NILASAILA INSTITUTE OF SCIENCE
&
TECHNOLOGY

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LECTURER NOTES ON:

SWITCH GEAR
AND
PROTECTIVE DEVICE (SGPD)

PREPARED BY- Er.BISWAJIT PARIDA

CONTENTS

(CHAPTER -1)

INTRODUCTION TO SWITCH GEAR

What is Switchgear:

Definition of Switchgear: The apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as switchgear**.**

The term 'switchgear' is a generic term that includes a wide range of switching devices like circuit breakers, switches, switch fuse units, off-load isolators, HRC fuses, contactors, miniature circuit breakers, ELCBs, GFCIs etc.

It also includes the combination of these switching devices with associated control, measuring, protecting and regulating equipment. The switchgear devices and their assemblies are used in connection with the generation, transmission, distribution, and conversion of electrical energy.

We all are familiar with low voltage switches and re-wirable fuses in our homes. Switches are used for opening and closing an electric circuit while fuses are used for over-current and short-circuit protection. In such a way, every electrical device wants a switching and a protecting device.

Various forms of switching and protective devices have been developed. Thus switchgear can be taken as a general term covering a wide range of equipment concerned with the switching, protection, and control of various electrical equipment.

The function of a Switchgear

Switchgear has to perform the functions of carrying, making and breaking the normal load current like a switch.

In addition, it has to perform the function of clearing the fault current for which sensing devices like current transformers, potential transformers and various types of relays, depending on the application, are employed.

There also has to be provision for metering, controlling and data, wherein innumerable devices are used for achieving the switching function.

Thus switchgear can include circuit breaker, current transformers, potential transformers, protective relays, measuring instruments, switches, fuses, MCBs, surge arrestors, isolators, and various associated types of equipment. (Related components can be found at electronic components distributor)

Now let's look into the components of switchgear in detail.

Components of Switchgear

Switchgear essentially consists of switching and protecting devices such as switches, fuses, isolators, circuit breakers, protective relays, control panels, lightning arrestors, current transformers, potential transformers, auto reclosures, and various associated equipment.

(For more details, visit a complete list on components of switchgear.)

Some types of equipment are designed to operate under both normal and abnormal conditions. Some equipment is meant for switching and not sensing the fault.

During normal operation, switchgear permits to switch on or off generators, transmission lines, distributors and other electrical equipment. On the other hand, when a failure (e.g. short circuit) occurs on any part of the power system, a heavy current flows through the equipment, threatening damage to the equipment and interruption of service to the customers.

However, the switchgear detects the fault and disconnects the unhealthy section from the system. (For more details visit working of a circuit breaker and protective relays.)

Similarly, switching and current interrupting devices play a significant role in the modern electrical network, right from generating stations, transmission substations at different voltages, distribution substations, and load centers. The switching device here is called a circuit breaker.

The circuit breaker, along with associated devices for protection, metering, and control regulation, is called switchgear.

Read in detail about Components of Switchgear

Evolution of Switchgear

The switchgear equipment is essentially concerned with switching and interrupting currents either under normal or abnormal operating conditions.

The tumbler switch with ordinary fuse is the simplest form of switchgear and was used to control and protect lights and other equipment in homes, offices, etc.

For circuits of a higher rating, a high-rupturing capacity (H.R.C.) fuse in conjunction with a switch may serve the purpose of controlling and protecting the circuit. However, such switchgear cannot be used profitably on a high voltage system (33 kV) for two reasons.

- Firstly, when a fuse blows, it takes some time to replace it and consequently, there is an interruption of service to the customers.
- Secondly, the fuse cannot successfully interrupt large fault currents that result from the faults on the high voltage system.

With the advancement of the power system, lines and other equipment operate at high voltages and carry large currents. When a short circuit occurs on the system, a heavy current flowing through the equipment may cause considerable damage.

In order to interrupt such heavy fault currents, automatic circuit breakers (or simply circuit breakers) are used.

A circuit breaker is one switchgear which can open or close an electrical circuit under both normal and abnormal conditions.

Even in instances where a fuse is adequate, as regards to breaking capacity, a circuit breaker may be preferable. It is because a circuit breaker can close circuits, as well as break them without replacement and thus has a wider range of use altogether than a fuse.

[For more details, go through What is a fuse and How it Works? and Working of Circuit Breaker]

Essential Features of Switchgear

The essential features of switchgear are :

1. Complete Reliability
2. Absolutely certain discrimination
3. Quick operation
4. Provision for manual control

1. 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.

This is not surprising because it is added to the power system to improve reliability. When a fault occurs on any part of the power system, they must operate to isolate the faulty section from the remainder circuit.

2. Absolutely certain discrimination

When a fault occurs on any section of the power system, the switchgear must be able to discriminate between the faulty section and the healthy section.

It should isolate the faulty section from the system without affecting the healthy section. This will ensure continuity of supply.

3. Quick operation

When a fault occurs on any part of the power system, the switchgear must operate quickly so that no damage is done to generators, transformers and other equipment by the short-circuit currents.

If the fault is not cleared quickly, it is likely to spread into healthy parts, thus endangering complete shut down of the system

4. Provision for manual control

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

Classification of Switchgear

Switchgear can be classified on the basis of the voltage level into the following

1. Low voltage (LV) Switchgear
2. Medium voltage (MV) Switchgear
3. High voltage (HV) Switchgear

1. Low Voltage Switchgear

Switchgear for low voltage applications is generally **rated up to 1000 V AC and 1500V DC**.

The commonly used low voltage devices include oil circuit breakers(OCBs), air circuit breakers (ACBs), switch fuse units (SFUs), off-load isolators, HRC fuses, earth leakage circuit breakers (ELCBs), Residual Current Protective Devices (RCCB & RCBO), miniature circuit breakers (MCB) and moulded case circuit breakers(MCCB) etc i.e. all the accessories required to protect the LV system.

The most common use of this is in LV distribution board.

Read more about Low Voltage Switchgear.

2. Medium Voltage Switchgear

Switchgear for medium voltage applications is rated from 3.3 kV to 33 kV class.
Medium voltage switchgear is mainly used for the distribution of electrical energy connected to various electrical networks. They include most of the substation equipment such as minimum oil circuit breakers, bulk oil circuit breakers, air magnetic, SF6 gas-insulated, vacuum, and gas-insulated switchgear.
They may metal-enclosed indoor type, metal-enclosed outdoor type, outdoor type without a metal enclosure, etc. The interruption medium maybe oil, SF6, and vacuum.
The main requirement of MV power network is to interrupt the current during faulty condition irrespective of what type of CB is used in the system. Although it may be capable of functioning in other conditions also.
Medium voltage switchgear should be capable of,

- Normal ON/OFF switching operation.
- Short circuit current interruption.
- Switching of capacitive currents.
- Switching of inductive currents.
- Some special application.

3. High Voltage Switchgear

The power system deals with the voltage above 36kV is referred to as high voltage.
As the voltage level is high the arcing produced during switching operation is also very high. So, special care to be taken during designing of high voltage switchgear.
High voltage circuit breakers (such as SF6 Circuit breaker or Vacuum Circuit breaker) are the main component of HV switchgear. Hence high voltage circuit breaker should have special features for safe and reliable operation.
Faulty tripping and switching operation of high voltage circuit breakers are comparatively very rare. Most of the time these circuit breakers remain at ON condition and may be operated after a long period of time. So Circuit Breakers must be reliable enough to ensure safe operation, as when required.
Read more about different types of High Voltage Circuit Breakers.

Indoor and Outdoor Switchgear

The main components of switchgear are circuit breakers, switches, bus-bars, instruments and instrument transformers. It is necessary to house the switchgear in power stations and substations 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 Switchgear**
2. **Indoor type Switchgear**

Outdoor Switchgear

For voltages beyond 66 kV, we install outdoor switchgear equipment.
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.
The figure shows a typical outdoor sub-station with switchgear equipment. The circuit breakers, isolators, transformers, bus-bars, and all other substation equipment occupy considerable space on account of large electrical clearance associated with high voltages.

Indoor Switchgear

For voltages below 66 kV, switchgear is generally installed indoor because of economic considerations.
It 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 localization and restriction of any fault to its place of origin.

Switchgear Equipment

Switchgear covers a wide range of equipment concerned with switching and interrupting currents under both normal and abnormal conditions. It includes switches, fuses, circuit breakers, relays, current transformer, and other equipment.
Read switchgear in the substation for more details.
A brief account of these devices is given below.

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. This is particularly true for circuits of high voltage and large current capacity.
The switches may be classified into

1. air switches
2. oil switches

The contacts of the former are opened in the air and that of the latter is opened in oil.

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. Read different types of air break switch.

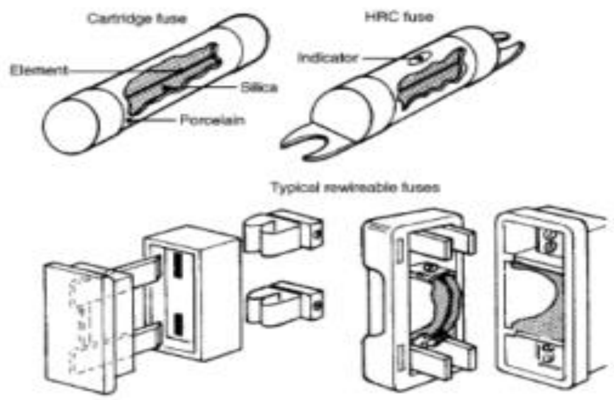
Isolator or disconnecting switch – It is essentially a knife switch and is designed to open a circuit under no load.

Oil switches – As the name implies, the contacts of such switches are opened under oil, usually transformer oil.

Air Break Switch

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.



Electrical Fuses Switchgear

3. Circuit Breakers

A circuit breaker is an equipment which can open or close a circuit under all conditions viz. no-load, full load and fault conditions. It is so designed that it can be operated manually (or by remote control) under normal conditions and automatically under fault conditions. For the latter operation, a relay circuit is used with a circuit breaker.

Low Voltage Circuit Breakers: Miniature Circuit Breaker, Moulded Case Circuit Breaker, Residual Current Circuit Breaker, Ground Fault Circuit Interrupter.

High Voltage Circuit Breakers: Vacuum Circuit Breaker, SF6 Circuit Breaker, Oil Circuit Breaker, Air Blast Circuit Breaker
Read Circuit Breaker – Operating Principle and Arcing Phenomenon.

4. Protective Relays

Protective relays are vital parts of the switchgear equipment.
A relay is a device which detects the fault and supplies information to the breaker for circuit interruption.
The function of a protective relay is to initiate a signal to circuit breakers for disconnecting the elements of the power system when it develops a fault.
When a fault occurs the relay contacts are closed and the trip coil of the circuit breaker is energized to open the contacts of the circuit breaker.
There have been rapid developments in relaying technology during the last two decades. The most important advancement has been due to the advent of computer technology which has helped in the development of numerical relays.
Read in detail How Protective Relays Work?

5. Instrument Transformers

Instrument transformers (current transformer and voltage transformer) are used in switchgear installations for the measurement of electrical parameters for protection and metering purposes.
An instrument transformer in which the secondary current is substantially proportional to the primary current and differs in phase from it by approximately zero degrees is called a current transformer (CT).
A voltage transformer (VT) is an instrument transformer in which the secondary voltage is substantially proportional to the primary voltage and differs in phase from it by approximately zero degrees.

6. Surge Arresters

Surge Suppressors or Surge Arrestors are very important components of switchgear and substation installations.
These are used to protect the substation equipment from temporary over-voltages, switching impulses, and lightning impulses, and to a certain extent, very fast transient over-voltages.
Historically, spark gaps with air insulation were used as surge suppressors. Lightning arrestors, surge capacitors, surge suppressing reactors, and thyrite resistors with series gaps were used in the past for this purpose.
Innovation in this field has resulted in the advent of two commonly used types, viz. the metal oxide-based (ZnO) type and C-R type of surge arrestors/ suppressors.

7. Auto Reclosures and sectionalisers

Auto reclosures and sectionalisers are used in the distribution networks of medium voltage switchgear up to 33 kV class.
These equipment are useful for the fast automatic restoration of supply following transient faults in the system. The faults may be due to frequent lightning surges and in areas where power lines run through forests and trees.

8. Disconnect Switch / Isolator

Disconnectors (Isolators) are devices which are generally operated off-load to provide isolation of main plant items for maintenance, on to isolate faulted equipment from other live equipment.
Air Insulated or open terminal disconnectors are available in several forms for different applications.
At the lower voltages, single break types are usual with either 'rocker' type or single end rotating post types being predominant.
At higher voltages, rotating center post, double end rotating post, vertical break, and pantograph type disconnectors are more common. Air break switches are used in lower voltage to disconnect on load.

Electrical Bus-Bar and its Types

Definition: An electrical bus bar is defined as a conductor or a group of conductor used for collecting electric power from the incoming feeders and distributes them to the outgoing feeders. In other words, it is a type of electrical junction in which all the incoming and outgoing electrical current meets. Thus, the electrical bus bar collects the electric power at one location.

The bus bar system consists the isolator and the circuit breaker. On the occurrence of a fault, the circuit breaker is tripped off and the faulty section of the bus bar is easily disconnected from the circuit.

The electrical bus bar is available in rectangular, cross-sectional, round and many other shapes. The rectangular bus bar is mostly used in the power system. The copper and aluminium are used for the manufacturing of the electrical bus bar.

The most common of the bus-bars are 40×4mm (160 mm^2); 40×5 mm (200 mm^2) ; 50×6 mm (300mm^2) ; 60×8 mm (480 mm^2) ; 80×8 (640 mm^2) and 100×10 mm (1000 mm^2).

The various types of bus bar arrangement are used in the power system. The selection of the bus bar is depended on the different factor likes reliability, flexibility, cost etc. The following are the electrical considerations governing the selection of any one particular arrangement.

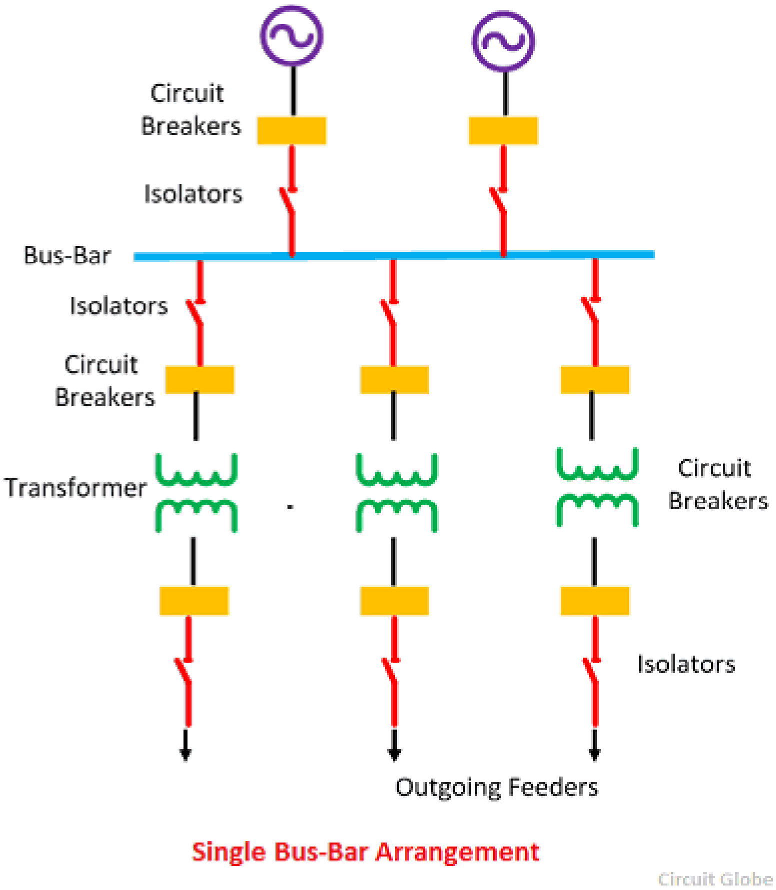
- The bus bar arrangement is simple and easy in maintenance.
- The maintenance of the system did not affect their continuity.
- The installation of the bus bar is cheap.

The small substation where continuity of the supply is not essential uses the single bus bar. But in a large substation, the additional bus bar is used in the system so that the interruption does not occur in their supply. The different type of electrical bus bar arrangement is shown in the figure below.

Single Bus-Bar Arrangement

The arrangement of such type of system is very simple and easy. The system has only one bus bar along with the switch. All the substation equipment like the transformer, generator, the feeder is connected to this bus bar only. The advantages of single bus bar arrangements are

- It has low initial cost.
- It requires less maintenance
- It is simple in operation



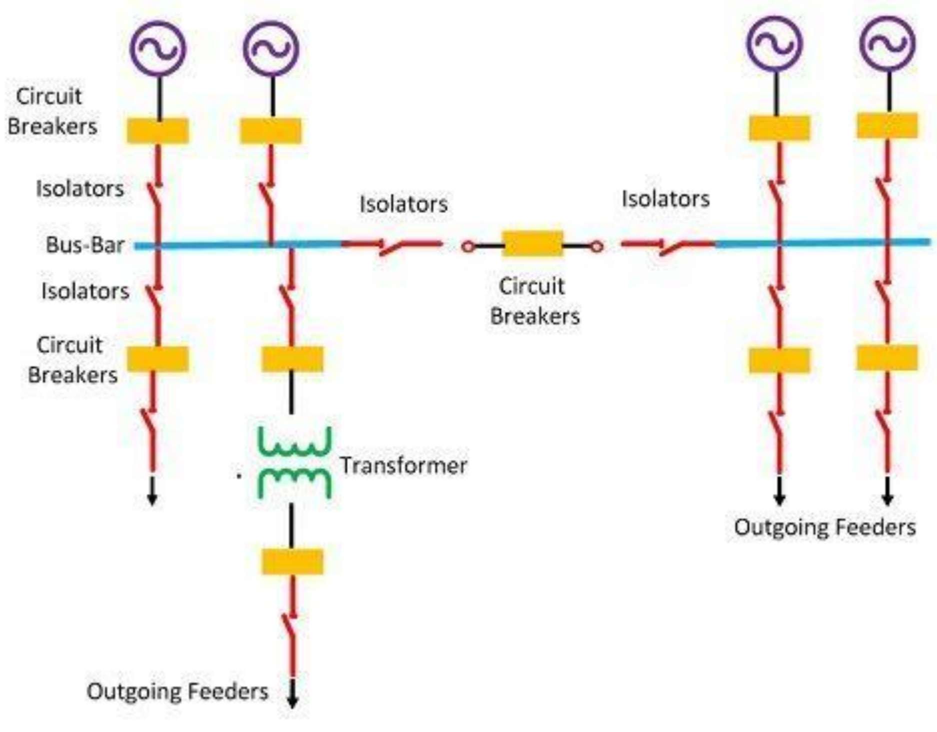
Single Bus-Bar Arrangement

Drawbacks of Single Bus-Bars Arrangement

- The only disadvantage of such type of arrangement is that the complete supply is disturbed on the occurrence of the fault.
- The arrangement provides the less flexibility and hence used in the small substation where continuity of supply is not essential.

Single Bus-Bar Arrangement with Bus Sectionalized

In this type of bus bar arrangement, the circuit breaker and isolating switches are used. The isolator disconnects the faulty section of the bus bar, hence protects the system from complete shutdown. This type of arrangement uses one addition circuit breaker which does not much increase the cost of the system.



Sectionalized Single Bus-Bar System

Advantage of single Bus-bar Arrangement with Bus Sectionalization

The following are the advantages of sectionalized bus bar.

- The faulty section is removed without affecting the continuity of the supply.
- The maintenance of the individual section can be done without disturbing the system supply.
- The system has a current limiting reactor which decreases the occurrence of the fault.

Disadvantages of Single Bus-Bar Arrangement with Sectionalization

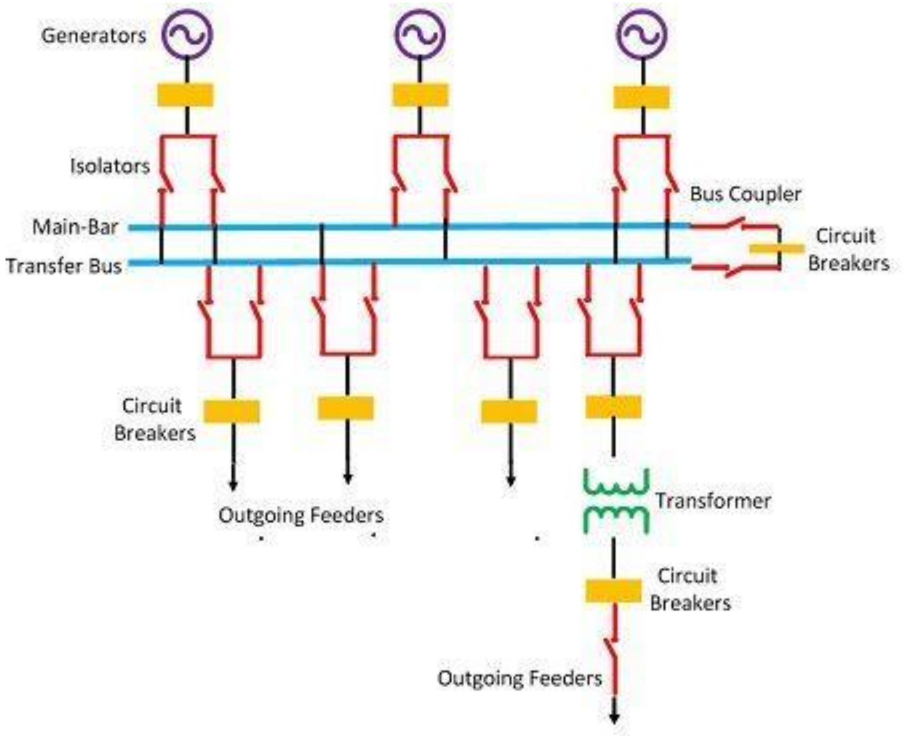
- The system uses the additional circuit breaker and isolator which increases the cost of the system.

Main and Transfer Bus Arrangement

Such type of arrangement uses two type of bus bar namely, main bus bar and the auxiliary bus bar. The bus bar arrangement uses bus coupler which connects the isolating switches and circuit breaker to the bus bar. The bus coupler is also used for transferring the load from one bus to another in case of overloading. The following are the steps of transferring the load from one bus to another.

1. The potential of both the bus bar kept same by closing the bus coupler.
2. The bus bar on which the load is transferred is kept close.
3. Open the main bus bar.

Thus, the load is transferred from the main bus to reserve bus.



Main And Transfer Bus Arrangement

Advantages of Main and Transfer Bus Arrangement

- The continuity of the supply remains same even in the fault. When the fault occurs on any of the buses the entire load is shifted to the another bus.
- The repair and maintenance can easily be done on the busbar without disturbing their continuity.
- The maintenance cost of the arrangement is less.
- The potential of the bus is used for the operation of the relay.

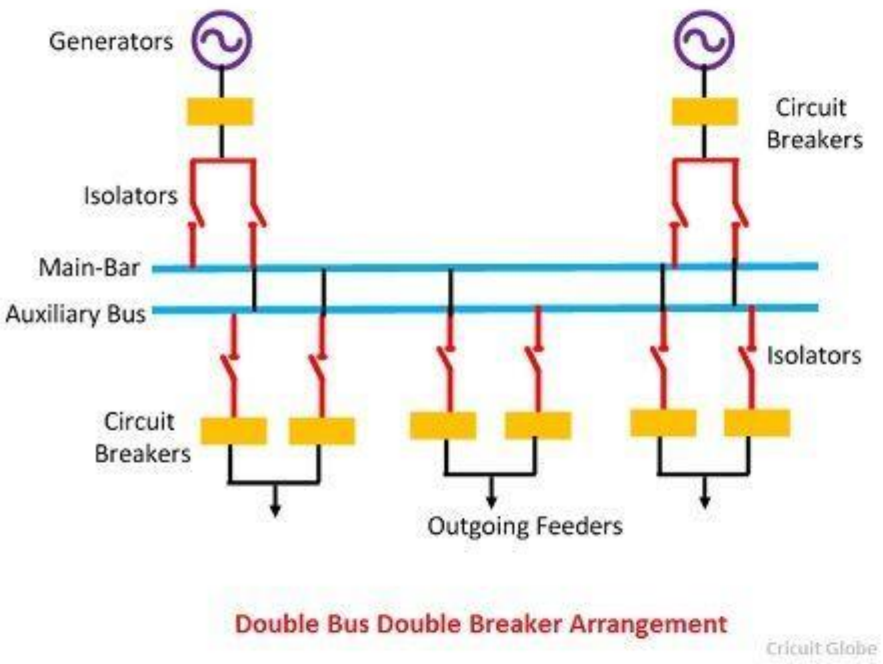
- The load can easily be shifted on any of the buses.

Disadvantages of Main and Transfer Bus Arrangement

- In such type of arrangements, two bus bars are used which increases the cost of the system.
- The fault on any of the bus would cause the complete shutdown on the whole substation.

Double Bus Double Breaker Arrangement

This type of arrangement requires two bus bar and two circuit breakers. It does not require any additional equipment like bus coupler and switch.



Advantages of Double Bus Double Breaker

- This type of arrangement provides the maximum reliability and flexibility in the supply. Because the fault and maintenance would not disturb their continuity.
- The continuity of the supply remains same because the load is transferrable from one bus to another on the occurrence of the fault.

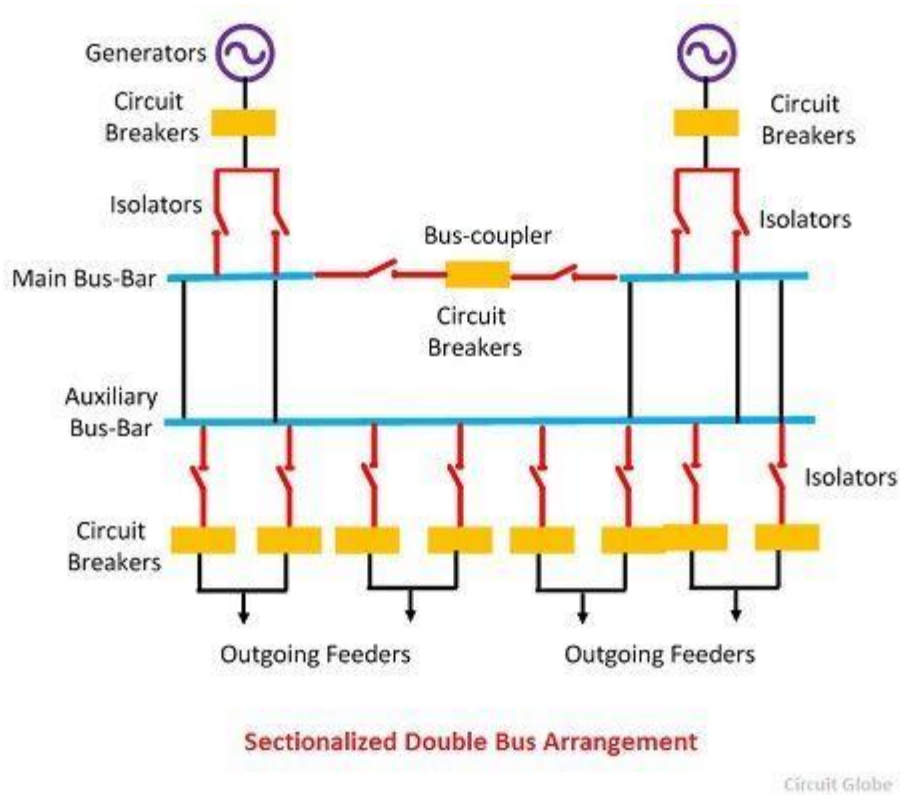
Disadvantages of double bus Double breaker

- In such type of arrangement two buses and two circuit breakers are used which increases the cost of the system.
- Their maintenance cost is very high.

Because of its higher cost, such type of bus-bars is seldom used in substations.

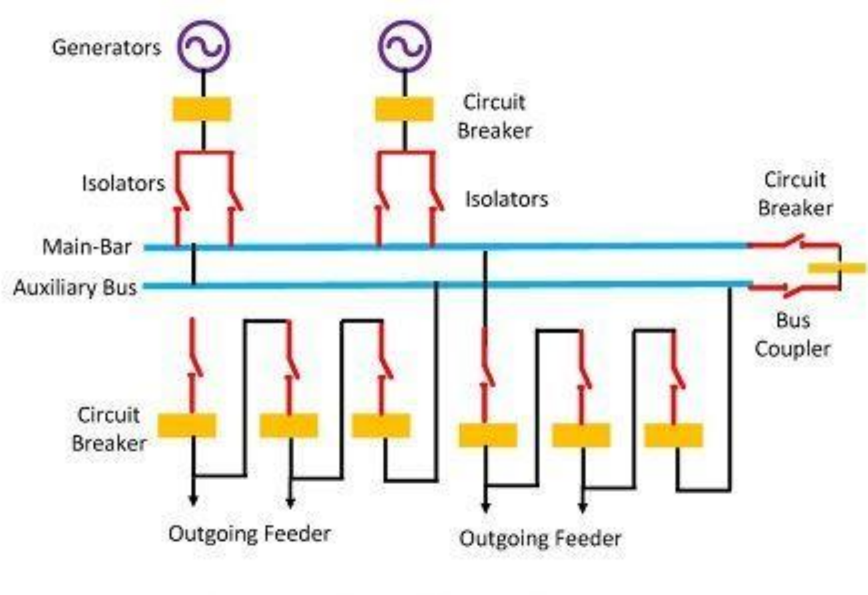
Sectionalized Double Bus Bar Arrangement.

In this type of bus arrangement, the sectionalized main bus bar is used along with the auxiliary bus bar. Any section of the busbar removes from the circuit for maintenance and it is connected to any of the auxiliary bus bars. But such type of arrangement increases the cost of the system. Sectionalization of the auxiliary bus bar is not required because it would increase the cost of the system.



One and a Half Breaker Arrangement

In this arrangement, three circuit breakers are required for two circuits. The each circuit of the bus bar uses the one and a half circuit breaker. Such type of arrangement is preferred in large stations where power handled per circuit is large.



One-and-a-Half Circuit Breaker Arrangement

Advantages of One and a Half Breaker Arrangement

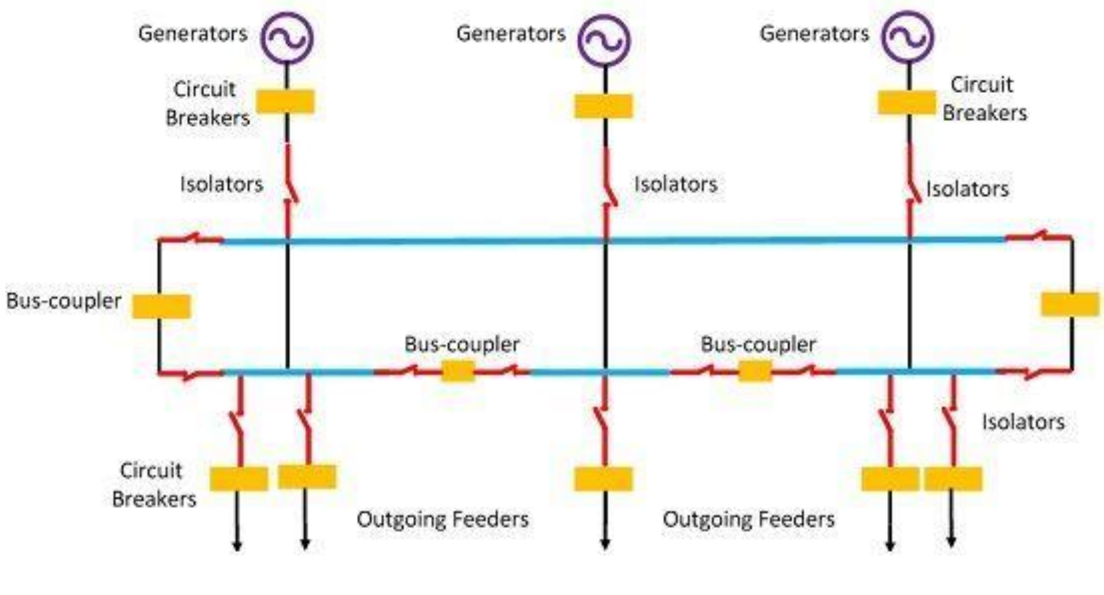
- It protects the arrangement against the loss of supply.
- The potential of the bus bar is used for operating the relay.
- In such type of arrangement, the additional circuits are easily added to the system.

Disadvantages of One and a Half Breaker Arrangement

- The circuit becomes complicated because of the relaying system.
- Their maintenance cost is very high.

Ring Main Arrangement

In such type of arrangement, the end of the bus bar is connected back to the starting point of the bus to form a ring.



Ring Main Arrangement

Advantages of Ring Main Arrangement

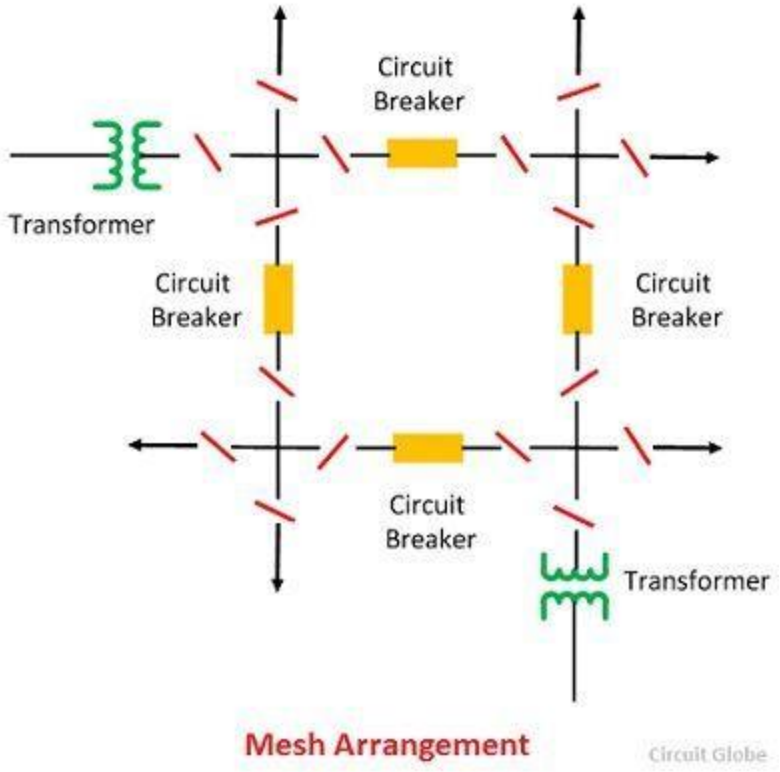
- Such type of arrangement will provide two paths for the supply. Thus the fault will not affect their working.
- The fault is localized for the particular section. Hence the complete circuit is not affected by the fault.
- In this arrangement, a circuit breaker can be maintained without interrupting the supply.

Disadvantages of Ring Main Arrangement

- Difficulties occur in the addition of the new circuit.
- Overloading occurs on the system if any of the circuit breakers is opened.

Mesh Arrangement

In such type of arrangement, the circuit breakers are installed in the mesh formed by the buses. The circuit is tapped from the node point of the mesh. Such type of bus arrangement is controlled by four circuit breakers.



