Lecture Note

on

Switchgear and Protective Devices

of

6th semester , Electrical Engineering Branch

Contents Written by

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TOPIC - 1

INTRODUCTION TO SWITCHGEAR

Definition of Switchgear:

A **switchgear** is a generic term which includes all the switching devices associated with power system protection. It also includes all devices associated with control, metering and regulating of electrical power systems. Assembly of such devices in a logical manner forms **switchgear**. In other words systems used for switching, controlling and protecting the electrical power circuits and different types of electrical equipment are known as **switchgear**. This is very basic **definition of switchgear**.

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.

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.
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.

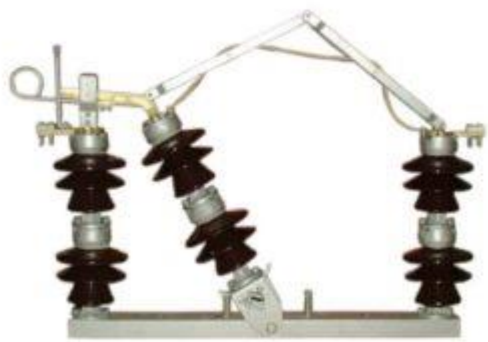
When the contacts of a switch are opened, an arc is produced in the air between the contacts. This is particularly true for circuits of high voltage and large current capacity.

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.

i. **Air-break switch** – It is an air switch and is designed to open a circuit under load. In order to quench the arc that occurs on opening such a switch, special arcing horns are provided.
ii. **Isolator or disconnecting switch** – It is essentially a knife switch and is designed to open a circuit under no load.
iii. **Oil switches** – As the name implies, the contacts of such switches are opened under oil, usually transformer oil.

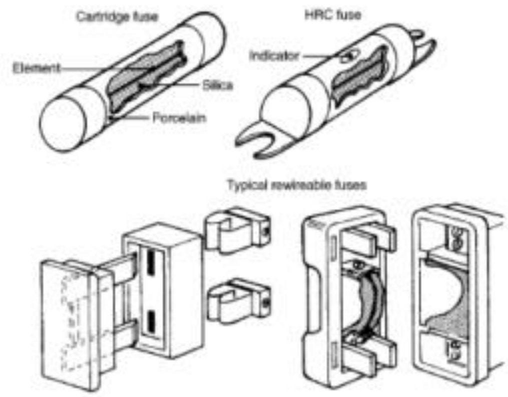


Air Break Switch

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**

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.

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.
These types of equipment are extensively used in the continents of America and Australia due to their distinct advantages over conventional switchgear.

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.

Types of Bus-Bar Arrangements: 8 Types

1. Single Bus-Bar Arrangement:
This is the simplest arrangement consisting of a single set of bus-bars for the full length of the switchboard and to this set of bus-bars are connected all the generators, transformers and feeders, as illustrated by single line diagram in Fig. 16.19.

Each generator and feeder is controlled by a circuit breaker. The isolators permit isolation of generators, feeders and circuit breakers from the bus-bars for maintenance. The chief advantages of such a bus-bar arrangement are low initial cost, less maintenance and simple operation.

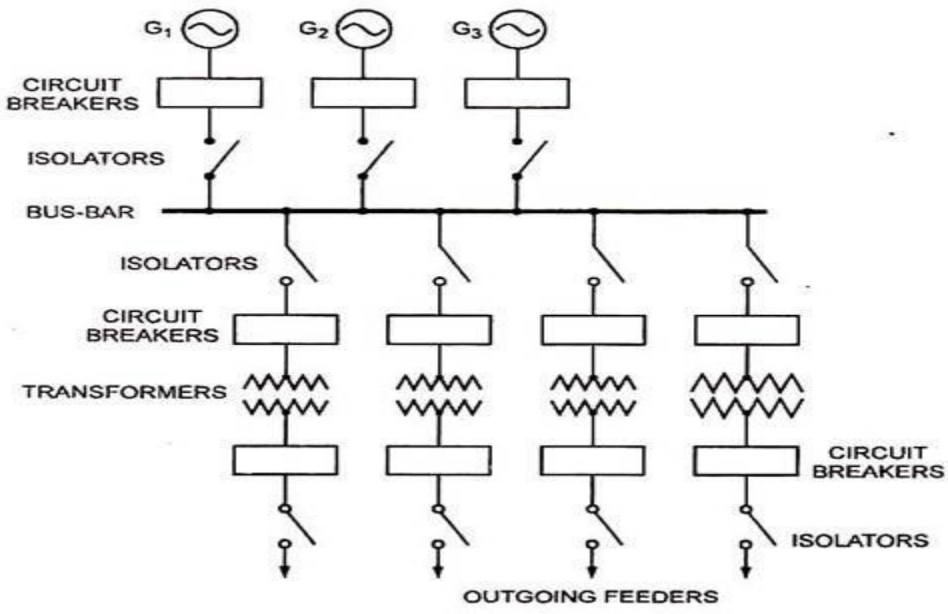


Fig. 16.19. ***Single Bus-Bar Arrangement***

The glaring drawback of this system is that in case of fault on the bus-bars, whole of the supply is affected and all the healthy feeders are disconnected. Moreover, when maintenance is to be carried out on any of the feeder sections or on a part of bus-bar the whole supply is to be disrupted. Thus such an arrangement provides least flexibility and immunity from total shutdown.

Such bus-bar arrangement is employed for switchboards, small and medium sized substations, small power stations and dc stations.

Single Bus-Bar Arrangement with Bus Sectionalization:

The bus-bar may be sectionalized by a circuit breaker and isolating switches so that a fault on one part does not cause a complete shutdown. In large generating stations, where several units are installed, it is a common practice to sectionalize the bus as illustrated in Fig. 16.20.

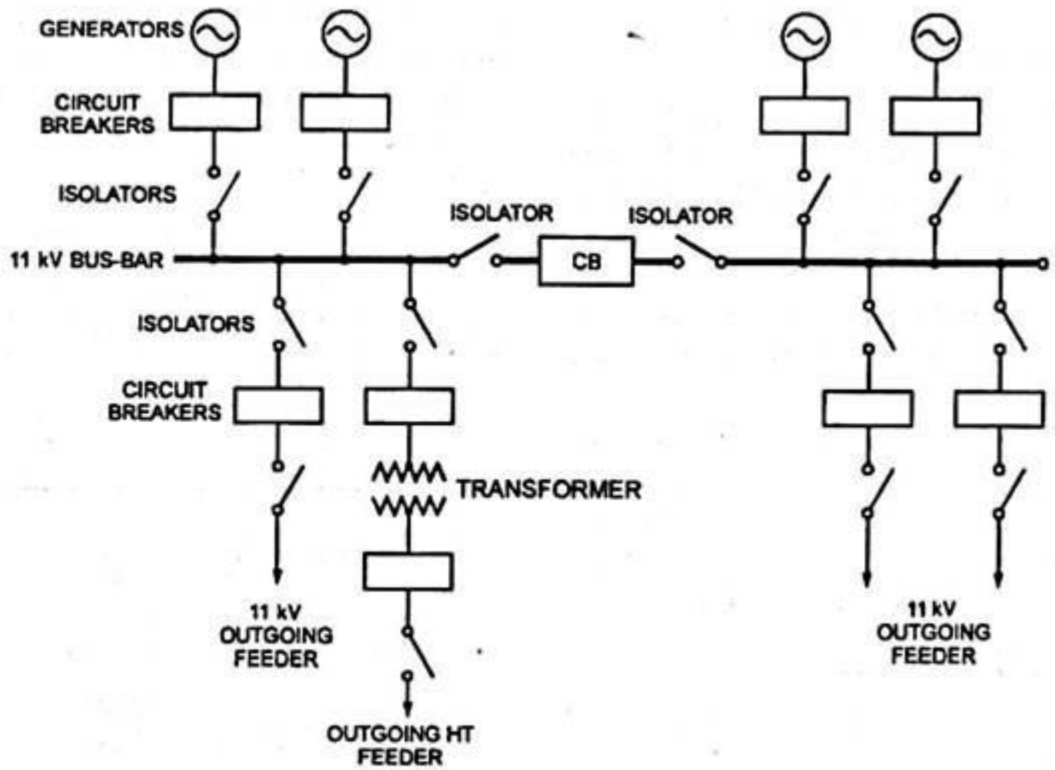


Fig. 16.20. ***Sectionalized Single Bus-Bar System***

Normally the number of sections of a bus-bar are 2 to 3 in a substation, but actually it is limited by the short-circuit current to be handled. In a sectionalized bus-bar arrangement only one additional circuit breaker is required which does not cost much in comparison to the total cost of the bus-bar system.

Such an arrangement provides three main advantages over simple single bus-bar arrangement:
Firstly, in the event of occurrence of fault on any section of the bus-bar, the faulty section can be isolated without affecting the supply of other section or sections.

Secondly, one section can be completely shut-down for maintenance and repairs without affecting the supply of the other section (s).

Thirdly, by adding a current limiting reactor between the sections the fault level (MVA) can be reduced thereby circuit breakers of lower capacity can be used.

At times air-break isolators were used in place of circuit breakers as bus-sectionalizer due to economy, but it must be remembered that any isolation affected by them must be affected under off-load conditions otherwise it may cause spark. It will be preferable to provide circuit breaker as a sectionalizing switch so that uncoupling of bus-bar may be carried out safely during load transfer. A double isolation is however necessary when the circuit breaker is employed as sectionalizing switch so that the maintenance work can be carried out on circuit breaker while the bus-bars are alive.

3. Main and Transfer Bus Arrangement:

This arrangement has been quite frequently adopted where the loads and continuity of supply justify additional costs. This arrangement provides additional flexibility, continuity of supply and allows periodic maintenance without total shutdown. Such an arrangement is suitable for highly interconnected power network in which flexibility is very important.

Figure 16.21 illustrates the main and transfer bus arrangement in a generating station. Such an arrangement consists of two bus-bars, known as main bus-bar and transfer bus-bar used as an auxiliary bus-bar. Each generator and feeder may be connected to either bus-bar with the help of bus coupler which consists of a circuit breaker and isolating switches. In this arrangement a bus coupler is usually used so that change-over from one bus-bar to the other can be carried out under load conditions. While transferring the load to the reserve bus, the following steps may be taken.

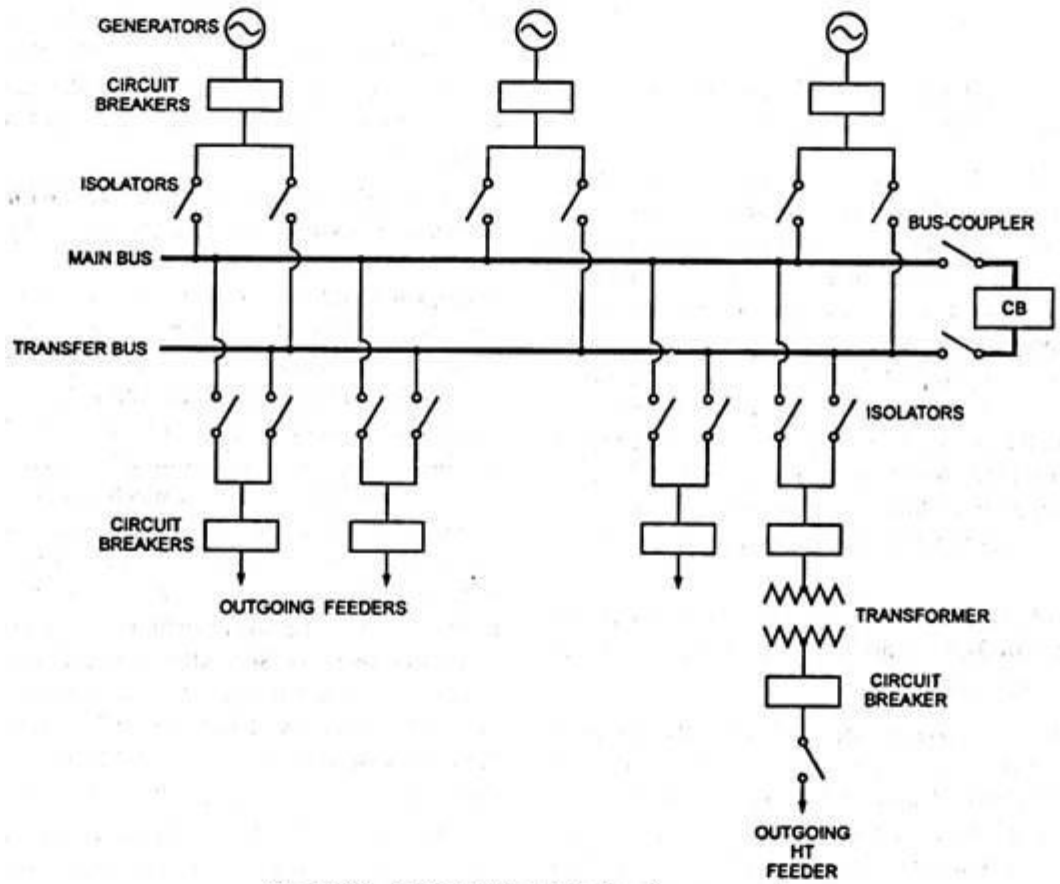


Fig. 16.21. ***Main and Transfer Bus Arrangement***

i. Close the bus-coupler (circuit breaker) so as to make the two buses at the same potential.

ii. Close isolators on the reserve bus.

iii. Open isolators on the main bus.

The load is now transferred to the reserve or auxiliary bus and main bus is disconnected.

The advantages and disadvantages of the arrangement are given below:

Advantages:

i. It ensures continuity of supply in case of bus fault. In the event of occurrence of fault on one of the bus, the entire load can be transferred to the other bus.

ii. Repair and maintenance can be carried out on the main bus without interrupting the supply as the entire load can be transferred to the auxiliary bus.

iii. Each load can be supplied from either bus.

iv. The in-feed and load circuit may be divided into two separate groups if required from operational considerations.

v. The testing and maintenance of feeder circuit breakers can be done by putting them on spare bus, thus keeping the main bus undisturbed.

vi. The maintenance cost of substation is lowered.

vii. The bus potential can be used for relays.

Disadvantages:
i. Additional costs.

ii. The bus is maintained or expanded by transferring all of the circuits to the auxiliary bus depending upon the remote backup relays and breakers for removing faults of the circuits. During this condition a line fault on any of the circuits of the bus would shut-down the entire station.

4. Double Bus Double Breaker Arrangement:
In very important power stations two circuit breakers are employed for each circuit, as illustrated in Fig. 16.22. Such a bus-bar arrangement does not require any bus-coupler and permits switch-over from one bus to the other whenever desired, without interruption. This bus arrangement is very costly and its maintenance cost is also high.

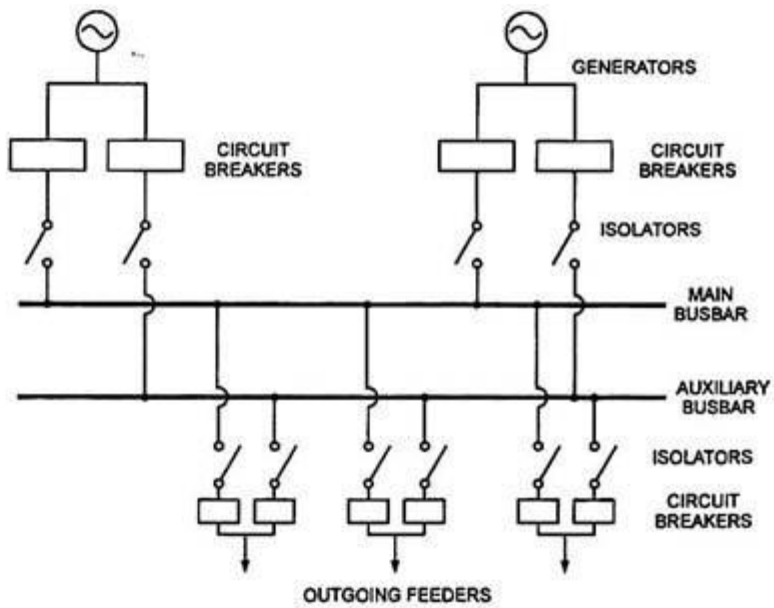


Fig. 16.22. ***Double Bus Double Breaker Arrangement***

This arrangement provides maximum flexibility and reliability as the faults and maintenance interrupt the supply to the minimum. A circuit breaker can be opened for repairs and usual checks and the load can be shifted on the other circuit breaker easily. But because of its higher cost, this arrangement is seldom used at the substations.

For 400 kV switchyards two main buses plus one transfer bus scheme is preferred. The transfer bus is used for transferring power from main bus 1 to main bus 2 and vice versa.

5. Sectionalized Double Bus Arrangement:

In this arrangement duplicate bus-bars are used with the main bus-bar in sections connected through a bus-coupler, as illustrated in Fig. 16.23. In this arrangement, any section of bus-bar can be isolated for maintenance, while any section may be synchronised with any other through the auxiliary bus-bar. Sectionalization of auxiliary bus-bar is not required and would increase the cost if done.

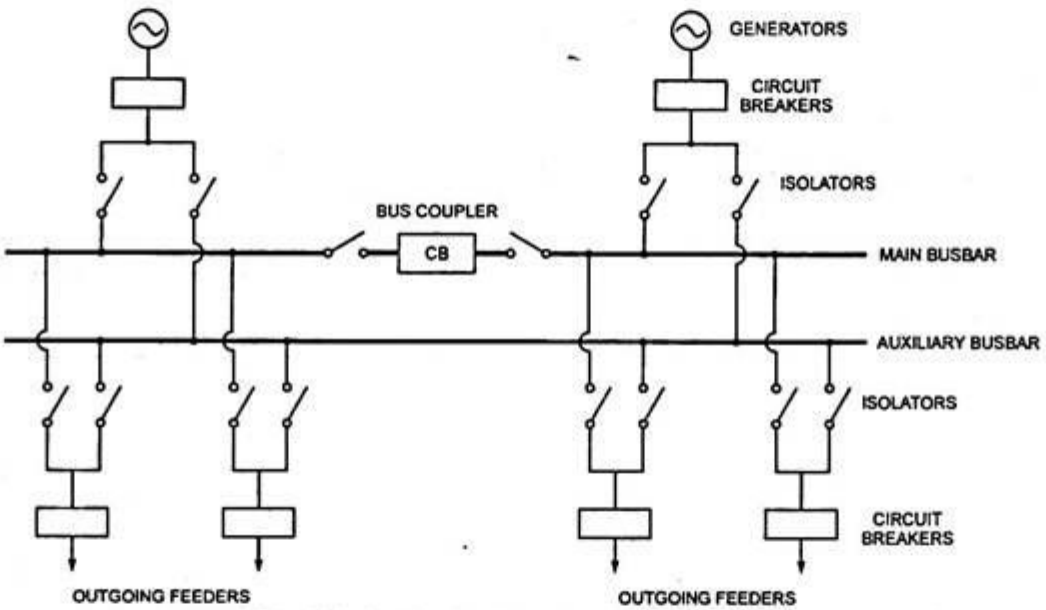


Fig. 16.23. ***Sectionalized Double Bus Arrangement***

6. One-and-a-Half Breaker Arrangement:
This is an improvement over double bus double breaker arrangement and it affects saving in the number of circuit breakers. This arrangement needs three circuit breakers for two circuits. The number of circuit breakers per circuit comes out to be 1½ hence the name. This arrangement is preferred in important large stations where power handled per circuit is large.

This arrangement is shown in Fig. 16.24. This arrangement provides high security against loss of supply as a fault in a bus or in a breaker will not interrupt the supply. Possibility of addition of circuits to the system is another advantage. The bus potential can be used as supply to relays, however, at the time of bus fault such potential to the relay should be thrown off.

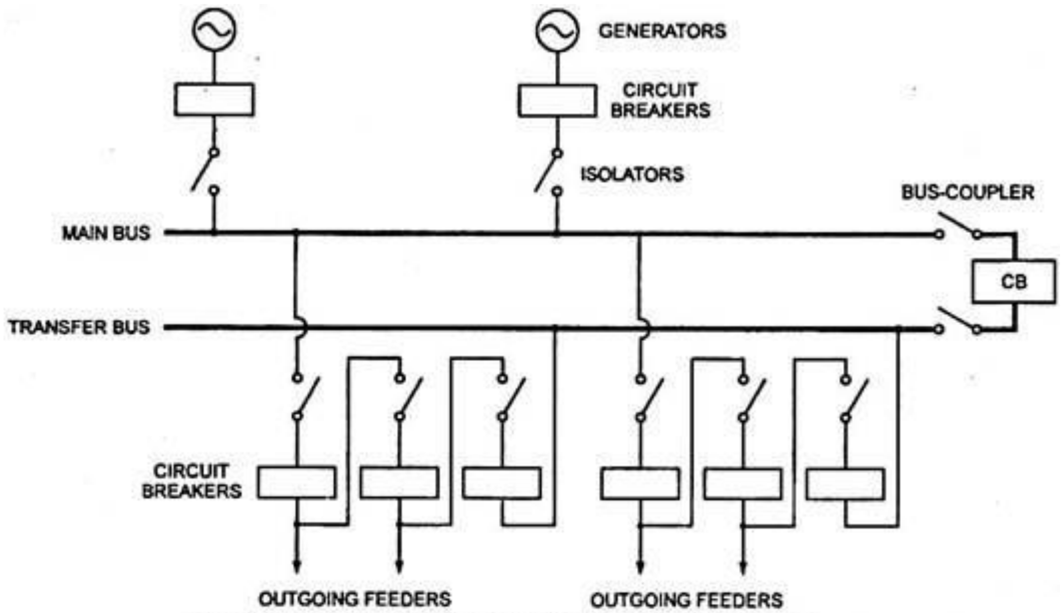


Fig. 16.24. ***One-and-a-Half Circuit Breaker Arrangement***

The main drawback of this arrangement is complications in relaying system because at the time of fault two breakers are to be opened. The other drawback is that for maintenance of circuit breakers if the load shedding is not used, two breakers are to be opened in which case the other circuit in the line-up will be operating with one breaker from one bus only. At the time of fault in that bus supply to the other circuit is also interrupted. The maintenance cost is higher.

The above arrangement has been used in important 400 kV and 750 kV substations.

7. Ring Main Arrangement:

This is an extension of the sectionalized bus-bar arrangement where the ends of the busbars are returned upon themselves to form a ring, as illustrated in Fig, 16.25. This arrangement provides greater flexibility as each feeder is supplied by two paths, so that the failure of a section does not cause any interruption of the supply. The effect of fault in one section is localised to that section alone.

