1 Radial feeder

The main characteristic of a radial system is that power can flow only in one direction, from generator or supply end to the load. It has the disadvantage that continuity of supply cannot be maintained at the receiving end in the event of fault. Time Graded Overcurrent Protection protection of a radial feeder can be achieved by using

a) Definite time relays

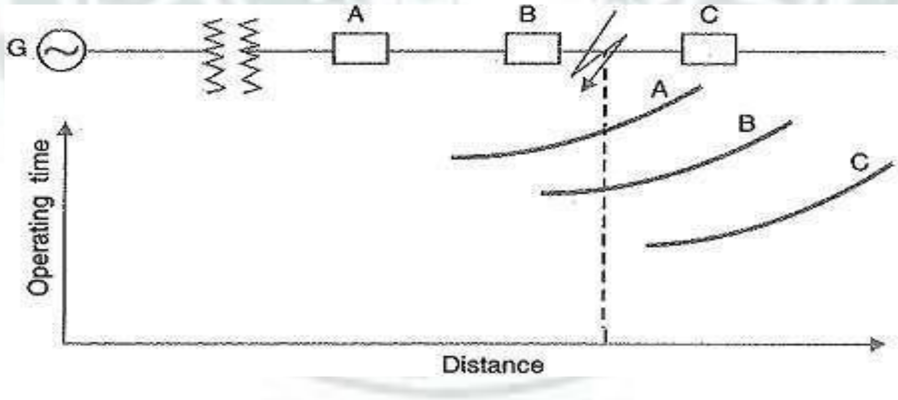
Using definite time relays: Figure shows the overcurrent protection of a radial feeder by definite time relays. The time of operation of each relay is fixed and is independent of the operating current. Thus relay D has an operating time of 0.5 second while for other relays, time delay is successively increased by 0.5 second. If a fault occurs in the section DE, it will be cleared in 0.5 second by the relay and circuit breaker at D because all other relays have higher operating time. In this way only section DE of the system will be isolated. If the relay at D fails to trip, the relay at C will operate after a time delay of 0.5 second i.e.

after 1 second from the occurrence of fault. The disadvantage of this system is that if there are a number of feeders in series, the tripping time for faults near the supply end becomes high (2 seconds in this case). However, in most cases, it is necessary to limit the maximum tripping time to 2 seconds. This disadvantage can be overcome to a reasonable extent by using inverse-time relays



b) Inverse Time Relays:

Figure shows overcurrent protection of a radial feeder using inverse time relays in which operating time is inversely proportional this arrangement, the farther the circuit breaker from the generating operating time.



The three relays at A, B and C are assumed to have inverse-time characteristics. A fault in section BC will give relay times which will allow breaker at B to trip out before the breaker at A.

6.4.3.2 Parallel feeders

Where continuity of supply is particularly necessary, two parallel feeders may be installed. If a fault occurs on one feeder, it can be disconnected from the system and continuity of supply can be maintained from the other feeder. The parallel feeders cannot be protected by non- directional overcurrent relays only. It is necessary to use directional relays also and to grade the time setting of relays for selective trippings.

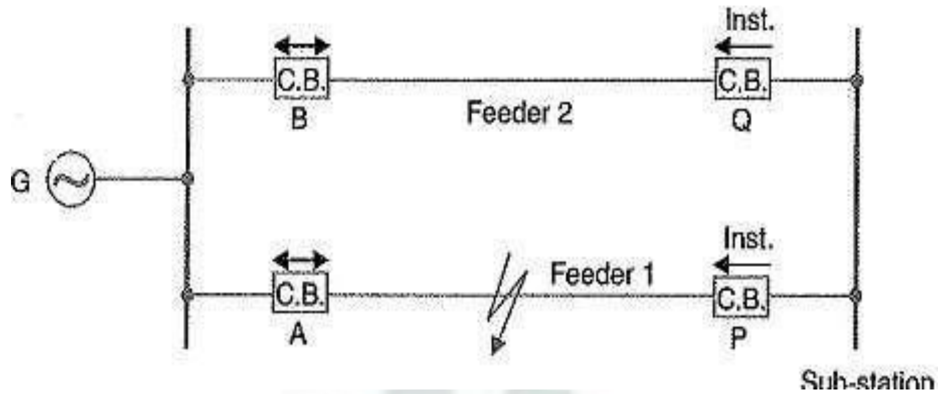


Figure shows the system where two feeders are connected in parallel between the generating station and the sub-station. The protection of this system requires that

- each feeder has a non-directional overcurrent relay at the generator end. These relays should have inverse-time characteristic.
- each feeder has a reverse power or directional relay at the sub-station end. These relays should be instantaneous type and operate only when power flows in the reverse direction e. in the direction of arrow at P and Q.

Suppose an earth fault occurs on feeder 1 as shown in Fig-6.16. It is desired that only circuit breakers at A and P should open to clear the fault whereas feeder 2 should remain intact to maintain the continuity of supply. In fact, the above arrangement accomplishes this job. The shown fault is fed via two routes, viz.

- Directly from feeder 1 via the relay A
- From feeder 2 via B, Q, sub-station and P

Therefore, power flow in relay Q will be in normal direction but is reversed in the relay P. This causes the, opening of circuit breaker at P. Also the relay A will operate while relay B remains inoperative. It is because these relays have inverse-time characteristics and current flowing in relay A is in excess of that flowing in relay B. In this way only the faulty feeder is isolated.

6.4.3.3 Ring Main System

In this system, various power stations or sub-stations are interconnected by alternate routes, thus forming a closed ring. In case of damage to any section of the ring, that section may be disconnected for repairs, and power will be supplied from both ends of the ring, thereby maintaining continuity of supply.