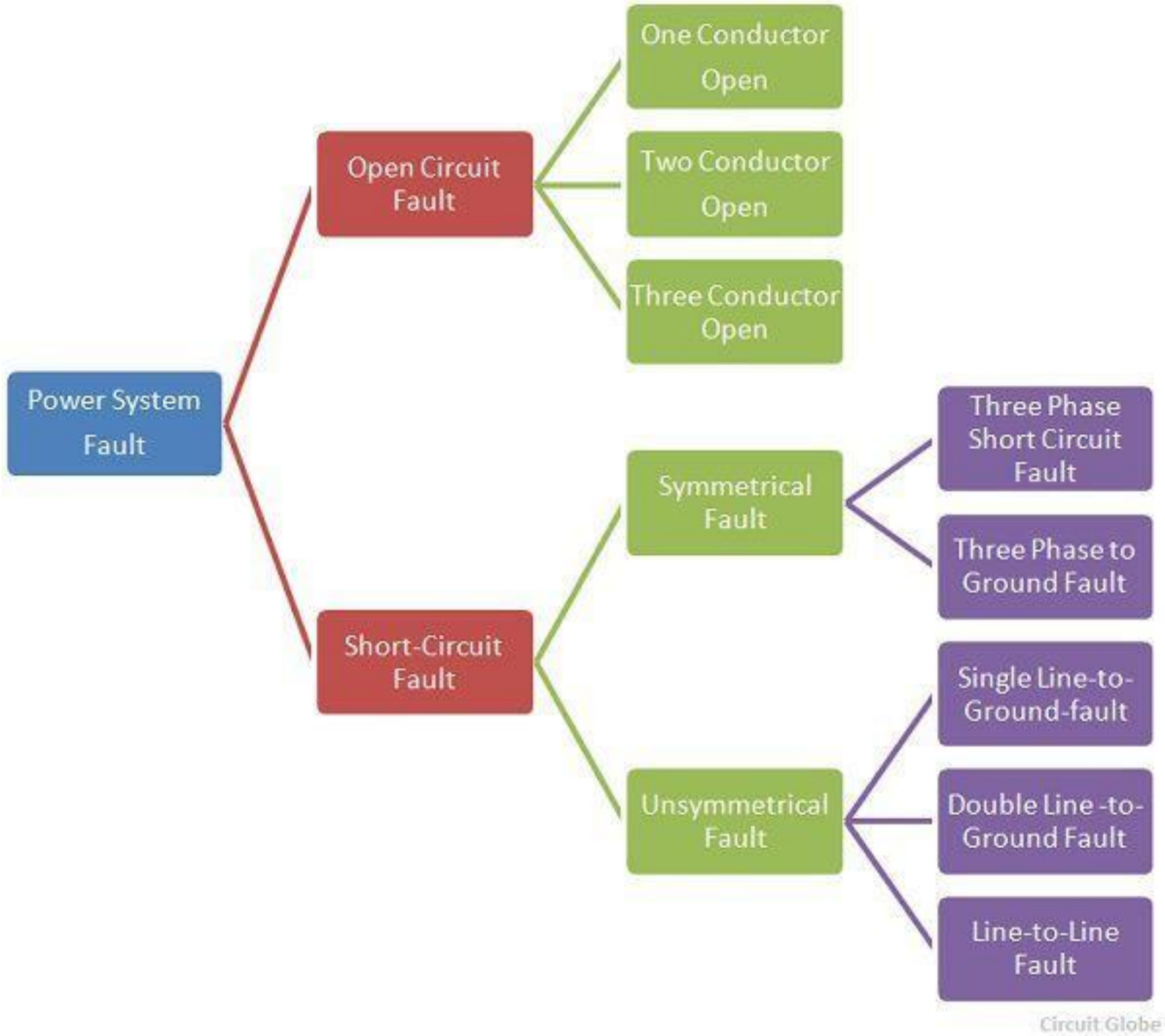
When a fault occurs on any section, two circuit breakers have to open, resulting in the opening of the mesh. Such type of arrangement provides security against bus-bar fault but lacks switching facility. It is preferred for substations having a large number of circuits.

Types of 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 fault in the power system is mainly categorised into two types they are

1. Open Circuit Fault
2. Short Circuit Fault.

The different types of power system fault are shown below in the image.



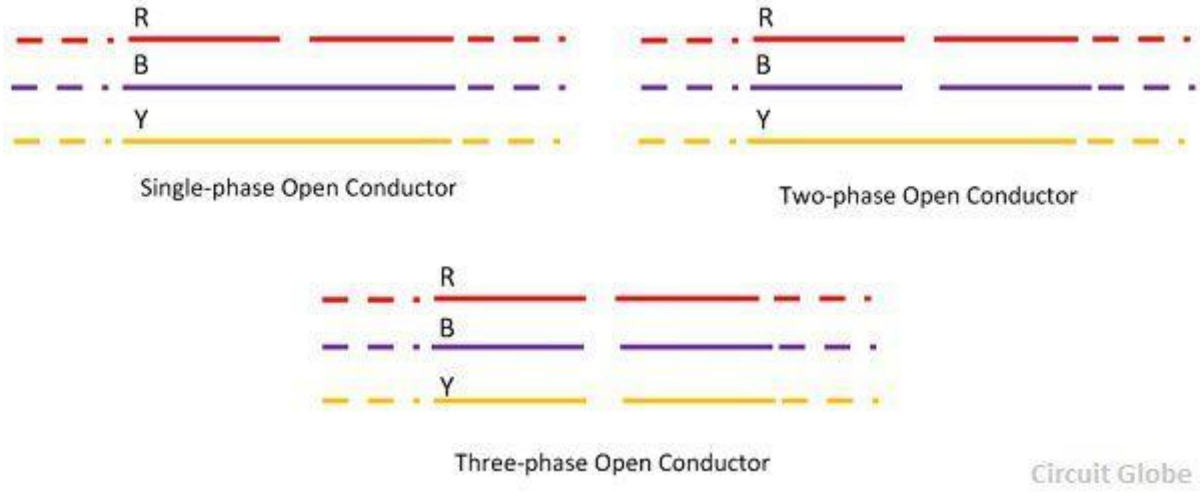
The faults in the power system may occur because of the number of natural disturbances like lightning, high-speed winds, earthquake, etc. It may also occur because of some accidents like falling off a tree, vehicle colliding, with supporting structure, aeroplane crashing, etc.

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.

The open circuit fault is shown in the figure below.



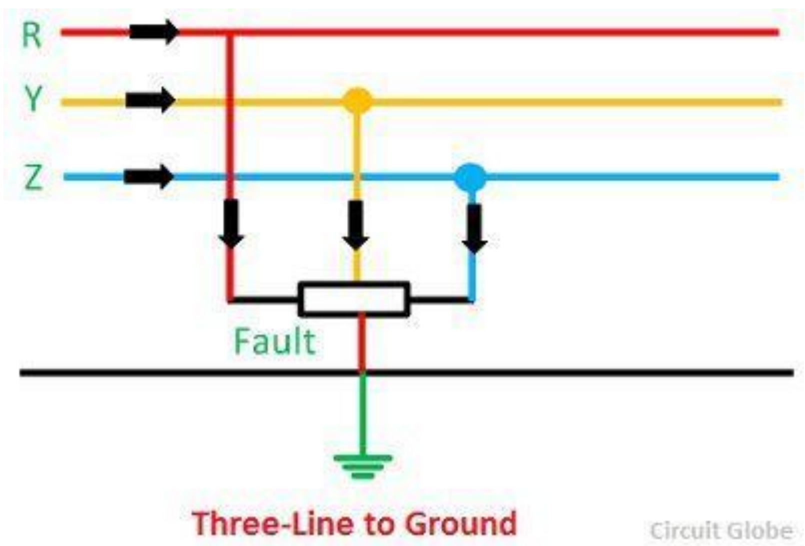
2. Short-Circuit Fault

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

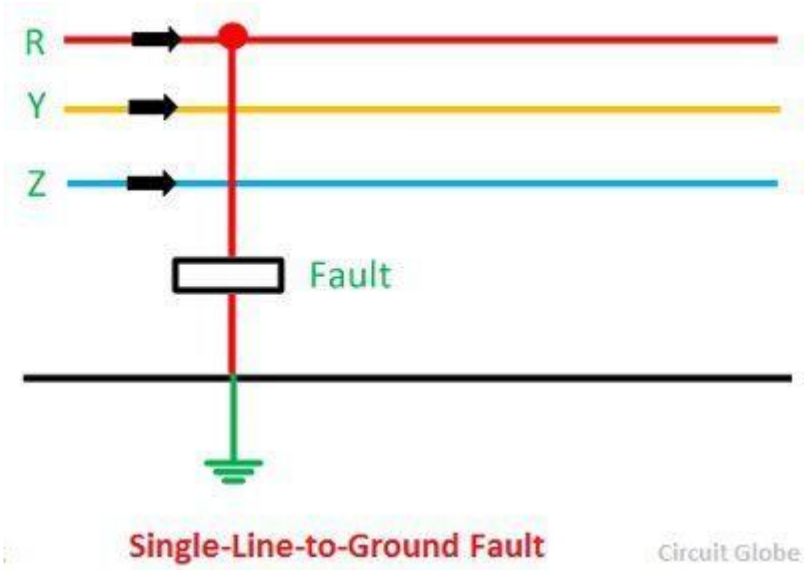
Symmetrical Fault

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 symmetrical faults mainly occur at the terminal of the generators. 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. The symmetrical fault is sub-categorized into line-to-line-to-line fault and three-phase line-to-ground-fault

a. 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.



b. 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 percent.



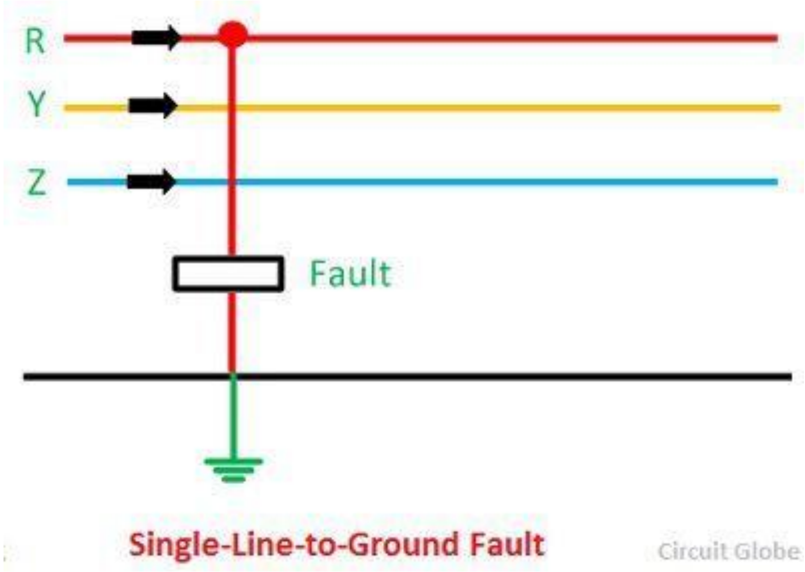
Unsymmetrical Fault

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

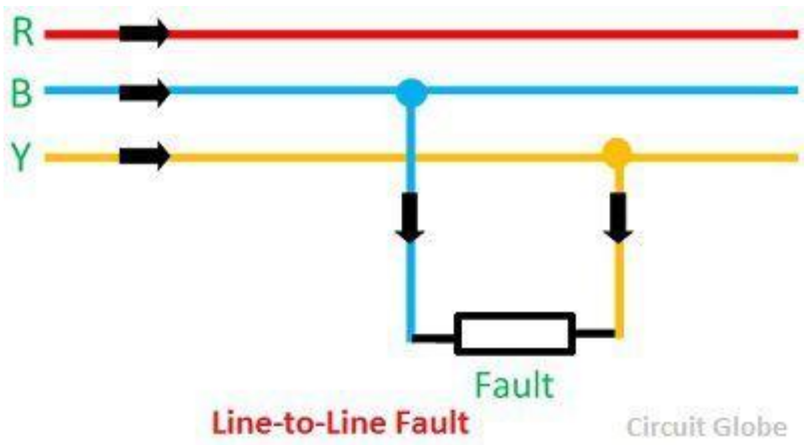
1. Single Line-to-ground (L – G) Fault
2. Line-to-Line Fault (L – L)
3. Double Line-to-ground (L – L – G) Fault

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

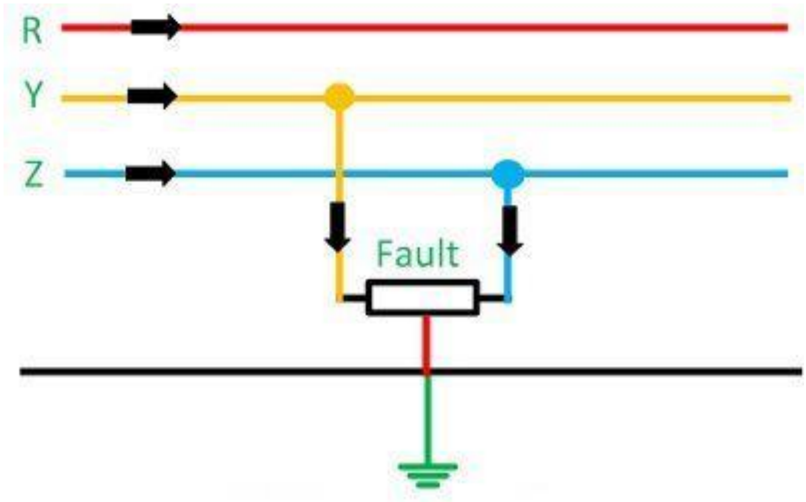
1. Single Line-to-Line Ground – The single line of ground fault occurs when one conductor falls to the ground or contact the neutral conductor. The 70 – 80 percent of the fault in the power system is the single line-to-ground fault.



2. 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%.



3. 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

The symmetrical and unsymmetrical fault mainly occurs in the terminal of the generator, and the open circuit and short circuit fault occur on the transmission line.

(CHAPTER-2)

FAULT CALCULATION

Symmetrical Faults on 3 Phase System:

Most of the Symmetrical Faults on 3 Phase System on the power system lead to a short-circuit condition. When such a condition occurs, a heavy current (called short circuit current) flows through the equipment, causing considerable damage to the equipment and interruption of service to the consumers. There is probably no other subject of greater importance to an electrical engineer than the question of determination of short circuit currents under fault conditions. The choice of apparatus and the design and arrangement of practically every equipment in the power system depends upon short-circuit current considerations.

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 symmetrical fault occurs when all the three conductors of a 3-phase line are brought together simultaneously into a short-circuit condition as shown in Fig. 17.1. This type of fault gives rise to symmetrical currents L e. equal fault currents with 120° displacement. Thus referring to Fig. 17.1, 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.

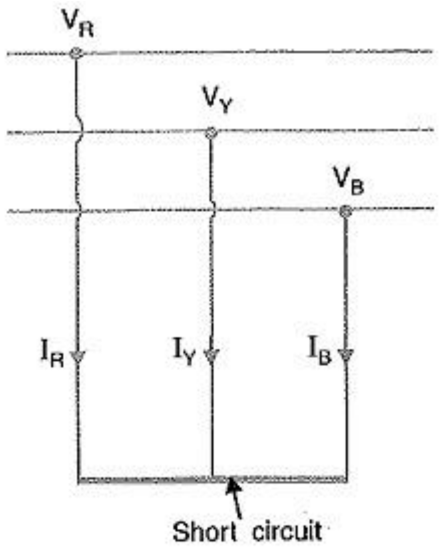


Fig. 17.1

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.

Limitation of Fault Current:

When a short circuit occurs at any point in a system, the short-circuit current is limited by the impedance of the system up to the point of fault. Thus referring to Fig. 17.2, if a Symmetrical Faults on 3 Phase System occurs on the feeder at point F, then the short circuit current from the generating station will have a value limited by the impedance of generator and transformer and the impedance of the line between the generator and the point of Symmetrical Faults on 3 Phase System. This shows that the knowledge of the impedance of various equipment and circuits in the line of the system is very important for the determination of short-circuit currents.

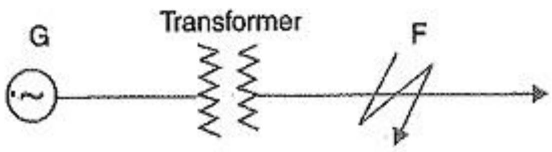


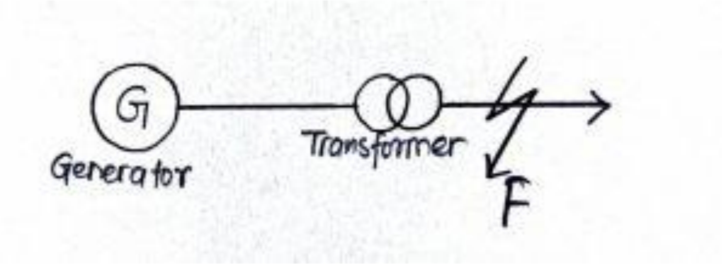
Fig. 17.2

In many situations, the impedances limiting the Symmetrical Faults on 3 Phase System current are largely reactive, such as transformers, reactors and generators. Cables and lines are mostly resistive, but where the total reactance in calculations exceeds 3 times the resistance, the latter is usually neglected. The error introduced by this assumption will not exceed 5%

Limitation to Fault Current

Limitation to Fault Current: The short circuit current produced during a fault in a system is limited by the impedance of the system up to that fault point. So the impedance of the system provides a limitation to fault current up to the fault point.

Considering the following figure where a fault occurs at the feeder denoted by F.



Here the fault current or the short circuit current generated from the generator or the generating station is limited by the impedance of the generator, transformer, and impedance of the line between the generating station up to the fault point.

Dependence of Short Circuit Current on System Size

The fault current or the short circuit current depends upon the size of the power system which will supply the fault current. The greater the system greater will be the fault level or the greater will the value of the short circuit current. As in a larger system, larger generators or larger generating stations will supply huge current to the fault point.We can summarize the increase in short circuit current or fault level with an increase in system size in the following points.

1. With a larger size system, the generator or generating stations will have larger kVA which will supply a huge fault current (short circuit current) to the fault point in a fault condition.
2. Large generators will have smaller impedance. Hence the limitation to the fault current by such small impedance will result in a larger value of short circuit current.
3. For a larger system, the current carrying capacity of the line is large. For larger current carrying capacity lines, the impedance of the line is small and hence the limitation to the fault current by such small impedance will result in a larger value of short circuit current.

Illustration of Limitation to Fault Current

Here we will illustrate the fact that for a larger system, the short circuit current or the fault level will be higher. For this, we will consider two cases and compare the short circuit current value.

Case-1:

Consider a 3 phase 400 V, 75 kW induction motor. This motor is connected to an infinite bus-bar through a 100 kVA transformer whose impedance is $Z_T = 0.1\ \Omega$.

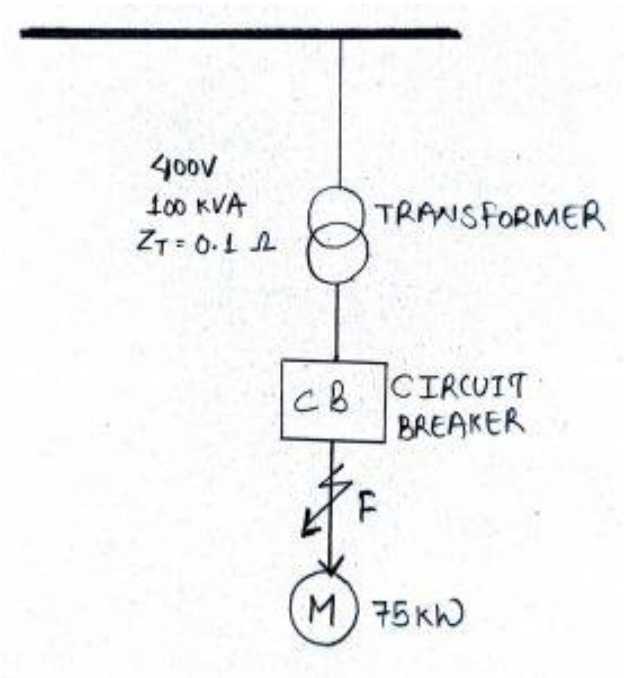


Figure: Case-1

Assuming the power factor to be 0.8 lagging. The full-load current if the motor is;

$$I_L = \frac{75\times1000}{\sqrt{3}\times400\times0.8} = 135\ A$$

Here, we consider a fault occurring at the point 'F'. The figure above shows this fault point clearly.

For this fault, the impedance of the transformer only limits the fault current.

The short circuit current is

$$I_{SC1} = \frac{Phase\ Voltage}{Impedance\ upto\ point\ F} = \frac{\frac{400}{\sqrt{3}}}{0.1} = 2310\ A$$

Case-2:

Consider a 3 phase 400 V, 75 kW induction motor which is connected to an infinite bus-bar through a 4000 kVA transformer whose impedance is given by Z_T = 0.015 Ω.

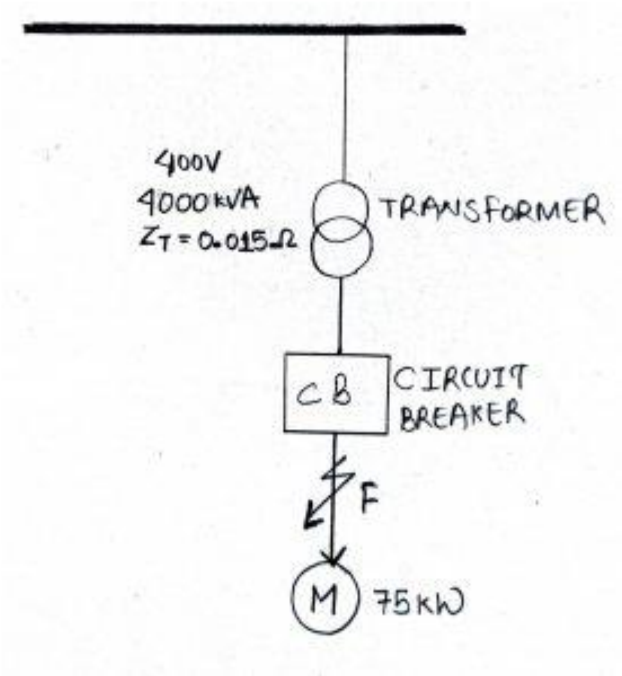


Figure: Case-2

Similarly, assuming the power factor to be 0.8 lagging. The full-load current if the motor is;

$$I_L = \frac{75\times1000}{\sqrt{3}\times400\times0.8} = 135\ A$$

Here, we consider a fault occurring at the point 'F'. The figure above shows this fault point clearly.

For this fault, the impedance of the transformer only limits the fault current.

The short circuit current is

$$I_{SC2} = \frac{Phase\ Voltage}{Impedance\ upto\ point\ F}$$
$$= \frac{\frac{400}{\sqrt{3}}}{0.015} = 15396\ A$$

<u>Conclusion:</u>

Here we considered two cases. Hence it is clear that the short circuit current for the larger systems in Case-2 has a higher short circuit current i.e. $I_{SC2} > I_{SC1}$.

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.

$$\%X = \frac{I\,X}{V} \times 100 \qquad ...(i)$$

i.e.

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 :

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

where X is the reactance in ohms.

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

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

$$= I \times \left(\frac{100}{\%X}\right) \qquad \text{[By putting the value of } X \text{ from exp. } (i)]$$

i.e. short circuit current is obtained by multiplying the full-load current by 100 / % X.

For instance, if the Percentage Reactance in Power System of an element is 20% and the full-load current is 50 A, then short-circuit current will be 50 x 100/20 = 250 A when only that element is in the circuit.

It may be worthwhile to mention here the advantage of using Percentage Reactance in Power System instead of ohmic reactance in short-circuit calculations. Percentage reactance values remain unchanged as they are referred though transformers, unlike ohmic reactances which become multiplied or divided by the square of transformation ratio. This makes the procedure simple and permits quick calculations.

Percentage Reactance and Base WA:

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 unimportant 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 Fig. 17.3. 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.

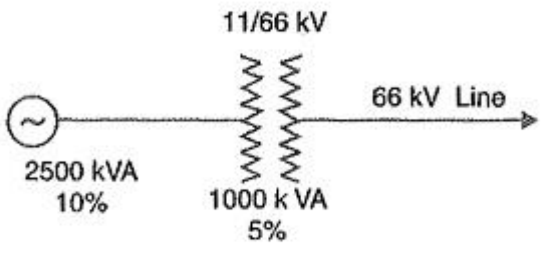


Fig. 17.3

(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 ;

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

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

(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.

(CHAPTER-3)

FUSES

FUSE

The fuse is an integral part of any circuit, whether electric or electronic, and protects against overload current. The device is attached to a metal strip that melts when the current exceeds its set value.

Due to the melting of this metal strip, the circuit opens and the current cannot proceed so any device attached to it cannot function. It is also known as an automatic disconnection system which is frequently shortened on ADS.

This is the easiest and cheapest security device to use which protects us against short circuits and overloads.

Why Do We Require Fuse?

The most direct and simple benefit of this is found in all our homes which protects the appliance in our house against overload current and short circuit. We use fuses in homes so that no defects are created in the wiring of the house which protects against fire caused by a short circuit of wiring.

When the fuse breaks down or is damaged, the over-voltage can cause a glare in it which can damage the appliance in the house. If you have a home, office, or factory, you need a fuse instead.

Many types of fuses are commonly used for circuit protection. Fuses are usually rated in amperes. This can usually be achieved by making the fuse wire length as short as possible. The length of the wire does not depend on the current rating, so the minimum length of the wire imposes a minimum value of resistance.

Characteristics of Fuses:

A few more features of the electric fuse are as follows:

Sr. No.	Characteristics of Fuse
1.	Current rating value
2.	Voltage rating value
3.	Temperature
4.	Voltage drop

1. Current rating value:

Continuing a higher amount of current that holds the device without melting is known as the current rating value. This can be measured in the value of ampere which is its thermal characteristics.

2. Voltage rating value:

Here the voltage is connected in series with the fuse which does not allow the volume of voltage to increase.

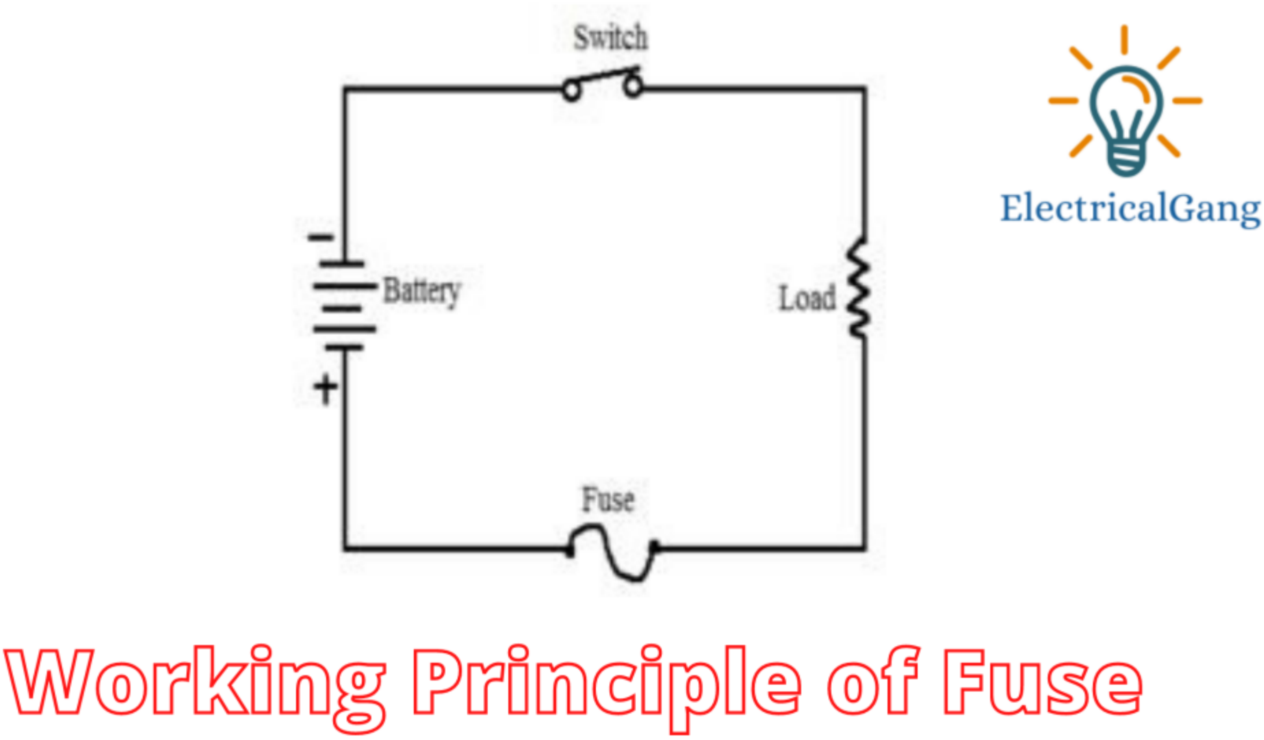
3. Temperature:

Here, the functional temperature of the fuse is high so that the current rating falls down. This melts the fuse.

4. Voltage drop:

However, if the fuse melts and the electrical circuit opens in a condition where a device is carrying a large amount of current, this will cause a change in resistance and minimize the voltage drop.

Working Principle of Fuse:



The working principle of a fuse is based on the temperature of the current. It is always made of thin metal wire and the fuse in the circuit is always connected in series.

When a high amount of current is carried in this circuit, the wire attached to it softens and opens the circuit. The current flowing in large quantities causes the wire to deteriorate quickly causing its lifespan to be shorter than regular.

The main function of a fuse depends on the heat of the current passing through it. In normal conditions, the current passing through the fuse will also be normal. As this current passes through it will generate heat and this heat will be absorbed into the atmosphere.

Due to this heat being absorbed into the atmosphere, its melting point remains lower than normal. While in case of fault there will be short-circuited current flow through the device. The value of this current is higher compared to the normal current intensity level.

This causes an increase in temperature in the fuse so this fuse continues to melt. In such a case the fuse protects from overload or short circuit. Since the fuse element is made of a highly selected metal conductor, it holds the fuse. Therefore the fuse only provides the required amount of noise current to the device.

Otherwise, in case of overload, it breaks the fuse it has overvoltage suppression capability.

$$\text{Fuse rating} = (\text{power (watts)} / \text{voltage (volts)}) \times 1.25$$

The rating of the fuse can be found with the help of the formula mentioned above.

Where

The power (watts) is indicated on the device.

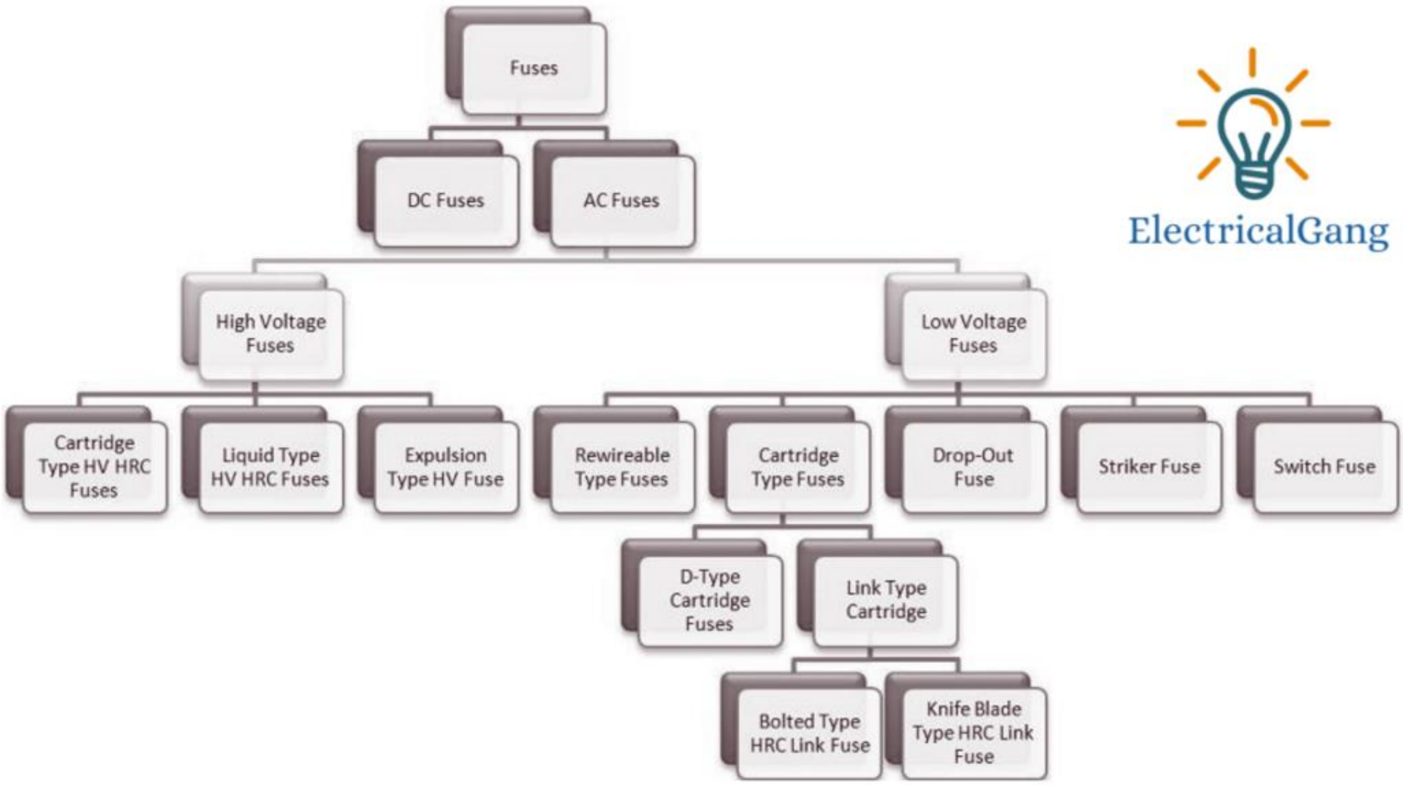
Voltage is in the form of incoming power.

Fuse can be designed with elements such as Q (Copper), Zen (Zinc), Al (Aluminum), and AG (Silver).

Different Types of Fuses:

Fuses can be classified into several types including AC type fuse and DC type fuse based on their application and again these are classified into different types based on voltage level.

You can easily understand from the chart shown below:



AC Types of Fuses:

AC fuses are smaller than DC fuses and have an oscillation of about 50 to 60 times per second, from the lowest to the highest. As a result, there is no possibility of an arc forming between the molten wire. For this reason, they can be creamed in smaller sizes.

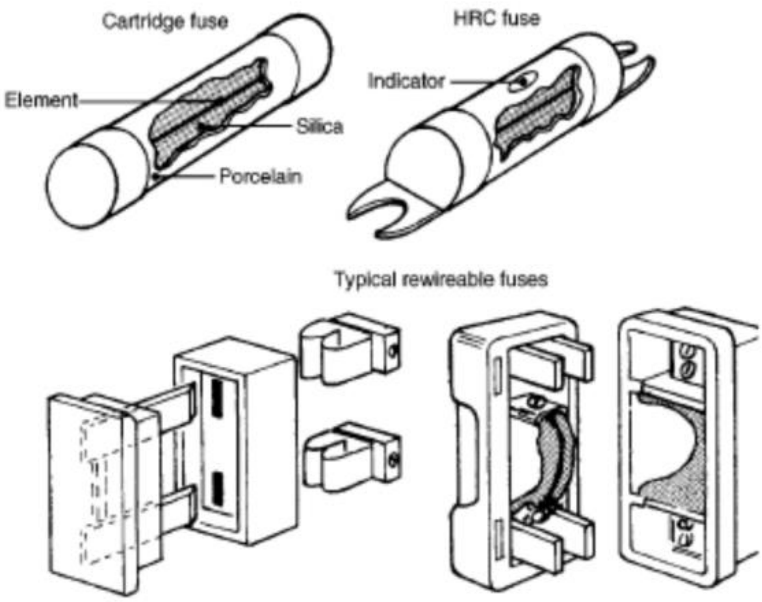
AC fuse can be classified into two parts one is a high voltage fuse and the other is a low voltage fuse, here LV and HV indicate low voltage and high voltage.

Low Voltage Fuses:

Low voltage fuses are divided into five types as follows:

Sr. No.	Low Voltage Fuse Type
1.	Rewirable Types of Fuses
2.	Cartridge Types of Fuses
3.	Dropout Types of Fuses
4.	Striker Types of Fuses
5.	Switch Type Fuse

1. Rewirable Types of Fuses:



Rewirable Types of Fuses

This type of fuse is included in the low category as it is used in homes and small industries. This fuse is made up of two parts consisting of a base with two terminals inside and outside.

The construction of this fuse is usually made of porcelain. The upper part of the fuse is the carrier, which holds the fuse element. This element is made of aluminum, tinned copper, and lead.

The advantage of the fuse carrier is that we can simply plug from the base of the fuse without the risk of any shock. If it is damaged due to overload, only the fuse carrier burns which we can easily change and reactivate.

2. Cartridge Types of Fuses:

This type of fuse also completely closes the container and metal contact. The main applications of this fuse include low voltage, high voltage, and small fuses. This fuse is classified into two parts one is D-type and the other is the link-type fuse.

2.1.D-type Cartridge Fuse:

This type of fuse is made up of a cartridge, a fuse base, an adapter ring, and a cap. The bottom of the fuse has a fuse cap which is filled with the fuse component by a cartridge with the help of an adapter ring.

It is made up of a cartridge, fuse base, cap, and adapter ring. The fuse base has a fuse cap, which is fitted to the fuse element with a cartridge through an adapter ring. The connection of the circuit is terminated when the cartridge makes contact through the tilted conductor.