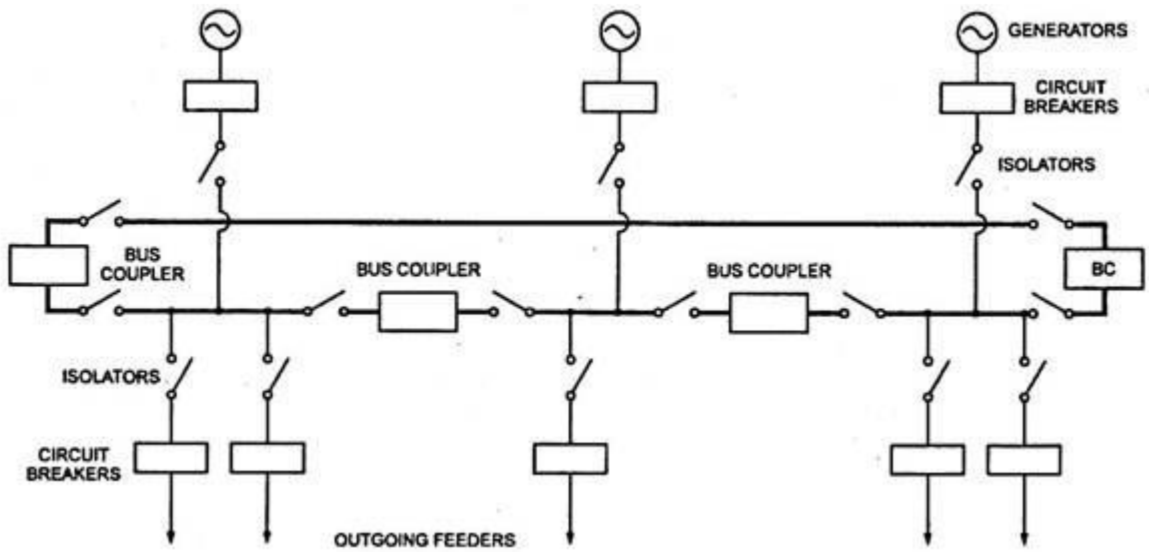


Fig. 16.25. *Ring Main Arrangement*

The rest of the sections continue to operate. Circuit breakers can be maintained without interrupting the supply. The cost is also not much as the numbers of breakers used are nearly the same as that of a single bus-bar system.

The drawbacks of the system are:
(i) Difficulties in addition of any new circuit in the ring,

(ii) Possibility of overloading of the circuits on opening of any section of the breaker, and

(iii) Necessity of supplying potential to relays separately to each of the circuit.

8. Mesh Arrangement:
This is another arrangement making economical use of circuit breakers in a substation. In this bus-bar arrangement, the circuit breakers are installed in the mesh formed by the buses, as illustrated in Fig. 16.26. The circuits are tapped from the node points of the mesh. In Fig. 16.26 eight circuits are controlled by four circuit breakers.

When fault occurs on any section, two circuit breakers have to open, resulting in opening of the mesh. This arrangement provides security against bus-bar faults but lacks switching facility. It needs fewer circuit breakers than that required by one-and-a-half breaker arrangement. It is preferred for substations having large number of circuits.

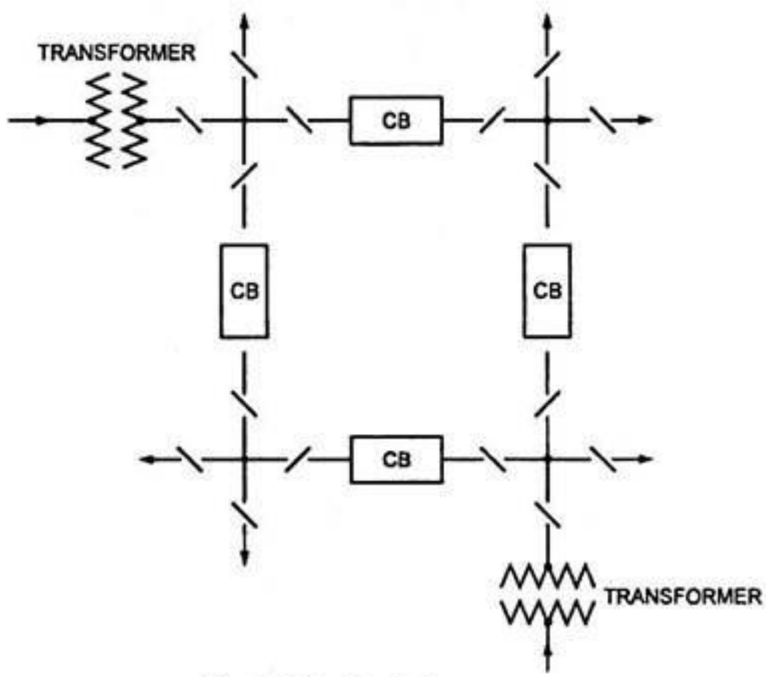


Fig. 16.26. *Mesh Arrangement*

SWITCHGEAR ACCOMMODATION It is necessary to house the switchgear in power stations and sub-stations in such a way so as to safeguard personnel during operation and maintenance and to ensure that the effects of fault on any section of the gear are confined to a limited region. Depending upon the voltage to be handled, switchgear may be broadly classified into (i) Outdoor type. For voltages beyond 66 kV, switchgear equipment is installed outdoor. It is because for such voltages, the clearances between conductors and the space required for switches, circuit breakers, transformers and others equipment become so great that it is not economical to install all such equipment indoor. (ii) Indoor type. For voltages below 66 kV, switchgear is generally installed indoor because of economic considerations. The indoor switchgear is generally of metal-clad type. In this type of construction, all live parts are completely enclosed in an earthed metal casing.

SHORT-CIRCUIT Whenever a fault occurs on a network such that a large current flows in one or more phases, a short-circuit is said to have occurred. When a short circuit occurs, a heavy current called short circuit current flows through the circuit. Consider a single phase generator of voltage V and internal impedance Zi is supplying to a load Z. Under normal conditions, the current in the circuit is limited by load impedance Z. However, if the load terminals get shorted due to any reason, the circuit impedance is reduced to a very low value ; being Zi in this case. As Zi is very small, therefore, a large current flows through the circuit. This is called short-circuit current.

CAUSES OF SHORT-CIRCUIT. A short circuit in the power system is the result of some kind of abnormal conditions in the system. It may be caused due to internal and/or external effects. (i) Internal effects are caused by breakdown of equipment or transmission lines, from deterioration of insulation in a generator, transformer etc. Such troubles may be due to ageing of insulation, inadequate design or improper installation. (ii) External effects causing short circuit include insulation failure due to lightning surges, overloading of equipment causing excessive heating; mechanical damage by public etc.

SHORT-CIRCUIT CURRENTS Most of the failures on the power system lead to short-circuit fault and cause heavy current to flow in the system. The calculations of these short-circuit currents are important for the following reasons : (i) A short-circuit on the power system is cleared by a circuit breaker or a fuse. It is necessary, therefore, to know the maximum possible values of short-circuit current so that switchgear of suitable rating may be installed to interrupt them. (ii) The magnitude of short-circuit current determines the setting and sometimes the types and location of protective system. (iii) The magnitude of short-circuit current determines the size of the protective reactors which must be inserted in the system so that the circuit breaker is able to withstand the fault current. (iv) The calculation of short-circuit currents enables us to make proper selection of the associated apparatus (e.g. bus-bars, current transformers etc.) so that they can withstand the forces that arise due to the occurrence of short circuits.

FAULTS IN A POWER SYSTEM -:

The complexity is increasing day by day in all sectors of the electrical energy system such as power generation, transmission, distribution, load system of electricity. Defects such as a short circuit in the power system can result in huge losses and reduce the reliability of the electrical system.

Defects in the electrical system are an uncommon occurrence caused by the failure of devices such as transformers and rotating machines, human errors, and environmental conditions. Electrical faults disrupt the flow of electricity, resulting in damage to appliances and the untimely death of humans, birds, and animals.

Types of Fault:

SI. No.	Types of Fault
1.	Short circuit fault
2.	Open circuit fault
3.	Symmetrical faults
4.	Unsymmetrical faults

There are mainly two types of faults in the three-phase power system, one is a short circuit fault, and the other is an open circuit fault. Apart from this, there are two other types of faults. Symmetrical faults, Unsymmetrical faults. Electrical faults can disrupt the power supply between two interstates.

In normal conditions, the flow of electricity in the power system is easy due to which all the equipment are working properly. But if a system fault occurs, it causes a large amount of current to be transmitted from the system which can damage the device running through it.

Defective equipment must be used in the power system, or a major mishap may occur. Defective equipment such as switchgear equipment, electromechanical relays, circuit breakers, and other protection devices need to be detected and analyzed to select or design.

1. Short circuit fault:

In short, a short circuit is any combination of two points or two phases, whether it is for any purpose or by accident. This is known as a short circuit fault. This is a small but very serious type of defect. As a result, more current is transmitted to the device or transmission line for a while.

If any device is turned on for a while in such a condition, the device can be extensively damaged. A short circuit fault is also known as a shunt fault.

This type of problem can be caused by the fusion and earthing coming together or the insulation between the two fuses melting. Short circuits can cause a variety of faults that may not be anything like this. Three-phase means, phase to phase, single phase to earth, two-phase to earth, phase to phase plus single phase to earth.

2. Open circuit fault:
Defects in open circuit faults are caused by damage to one or more conductors. The following is the diagram of the open circuit for single-phase damage, two-phase damage, and three-phase damage.

The most common causes of this defect include joint failure of cable and overhead lines and failure of one or more phases of the circuit breaker and melting of the fuse or conductor in one or more phases. **Open circuit faults are also known as series faults.**
Thus, apart from the three-phase open circuit, there are two other types of faults which are called asymmetrical or unbalanced faults. Thus keep in mind that the transmission line operates with the first balanced load of the open-circuit fault.

If one of the three phases spreads, the load of the alternator decreases, and the speed of the alternator increases due to the low load, so it moves a little faster than the synchronous speed. This over the speed of the alternator causes overvoltage in the transmission line.

Thus single-phase, two-phase open-circuit conditions create an imbalance of voltage and current in the electrical system, which causes a lot of damage to the devices.

3. Symmetrical faults:
This is a very serious type of defect, and the power system is frequent. This type of defect is also known as balanced defects.

These are of two types, such as a line to ground (L-L-L-G) and line to line (L-L-L). Electrical fault This type of defect is found in only 2 to 5%. If such a fault occurs then the system remains balanced.

But the device of electricity is severely damaged.

3. **Unsymmetrical Faults:**
   Such faults are more common and less severe than symmetrical faults.

There are mainly 3 types of Unsymmetrical Faults which are as under.

1.Line to ground(L – G)
2.Line to the line(L – L)
3.Double line to ground(L – L- G)

The line to ground :This type of fault is the most common and accounts for 60 to 70%. The main reason for such a fault is the contact of the conductor with the ground. Defects in 15 to 20 percent of cases are double lines of soil and are the main reason for both carriers to contact the soil.

The line-to-line :This type of fault occurs when two main conductors come in contact with each other due to air pressure. The proportion of such faults is 5 to 10%.

Double line to ground :This type of defect can also be called an unbalanced defect because it causes an imbalance in the system. An imbalance of the system means that the barrier values are different in each phase, causing the imbalance current to flow in the phase. This is more difficult to analyze and is run on the same phase basis as the three-phase balanced defect.

Causes of Electrical Fault:
There are 4 main causes of electrical fault which are as under.

SI. No.	Causes of Electrical Fault
1.	Weather conditions
2.	Equipment failures
3.	Human errors

4. Smoke of fires

1. Weather conditions:
Due to the lack of electricity in the weather, heavy rains in the monsoon season, extreme winds in the cold season, snowfall, etc., can cause damage to the transmission line and disrupt the power supply. Such natural conditions can cause damage to electrical installations.

2. Equipment failures:
Short circuit faults occur due to various electrical equipment such as transformers, generators, motors, switching devices, insulation defects of cable over time, and winding. Such a defect results in high current flowing through the device or apparatus which damages it.

3. Human errors:
Electrical system Some errors are also caused by man. Such as selection of improper rating of devices, forgetting of metal or electrical condensing parts after servicing or maintenance, switch off of the circuit when charging circuit, etc.

4. The smoke of fires:
Ionization of air due to smoke particles, resulting in a spark between the lines or conductors towards the insulator around the overhead lines. Insulators lose their insulating capacity due to the high noise caused by this flashover.

Protection Devices Against Electrical Faults:
Electrical power systems can be repaired by preventing human errors when natural weather conditions are not in human hands and cannot be prevented. So if we separate the circuit from the main power in case of fault formation, we can prevent a lot of real damage. Some of these fault limiting devices include fuses, circuit breakers, relays, etc.

1. Fuse:

Fuse is a primary safety device that is a thin wire enclosed in a casing or glass that connects two metal parts. This wire melts when more current flows in the circuit. The type of fuse depends on the voltage on which it will operate. It is necessary to replace this wire once it is burnt.

2. Circuit Breaker:

It normalizes the circuit as well as gives a break in abnormal conditions. When a fault occurs it causes automatic tripping of the circuit. It can be an electromechanical circuit breaker such as a vacuum/oil circuit breaker, etc., or an ultrafast electronic circuit breaker.

3. Lighting Power Protection Devices:

These include Lightning Arresters and grounding devices that protect the system against lightning and surge voltage.

TOPIC – 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, ly 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.

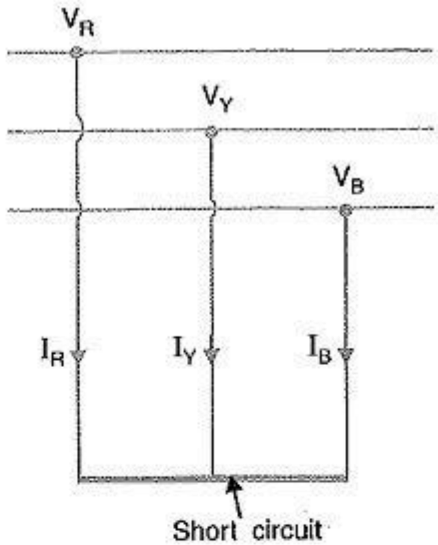


Fig. 17.1

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 upto 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.

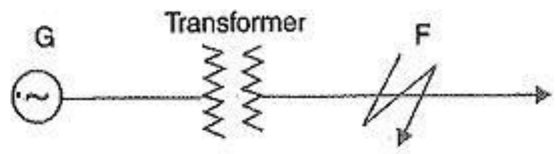


Fig. 17.2

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%.

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 currentis flowing.

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

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 andkV as under :

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

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 KVA:

It is clear from exp. (ii) above that percentage reactance of an equipment depends upon its kVA rating. Generally, the various equipments used in the power system have different kVA ratings. Therefore, it is necessary to find the Percentage Reactance in Power System of all the elements on a common kVA rating. This common kVA rating is known as **base kVA**. The value of this base kVA is quite unimportant andmay 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% at2000 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.

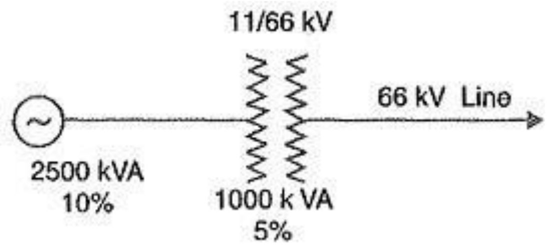


Fig. 17.3

(i) Suppose we choose 2500 kVA as the common base kVA. On this base value, thereactances 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 ;

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

$\therefore$ 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.

Short Circuit kVA:

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

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

Let

V = normal phase voltage in volts

I = full-load current in amperes at base kVA

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

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

Short-circuit kVA for 3-phase circuit

$$= \frac{3\,V\,I_{SC}}{1000}$$

$$= \frac{3\,V\,I}{1000} \times \frac{100}{\%X}$$

$$= \text{Base kVA} \times \frac{100}{\%X}$$

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

Reactor Control of Short-Circuit Currents:

With the fast expanding power system, the fault level (i.e. the power available to flow into a fault) is also rising. The circuit breakers connected in the power system must be capable of dealing with maximum possible short-circuit currents that can occur at their points of connection. Generally, the reactance of the system under fault conditions is low and fault currents may rise to a dangerously high value. If no steps are taken to limit the value of these short- circuit currents, not only will the duty required of circuit breakers be excessively heavy, but also damage to lines and other equipment will almost certainly occur.

In order to limit the short-circuit currents to a value which the circuit breakers can handle, additional reactances known as reactors are connected in series with the system at suitable points. A reactor is a coil of number of turns designed to have a large inductance as compared to its ohmic resistance. The forces on the turns of these reactors under short-circuit conditions are considerable and, therefore, the windings must be solidly braced. It may be added that due to very small resistance of reactors, there is very little changein the efficiency of the system.

Advantages

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

Location of Reactors in Power System:

Short circuit current limiting Location of Reactors in Power System may be connected

1. ***in series with each generator***
2. ***in series with each feeder and***
3. ***in bus-bars.***

No definite statement can be given as to which one of the above locations is preferable; each installation has its own particular demands which must be carefully considered before a choice of Location of Reactors in Power System can be made.

1. Generator Reactors:

When the reactors are connected in series with each generator, they are known as **generator reactors** (see Fig. 17.4). In this case, the reactor may be considered as a part of leakage reactance of the generator ; hence its effect is to protect the generator in the case of any short-circuit beyond the reactors.

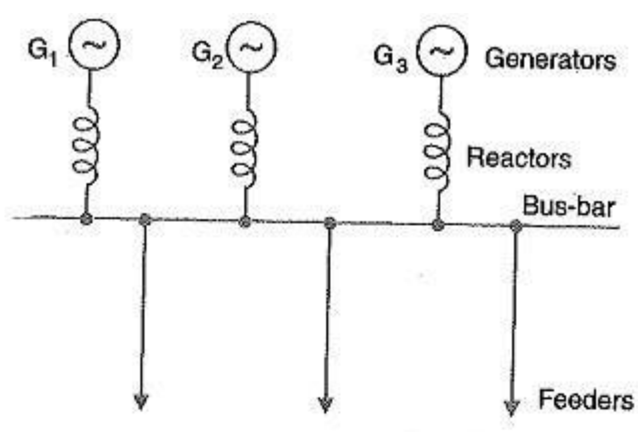


Fig. 17.4

Disadvantages

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

Due to these disadvantages and also since modern power station generators have sufficiently large leakage reactance to protect them against short-circuit, it is not a common practice to use separate reactors for the generators.

2. Feeder Reactors:

When the reactors are connected in series with each feeder, they are known as **feeder reactors** (see Fig. 17.5). Since most of the short-circuits occur on feeders, a large number of reactors are used for such circuits. Two principal advantages are claimed for feeder Location of Reactors in Power System. Firstly, if a fault occurs on any feeder, the voltage drop in its reactor will not affect the bus-bars voltage so that there is a little tendency for the generator to lose synchronism. Secondly, the fault on a feeder will not affect other feeders and consequently the effects of fault are localized.

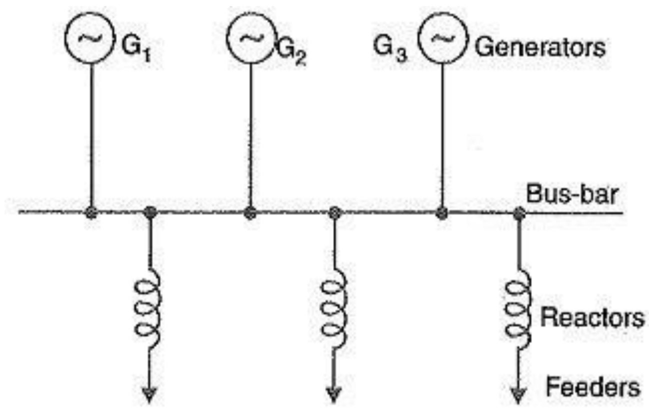


Fig. 17.5

Disadvantages

- **There is a constant power loss and voltage drop in the reactors even during normal opera**
- **If a short-circuit occurs at the bus-bars, no protection is provided to the generators. However, this is of little importance because such faults are rare and modern generators have considerable leakage reactance to enable them to withstand short-circuit across their terminals**

- **If the number of generators is increased, the size of feeder reactors will have to be increased to keep the short-circuit currents within the ratings of the feeder circuit breakers.**

3. Bus-bar reactors:

The above two methods of locating reactors suffer from the disadvantage that there is considerable voltage drop and power loss in the Location of Reactors in Power System even during normal operation. This disadvantage can be overcome by locating the reactors in the bus-bars. There are two methods for this purpose, namely ; Ring system and Tie-Bar system.

(i) Ring system: In this system, bus-bar is divided into sections and these sections are connected through reactors as shown in Fig. 17.6. Generally, one feeder is fed from one generator only. Under normal operating conditions, each generator will supply its own section of the load and very little power will be fed by other generators. This results in low power loss and voltage drop in the reactors. However, the principal advantage of the system is that if a fault occurs on any feeder, only one generator (to which the particular feeder is connected) mainly feeds the fault current while the current fed from other generators is small due to the presence of Location of Reactors in Power System. Therefore, only that section of bus-bar is affected to which the feeder is connected, the other sections being able to continue in normal operation.

Bus bar

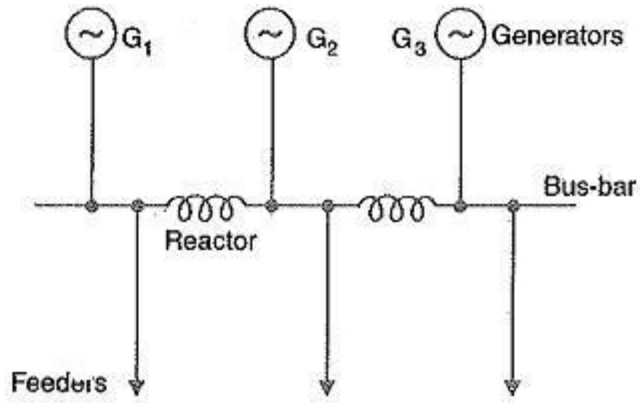


Fig. 17.6

(ii) Tie-Bar system: Fig. 17.7 shows the tie-bar system. Comparing the ring system with tie-bar system, it is clear that in the tie-bar system, there are effectively To bar two reactors in series between sections so that Location of Reactors in Power System must have approximately half the reactance of those used in a comparable ring system. Another advantage of tie-bar system is that additional generators may be connected to the system without requiring changes in the existing reactors. However, this system has the disadvantage that it requires an additional bus-bar i.e. the tie-bar.