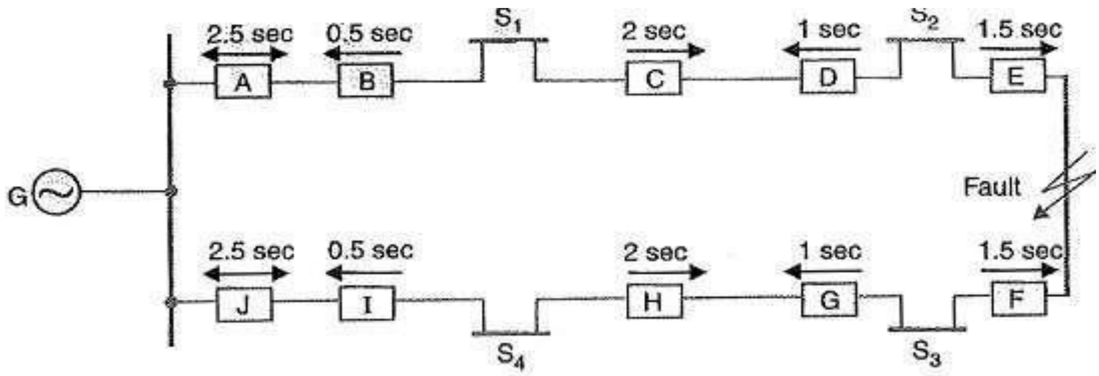


Figure.shows the single line diagram of a typical ring main system consisting of one generator G supplying four sub-stations S1, S2, S3 and S4. In this arrangement, power can flow in both directions under fault conditions. Therefore, it is necessary to grade in both directions round the ring and also to use directional relays. In order that only faulty section of the ring is isolated under fault conditions, the types of relays and their time settings should be as follows :

- The two lines leaving the generating station should be equipped with non-directional overcurrent relays (relays at A and J in this case).
- At each sub-station, reverse power or directional relays should be placed in both incoming and outgoing lines (relays at B, C, D, E, F, G, H and I in this case).
- There should be proper relative time-setting of the relays. As an example, going round the loop G S1 S2 S3 S4 G ; the outgoing relays (viz at A, C, E, G and I) are set with decreasing time limits e.g.

Similarly, going round the loop in the opposite direction (i.e. along G S1 S2 S3 S4 G), the outgoing relays (J, H, F, D and B) are also set with a decreasing time limit e.g.

Suppose a short circuit occurs at the point as shown in Fig. In order to ensure selectivity, it is desired that only circuit breakers at E and F should open to clear the fault whereas other sections of the ring should be intact to maintain continuity of supply. In fact, the above arrangement accomplishes this job. The power will be fed to the fault via two routes viz (i) from G around S1 and S2 and (ii) from G around S4 and S3. It is clear that relays at A, B, C and D as well as J, I, H and G will not trip. Therefore, only relays at E and F will operate before any other relay operates because of their lower time-setting.

Chapter - 7

PROTECTION AGAINST OVERVOLTAGE AND LIGHTENING

7.1 VOLTAGE SURGE OR TRANSIENT VOLTAGE

A sudden rise in voltage for a very short duration on the power system is known as a Voltage Surge or Transient Voltage.

Transients or surges are of temporary nature and exist for a very short duration (a few hundred μs) but they cause over Voltage Surge on the power system. They originate from switching and from other causes but by far the most important transients are those caused by lightning striking a transmission line. When lightning strikes a line, the surge rushes along the line, just as a flood of water rushes along a narrow valley when the retaining wall of a reservoir at its head suddenly gives way. In most of the cases, such surges may cause the line insulators (near the point where lightning has struck) to flash over and may also damage the nearby transformers, generators or other equipment connected to the line if the equipment is not suitably protected.

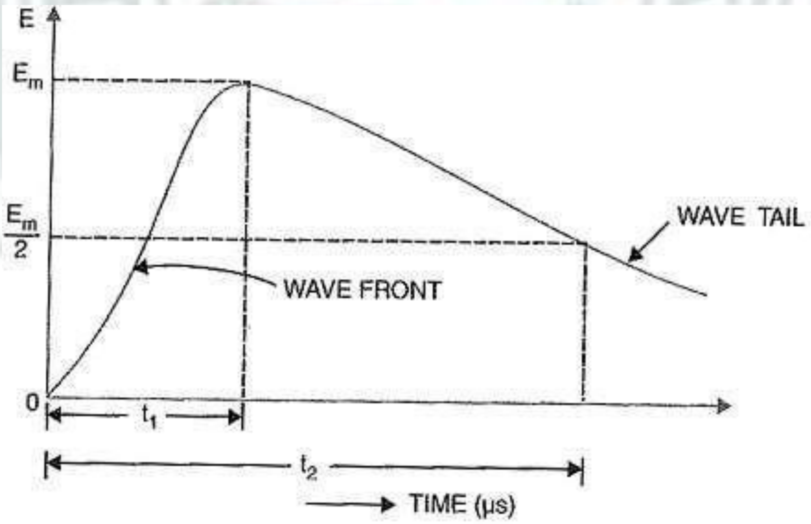


Figure shows the wave-form of a typical lightning surge. The voltage build-up is taken along y-axis and the time along x-axis. It may be seen that lightning introduces a steep-fronted wave. The steeper the wave front, the more rapid is the build-up of voltage at any point in the network. In most of the cases, this build-up is comparatively rapid, being of the order of 1-5 μs. Voltage Surge are generally specified in terms of rise time t_1 and the time t_2 to decay to half of the peak value. For example, a 1/50 μs surge is one which reaches its maximum value in 1μs and decays to half of its peak value is 50 μs.

7.1.1 Causes of Overvoltages

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

1. Internal causes
   - Switching surges
   - Insulation failure
   - Arcing ground
   - Resonance
2. External causes

Lightning 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 over voltages mainly take care of lightning surges.