2.2 Link Type Fuse:

This type of fuse is also known as HRC fuse or BS type fuse. In this type of fuse, the current flow with the fuse element is specified under standard conditions.

Current type by fuse element in BS type fuse The flow is given in normal condition. The arc produced in the fuse burner is controlled by porcelain, ceramic, and silver. The container of the fuse element is filled with silica sand.

Fuses of this type are classified into two parts, one being the blade type and the bolted type.

2.2.1 Blade and Bolted Types of Fuses:

The fuse of the knife-type fuse is made with the help of plastic. This type of fuse can only be interchangeable in an electric circuit without any load. In bolted type fuses, the plates of these fuses are set at the base of the fuse.

3. Dropout Types of Fuses:

In this fuse type, the fuse melting forms an element going down from gravity in terms of its minimum support. This is useful for those who have a transformer in the outside environment

4. Striker Types of Fuses:

This type of fuse is used to close or trip a circuit. This fuse has plenty of power and displacement.

5. Switch Type Fuse:

The switch-type fuse is closed with a metal switch and fuse. This type of fuse is used in small and intermediate voltage levels.

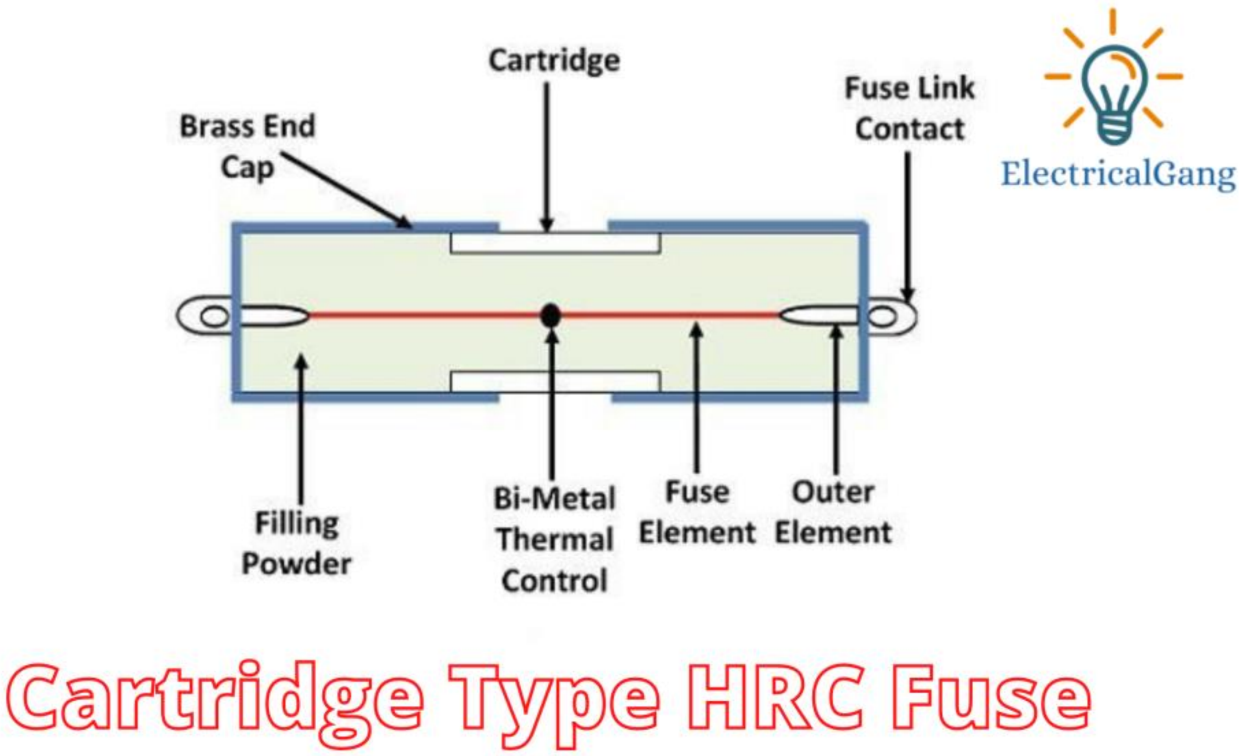
HV (High Voltage) Types of Fuses:

Such fuses are commonly used for transformers such as instrument transformers, small power transformers, and power systems, etc. These fuses are usually taken for voltages above 1500 V to 138000 V.

Such fuses are classified into 3 parts which are as follows:

Sl. No.	HV (High Voltage) Type of Fuse
1.	Cartridge Type HRC Fuse
2.	Liquid Type HRC Fuse
3.	Expulsion HV Types of Fuses

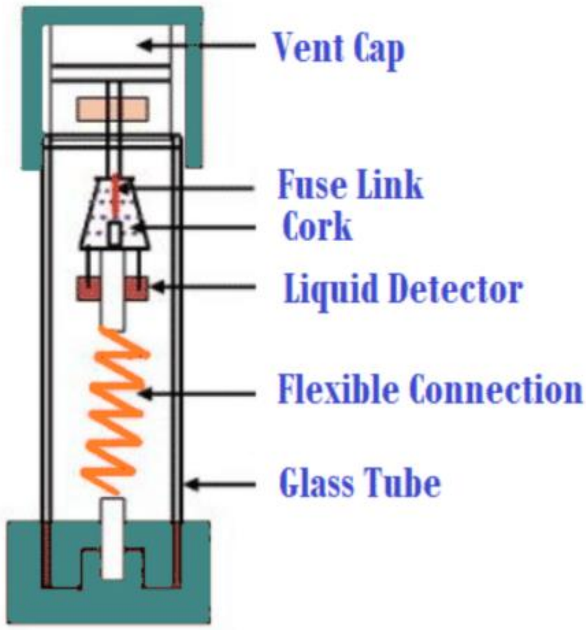
1. Cartridge Type HRC Fuse:



The fuse element of the HRC fuse is cut in the shape of a helix to reduce the effect of the corona on the high voltage. In it, 2 fuse elements are placed in parallel to each other which is low resistance and the other is high resistance.

A low resistance wire conducts a normal current that blows reducing the short-circuit current in the fault state.

2. Liquid Type HRC Fuse:



Liquid Type HRC Fuse

This type of fuse is filled with carbon tetrachloride and sealed evenly from both ends. When a fault occurs the current exceeds the prescribed limit and the fuse element blows. Fuse fluid HRC acts as an arc extinguisher for fuse types This is used to protect the transformer and to support the circuit breaker.

3. Expulsion HV Types of Fuses:

Due to the low cost of such fuses, they are widely used for the protection of feeders and transformers. They are specially designed for 11KV and their filling capacity is up to 250 MVA.

This type of fuse consists of a hollow open-end tube made of synthetic resin-bonded paper. Fuse elements are placed in the tube, and the ends of the tube are connected to each end with proper fittings.

The arc generating blows into the inner casing of the cylinder, and the shaped gases destroy the arc.

Advantages and Disadvantages of Electric Fuse:

Advantages of Electric Fuse:

Some of the Advantages of fuse are as follows:

- Low cost and low maintenance.
- The device is fully automatic requiring less time compared to circuit breakers.
- Since fuses are available in smaller sizes, they induce a currently restricted effect in unusual conditions.

Disadvantages of Electric Fuse:

Some of the disadvantages of fuse are as follows:

- If the burn is emptied at the time of the fault, more time is needed to replace it.
- The time-current feature will not always be synchronized with the security element.

Applications of Different Types of Fuses:

The application of different types of fuse is as follows:

- Electrical cabling in the home.
- Laptops.
- Power transformers.
- Electrical appliances, such as AC (air conditioners), TVs, vending machines, music systems, and many more.

Difference Between Fuse and Circuit Breaker

The Difference Between the Fuse and Circuit Breaker is explained considering various factors like Working Principle, Reusability, Indication of status, Requirement of Auxiliary equipment, Temperature, Characteristic Curve, Function, Protection, Breaking Capacity, Operating time, Cost, and Mode of Operation.

The Difference Between Fuse and Circuit Breaker is given below in the tabulated form

BASIS	FUSE	CIRCUIT BREAKER
Working Principle	Fuse works on the electrical and thermal properties of the conducting materials.	Circuit breaker works on the Electromagnetism and switching principle.
Reusability	Fuses can be used only once.	Circuit breakers can be used a number of times.
Status indication	It does not give any indication.	It gives an indication of the status
Auxiliary contact	No auxiliary contact is required.	They are available with auxiliary contact.
Switching Action	Fuse cannot be used as as an ON/OFF switch.	The Circuit breaker is used as an ON/OFF switches.

BASIS	FUSE	CIRCUIT BREAKER
Temperature	They are independent of ambient temperature	Circuit breaker Depends on ambient temperature
Characteristic Curve	The Characteristic curve shifts because of the ageing effect.	The characteristic curve does not shift.
Protection	The Fuse provides protection against only power overloads	Circuit breaker provides protection against power overloads and short circuits.
Function	It provides both detection and interruption process.	Circuit breaker performs only interruption. Faults are detected by relay system.
Breaking capacity	Breaking capacity of the fuse is low as compared to the circuit breaker.	Breaking capacity is high.
Operating time	Operating time of fuse is very less (0.002 seconds)	Operating time is comparatively more than that of the fuse. (0.02 – 0.05 seconds)
Version	Only single pole version is available.	Single and multiple version are available.
Mode of operation	Completely automatically.	Manually as well as automatically operated.
Cost	Cost of fuse is low.	Cost of circuit breaker is high.

A Fuse is an electrical device made up of glass, porcelain, or plastic material containing a thin piece of wire. If any faults occur in the system and an over-current flow through the circuit, the fuse automatically melts and breaks the contact of the circuit. Thus, protecting the appliances from any damage.

The Circuit Breaker also performs a similar function as that of the fuse but by electromagnetic principle. The circuit breaker also protects the appliances from getting damaged due to overload current.

Difference Between Fuse and Circuit Breaker

1. Fuse works on the principle of electrical and thermal properties of the conducting materials whereas the circuit breaker works on the Electromagnetism and Switching principle.
2. Fuses once used cannot be reused again, but the circuit breaker can be reused. Hence, there is no need to change the circuit breaker after any fault takes place and the coil is tripped.
3. No auxiliary contact is required in the case of fuse but in circuit breaker, auxiliary contact is required.
4. Fuse cannot be used as an ON/OFF switch whereas circuit breaker can be used as an ON/OFF switch.
5. Fuses are independent of ambient temperature, but circuit breaker depends on ambient temperature.
6. The characteristic curve of the Fuse shifts because of the aging effect and, as a result, it causes nuisance and tripping. The curve of the Circuit Breaker does not shift.
7. The Fuse provides protection against only power overloads whereas circuit breaker provides protection for both power overloads and short circuits.
8. The Fuse provides both detection and interruption processes. The circuit breaker performs only interruption; a relay system is attached for detection of any fault in the circuit.
9. The breaking capacity of the fuse is low as compared to that of a Circuit Breaker.
10. The operating time of the fuse is very less about 0.002 seconds, whereas the operating time of a circuit Breaker is comparatively more than that of the fuse. It is about 0.02 – 0.05 seconds.
11. The mode of operation of the fuse is completely automatic, but circuit breakers can be operated manually as well as automatically with the help of a relay system.
12. The cost of the fuse is low, whereas circuit breakers are more costly.

(CHAPTER-4)

CIRCUIT BREAKER

Introduction:

During the operation of power system, it is often desirable and necessary to switch on or off the various circuits (e.g., transmission lines, distributors, generating plants etc.) under both normal and abnormal conditions. In earlier days, this function used to be performed by a switch and a fuse placed in series with the circuit. However, such a means of control presents two disadvantages.

1. Firstly, when a fuse blows out, it takes quite some time to replace it and restore supply to the customers.
2. Secondly, a fuse cannot successfully interrupt heavy fault currents that result from faults on modern high- voltage and large capacity circuits.

- Due to these disadvantages, the use of switches and fuses is limited to low voltage and small capacity circuits where frequent operations are not expected e.g., for switching and protection of distribution transformers, Lighting circuits, branch circuits of distribution lines etc.

- With the advancement of power system, the lines and other equipment operate at very high voltages and carry large currents. The arrangement of switches along with fuses cannot serve the desired function of switchgear in such high capacity circuits. This necessitates employing a more dependable means of control such as is obtained by the use of **circuit breakers.**

- *A circuit breaker can make or break a circuit either manually or automatically under all conditions viz., no-load, full- load and short-circuit conditions*.

- This characteristic of the circuit breaker has made it very useful equipment for switching and protection of various parts of the power system.

- ***A circuit breaker is a piece of equipment which can***

  (i) Make or break a circuit either manually or by remote control under normal conditions.

  (ii) Break a circuit automatically under fault conditions

  (iii) Make a circuit either manually or by remote control under fault conditions

Thus a circuit breaker incorporates manual (or remote control) as well as automatic control for switching functions. The latter control employs relays and operates only under fault conditions.

Operating principle:

A circuit breaker essentially consists of fixed and moving contacts, called Electrodes. Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty. Of course, the contacts can be opened manually or by remote control whenever desired. When a fault occurs on any part of the system, the trip coils of the circuit breaker get energized and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

- When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them. The current is thus able to continue until the discharge ceases.
- The production of arc not only delays the current interruption process but it also generates enormous heat which may cause damage to the system or to the circuit breaker itself.
- Therefore, the main problem in a circuit breaker is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

Arc Phenomenon:

When a short circuit occurs, a heavy current flows through the contacts of the circuit breaker before they are opened by the protective system. At the instant when the contacts begin to separate, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature. The heat produced in the medium between contacts (usually the medium is oil or air) Is sufficient to ionize the air or vaporize and ionize the oil. The ionized air or vapor acts as conductor and an arc is struck between the contacts.

- The potential difference between the contacts is quite small and is just sufficient to maintain the arc.
- The arc provides a low resistance path and consequently the current in the circuit remains UN interrupted so long as the arc persists.
- During the arcing period, the current flowing between the contacts depends upon the arc resistance. The greater the arc resistance, the smaller the current that flows between the contacts.

The arc resistance depends upon the following factors:

1. **Degree of ionization**- the arc resistance increases with the decrease in the number of ionized particles between the contacts.

2. **Length of the arc**— the arc resistance increases with the length of the arc i.e., separation of contacts.

3. **Cross-section of arc**— the arc resistance increases with the decrease in area of X-section of the arc.

Principles of Arc Extinction:

Before discussing the methods of arc extinction, it is necessary to examine the factors responsible for the maintenance of arc between the contacts. These are:

1. Potential difference between the contacts.
2. Ionized particles between contacts taking these in turn.

- When the contacts have a small separation, the Potential difference between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that Potential

  difference becomes inadequate to maintain the arc. However, this method is impracticable in high voltage system where a separation of many meters may be required.

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

  particles from the space between the contacts.

Methods of Arc Extinction (or) Interruption:

There are two methods of extinguishing the arc in circuit breakers viz.

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

- The principal disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in D.C. circuit breakers and low-capacity a.c. circuit breakers.

The resistance of the arc may be increased by:

1. **Lengthening the arc:** The resistance of the arc is directly proportional to its length. The length of the arc can be increased by increasing the gap between contacts.

2.**Cooling the arc:** Cooling helps in the deionization of the medium between the contacts. This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

2. **Reducing X-section of the arc:** If the area of X-section of the arc is reduced, the voltage necessary to maintain the arc is increased. In other words, the resistance of the arc path is increased. The cross-section of the arc can be reduced by letting the arc pass through a narrow opening or by having smaller area of contacts.
3. **Splitting the arc**: The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthening and cooling. The arc may be split by introducing some conducting plates between the contacts.

Low resistance or Current zero method:

In this method is employed for arc extinction in a.c. circuits only. 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. All Modern high power a.c. circuit breakers employ this method for arc extinction.

- In an a.c. system, current drops to zero after every half-cycle. At every current zero, the arc extinguishes for a brief moment.
- Now the medium between the contacts contains ions and electrons so that it has small dielectric strength and can be easily broken down by the rising contact voltage known as restriking voltage.
- If such a breakdown does occur, the arc will persist for another half cycle.
- If immediately after current zero, the dielectric strength of the medium between contacts is built up more rapidly than the voltage across the contacts, the arc fails to restrike and the current will be interrupted.

The rapid increase of dielectric strength of the medium near current zero can be achieved by:

- Causing the ionized particles in the space between contacts to recombine into neutral molecules.
- Sweeping the ionized particles away and replacing them by un ionized particles.

Therefore, the real problem in a.c. arc interruption is to rapidly de ionize the medium between contacts as soon as the current becomes zero so that the rising contact voltage or restriking voltage cannot breakdown the space between contacts.

The de-ionization of the medium can be achieved by:

1.Lengthening of the gap: The dielectric strength of the medium is proportional to the length of the gap between contacts. Therefore, by opening the contacts rapidly, higher dielectric strength of the medium can be achieved.

2.High pressure: If the pressure in the vicinity of the arc is increased, the density of the particles constituting the discharge also increases. The increased density of particles causes higher rate of de-ionization and consequently the dielectric strength of the medium between contacts is increased.

3.Cooling: Natural combination of ionized particles takes place more rapidly if they are allowed to cool. Therefore, dielectric strength of the medium between the contacts can be increased by cooling the arc.

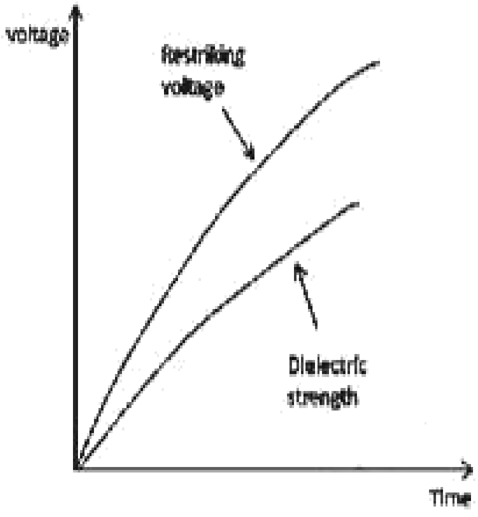
4.Blast effect: If the ionized particles between the contacts are swept away and replaced by UN ionized particles, the dielectric strength of the medium can be increased considerably. This may be achieved by a gas blast directed along the discharge or by forcing oil into the contact space.

There are two theories to explain the Zero current interruption of the Arc:

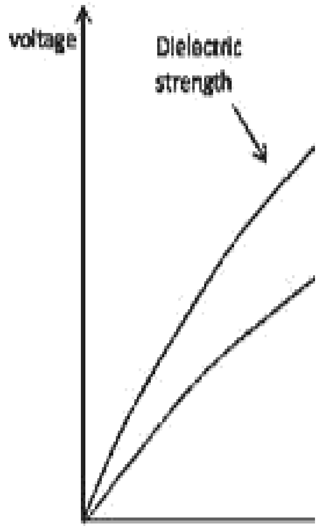
1. Recovery rate theory (Slepain's Theory)
2. Energy balance theory (Cassie's Theory)

Recovery rate theory (Slepain's Theory):

The arc is a column of ionized gases. To extinguish the arc, the electrons and ions are to be removed from the gap immediately after the current reaches a natural zero. Ions and electrons can be removed either by recombining them in to neutral molecules or by sweeping them away by inserting insulating medium (gas or liquid) into the gap. The arc is interrupted if ions are removed from the gap recovers its dielectric strength is compared with the rate at which the restriking voltage (transient voltage) across the gap rises. If the dielectric strength increases more rapidly than the restriking voltage, the arc is extinguished. If the restriking voltage rises more rapidly than the dielectric strength, the ionization persists and breakdown of the gap occurs, resulting in an arc for another half cycle.



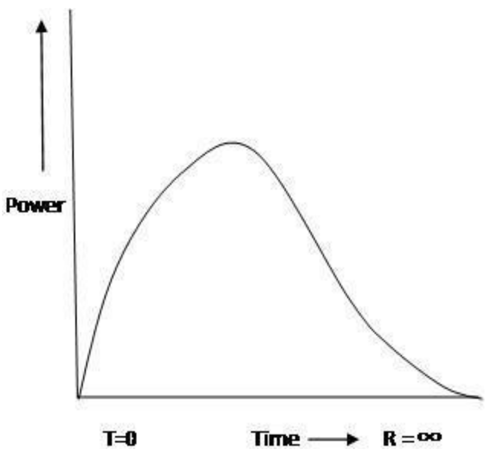
(a) Arc Extinguishes



(b) Arc Persist

Energy balance theory (Cassie's Theory):

The space between the contacts contains some ionized gas immediately after current zero and hence, it has a finite post –zero moment, power is zero because restriking voltage is zero. When the arc is finally extinguished, the power gain becomes zero, the gap is fully de-ionized and its resistance is infinitely high. In between these two limits, first the power increases, reaches a maximum value, then decreases and finitely reaches zero value as shown in figure. Due to the rise of restriking voltage and associated current, energy is generated in the space between the contacts. The energy appears in the form of heat. The circuit breaker is designed to remove this generated heat as early as possible by cooling the gap, giving a blast air or flow of oil at high velocity and pressure. If the rate of removal of heat is faster than the rate of heat generation the arc is extinguished. If the rate of heat generation is more than the rate of heat dissipation, the space breaks down again resulting in an arc for another half cycle.



Important Terms:

The following are the important terms much used in the circuit breaker analysis:

1. **Arc Voltage:**

It is the voltage that appears across the contacts of the circuit breaker during the arcing period. 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. At current zero, the arc voltage rises rapidly to peak value and this peak voltage tends to maintain the current flow in the form of arc.

2. **Restriking 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. This transient voltage is known as restriking voltage (Fig. 19.1).

The current interruption in the circuit depends upon this voltage. If the restriking voltage rises more rapidly than the dielectric strength of the medium between the contacts, the arc will persist for another half-cycle. On the other hand, if the dielectric strength of the medium builds up more rapidly than the restriking voltage, the arc fails to restrike and the current will be interrupted.

3. **Recovery voltage:**

It is the normal frequency (50 Hz) R.M.S. voltage that appears across the contacts of the circuit breaker after final arc extinction. It is approximately equal to the system voltage.

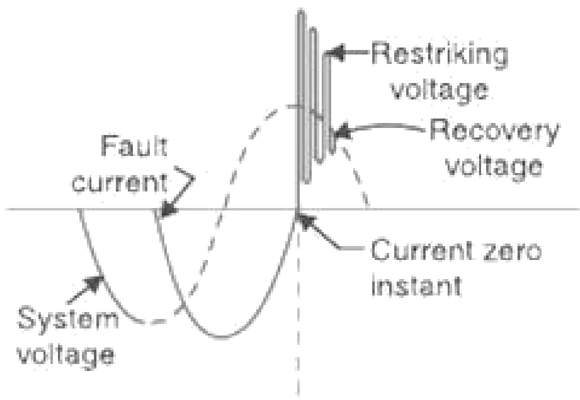
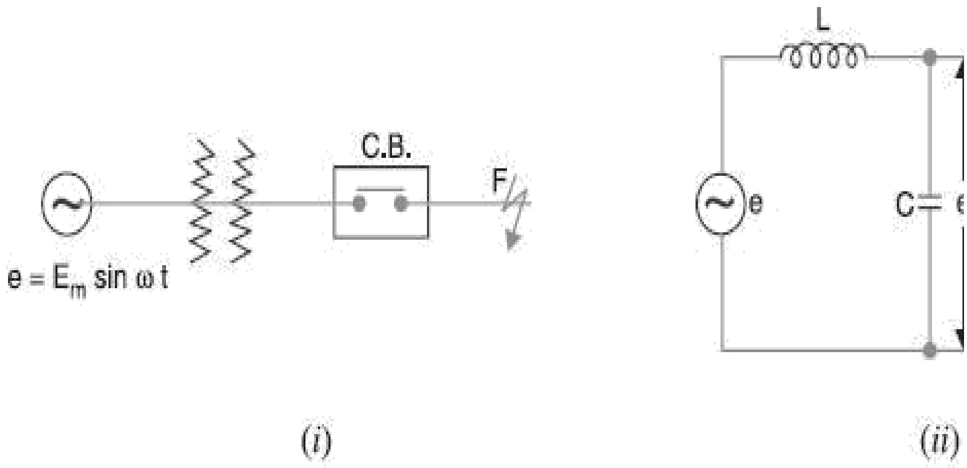


Fig. 19.1

When contacts of circuit breaker are opened, current drops to zero after every half cycle. At some current zero, the contacts are separated sufficiently apart and dielectric strength of the medium between the contacts attains a high value due to the removal of ionized particles. At such an instant, the medium between the contacts is strong enough to prevent the breakdown by the restriking voltage. Consequently, the final arc extinction takes place and circuit current is interrupted. Immediately after final current interruption, the voltage that appears across the contacts has a transient part (See Fig.19.1). However, these transient oscillations subside rapidly due to the damping effect of system resistance and normal circuit voltage appears across the contacts. The voltage across the contacts is of normal frequency and is known as recovery voltage.

Expression for Restriking voltage and RRRV:

The power system contains an appreciable amount of inductance and some capacitance. When a fault occurs, the energy stored in the system can be considerable. Interruption of fault current by a circuit breaker will result in most of the stored energy dissipated within the circuit breaker, the remainder being dissipated during oscillatory surges in the system. The oscillatory surges are undesirable and, therefore, the circuit breaker must be designed to dissipate as much of the stored energy as possible.



(i) (ii)

Fig. 19.17

Fig. 19.17 (i) shows a short-circuit occurring on the transmission line. Fig 19.17 (ii) shows its equivalent circuit where L is the inductance per phase of the system up to the point of fault and C is the capacitance per phase of the system. The resistance of the system is neglected as it is generally small.

Rate of rise of re-striking voltage:

It is the rate of increase of re-striking voltage and is abbreviated by R.R.R.V. usually; the voltage is in kV and time in microseconds so that R.R.R.V. is in kV/μ sec.

Consider the opening of a circuit breaker under fault conditions Shown in simplified form in Fig. 19.17

(ii) above. Before current interruption, the capacitance C is short-circuited by the fault and the short-circuit current through the breaker is limited by Inductance L of the system only. Consequently, the short-circuit current will lag the voltage by 90º as shown in Fig. 19.18, where I Represents the short-circuit current and ea represents the arc voltage. It may be seen that in this condition, the *entire generator voltage appears across inductance L.

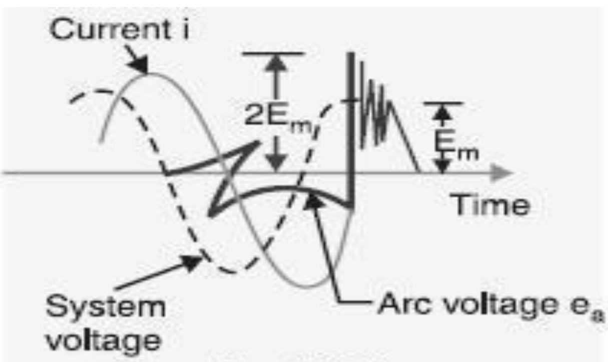


Fig. 19.18

When the contacts are opened and the arc finally extinguishes at some current zero, the generator voltage e is suddenly applied to the inductance and capacitance in series.

The voltage across the capacitance which is the voltage across the contacts of the circuit breaker can be calculated in terms of L, C, f_n and system voltage. The mathematical expression for transient condition is as follows.

As $v_C(t) = 0$ at $t=0$, constant= 0

$v_C(t)=E(1-\cos w_n t)$ or $v_C(t)=E(1-\cos \frac{1}{\sqrt{LC}} t)$ = Restriking voltage

The maximum value of restriking voltage = $2E_{peak}$ = 2 X Peak value of system voltage

The rate of rise of restriking voltage (RRRV) = $\frac{d}{dt} E(1 - \cos w_n t)$

$= w_n E \sin w_n t$

The maximum value of RRRV= $w_n E = w_n E_{peak}$

Which appears across the capacitor C and hence across the contacts of the circuit breaker. This transient voltage, as already noted, is known as re-striking voltage and may reach an instantaneous peak value twice the peak phase-neutral voltage i.e. 2 E_m . The system losses cause the oscillations to decay fairly rapidly but the initial overshoot increases the possibility of re-striking the arc.

It is the rate of rise of re-striking voltage (R.R.R.V.) which decides whether the arc will re-strike or not. If R.R.R.V. is greater than the rate of rise of dielectric strength between the contacts, the arc will re-strike. However, the arc will fail to re-strike if R.R.R.V. is less than the rate of increase of dielectric strength between the contacts of the breaker.

The value of R.R.R.V. depends up on:

1. Recovery voltage
2. Natural frequency of oscillations

For a short-circuit occurring near the power station bus-bars, C being small, the natural frequency **f_n** will be high. Consequently, R.R.R.V. will attain a large value. Thus the worst condition for a circuit breaker would be that when the fault takes place near the bus-bars.

Current chopping:

It is the phenomenon of current interruption before the natural current zero is reached. Current chopping mainly occurs in air-blast circuit breakers because they retain the same extinguishing power irrespective of the magnitude of the current to be interrupted. When breaking low currents (e.g., transformer magnetizing current) with such breakers, 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 known as current chopping and results in the production of high voltage transient across the contacts of the circuit breaker as discussed below:

Consider again Fig. 19.17 (ii) repeated as Fig. 19.19 (i). Suppose the arc current is i when it is chopped down to zero value as shown by point a in Fig. 19.19 (ii). As the chop occurs at current i, therefore, the energy stored in inductance is $L\,i^2/2$.

This energy will be transferred to the capacitance C, charging the latter to a prospective voltage e given by:

$$\frac{Li^2}{2} = \frac{Cv^2}{2} \quad \text{(or)} \quad v = i\sqrt{\frac{L}{C}} \text{ volts}$$

The prospective voltage e is very high as compared to the dielectric strength gained by the gap so that the breaker restrike. As the de-ionizing force is still in action, therefore, chop occurs again but the arc current this time is smaller than the previous case. This induces a lower prospective voltage to re-ignite the arc. In fact, several chops may occur until a low enough current is interrupted which produces insufficient induced voltage to re-strike across the breaker gap. Consequently, the final interruption of current takes place.

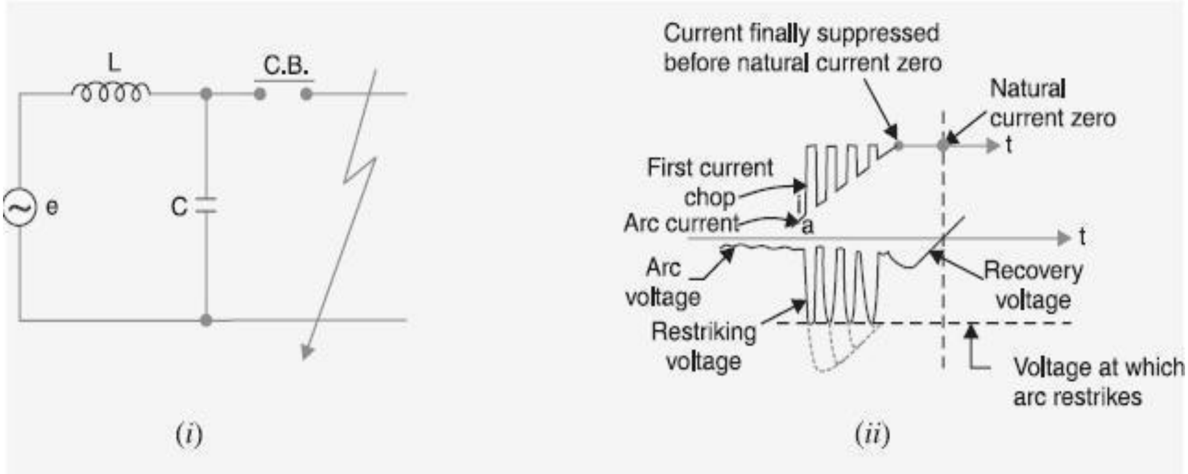


Fig. 19.19

Excessive voltage surges due to current chopping are prevented by shunting the contacts of the breaker with a resistor (resistance switching) such that re ignition is unlikely to occur. This is explained in Art 19.19.

Capacitive current breaking:

Another cause of excessive voltage surges in the circuit breakers is the interruption of capacitive currents. Examples of such instances are opening of an unloaded long transmission line, disconnecting a capacitor bank used for power factor improvement etc. Consider the simple equivalent circuit of an unloaded transmission line shown in Fig.19.20. Such a line, although unloaded in the normal sense, will actually carry a capacitive current I on account of appreciable amount of capacitance C between the line and the earth.

Let us suppose that the line is opened by the circuit breaker at the instant when line capacitive current is zero [point 1 in Fig. 19.21. At this instant, the generator voltage V g will be maximum (i.e. V gm) lagging behind the current by 90º. The opening of the line leaves a standing charge on it (i.e., end B of the line) and the capacitor C1 is charged to V gm. However, the generator end of the line (i.e., end A of the line) continues its normal sinusoidal variations. The voltage V r across the circuit breaker will be the difference between the voltages on the respective sides. Its initial value is zero (point 1) and increases slowly in the beginning. But half a cycle later [point R in Fig. 19.21], the potential of the circuit breaker contact _A ' becomes maximum negative which causes the voltage across the breaker (V r) to become 2 V gm. This voltage may be sufficient to restrike the arc. The two previously separated parts of the circuit will now be joined by an arc of very low resistance. The line capacitance discharges at once to reduce the voltage across the circuit breaker, thus setting up high frequency transient. The peak value of the initial transient will be twice the voltage at that instant i.e., −4 V gm. This will cause the transmission voltage to swing to −4V gm to + V gm i.e., −3V gm.

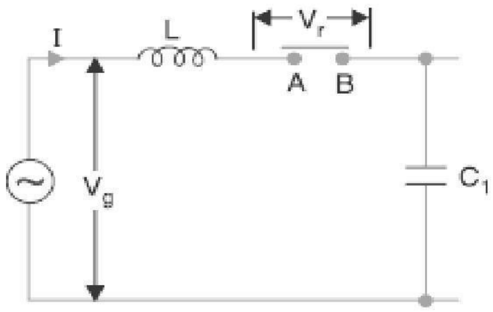


Fig. 19.20

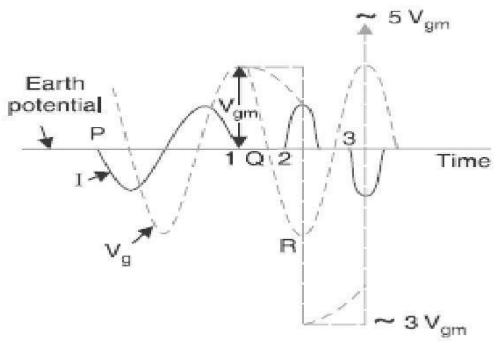


Fig. 19.21

The re-strike arc current quickly reaches its first zero as it varies at natural frequency. The voltage on the line is now −3 Vgm and once again the two halves of the circuit are separated and the line is isolated at this potential. After about half a cycle further, the aforesaid events are repeated even on more formidable scale and the line may be left with a potential of 5V gm above earth potential. Theoretically, this phenomenon may proceed infinitely increasing the voltage by successive increment of 2 times V gm.

While the above description relates to the worst possible conditions, it is obvious that if the gap breakdown strength does not increase rapidly enough, successive re-strikes can build up a dangerous voltage in the open circuit line. However, due to leakage and corona loss, the maximum voltage on the line in such cases is limited to 5 V gm.

Resistance Switching:

It has been discussed above that current chopping, capacitive current breaking etc. give rise to severe voltage oscillations. These excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R connected across the circuit breaker contacts as shown in the equivalent circuit in Fig. 19.22. This is known as resistance switching.

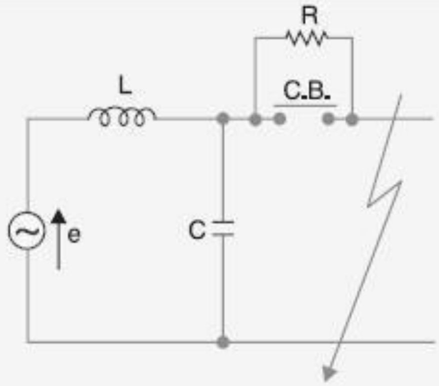


Fig. 19.22

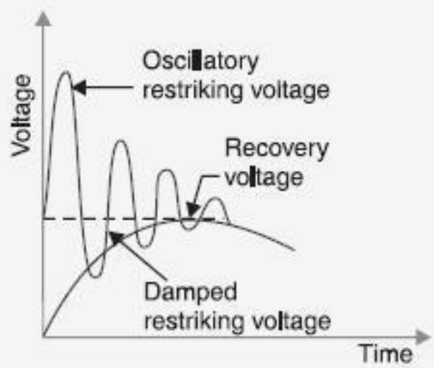


Fig. 19.23

Referring to Fig. 19.22, when a fault occurs, the contacts of the circuit breaker are opened and an arc is struck between the contacts. Since the contacts are shunted by resistance R, a part of arc current flows through this resistance. This results in the decrease of arc current and an increase in the rate of de-ionization of the arc path. Consequently, the arc resistance is increased. The increased arc resistance leads to a further increase in current through shunt resistance. This process continues until the arc current becomes so small that it fails to maintain the arc. Now, the arc is extinguished and circuit current is interrupted.