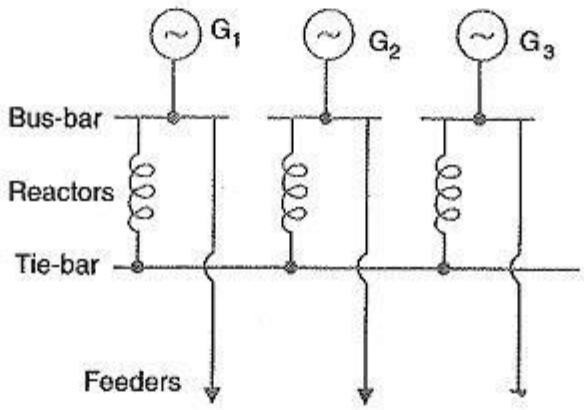


Fig. 17.7

Steps for Symmetrical Fault Calculations:

It has already been discussed that 3-phase short-circuit faults result in symmetrical fault currents i.e. fault currents in the three phases are equal in magnitude but displaced 120° electrical from one another. Therefore, problems involving such faults can be solved by considering one phase only as the same conditions prevail in the other two phases. The procedure for the solution of such faults involves the following steps :

- Draw a single line diagram of the complete network indicating the rating, voltage and percentage reactance of each element of the network.
- Choose a numerically convenient value of base kVA and convert all percentage reactances to this base value.
- Corresponding to the single line diagram of the network, draw the reactance diagram showing one phase of the system and the neutral. Indicate the % reactances on the base kVA in the reactance diagram.

The transformer in the system should be represented by a reactance inseries.

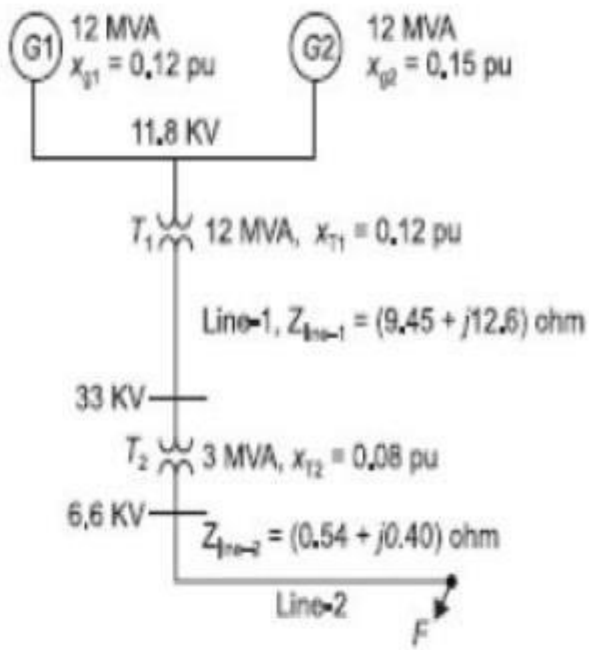
- Find the total % reactance of the network upto the point of fault. Let itbe X%.
- Find the full-load current corresponding to the selected base kVA andthe normal system voltage at the fault point. Let it be I.
- Then various short-circuit calculations are :

$$\text{Short-circuit current, } I_{SC} = I \times \frac{100}{\%X}$$

$$\text{Short-circuit kVA} = \text{Base kVA} \times \frac{100}{\%X}$$

Numerical problems on Symmetrical Fault :

Q1. A radial power system network is shown in fig. a three phase balanced fault occurs at F. Determine the fault current and the line voltage at 11.8 KV bus underfault condition.



Solution:

Let Base MVA = 12

Base Voltage = 11.8 KV.

$$x_{g1} = j0.12 \text{ pu}, \quad x_{g2} = j0.15 \text{ pu}$$

$$x_{T1} = j0.12 \text{ pu},$$

$$x_{T2} = j0.08 \times \frac{12}{3} = j0.32 \text{ pu}$$

Base voltage for line-1 is 33 KV.

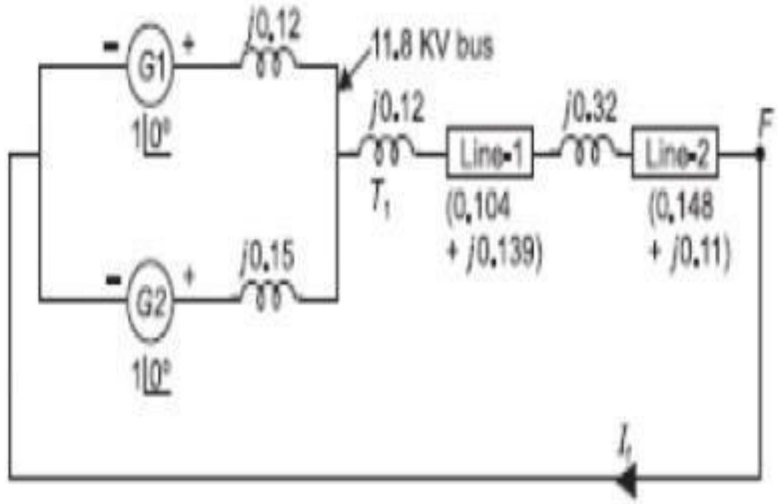
Base voltage for line-2 is 6.6 KV.

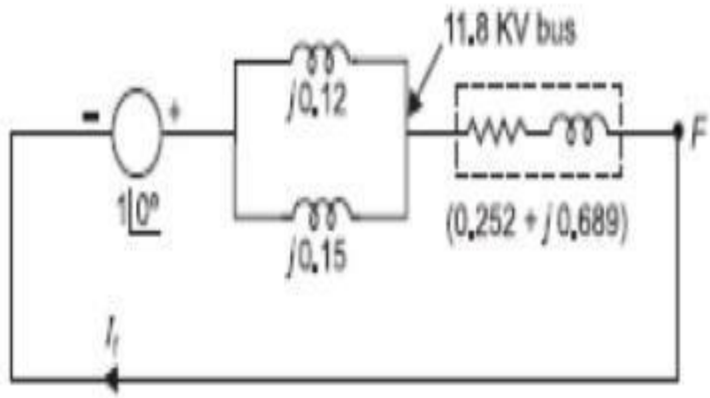
$$Z_{B,\text{line-1}} = \frac{(33)^2}{12} = 90.75 \text{ ohm.}$$

$$Z_{B,\text{line-2}} = \frac{(6.6)^2}{12} = 3.63 \text{ ohm.}$$

$$\therefore \quad Z_{\text{line-1}} = \frac{(9.45 + j12.6)}{90.75} = (0.104 + j0.139) \text{ pu}$$

$$Z_{\text{line-2}} = \frac{(0.54 + j0.40)}{3.63} = (0.148 + j0.11) \text{ pu}$$


G1
j0.12
11.8 KV bus
1|0°
j0.12
Line-1
j0.32
Line-2
F
T1
(0.104
+ j0.139)
(0.148
+ j0.11)
G2
j0.15
1|0°
If


11.8 KV bus
j0.12
F
1|0°
(0.252 + j 0.689)
j0.15
If

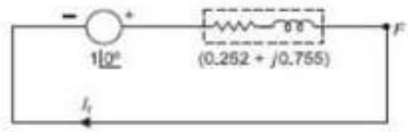


Fig. 8.12(c)

Base current $I_B = \dfrac{12 \times 1000}{\sqrt{3} \times 6.6} = 1049.7$ Amp.

Now $I_f = \dfrac{1\angle 0^\circ}{(0.252 + j0.755)} = 1.256\angle -71.5^\circ$ pu

$\therefore$ $I_f = 1.256\angle -71.5^\circ \times 1049.7$

$\therefore$ $I_f = 1318.4\angle -71.5^\circ$ Amp.

Total impedance between F and 11.8 KV bus

$= (0.252 + j0.689)$ pu

Voltage at 11.8 KV bus

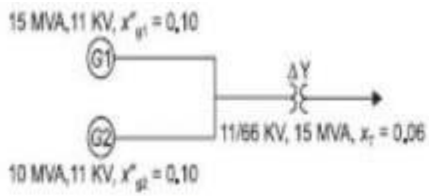
$= 1.256\angle -71.5^\circ \times (0.252 + j0.689)$

$= 0.921\angle -1.6^\circ$ pu

$= 0.921\angle -1.6^\circ \times 11.8$ KV

$= 10.86\angle -1.6^\circ$ KV. Ans.

Q2. Two generators G1 and G2 are rated 15MVA, 11KV and 10MVA, 11KV respectively. The generators are connected to a transformer as shown in fig. Calculate the sub transient current in each generator when a three phase faultoccurs on the high voltage side of the transformer.



Solution: Choose a base 15 MVA

$$x''_{g1} = j0.10 \text{ pu}$$

$$x''_{g2} = j0.10 \times \frac{15}{10} = j0.15 \text{ pu}$$

$$x_T = j0.06 \text{ pu}$$

$$I_f = \frac{V_s}{j0.12} = \frac{1}{j0.12} = -j8.33 \text{ pu}$$

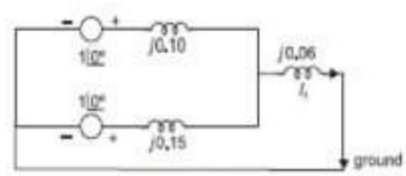


Fig. 8.7(a)

$$I''_{g1} = \frac{j0.15}{j(0.1+0.15)} \times (-j8.33)$$

$$= -j5.0 \text{ pu}$$

$$I''_{g2} = \frac{j0.10}{j(0.1+0.15)} \times (-j8.33) = -j3.33 \text{ pu}$$

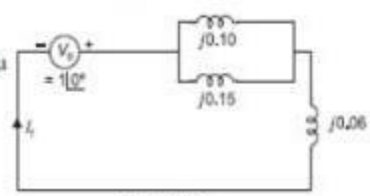


Fig. 8.7(b)

Base current

$$I_B = \frac{15 \times 1000}{\sqrt{3} \times 11} = 787.3 \text{ Amp.}$$

$$\therefore \quad I''_{g1} = -j5 \times 787.3 = -j3.936 \text{ KA.}$$

$$I''_{g2} = -j3.33 \times 787.3 = -j2.621 \text{ KA.}$$

$$I_f = -j8.33 \times 787.3 = -j6.557 \text{ KA.}$$

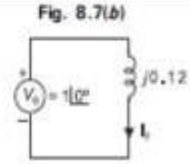


Fig. 8.7(c)

TOPIC-3

FUSES

Fuses Definition:

Fuses Definition States that : A fuses is a short piece of metal, inserted in the circuit, which melts when excessive current flows through it and thus breaks the circuit.

The fuse element is generally made of materials having low melting point, high conductivity and least deterioration due to oxidation e.g., silver copper etc. It is inserted in series with the circuit to be protected. Under normal operating conditions, the fuse element is at a temperature below its melting point. Therefore, it carries the normal current without overheating. However, when a short-circuit or overload occurs, the current through the fuse increases beyond its rated value. This raises the temperature and fuse element melts (or blows out), disconnecting the circuit protected by it. In this way, a fuse protects the machines and equipment from damage due to excessive currents.

The time required to blow out the fuse depends upon the magnitude of excessive current. The greater the current, the smaller is the time taken by the fuse to blow out. In other words, a fuse has inverse time-current characteristics as shown in Fig. 20.1. Such a characteristic permits its use for over current protection.

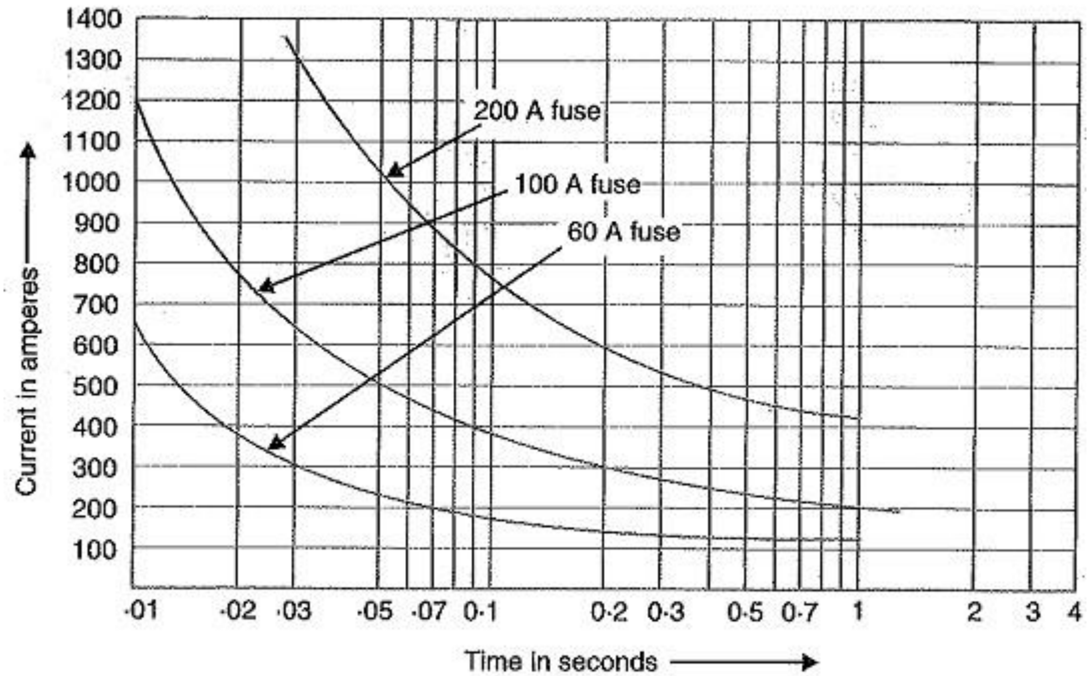


Fig. 20.1

Advantages

- It is the cheapest form of protection available.
- It requires no maintenance.
- Its operation is inherently completely automatic unlike a circuit breaker which requires an elaborate equipment for automatic action.
- It can break heavy short-circuit currents without noise or smoke.
- The smaller sizes of fuse element impose a current limiting effect under short-circuit conditions.
- The inverse time-current characteristic of a Fuses Definition makes it suitable for over current protection.
- The minimum time of operation can be made much shorter than with the circuit breakers.

Disadvantages

- Considerable time is lost in rewiring or replacing a fuse after operation.
- On heavy short-circuits, discrimination between fuses in series cannot be obtained unless there is sufficient difference in the sizes of the Fuses Definition concerned.
- The current-time characteristic of a fuse cannot always be co-related with that of the protected apparatus.

Characteristics of Fuse Element:

The function of a fuse is to carry the normal current without overheating but when the current exceeds its normal value, it rapidly heats up to melting point and disconnects the circuit protected by it. In order that it may perform this function satisfactorily, the fuse element should have the following desirable characteristics :

1. **low melting point e.g., tin, lead.**
2. **high conductivity e.g., silver, copper.**
3. **free from deterioration due to oxidation e.g., silver**
4. **low cost e.g., lead, tin, copper.**

The above discussion reveals that no material possesses all the characteristics. For instance, lead has low melting point but it has high specific resistance and is liable to oxidation. Similarly, copper has high conductivity and low cost but oxidizes rapidly. Therefore, a compromise is made in the selection of material for a Fuses Definition.

Fuse Element Materials:

The most commonly used materials for fuse element are lead, tin, copper, zinc and silver. For small currents up to 10 A, tin or all alloy of lead and tin (lead 37%, tin 63%) is used for making the fuse element. For larger currents, copper or silver is employed. It is a usual practice to tin the copper to protect it from oxidation. Zinc (in strip form only) is good if a Fuses Definition with considerable time-lag is required i.e., one which does not melt very quickly with a small overload.

The present trend is to use silver despite its high cost due to the following reasons :

- It is comparatively free from oxidation.
- It does not deteriorate when used in dry air.
- The coefficient of expansion of silver is so small that no critical fatigue occurs. Therefore, the fuse element can carry the rated current continuously for a long time.
- The conductivity of silver is very high. Therefore, for a given rating of fuse element, the mass of silver metal required is smaller than that of other materials. This minimizes the problem of clearing the mass of vaporized material set free on fusion and thus permits fast operating speed.
- Due to comparatively low specific heat, silver fusible elements can be raised from normal temperature to vaporization quicker than other fusible elements. Moreover, the resistance of silver increases abruptly as the melting temperature is reached, thus making the transition from melting to vaporization almost instantaneous. Consequently, operation becomes very much faster at higher

- Silver vaporizes at a temperature much lower than the one at which its vapour will readily Therefore, when an arc is formed through the vaporized portion of the element, the arc path has high resistance. As a result, short-circuit current is quickly interrupted.

Important Terms in Fuses

The following terms are much used in the analysis of fuses :

- **Current rating of fuse element:** It is the current which the fuse element can normally carry without overheating or It depends upon the temperature rise of the contacts of the fuse holder, fuse material and the surroundings of the Fuses Definition.
- **Fusing current:** It is the minimum current at which the fuse element melts and thus disconnects the circuit protected by it. Obviously, its value will be more than the current rating of the fuse element.

For a round wire, the approximate relationship between fusing current I and diameter d of the wire is

$$I = k d^{3/2}$$

where k is a constant, called the **fuse constant**. Its value depends upon the metal of which the fuse element is made. Sir W.H. Preece found the value of k for different materials as given in the table below :

S. No.	Material	Value of k	
		d in cm	d in mm
1	Copper	2530	80
2	Aluminium	1873	59
3	Tin	405·5	12·8
4	Lead	340·6	10·8

The fusing current depends upon the various factors such as :

1. **material of fuse element**
2. **length — the smaller the length, the greater the current because a short fuse can easily conduct away all the heat**
3. **diameter**
4. **size and location of terminals**
5. **previous history**
6. **type of enclosure used**

- **Fusing factor:** It is the ratio of minimum fusing current to the current rating of the fuse element i.e.

$$\text{Fusing factor} = \frac{\text{Minimum fusing current}}{\text{Current rating of fuse}}$$

Its value is always more than one. The smaller the fusing factor, the greater is the difficulty in avoiding deterioration due to overheating and oxidation at rated carrying current. For a semi-enclosed or rewirable Fuses Definition which employs copper wire as the fuse element, the fusing factor is usually 2. Lower values of fusing factor can be employed for enclosed type cartridge fuses using silver or bimetallic elements.

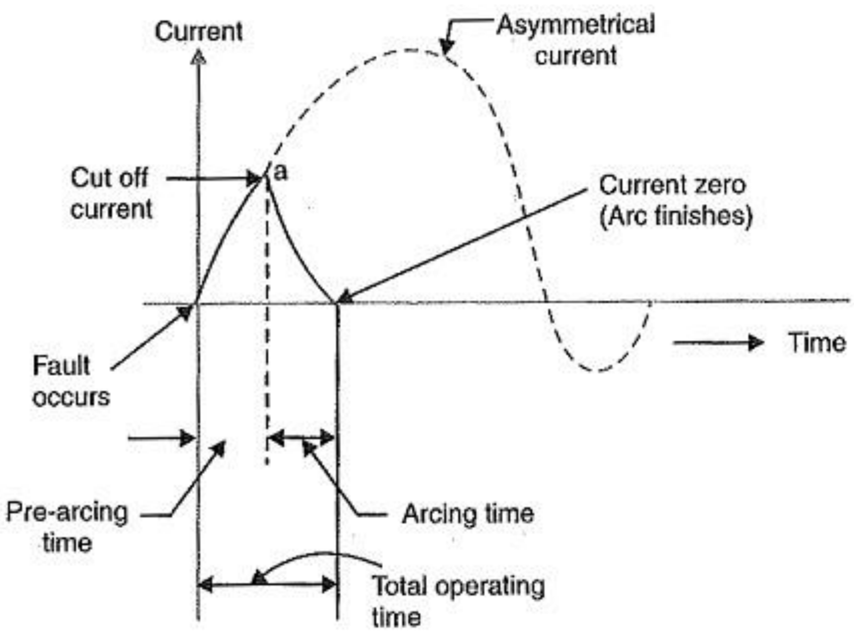


Fig. 20.2

- **Prospective Current:** Fig. 20.2 shows how a.c. current is cut off by a fuse. The fault current would normally have a very large first loop, but it actually generates sufficient energy to melt the fuseable element well before the peak of this first loop is reached. The r.m.s. value of the first loop of fault current is known as prospective current. Therefore, prospective current can be defined as under:

It is the r.m.s. value of the first loop of the fault current obtained if the fuse is replaced by an ordinary conductor of negligible resistance.

- **Cut-off current:** It is the maximum value of fault current actually reached before the fuse melts.

On the occurrence of a fault, the fault current has a very large first loop due to a fair degree of asymmetry. The heat generated is sufficient to melt the fuse element well before the peak of first loop is reached (point ‘a’ in Fig. 20.2). The current corresponding to point ‘a’ is the cut off current. The cut off value depends upon

- current rating of fuse
- value of prospective current
- asymmetry of short-circuit current

It may be mentioned here that outstanding feature of fuse action is the breaking of circuit before the fault current reaches its first peak. This gives the Fuses Definition a great advantage over a circuit breaker since the most severe thermal and electro-magnetic effects of short-circuit currents (which occur at the peak value of prospective current) are not experienced with fuses. Therefore, the circuits protected by fuses can be designed to withstand maximum current equal to the cut-off value. This consideration together with the relative cheapness of fuses allows much saving in cost.

- **Pre-arcing time:** It is the time between the commencement of fault and the instant when cut off occurs.

When a fault occurs, the fault current rises rapidly and generates heat in the fuse element. As the fault current reaches the cut off value, the fuse element melts and an arc in initiated. The time from the start of the fault to the instant the arc is initiated is known as pre-arcing time. The pre-arcing time is generally small : a typical value being 0.001 second

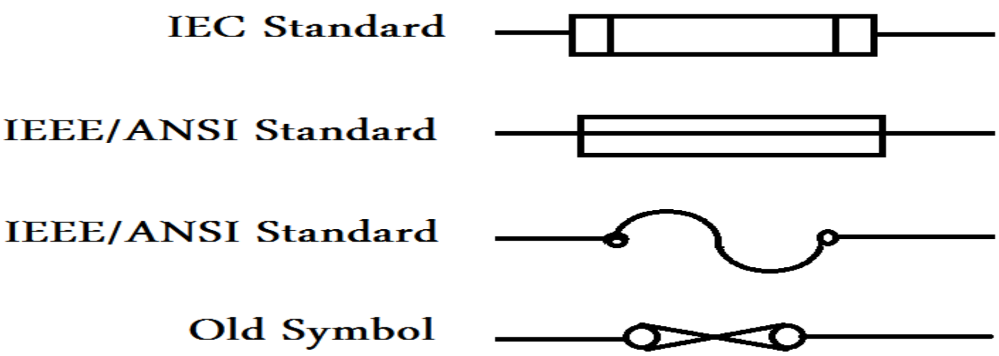
- **Arcing time:** This is the time between the end of pre-arcing time and the instant when the arc is extinguished.
- **Total operating time:** It is the sum of pre-arcing and arcing times.