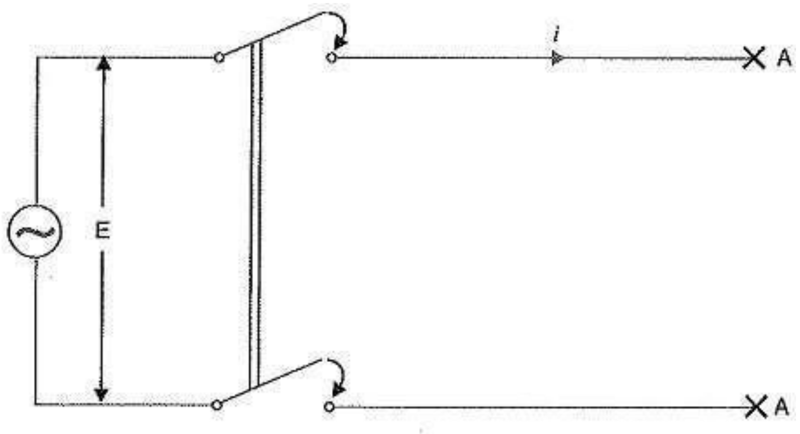
7.1.1.1 Internal Causes of Overvoltages:

Internal causes of over voltages 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 over voltages.

1. **Switching Surges:**

The overvoltages produced on the power system due to switching operations are known as switching surges.

(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 Figure below.



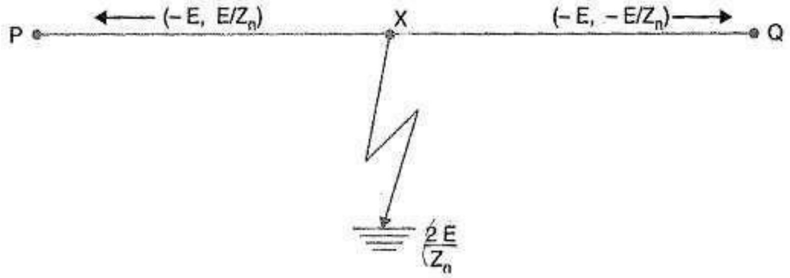
When the unloaded line is connected to the voltage source, a voltage wave is set up which travels along the line. On reaching the terminal point A, it is reflected back to the supply end without change of sign. This causes voltage doubling i.e. voltage on the line becomes twice the normal value. If $E_{r.m.s.}$ is the supply Voltage Surge, 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 of 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=1000Ω 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 $\sqrt{2}$ x 100 x 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. It is briefly discussed 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 magnetizing current) with air-blast breaker, the powerful de-ionizing 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.

2. **Insulation failure:**

The most common case of insulation failure in a power system is the grounding of conductor (i.e. insulation failure between line and earth) which may cause overvoltages in the system. This is illustrated in Figure.



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 XQ and XP, containing currents $-E/Z_n$ and $+E/Z_n$ respectively. Both these currents pass through X to earth so that current to earth is $2\ E/Z_n$.

3. **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 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 Voltage Surge. 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 prevented by earthing the neutral.

4. **Resonance:**

Resonance in an electrical system occurs when inductive reactance of the circuit becomes equal to capacitive reactance. Under resonance, the impedance of the circuit is equal to resistance of the circuit and the pl. 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 resonance may occur due to 5th or higher harmonics and in case of underground cables too.

7.2 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 cloud to be charge. The most accepted one is that during the uprush of warm moist air from earth 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.

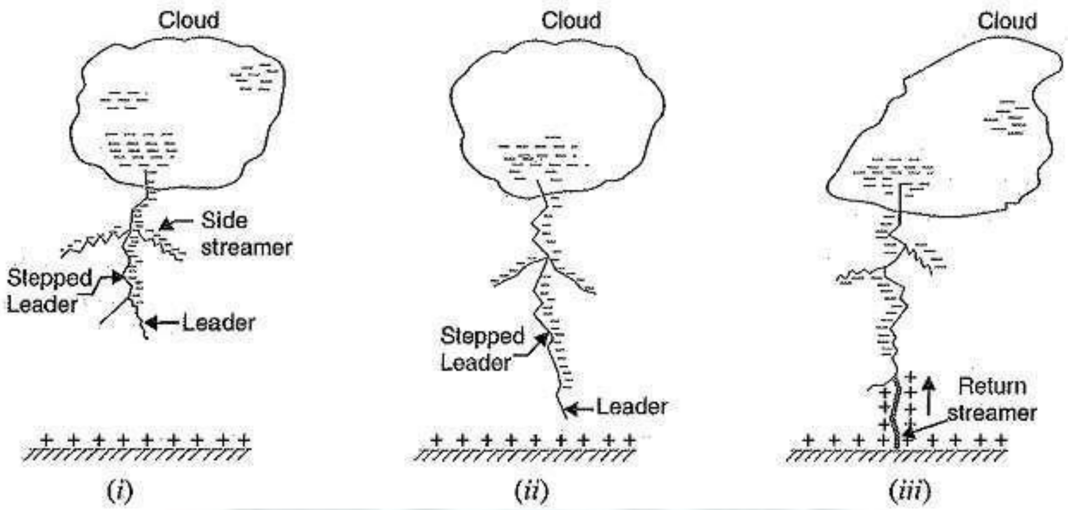
When the drops of water accumulate, they form clouds, and hence cloud may possess either a positive or a negative charge, depending upon the charge of drops of water they contain. The charge on a cloud may become so great that it may discharge to another cloud or to earth and we call this discharge as 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.

7.2.1 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. 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 :



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 figure. 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. Above figure 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.

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 above figure)] 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 return streamer the positive charge. This phenomenon causes a sudden spark which we call lightning. With the resulting neutralization 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 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.
- If has been found that 87% of all lightning strokes result from negatively charged clouds and only 13% originate from positively charged clouds,
- It has been estimated that throughout the world, there occur about 100 lightning strokes per
- Lightning discharge may have currents in the range of 10 kA to 90 kA.