Switchgear Components:

The following are some important components common to most of the circuit breakers:

1. Bushings
2. Circuit breaker contacts
3. Instrument transformers
4. Bus-bars and conductors

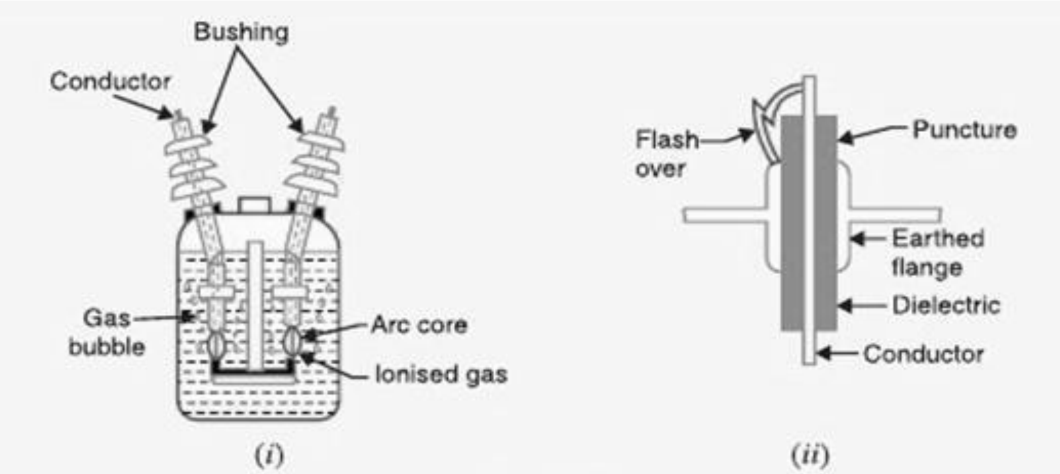


Fig. 19.13

Bushings:

When a high voltage conductor passes through a metal sheet or frame which is at earth potential, the necessary insulation is provided in the form of bushing. The primary function of the bushing is to prevent electrical breakdown between the enclosed conductor and the surrounding earthed metal work. Fig. 19.13 (i) shows the use of bushing for a plain-break oil circuit breaker. The high voltage conductor passes through the bushing made of some insulating material (e.g., porcelain, steatite). Although there are several types of bushing (e.g., condenser type, oil filled etc.), they perform the same function of insulating the conductor from earthed tank. The failure of the bushing can occur in two ways. Firstly, the breakdown may be caused by puncture i.e., dielectric failure of the insulating material of the bushing. Secondly, the breakdown may occur in the form of a flash-over between the exposed conductor at either end of the bushing and the earthed metal. Fig. 19.13 (ii) illustrates these two possibilities. The bushings are so designed that flash-over takes place before they get punctured. It is because the puncture generally renders the bushing insulation unserviceable and incapable of withstanding the normal voltage. On the other hand, a flash-over may result in comparatively harmless burning of the surface of the bushing which can then continue to give adequate service pending replacement.

Circuit breaker contacts:

The circuit breaker contacts are required to carry normal as well as short-circuit current. In carrying the normal current, it is desirable that the temperature should not rise above the specified limits and that there should be low voltage drop at the point of contact. In carrying breaking and making short-circuit currents, the chief effects to be dealt with are melting and Vaporization by the heat of the arc and those due to electromagnetic forces. Therefore, the design of contacts is of considerable importance for satisfactory operation of the circuit breakers. There are three types of circuit breaker contacts viz.

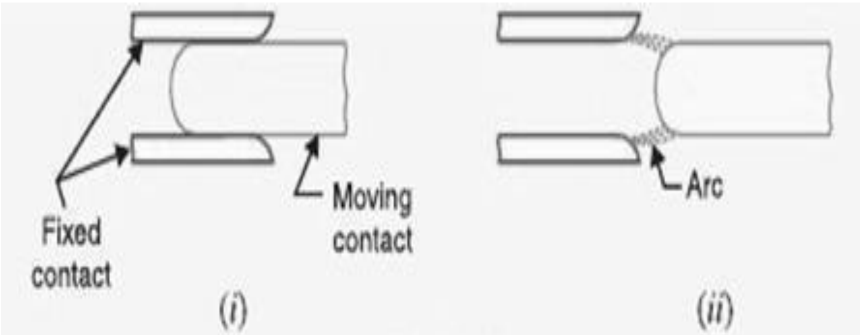


Fig. 19.14

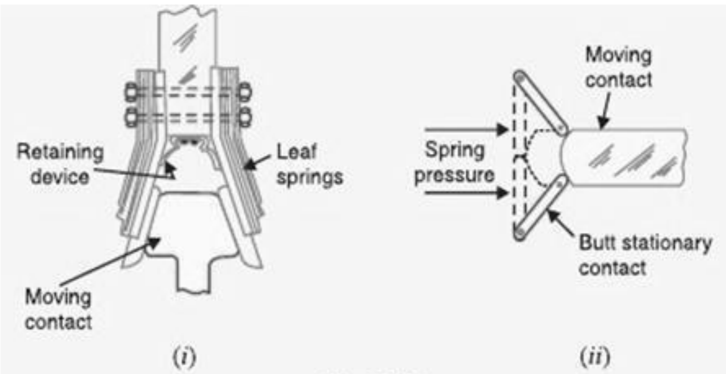


Fig. 19.15

(a) **Tulip type contacts:** Fig. 19.14 (i) shows the Tulip type contact. It consists of moving contact which moves inside the fixed contacts. At contact separation, the arc is generally established between the tips of the fixed contacts and the tip of the moving contact as shown in Fig. 19.14 (ii). The advantage of this type of contact is that arcing is confined to the regions which are not in contact in the fully engaged position

Finger and wedge contacts: Fig. 19.15 (i) shows the finger and wedge type contact. This type of contact is largely used for low-voltage oil circuit breakers owing to the general unsuitability for use with arc control devices.

(b) **Butt contacts**: Fig. 19.15 (ii) shows the butt type contact and is formed by the springs and the moving contact. It possesses two advantages. Firstly, spring pressure is available to assist contact separation. This is useful in single-break oil circuit breakers and air-blast circuit breakers where relatively small ―loop‖ forces are available to assist in opening. Secondly, there is no grip force so that this type of contact is especially suitable for higher short circuit rating.

Instrument transformers:

In a modern power system, the circuits operate at very high voltages and carry current of thousands of amperes. The measuring instruments and protective devices cannot work satisfactorily if mounted directly on the power lines. This difficulty is overcome by installing instrument transformers on the power lines. The function of these instrument transformers is to transform voltages or currents in the power lines to values which are convenient for the operation of measuring instruments and relays.

There are two types of instrument transformers viz.

1. Current transformer (C.T.)
2. Potential transformer (P.T.)

The primary of current transformer is connected in the power line. The secondary winding provides for

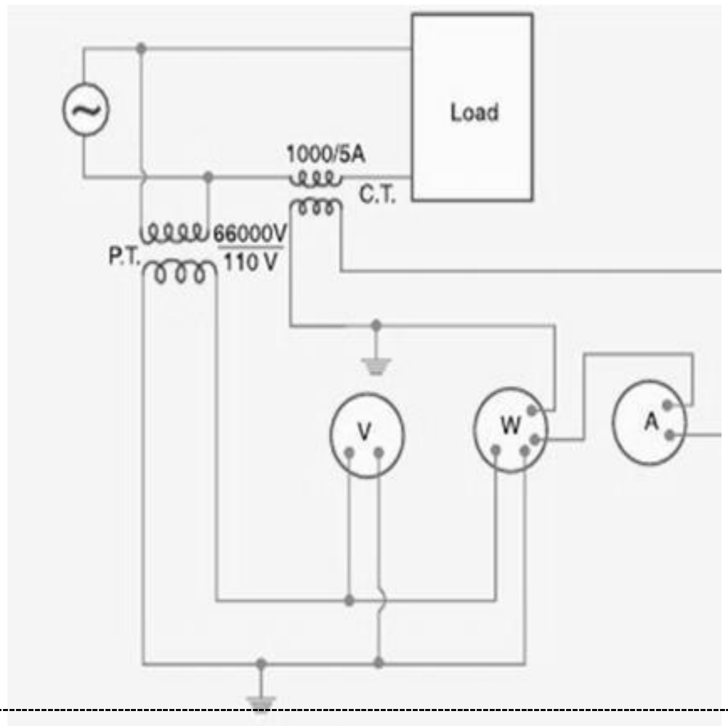


Fig. 19.16

the instruments and relays a current which is a constant fraction of the current in the line similarly, a potential transformer is connected with its primary in the power line. The secondary provides for the instruments and relays a voltage which is a known fraction of the line voltage. Fig. 19.16 shows the use of instrument transformers. The

*potential transformer rated 66,000/110V provides a voltage supply for the potential coils of voltmeter and wattmeter. The current transformer rated 1000/5 A supplies current to the current coils of wattmeter and ammeter.

The use of instrument transformers permits the following advantages:

(a) They isolate the measuring instruments and relays from high-voltage power circuits.

(b) The leads in the secondary circuits carry relatively small voltages and currents. This permits to use wires of smaller size with minimum insulation.

Bus-bars and conductors: The current carrying members in a circuit breaker consist of fixed and moving contacts and the conductors connecting these to the points external to the breaker. If the switchgear is of outdoor type, these connections are connected directly to the overhead lines. In case of indoor switchgear, the incoming conductors to the circuit breaker are connected to the bus bars.

Circuit Breaker Ratings:

A circuit breaker may be called upon to operate under all conditions. However, major duties are imposed on the circuit breaker when there is a fault on the system in which it is connected. Under fault conditions, a circuit breaker is required to perform the following three duties:

(i) It must be capable of opening the faulty circuit and breaking the fault current.

(ii) It must be capable of being closed on to a fault.

(iii) It must be capable of carrying fault current for a short time while another circuit breaker (in series) is clearing the fault.

Corresponding to the above mentioned duties, the circuit breakers have three ratings viz.

1. Breaking capacity
2. Making capacity and
3. Short-time capacity.

Breaking capacity: It is current (r.m.s.) that a circuit breaker is capable of breaking at given recovery voltage and under specified conditions (e.g., power factor, rate of rise of restriking voltage).

The breaking capacity is always stated at the r.m.s. value of fault Current at the instant of contact separation. When a fault occurs, there is considerable asymmetry in the fault current due to the Presence of a d.c. component. The d.c. component dies away rapidly, a typical decrement factor being 0·8 per cycle. Referring to

Fig. 19.24, the contacts are separated at DD´ At this instant, the fault current has

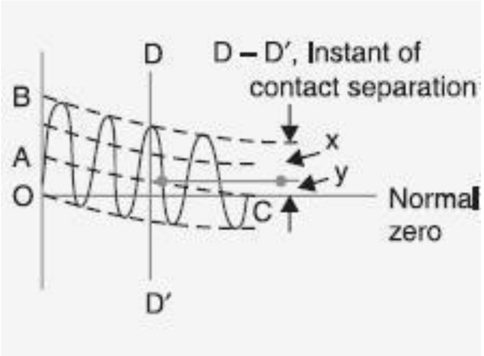


Fig. 19.24

x = maximum value of a.c.

component y = d.c. component

Symmetrical breaking current = r.m.s. value of a.c. component

$= \frac{x}{\sqrt{2}}$

Asymmetrical breaking current = r.m.s. value of total current

$= \sqrt{\left(\frac{x}{\sqrt{2}}\right)^2 + y^2}$

It is a common practice to express the breaking capacity in MVA by taking into account the rated breaking current and rated service voltage. Thus, if I is the rated breaking current in amperes and V is the rated service line voltage in volts, then for a 3-phase circuit,

$$\text{Breaking capacity} = \sqrt{3} \times V \times I \times 10^{-6} \text{ MVA}$$

In India (or Britain), it is a usual practice to take breaking current equal to the symmetrical breaking current. However, American practice is to take breaking current equal to asymmetrical breaking current. Thus the American rating given to a circuit breaker is higher than the Indian or British rating.

It seems to be illogical to give breaking capacity in MVA since it is obtained from the product of Short- circuit current and rated service voltage. When the short-circuit current is flowing, there is only a small voltage across the breaker contacts, while the service voltage appears across the contacts only after the current has been interrupted. Thus MVA rating is the product of two quantities which do not exist simultaneously in the circuit.

Therefore, the *agreed international standard of specifying breaking capacity is defined as the rated symmetrical breaking current at a rated voltage.

Making capacity:

There is always a possibility of closing or making the circuit under short circuit conditions. The capacity of a breaker to ―make‖ current depends upon its ability to withstand and close successfully against the effects of electromagnetic forces. These forces are proportional to the square of maximum instantaneous current on closing. Therefore, making capacity is stated in terms of a peak value of current instead of r.m.s. value.

The peak value of current (including d.c. component) during the first cycle of current wave after the closure of circuit breaker is known as making capacity.

It may be noted that the definition is concerned with the first cycle of current wave on closing the circuit breaker. This is because the maximum value of fault current possibly occurs in the first cycle only when maximum asymmetry occurs in any phase of the breaker. In other words, the making current is equal to the maximum value of asymmetrical current. To find this value, we must multiply symmetrical breaking current by

$\sqrt{2}$ to convert this from r.m.s. to peak, and then by 1·8 to include the ―doubling effect‖ of maximum asymmetry. The total multiplication factor becomes $\sqrt{2} \times 1{\cdot}8 = 2{\cdot}55$.

Making capacity =2·55 X Symmetrical breaking capacity

Short-time rating:

It is the period for which the circuit breaker is able to carry fault current while remaining closed. Sometimes a fault on the system is of very temporary nature and persists for 1 or 2 seconds after which the fault is automatically cleared. In the interest of continuity of supply, the breaker should not trip in such situations. This means that circuit breakers should be able to carry high current safely for some specified period while remaining closed i.e., they should have proven short-time rating. How ever, if the fault persists for duration longer than the specified time limit, the circuit breaker will trip, disconnecting the faulty section.

The short-time rating of a circuit breaker depends upon its ability to withstand The electromagnetic force effects and The temperature rise.

Normal current rating:

It is the r.m.s. value of current which the circuit breaker is capable of carrying continuously at its rated frequency under specified conditions. The only limitation in this case is the temperature rise of current-carrying parts.

Circuit Breaker

Classification of Circuit Breakers:

There are several ways of classifying the circuit breakers. However, the most general way of classification is on the basis of medium used for arc extinction. The medium used for arc extinction is usually oil, air, sulphur hexafluoride (SF6) or vacuum. Accordingly, circuit breakers may be classified into:

1. **Oil circuit breakers:** which employ some insulating oil (e.g., transformer oil) for arc extinction?
2. **Air-blast circuit breakers:** in which high pressure air-blast is used for extinguishing the arc.
3. **Sulphur hexafluoride circuit breakers:** in which sulphur hexafluoride (SF6) gas is used for arc extinction.
4. **Vacuum circuit breakers:** in which vacuum is used for arc extinction.

Each type of circuit breaker has its own advantages and disadvantages. In the following sections, we shall discuss the construction and working of these circuit breakers with special emphasis on the way the arc extinction is facilitated.

Oil Circuit Breakers:

In such circuit breakers, some insulating oil (e.g., transformer oil) is used as an arc quenching medium. The contacts are opened under oil and an arc is struck between them. The heat of the arc evaporates the surrounding oil and dissociates it into a substantial volume of gaseous hydrogen at high pressure. The hydrogen gas occupies a volume about one thousand times that of the oil decomposed. The oil is, therefore, pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region and adjacent portions of the contacts (See Fig. 19.2). The arc extinction is facilitated mainly by two processes. Firstly, the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionization of the medium between the contacts. Secondly, the gas sets up turbulence in the oil and forces it into the space between contacts, thus eliminating the arcing products from the arc path. The result is that arc is extinguished and circuit current †interrupted.

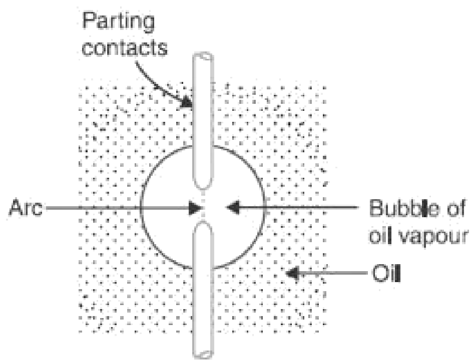


Fig. 19.2

The advantages of oil as an arc quenching medium are:

1. It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.
2. It acts as an insulator and permits smaller clearance between live conductors and earthed components.
3. The surrounding oil presents cooling surface in close proximity to the arc.

The disadvantages of oil as an arc quenching medium are:

1. It is inflammable and there is a risk of a fire.
2. It may form an explosive mixture with air
3. The arcing products (e.g., carbon) remain in the oil and its quality deteriorates with successive operations. This necessitates periodic checking and replacement of oil.

Types of Oil Circuit Breakers:

The oil circuit breakers find extensive use in the power system. These can be classified into the following

types:

1. Bulk oil circuit breakers
2. Low oil circuit breakers

Bulk oil circuit breakers:

Which use a large quantity of oil. The oil has to serve two purposes. Firstly, it extinguishes the arc during opening of contacts and secondly, it insulates the current conducting parts from one another and from the earthed tank. Such circuit breakers may be classified into:

1. Plain break oil circuit breakers

2. Arc control oil circuit breakers.

In the former type, no special means is available for controlling the arc and the contacts are directly exposed to the whole of the oil in the tank. However, in the latter type, special arc control devices are employed to get the beneficial action of the arc as efficiently as possible.

Plain Break Oil Circuit Breakers:

A plain-break oil circuit breaker 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. It has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather-tight earthed tank containing oil up to a certain level and an air cushion above the oil level. The air cushion provides sufficient room to allow for the reception of the arc gases without the generation of unsafe pressure in the dome of the circuit breaker. It also absorbs the

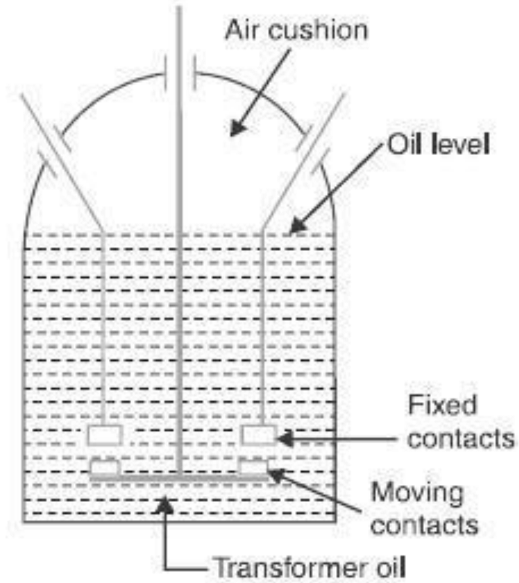


Fig. 19.3

mechanical shock of the upward oil movement. Fig. 19.3 shows a double break plain oil circuit breaker. It is called a double break because it provides two breaks in series.

Under normal operating conditions, the fixed and moving contacts remain closed and the breaker carries the normal circuit Current. When a fault occurs, the moving contacts are pulled down by the protective system and an arc is struck which vaporizes the oil mainly into hydrogen gas.

The arc extinction is facilitated by the following processes:

The hydrogen gas bubble generated around the arc cools the arc column and aids the deionization of the medium between the contacts.

The gas sets up turbulence in the oil and helps in eliminating the arcing products from the arc path.

Disadvantages:

- There is no special control over the arc other than the increase in length by separating the moving contacts. Therefore, for successful Interruption, Long arc length is necessary.
- These breakers have long and inconsistent arcing times.
- These breakers do not permit high speed interruption.

Due to these disadvantages, plain-break oil circuit breakers are used only for low voltage applications where high breaking-capacities are not important. It is a usual practice to use such breakers for low capacity installations for Voltages not exceeding 11 kV.

Arc Control Oil Circuit Breakers:

In case of plain-break oil circuit breaker discussed above, 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, namely:

1. **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.

2. **Forced-blast oil circuit breakers**— in which arc control is provided by mechanical means external to the circuit breaker.

Self-blast oil circuit breakers:

In this type of circuit breaker, the gases produced during arcing are confined to a small volume by the use of an insulating rigid pressure chamber or pot surrounding the contacts. Since the space available for the arc gases is restricted by the chamber, a very high pressure is developed to force the oil and gas through or around the arc to extinguish it. The magnitude of pressure developed depends upon the value of fault current to be interrupted. As the pressure is generated by the arc itself, therefore, such breakers are some times called self-generated pressure oil circuit breakers.

The pressure chamber is relatively cheap to make and gives reduced final arc extinction gap length and arcing time as against the plain-break oil circuit breaker. Several designs of pressure chambers (sometimes called explosion pots) have been developed and a few of them are described below:

Plain explosion pot:

It is a rigid cylinder of insulating material and encloses the fixed and moving contacts (See Fig. 19.4). The moving contact is a cylindrical rod passing through a restricted opening (called throat) at the bottom. When a fault occurs, the contacts get separated and an arc is struck between them. The heat of the arc decomposes oil into a gas at very high pressure in the pot. This high pressure forces the oil and gas through and round the arc to extinguish it. If the final arc extinction does not take place while the moving contact is still within the pot, it occurs immediately after the moving contact leaves the pot. It is because emergence of the moving contact from the pot is followed by a violent rush of gas and oil through the throat producing rapid extinction.

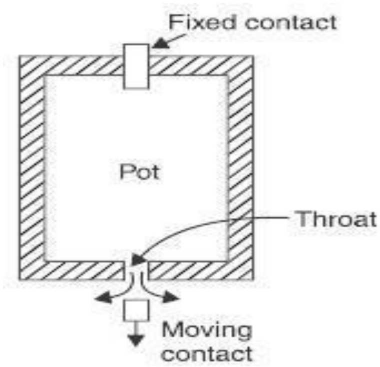


Fig. 19.4

The principal limitation of this type of pot is that it cannot be used for very low or for very high fault currents. With low fault currents, the pressure developed is small, thereby increasing the arcing time. On the other hand, with high fault currents, the gas is produced so rapidly that explosion pot is liable to burst due to high pressure. For this reason, plain explosion pot operates well on moderate short-circuit currents only where the rate of gas evolution is moderate

Cross jet explosion pot:

This type of pot is just a modification of plain explosion pot and is illustrated in Fig. 19.5. It is made of insulating material and has channels on one side which act as arc splitters. The arc splitters help in increasing the arc length, thus facilitating arc extinction. When a fault occurs, the moving contact of the circuit breaker begins to separate. As the moving contact is withdrawn, the arc is initially struck in the top of the pot. The gas generated by the arc exerts pressure on the oil in the back passage. When the moving contact uncovers the arc splitter ducts, fresh oil is forced *across the arc path. The arc is, therefore, driven sideways into the —arc splitters‖ which increase the arc length, causing arc extinction.

The cross-jet explosion pot is quite efficient for interrupting heavy fault currents. However, for low fault currents, the gas pressure is †small and consequently the pot does not give a satisfactory operation.

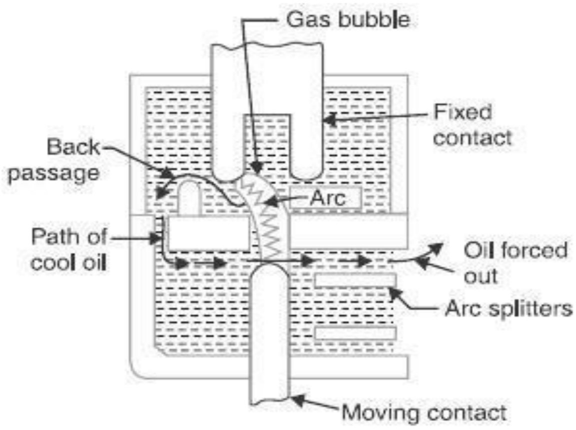


Fig. 19.5

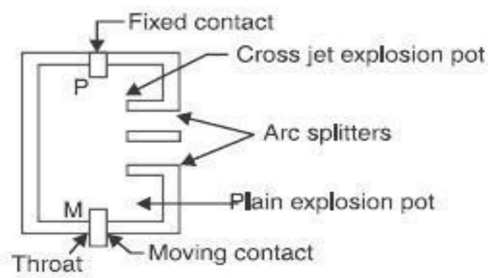


Fig. 19.6

Self-compensated explosion pot:

This type of pot is essentially a combination of plain explosion pot and cross jet explosion pot. Therefore, it can interrupt low as well as heavy short circuit currents with reasonable accuracy. Fig. 19.6 shows the schematic diagram of self-compensated explosion pot. It consists of two chambers; the upper chamber is the cross-jet explosion pot with two arc splitter ducts while the lower one is the plain explosion pot. When the short- circuit current is heavy, the rate of generation of gas is very high and the device behaves as a cross-jet explosion pot. The arc extinction takes place when the moving contact uncovers the first or second arc splitter duct. However, on low short-circuit currents, the rate of gas generation is small and the tip of the moving contact has the time to reach the lower chamber. During this time, the gas builds up sufficient pressure as there is very little leakage through arc splitter ducts due to the obstruction offered by the arc path and right angle bends. When the moving contact comes out of the throat, the arc is extinguished by plain pot action.

It may be noted that as the severity of the short circuit current increases, the device operates less and less as a plain explosion pot and more and more as a cross-jet explosion pot. Thus the tendency is to make the control self- compensating over the full range of fault currents to be interrupted.

Forced-blast oil circuit breakers:

In the self-blast oil circuit breakers discussed above, the arc itself generates the necessary pressure to force the oil across the arc path. The major limitation of such breakers is that arcing times tend to be long and inconsistent when operating against currents considerably less than the rated currents. It is because the gas generated is much reduced at low values of fault currents. This difficulty is overcome in forced-blast oil circuit breakers in which the necessary pressure is generated by external mechanical means independent of the fault currents to be broken.

In a forced -blast oil circuit breaker, oil pressure is created by the piston-cylinder arrangement. The movement of the piston is mechanically coupled to the moving contact. When a fault occurs, the contacts get separated by the protective system and an arc is struck between the contacts. The piston forces a jet of oil towards the contact gap to extinguish the arc. It may be noted that necessary oil pressure produced does not in any way depend upon the fault current to be broken.

Advantages:

1. Since oil pressure developed is independent of the fault current to be interrupted, the performance at low currents is more consistent than with self-blast oil circuit breakers.

2. The quantity of oil required is reduced considerably.

Low Oil Circuit Breakers:

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 increase the fire risk and maintenance problems.

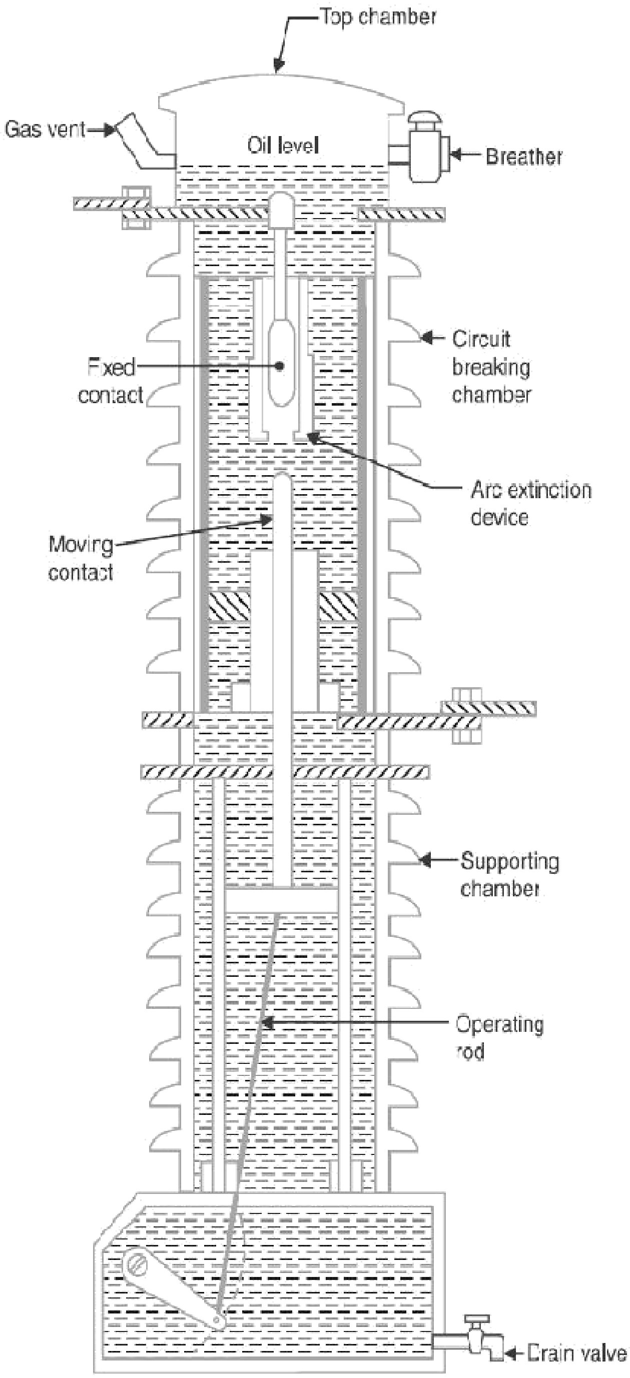


Fig. 19.7 Low-oil Circuit Breaker

The fact that only a small percentage of oil (about 10% of total) in the bulk oil circuit breaker is actually used for arc extinction leads to the question as to why the remainder of the oil, that is not immediately surrounding the device, should not be omitted with consequent saving in bulk, weight and fire risk. This led to the development of low-oil circuit breaker. A low oil circuit breaker employs solid materials for insulation purposes and uses a small quantity of oil which is just sufficient for arc extinction. As regards quenching the arc, the oil behaves identically in bulk as well as low oil circuit breaker. By using suitable arc control devices, the arc extinction can be further facilitated in a low oil circuit breaker.

Construction:

Fig 19.7 shows the cross section of a single phase low oil circuit breaker. There are two compartments separated from each other but both filled with oil. The upper chamber is the circuit breaking chamber while the lower one is the supporting chamber. The two chambers are separated by a partition and oil from one chamber is prevented from mixing with the other chamber. This arrangement permits two advantages. Firstly, the circuit breaking chamber requires a small volume of oil which is just enough for arc extinction. Secondly, the amount of oil to be replaced is reduced as the oil in the supporting chamber does not get contaminated by the arc.

Supporting chamber:

It is a porcelain chamber mounted on a metal chamber. It is filled with oil which is physically separated from the oil in the circuit breaking compartment. The oil inside the supporting chamber and the annular space formed between the porcelain insulation and bakelised paper is employed for insulation purposes only.

Circuit-breaking chamber:

It is a porcelain enclosure mounted on the top of the supporting compartment. It is filled with oil and has the following parts:

1. upper and lower fixed contacts
2. Moving contact
3. Turbulator

The moving contact is hollow and includes a cylinder which moves down over a fixed piston. The turbulator is an arc control device and has both axial and radial vents. The axial venting ensures the interruption of low currents whereas radial venting helps in the interruption of heavy currents.

Top chamber:

It is a metal chamber and is mounted on the circuit-breaking chamber. It provides expansion space for the oil in the circuit breaking compartment. The top chamber is also provided with a separator which prevents any loss of oil by centrifugal action caused by circuit breaker operation during fault conditions.

Operation:

Under normal operating conditions, the moving contact remains engaged with the upper fixed contact. When a fault occurs, the moving contact is pulled down by the tripping springs and an arc is struck. The arc energy vaporizes the oil and produces gases under high pressure. This action constrains the oil to pass through a central hole in the moving contact and results in forcing series of oil through the respective passages of the tabulator. The process of tabulation is orderly one, in which the

the effect of separate streams of oil moving across each section in turn and bearing away its gases.

A low oil circuit breaker has the following advantages over a bulk oil circuit breaker:

1. It requires lesser quantity of oil.
2. It requires smaller space.
3. There is reduced risk of fire.
4. Maintenance problems are reduced.

A low oil circuit breaker has the following disadvantages as compared to a bulk oil circuit breaker:

1. Due to smaller quantity of oil, the degree of carbonization is increased.
2. There is a difficulty of removing the gases from the contact space in time.
3. The dielectric strength of the oil deteriorates rapidly due to high degree of carbonization.

Maintenance of Oil Circuit Breakers:

The maintenance of oil circuit breaker is generally concerned with the checking of contacts and dielectric strength of oil. After a circuit breaker has interrupted fault currents a few times or load currents several times, its contacts may get burnt by arcing and the oil may lose some of its dielectric strength due to carbonization. This results in the reduced rupturing capacity of the breaker. There fore, it is a good practice to inspect the circuit breaker at regular intervals of 3 or 6 months.

During inspection of the breaker, the following points should be kept in view:

- Check the current carrying parts and arcing contacts. If the burning is severe, the contacts should be replaced.
- Check the dielectric strength of the oil. If the oil is badly discolored, it should be changed or reconditioned. The oil in good condition should withstand 30 kV for one minute in a standard oil testing cup with 4 mm gap between electrodes.
- Check the insulation for possible damage. Clean the surface and remove carbon deposits with a strong and dry fabric.
- Check the oil level.
- Check closing and tripping mechanism.

Air-Blast Circuit Breakers:

These breakers employ a high pressure *air-blast as an arc quenching medium. The contacts are opened in a

flow of air-blast established by the opening of blast valve. The air-blast cools the arc and sweeps away the arcing products to the atmosphere. This rapidly increases the dielectric strength of the medium between contacts and prevents from re-establishing the arc. Consequently, the arc is extinguished and flow of current is interrupted.

An air-blast circuit breaker has the following advantages over an oil circuit breaker:

1. The risk of fire is eliminated.
2. The arcing products are completely removed by the blast whereas the oil deteriorates with successive operations; the expense of regular oil replacement is avoided.
3. The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small. This reduces the size of the device.
4. The arcing time is very small due to the rapid build up of dielectric strength between contacts. Therefore, the arc energy is only a fraction of that in oil circuit breakers, thus resulting in less burning of contacts.
5. Due to lesser arc energy, air-blast circuit breakers are very suitable for conditions where frequent operation is required.
6. The energy supplied for arc extinction is obtained from high pressure air and is independent of the current to be interrupted.

The use of air as the arc quenching medium offers the following disadvantages:

1. The air has relatively inferior arc extinguishing properties.
2. The air-blast circuit breakers are very sensitive to the variations in the rate of rise of re striking voltage.
3. Considerable maintenance is required for the compressor plant which supplies the air-blast.
4. The air blast circuit breakers are finding wide applications in high voltage installations.
5. Majority of the circuit breakers for voltages beyond 110 kV are of this type.

Types of Air-Blast Circuit Breakers:

Depending upon the direction of air-blast in relation to the arc, air-blast circuit breakers are classified into:

1. **Axial-blast type** in which the air-blast is directed along the arc path as shown in Fig. 19.8(i).
2. **Cross-blast type** in which the air-blast is directed at right angles to the arc path as shown in Fig. 19.8 (ii).
3. **Radial-blast type** in which the air-blast is directed radially as shown in Fig. 19.8 (iii).

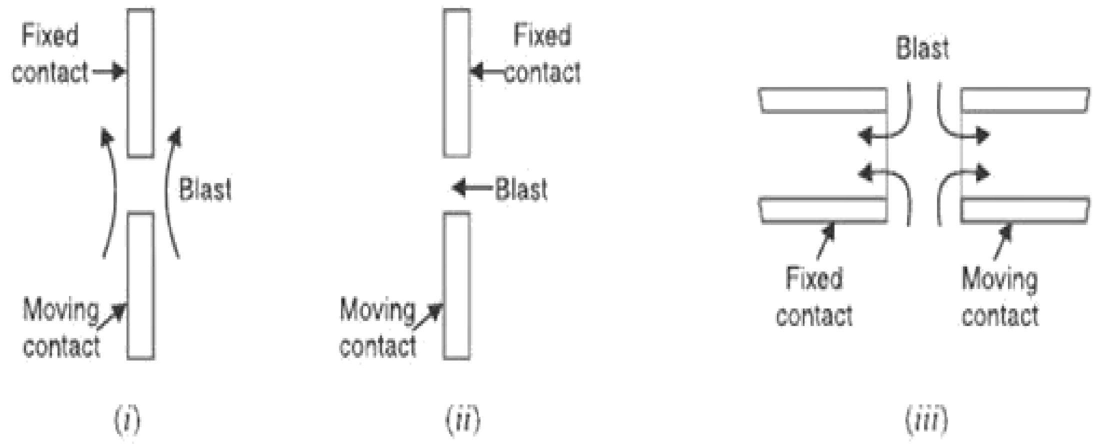


Fig. 19.8

Axial-blast air circuit breaker:

Fig 19.9 shows the essential components of a typical axial blast air circuit breaker. The fixed and moving contacts are held in the closed position by spring pressure under normal conditions. The air reservoir is connected to the arcing chamber through an air valve. This valve remains closed under normal conditions but opens automatically by the tripping impulse when a fault occurs on the system.