It may be noted that operating time of a fuse is generally quite low (say 0.002 sec.) as compared to a circuit breaker (say 0.2 sec or so). This is an added advantage of a fuse over a circuit breaker. A fuse in series with a circuit breaker of low-breaking capacity is a useful and economical arrangement to provide adequate short-circuit protection. It is because the fuse will blow under fault conditions before the circuit breaker has the time to operate.

- **Breaking capacity:** It is the r.m.s. value of a.c. component of maximum prospective current that a fuse can deal with at rated service voltage.

Fuse Current Carrying Capacity

Current carrying capacity is the amount of current which a fuse can easily conduct without interrupting the circuit.



Fuse Symbol

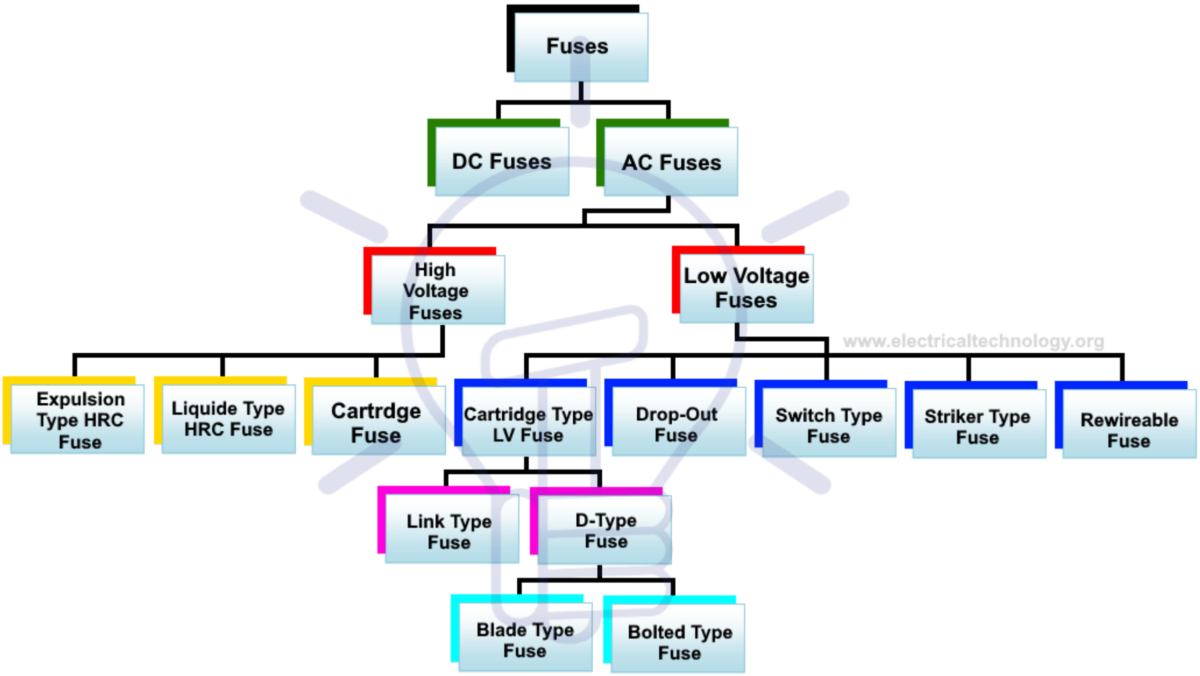
Types of Fuses

There are **different types of fuses** available in the market and they can be categories on the basis of Different aspects.

Fuses can be divided into two main categories according to the type of input supply voltage.

- AC fuses
- DC fuses

There is a little difference between AC and DC fuses used in the AC and DC Systems which has been discussed below.



Fuses can be divided into two main categories according to the type of input supply voltage.

- AC fuses
- DC fuses

There is a little difference between AC and DC fuses used in the AC and DC Systems which has been discussed below.

DC Fuses

In a DC system, when the metallic wire melts because of the heat generated by the over current, then Arc is produced and it is very difficult to extinguish this arc because of DC constant value. So in order to minimize the fuse arcing, DC fuse are little bigger than an AC fuse which increases the distance between the electrodes to reduce the arc in the Fuse.

AC Fuses

On the other hand, i.e. in the AC system, voltage with 60Hz or 50Hz frequency changes its amplitude from zero to 60 times every second, so arc can be extinct easily as compared to DC. Therefore, AC fuses are a little bit small in sizes as compared to DC fuses.

Fuses can also be categorized based on one time or multiple Operations.

Cartridge Fuses

Cartridge fuses are used to protect electrical appliances such as motors, air-conditions, refrigerator, pumps etc, where high voltage rating and currents are required. They are available up to 600A and 600V AC and widely used in industries, commercial as well as home distribution panels.

There are two types of Cartridge fuses. 1. **General purpose fuse** with no time delay and 2. **Heavy-duty cartridge fuses** with time delay. Both are available in 250V AC to 600V AC and its rating can be found on the end cap or knife blade.

Cartridge Fuses are enclosed in a base and can be divided further in Link type cartridge fuses and D Type Cartridge Fuses.

D – Type Cartridge Fuse

D-Types fuse contains an adapter ring, base, cap and cartridge. Fuse base is connected to the fuse cap where the cartridge is inside the fuse cap. The circuit is completed when the tip of the cartridge makes contacts through the fuse link conductor.

Cartridge Fuses

HRC (High Rupturing Capacity) Fuse or Link Type Cartridge Fuse

We have already discussed in very details about HRC fuse (High Rupturing Capacity) construction, operation and their applications. It also covers different types of HRC fuses like DIN type, NH Type, Blade Type, Liquid Type HRC Fuse, Expulsion Type HV Fuse, advantages & disadvantage etc.

Types of HRC fuse

High Voltage Fuses

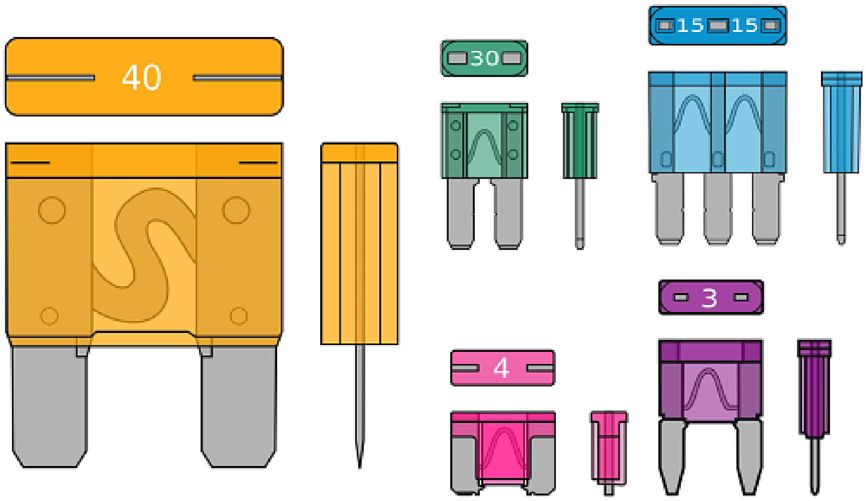
High Voltage (HV) fuses are used in power systems to protect the power transformer, distribution transformers and instrument transformer etc. where circuit breakers may not be able to protect the system. High Voltage fuses are rated for more than 1500V and up to 13kV.

The element of High Voltage fuse is generally made of copper, silver or tin. The fuse link chamber may filled with boric acid in case of expulsion type HV (High Voltage) Fuses

Automotive, Blade Type & Bolted Type Fuses

These types of fuses (also known as **spade** or **plug-in fuses**) come in plastic body and two metal caps to fit in the socket. Mostly, they are used in **automobiles** for wiring and short circuit protection. Fuse Limiters, Glass Tube (also known as Bosch Fuse) are widely used in automotive industries. The rating of automobile fuses are low as 12V to 42V.

In bolted types of fuses, the base of the fuse contacted directly to the base of the fuse, same like HRC Fuses.



Blade Type Fuses: Used in Automobiles

SMD Fuses (Surface Mount Fuse), Chip , Radial, and Lead Fuses

SMD Fuses (Surface Mount Device and the name derived from SMT = Surface Mount Technology) are chip types of fuses (also known as electronic fuse) are used in DC power applications like Hard Drive, DVD players, Camera, cell phones etc where space playing an important role because SMD fuses are very tinny in size and hard to replace as well.
Below are some additional types of SMD Fuses and Leaded fuses.

- Slow – Blow Chip Fuses
- Fast Acting Chip Fuses
- Very Fast Acting Chip Fuses
- Pulse Tolerant Chip Fuses
- High Current Rated Chip Fuses
- Telecom Fuses
- Through-hole styles fuses
- Radial Fuse
- Lead Fuse
- Axial Fuse

Rewirable Fuses

The most famous kit-kat fuse (also known as rewireable fuse) mostly used in industries and home electrical wiring for small current applications in Low Voltage (LV) systems.
Rewireable fuse contains 2 basic parts. The inner fuse element as fuse carrier made of tinned copper, Aluminum, Lead etc and the base made of porcelain having the IN and OUT terminals which is used to be in series with the circuit to protect.
The main advantage of a rewireable fuse is that It can be rewired easily in case it is blown due to short circuit or over current which melts the fuse elements. Simple, put another wire of fuse elements with the same rating as before.

Thermal Fuses

As mentioned above, thermal fuse is a one time used only fuse. They are temperature sensitive fuse and the fuse element is made of temperature sensitive alloy. They are known as Thermal Cutouts (TCO) or Thermal Links.
In a thermal fuse, the fuse element holds a mechanical spring contact which is normally closed. When high currents due to over current and short circuit flow through the elements of the fuse, the fuse elements melts down which lead to release the spring mechanism and prevent the arc and fire and protect the connected circuit.

Resettable Fuses

Resettable fuse is a device, which can be used multiple times without replacing it. They open the circuit, when an over current event occurs and after some specific time they connect the circuit again. Polymeric positive temperature coefficient device (PPTC, commonly known as a resettable fuse, poly-switch or poly-fuse) is a passive electronic component used to protect against short current faults in electronic circuits.

Application of resettable fuses is overcome where manually replacing fuses is difficult or almost impossible, e.g. fuse in the nuclear system or in an aerospace system.

Uses and Applications of Fuses

Different types of Electrical and Electronic Fuses can be used in all types of electrical and electronic systems and applications including:

- Motors
- Transformers

- Air-conditions
- Home distribution boards
- General electrical appliances and devices
- Laptops
- Cell phones
- Game systems
- Printers
- Digital cameras
- DVD players
- Portable Electronics
- LCD monitors
- Scanners
- Battery packs
- Hard disk drives
- Power convertors

Fuse vs Circuit Breakers

Fuse	**Circuit Breaker**
Works on the thermal and electrical properties of the conducting materials	Works on the switching principle and electromagnetism
It doesn't give any indication of overloads	It gives an indication of overloads
Fuse can only be used once	A circuit breaker can be used many numbers of times
Provides protection against power overloads	Provides protection against power overloads and short circuits
It detects and interrupts faulty circuit conditions	It performs the interruption process only. Faults are detected by a relay system.
Low breaking capacity compared to the circuit breaker	High breaking capacity
Automatic operation	Can either be automatic or manually operated
Operating time of fuse is 0.002 seconds	Operating time of the circuit breaker is 0.02 – 0.05 seconds
Low Cost	High Cost

TOPIC - 4

CIRCUIT BREAKERS

Definition:
A circuit breaker means the device which breaks (Open) the circuit under the abnormal condition and protects the system from hazards.
The function of a circuit breaker is to isolate the faulty point of the power system in case of abnormal conditions such as faults.
Keep reading to understand the working principle of the circuit breaker.
Different types of circuit breakers are used to perform this function. There are low voltage circuit breakers and high voltage circuit breakers. High voltage circuit breakers are mainly used in substation and low voltage CB are used in home circuits.
Important high voltage circuit breakers used in the electrical substation are

- SF6 Circuit breaker and
- Vacuum Circuit breaker.

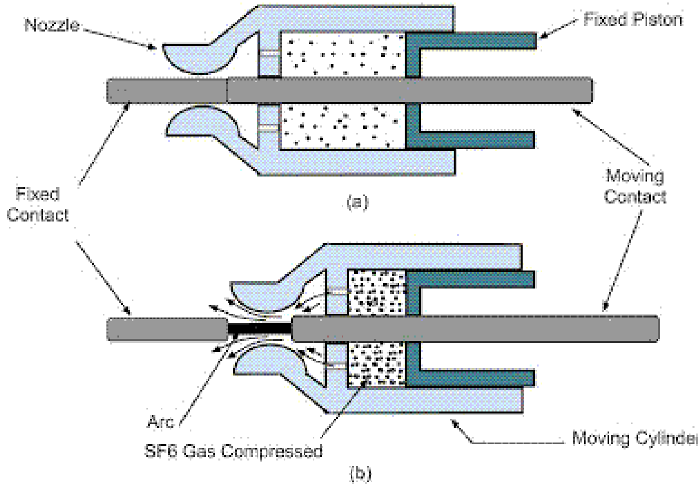
Low voltage CB includes

- Miniature Circuit breaker (MCB),
- Molded Case Circuit Breaker (MCCB),
- Residual Current Circuit breaker (RCCB) or
- Ground Fault Circuit Interrupter (GFCI)

A protective relay is another important device in the power system switchgear. Relay detects abnormal conditions and sends a tripping signal to the circuit breaker. After receiving the tripping command from the relay, the circuit breaker isolates the faulty part from the power system.
A **circuit breaker** essentially consists of fixed and moving contacts, called electrodes. These contacts are placed in the closed chamber containing a fluid containing medium (either liquid or gas) which quenches the arc formed between the contacts.
Under normal **operating** conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty.
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 breaker get energized. The moving contacts are pulled apart by some mechanism, thus opening the circuit.

Circuit Breaker Working Principle

The working principle of the circuit breaker is explained in this section.
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.



Working of an SF6 Circuit Breaker

The production of arc not only delays the current interruption process but it also generates enormous heat. This heat may cause damage to the system or to the 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.

Arcing Phenomenon in Circuit Breaker

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. Also, a 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 a conductor and an arc is struck between the contact.

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 uninterrupted 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:

The degree of ionization – the arc resistance increases with the decrease in the number of ionized particles between the contacts.
Length of the arc – the arc resistance increases with the length of the arc i.e. separation of contacts.
Cross-section of arc – the arc resistance increase with the decrease in the area of cross-section of the arc.

Different Methods of Arc Extinction

Basically, there are two ways in which you can extinguish the arc between the contacts of a circuit breaker. They are:

- High Resistance Method
- Low Resistance Method

High Resistance Method

In the High Resistance method, the resistance of the arc is increased so that the current will become insignificant to maintain the arc. There are several ways in which you can implement the High Resistance Method.

Some ways to increase the resistance of the arc are:

- Increasing the arc length
- Cooling the arc
- Reducing the area of cross section of the arc
- Splitting the arc

This method is usually implemented in DC Circuit breakers and Low Capacity AC Circuits as it produces enormous amount of heat during the arc extinction.

Low Resistance Method

In the low resistance method, as the name suggests, the resistance of the arc maintained low until the current becomes zero and the arc extinguishes naturally. Hence, this method is also known as Current Zero Method.

The low resistance method is often implemented in high power AC circuit breakers as this method prevents restriking of the arc even when the voltage across the contacts rises.

Another important factor to consider is the ionization of the medium and the tendency of ionized particles to maintain the arc. If the medium between the contacts is deionized, as quickly as possible, the possibility of restriking can be reduced significantly.

Deionization of the medium can be achieved by the following ways:

- Increasing the gap between the contacts
- Increasing the pressure
- Cooling the arc
- Gas Blast effect

Arc Voltage:
As soon as the Breaker contacts open, an arc is formed between the contacts of the Circuit Breaker. ***The voltage which appears across the contacts of the Breaker during this arcing period is called the Arc Voltage.*** Its value is low but when the value of arc current reaches to zero, arc voltage will shoot up to its peak value which in turn will try to main the arc across the contacts.
So here we come to a voltage which shoots up to peak when the current crosses to its zero. Actually this is the origination of Restriking Voltage.
Restriking Voltage:
As the arcing current crosses zero, a high frequency transient voltage appears across the contacts of the Circuit Breaker. This Transient voltage is known as Restriking Voltage. Now, two question should strike in your smart brain.
First, why voltage shoots up when arcing current crosses zero?
Second, why high frequency voltage during transient period?

First, as the power system has appreciable amount of inductance, thus the fault current must lag behind the system voltage by 90°. Therefore, when the arcing current crosses zero, the voltage across the contacts of Circuit Breaker shoots up to its peak value.
Second, as the voltage reaches its peak, it restrikes the arc and try to maintain the arc. Due to this the arcing current will increase from its zero and correspondingly the voltage must also decrease. The combined effect of increasing current and decreasing voltage across the

contact will bring the voltage back to its normal value within few mili seconds as shown in figure below. Thus we see that voltage has very few mili seconds to come back to its normal waveform from its peak, and hence voltage will do the thing faster and therefore it will be of high frequency as shown in figure below.

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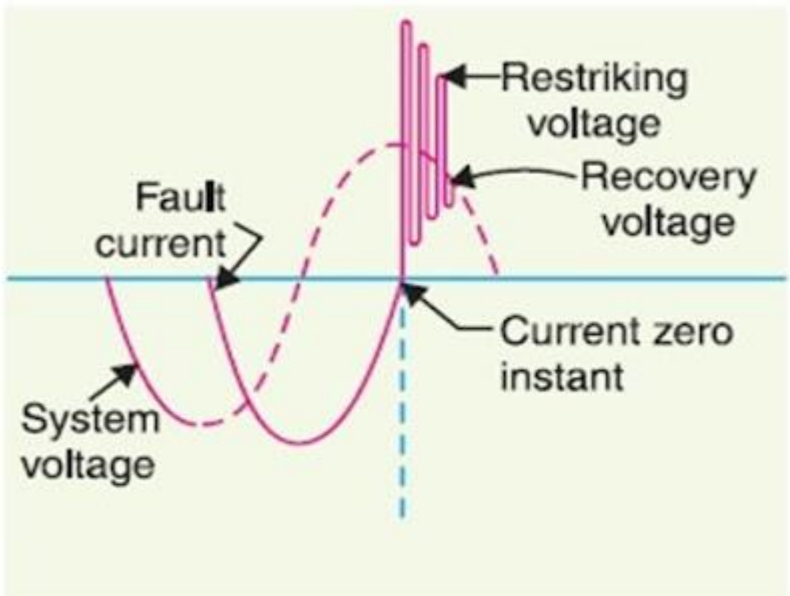


Restriking Voltage has a very important role in the arc extinction process. If the Restriking Voltage rises more rapidly than the dielectric strength of the medium between the contacts of the Circuit Breaker, the arc will persists for next half cycle and after next half cycle, arcing current will again reach to its zero and we will again get a chance. If this time the rate of rise of dielectric strength of medium between the contacts is more than rate of rise of Restriking Voltage then arc will extinguish.

Therefore, for arc extinction

Rate of Rise of Restriking Voltage < Rate of Rise of Dielectric Strength of Medium

So finally arc extinguished. So the voltage across the contacts of the Circuit Breaker will be normal 50 Hz / 60 Hz system voltage.

Recovery Voltage:

Recovery Voltage is the normal frequency RMS voltage that appears across the contacts of the Circuit Breaker after final arc extinction. It is equal to the system voltage.

Classification of Circuit Breakers

There are several ways of classifying different circuit breakers. Some of the common criteria used for classification of circuit breakers are:

- Intended Voltage Applications
- Location of the installation
- Design Characteristics
- Method and medium used for current interruption (Arc Extinction)

Even though there are several ways to classify circuit breakers, the classification based on the medium and method of current interruption is most general and significant in the industry as well. For now, we will briefly about all these classifications and in the later sections, we will discuss the main classification (i.e. based on method of arc extinction) more thoroughly.

Based on Voltage Class

The first logical classification of circuit breakers is based on the operating voltage intended for the circuit breakers to be used. There are two types of circuit breakers based on the voltage level. They are:

- Low Voltage Circuit Breakers, which are intended to be used at voltages up to 1000V.
- High Voltage Circuit Breakers, which are intended to be used at voltages greater than 1000V.

Again, high voltage circuit breakers are further divided into 123kV or above and 72.5kV or below.

Based on Type of Installation

Circuit breakers are also classified based on the location of installation i.e. outdoor or indoor installation. These circuit breakers are usually high voltage circuit breakers. Indoor circuit breakers are designed to be used inside buildings or with special weather resistant enclosures, usually a metal clad switchgear enclosure.

In fact, the main difference between indoor and outdoor circuit breakers is the packaging structures and enclosures while the internal structure like current carrying parts, interrupting mechanism and operation are pretty much the same.

Based on Type of External Design

The classification of circuit breakers is also done based on the physical structural design and it is usually done in two ways. They are:

- Dead Tank Type Circuit Breakers
- Live Tank Type Circuit Breakers

In Dead Tank Type Circuit Breakers, the switching device is placed in a vessel at ground potential and it is surrounded by interrupters and insulating medium. One the other hand, in a Live Tank Type Circuit Breaker, the vessel containing the interrupters and insulating medium is at higher potential than ground.

Dead Tank Circuit Breakers are more common in the US while Live Tank Circuit Breakers are frequently used in Europe and Asia.

Based on Type of Interrupting Medium

The most significant and important classification of circuit breakers is based on the interrupting medium and arc extinction method. In fact, the current interrupting medium and the arc extinction method have become the main factors in designing the circuit breakers and also, they dictated the overall design parameters.

Originally, oil and air served as the interrupting medium and continue to be still used even after almost a century since their first implementation.

There are two newer techniques, one involving vacuum and the other one based on Sulfurhexafluoride (SF_6) gas as the interrupting medium. These two dominate today's circuit breaker industry but oil and air circuit breakers are also still in service.

Different Types of Circuit Breakers

Since the general and most common way of classification of circuit breakers is based on medium used for arc extinction, we will see different types of circuit breakers based on the same.