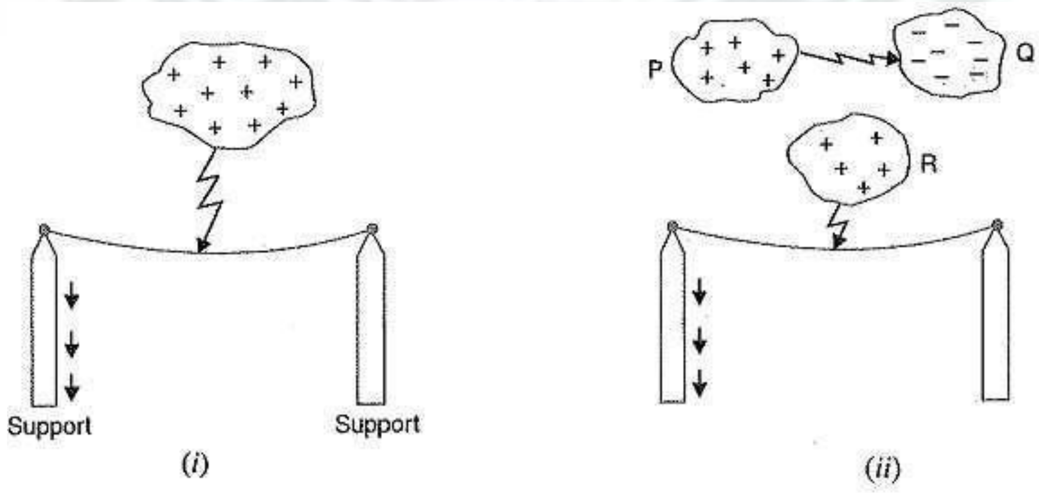
7.2.2 Types of Lightning Strikes

There are two Types of Lightning Strikes may strike the power system (e.g. overhead lines, towers, sub-stations etc.), namely;

7.2.2.1 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.



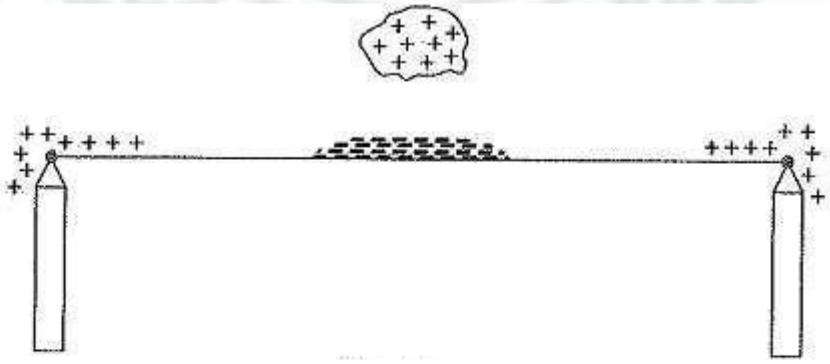
(i) In stroke A, the lightning discharge is from the cloud to the subject equipment i.e. an over- head line in this case as shown in above figure. The cloud will induce a charge of opposite sign on the tall object (e.g. an overhead line in this case). When the potential between the cloud and line exceeds the breakdown value of air, the lightning discharge occurs between the cloud and the line.

(ii) (ii) In stroke B, the lightning discharge occurs on the overhead line as a result of stroke A between the clouds as shown in above figure. 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.

(iii) 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.

7.2.2.2 Indirect stroke

Indirect strokes result from the electrostatically induced charges on the conductors due to the presence of charged clouds. This is illustrated in figure below. 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. 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 Types of Lightning Strikes strokes.



7.2.3 Harmful Effects of Types of Lightning Strikes

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 travelling 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 Types of Lightning Strikes hit the windings of a transformer or generator, it may cause considerable damage. The inductance of the wiiidings 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 toms 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.

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

7.2.4 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 equipment 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 :

- Earthing screen
- Overhead ground wires
- Lightning arresters or surge diverters

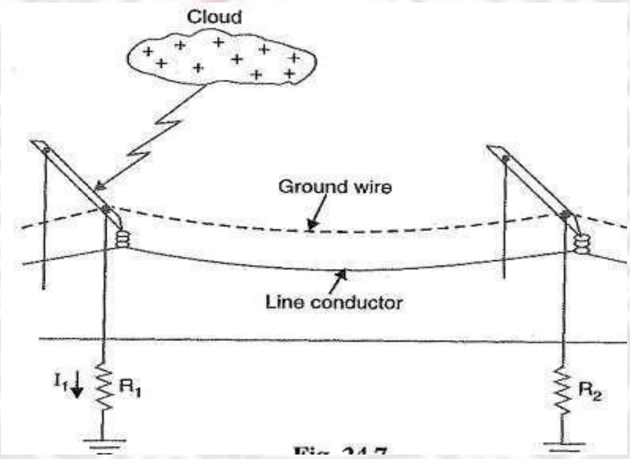
Earthing screen provides protection to power stations and sub-stations against direct strokes whereas overhead ground wires protect the transmission lines against direct lightning strokes. Flow-ever; lightning arresters or surge diverters protect the station apparatus against both direct strokes and 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 at least 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 figure below. 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 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 Types of Lightning Strikes. 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 ;

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

- It provides considerable protection against direct lightning strokes on transmission lines.
- A grounding wire provides damping effect on any disturbance travelling along the line as it acts as a short-circuited secondary.
- 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

- It requires additional cost.
- 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

7.2.5 Lightning Arrester

Definition: The device which is used for the protection of the equipment at the substations against travelling waves, such type of device is called lightning arrester or surge diverter. In other words, lightning arrester diverts the abnormals high voltage to the ground without affecting the continuity of supply. It is connected between the line and earth, i.e., in parallel with the equipment to be protected at the substation.