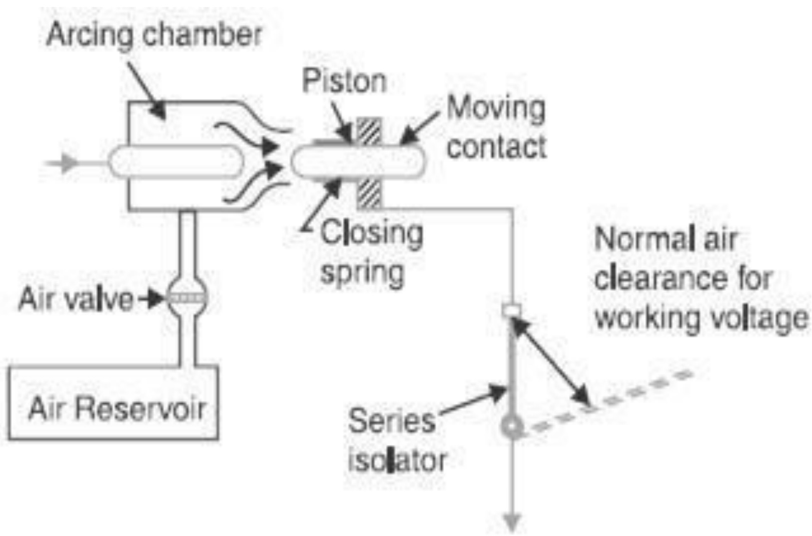


Fig. 19.9

When a fault occurs, the tripping impulse causes opening of the air valve which connects the circuit breaker reservoir to the arcing chamber. The high pressure air entering the arcing chamber pushes away the moving contact against spring pressure. The moving contact is separated and an arc is struck. At the same time, high pressure air blast flows along the arc and takes away the ionized gases along with it. Consequently, the arc is extinguished and current flow is interrupted.

It may be noted that in such circuit breakers, the contact separation required for interruption is generally small (1·75 cm or so). Such a small gap may constitute inadequate clearance for the normal service voltage. Therefore, an isolating switch is incorporated as a part of this type of circuit breaker. This switch opens immediately after fault interruption to provide the necessary clearance for insulation.

Cross-blast air breaker:

In this type of circuit breaker, an air-blast is directed at right angles to the arc. The cross-blast lengthens and forces the arc into a suitable chute for arc extinction. Fig. 19.10 shows the essential parts of a typical cross- blast Air circuit breaker. When the moving contact is withdrawn, an arc is struck between the fixed and moving contacts. The high pressure cross-blast Forces the arc into a chute consisting of arc splitters and baffles. The splitters serve to increase the length of the arc and baffles give improved cooling. The result is that arc is extinguished and flow of Current is interrupted. Since blast pressure is same for all currents, the inefficiency at low currents is eliminated. The final gap for interruption is great enough to give normal insulation clearance so that a series isolating switch is not necessary.

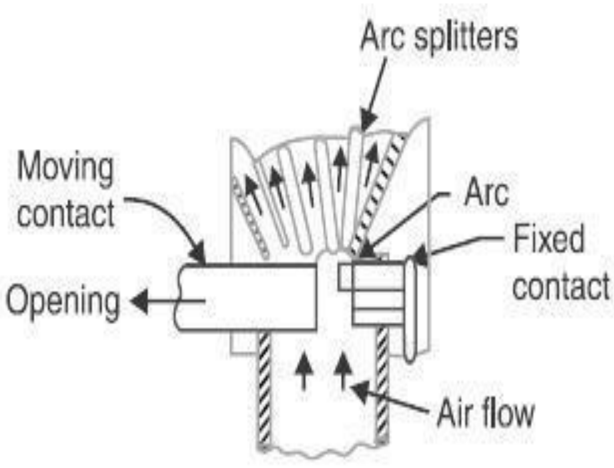


Fig. 19.10

SULPHUR HEXAFLUORIDE(SF6)

In such circuit breakers, sulphur hexafluoride (SF6) gas is used as the arc quenching medium. The SF6 is an electro-negative gas and has a strong tendency to absorb free electrons. The contacts of the breaker are opened in a high pressure flow of SF6 gas and an arc is struck between them. The conducting free electrons in the arc are rapidly captured by the gas to form relatively immobile negative ions. This loss of conducting electrons in the arc quickly builds up enough insulation strength to extinguish the arc. The SF6 circuit breakers have been found to be very effective for high power and high voltage service.

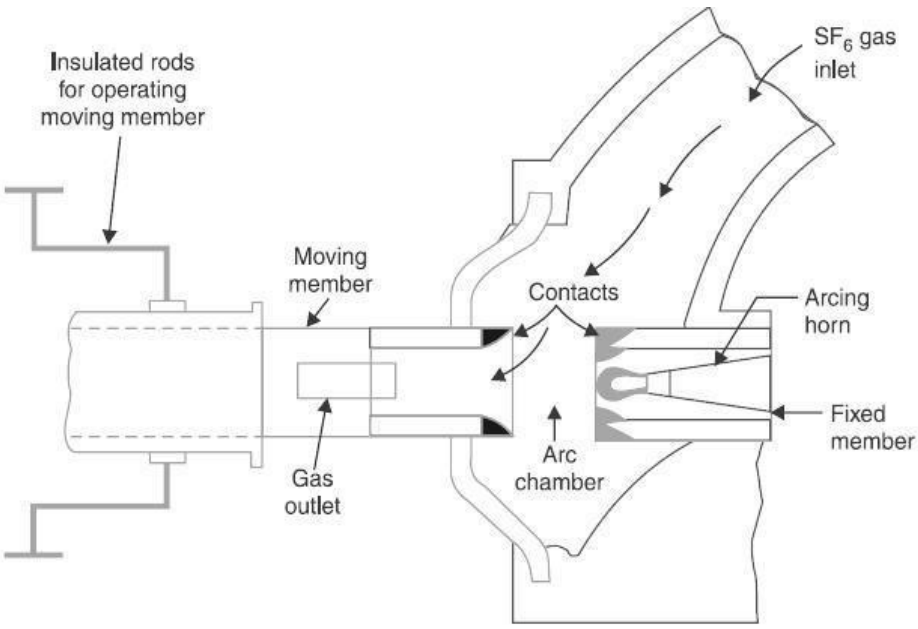


Fig. 19.11

Construction:

Fig. 19.11 shows the parts of a typical SF6 circuit breaker. It consists of fixed and moving contacts enclosed in a chamber (called arc interruption chamber) containing SF6 gas. This chamber is connected to SF6 gas reservoir. When the contacts of breaker are opened, the valve mechanism permits a high pressure SF6 gas from the reservoir to flow towards the arc interruption chamber. The fixed contact is a hollow cylindrical current carrying contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides to permit the SF6 gas to let out through these holes after flowing along and across the arc. The tips of fixed contact, moving contact and arcing horn are coated with copper-tungsten arc resistant material. Since SF6 gas is Costly, it is reconditioned and reclaimed by suitable auxiliary system after each operation of the breaker.

Working:

In the closed position of the breaker, the contacts remain surrounded by SF6 gas at a pressure of about 2·8 kg/cm. When the breaker operates, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronized with the opening of a valve which permits SF6 gas at 14 kg/cm pressure from the reservoir to the arc interruption chamber. The high pressure flow of SF6 rapidly absorbs the free electrons in the arc path to form immobile negative ions which are ineffective as charge carriers. The result is that the medium between the contacts quickly builds up high dielectric strength and causes the extinction of the arc. After the breaker operation (i.e., after arc extinction), the valve is closed by the action of a set of springs.

Advantages:

Due to the superior arc quenching properties of SF6 gas, the SF6 circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below:

1. Due to the superior arc quenching property of SF6, such circuit breakers have very short arcing time.
2. Since the dielectric strength of SF6 gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.
3. The SF6 circuit breaker gives noiseless operation due to its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker
4. The closed gas enclosure keeps the interior dry so that there is no moisture problem.
5. There is no risk of fire in such breakers because SF6 gas is non-inflammable.
6. There are no carbon deposits so that tracking and insulation problems are eliminated.
7. The SF6 breakers have low maintenance cost, light foundation requirements and minimum auxiliary equipment.
8. Since SF6 breakers are totally enclosed and sealed from atmosphere, they are particularly suitable where explosion hazard exists e.g., coal mines.

Disadvantages:

1. SF6 breakers are costly due to the high cost of SF6.
2. Since SF6 gas has to be reconditioned after every operation of the breaker, additional equipment is required for this purpose.

Applications:

A typical SF6 circuit breaker consists of interrupter units each capable of dealing with currents up to 60 kA and voltages in the range of 50—80 kV. A number of units are connected in series according to the system voltage. SF6 circuit breakers have been developed for voltages 115 kV to 230 kV, power ratings 10 MVA to 20 MVA and interrupting time less than 3 cycles.

Vacuum Circuit Breakers (VC B):

In such breakers, vacuum (degree of vacuum being in the range from 10 to 10 torr) is used as the arc quenching medium. Since vacuum offers the highest insulating strength, it has far superior arc quenching properties than any other medium. For example, when contacts of a breaker are opened in vacuum, the interruption occurs at first current zero with dielectric strength between the contacts building up at a rate thousands of times higher than that obtained with other circuit breakers.

Principle:

The production of arc in a vacuum circuit breaker and its extinction can be explained as follows:

When the contacts of the breaker are opened in vacuum (10 to 10 torr), an arc is produced between the contacts by the ionization of metal vapours of contacts. However, the arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc rapidly condense on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength. The reader may note the salient feature of vacuum as an arc quenching medium. As soon as the arc is produced in vacuum, it is quickly extinguished due to the fast rate of recovery of dielectric strength in vacuum.

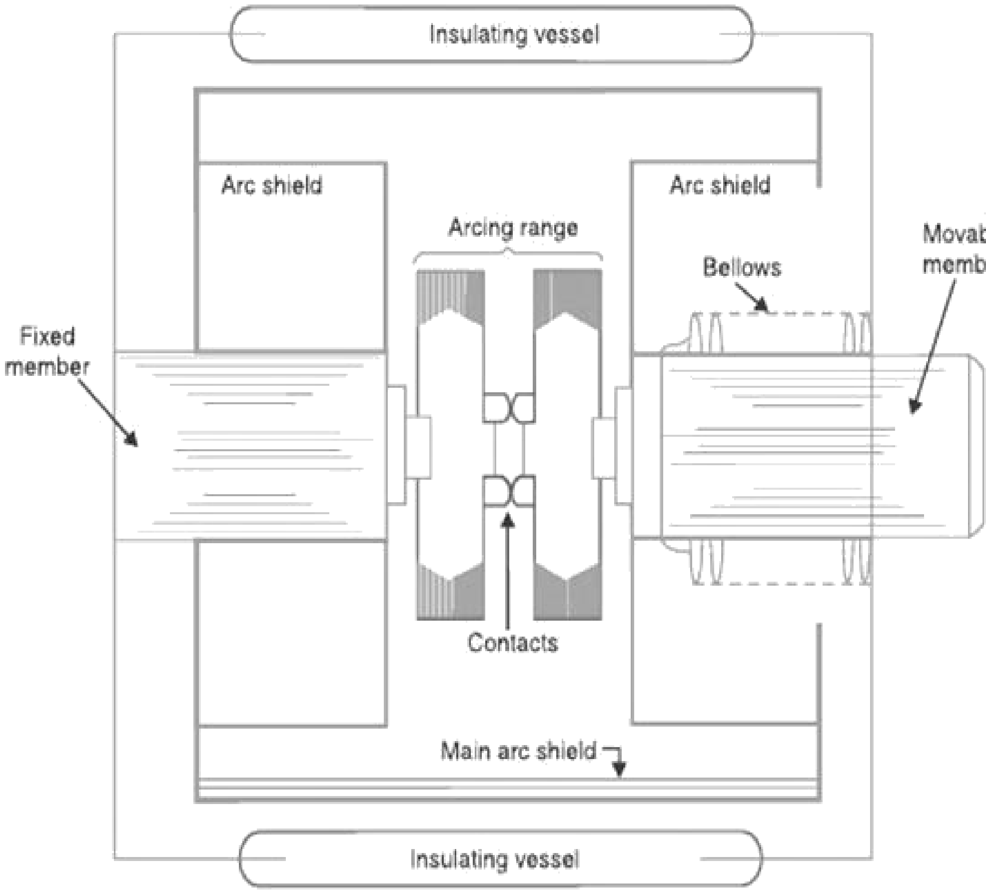


Fig. 19.12

Construction:

Fig. 19.12 shows the parts of a typical vacuum circuit breaker. It consists of fixed contact, moving contact and arc shield mounted inside a vacuum chamber. The movable member is connected to the control mechanism by stainless steel bellows. This enables the permanent sealing of the vacuum chamber so as to eliminate the possibility of leak. A glass vessel or ceramic vessel is used as the outer insulating body. The arc shield prevents the deterioration of the internal dielectric strength by preventing metallic vapours falling on the inside surface of the outer insulating cover.

Working:

When the breaker operates, the moving contact separates from the fixed contact and an arc is struck between the contacts. The production of arc is due to the ionization of metal ions and depends very much upon the material of contacts. The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in a short time and seized by the surfaces of moving and fixed members and shields. Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker occurs with a short contact separation (say 0·625 cm).

Vacuum circuit breakers have the following advantages:

1. They are compact, reliable and have longer life.
2. There is no generation of gas during and after operation.
3. They can interrupt any fault current. The outstanding feature of a V C B is that it can break any heavy fault current perfectly just before the contacts reach the definite open position.
4. They require little maintenance and are quiet in operation.
5. They have low arc energy.
6. They have low inertia and hence require smaller power for control mechanism.

Applications:

For a country like India, where distances are quite large and accessibility to remote areas difficult, the installation of such outdoor, maintenance free circuit breakers should prove a definite advantage. Vacuum circuit breakers are being employed for outdoor applications ranging from 22 kV to 66 kV. Even with limited rating of say 60 to 100 MVA, they are suitable for a majority of applications in rural areas.

(CHAPTER-5)

PROTECTIVE RELAYS

Protective Relay:

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.

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

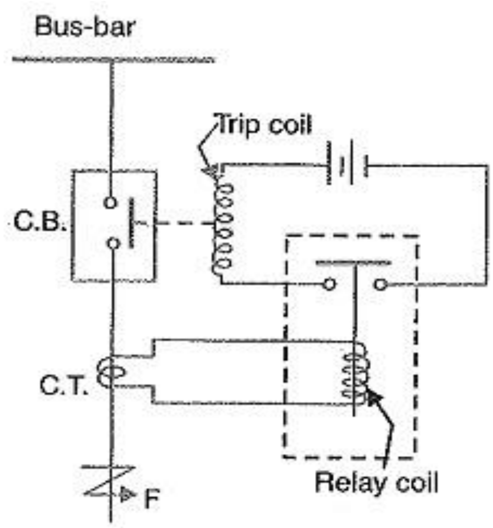


Fig. 21.1

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

- First part is the primary winding of a current transformer (CT.) which is connected in series with the line to be protected.
- Second part consists of secondary winding of C.T. and Cu. the relay operating coil.
- Third part is the tripping circuit which may be either a.c. or d.c. It consists of a source of supply, the trip coil of the circuit breaker and the relay stationary contacts.

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

Fundamental Requirements of Protective Relay:

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

1. **Selectivity**
2. **Speed**
3. **Sensitivity**
4. **Reliability**
5. **Simplicity**
6. **Economy**

1. Selectivity: It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system.

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

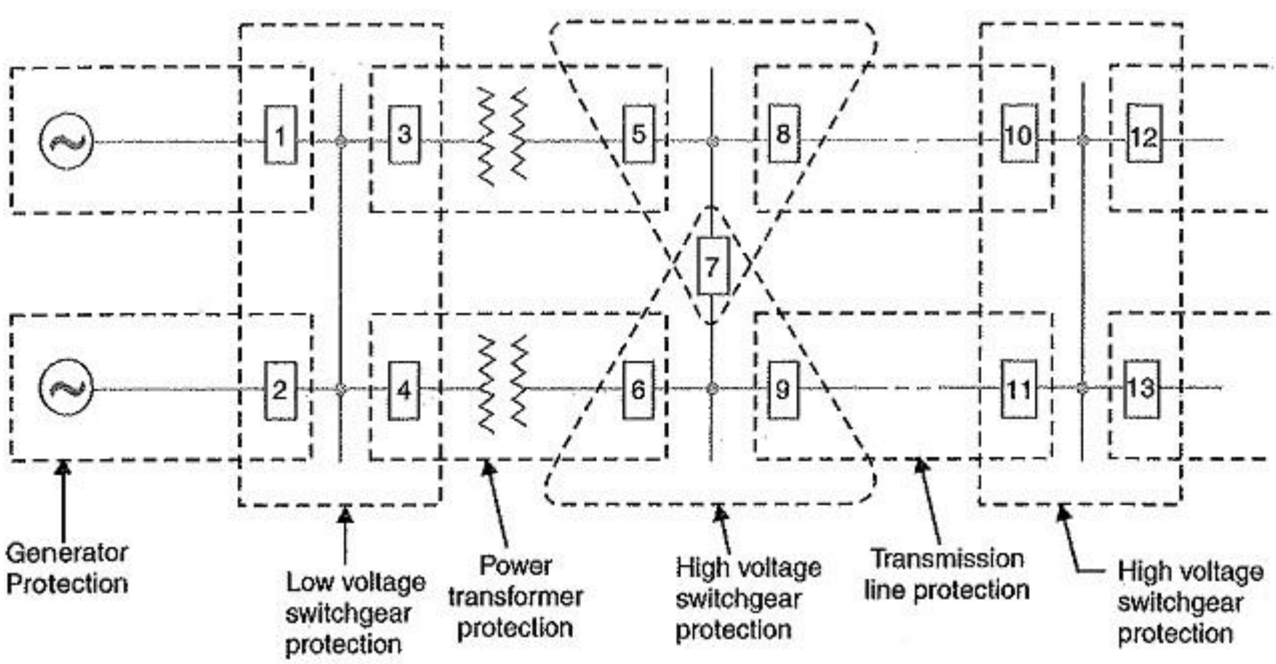


Fig. 21.2

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

- Generators
- Low-tension switchgear
- Transformers
- High-tension switchgear
- Transmission lines

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

2. Speed: The relay system should disconnect the faulty section as fast as possible for the following reasons

- Electrical apparatus may be damaged if they are made to carry the fault currents for a long time.
- A failure on the system leads to a great reduction in the system voltage. If the faulty section is not disconnected quickly, then the low voltage created by the fault may shut down consumers motors and the generators on the system may become unstable.
- The high speed relay system decreases the possibility of development of one type of fault into the other more severe type.

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

4. Reliability: It is the ability of the Protective Relay system to operate under the pre-determined conditions. Without reliability, the protection would be rendered largely ineffective and could even become a liability.

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

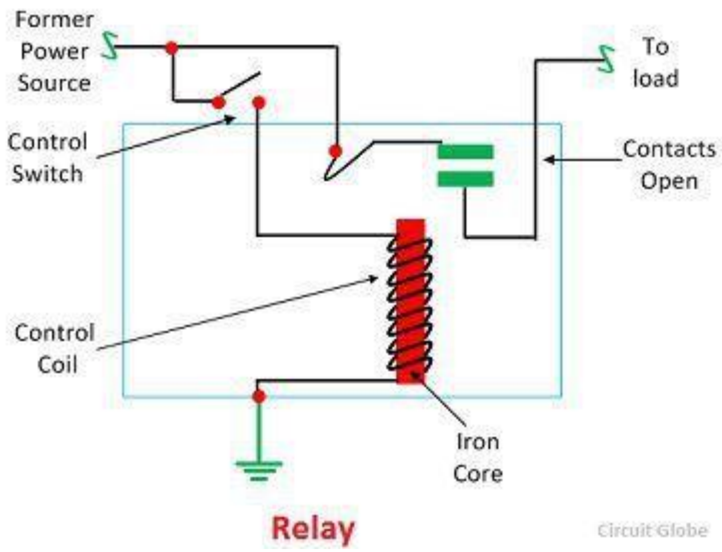
6. Economy: The most important factor in the choice of a particular protection scheme is the economic aspect. Sometimes it is economically unjustified to use an ideal scheme of protection and a compromise method has to be adopted. As a rule, the protective gear should not cost more than 5% of total cost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

Relay

Definition: The relay is the device that open or closes the contacts to cause the operation of the other electric control. It detects the intolerable or undesirable condition with an assigned area and gives the commands to the circuit breaker to disconnect the affected area. Thus protects the system from damage.

Working Principle of Relay

It works on the principle of an electromagnetic attraction. When the circuit of the relay senses the fault current, it energises the electromagnetic field which produces the temporary magnetic field.



This magnetic field moves the relay armature for opening or closing the connections. The small power relay has only one contacts, and the high power relay has two contacts for opening the switch.

The inner section of the relay is shown in the figure below. It has an iron core which is wound by a control coil. The power supply is given to the coil through the contacts of the load and the control switch. The current flows through the coil produces the magnetic field around it.

Due to this magnetic field, the upper arm of the magnet attracts the lower arm. Hence close the circuit, which makes the current flow through the load. If the contact is already closed, then it moves oppositely and hence open the contacts.

Pole and Throw

The pole and throws are the configurations of the relay, where the pole is the switch, and the throw is the number of connections. The single pole, the single throw is the simplest type of relay which has only one switch and only one possible connection. Similarly, the single pole double throw relay has a one switch and two possible connections.

Construction of Relay

The relay operates both electrically and mechanically. It consists electromagnetic and sets of contacts which perform the operation of the switching. The construction of relay is mainly classified into four groups. They are the contacts, bearings, electromechanical design, terminations and housing.

Contacts – The contacts are the most important part of the relay that affects the reliability. The good contact gives limited contact resistance and reduced contact wear. The selection of the contact material depends upon the several factors like nature of the current to be interrupted, the magnitude of the current to be interrupted, frequency and voltage of operation.

Bearing – The bearing may be a single ball, multi-ball, pivot-ball and jewel bearing. The single ball bearing is used for high sensitivity and low friction. The multi-ball bearing provides low friction and greater resistance to shock.

Electromechanical design – The electromechanical design includes the design of the magnetic circuit and the mechanical attachment of core, yoke and armature. The reluctance of the magnetic path is kept minimum for making the circuit more efficient. The electromagnet is made up of soft iron, and the coil current is usually restricted to 5A and the coil voltage to 220V.

Terminations and Housing – The assembly of an armature with the magnet and the base is made with the help of spring. The spring is insulated from the armature by moulded blocks which provide dimensional stability. The fixed contacts are usually spot welded on the terminal link.

Electromagnetic Attraction Relays Working & Construction:

In Electromagnetic Attraction Relays, there is a coil which energises an electromagnet.When the operating current becomes large, the magnetic field produced by an electromagnet is so high that it attracts the armature or plunger, making contact with the trip circuit contacts.These are the simplest type of relays.

The various types of electromagnetic attraction type relays are

1. Attracted armature relay

2. Solenoid and plunger type relay

Attracted Armature Type Relay:

There are two types of structures available for attracted armature type relay which are,

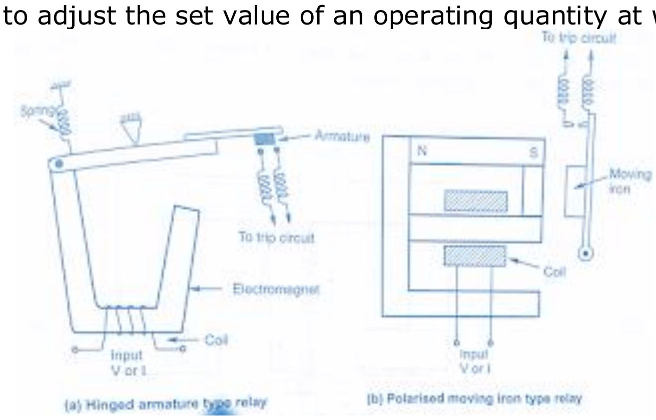
i) Hinged armature type

ii) Polarised moving iron type

The two types of attracted armature type relays are shown in the Figure(a) and (b).In attracted armature type, there exists a laminated electromagnet which carries a coil.The coil is energised by the operating quantity which is proportional to the circuit voltage or current.The armature or a moving iron is subjected to the magnetic force produced by the operating quantity.The force produced is proportional to the square of current hence Electromagnetic Attraction Relays relays can be used for a.c. as well as d.c.

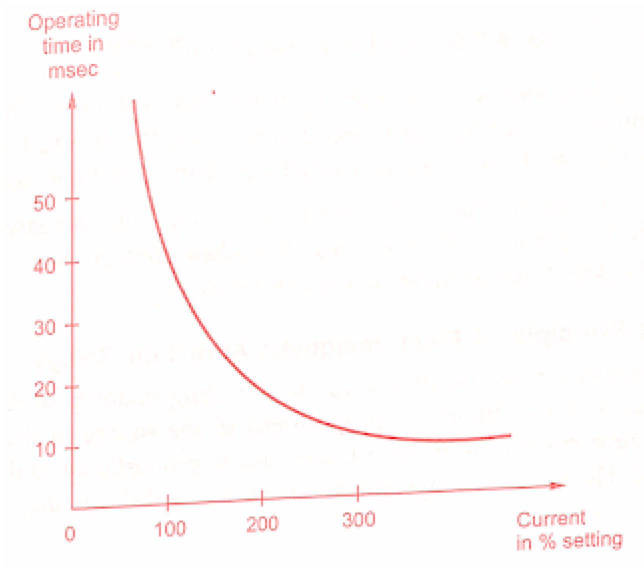
The spring is used to produce restraining force.When the current through coil increases beyond the limit under fault conditions, armature gets attracted.Due to this, it makes contact with contacts of a trip circuit, which results in an opening of a circuit breaker.The minimum current at which the armature gets attracted to close the trip circuit is called pickup current.

Generally, the number of tappings are provided on the relay coil with which its turns can be selected as per the requirement.This is used to adjust the set value of an operating quantity at which relay should operate.



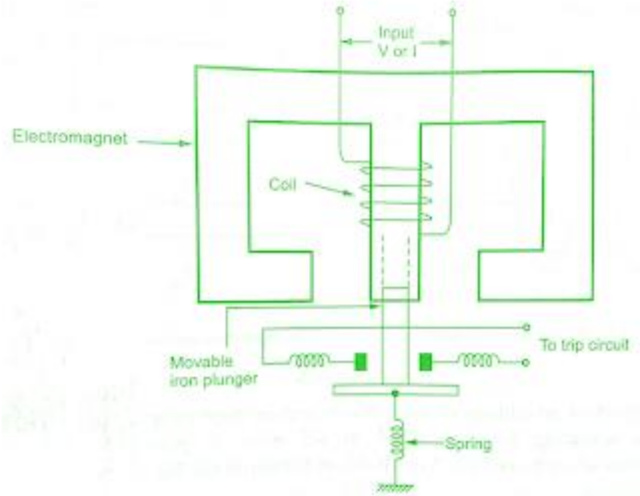
(a) Hinged armature type relay (b) Polarised moving iron type relay

An important advantage of such relays is their high operating speed. In modern relays an operating time as small as 0.5ms is possible.The current-time characteristics of such relays is hyperbolic, as shown in the figure below.



Solenoid and Plunger Type Relay:

The below figure is Solenoid and Plunger Type Relay which works on the principle of electromagnetic attraction.



It consists of a solenoid which is nothing but an electromagnet. It also consists a movable iron plunger. Under normal working conditions, the spring holds the plunger in the position such that it cannot make contact with trip circuit contacts.

Under fault conditions, when the current through relay coil increases, the solenoid draws the plunger upwards.Due to this,it makes contact with the trip circuit contacts, which results in an opening of a circuit breaker.

Operating Principle of Electromagnetic Attraction Relays:

The electromagnetic force produced due to the operating quantity which is exerted on the armature, moving iron or plunger is proportional to the square of the flux in the air gap.Thus neglecting the saturation effect, the force is proportional to the square of the operating current. Hence such relays are useful for a.c. and d.c. both.

For d.c operation :

In d.c. operation, the electromagnetic force is constant. When this force exceeds the restraining force, the relay operates.

Now $F_e = K_1 I^2$

where F_e = Electromagnetic force

K_1 = Constant

I = Operating current in a coil

And $F_r = K_2$

where F_r = Restraining force due to spring including friction

K_2 = Constant

On the verge of relay operating, the electromagnetic force is just equal to the restraining force.

$$K_1 I^2 = K_2$$

$$I^2 = \frac{K_2}{K_1}$$

$$\boxed{I = \sqrt{\frac{K_2}{K_1}} = \text{Constant}}$$

This is the current at which relay operates in case of d.c. operation.

<u>For a.c. operation</u> : In a.c. electromagnetic relays, the electromagnetic for proportional to square of the current but it is not constant. It is given by,

$$F_e = K I^2 = \frac{1}{2} K I_m^2 - \frac{1}{2} K I_m^2 \cos 2\omega t$$

where I_m = Maximum value of the operating current

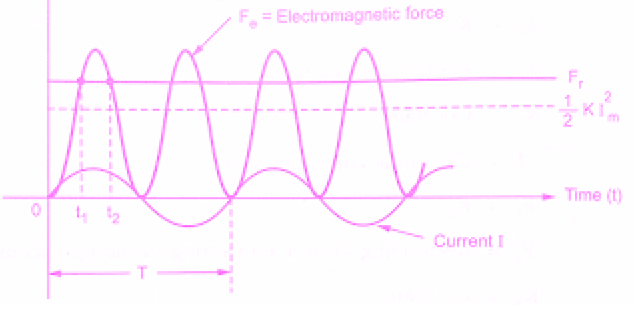
K = Constant

It shows that the electromagnetic force consists of two components,

i) Constant, independent of time.

ii) Pulsating at double the frequency of applied voltage.

The total force thus pulsates at double the frequency. If the restraining force F_r which is produced by the spring is constant then the armature of relay will be picked up at time t_1 and it drops off at time t_2 as shown in the below figure.



Thus relay armature pulsates at double frequency. This causes the relay to hum and produces a noise. It may cause damage to the relay contacts. To overcome this difficulty, the air gap flux producing an electromagnetic force is divided into two fluxes acting simultaneously but differing in time phase. This causes resulting electromagnetic force to be always positive. If this is always greater than restraining force Fr then armature will not vibrate. The phase lag between the two components of flux can be easily produced using shading in a relay. The flux through the shaded pole lags behind the flux through the unshaded part.

Advantages of Electromagnetic Relays:

The various advantages of electromagnetic relays are

1. Can be used for both a.c. and d.c.

2. They have fast operation and fast reset.

3.Electromagnetic Attraction Relays are almost instantaneous.Though instantaneous, the operating to varies with current. With extra arrangements like dashpot, copper ring etc, slow operating and resetting times can be obtained.

4. High operating speed with operating time in few milliseconds also can be achieved.

5. The pickup can be as high as 90-95% for d.c. operation and 60 to 90% for the d.c. operation.

6. Modern relays are compact, simple, reliable and robust.

Disadvantages of Electromagnetic Relays:

The few disadvantages of Electromagnetic Attraction Relays are,

1. The directional feature is absent.

2. Due to fast operation the working can be affected by the transients. As transients contain d.c. as well as pulsating component, under steady state value less than set value, the relay can operate during transients.

Applications of Electromagnetic Relays:

The various applications of Electromagnetic Attraction Relays are,

1.The protection of various a.c. and d.c. equipments.

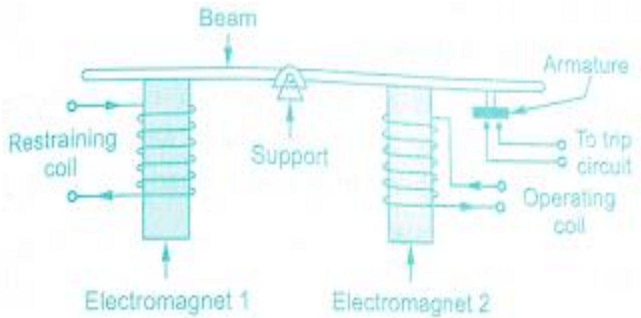
2.The over/under current and over/under voltage protection of various a.c. and d.c. equipments.

3.In the definite time lag over current and earth fault protection along with definite time lag over current relay.

4.For the differential protection.

5.Used as auxiliary relays in the contact systems of protective relaying schemes.

Balanced beam relay:



The balanced beam relay is also a type of attracted armature type relay. It consists of a beam carrying two electromagnets at its ends.One electromagnet produces operating torque while the other produces restraining torque.The beam is supported at the middle.

Under normal operating conditions, the two torques are equal and beam remains horizontal.The construction is shown in the above figure. When there is a fault, the operating current is high and produces high operating torque. Thus the beam gets deflected more on operating side.

Due to this, armature fitted at end of the beam gets pulled and makes contact with the contacts of trip circuit. Thus the trip circuit operates.It is robust and fast in operation.Generally only one cycle is enough for the operation. But due to the d.c. transients, it is not accurate.Now a days, this type of relay is not used.

Induction type relay

Induction type relays are most widely used for protective-relaying purposes involving ac quantities.

They are not usable with DC quantities, owing to the principle of operation

An induction type relay is split-phase induction motor with contacts.

Actuating force is developed in a movable element, that may be a disc or other form of rotor of non-magnetic current-conducting material ,by the interaction of electromagnetic fluxes with eddy currents that are induced in the rotor by these fluxes.

Induction Disc Relay

In this type of relay,a metal disc is allowed to rotate between two electromagnets.The electromagnets are energized by the interaction of the flux of one of the magnets and the eddy current induced in the disc by other.

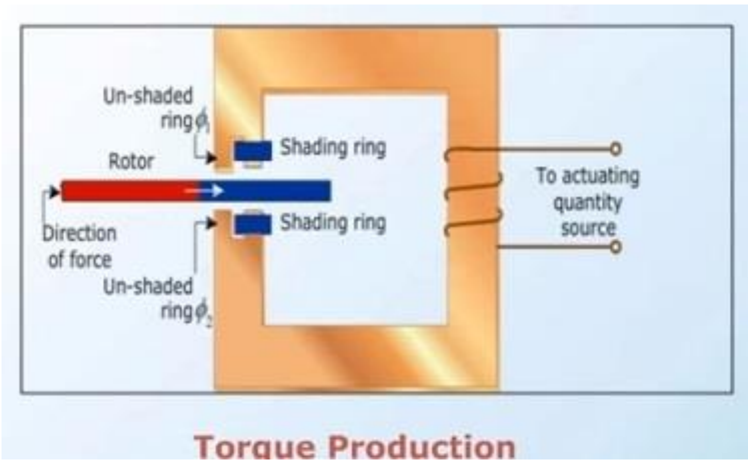
The different types of structure that have been used are commonly called

Shaded pole watt-hour meter

Shaded Pole Structure

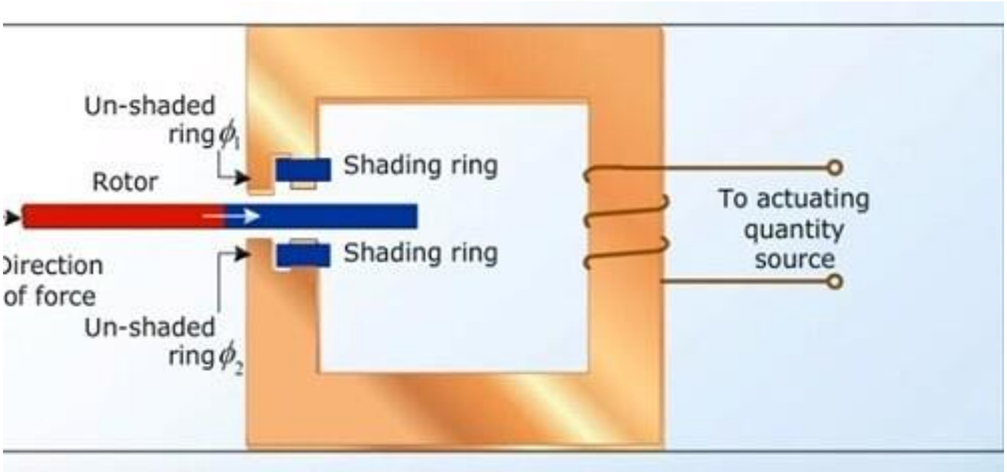
The shaded pole structure is generally actuated by current flowing in a single coil on a magnetic structure containing an air gap.