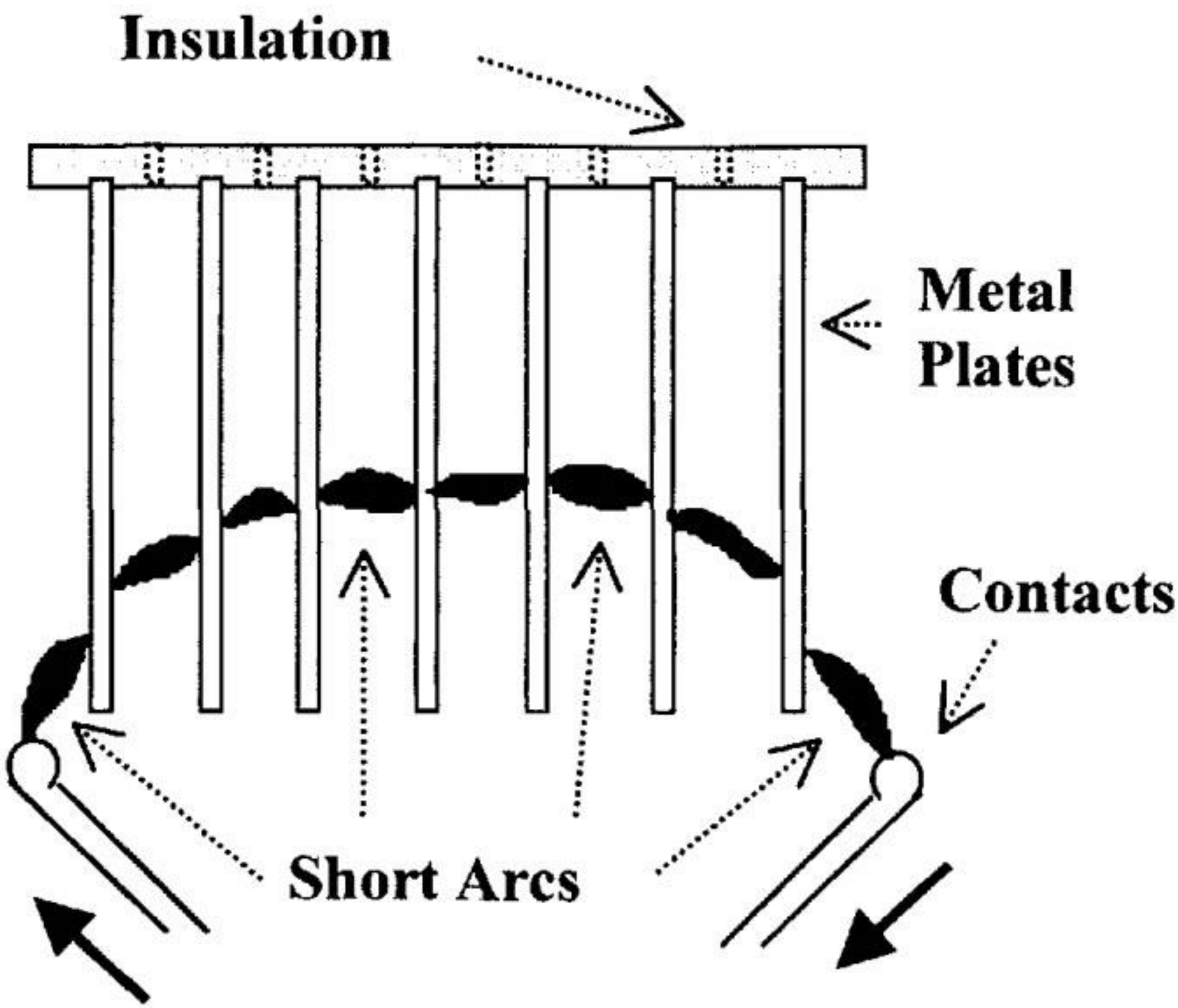
Usually, the medium used for extinction of arc is air, oil, Sulfurhexafluoride gas or vacuum. Hence, the different types of circuit breakers based on these media are:

- Air Magnetic Circuit Breakers
- Air Blast Circuit Breakers
- Oil Circuit Breakers
- Sulfurhexafluoride (SF_6) Circuit Breakers
- Vacuum Circuit Breakers

Each type has its advantages and disadvantages and we will take a look as all these different types of circuit breakers in detail.

Air Magnetic Circuit Breakers

The first circuit breaker is the Air Magnetic Circuit Breaker. It is also called as Arc Chute Circuit Breaker. Usually, it consists of a number of plates between the contacts and are made up of either metallic or insulated materials.



When the arc is struck, it comes in contact with the series of metal plates. As a result, the main arc is divided into a number of smaller arcs that across the plates and the voltage drop is usually 30 to 40 volts. In this type of circuit breaker, the plates are usually metallic.

Another type of arc chute circuit breaker is based on a magnetic low-out assist. This type usually uses insulated arcing plates and are made of ceramic.

In this type, the arc is first made to travel between the insulating plates to elongate the arc. Then the arc is cooled by diffusion. When the circuit breaker begins to open and the arc is initiated, the separation between the contacts is increased. A coil, which is not part of the main conducting circuit, comes into contact with the current.

The magnetic field created by this coil will exert a force on the arc and as a result, the arc tends to move deeper into the chute.

Air Blast Circuit Breakers

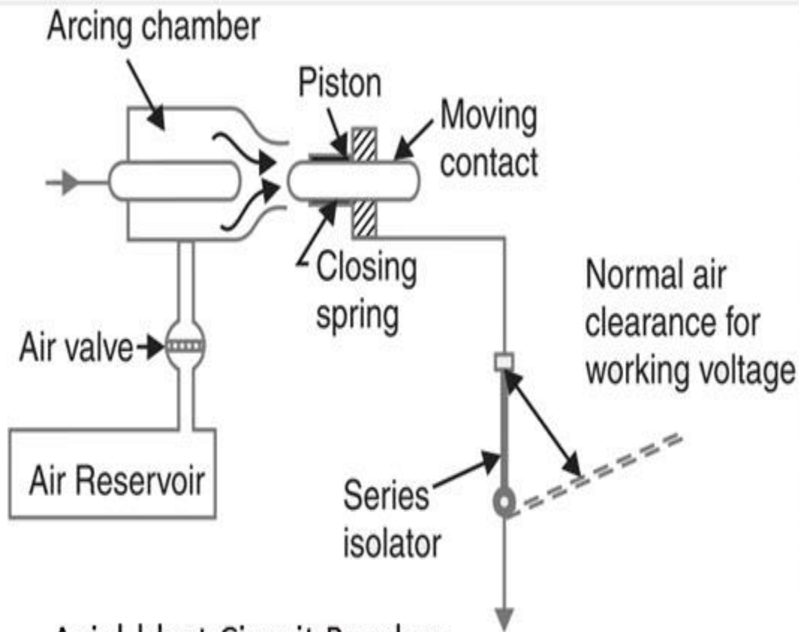
The second 'air' based circuit breakers are air blast circuit breakers. In this type, a high-pressure air-blast is used as arc extinguishing medium. In case of a fault, the air-blast, controlled by a blast valve, will open the contacts and also cools the arc.

The arc and the arching products are swept into the atmosphere, which rapidly increases the dielectric strength of the medium. As a result, the restriking of arc is prevented. The arc is extinguished consequently and the flow of current is completely interrupted.

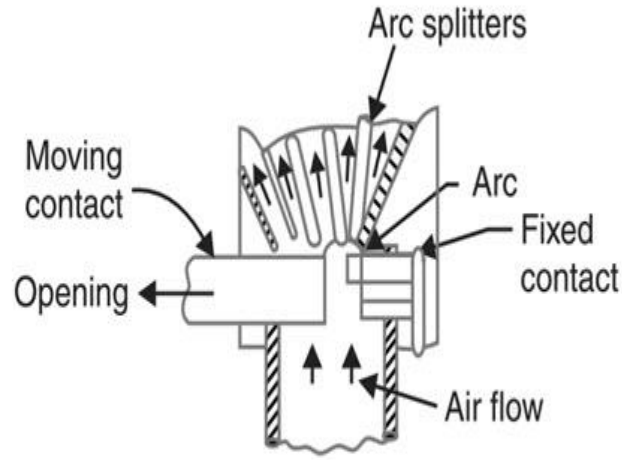
There are three types of air blast circuit breakers based on the direction of the air-blast in relation to the arc. They are:

- Axial Blast Type
- Cross Blast Type
- Radial Blast Type

In axial-blast circuit breakers, the air-blast flows in the same direction as the arc. The high-pressure air-blast will push the moving contact away, opening the circuit and also pushes the arc along with it.



Axial-blast Circuit Breaker



Cross-blast Circuit Breaker

The air-blast in cross-blast type circuit breakers is perpendicular to the arc path and in radial-blast type circuit breakers, it is directed radially.

Advantages

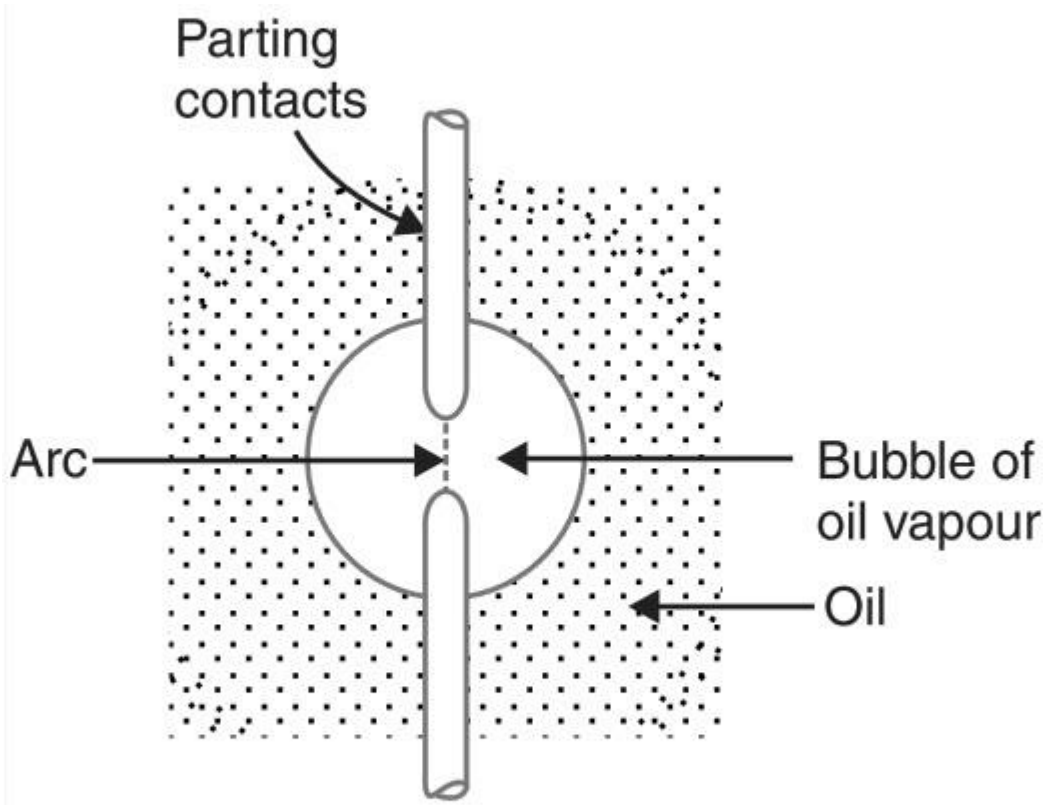
- Risk of fire is eliminated.
- Arcing products are completely removed by the air-blast.
- Significantly faster increase in dielectric strength. Hence, the contact gap can be less, resulting in smaller device.
- Arcing time is very small and the arc energy is also small. Suitable for frequent operations.
- Air-blast is independent to the interrupting current.

Disadvantages

- Arc extinguishing properties of air are inferior.
- Sensitive to variations in restricting voltage.
- Air-blast compressor needs to be maintained.

Oil Circuit Breakers

In Oil Circuit Breakers, an insulating oil is used as the arc extinguishing medium. As the contacts are opened in oil, when the arc strikes, the surrounding oil is evaporated as hydrogen gas.



The hydrogen gas bubble will surround the arc region. Hydrogen gas, due to its high thermal conductivity, cools the arc and also deionizes the medium. Also, the gas causes turbulence in the surrounding oil and all the arcing products are pushed away from the arc.

There are two types of oil circuit breakers. They are:

- Bulk Oil Circuit Breakers
- Low Oil Circuit Breakers

As the name suggests, bulk oil circuit breakers use a significantly large quantity of oil. Further, bulk oil circuit breakers are again divided into two types.

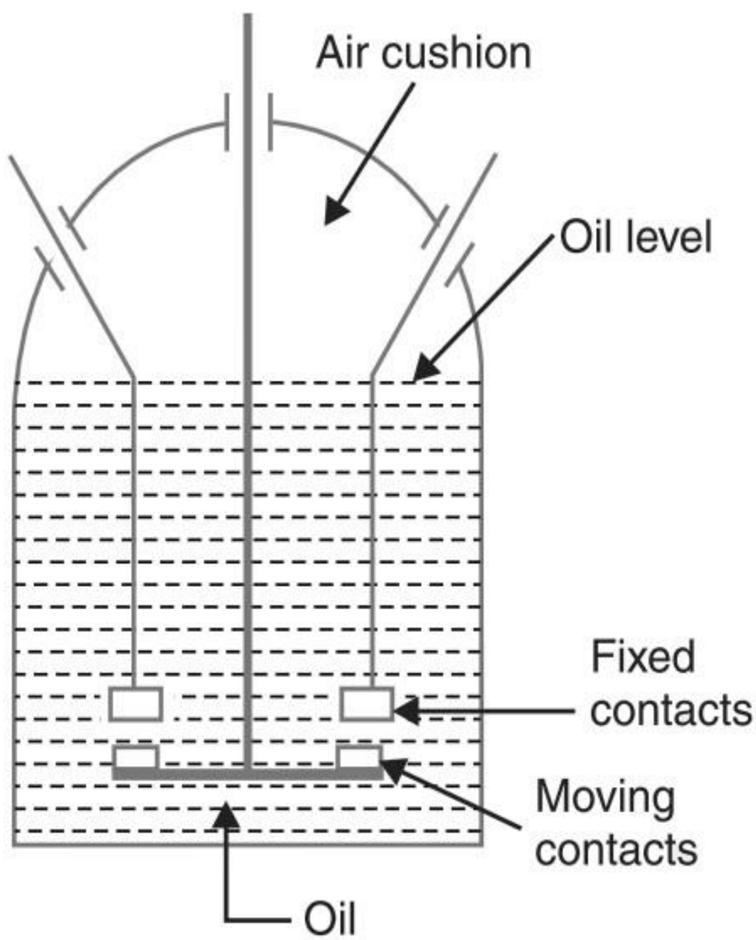
- Plain Break Oil Circuit Breakers
- Arc Control Oil Circuit Breakers

In Plain Break Oil Circuit Breakers, the contacts are separated in the oil tank and the system for arc control is to increase the separation of the contacts. When a critical gap between the contacts is reached, the arc extinction occurs.

The lack of control over the arc in plain break oil circuit breakers is overcome in Arc Control Oil Circuit Breakers. The arc control is implemented in two ways known as:

- Self-blast Oil Circuit Breakers
- Forced-blast Oil Circuit Breakers

In self-blast type breakers, an insulating rigid pressure chamber is used with the contacts and the gases released during arcing are confined to this chamber or pot. The high pressure developed in the small chamber will force the oil as gas to go through the arc and subsequently extinguishing it.



There are three type or designs of pressure pots in Self-blast Oil Circuit Breakers. They are:

- Plain Explosion Pot
- Cross Jet Explosion Pot
- Self-compensated Explosion Pot

Coming to Forced-blast Oil Circuit Breakers, a piston cylinder is used to create the necessary oil pressure in contrast to Self-blast Oil Circuit Breakers, where the pressure is developed by the arc itself.

In all the Bulk Oil Circuit Breakers mentioned above, the oil has two jobs. One is to act as an arc extinguishing medium and the other is to insulate live circuit from earth. Only a small percentage (10% or less) is actually used for arc extinction and the majority of the oil is used for insulating purpose.

In Low Oil Circuit Breakers, oil is used for arc extinction and a solid material like porcelain and paper are used for insulation.

Advantages

- Oil has excellent cooling property and the arc energy converts the oil into gas.
- Acts as insulator between live wires and earth.

Disadvantages

- Oil is inflammable and is a fire hazard.
- Arcing products cannot escape and remain in the oil.

Maintenance of Oil Circuit Breakers

The maintenance of oil circuit breakers consists of checking of contacts and dielectric strength of the oil. After fault has been interrupted by circuit breaker, fault current flows for short time or load current for several times, its contacts may be burnt due to arcing. Also there may be some loss of dielectric strength of oil due to carbonization. This will reduce rupturing capacity of the breaker. Thus periodic checking of circuit breakers is essential after regular interval of 3 or 6 months.

Following points should be kept in mind while checking:

i) Check the current carrying parts. It they are burnt replace them.

ii) Check the dielectric strength of oil. If its colour is changed then it should be changed or reconditioned. The oil in good condition withstands 30 kV for one minute with 4mm gap between electrodes.

iii) Check the insulation for any damage. Clean the surface with removal of carbon deposites with strong and dry fabric.

iv) The oil level should be checked.

v) The closing and tripping mechanism should be checked.

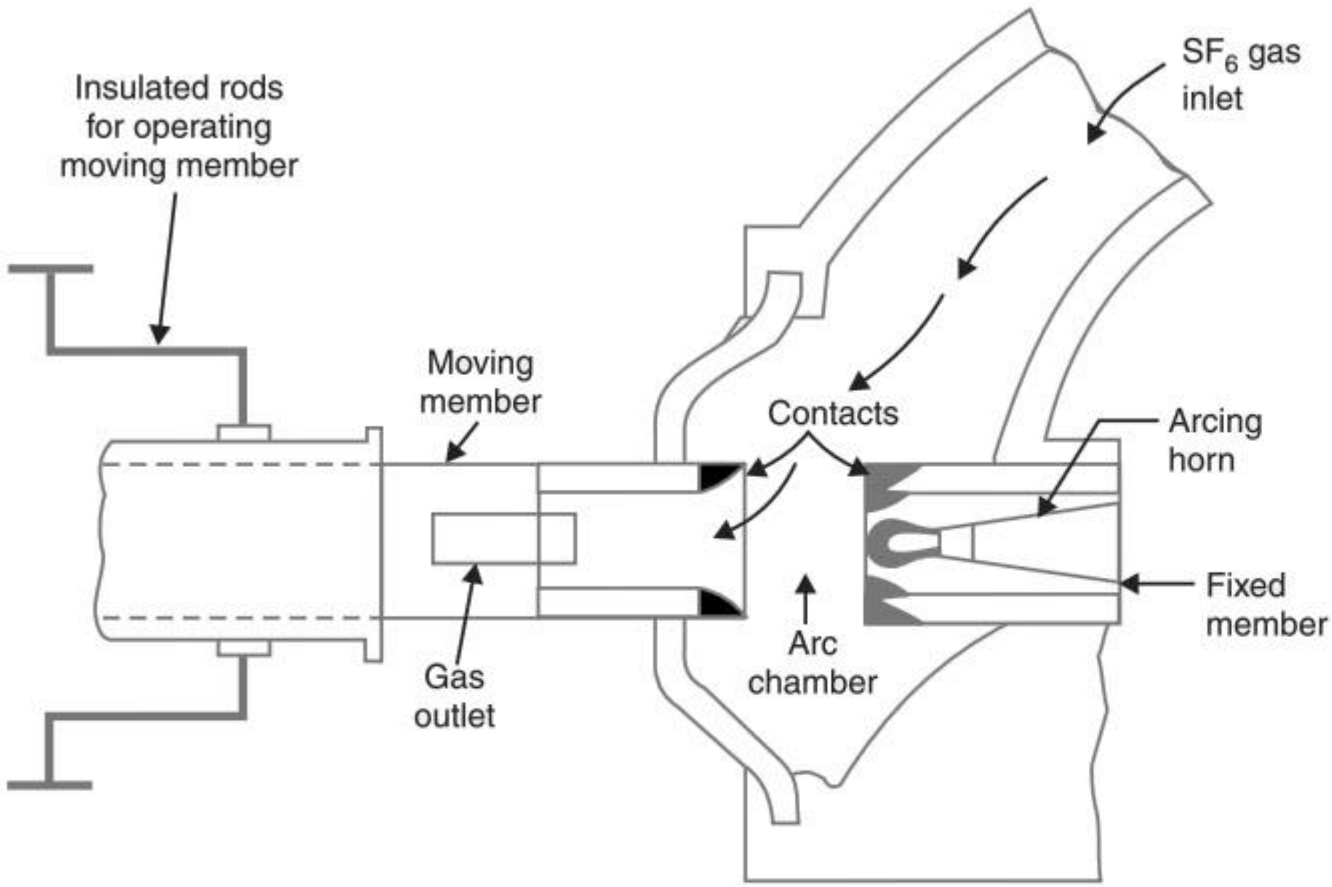
Sulfurhexafluoride (SF_6) Circuit Breakers

In Sulfur Hexafluoride circuit breakers, Sulfur Hexafluoride with chemical formula SF_6, is used as the arc extinguishing medium.

The Sulfurhexafluoride gas is electro-negative in nature i.e. it attracts free electrons. When the circuit contacts are opened, a high pressure Sulfurhexafluoride gas flows through the chamber as the arc strikes.

Free electrons produced during the arcing are quickly absorbed by the SF_6 gas resulting in immobile negative ions. As the arc loses its conducting electrons, the insulating strength of the surrounding medium is quickly increased and the arc completely extinguishes.

Following image shows a simplified construction of SF_6 Circuit Breaker. Both the fixed and moving contacts are placed in arc chamber, which contains Sulfurhexafluoride gas. When the contacts open, a high pressure SF_6 gas from a reservoir will flow through the chamber's inlet.



Advantages

- Superior arc extinguishing property.
- Can interrupt larger currents as the dielectric strength of SF_6 gas is almost 3 times greater than air.
- Noise free operation and no exhaust into atmosphere.
- Moisture free operation as the gas filled chamber keeps in interior dry.
- Very low maintenance and requires minimum equipment.
- Suitable for hazardous and hostile conditions like coal mines as the breakers are enclosed and sealed.