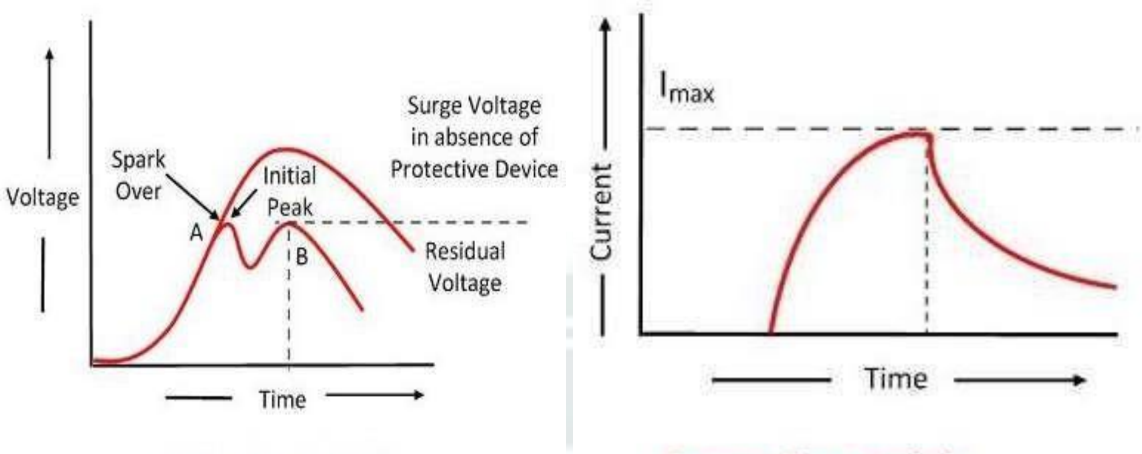
The following are the damages that are caused by the travelling wave on the substation equipment.

1. The high peak or crest voltage of the surge may cause flash-over in the internal winding thereby spoil the winding insulation.
2. The steep wave fronts of the surges may cause external flashover between the terminal of the transformer.
3. The highest peak voltage of the surge may cause external flashover, between the terminal of the electrical equipment which may result in damage to the insulator.

7.2.5.1 Working of Lightning Arrester

When a travelling wave reaches the arrestor, its sparks over at a certain prefixed voltage as shown in the figure below. The arrestor provides a conducting path to the waves of relatively low impedance between the line and the ground. The surge impedance of the line restricts the amplitude of current flowing to ground.

The lightning arrester provides a path of low impedance only when the travelling surge reaches the surge diverter, neither before it nor after it. The insulation of the equipment can be protected if the shape of the voltage and current at the diverter terminal is similar to the shape shown below.



Voltage Characteristic

Current Characteristic

An ideal lightning arrester should have the following characteristics;

1. It should not draw any current during normal operating condition, i.e., it sparks-over voltage must be above the normal or abnormal power frequency that may occur in the system.
2. Any transient abnormal voltage above the breakdown value must cause it to break down as quickly as possible so that it may provide a conducting path to ground.
3. When the breakdown has taken place, it should be capable of carrying the resulting discharge current without getting damaged itself and without the voltage across it exceeding the breakdown value.
4. The power frequency current following the breakdown must be interrupted as soon as the transient voltage has fallen below the breakdown value.

There are many types of lightning arrester which are used to protect the power system. The choices of the lightning arrester depend on the factor like, voltage and frequency of the line, cost, weather condition and reliability.

7.2.5.2 Location of Lightning Arrester

The lightning arrester is located close to the equipment that is to be protected. They are usually connected between phase and ground in an AC system and pole and ground in case of the DC system. In an AC system, separate arrester is provided for each phase.

In an extra-high voltage AC system the surge diverter is used to protect the generators, transformers, bus bars, lines, circuit breakers, etc. In HVDC system the arrester is used to protect the buses, valves converter units reactors, filter, etc.

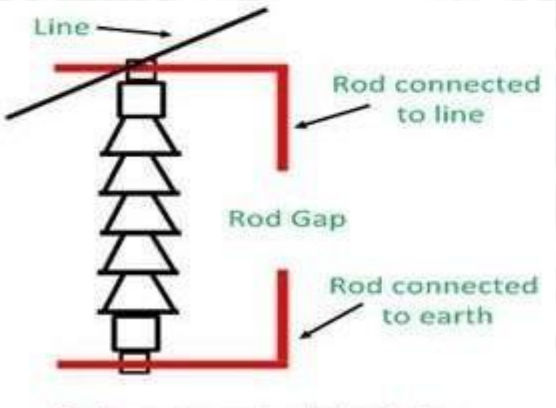
7.2.5.3 Types of Lightning Arresters

The lightning arrester protects the electrical equipment from lightning. It is placed very near to the equipment and when the lightning occurs the arrester diverts the high voltage wave of lightning to the ground. The selection of arrester depends on the various factors like voltage, current, reliability, etc.

The lightning arrestor is mainly classified into some different types. These types are;.

1. Rod Gap Arrester.

It is one of the simplest forms of the arrester. In such type of arrester, there is an air gap between the ends of two rods. The one end of the arrester is connected to the line and the second end of the rod is connected to the ground. The gap setting of the arrester should be such that it should break before the damage. When the high voltage occurs on the line, the gap sparks and the fault current passes to the earth. Hence the equipment is protected from damage.



Rod gap on an insulator string

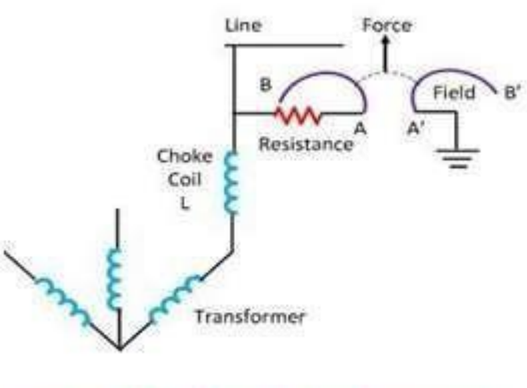
The difficulty with the rod arrester is that once the spark having taken place it may continue for some time even at low voltages. To avoid it a current limiting reactor in series with the rod is used. The resistance limits the current to such an extent that it is sufficient to maintain the arc. Another difficulty with the road gap is that the rod gap is liable to be damaged due to the high temperature of the arc which may cause the rod to melt.

Limitations

- 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.
- The rods may melt or get damaged due to excessive heat produced by the arc.
- The climatic conditions (e.g. rain, humidity, temperature etc.) affect the performance of rod gap arrester.
- The polarity of the surge also affects the performance of this arrester.