The air gap flux produced by this current is split into two out-of-phase components by a so called “shading ring” generally of copper,that encircles part of the pole face of each pole at the air gap



Watt-hour meter structure

It contain two separate coils on two different magnetic circuits,each of which produces one of the two necessary fluxes for driving the rotor,which is also a disc.

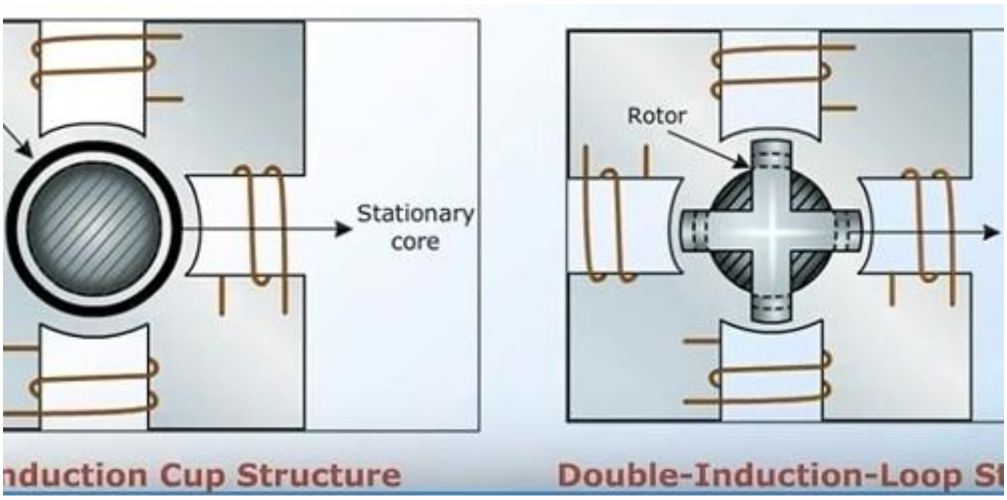


watt-hour- meter-structure551×236 24.3 KB

Induction Cup Relay

There are two structure in which the most close resemble induction motor,except the rotor iron is stationary,only the rotor-conductor portion being free to rotate.

The cup structure employs a hollow cylindrical rotor. The double-loop structure employs two loops at right angles to one another.



Induction Cup Relay643×245 42.4 KB

It is practically suited as directional or phase comparison units.this is because, besides their sensitivity, induction cup relays have study non-vibrating torque and their parasitic torque due to current or voltage alone are small.

Induction cup structures are more efficient torque producers than either shaded-pole or watt hour meter structure

Advantages of Induction Relay

They have fast operation and fast reset High operating speed with high operating time in few milliseconds can also be achieved. Modern relays are compact, simple ,reliable and robust.

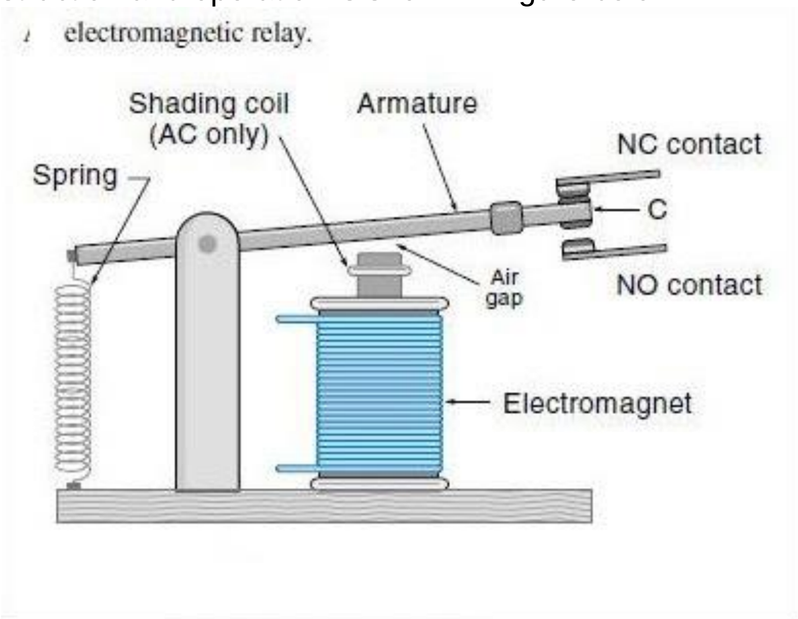
Disadvantages

The directional feature is absent Due to the fast operation,the working can be affected by the transients

Pick-up Current, Plug Setting Multiplier (PSM) and Time Setting Multiplier (TSM)

Plug Setting Multiplier and Time Setting Multiplier are used only for Electromechanical Relays. These terms or parameters are not so used in Numerical Relays but they are conceptually used and incorporated in Numerical Relays too but the way of their implementation is quite different than that of Electromechanical Relays. In this post we will focus on the concept and implementation of Plug Setting Multiplier and Time Setting Multiplier for Electromechanical Relays.

As we know that an Electromechanical Relay has a coil which when energized, operates the Relay to have contact changeover. But there shall be some minimum current which when flows through the Relay coil, produces enough magnetic force to pull the lever to make contact change over. Isn't it? Yes, if you ever get a chance to see electromechanical relay, you will observe that there is a flapper kind of thing which is attached with the lever. The lever in turn is attached with contacts. Thus when a specified current flows through the relay coil, then only it will produce enough magnetic pull to attract the flapper and lever to operate the Relay. A simple picture of relay demonstrating its construction and operation is shown in figure below.

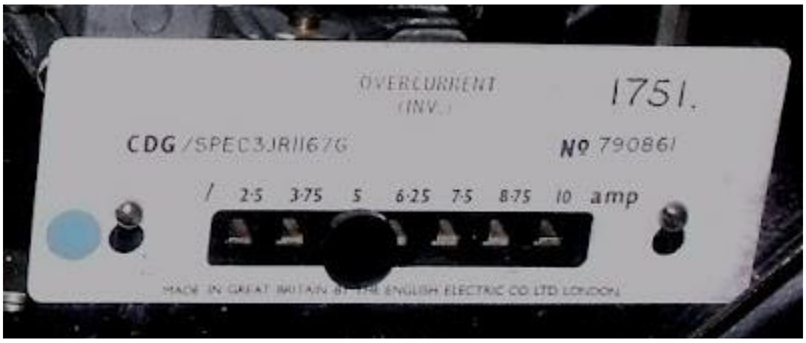


This minimum current in the Relay coil at which Relay starts to operate is called Pick-up Current. If the current through the Relay coil is less than the pick-up value then Relay won't operate. On contrary, if the current through the Relay coil is more than the Pick-up current, Relay will operate. In industries, we normally perform Relay Pick-up and Drop-off Test to check the healthiness of relays. Hope your concept of Pick-up current of Relay is clear now. Now we will move on to Current Setting of electromechanical relays.

Current Setting of Electromechanical Relays: Current Setting of relay is nothing but adjusting its pick-up value. Suppose we are using a CT of ratio 1000/1 A and the pick-up current needs to be set at 1.2 A. Then we will simply put the plug provided on relay coil to 120% or 1.2. Thus we can say that

Pick-up current = Plug Position x Rated CT Secondary Current.

The plug or tapping is provided on the Relay Coil so that changing the position of Plug changes the number of turns of the relay coil as shown in figure below.



As shown in figure above, the plug is kept at 5. This means that pick-up current of relay will be 5 times of rated CT Secondary current. Likewise, if we put the plug at 8.75 then pick-up current of relay will be 8.75 times of the rated CT Secondary current.

Plug Setting Multiplier (PSM): Plug Setting Multiplier (PSM) is defined as the ratio of fault current to the pick-up current of the relay. Thus,

PSM = Fault Current / Pick-up Current

= Fault Current / (Plug Position x Rated CT Secondary Current)

Suppose we are using CT of 100/1 A, a fault current of, say 5000 A is flowing through the network protected by the relay.

Fault current in CT secondary = (5000×1) / 100 = 50 A

Assume that Current Setting or the position of plug is at 5 then

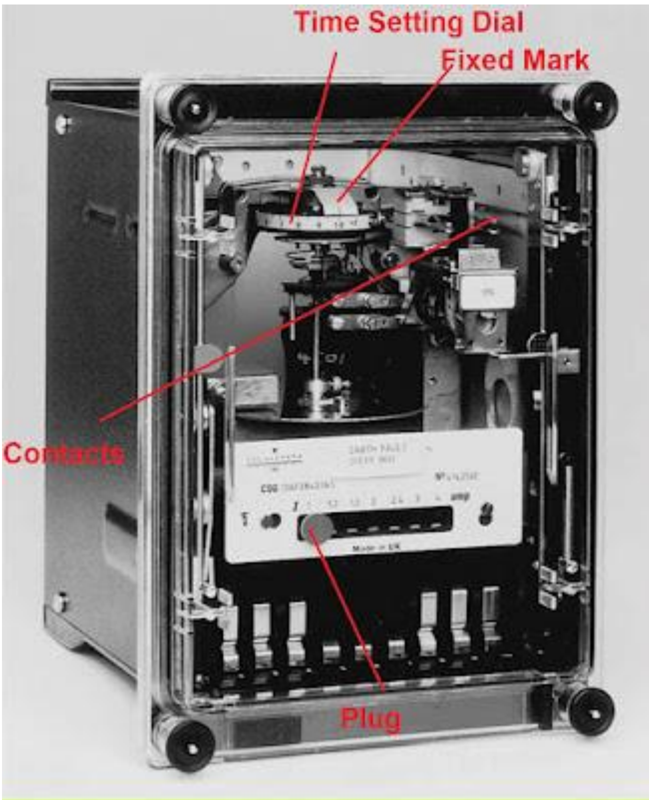
PSM = 50 / (1×5) =10

It shall be noted here that we shall not bother about PSM for instantaneous relay rather we shall consider PSM for relays having characteristics of Inverse Time, Very Inverse Time etc.

For Detail on Relay Characteristics read Over Current Relay and Its Characteristics

Time Setting Multiplier (TSM): Again it is worthwhile to mention that we shall not bother about TSM for instantaneous relay rather we shall consider TSM for relays having characteristics of Inverse Time, Very Inverse Time etc.

A Relay is generally provided with control to adjust the time of operation of the Relay. This adjustment is known as Time Setting Multiplier or TSM. Normally a Time Setting Dial is provided which is calibrated from 0 to 1 s in step of 0.05 s. For practical exposure, let us consider a relay as shown in figure below. Please Zoom the image to clearly view every part of the Relay for better understanding.



As can be seen from the figure, there is a Time Setting Dial which is rotated to set the time of operation of the relay. Lets say we want to set the time on Time Setting Dial to 0.5 s, then we need to rotate the dial till 0.5 s on the dial matches with the fixed mark provided. So in this case, our TSM is 0.5.

Types of Protection:

When a fault occurs on any part of electric power system, it must be cleared quickly in order to avoid damage and/or interference with the rest of the system. It is a usual practice to divide the Types of Pro

1. Primary Protection: It is the protection scheme which is designed to protect the component parts of the power system. Thus referring to Fig. 21.29, each line has an over current relay that protects the line. If a fault occurs on any line, it will be cleared by its relay and circuit breaker. This forms the primary or main protection and serves as the first line of defence.

The service record of primary relaying is very high with well over ninety percent of all operations being correct. However, sometimes faults are not cleared by primary relay system because of trouble within the relay, wiring system or breaker. Under such conditions, back-up protection does the required job.

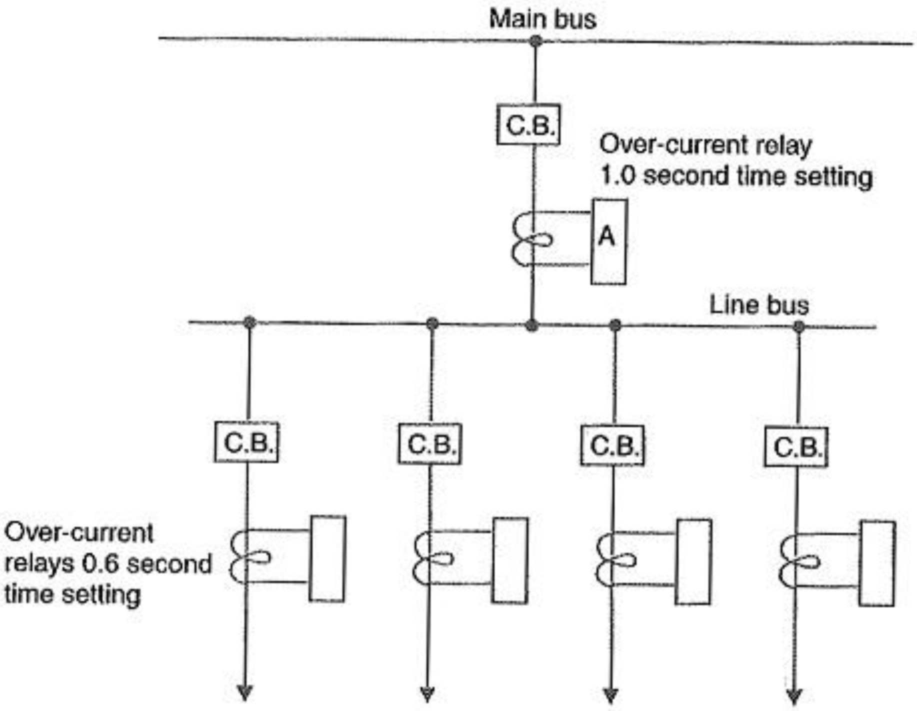


Fig. 21.29

2. Back-up protection: It is the second line of defense in case of failure of the primary protection. It is designed to operate with sufficient time delay so that primary relaying will be given enough time to function if it is able to. Thus referring to Fig. 21.29, relay A provides back-up protection for each of the four lines. If a line fault is not cleared by its relay and breaker, the relay A on the group breaker will operate after a definite time delay and clear the entire group of lines.

It is evident that when back-up relaying functions, a larger part is disconnected than when primary relaying functions correctly. Therefore, greater emphasis should be placed on the better maintenance of primary relaying

(CHAPTER-6)

PROTECTION OF ELECTRICAL POWER EQUIPMENT & LINES

Protection of Alternators

The generating units, especially the larger ones, are relatively few in number and higher in individual cost than most other equipments. Therefore, it is desirable and necessary to provide protection 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 :

(i) Failure of prime-mover **(*ii*)** Failure of field
(*iii*) Over current **(*iv*)** Over speed
unbalanced

(*v*) over voltage **(*vi*)**Loading
(*vii*) stator winding faults

(i) 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.

(a) 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. There-fore, automatic protection is not required.

(b) In case of hydro-generator sets, protection against inverted running is achieved by pro-viding 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 system. Therefore, in this case also electrical protection is not necessary.

(c) 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 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 synchronising and phase swinging.

(ii) 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.

(iii) Over current. It occurs mainly due to partial breakdown of winding insulation or due to overload on the supply system. Over current protection for alternators is considered un-necessary because of the following reasons :

(a) 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.

(b) The disadvantage of using overload protection for 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.

(iv) 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.

(v) Over-voltage. The field excitation system of modern alternators is so designed that over-voltage conditions at normal running speeds cannot occur. However, overvoltage 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

(a) trip the main circuit breaker to disconnect the faulty alternator from the system
(b) disconnect the alternator field circuit

(vi) 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.

Fig. 22.1 shows the schematic arrangement for the protection of alternator 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 cur-rents flowing in the secondaries is also zero and no Current flows through the operating coil of the relay. However, if un-balancing occurs, the currents induced 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.

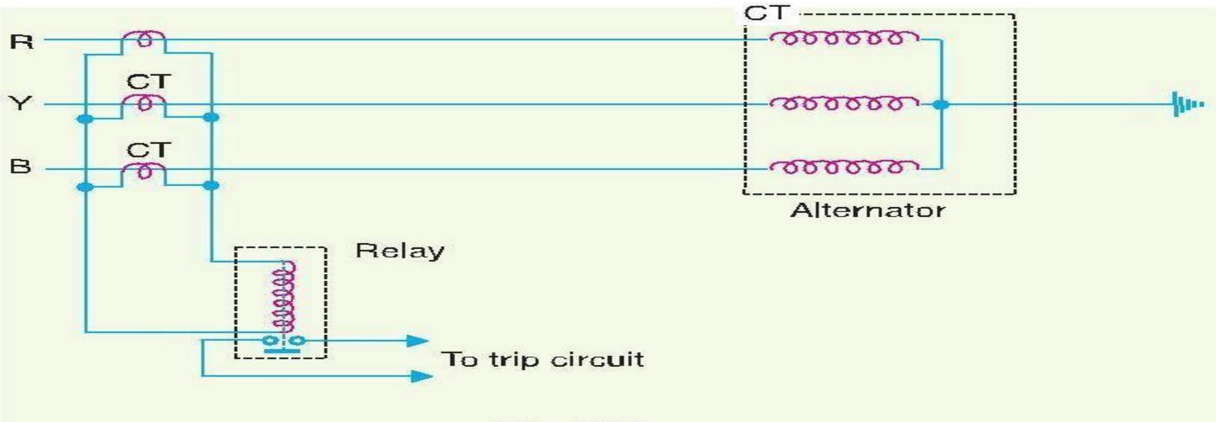


Fig. 22.1

vii)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 :

(a) fault between phase and ground

(b) fault between phases

(c) 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 minimise 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. This system of protection is dis-cussed in the following section.

Differential Protection of Alternators

The most common system used for the protection of stator winding faults employs circulating-current principle (Refer back to Art. 21.18). In this scheme of protection, currents at the two ends of the protected section are compared. Under normal operating conditions, these currents are equal but may become unequal on the occurrence of a fault in the protected section. The difference of the currents under fault conditions is arranged to pass through the operating coil of the relay. The relay 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. Fig. 22.2 shows the schematic arrangement of current differential protection for a 3-phase alternator. Identical current transformer pairs CT_1 and CT_2 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*.

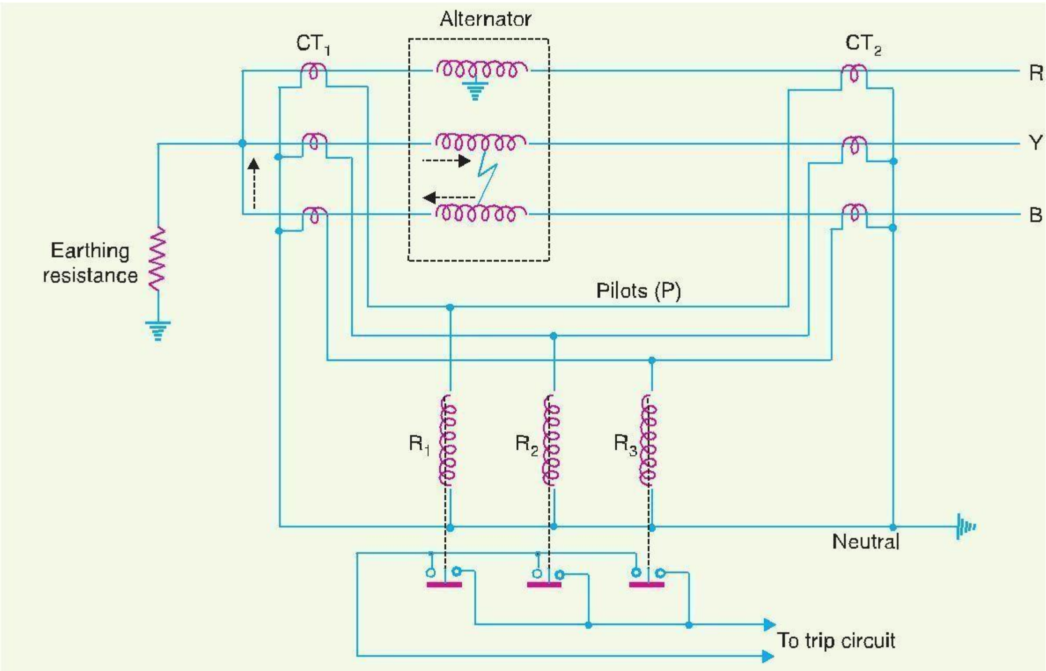


Fig. 22.2

The relay coils are connected in star, the neutral point being connected to the current-trans-former 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 Fig. 22.2, it is clear that the relays are connected in shunt across each circulating path. Therefore, the circuit of Fig. 22.2 can be

shown in a simpler form in Fig. 22.3. 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. There - B fore, 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-phasefault occurs, this condition nolonger holds good and the differential current flowing through the relay circuit oper- ates the relay to trip the circuit breaker.

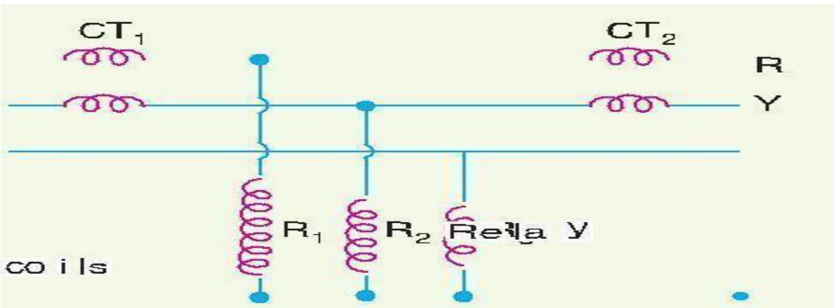


Fig. 22.3

(i) Suppose an earth fault occurs on phase *R* due to breakdown of its insulation to earth as shown in Fig. 22.2. 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 corre-sponding 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 Fig. 22.2. The short-circuit current circulates *via* the neutral end connection through the two windings and through the fault as shown by the dotted arrows. The currents in the secondaries of two CTs in each affected phase will become unequal and the differ-ential current will flow through the operating coils of the relays (*i.e.* R_2 and R_3) con-nected 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 energising causes ***(i)*** opening of the breaker connecting the alternator to the bus-bars and ***(ii)*** opening of the *field circuit of the alternator.

It is a prevailing practice to mount current transformers CT_1 in the neutral connections (usually in the alternator pit) and current transformers CT_2 in the switch-gear equipment. In some cases, the alternator is located at a considerable distance from the switchgear. As the relays are located close to the circuit breaker, therefore, it is not convenient to connect the relay coils to the actual physical mid-points of the pilots. Under these circumstances, balancing resistances are inserted in the shorter lengths of the pilots so that the relay tapping points divide the whole secondary impedance of two sets of CTs into equal portions. This arrangement is shown in Fig. 22.4. These resistances are usually adjustable in order to obtain the exact balance.

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.

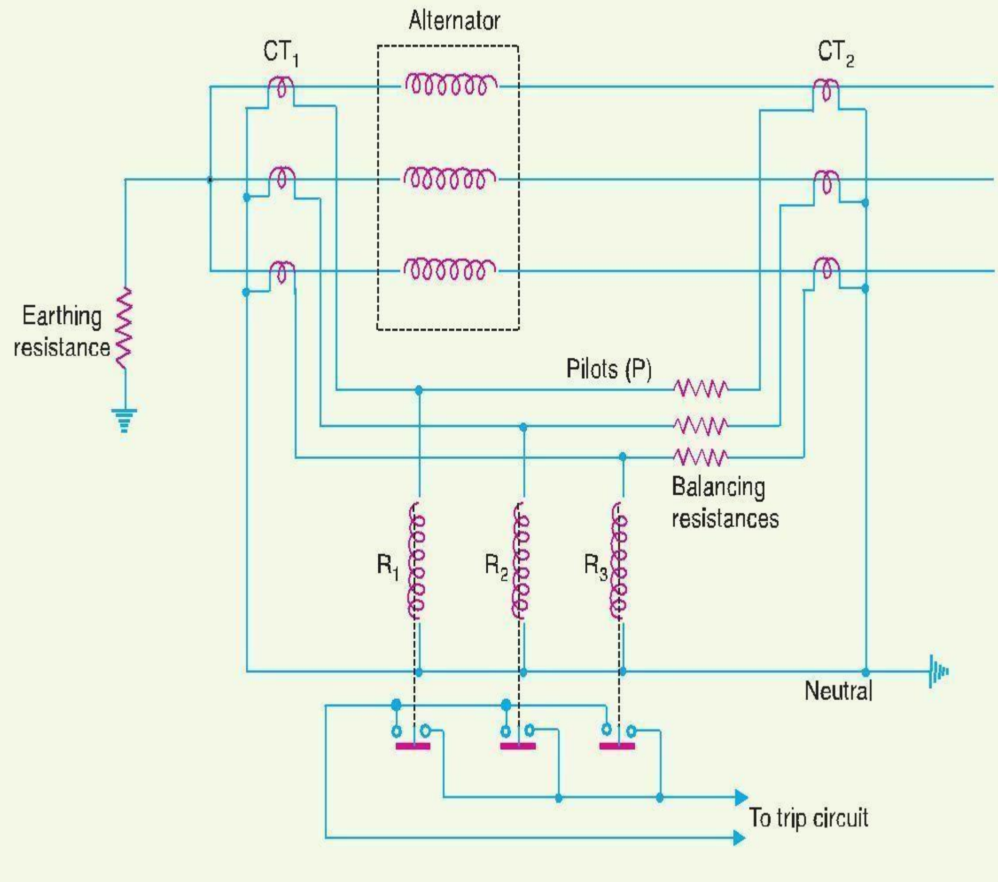


Fig. 22.4

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.

Modified Differential Protection for Alternators

If the neutral point of a star-connected alternator is earthed through a high resistance, protection schemes shown in Fig. 22.2 or 22.4 will not provide sufficient sensitivity for earth-faults. It is be-cause the high earthing resistance will limit the earth-fault currents to a low value, necessitating relays with low current settings if adequate portion of the generator winding is to be protected. However, too low a relay setting is undesirable for reliable stability on heavy through phase-faults. In order to overcome this difficulty, a modified form of differential protection is used in which the setting of earth faults is reduced without impairing stability.

The modified arrangement is shown in Fig. 22.5. The modifications affect only the relay con-nections and consist in connecting two relays for phase-fault protection and the third for earth-fault protection only. The two phase elements (PC and PA) and balancing resistance (BR) are connected in star and the earth relay (ER) is connected between this star point and the fourth wire of circulating current pilot-circuit.

Operation. Under normal operating conditions, currents at the two ends of each stator winding will be equal. Therefore, there is a balanced circulating current in the phase pilot wires and no current flows through the operating coils of the relays. Consequently, the relays remain inoperative.

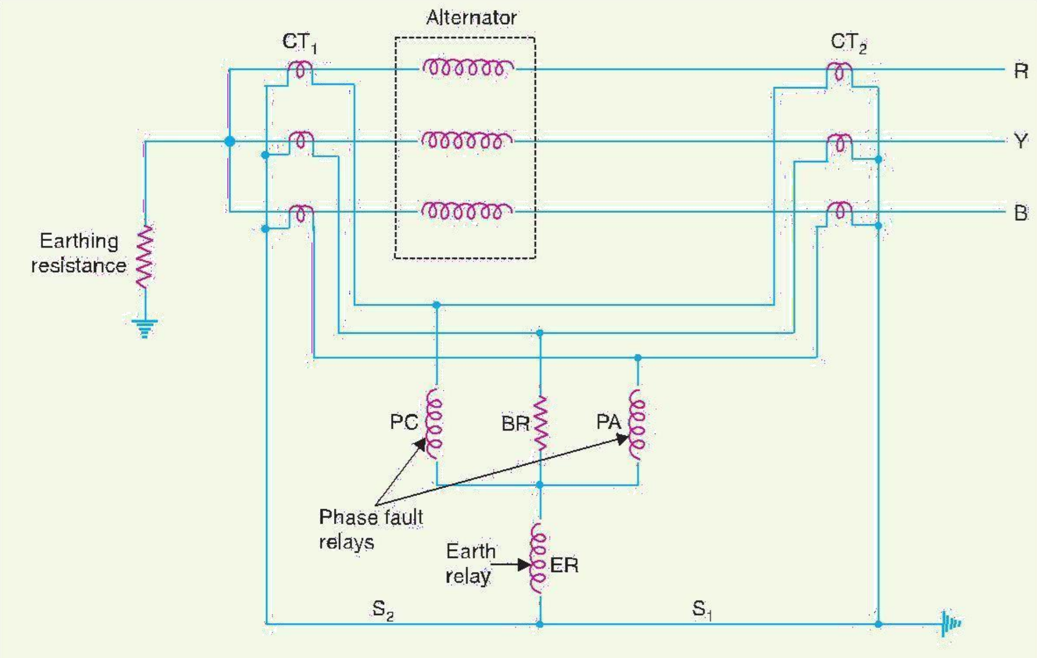


Fig. 22.5

If an earth-fault occurs on any one phase, the out-of-balance secondary current in CTs in that phase will flow through the earth relay *ER* and *via* pilot S_1 or S_2 to the neutral of the current transform-ers. This will cause the operation of earth relay only. If a fault occurs between two phases, the out-of-balance current will circulate round the two transformer secondaries *via* any two of the coils *PA* , *B R*, *PC* (the pair being decided by the two phases that are faulty) without passing through the earth relay *ER*. Therefore, only the phase-fault relays will operate.

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. Fig. 22.6 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 transform-ers secondaries. The protection against earth faults is limited to the region between the neutral and the line current transformers.

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

current to the relay.If an earth-fault develops at F_2 external to the protected zone, the sum of the currents at the terminals of the alternator is exactly equal to the current in the neutral connection and hence no

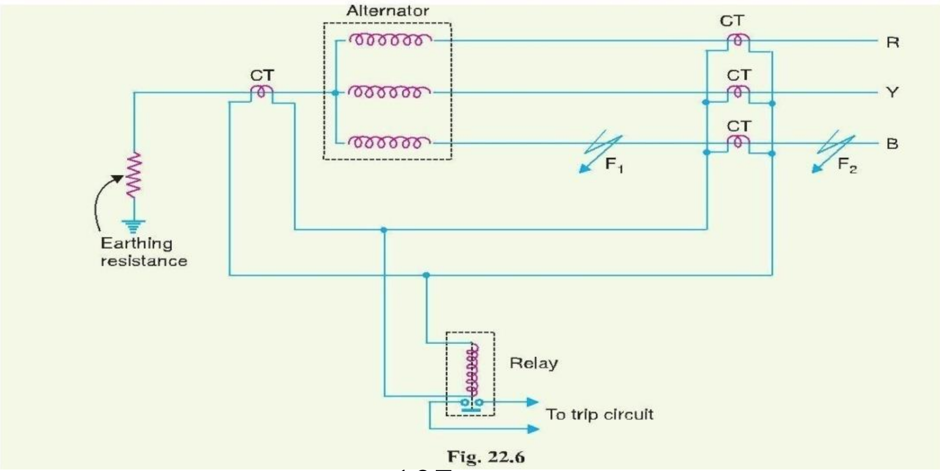


Fig. 22.6

Protection of transformer and circuits

The electrical equipment and circuits in a substation must be protected in order to limit the damages due to abnormal currents and over voltages.

All equipment installed in a power electrical system have standardized ratings for short-time withstand current and short duration power frequency voltage. The role of the protections is to ensure that these withstand limits can never be exceeded, therefore clearing the faults as fast as possible.

In addition to this first requirement a system of protection must be selective. Selectivity means that any fault must be cleared by the device of current interruption (circuit breaker or fuses) being the nearest to the fault, even if the fault is detected by other protections associated with other interruption devices.

As an example for a short circuit occurring on the secondary side of a power transformer, only the circuit breaker installed on the secondary must trip. The circuit breaker installed on the primary side must remain closed. For a transformer protected with MV fuses, the fuses must not blow.

They are typically two main devices able to interrupt fault currents, circuit breakers and fuses :

- The circuit breakers must be associated with a protection relay having three main functions:
  - Measurement of the currents
  - Detection of the faults
  - Emission of a tripping order to the breaker
- The fuses blow under certain fault conditions.

Transformer protection

Stresses generated by the supply

Two types of over voltages may stress and even destroy a transformer:

- The lightning over voltages due to lightning stroke falling on or near an overhead line supplying the installation where the transformer is installed
- The switching over voltages generated by the opening of a circuit breaker or a load break switch for instance.

Depending of the application, protection against these two types of voltage surges may be necessary and are often ensured by means of Z_nO surge arrestors preferably connected on the MV bushing of the transformer.

Stresses due to the load

A transformer overload is always due to an increase of the apparent power demand (kVA) of the installation. This increase of the demand can be the consequence of either a progressive adjunction of loads or an extension of the installation itself. The effect of any overload is an increase of the temperature of oil and windings of the transformer with a reduction of its life time.

The protection of a transformer against the overloads is performed by a dedicated protection usually called thermal overload relay. This type of protection simulates the temperature of the transformer’s windings. The simulation is based on the measure of the current and on the thermal time constant of the transformer. Some relays are able to take into account the effect of harmonics of the current due to non-linear loads such as rectifiers, computers, variable speed drives etc. This type of relay is also able to evaluate the remaining time before the emission of the tripping order and the time delay before re-energizing the transformer.

In addition, oil-filled transformers are equipped with thermostats controlling the temperature of the oil.

Dry-type transformers use heat sensors embedded in the hottest part of the windings insulation.

Each of these devices (thermal relay, thermostat, heat sensors) generally provides two levels of detection:

- A low level used to generate an alarm to advise the maintenance staff,
- A high level to de-energize the transformer.

Internal faults in oil filled transformers

In oil filled transformers, internal faults may be classified as follow:

- Faults generating production of gases, mainly:
  - Micro arcs resulting from incipient faults in the winding insulation
  - Slow degradation of insulation materials
  - Inter turns short circuit
- Faults generating internal over pressures with simultaneously high level of line over currents:
  - Phase to earth short circuit
  - Phase to Phase short circuit.

These faults may be the consequence of external lightning or switching over voltage.

Depending on the type of the transformer, there are two kinds of devices able to detect internal faults affecting an oil filled transformer.

- The Buchholz dedicated to the transformers equipped with an air breathing conservator (see Fig. B16a).

  The buchholz is installed on the pipe connecting the tank of the transformer to the conservator (see Fig. B16b).

  It traps the slow emissions of gasses and detect the flow back of oil due to the internal over pressures

  Fig. B16 – Breathing transformer protected by buchholz

[

[b] Transformer with conservator

- The DGPT (Detection of Gas, Pressure and Temperature, see Fig. B18) for the integral filled transformers (see Fig. B17). This type of transformer is manufactured up to around10 MVA. The DGPT as the buchholz detects the emissions of gasses and the internal over pressures. In addition it monitors the temperature of the oil.

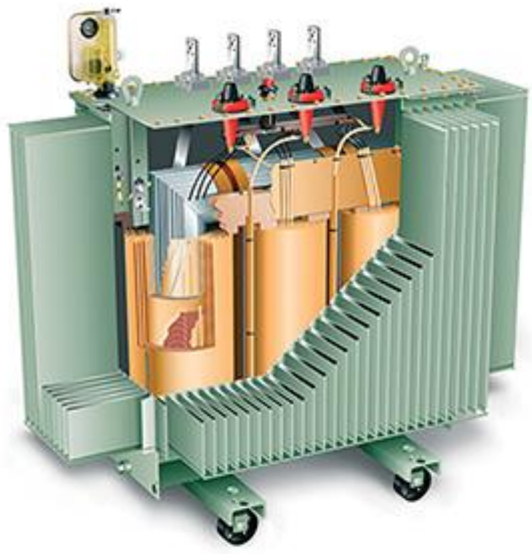


Fig. B17 – Integral filled transformer

Fig. B18 – DGPT (Detection of Gas, Pressure and Temperature) protection relay for integral filled transformers

[a] Transformer protection relay (DGPT)

[b] Contacts of the DGPT (cover removed)

Concerning the monitoring of gas and temperature the buchholz and the DGPT provide two levels of detection:

- A low level used to generate an alarm to advise the maintenance staff,
- A high level to trip the switching device installed on the primary side of the transformer (circuit breaker or load break switch associated with fuses).

In addition, both the buchholz and the DGPT are suitable for oil leakages detection.