Disadvantages

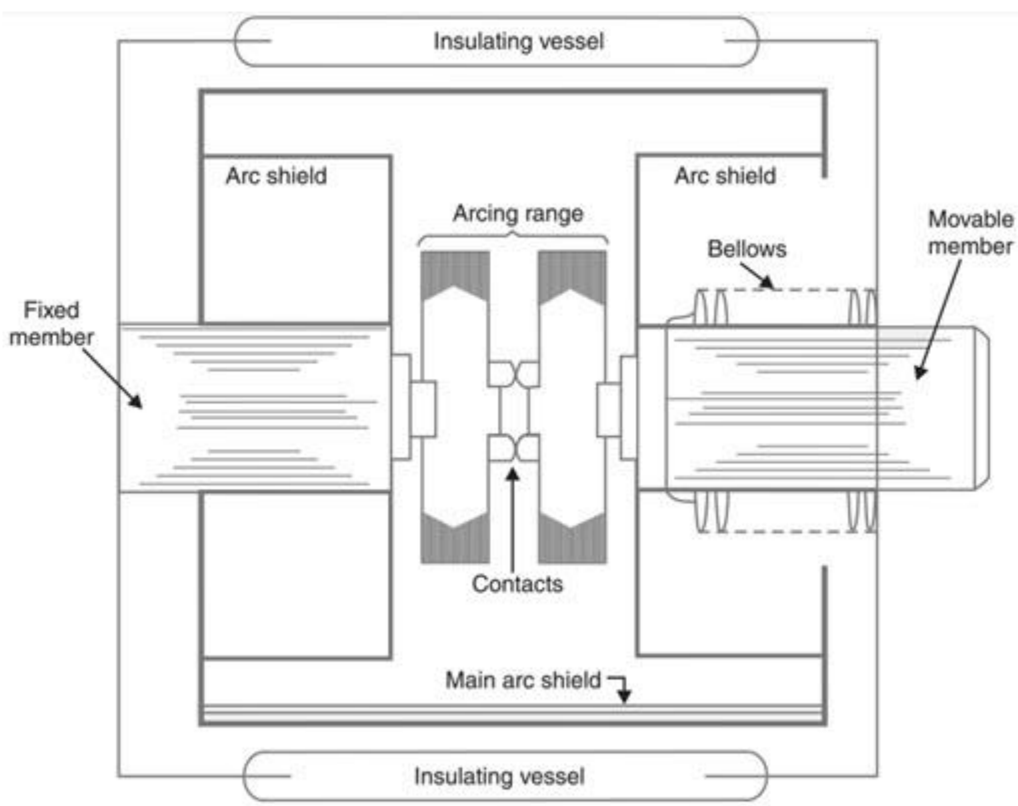
- Sulfurhexafluoride gas is very costly.
- SF_6 has to be reconditioned after every operation.
- This high pressure Sulfurhexafluoride gas will absorb all the conducting free electrons and as a result causes the extinction of the arc.

Vacuum Circuit Breakers

In vacuum circuit breakers or VCB, the arc extinguishing medium is, well Vacuum. It offers superior arc extinguishing properties than other medium as it has the highest insulating strength.

When the contacts of the circuit breaker in vacuum are opened, an arc is formed due to ionization of the metal vapours of the contacts. But the arc is quickly extinguished as the vapours rapidly condense.

A typical vacuum circuit breaker is shown in the following image. It consists of a moving contact and a fixed contact and also an arc shield mounted in a vacuum chamber. The outer insulating body is usually made up of glass or ceramic.



Advantages

- No fire hazards.
- Compact, very reliable and have very long life.
- No gas is generated during or after operation.
- No or very little maintenance.
- VCB can interrupt any fault current.
- Can withstand lightning strikes.
- Low arc energy is released.

SWITCHGEAR COMPONENT :

A switchgear assembly has two types of components:

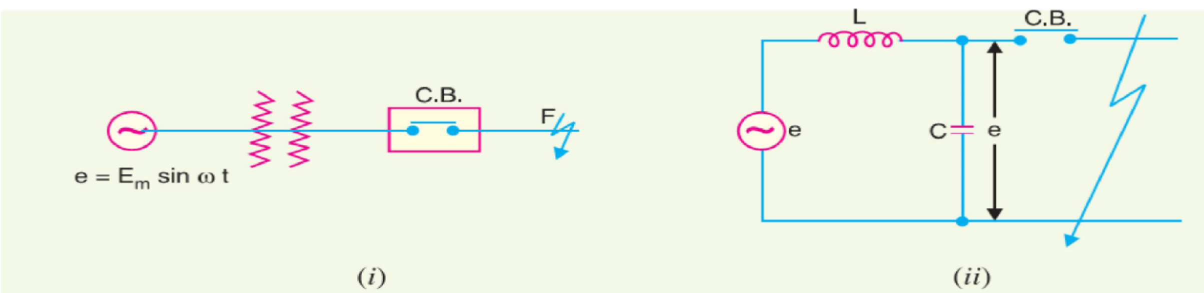
- Power conducting components, such as switches, circuit breakers, fuses, and lightning arrestors, that conduct or interrupt the flow of electrical power.
- Control systems such as control panels, current transformers, potential transformers, protective relays, and associated circuitry, that monitor, control, and protect the power conducting components.

Problems of Circuit Interruption

- 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.

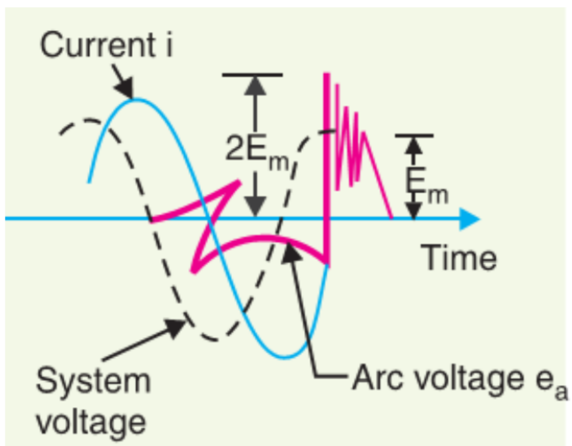
The oscillatory surges are undesirable and, therefore, the circuit breaker must be designed to dissipate as much of the stored energy as possible.



The figure above represents
equivalent circuit where L is the inductance per phase of the system(including generator, transformer and transmission line) 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.

(i) 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 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. below, where I represents the short-circuit current and ea represents the arc volt-

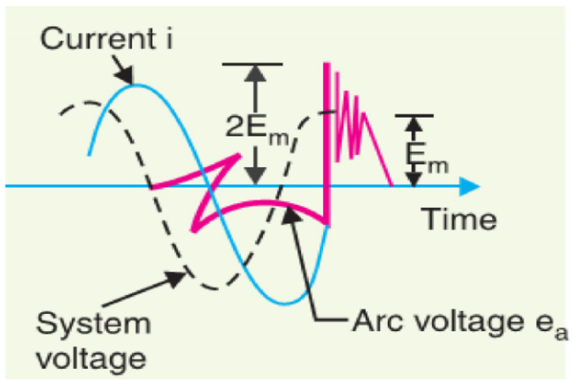


age. It may be seen that in this condition, the *entire generator voltage appears across inductance L.

When the contacts are opened and the arc finally extinguishes at some current zero, the generator voltage eis suddenly applied to the inductance and capacitance in series. This L–C combination forms an oscillatory circuit and produces a transient of frequency :

$$f_n = \frac{1}{2\pi\sqrt{LC}}$$

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 Em 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 upon :

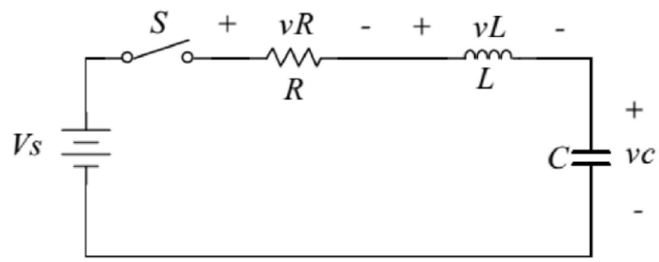
(a) recovery voltage

(b) natural frequency of oscillations

For a short-circuit occurring near the power station bus-bars, C being small, the natural frequency $f_n \; (= 1/2\,\pi\,\sqrt{LC})$

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.



$$vR + vL + vc = Vs$$

$$i = C\frac{dvc}{dt}$$

$$vR = iR = RC\frac{dvc}{dt}$$

$$vL = L\frac{di}{dt} = LC\frac{d^2vc}{dt^2}$$

$$\frac{d^2vc}{dt^2}+\frac{R}{L}\frac{dvc}{dt}+\frac{1}{LC}vc=\frac{1}{LC}Vs$$

$$s^2+\frac{R}{L}s+\frac{1}{LC}=0$$

$\alpha=\frac{R}{2L}$: Damping rate

$\omega_o=\frac{1}{\sqrt{LC}}$: Natural frequency

$$s1=-\alpha+\sqrt{\alpha^2-\omega_o^2}$$

$$s2=-\alpha-\sqrt{\alpha^2-\omega_o^2}$$

$$vc = Vs + A_1 e^{s1t} + A_2 e^{s2t}$$

	Series	Parallel
ω_o	$\omega_o = \frac{1}{\sqrt{LC}}$	$\omega_o = \frac{1}{\sqrt{LC}}$
α	$\alpha = \frac{R}{2L}$	$\alpha = \frac{1}{2RC}$
Critically Damped	$\alpha = \omega_o$ Response: $A_1 t e^{-\alpha t} + A_2 e^{-\alpha t}$	
Under Damped	$\alpha < \omega_o$ Response: $\underbrace{e^{-\alpha t}}_{Decaying} \underbrace{\left(K_1 \cos \omega_d t + K_2 \sin \omega_d t\right)}_{Oscillatory}$ Where $\omega_d \equiv \sqrt{\omega_o^2 - \alpha^2}$	
Over Damped	$\alpha > \omega_o$ Response: $A_1 e^{s1t} + A_2 e^{s2t}$ Where $s1, 2 = -\alpha \pm \sqrt{\alpha^2 - \omega_o^2}$	

(ii) Current chopping. It is the phenomenon of current interruption before the natural current zero is reached.

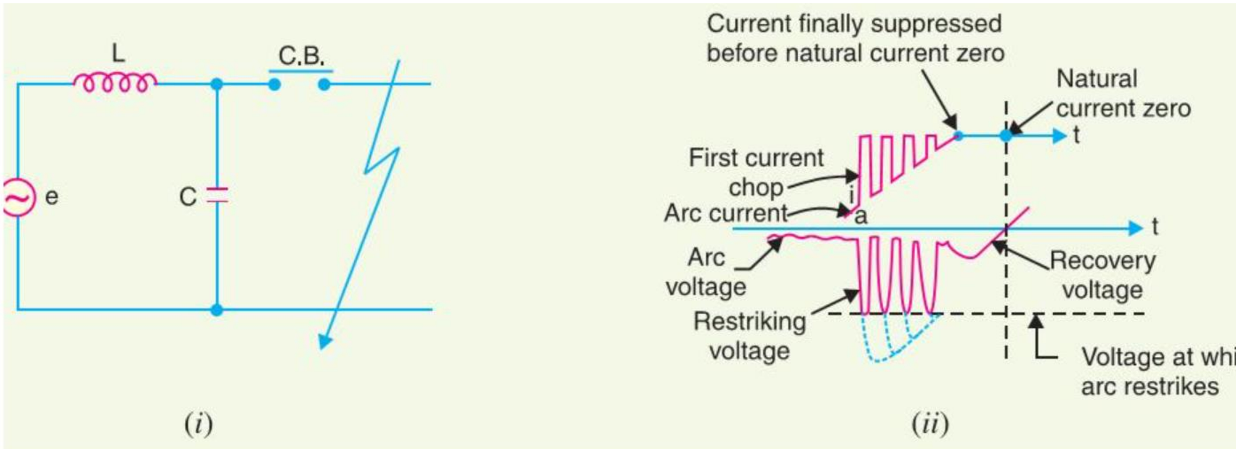
Current chopping **mainly occurs in air-blast circuit breakers because they retain the same extinguishing power irrespective of the magnitude of the current to be interrupted. When breaking low currents (e.g., transformer magnetising current) with such breakers, the powerful de-ionising effect of air-blast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

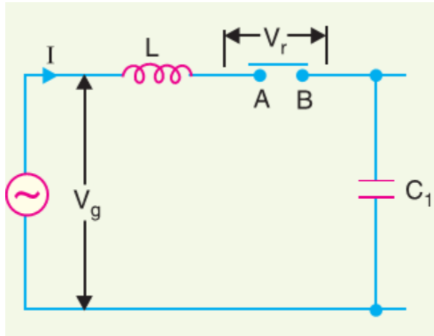
$$\frac{1}{2} L i^2 = \frac{C e^2}{2}$$

$$e = i \sqrt{\frac{L}{C}} \text{ volts}$$

For example, if L and C are 4mH and 0·001 μF respectively, a current chop of magnitude 50 A would induce a voltage of

$$e = i\sqrt{\frac{L}{C}} = 50\sqrt{\frac{4 \times 10^{-3}}{0 \cdot 001 \times 10^{-6}}} = 100 \times 10^3 \text{ volts} = 100 \text{ kV}$$


L
C.B.
e
C
(i)
Current finally suppressed
before natural current zero
Natural
current zero
t
First current
chop
i
Arc current
a
t
Arc
voltage
Recovery
voltage
Restriking
voltage
Voltage at whic
arc restrikes
(ii)

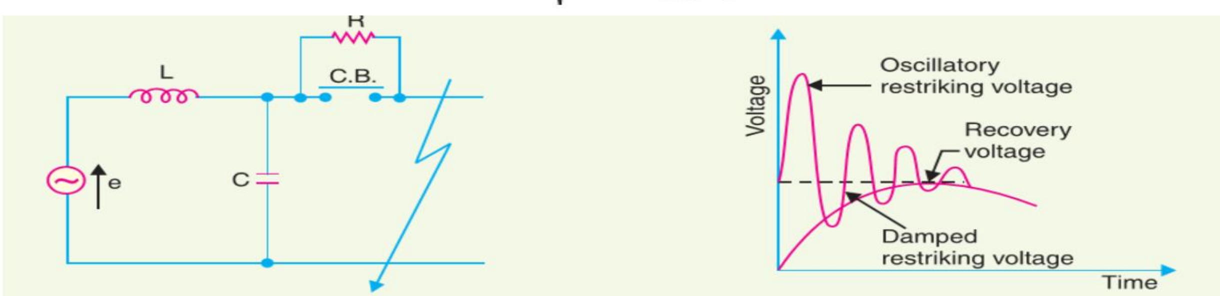


(iii) Capacitive current breaking. Another cause of excessive voltage surges in the circuit breakers is the interruption of capacitive currents. Examples of such instances are opening of an unloaded long transmission line, disconnecting a capacitor bank used for power factor improvement etc.

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 Rconnected across the circuit breaker contacts as shown in the equivalent circuit in Fig. below This is known as resistance switching.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{1}{4R^2C^2}}$$



R is so chosen that the circuit is critically damped. The value of R required for critical damping is $0{\cdot}5\sqrt{L/C}$. Fig. 19.23 shows the oscillatory growth and exponential growth when the circuit is critically damped.

To sum up, resistors across breaker contacts may be used to perform one or more of the following functions :

(i) To reduce the rate of rise of re-striking voltage and the peak value of re-striking voltage.

(ii) To reduce the voltage surges due to current chopping and capacitive current breaking.

(iii) To ensure even sharing of re-striking voltage transient acorss the various breaks in multibreak circuit breakers. It may be noted that value of resistance required to perform each function is usually different. However, it is often necessary to compromise and make one resistor do more than one of these functions.

Circuit Breaker Ratings

- A circuit breaker may be called upon to operate under all conditions. However, major duties areimposed 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.
- **(i)breaking capacity.**
- **(ii)making capacity**
- **and (iii)short-time capacity.**
- (i) 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).

(i) 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).

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

(ii) Making capacity.

There is always a possibility of closing or making the circuit under shortcircuit 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.

Making capacity =2·55 ×Symmetrical breaking capacity

(iii) 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.

(iv) 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.

Example 19.1. *A circuit breaker is rated as 1500 A, 1000 MVA, 33 kV, 3-second, 3-phase oil circuit breaker. Find (i) rated normal current (ii) breaking capacity (iii) rated symmetrical breaking current (iv) rated making current (v) short-time rating (vi) rated service voltage.*

Solution.

(*i*) Rated normal current = **1500 A**

(*ii*) Breaking capacity = **1000 MVA**

(*iii*) Rated symmetrical breaking current $= \dfrac{1000 \times 10^6}{\sqrt{3} \times 33 \times 10^3}$ = **17496 A** (r.m.s.)

(*iv*) Rated making current = $2{\cdot}55 \times 17496$ = **44614 A** (peak)

(*v*) Short-time rating = **17496A** for 3 seconds

(*vi*) Rated service voltage = **33 kV** (r.m.s.)

Example 19.2. *A 50 Hz, 11 kV, 3-phase alternator with earthed neutral has a reactance of 5 ohms per phase and is connected to a bus-bar through a circuit breaker. The distributed capacitance upto circuit breaker between phase and neutral in 0·01 µF. Determine*

(*i*) *peak re-striking voltage across the contacts of the breaker*

(*ii*) *frequency of oscillations*

(*iii*) *the average rate of rise of re-striking voltage upto the first peak*

Solution.

Inductance per phase, $L = \dfrac{X_L}{2\pi f} = \dfrac{5}{2\pi \times 50} = 0{\cdot}0159\text{ H}$

Capacitance per phase, $C = 0{\cdot}01\,\mu\text{F} = 10^{-8}\text{ F}$

(*i*) Maximum value of recovery voltage (phase to neutral)

$$E_{max} = \sqrt{2} \times \frac{11}{\sqrt{3}} = 8{\cdot}98\text{ kV}$$

∴ Peak re-striking voltage $= 2\,E_{max} = 2 \times 8{\cdot}98 =$ **17·96 kV**

(*ii*) Frequency of oscillations is

$$f_n = \frac{1}{2\,\pi\,\sqrt{LC}} = \frac{1}{2\pi\,\sqrt{0{\cdot}0159 \times 10^{-8}}} = \textbf{12,628 Hz}$$

(*iii*) Peak re-striking voltage occurs at a time t given by ;

$$t = \frac{1}{2\,f_n} = \pi\,\sqrt{LC} = \pi\,\sqrt{0{\cdot}0159 \times 10^{-8}} = 39{\cdot}6 \times 10^{-6}\text{ sec} = 39{\cdot}6\,\mu\text{ sec}$$

∴ Average rate of rise of re-striking voltage

$$= \frac{\text{Peak re-striking voltage}}{\text{Time upto first peak}} = \frac{17{\cdot}96\text{ kV}}{39{\cdot}6\,\mu\text{ sec}}$$

$$= 0{\cdot}453\text{ kV}/\mu\text{ sec} = \mathbf{453 \times 10^3\ kV/sec}$$

TOPIC- 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.

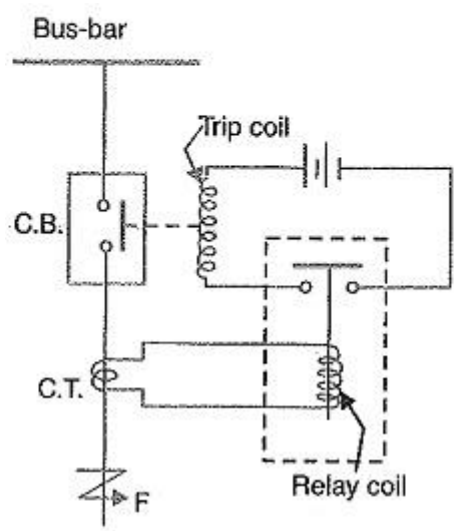


Fig. 21.1

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.

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 costa 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.

What is inside a Relay

An electromechanical relay is basically designed using few mechanical parts like Electromagnet, a movable armature, contacts, yoke, and a spring/frame/stand, these parts are showing in the **internal pictures of Relay** below. All these are arranged logically to form into a relay.

Electromagnet: An Electromagnet plays a major role in the **working of a relay**. It is a metal which doesn’t have magnetic property but it can be converted into a magnet with the help of an electrical signal. We know that when current passes through the conductor it acquires the properties of a magnet. So, when a metal winded with a copper wire and driven by the sufficient power supply, that metal can act as a magnet and can attract the metals within its range.

Movable Armature: A movable armature is a simple metal piece which is balanced on a pivot or a stand. It helps in making or breaking the connection with the contacts connected to it.

Contacts: These are the conductors that exist within the device and are connected to the terminals.

Yoke: It is a small metal piece fixed on a core in order to attract and hold the armature when the coil is energized.

Spring (optional): Few relays don't need any spring but if it is used, it is connected to one end of the armature to ensure its easy and free movement. Instead of a spring, a metal stand like structure can be used.

Relay Working Principle

Now let's understand how a relay works in a normally closed condition and normally open condition.

Relay in NORMALLY CLOSED condition:

When no voltage is applied to the core, it cannot generate any magnetic field and it doesn't act as a magnet. Therefore, it cannot attract the movable armature. Thus, the initial position itself is the armature connected in normally closed position (NC).

Relay in NORMALLY OPENED condition:

When sufficient voltage is applied to the core it starts to create a magnetic field around it and acts as a magnet. Since the movable armature is placed within its range, it gets attracted to that magnetic field created by the core, thus the position of the armature is being altered. It is now connected to the normally opened pin of the relay and external circuit connected to it function in a different manner.

The functionality of the external circuit depends upon the connection made to the relay pins.

So finally, we can say that when a coil is energized the armature is attracted and the switching action can be seen, if the coil is de-energized it loses its magnetic property and the armature goes back to its initial position.

Types of an Electromagnetic Relay

By their working principle, the electromagnetic relay is mainly classified into two types. These are

1. Electromagnetic Attraction Relay
2. Electromagnetic Induction Relay

1. Electromagnetic Attraction Relay

In this relay, the armature is attracted to the pole of a magnet. The electromagnetic force exerted on the moving element is proportional to the square of the current flow through the coil. This relay responds to both the alternating and direct current.

For AC quantity the electromagnetic force developed is given as

$$F_e = KI^2 = K(Imax\ sin\omega t)^2$$

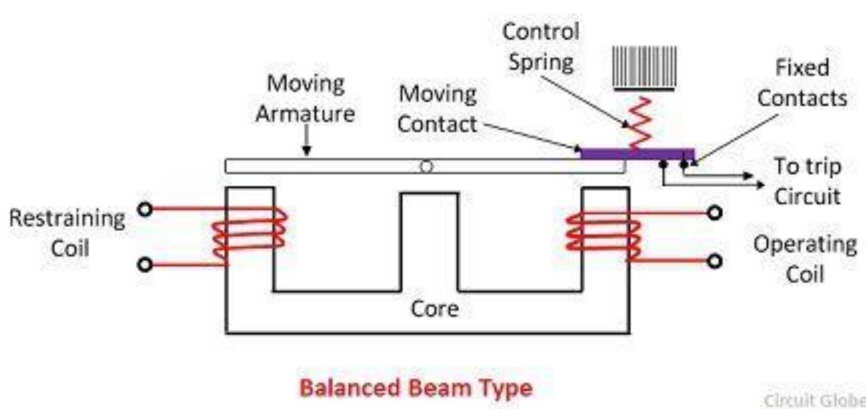
$$= \frac{1}{2}K[1^2_{max} - I^2_{max}cos2\omega t]$$

The above equation shows that the electromagnetic relay consists two components, one constant independent of time and another dependent upon time and pulsating at double supply frequency. This double supply frequency produces noise and hence damage the relay contacts.