2. Horn Gap Arrester

It consists of two horns shaded piece of metal separated by a small air gap and connected in shunt between each conductor and earth. The distance between the two electrodes is such that the normal voltage between the line and earth is insufficient to jump the gap. But the abnormal high voltage will break the gap and so find a path to earth.



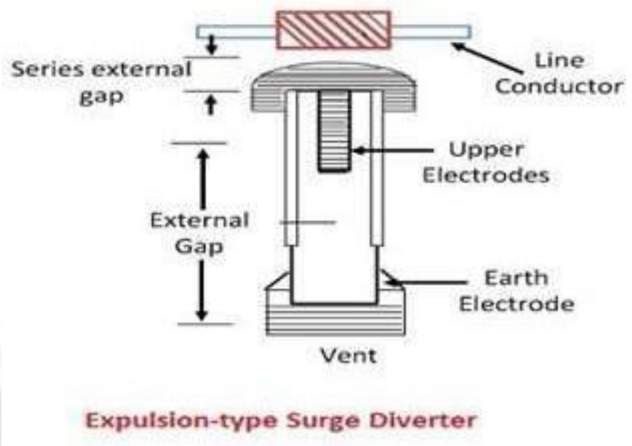
Horn Gap With Choke Coil and Resistance

Advantages

- The arc is self-clearing. Therefore, this type of arrester does not cause short-circuiting of the system after the surge is over as in the case of rod gap.
- Series resistance helps in limiting the follow current to a small value. Limitations
- The bridging of gap by some external agency (e.g. birds) can render the device useless.
- The setting of horn gap is likely to change due to corrosion or pitting. This adversely affects the performance of the arrester.
- The time of operation is comparatively long, say about 3 seconds. In view of the very short operating time of modern protective gear for feeders, this time is far long.

3. Expulsion Type Lightning Arrester

Expulsion type arrester is an improvement over the rod gap in that it seals the flow of power frequency follows the current. This arrester consists of a tube made up of fibre which is very effective, isolating spark gap and an interrupting spark gap inside the fibre tube.



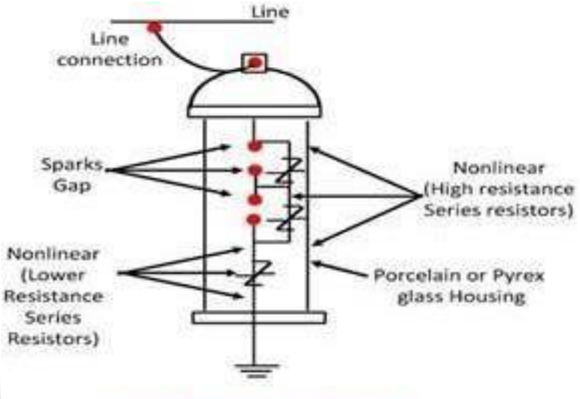
During operation, the arc due to the impulse spark over inside the fibrous tube causes some fibrous material of the tube to volatile in the form of the gas, which is expelled through a vent from the bottom of the tube. Thus, extinguishing the arc just like in circuit breakers.

Advantages

- They are not very expensive.
- They are improved form of rod gap arresters as they block the flow of power frequency follow currents,
- They can be easily installed. Limitations
- An expulsion type arrester can perform only limited number of operations as during each operation some of the fiber material is used up.
- This type of arrester cannot be mounted in enclosed equipment due to the discharge of gases during operation.
- Due to the poor volt/amp characteristic of the arrester, is not suitable for the protection of expensive equipment.

4. Valve Type Lightning Arrester

Such type of resistor is called nonlinear diverter. It essentially consists a divided spark gap in series with a resistance element having the nonlinear characteristic.



Valve Type Lightning Arrester

The divided spark gap consists of some identical elements coupled in series. Each of them consists two electrodes with the pre-ionization device. Between each element, a grading resistor of high ohmic value is connected in parallel.

(i) The spark gap is a multiple assembly consisting of a number of identical spark gaps in Each gap consists of two electrodes with a fixed gap spacing. The voltage distribution 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 resistance 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.

Working:

Under normal conditions, the normal system voltage is insufficient to cause the breakdown of air gap assembly. On the occurrence of an overvoltage, the breakdown of the series spark gap takes place and the surge current is conducted to earth via the non-linear resistors. Since the magnitude of surge current is very large, the non-linear elements will offer a very low resistance to the passage of surge. The result is that the surge will rapidly go to earth instead of being sent back over the line. When the surge is over, the non-linear resistors assume high resistance to stop the flow of current.

Advantages

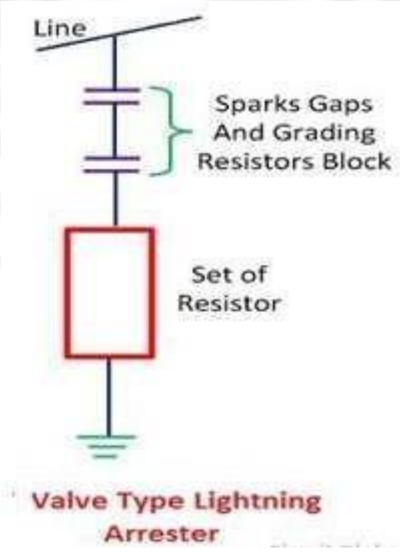
- They provide very effective protection (especially for transformers and cables) against
- They operate very rapidly taking less than a second.
- The impulse ratio is practically unity. Limitations
- They may fail to check the surges of very steep wave front from reaching the terminal This calls for additional steps to check steep-fronted waves.
- Their performance is adversely affected by the entry of moisture into the enclosure. This necessitates effective sealing of the enclosure at all times.

Applications

According to their application, the valve type arresters are classified as (i) station type and (ii) line type. The station type arresters are generally used for the protection of important equipment in power stations operating on voltages upto 220 kV or higher. The line type arresters are also used for stations handling voltages upto 66 kV

Working of Valve Type Lightning Arrester

During the slow voltage variations, there is no sparks-over across the gap. But when the rapid change in voltage occurs, the potential is no longer evenly graded across the series gap. The influence of unbalancing capacitance between the sparks gaps and the ground prevails over the grounded resistance. The impulse voltage is mainly concentrated on the upper spark gap which in spark over cause the complete arrester to spark over to.