Overloads and internal faults in dry type transformers

(see Fig. B19 and Fig. B20)

The dry type transformers are protected against over-heating due to possible downstream overloads by a dedicated relay monitoring thermal sensors embedded in the windings of the transformer (see Fig. B20).

The internal faults, mainly inter turns and phase to earth short circuits occurring inside a dry type transformers are cleared either by the circuit breaker or the fuses installed on the primary side of the transformer. The tripping of the circuit breakers when used is ordered by the phase to phase and phase to earth over current protections.

Inter turns faults need a dedicated attention:

- They generally generate moderate line over currents. As an example when 5 % of a HV winding are short circuited the line current of the transformer does not exceed 2 In, for a short circuit affecting 10 % of the winding the line current is limited around 3 In.
- Fuses are not appropriate to clear properly such currents
- Dry type transformers are not equipped with additional protection devices such as DGPT dedicated to internal faults detection.

Hence, internal faults generating low level of line over current may not be safely cleared by fuses. Protection by means of over current relay with adequate characteristic and settings is preferred (Schneider Electric VIP relay range for example).

Fig. B19 – Dry type transformer

Fig. B20 – Thermal relay for protection of dry type transformer (Ziehl)

Selectivity between the protective devices upstream and downstream of the transformer

It is a common practice to ensure the selectivity between the MV circuit breaker or fuses installed on the primary side of a transformer and the LV circuit breaker.

The characteristics of the protection ordering the tripping or the MV circuit breaker or the operating curves of the fuses when used must be such as in case of downstream fault the LV circuit breaker only trips. The MV circuit breaker must remain closed or the fuse must not blow.

The tripping curves of MV fuses, MV protection and LV circuit breakers are given by graphs giving the operating time as a function of the current.

The curves are in general inverse-time type. LV circuit breakers have an abrupt discontinuity which defines the limit of the instantaneous action.

Typical curves are shown in Fig. B21.

Selectivity between LV circuit breaker and MV fuses

(see Fig. B21 and Fig. B22)

- All parts of the MV fuse curve must be above and to the right of the LV CB curve.
- In order to leave the fuses unaffected (i.e. undamaged), the two following conditions must be satisfied:
  - All parts of the minimum pre-arcing fuse curve must be shifted to the right of the LV CB curve by a factor of 1.35 or more.
    Example: where, at time T, the CB curve passes through a point corresponding to 100 A, the fuse curve at the same time T must pass through a point corresponding to 135 A, or more, and so on.
  - All parts of the fuse curve must be above the CB curve by a factor of 2 or more
    Example: where, at a current level I the CB curve passes through a point corresponding to 1.5 seconds, the fuse curve at the same current level I must pass through a point corresponding to 3 seconds, or more, etc.

The factors 1.35 and 2 are based on the maximum manufacturing tolerances given for MV fuses and LV circuit breakers.

In order to compare the two curves, the MV currents must be converted to the equivalent LV currents, or vice-versa.

Fig. B21 – Selectivity between MV fuse operation and LV circuit breaker tripping, for transformer protection
Fig. B22 – MV fuse and LV circuit breaker configuration

Selectivity between LV circuit breaker and MV circuit breaker

- All parts of the minimum MV circuit breaker curve must be shifted to the right of the LV CB curve by a factor of 1.35 or more:
  - Example: where, at time T, the LV CB curve passes through a point corresponding to 100 A, the MV CB curve at the same time T must pass through a point corresponding to 135 A, or more, and so on.
- All parts of the MV CB curve must be above the LV CB curve. The time difference between the two curves must be 0.3 s at least for any value of the current.

The factors 1.35 and 0.3 s are based on the maximum manufacturing tolerances given for MV current transformers, MV protection relay and LV circuit breakers.

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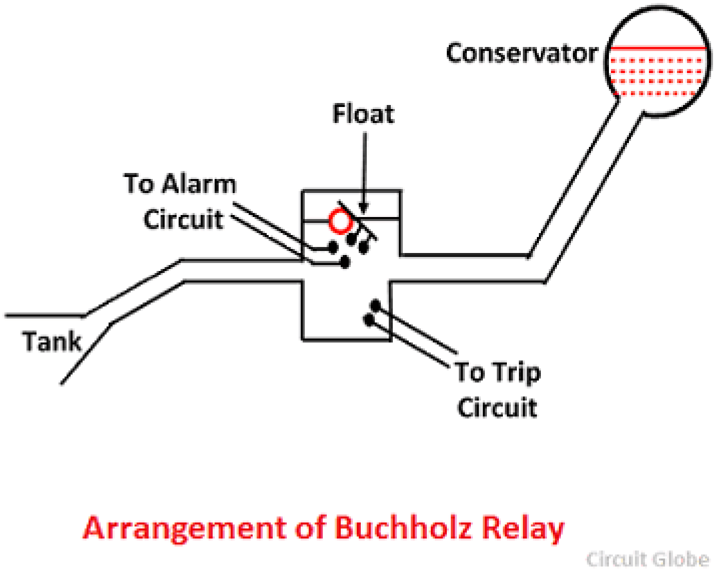
Buchholz Relay

Definition: The Buchholz relay protects the transformer from internal faults**.** It is the gas actuated relay**.** The Buchholz relay is placed between the main tank and the conservator. Such type of relay is used in the transformer having the rating higher than 500KVA. It is not used in small transformer because of economic consideration.

Working Principle of Buchholz Relay

When the fault occurs inside the transformer, the temperature of the oil increases. The oil evaporates in the form of the gas. The generation of the gas depends on the magnitude of the fault occurs inside the transformer. The internal failure occurs in the transformer either because of the insulation breakdown between the winding or the winding have the weak initial contact.



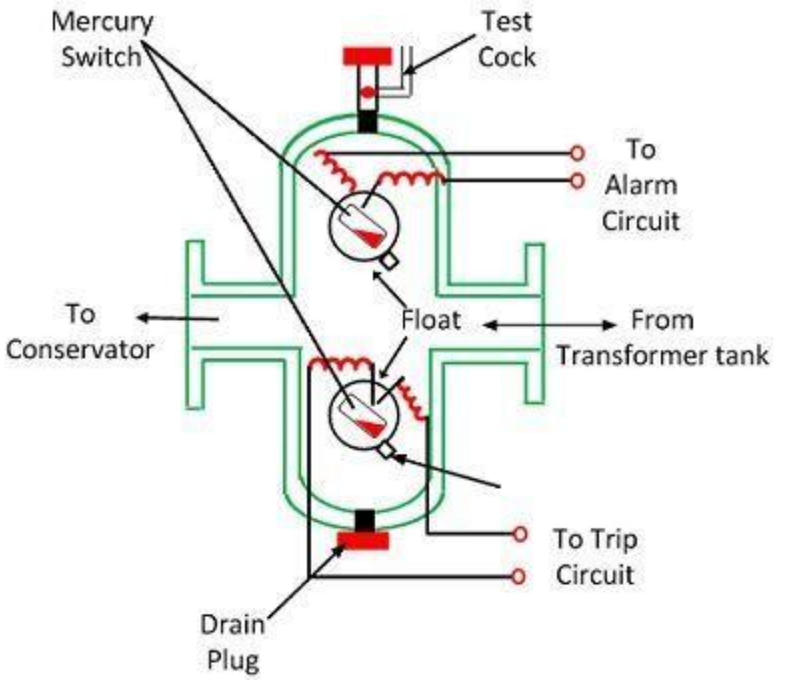
Arrangement of Buchholz Relay

The fault induces the arc which increases the temperature of the gas. The oil becomes evaporated and moves upwards. The Buchholz relay detects the failure and gives the alarm to the personnel. The transformer is disconnected from the main supply for maintenance.

Construction of Buchholz Relay

The Buchholz relay has two hinged which is placed in the metallic chamber. This metallic chamber is connected through the pipe between the conservator and main tank.

The one of the hinged is placed in the upper portion of the metallic chamber along with the mercury switch. This mercury switch is used for activating the alarm. The other float is placed in the lower portion of the metallic chamber along with the mercury switch. The mercury switch is used for actuating the tripping circuit.



Buchholz Relay

Circuit Globe

Operation of Buchholz Relay

The internal fault of the transformer induces the arc inside the main tank. The oil of the transformer starts heating because of the thermal effect. The gas moves upwards, and few of their vapours are collected in the upwards area of the main tank. Because of the evaporation, the level of oil inside the transformer tank starts decreasing.

The mercury switch placed inside the metallic chamber becomes tripped, and the relay gives the alarm to the personnel. The supply of the transformer becomes close, and it is disconnected to the system for maintenance. The relay has test cock which is used for releasing the pressure of the chamber.

When the severe fault occurs inside the transformer, the lower mercury switch placed inside the metallic chamber becomes slightly tilted because of which the tripping circuit becomes closed. Thus, the transformer is disconnected from the main circuit.

Limitations of Buchholz Relay

The following are the disadvantages of Buchholz relay.

1. The relay is used only in oil immersed transformer.
2. It can only detect the fault below oil level.
3. This relay does not protect the connecting cables. Hence separate protection is used for the cables.
4. The response time of the relay is high.

The minimum operating time of the relay is 0.1 seconds.

Protection of Busbars and Lines

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 equipments connected to that section must be tripped out to give complete isolation.

The standard of construction for busbars 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 com-monly used schemes for busbar protection are :

(i) Differential protection ***(ii)*** Fault bus protection

(i) 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 relay.

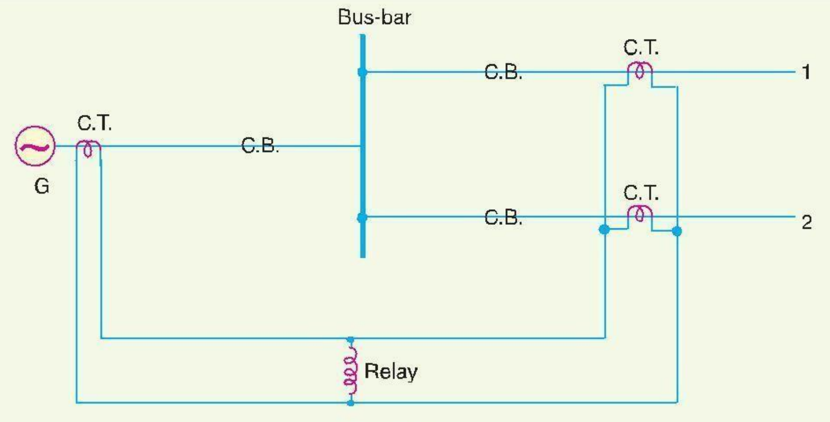


Fig. 23.1

Fig. 23.1 shows the single line diagram of current differential scheme for a station busbar. The busbar is fed by a generator and supplies load to two lines. The secondaries of current transformers in the generator lead, in line 1 and in line 2 are all connected in parallel. The protective relay is connected across this parallel connection. All *CT*s 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.

(ii)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 part. 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.

Fig. 23.2 show the schematic arrangement of fault bus protection. The metal supporting struc-ture 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.

Protection of Busbars and Lines

porting 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.

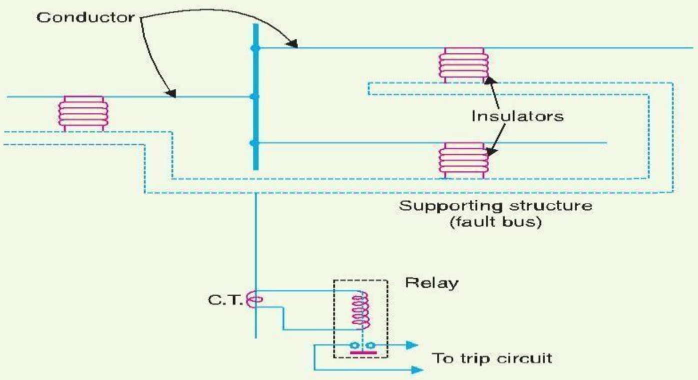


Fig. 23.2

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 :

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

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

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

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

(i) Time-graded over current protection

(ii) Differential protection

(iii) Distance protection

Fig. 23.3

Fig. 23.3 shows the symbols indicating the various types of relay

Time-Graded Overcurrent Protection

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

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 protection of a radial feeder can be achieved by using (*i*) definite time relays and (*ii*) inverse time relays.

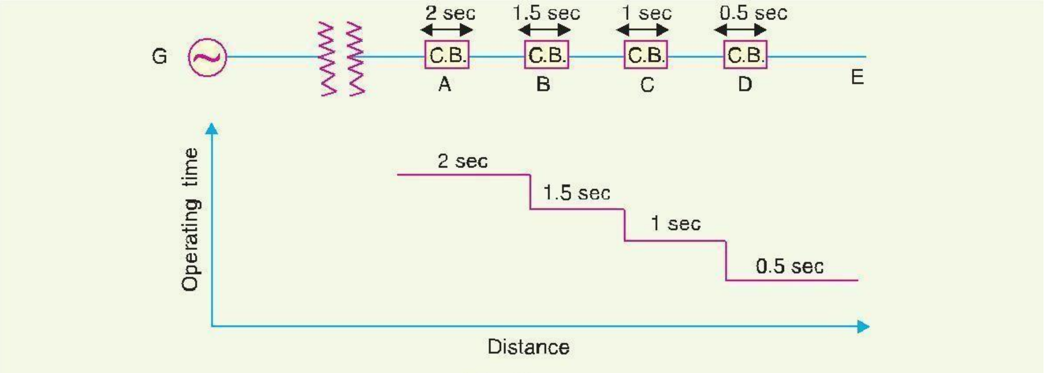


Fig. 23.4

(i) *Using definite time relays.* Fig. 23.4 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.

(ii) *Using inverse time relays.* Fig. 23.5 shows overcurrent protection of a radial feeder using

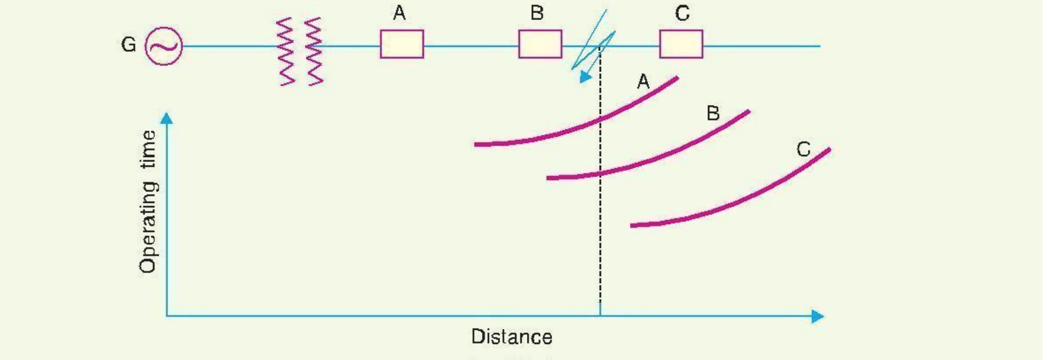
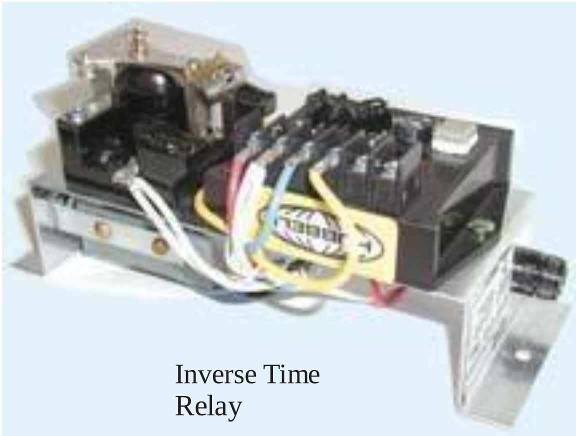


Fig. 23.5

inverse time relays in which operating time is inversely proportional to the operating current. With this arrangement, the farther the circuit breaker from the generating station, the shorter is its relay operating time.

The three relays at *A* , *B* and *C* are as-sumed 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* .



Inverse Time Relay

2. Parallel feeders. Where continu-ity 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.

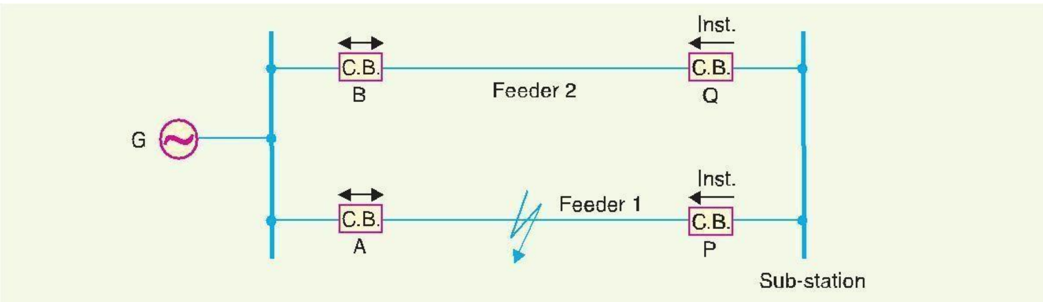


Fig. 23.6

Fig. 23.6 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

(i) each feeder has a non-directional overcurrent relay at the generator end. These relays should have inverse-time characteristic.

(ii) 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 *i.e.* in the direction of arrow at *P* and *Q*.

Suppose an earth fault occurs on feeder 1 as shown in Fig. 23.6. 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.*

(a) directly from feeder 1 *via* the relay *A*

(b) 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 inop-

erative. 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.

3. Ring main system. In this system, various power stations or sub-stations are intercon-nected 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.

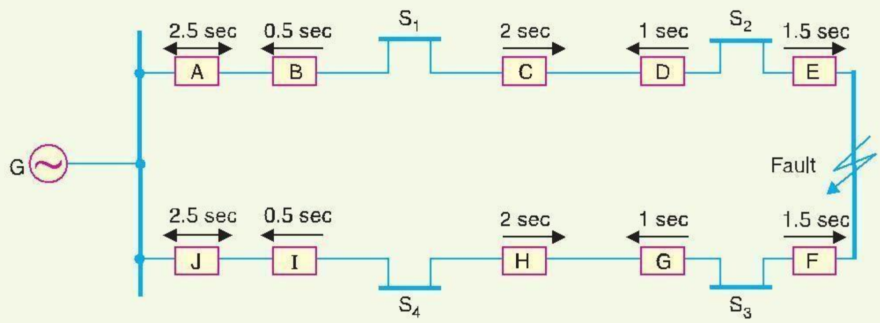


Fig. 23.7

Fig. 23.7 shows the single line diagram of a typical ring main system consisting of one generator *G* supplying four sub-stations S_1, S_2, S_3 and S_4. 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 :

(i) The two lines leaving the generating station should be equipped with non-directional overcurrent relays (relays at *A* and *J* in this case).

(ii) 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).

(iii) There should be proper relative time-setting of the relays. As an example, going round the loop $G\ S_1\ S_2\ S_3\ S_4\ G$; the outgoing relays (*viz* at *A* , *C*, *E*, *G* and *I*) are set with decreasing time limits *e.g.*

$A = 2{\cdot}5$ sec, $C = 2$ sec, $E = 1{\cdot}5$ sec $G = 1$ sec and $I = 0{\cdot}5$ sec

Similarly, going round the loop in the opposite direction (*i.e.* along $G\ S_4\ S_3\ S_2\ S_1\ G$), the *outgoing relays* (*J*, *H*, *F*, *D* and *B*) are also set with a decreasing time limit *e.g.*

$J = 2{\cdot}5$ sec, $H = 2$ sec, $F = 1{\cdot}5$ sec, $D = 1$ sec, $B = 0{\cdot}5$ sec.

Suppose a short circuit occurs at the point as shown in Fig. 23.7. 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 accom-plishes this job. The power will be fed to the fault *via* two routes *viz* (*i*) from *G* around S_1 and S_2 and (*ii*) from *G* around S_4 and S_3. 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

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 protection schemes in use for the lines. However, only the follow-

Protection of Busbars and Lines

ing two schemes will be discussed :

- * Merz-Price voltage balance system
- * Translay scheme

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

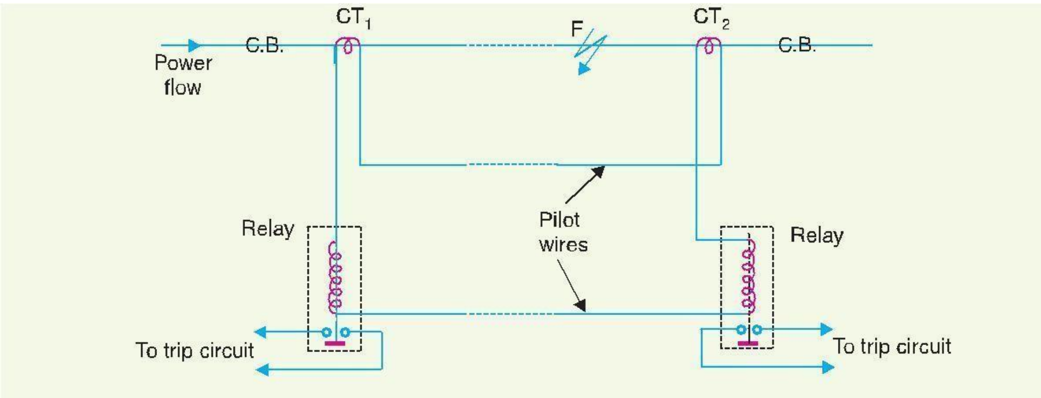
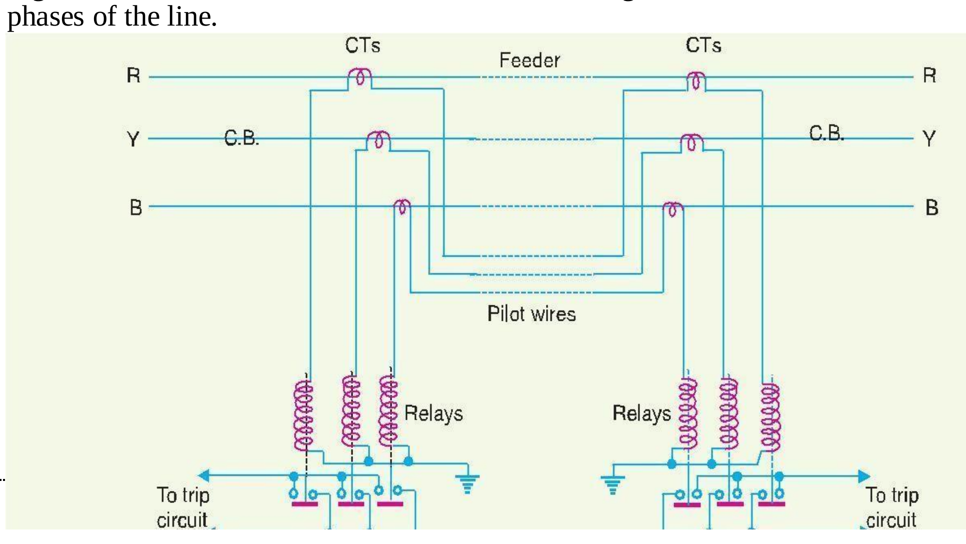


Fig. 23.8

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 *CT*s at the two ends of the line. The result is that no current flows through the relays. Suppose a fault occurs at point *F* on the line as shown in Fig. 23.8. This will cause a greater current to flow through CT_1 than through CT_2. Consequently, their secondary voltages become unequal and circulating current flows through the pilot wires and relays. The circuit breakers at both ends of the line will trip out and the faulty line will be isolated

Fig. 23.9 shows the connections of Merz-Price voltage balance scheme for all the three phases of the line.



Advantages

(i) This system can be used for ring mains as well as parallel feeders.

(ii) This system provides instantaneous protection for ground faults. This decreases the possi-bility of these faults involving other phases.

(iii) This system provides instantaneous relaying which reduces the amount of damage to over-head conductors resulting from arcing faults.

Disadvantages

(i) Accurate matching of current transformers is very essential.

(ii) If there is a break in the pilot-wire circuit, the system will not operate.

(iii) This system is very expensive owing to the greater length of pilot wires required.

(iv) In case of long lines, charging current due to pilot-wire capacitance* effects may be suffi-cient to cause relay operation even under normal conditions.

(v) This system cannot be used for line voltages beyond 33 kV because of constructional diffi-culties in matching the current transformers.

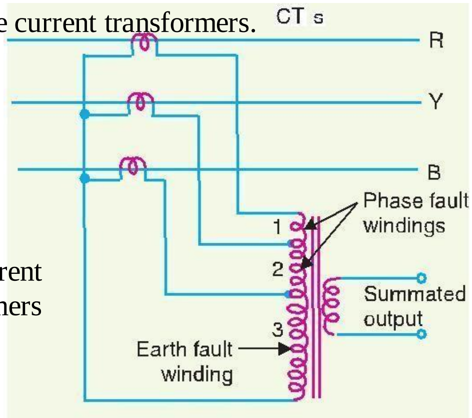


Fig. 23.10

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 in Art. 21.20. This can be extended to 3-phase system by applying one re-lay at each end of each phase of the 3-phase line. However, it is possible to make further simplifica-tion by combining currents derived from all phases in a single relay at each end, using the principle of *summation transformer* (See Fig. 23.10). A summation transformer is a device that reproduces the polyphase line currents as a single-phase quantity. The three lines *CT*s are connected to the tapped primary of summation transformer. Each line *CT* energises a different number of turns (from line to neutral) with a resulting single phase output. The use of summation transformer permits two advan-tages *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 Fig. 23.11. The relays used in the scheme are essentially overcurrent induction type relays. Each relay has two electromagnetic elements. The upper element carries a winding (11 or 11 *a*) which is energised as a summation transformer from the secondaries of the line *CT*s 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.

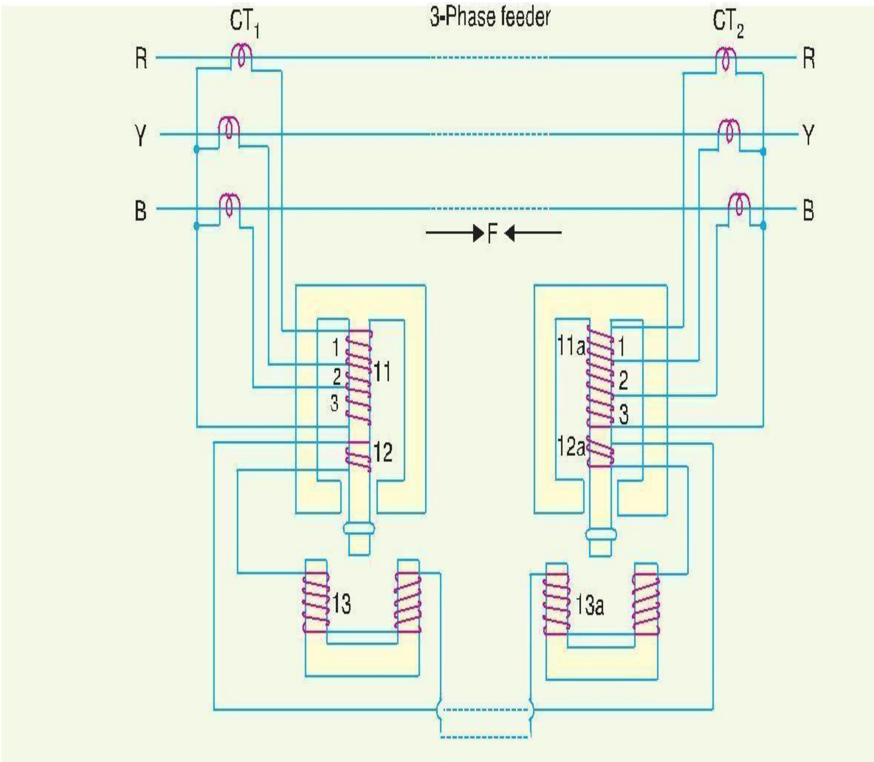


Fig. 23.11

Operation. When the feeder is sound, the currents at its two ends are equal so that the secondary currents in both sets of *CT*s 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 12*a*. Since these windings are connected in opposition, no current flows in them or in the operating windings 13 and 13*a*. 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, 13*a* 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.

(i) Suppose a fault *F* occurs between phases *R* and *Y* and is fed from both sides as shown in Fig. 23.11. This will energise only section 1 of primary windings 11 and 11*a* and induce voltages in the secondary windings 12 and 12*a*. As these voltages are now additive*, therefore, current will circulate through operating coils 13, 13*a* 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 11*a* whereas that between *R* and *B* will energise the sections 1 and 2.

(ii) Now imagine that an earth fault occurs on phase *R*. This will energise sections 1, 2 and 3 of the primary windings 11 and 11*a*. Again if fault is fed from both ends, the voltages induced in the secondary windings 12 and 12*a* are additive and cause a current to flow through the operating coils 13, 13*a*. 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 11*a* 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 11*a*.

Advantages

(i) The system is economical as only two pilot wires are required for the protection of a 3-phase line.

(ii) Current transformers of normal design can be used.

(iii) The pilot wire capacitance currents do not affect the operation of relays.

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 expen-sive 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 with-out employing pilot wires.

The principle and operation of distance relays have al-ready been discussed in chapter 21. We shall now consider its application for the protection of transmission lines. Fig. 23.12 (i) 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 A B, then only relay at A will operate. In this manner, instantaneous protection can be obtained for all conditions of operation.

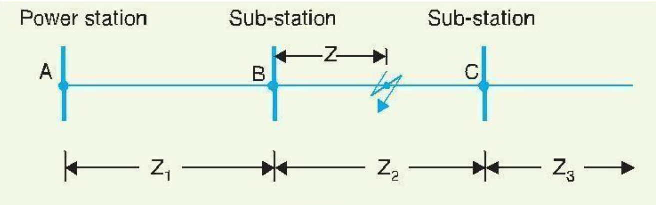


Fig. 23.12 (i)

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 Fig. 23.12 (i)] would not be very reliable in distinguishing between a fault at 99% of the distance A B and the one at 101% of distance A B. This difficulty is overcome by using *'three-zone'* distance protection shown in Fig. 23.12 (ii).

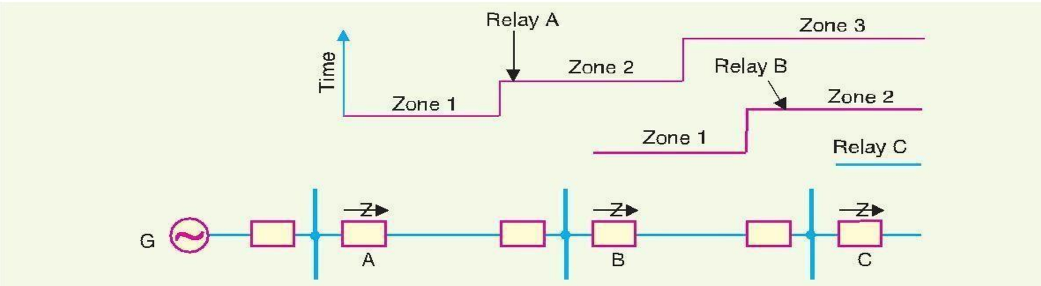


Fig. 23.12 (ii)

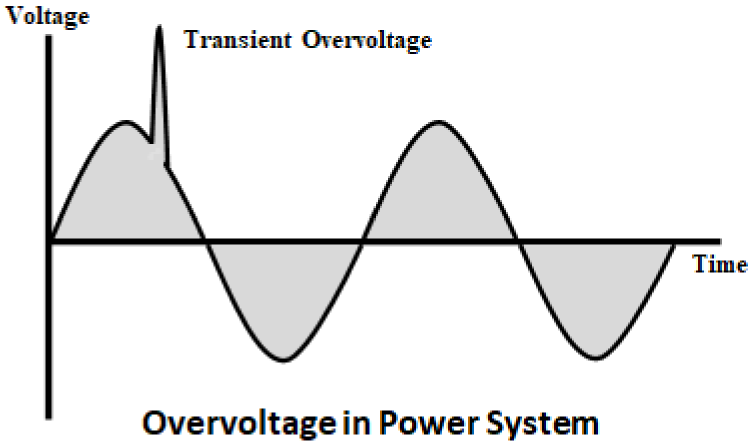
(CHAPTER-7)

PROTECTION AGAINST OVER VOLTAGE AND LIGHTING

Overvoltage or Voltage Surge in Power System - :

The overvoltage or transients or surge voltages are the voltages whose values are much more than the normal voltages. These are of short duration which can cause malfunction or failure of equipment in the system depending upon the severity of the voltage level. The overvoltage with a level above twice the standard peak voltage of the system will cause degradation of electronic components and insulation in the equipment of the system. The main causes of over voltages in power systems are classified as,

- Internal causes, and
- External causes.



Overvoltage in Power System

Overvoltage due to Internal Causes :

These causes are due to some abnormal conditions generated in the circuit itself. These abnormal conditions not only change the system's parameters but also damage the circuit under severe conditions. Internal causes of over voltages are mainly due to,

- Switching surges,
- Insulation failure,
- Arcing ground, and
- Resonance.

Switching Surges :

Switching surges are the over voltages produced on a power system due to switching operations. The study of switching surges is important for designing the insulation of winding and for insulation coordination of EHV lines. Some of the causes for the production of switching surges are listed below,

- Switching of an Unloaded Line or Open Line - Switching surges due to switching of an unloaded line arise due to traveling wave phenomenon being originated and due to sudden application of a voltage in the line as soon as the circuit breaker at the sending end is closed. Successive reflection of the voltage wave causes over voltages in the line.
- Switching of a Loaded Line - Surges are also produced during the switching operation of a loaded line. Let us consider a loaded line and is suddenly interrupted which results in a voltage setup of $2Z_n$ i across the switch. Where i is the initial value of current at the time of opening of the line and Z_n is the natural impedance of the line. If V_p is the phase voltage and V_s is the voltage across the switch, then the maximum value of voltage to which a line may be subjected is,

$$V_m = V_p + V_s \text{ kV}$$

- Reactor Switching - Reactor switching may cause current chopping. Current chopping is the phenomenon of current interruption before the natural current zero is reached. Current chopping results in the production of high voltages due to the transfer of energy in inductance (1/2 LI^2) to capacitance (1/2 CV^2) across the contacts of the circuit breaker. Over voltages due to current chopping can be reduced by resistance switching.
- Short-circuits and Line-faults Interruption - In a circuit breaker, after clearing faults a transient restriking voltage appears which may cause over voltages.
- Auto-reclosing of Circuit-breaker in Long EHV Lines - High-speed three-phase auto-reclosure generates surges in long lines due to closure on the trapped change of the line. The surge voltages are influenced by non-simultaneous reclosure of all the three-phase poles.
- Opening of Only One Phase due to Occurrence of Fault Cable Charging Circuit Switching OFF - In a 3-phase system, when a fault occurs on any one phase, then the phase voltage of the remaining two phases will increase beyond its normal value until the fault is cleared. This rise in voltage across the healthy phases appears as a surge.

Insulation Failure :

The over voltages are also caused due to the insulation failure between line and ground or the grounding of the conductor in a power system.

Arcing Ground :

Arcing ground is commonly caused in long transmission line operations on high voltages due to oscillation. The high voltage surges produced due to the arcing ground can damage the power system apparatus severely. The voltage produced due to arcing grounds is nearly 3 to 4 times the power frequency voltage. Arcing grounds can be avoided by earthing the neutral.

Resonance :

In an electrical system when inductive reactance of the circuit becomes equal to capacitive reactance, resonance takes place. High voltage surges are produced in the power system due to resonance in transmission lines. Resonance rarely occurs as the capacitance is very small. In the case of cables, resonance may occur due to the 5th harmonic component.

Overvoltage due to External Causes :

External causes of over voltages in a power system are mainly due to lightning. The other factors which cause over voltages are as follows,

- Indirect lightning strokes such as lightning discharge taking place near the line result in electromagnetically induced over voltages.
- Different atmospheric conditions along the line length will cause overvoltages.
- Over voltages are produced due to friction between the atmospheric particles such as dust, dry snow, etc.
- Over voltages are produced due to lightning between the two nearby clouds.

In general, the majority of faults on the power system are transient in nature and caused due to switching operations or lightning surges. However, the surges cause due to lighting strokes have a very high voltage of million volts, which can cause the insulation breakdown and further damage the components of the power system. The high voltages produced can also cause disturbances in neighborhood transmission lines. Hence, it is necessary to protect all the lines and equipment connected to the network in power systems.

The underground cables are not affected by lightning surges and can be protected against lightning surges. The protection of overhead lines from lightning surges is done by running one or more wires above the overhead lines, which is at ground potential. These wires are also called ground wires.

Switching surges do not affect systems where operating voltages are below 230kV. However, switching surges cause damage to power systems where the operating voltage is above 230kV and it is worse for operating voltages above 700kV. Hence protection system should be employed.