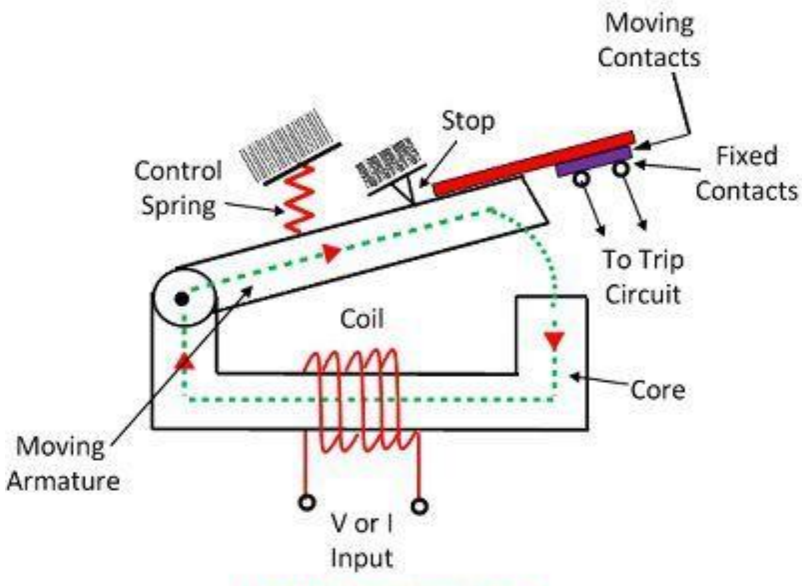
The difficulty of a double frequency supply is overcome by splitting the flux developing in the electromagnetic relay. These fluxes were acting simultaneously but differ in time phase. Thus the resulting deflecting force is always positive and constant. The splitting of fluxes is achieved by using the electromagnet having a phase shifting networks or by putting shading rings on the poles of an electromagnet.

The electromagnetic attraction relay is the simplest type of relay which includes a plunger (or solenoid), hinged armature, rotating armature (or balanced) and moving iron polarised relay. All these relays are shown below.

a. Balanced Beam Relay – In such type of relay two quantities are compared because the electromagnetic force developed varies as the square of the ampere-turn. The ratio of an operating current for such relay is low. If the relay is set for fast operation, then it will tend to overreach on a fast operation.



b. Hinged armature relay – The sensitivity of the relay can be increased for DC operation by adding the permanent magnet. This relay is also known as the polarised moving relay.



Hinged Armature Type

2. Electromagnetic Induction Relay

The electromagnetic relay operates on the principle of a split-phase induction motor. The initial force is developed on the moving element that may be disc or another form of the rotor of the non-magnetic moving element. The force is developed by the interaction of electromagnetic fluxes with eddy current, that is induced in the rotor by these fluxes.

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

a. Shaded pole structure
b. Watt-hour meter or double winding structure
c. Induction cup structure.

Induction Relays:

The **induction type relays** are also called **magnitude relays**.These relays work on the principle of the induction motor or an energy meter.In these relays, a metallic disc is allowed to rotate between the two electromagnets.The coils of the electromagnets are energised with the help of alternating currents.

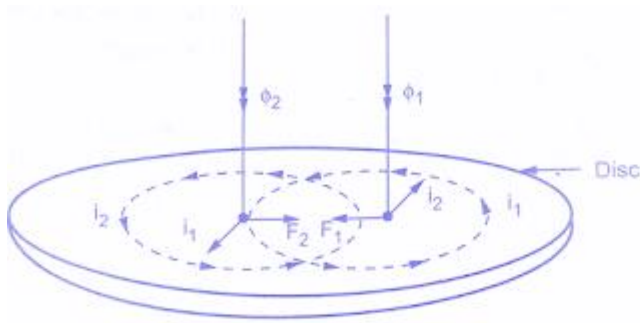
The torque is produced in **Induction relays** due to the interaction of one alternating flux with eddy currents induced in the rotor by another alternating flux.The two fluxes have the same frequency but are displaced in time and space. As the interaction of alternating fluxes is the base of operation of **Induction relays**, these are not used for the d.c. quantities.These are widely used for protective relaying involving only a.c. quantities.

Torque Equation for Induction Type Relays:

As mentioned earlier, the alternating currents supplied to two electromagnets produce the two alternating fluxes $\varphi 1$ and $\varphi 2$.These two fluxes have the same frequency but they have a phase difference of α in between them such that $\varphi 2$ leads $\varphi 1$.Thus the two fluxes can be mathematically expressed as,

$$\varphi 1 = \varphi 1m \sin \omega t$$

$$\varphi 2 = \varphi 2m \sin (\omega t+\alpha)$$



These alternating fluxes cause the induced e.m.f.s in the rotor. Due to the induced e.m.f.s, the eddy currents i1 and i2 are circulated in the disc.The two eddy currents react with each other to produce a force which acts on the rotor.

The figure above shows how the forces are produced in a section of the rotor due to the alternating fluxes.The instant considered to show the various quantities is when both the fluxes are directed downwards and are increasing in magnitude.The induced eddy currents lag behind the respective fluxes by 90^0.

Assumption: The parts of the rotor in which rotor currents flow have negligible self-inductance and hence the rotor currents are in phase with the respective induced voltages.The induced voltages are proportional to the rate of change of fluxes and hence the eddy currents also are proportional to the rate of change of fluxes. Hence we can write,

$$i_1 \propto \frac{d\phi_1}{dt}$$

$$i_2 \propto \frac{d\phi_2}{dt}$$

Substituting ϕ_1 and ϕ_2 from (1) and (2) we get,

$$i_1 \propto \frac{d(\phi_{1m} \sin \omega t)}{dt} \propto \phi_{1m} \cos \omega t$$

$$i_2 \propto \frac{d\,[\phi_{2m} \sin(\omega t + \alpha)]}{dt} \propto \phi_{2m} \cos(\omega t + \alpha)$$

The forces are produced due to the interaction of φ1 with i2 and φ2 with i1.

∴ $F1 \propto \varphi 1\ i2$ and $F2 \propto \varphi 2\ i1$

The directions of F1 and F2 can be obtained by Flemings left-hand rule.It can be seen from the above figure that the two forces are acting in the opposite directions and hence the net force acting on the disc is proportional to the difference between the two forces.

∴ $F \propto F2 - F1$

∴ $F \propto \varphi 2\ i1 - \varphi 1\ i2$

Substituting the proportional expressions of $\varphi 1$, $\varphi 2$, $i1$, $i2$ in the above equation we get,

$$F \propto [\phi_{2m} \sin(\omega t + \alpha)\, \phi_{1m} \cos \omega t - \phi_{1m} \sin \omega t\, \phi_{2m} \cos(\omega t + \alpha)]$$

$$\propto \phi_{1m} \phi_{2m} [\sin(\omega t + \alpha) \cos(\omega t) - \sin(\omega t) \cos(\omega t + \alpha)]$$

$$\propto \phi_{1m} \phi_{2m} [\sin(\omega t + \alpha - \omega t)]$$

$$F \propto \phi_{1m} \phi_{2m} \sin \alpha \quad \ldots$$

The equation above gives the net force acting on the disc which is proportional to sin $\propto$.

Substituting the r.m.s values of the fluxes instead of maximum values we get,

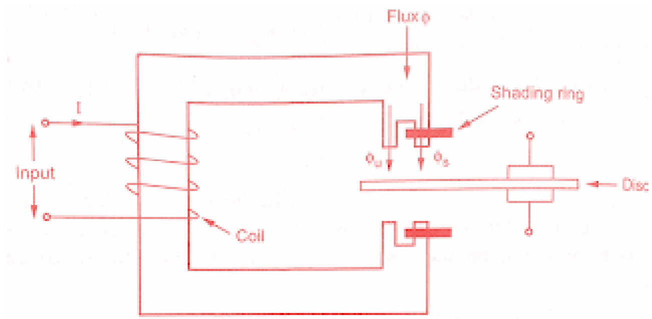
$$F \propto \varphi 1\, \varphi 2 \sin \propto$$

It is important to note that the net force or torque acting on the disc is same at every instant.The action of **Induction relay** under such force is free from vibrations. It can be observed from the above equation that if $\propto$ is zero then the net force is zero and disc cannot rotate.Hence there must exist a phase difference between the two fluxes.The torque is maximum when the phase difference $\propto$ is 90°.

The direction of the net force which decides the direction of rotation of disc depends on which flux is leading the other.In practice, various constructions are used to produce phase displacement between the two fluxes.

Shaded Pole Type Induction Relay:

The construction of **Shaded Pole Type Induction Relay** is shown in below figure.



It consists of an aluminium disc which is free to rotate in an air gap of an electromagnet.The part of pole face of each pole is shaded with the help of copper band or ring.This is called shading ring.The total flux φ produced due to the alternating current split into two fluxes displaced in time and space due to the shading ring.

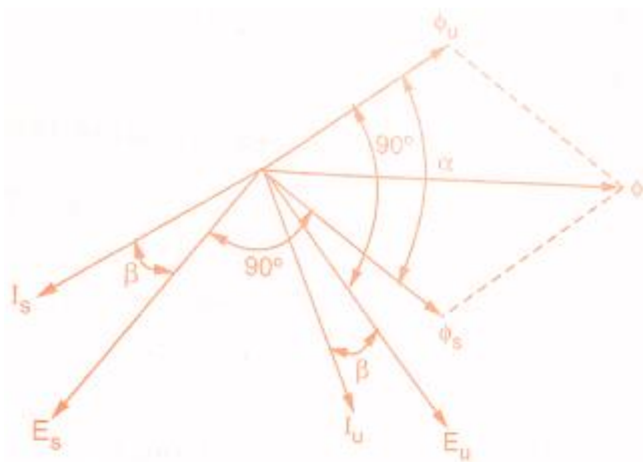
Due to the alternating flux, e.m.f gets induced in the shading ring.This e.m.f drives the currents causing the flux to exist in shaded portion.This flux lags behind the flux in the unshaded portion by angle ∝.

Let φs = Flux in shaded portion
φu = Flux in unshaded portion
Es = E.M.F. induced in the disc due to φs
Eu = E.M.F. induced in the disc due to φu
Is = Induced current due to Es
Iu = Induced current due to Eu

Eu lags behind φu by 90° while Es lags behind φs by 90°.The current Is lags Es by small angle β while Iu lags Eu by small angle β.This angle is generally neglected and Is and Iu are assumed to be in phase with Es and Eu respectively, in practice.The phasor diagram is shown in the figure below.

As proved in the previous section, neglecting It we get,

$$T \propto \varphi s \, \varphi u \sin \propto \qquad \text{(where } T = \text{Torque)}$$



Assuming fluxes φs and φu to be proportional to the current I in the relay coil we can write,

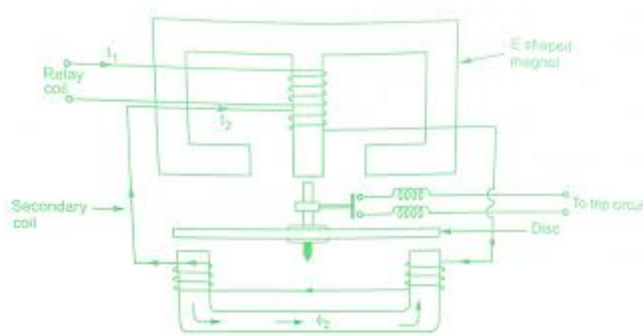
$$T \propto I^2 \sin \propto$$

$$\therefore \quad T = kI^2 \qquad (k = \text{Constant})$$

As sin ∝ is constant for the given design.Thus the torque is proportional to the Aare of the current through the coil.

Watthour Meter Type Induction Relay:

The construction of **Watthour Meter Type Induction relay** is similar to the watthour meter which is very popularly used everywhere.Thus relay has double winding structure.The arrangement is shown in the figure below.



It consists of two magnets, one E shaped magnet and other U shaped magnet.The disc is free to rotate in between these two magnets.The upper E shaped magnet carries both primary winding which is relay coil and the secondary winding.The primary carries the relay current I1 which produces the flux φ1.The e.m.f gets induced in the secondary due to this flux.This drives current I2 through secondary.

Due to this current I2, flux φ2 gets produced in the lower magnet.This flux lags behind the main flux φ1 by an angle ∝.Due to the interaction of these two fluxes, the torque is exerted on the disc and disc rotates.

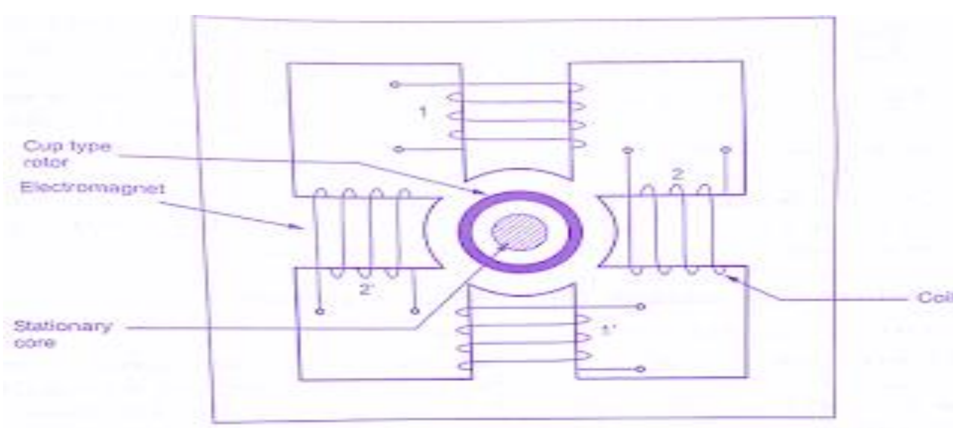
Assuming that the entire flux φ1 enters the disc from upper magnet and entire flux φ2 enters the disc from lower magnet, we can write,

$$T \propto \varphi 1 \; \varphi 2 \sin \propto$$

In **Watthour Meter Type Induction relay**, the tapping can be provided on the primary.With the help of this suitable number of primary turns can be selected and hence current setting can be adjusted.Most of the **induction relays** are of this type.An important feature of **Watthour Meter Type Induction relay** is that its operation can be controlled by opening or closing of the secondary winding.It is opened, no current can flow through secondary hence flux $\varphi 2$ cannot be produced and hence no torque can be produced.Thus relay can be made inoperative opening the secondary winding.

Induction Cup Relay:

The construction of **induction cup relay** is very similar to an inductionmotor asshowninbelowfigure.

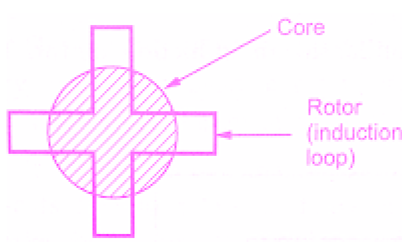


The stator consists of two, four or more poles.These are energized by the relay coils.The figure below shows 4 pole structure and the two pairs of coils. The coils 1 and 1' are connected while the coils 2 and 2' are connected to form two pairs of coils.The rotor is hollow cylindrical cup type in structure. Compared to induction motor the difference is that in **induction cup relay** the rotor core is stationary and only rotor conductor portion is free to rotate about its axis.

The currents and respective fluxes produced by the two pairs of coils are displaced from each other by angle $\propto$. Thus the resultant flux in the air gap is rotating.So rotating magnetic field is produced by two pairs of coils. Due to this, eddy currents are induced in the cup type rotor.

These currents produce the flux. The interaction of the two fluxes produce the torque and the rotor rotates in the same direction as that of rotating magnetic field.A control spring and the back stop carried on an arm attached to the spindle of the cup, are responsible to prevent continuous rotation
.

Induction cup relay is very fast in operation.The operating time of the order of 10 milliseconds is possible with this type. This is because the rotor is light having very low moment of (induction loop) inertia.The induction cup structure can be used for two quantity or single quantity relays.



A single quantity relay means both the coils are fed by the same actuating quantity with a fixed phase angle shift in between them. To reduce the rotor inertia and to make the operation faster, double induction loop structure is used.Such a structure is shown in the above figure.

In all, the **induction relays** are widely used for protective relays involving a.c quantities.High, low and adjustable speeds are possible in these relays. Various shapes of time against operating quantity curves can be obtained.

Pick up Current :

The current for which the relay initiates its operation is called **pick up current of relay**.

Current Setting of Relay :

The **current setting of relay** is expressed in percentage ratio of relay pick up current to the rated secondary current of CT.
That means,

$$Current\ setting\ =\ \frac{Pick\ up\ current}{Rated\ secondary\ current\ of\ CT} \times 100\%$$

For example, suppose, you want that, an over current relay should operate when the system current just crosses 125% of rated current. If the relay is rated with 1 A, the normal pick up current of the relay is 1 A and it should be equal to secondary rated current of current transformer connected to the relay.
Then, the relay will be operated when the current of CT secondary becomes more than or equal to 1.25 A.
As per definition,

$$Current\ setting\ =\ \frac{1.25}{1}\ \times\ 100\%\ =\ 125\%$$

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

Plug Setting Multiplier of Relay :

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

$$PSM = \frac{Fault\ current\ in\ relay\ coil}{Pick\ up\ current}$$

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

Suppose we have connected on protection CT of ratio 200/1 A and current setting is 150%.
Hence, pick up current of the relay is, 1 × 150 % = 1.5 A
Now, suppose fault current in the CT primary is 1000 A. Hence, fault current in the CT secondary, i.e., in the relay coil is, 1000 × 1/200 = 5A
Therefore PSM of the relay is, 5 / 1.5 =3.33

Time setting multiplier :

The time setting multiplier is nothing but an adjusting or speeds up the tripping mechanism of the relay (it is called as the dial).

The dial is nothing but a rotating disc, which rotates when the fault current in the relay coil reaches the pickup current.

It means, one end connects with the tripping mechanism and another end connect with the relay operation mechanism.

By changing the dial or disc position we can increase or decrease the tripping time of the relay. Refer the below TMS picture.

The total relay operating time= Plug setting Multiplier time (Which is available in the relay) * Time Multiplier Setting

Take an example of the above mentioned, in this, consider relay TMS is 10% and PSM=8.. Hence the timing for PSM 8, Time =2 sec…then the relay operating time is 2 * 10% = 0.02sec.

Different Functional Relays :

1.DISTANCE RELAY :

Distance relays respond to the voltage and current, i.e., the impedance, at the relay location. The impedance per mile is fairly constant so these relays respond to the distance between the relay location and the fault location.

As the power systems become more complex and the fault current varies with changes in generation and system configuration, directional overcurrent relays become difficult to apply and to set for all contingencies, whereas the distance relay setting is constant for a wide variety of changes external to the protected line.

There are three general distance relay types

IMPEDANCE RELAY

The impedance relay has a circular characteristic centered at the origin of the R-X diagram. It is nondirectional and is used primarily as a fault detector.

ADMITTANCE RELAY

The admittance relay is the most commonly used distance relay. It is the tripping relay in pilot schemes and as the backup relay in step distance schemes. Its characteristic passes through the origin of the R-X diagram and is therefore directional. In the electromechanical design it is circular, and in the solid state design, it can be shaped to correspond to the transmission line impedance.

REACTANCE RELAY

The reactance relay is a straight-line characteristic that responds only to the reactance of the protected line. It is nondirectional and is used to supplement the admittance relay as a tripping relay to make the overall protection independent of resistance. It is particularly useful on short lines where the fault arc resistance is the same order of magnitude as the line length.

Induction Type Overcurrent Relay(Non-Directional):

This Induction Type Overcurrent Relay works on the induction principle and initiates corrective measures when current in the circuit exceeds the predetermined value. The actuating source is a current in the circuit supplied to the relay from a current transformer. These relays are used on a .c. circuits only and can operate for fault current flow in either direction.

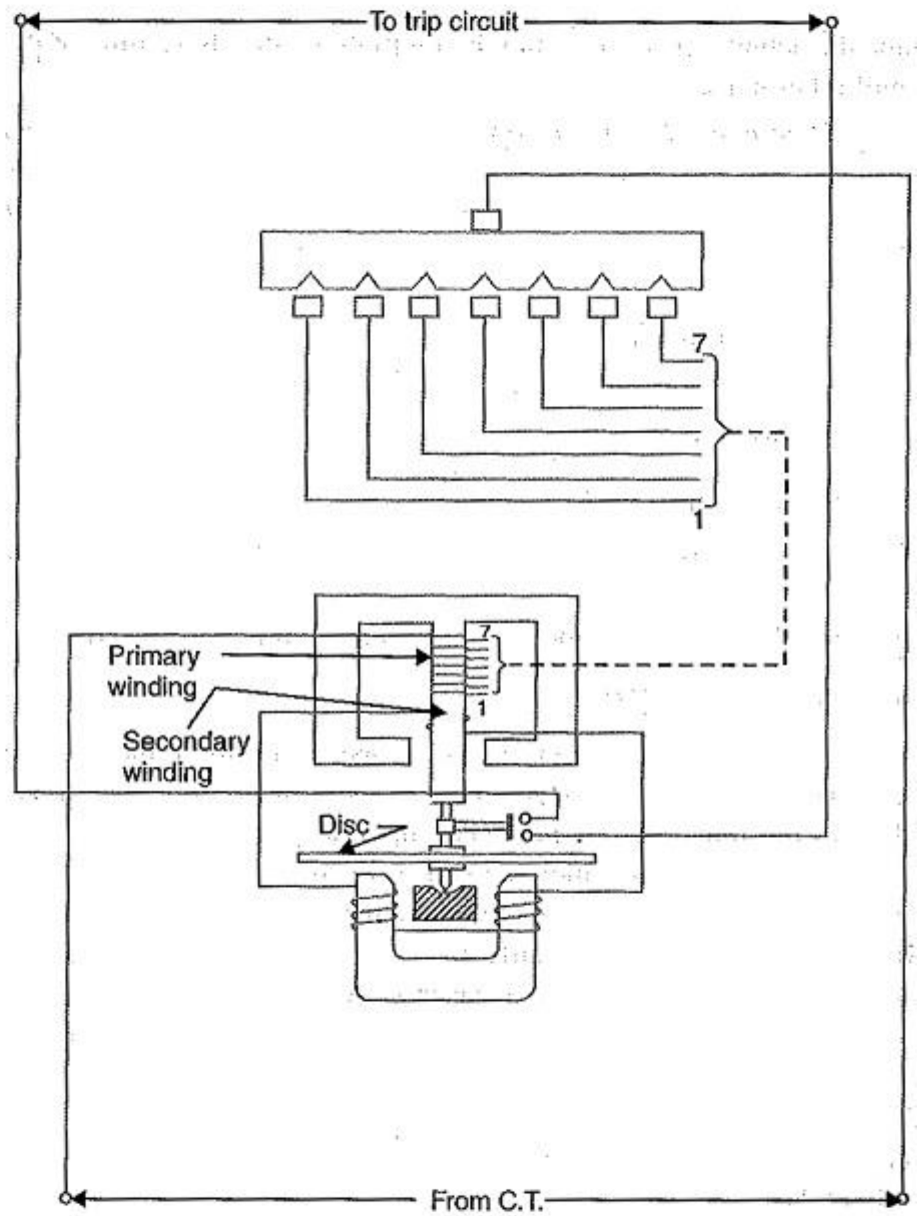


Fig. 21 .17

Constructional details: Fig. 21.17 shows the important constructional details of a typical non-directional induction type overcurrent relay. It consists of a metallic (aluminium) disc which is free to rotate in between the poles of two electromagnets. The upper electromagnet has a primary and a secondary winding. The primary is connected to the secondary of a C.T. in the line to be protected and is tapped at intervals. The tappings are connected to a plug-setting bridge by which the number of active turns on the relay operating coil can be varied, thereby giving the desired current setting. The secondary winding is energized by induction from primary and is connected in series with the winding on the lower magnet. The controlling torque, is provided by a spiral spring.