For low voltage, there is no spark-over across the gaps due to the effect of parallel resistor. The slow changes in applied voltage are not injurious to the system. But when the rapid changes in voltage occur across the terminal of the arrester the air gap spark of the current is discharged to ground through the non-linear resistor which offers very small resistance.

After the passage of the surge, the impressed voltage across the arrester falls, and the arrester resistance increases until the normal voltage restores. When the surge diverter disappears, a small current at low power frequency flow in the path produced by the flash over. This current is known as the power follow current.

The magnitude of the power follows current decreases to the value which can be interrupted by the spark gap as they recover their dielectric strength. The power follow current is extinguished at the first current and the supply remains uninterrupted. The arrester is ready for the normal operation. This is called resealing of the lightning arrester.

Types of Valve Type Lightning Arrester

The valve type lightning arrester may be station types, line types, arresters for the protection of the rotating machine distribution type or secondary type.

Station Type Valve Lightning Arrester – This type of valve is mainly employed for the protection of the critical power equipment in the circuit of 2.2kV to 400kV and higher. They have the high capacity of energy dissipation.

Line Type Lightning Arrester – The line type arresters are used for the protection of substation equipment. Their cross-sectional area is smaller, lighter in weight and cheaper in cost. They permit higher surge voltage across their terminal in comparison to station type and have lower surge carrying capacity.

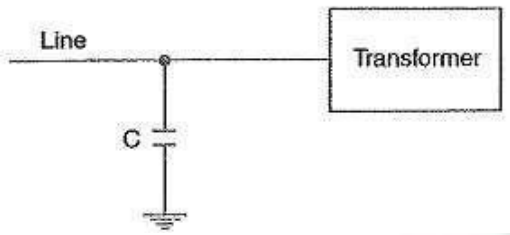
Distribution arrester – Such type of arrester is usually mounted on the pole and are employed for the protection of the generators and motors

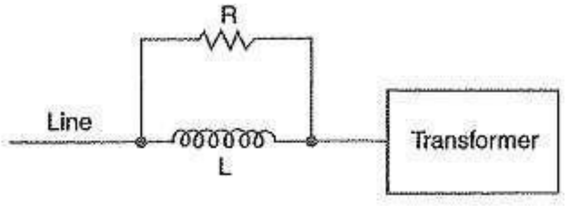
7.3 SURGE ABSORBER

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 Absorber.

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

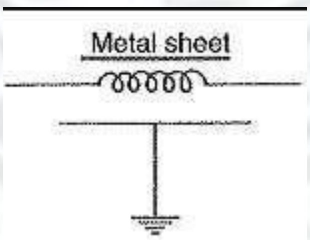
Although both surge diverter and surge absorber eliminate the surge, the manner in which it is done is different in the two devices. The surge diverter diverts the surge to earth but the surge absorber absorbs the surge energy. A few cases of surge absorption are discussed below :





(i) A condenser connected between the line and earth can act as a surge absorber. The above Fig-(a). shows how a capacitor acts as surge absorber to protect the transformer winding. Since the reactance of a condenser is inversely proportional to frequency, it Will be low at high frequency and high at low frequency. Since the surges are of high frequency, the capacitor acts as a short circuit and passes them directly to earth. However, for power frequency, the reactance of the capacitor is very high and practically no current flows to the ground.

(ii) Another type of surge absorber consists of a parallel combination of choke and resistance connected in series with the line as shown in Fig-(b). The choke offers high reactance to surge frequencies ($X_L=2\pi fL$). The surges are, therefore, forced to flow through the resistance R where they are dissipated.



(iii) Above figure shows the another type of surge absorber. It is called Ferranti surge absorber. It consists of an air cored inductor connected in series with the line. The inductor is surrounded by but insulated from an earthed metallic sheet called dissipator. This arrangement is equivalent to a transformer with short-circuited secondary. The inductor forms the primary whereas the dissipator forms the short- circuited secondary. The energy of the surge is used up in the form of heat generated in the dissipator due to transformer action. This type of surge absorber is mainly used for the protection of transformers.

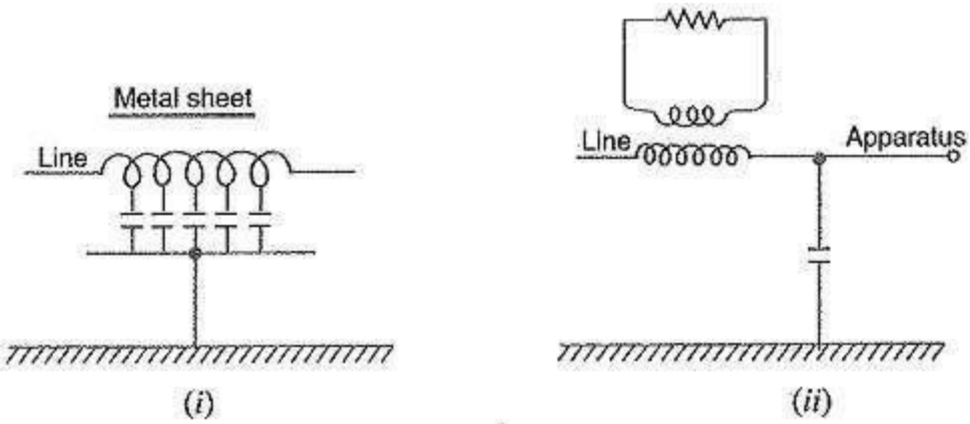


Fig.(i) shows the schematic diagram of 66 kV Ferranti surge absorber while Fig.(ii) shows its equivalent circuit.