Lightning Stroke

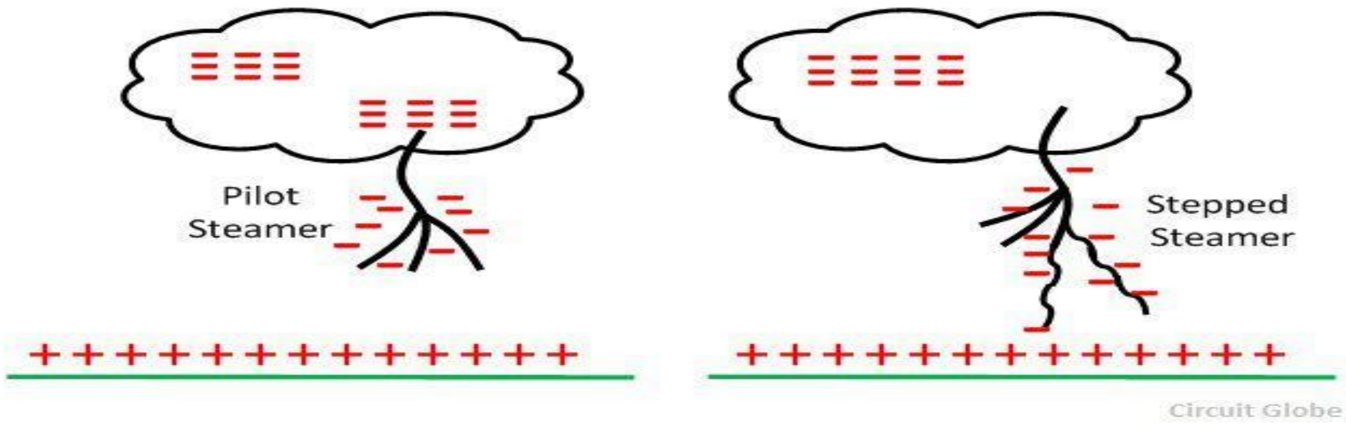
Definition: Lightning stroke is the direct discharge of an electrical charge between the atmosphere and the object of earth. It is a sudden flow of electric charge between the electrical charge area of a cloud also called intra-cloud and another cloud called (CC lightning) or between the charged cloud and the ground (CG lightning.

The charge region of the cloud is equal to the electric discharge. When the cloud charge is discharged on the ground, then it is called a strike, and if the discharge is hit on the object, then it is called flash. The lightning occurs in the form of the plasma and sound in the form of thunder.

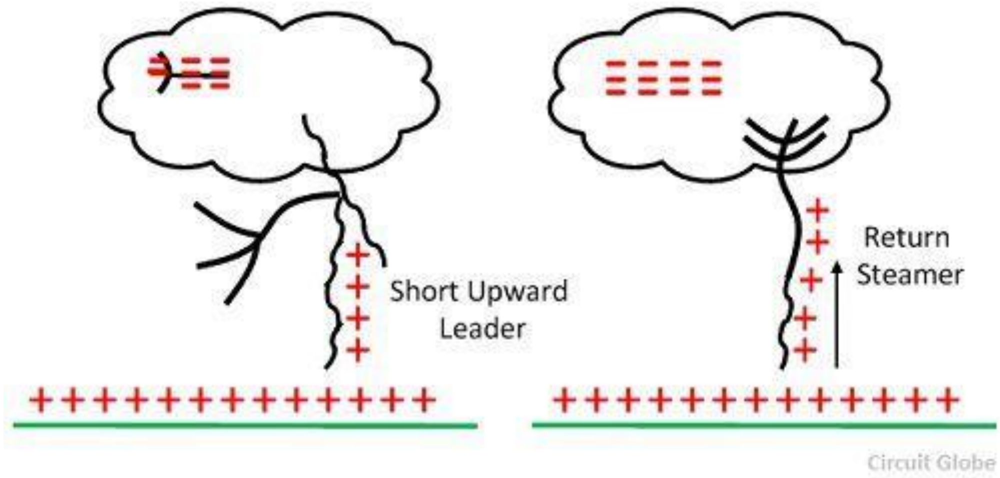
Mechanism of the Lightning Discharge

In the atmosphere, the positive, as well as the negative ions in the air, attach themselves to the small dust particles. The water drops present in the air also get charged because of polarisation by induction. These charged particles and water drops charged the clouds. The positive ions are collected in the upper region, and the negative ions are collected in the lower region of the cloud because of their mass.

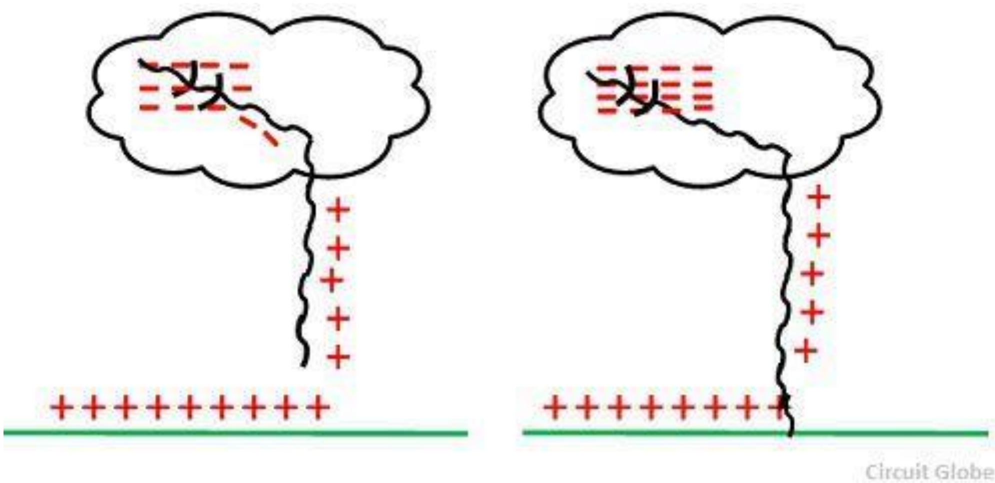
When the charge cloud passes over the earth, it induces an opposite charge in the earth below. The potential difference in the cloud is not much greater than that at the earth’s surface, the discharge originates in the clouds. The potential gradient of the clouds is not uniform, and it is of the order of 10 – 30 KV/cm in any part of the cloud. The initial discharge which is also called **pilot discharge or pilot leader** moves slowly towards it from the earth.



The first discharge moves to earth in steps of about 50 meters each and is, therefore, termed the stepped leader. The pilot leader carries a charge with it, and the potential gradient at its tips is very high. It ionises the air and provides a path or channel for the pilot leader. The channel also becomes charged. The pilot leader carries secondary steamer which branches out from it.



When the pilot steamer reaches near the earth, the electric field intensity increases and due to this, the charges of an opposite polarity in the form of a short steam rises from the earth to meet the tip of downward leader. When a contact is made between the pilot leader and the short upward steamer, a return streamer travel from the earth to cloud along the ionised channel formed by the pilot leader. The return steamer moves very fast and produces the well known, intensely luminous lightning flash.



The potential of the portion of the cloud from where the discharge originated is lowered by the passage of the charge through the ionised channel to the earth. But the other portion of the clouds remains charged. Therefore, a high potential develops between the original charge centre and another charge centre in the clouds.

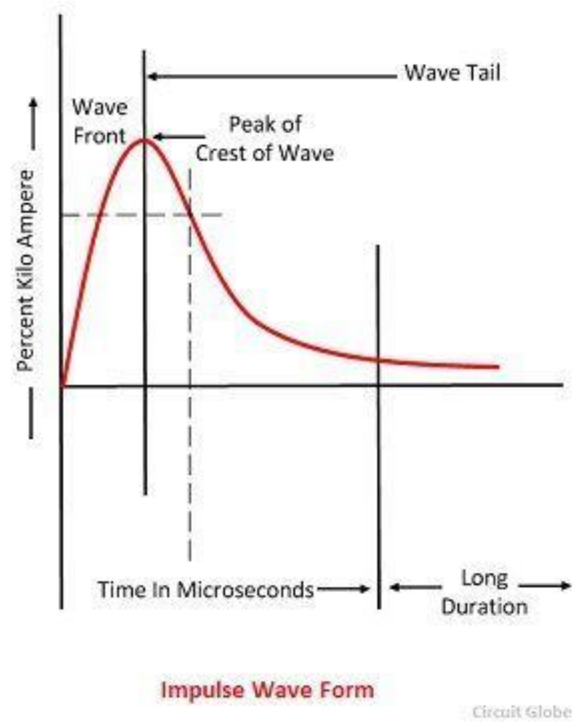
The charge of the other charge centre is first transferred to the first one, and then it passes to the earth through the ionised channel made by the first discharge. The second’s discharge is unbranched and without steps. Its velocity is more than that of the pilot leader. This is known as the dart leader, and it is also followed by the return strokes.

Similarly, the other charges are discharged to the earth in the form of leader and return strokes along the same ionised channel. Lightning strokes with any discharge are known as multiple or repetitive strokes. The lightning is called referred to as hot or cold depending upon the magnitude and duration of the stroke.

The stroke of lightning has a low current but long duration. It causes the fire when it strokes on the object. The stroke of cold, lightning has a high current, but it is of short duration. It causes an explosion when it strikes on an object.

Waves Shapes of Stroke Currents

The wave shapes consist of a portion showing the steep rise of voltage up to a peak or crest value called the wavefront, and the other portion showing the decay of voltage called the wave tail. Such a wave shape may be represented as the difference of two exponentials, thus



$$e = E\left(\varepsilon^{-\alpha t} - \varepsilon^{-\beta t}\right)$$

Where the ∝ and β show the constants which determine the shapes. The waves are defined by times t_1 and t_2 in milliseconds. The times to reach the impulse current or voltage to its maximum amplitude is denoted by t_1, while t_2 denotes the times when the current or voltages has fallen to one-half of its peak value.

Types of Lightning Stroke

The lightning stroke affects the lines in two ways

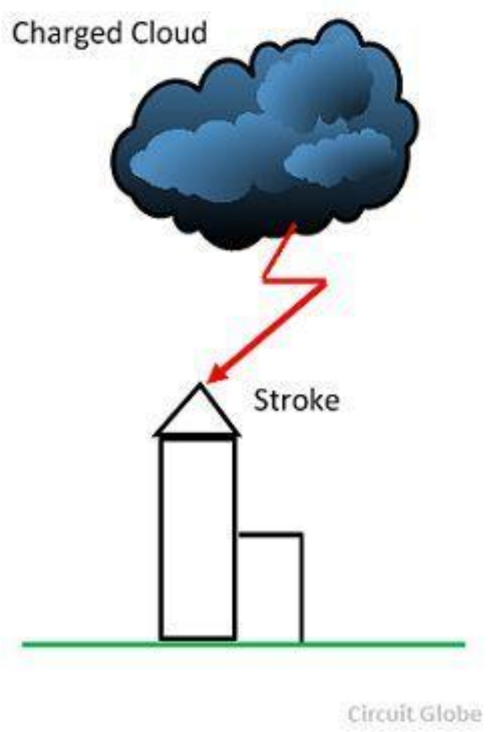
1. Direct stroke

2. Electrostatic induction.

These ways are explained below in details.

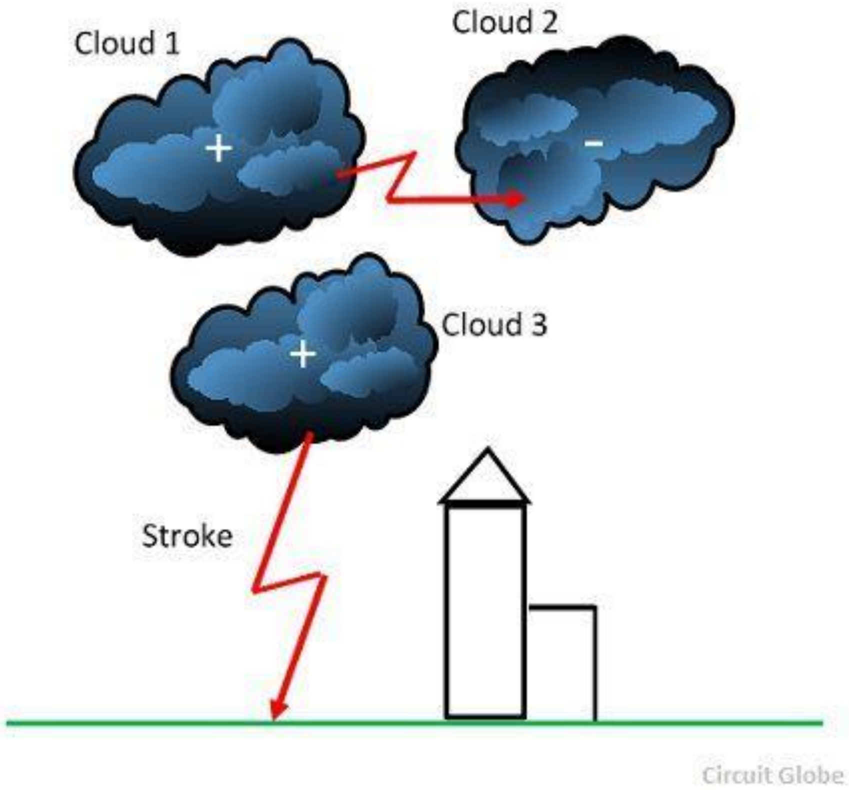
1. Direct Stroke

In the direct lightning strokes, the cloud attains a large amount of charge and induces an opposite charge on taller objects such as temple, churches or mosques. When the intensity of electrostatic field becomes sufficiently great to ionise the neighbouring air, the air break down and discharge takes place between the cloud and the object. Such types of discharge take a long time to produce, and it strikes the highest and the most sharply pointed building in the neighbourhood.



2. Electrostatic Induction Stroke

Consider the three clouds, clouds 1 and 3 are positively charged, and cloud 2 is negatively charged as shown in the figure below.



The potential of cloud 3 is reduced due to the presence of the charged cloud 2. On the flash over from Cloud 1 to Cloud 2, both these clouds are discharged rapidly, and class 3 assumes a much potential and flashes to earth very rapidly. It is the most dangerous strokes because it ignores taller building and reaches directly to the ground. This stroke is called the induces strokes.

Lightning Arrester

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 twelve types. These types are;

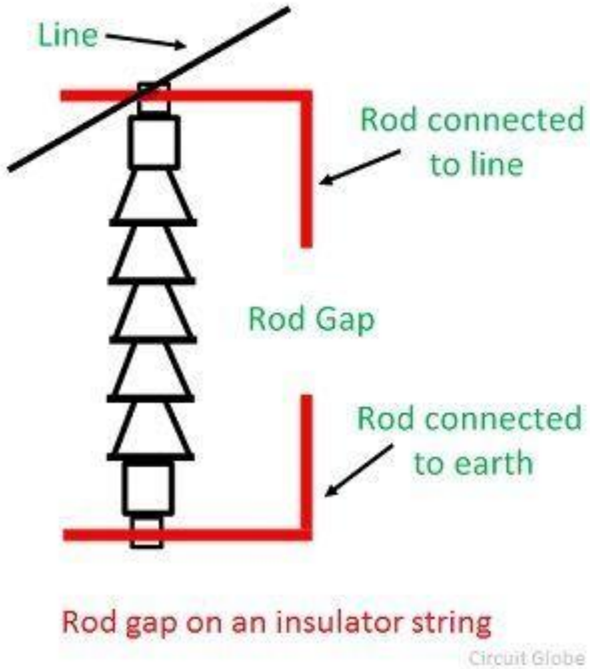
Types of Lightning Arresters

1. Road Gap Arrester
2. Sphere Gap Arrester
3. Horn Gap Arrester
4. Multiple-Gap Arrester
5. Impulse Protective Gap
6. Electrolytic Arrester
7. Expulsion Type Lightning Arrester
8. Valve Type Lightning Arresters
9. Thyrite Lightning Arrester
10. Auto valve Arrester
11. Oxide Film Arrester
12. Metal Oxide Lightning Arresters

Their types are explained below in details.

1. Rod Gap Arrester

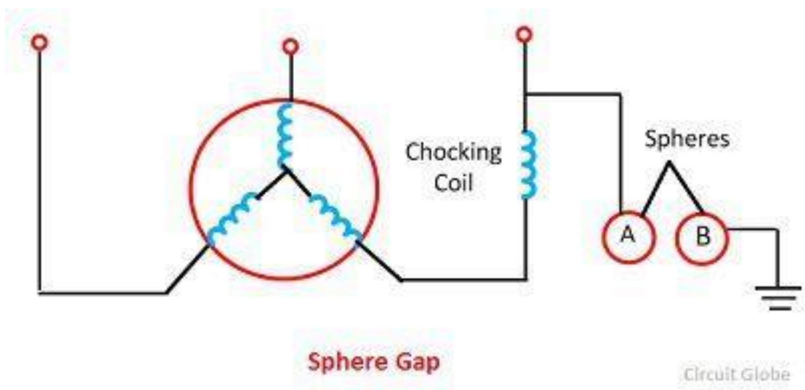
It is one of the simplest forms of the arrester. In such type of arrester, there is an air gap between the ends of two rods. The one end of the arrester is connected to the line and the second end of the rod is connected to the ground. The gap setting of the arrester should be such that it should break 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.



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.

2. Sphere Gap Arrester

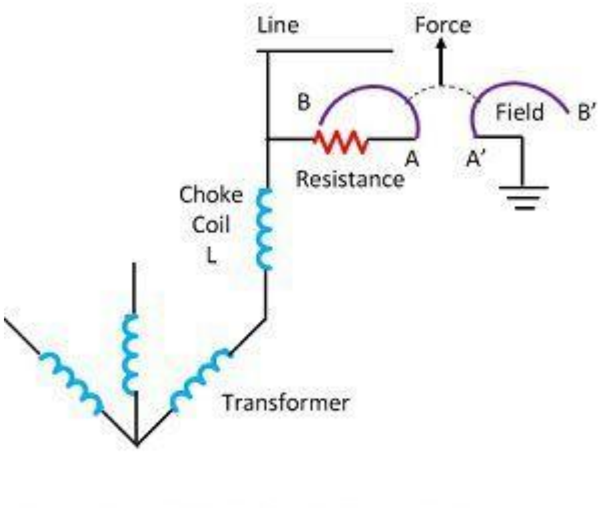
In such type of devices, the air gap is provided between two different spheres. One of the spheres is connected to the line, and the other sphere is connected to the ground. The spacing between the two spheres is very small. A choking coil is inserted between the phase winding of the transformer and spheres is connected to the line.



The air gap between the arrester is set in such a way so that the discharge must not take place at normal operating condition. The arc will travel up the sphere as the heated air near the arc tend to rise upward and lengthening till it is interrupted automatically.

3. Horn Gap Arrester

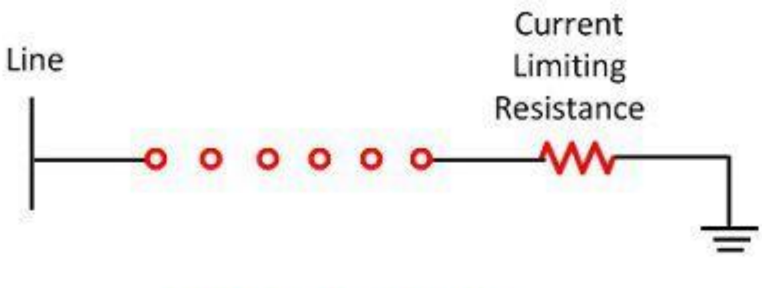
It consists of two horns shaded piece of metal separated by a small air gap and connected in shunt between each conductor and earth. The distance between the two electrodes is such that the normal voltage between the line and earth is insufficient to jump the gap. But the abnormal high voltage will break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



Horn Gap With Choke Coil and Resistance

4. Multiple- Gap Arrester

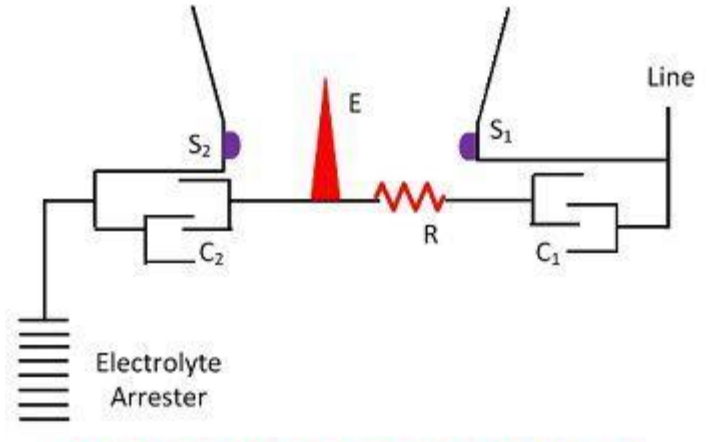
The multiple gap arrester consists a series of small metal cylinder insulated from one another and separated by an air gap. The first and the last of the series is connected to ground. The number of gaps required depends on the line voltage.



Multiple-Gap Arrester

5. Impulse Protective Gap

The protective impulse gap is designed to have a low voltage impulse ratio, even less than one and to extinguish the arc. Their working principle is very simple as shown in the figure below. It consists of two sphere electrode S_1 and S_2 which are connected respectively to the line and the arrester.



Impulse Protective Gap with Electrolytic Arrester

The auxiliary needle is placed between the mid of two sphere S_1 and S_2. At normal frequency, the impedance of the capacitance C_1 is quite large as compared to the impedance of resistor R. If C_1 and C_2 are equal the potential of the auxiliary electrode will be midway between those of the S_1 and S_2 and the electrode has no effect on the flash over between them.

When the transient occurs the impedance of capacitor C_1 and C_2 decrease and the impedance of the resistor now become effective. Due to this, the whole of the voltage is concentrated across the gap between E and S_1. The gap at once breakdown, the rest of the length between E and S_2 immediately follow.

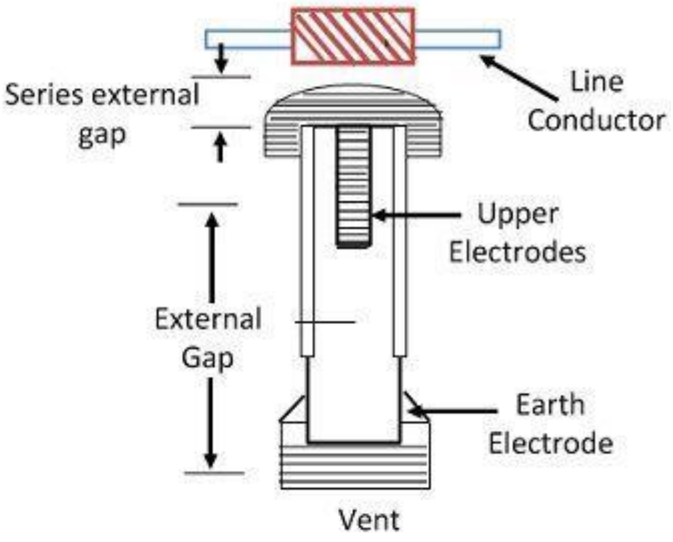
6. Electrolyte Arrester

In such type of arrester have high a large discharge capacity. It operates on the fact that the thin film of aluminium hydroxide deposits on the aluminium plates immersed in the electrolyte. The plate acts as a high resistance to a low value but a low resistance to a voltage above a critical value.

Voltage more than 400 volts causes a puncture and a free flow of current to earth. When the voltage remains its normal value of 440 volts, the arrester again offers a high resistance in the path and leakage stops.

7. 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.



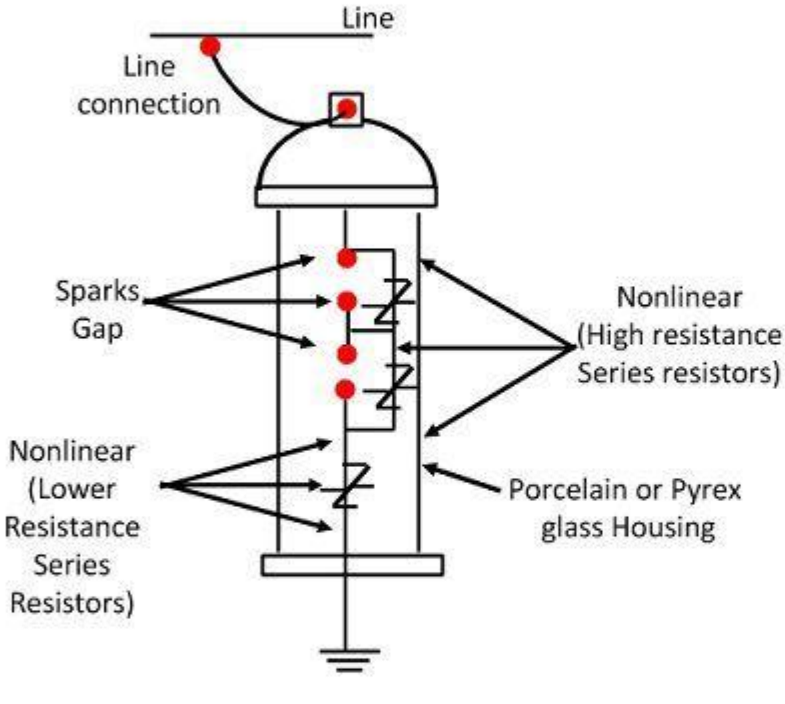
Expulsion-type Surge Diverter

Circuit Globe

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.

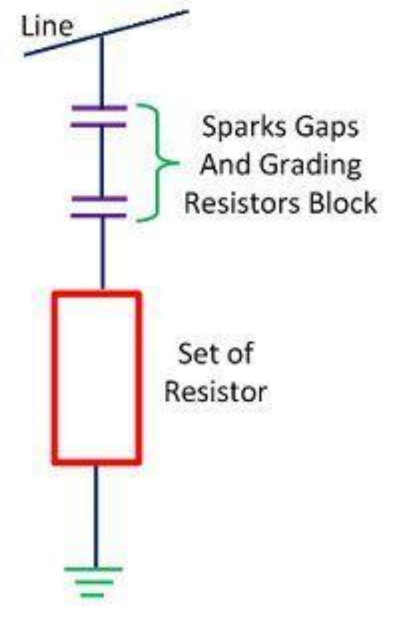
8. Valve Type Lightning Arrester

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.



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.

9. Thyrite Lightning Arrester

Such type of arrester is most commonly used for the protection against dangerous high voltage. It consists the thyrite which is an inorganic compound of ceramic material. The resistance of such material decreases rapidly from high value to low value and for current from a low value to high value.

It consists a disc whose both the side is sprayed so as to give the electric contact between the consecutive disc. The disc is assembled inside the glazed porcelain container. It is used in conjunction with the container.

When the lightning takes place, the voltage is raised, and breakdowns of the gaps occur, the resistance falls to a very low value, and the wave is discharged to earth. After the surge has passed the thyrite again come back to its original position.

10 Autovalve Arrester

Such type of arrester consists some flat discs of a porous material stacked one above the other and separated by the thin mica rings. The disc material is not homogenous and conducting material also have been added. Therefore the glow discharge occurs in the capillaries of the material and voltage drop to about 350 volts per unit. The discs are arranged in such a way that normal voltage may not cause a discharge to occur.

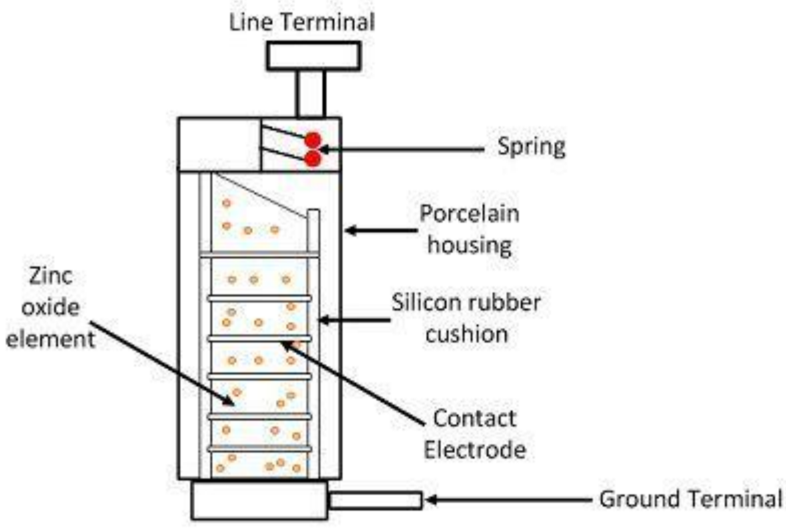
11. Oxide Film Arrester

It consists of pellets of lead peroxide with a thin, porous coating of litharge arranged in a column and enclosed in a tube of diameter. Out of the two lead, the upper is connected to the line, while the lower is connected to the earth. The tube contains a series spark gap.

When an overvoltage occurs an arc passes through the series spark gap and an additional voltage is applied to the pellet column and a discharge takes place. After the discharge, the resistance of the pellet gun increases till only very small current flow through it. This small current is finally interrupted by the series spark gaps.

12. Metal Oxide Lightning Arrester

Such Types of diverter are also known as gapless surge diverters, or Zinc oxide diverter. The base material used for manufacturing metal oxide resistor is zinc oxide. It is a semiconducting N-type material. The material is doped by adding some fine power of insulating oxides. The powder is treated with some processes and then it is compressed into a disc-shaped. The disc is then enclosed in a porcelain housing filled with nitrogen gas or SF6.



Zinc Oxide Surge Arrester

This arrester consists a potential barrier at the boundaries of each disc of ZNO. This potential barrier controls the flow of current. At normal operating condition, the potential barrier does not allow the current to flow. When an overvoltage occurs, the barrier collapse and sharp transition from insulating to conducting take place. The current start flowing and the surge is diverted to ground.

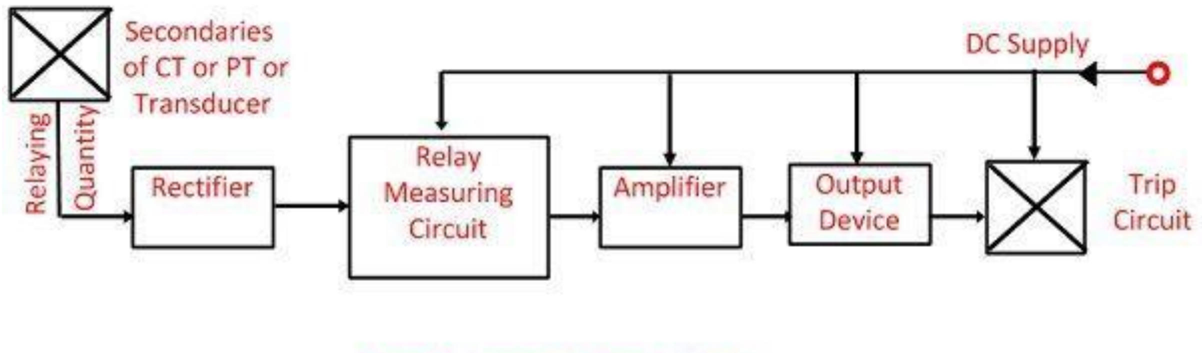
(CHAPTER-8)

STATIC RELAY

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.

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



Block Diagram of Static Relay

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

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

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

Advantages of Static Relay

The following are the benefits of static relays.

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.

Instantaneous Over current Relays:

If the relay operates instantly without any intentional time delay, this characteristic can generally be satisfied by a relay of the non-polarized attracted armature type. This relay has a special advantage of reducing the time of operation to a minimum for faults very close to the source, where the fault current is the greatest. The Instantaneous Over current Relays is effective only where the impedance between the relay and source Z_s is small compared to the protected section impedance Z_l.

One of the most important considerations in overcurrent and overvoltage applications is speed of operation. With hinged armature relays, operating times of 0.010 second at three times the setting can be obtained. Such relays are used for restricted earth-fault and other forms of circulating current protection. With so fast an operation it is likely that the relay may operate on transients beyond the normal range of setting.

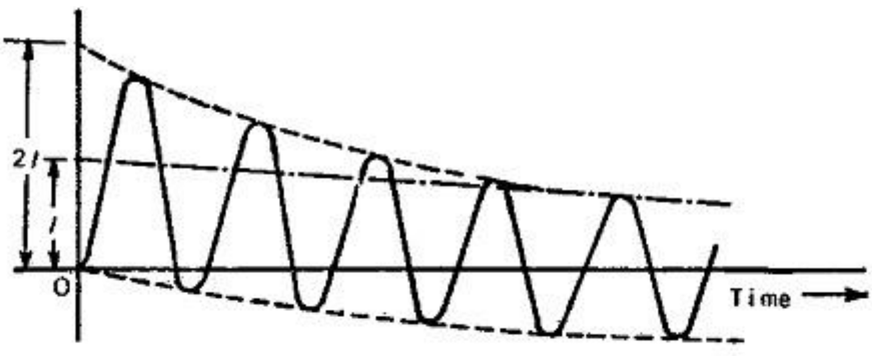


FIGURE 4.9 Offset current wave.

A relay is said to overreach when it operates at a current which is lower than its setting. Now at the time of fault occurrence the current wave is not symmetrical but offset as shown in Fig. (4.9).

The relay is set for symmetrical currents but responds to both symmetrical and offset current waves which persist for a few cycles. The overreach depends on the design of the relay as well as on the parameters of the power system on which it is used. The X/R ratio of the system from the source to the fault, controls the degree of offset and rate of decrement of the current wave, and the ratio Z_s/Z_l, determines the degree of overreach which will occur.

The current setting is proportional to $1/(Z_s + Z_l)$ so that with 100%, offset the pickup would occur with half the symmetrical value of current, i.e. the operating current is now proportional to $1/2(Z_s + Z_l)$

Since Z_s is fixed, the effective length of the line protected is increased, consequently the overreach may be more than twice the length of the protected section. If K is the overreach,then

i.e. with 100% offset current wave-the Instantaneous Overcurrent Relays will overreach to more than twice the length of the protected section.

Actually the overreach will be reduced by the operating time of the relay because the d.c. component of the fault current will be decaying exponentially, so that

$$i = \frac{E_{\max}\sin(\omega t+\psi-\phi)}{\sqrt{R^2+(\omega L)^2}} + \frac{E_{\max}\epsilon^{-rt/L}\sin(\psi-\phi)}{\sqrt{R^2+(\omega L)^2}}$$

$$= I_{\max}\left[\sin(\omega t+\psi-\phi)+A\epsilon^{-rt/L}\right]$$

where Φ is the phase angle of the circuit ($\tan^{-1}\omega L/R$), ψ is the time in radians after time zero at which the fault occurs and t is the time after the inception of the fault. Modern compensated relays are available which have a very low transient overreach (approximately 5%), they do not respond to offset waves by the use of a d.c. filter. In the U.S.A. induction cup instantaneous units are used, because they are less sensitive to the d.c. offset component.

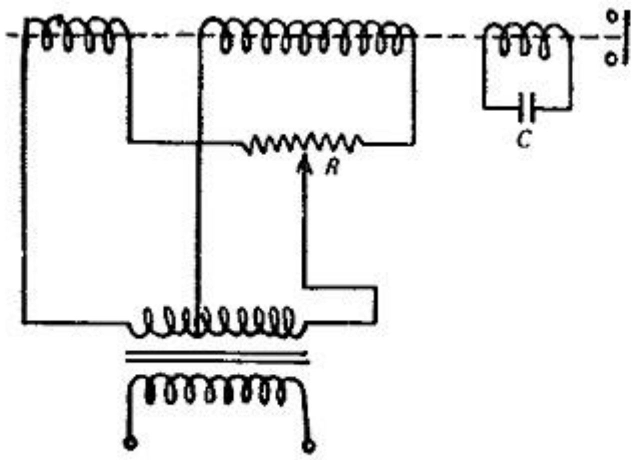


FIGURE 4.10 Instantaneous overcurrent relay with negligible overreach.

Another simple arrangement to achieve low transient overreach designed for high set overcurrent protection is shown in Fig. (4.10). The capacitor across the auxiliary winding on the operating magnet causes the circuit to resonate at 50 H_s so that the current takes a short time to build up to the getting value. The potentiometer adjustment of the setting provides a setting range maximum to minimum of 4 to 1.

Basic on Inverse Definite Minimum Time Over-current Relay (IDMT

Relay)

Working Principle of an Over-current Relay: In an over current relay or o/c relay the actuating quantity is only current .There is only one current operated element in the relay, no voltage coil etc.are required to construct this protective relay.In an over current relay, there would be essentially a current coil. When normal current flows through this coil, the magnetic effect generated by thecoil 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.