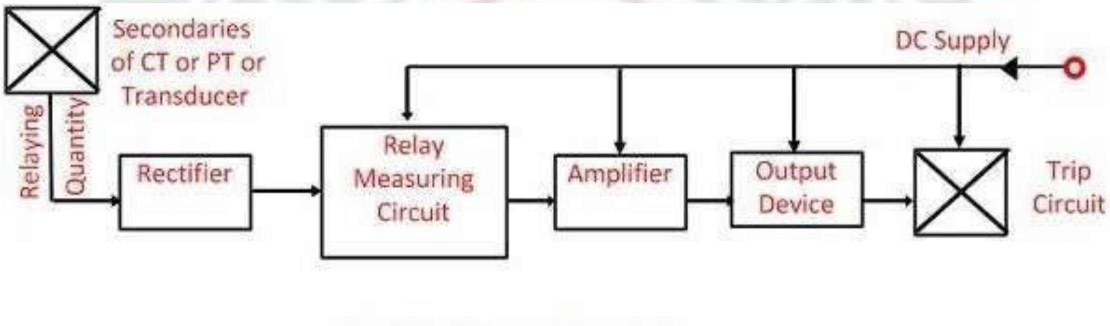
Chapter - 8

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.

8.1 ADVANTAGES OF STATIC RELAY

The following are the benefits of static relays.

1. The static relay consumes very less power because of which the burden on the measuring instruments decreases and their accuracy increases.
2. The static relay gives the quick response, long life, high reliability and accuracy and it is shockproof.
3. The reset time of the relay is very less.
4. It does not have any thermal storage problems.
5. The relay amplifies the input signal which increases their sensitivity.
6. The chance of unwanted tripping is less in this relay.
7. The static relay can easily operate in earthquake-prone areas because they have high resistance to shock.

LIMITATIONS OF STATIC RELAY

1. 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.
2. The relay is easily affected by the high voltage surges. Thus, precaution should be taken for avoiding the damages through voltage spikes.
3. The working of the relay depends on the electrical components.
4. The relay has less overloading capacity.
5. The static relay is more costly as compared to the electromagnetic relay.
6. The construction of the relay is easily affected by the surrounding interference.

For integrated protection and monitoring systems programmable microprocessor controlled static relays are preferred.

8.2 OVER CURRENT RELAYS

Working Principle of Over Current 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.

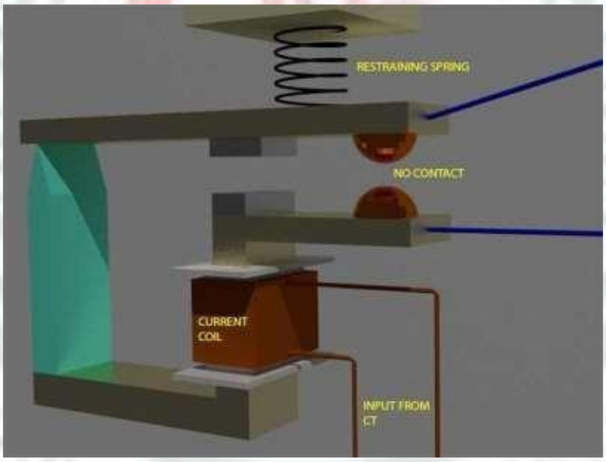
Types of Over Current Relay

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

1. Instantaneous over current relay.
2. Definite time over current relay.
3. 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



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 can not be avoided practically. In practice the operating time of an instantaneous relay is of the order of a few milliseconds. Fig.

Definite Time Over Current Relay

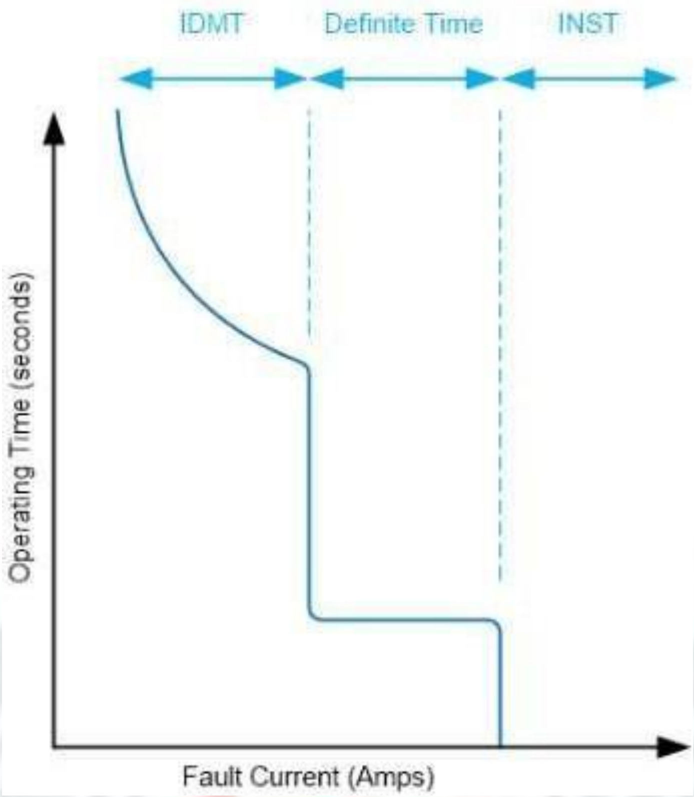
This relay is created by applying intentional time delay after crossing pick up value of the current. A definite time over current relay can be adjusted to issue a trip output at definite amount of time after it picks up. Thus, it has a time setting adjustment and pick up adjustment.

Inverse Time Over Current Relay

Inverse time is a natural character of any induction type rotating device. This means the speed of rotation of rotating art of the device is faster if input current is increased. In other words, time of operation inversely varies with input current. This natural characteristic of electromechanical induction disc relay in very suitable for over current protection. This is because, in this relay, if fault is more severe, it would be cleared more faster. Although time inverse characteristic is inherent to electromechanical induction disc relay, but the same characteristic can be achieved in microprocessor based relay also by proper programming.

8.3 Inverse Definite Minimum Time over Current Relay or IDMT O/C Relay

Ideal inverse time characteristics can not 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.


IDMT
Definite Time
INST
Operating Time (seconds)
Fault Current (Amps)