The spindle of the disc carries a moving contact which bridges two fixed contacts (connected to trip circuit) when the disc rotates through a pre-set angle. This angle can be adjusted to any value between 0° and 360^0. By adjusting this angle, the travel of the moving contact can be adjusted and hence the relay can be given any desired time setting.

Operation: The driving torque on the aluminium disc is set up due to the induction principle as discussed in Art. 21.5. This torque is opposed by the restraining torque provided by the spring. Under normal operating conditions, restraining torque is greater than the driving torque produced by the relay coil current, Therefore, the aluminium disc remains stationary. However, if the current in the protected circuit exceeds the pre-set value, the driving torque becomes greater than the restraining torque. Consequently, the disc rotates and the moving contact bridges the fixed contacts when the disc has rotated through a pre-set angle. The trip circuit operates the circuit breaker which isolates the faulty section.

Induction Type Directional Power Relay:

This Induction Type Directional Power Relay operates when power in the circuit flows in a specific direction Unlike a non-directional overcurrent relay, a directional power relay is so designed that it obtains its operating torque by the interaction of magnetic fields derived from both voltage and current source of the circuit it protects. Thus this type of relay is essentially a wattmeter and the direction of the torque set up in the relay depends upon the direction of the current relative to the voltage, with which it is associated.

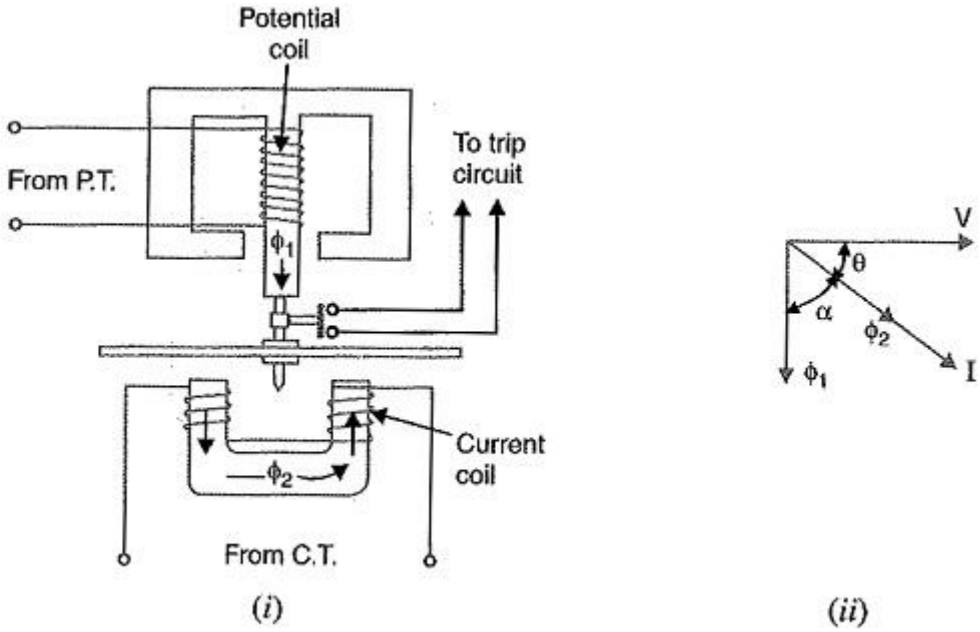


Fig. 21.18

Constructional details: Fig. 21.18 shows the essential parts of a typical induction type directional power relay. It consists of an aluminum disc which is free to rotate in between the poles of two electromagnets. The upper electromagnet carries a winding (**called potential coil**) on the central limb which is connected through a potential transformer (P.T.) to the circuit voltage source. The lower electromagnet has a separate winding (called current coil) connected to the secondary of C.T. in the line to be protected. The current coil is provided with a number of tappings connected to the plug-setting Midge (not shown for clarity). This permits to have any desired current setting. The restraining torque is provided by a spiral spring.

The spindle of the disc carries a moving contact which bridges two fixed contacts when the disc has rotated through a pre-set angle. By adjusting this angle, the travel of the moving disc can be adjusted and hence any desired time-setting can be given to the relay.

Operation: The flux Φ_1 due to current in the potential coil will be nearly 90° lagging behind the applied voltage V. The flux Φ_2 due to current coil will be nearly in phase with the operating current I.

[See vector diagram in Fig. 21.18 (ii)]. The interaction of fluxes Φ_1 and Φ_2 with the eddy currents induced in the disc produces a driving torque given by :

$$T \propto \phi_1 \phi_2 \sin \alpha \qquad \text{[See Art. 21.5]}$$

$$\text{Since} \quad \phi_1 \propto V, \quad \phi_2 \propto I \quad \text{and} \quad \alpha = 90 - \theta$$

$$T \propto V I \sin (90 - \theta)$$

$$\propto V I \cos \theta$$

$$\propto \text{power in the circuit}$$

It is clear that the direction of driving torque on the disc depends upon the direction of power flow in the circuit to which the relay is associated. When the power in the circuit flows in the normal direction, the driving torque and the restraining torque (due to spring) help each other to turn away the moving contact from the fixed contacts. Consequently, the relay remains inoperative. However, the reversal of current in the circuit reverses the direction of driving torque on the disc. When the reversed driving torque is large enough, the disc rotates in the reverse direction and the moving contact closes the trip circuit. This causes the operation of the circuit breaker which disconnects the faulty section.

Induction Type Directional Overcurrent Relay:

The directional power relay is unsuitable for use as a directional protective relay under short-circuit conditions. When a short-circuit occurs, the system voltage falls to a low value and there may be insufficient torque developed in the relay to cause its operation. This difficulty is overcome in the Induction Type Directional Overcurrent Relay which is designed to be almost independent of system voltage and power factor

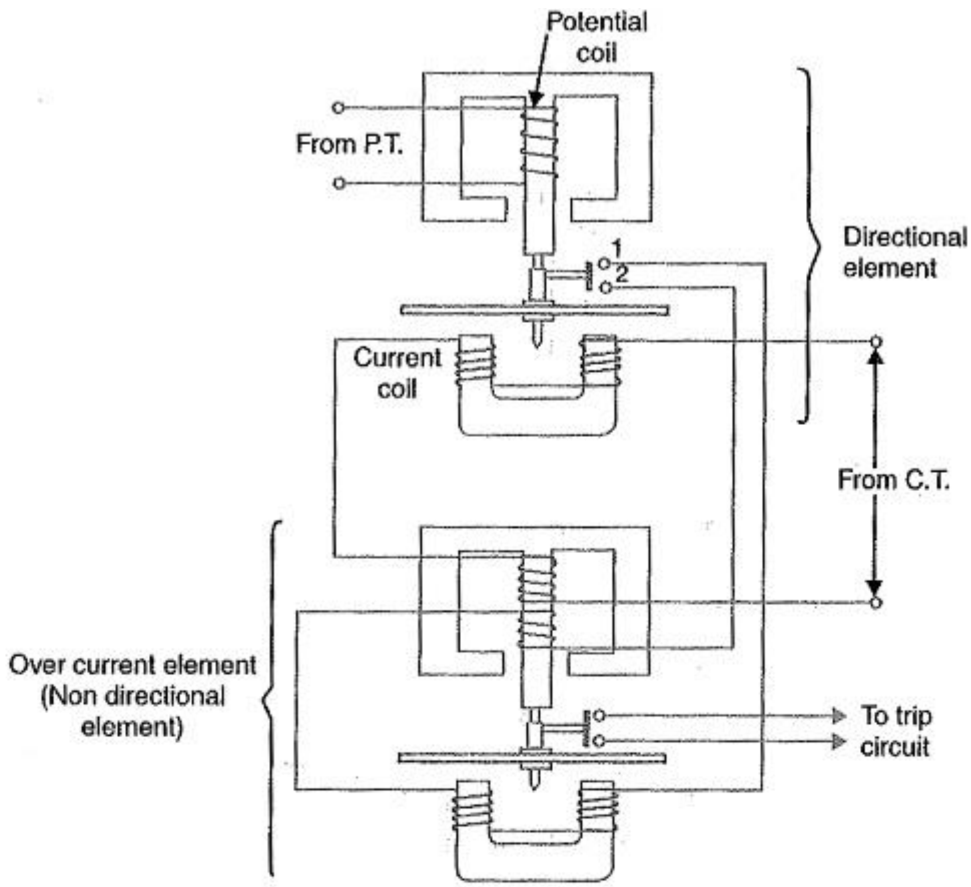


Fig. 21.19

Constructional details: Fig. 21.19 shows the constructional details of a typical Induction Type Directional Overcurrent Relay. It consists of two relay elements mounted on a common case viz.

1. **Directional element and**
2. **Non-directional element.**

1. Directional element: It is essentially a directional power relay which operates when power flows in a specific direction. The potential coil of this element is connected through a potential transformer (P.T.) to the system voltage. The current coil of the element is energised through a C.T. by the circuit current. This winding is carried over the upper magnet of the non-directional element. The trip contacts (1 and 2) of the directional element are connected in series with the secondary circuit of the overcurrent element. Therefore, the latter element cannot start to operate until its secondary circuit is completed. In other words, the directional element must operate first (i.e. contacts I and 2 should close) in order to operate the overcurrent element.

2. Non-directional element: It is an overcurrent element similar in all respects to a non-directional overcurrent relay described in Art. 21.11. The spindle of the disc of this element carries a moving contact which closes the fixed contacts (trip circuit contacts) after the operation of directional element.

It may be noted that plug-setting bridge is also provided in the relay for current setting but has been omitted in the figure for clarity and simplicity. The tappings are provided on the upper magnet of overcurrent element and are connected to the bridge.

Operation: Under normal operating conditions, power flows in the normal direction in the circuit protected by the relay. Therefore, Induction Type Directional Overcurrent Relay (upper element) does not operate, thereby keeping the overcurrent element (lower element) unenergised. However, when a short-circuit occurs, there is a tendency for the current or power to flow in the reverse direction. Should this happen, the disc of the upper element rotates to bridge the fixed contacts 1 and 2. This completes the circuit for overcurrent element.

The disc of this element rotates and the moving contact attached to it closes the trip circuit. This operates the circuit breaker which isolates the faulty section. The two relay elements are so arranged that final tripping of the current controlled by them is not made till the following conditions are satisfied :

1. **current flows in a direction such as to operate the directional element.**
2. **current in the reverse direction exceeds the pre-set value.**
3. **excessive current persists for a period corresponding to the time setting of overcurrent element.**

DIFFERENTIAL RELAY :

Differential protective relaying is the most positive in selectivity and in action. It operates on the principle of comparison between the phase angle and magnitudes of two or more-similar electrical quantities. Comparing two electrical quantities in a circuit by means of differential relays is simple in application and positive in action.

For example, in comparison of the current entering a line and the current leaving it, if more current enters the protected line than leaves it, the extra current must flow in the fault. The difference between the two electrical quantities can operate a relay to isolate the circuit.

A differential relay is defined as the relay that operates when the phasor difference of two or more similar electrical quantities exceeds a predetermined amount.

This means that for a differential relay, it should have:
(i) Two or more similar electrical quantities and

(ii) These quantities should have phase displacement (normally approximately 180°) for the operation of the relay.

Almost any type of relay, when connected in a certain way, can be made to operate as a differential relay. In other words, it is not so much the relay construction as the way the relay is connected in a circuit that makes it a differential relay. Most of the differential relays are of the "current differential" type in which phasor difference between the current entering the winding and current leaving the winding is used for sensing and relay operation.

Differential protection is generally unit protection. The protected zone is exactly determined by the location of CTs and PTs. The phasor difference is achieved by suitable connections of secondaries of CTs or PTs.

Differential protection principle is employed for the protection of generators, generator-transformer units, transformers, feeders (transmission lines), large motors and bus-bars.

Types of Differential Relays:

1. Current Differential Relays:

An arrangement of an overcurrent relay connected to operate as differential relay is shown in Fig. 3.57. The dotted line represents the system element that is to be protected by the differential relay. This system element might be a length of circuit, a portion of the bus or a winding of a generator or that of a transformer. A pair of CTs are fitted on either end of the section to be protected. The secondaries of CTs are connected in series with the help of pilot wires in such a way that they carry the induced currents in the same direction. The operating coil of an overcurrent relay is connected across the CT secondary circuit, as shown in Fig. 3.57.

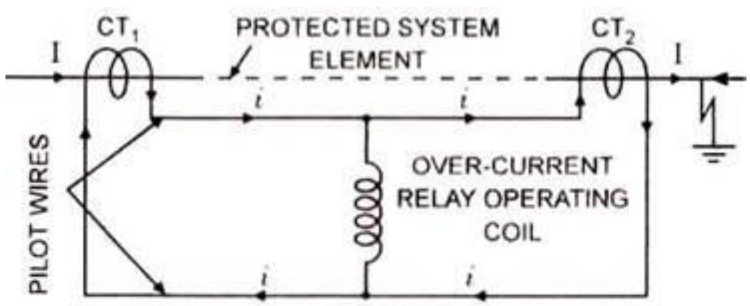
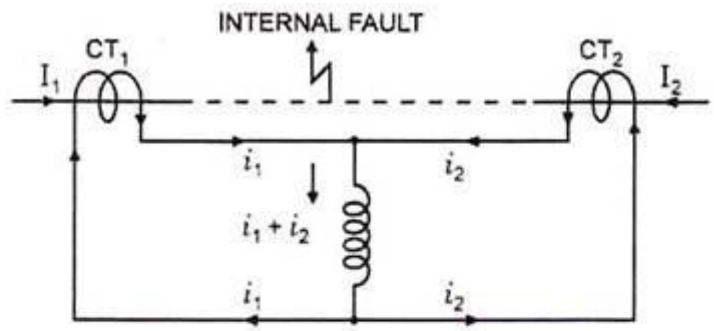


Fig. 3.57. (*a*) *For an External Load or Fault*

Normally when there is no fault or there is an external fault [Fig. 3.57 (a)] the currents in the two CT's secondaries are equal and the relay operating coil, therefore, does not carry any current.

But should a short circuit develop anywhere between internal fault the two CTs, the conditions will exist as shown in Fig. 3.57 (b). If the current flows to the fault from both sides as shown, the sum of the CT secondary currents will flow through the differential relay. It is not necessary that fault current flows to the fault from both sides to cause secondary current to flow to the differential relay.



(b) For an Internal Fault

Fig. 3.57. ***Principle of Current Differential Relay***

A flow on one side only, or even some current flowing out of one side while a larger current entering the other side will cause a differential current to flow through the relay operating coil. In the other words, the differential relay current will be proportional to the phasor difference between the currents entering and leaving the protected element; and, if the differential current exceeds the relay's pick-up value, the relay will operate.

Differential Protection for 3-Phase Circuits:

The above principle can be extended to a system element having several connections. A three-phase circuit is only necessary, as before, that all the CTs have the same ratio, and that they be connected so that the differential relay carries no current when the total current entering the circuit is vectorially equal to that current leaving the circuit.

During normal operating conditions the three secondary currents of CTs are balanced and no current flows through the relay coil. But during fault in the protected zone, the balance is disturbed and differential current flows through the relay operating coil and when the differential current exceeds the relay's pick-up value, the relay operates.

he principle can still be applied for the protection of a 3-phase power transformer, but in this case, the ratios and connections of the CTs on the opposite sides of the power transformer must be such as to compensate for the magnitude and phase-angle change between the power transformer currents on either side.

Difficulties Associated with Differential Protection:

1. Difference in Length of Pilot Wires:

The power system element under protection and CTs are located at different places and normally it is not possible to connect the relay operating coil to the equipotential points. However, this difficulty can be overcome by connecting adjustable resistors in series with the pilot wires.

2. CT Ratio Errors during Short Circuits:

The CTs used may have almost equal ratio at normal currents, but during short-circuit conditions, the primary currents are unduly large and the ratio errors of CTs on either side differ. This is due to (i) inherent difference in characteristic of CTs arising out of difference in magnetic circuit, saturation conditions etc. (ii) unequal dc components in the short-circuit currents.

Saturation of Magnetic Circuits of CTs under Short-Circuit Condition:

The differential relay of the type explained above is likely to operate inaccurately with heavy through (i.e., external) faults. The relay may lose its stability for through faults. This drawback is overcome by using percentage-differential relay or biased-differential relay.

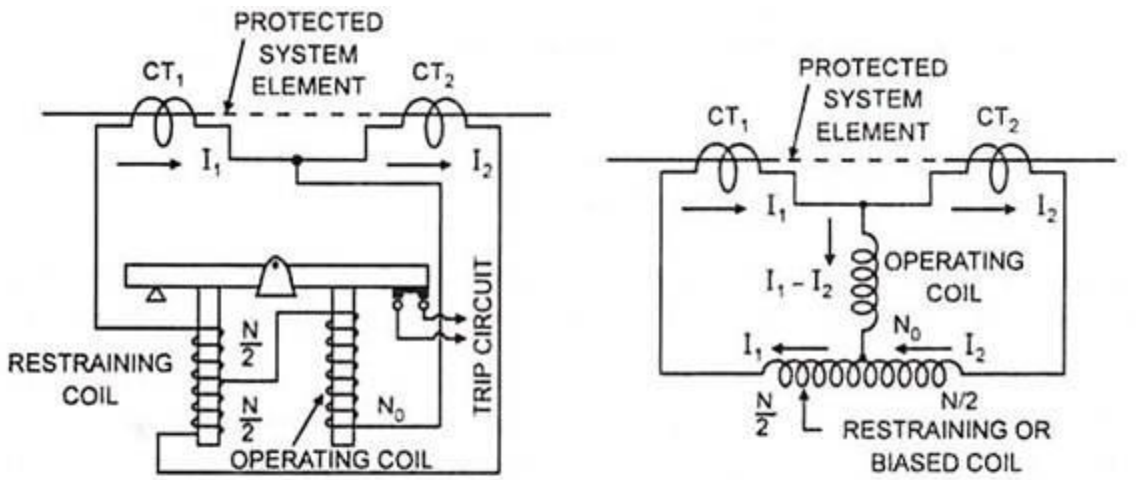
Magnetizing Current Inrush at the Switching Instant:

When the power transformer is connected to the supply, a large current (about 6 to 10 times full-load current) inrush takes place. The differential relay operates due to such inrush current, though the transformer has no fault. However, this difficulty is overcome by providing harmonic restraint for the differential relay. This relay filters the harmonic component from the inrush current and supplies it to the restraining coil. The harmonic content of the magnetizing current is used to obtain restraining torque during switching-in of transformer.

Tap-Changing:

Transformer transformation ratio is changed whenever the taps are changed. Due to this CT ratios do not match with the new-tap settings and result in flow of current in pilot wires even during healthy condition. However, this problem is also overcome by employing biased- differential relay.

2. Biased or Percentage-Differential Relay:
The most extensively used form of differential relay is the percentage-differential or beam biased relay. This is essentially the same as the overcurrent type of current- balance relay, but it is connected in a differential circuit, as illustrated in Fig. 3.59 (a). Schematic arrangement is shown in Fig. 3.59 (a) while equivalent circuit is shown in Fig. 3.59 (b).



(a) Schematic Arrangement *(b) Equivalent Circuit Diagram*

Fig. 3.59. ***Biased- or Percentage-Differential Relay***

This system consists of an additional restraining coil connected in the pilot wires, as shown in the figure and current induced in both CTs flows through it. The operating coil is connected to the mid-point of the restraining coil. The reason for using this modification in circulating current differential relay is to overcome the trouble arising out of differences in CT ratios for high values of external short-circuit currents.

The torque due to restraining coil prevents the closing of trip circuit contacts, while the torque due to operating coil tends to close the trip circuit contacts. Under normal operating conditions and through load conditions, the torque developed by restraining coil is greater than the operating coil torque. Thus the relay remains inoperative. When an internal fault occurs, the operating torque exceeds the restraining torque. Consequently the trip circuit contacts are closed to open the circuit breaker. The restraining torque may be adjusted by varying the number of turns of the restraining coil.

The differential current required to operate this relay is a variable quantity, owing to the effect of the restraining coil. The differential current in the operating coil is proportional to $(I_1 - I_2)$ and the equivalent current in the restraining coil is proportional to $[(I_1 + I_2)/2]$ as the operating coil is connected to the mid-point of the restraining coil.
The torque developed by the operating coil is proportional to the ampere-turns i.e., $T_0 \propto (I_1 - I_2)\ N_0$ where N_0 is the number of turns on the operating coil. The torque due to restraining coil $T \propto [(I_1 + I_2)/2]N$ Where, N is the number of turns on the restraining coil. For external faults both I_1 and I_2 increase and thereby the restraining torque increases which prevents the mal-operation.
It is clear from the operating characteristic of the relay, that except for the effect of the control spring at low currents, the ratio of the differential operating current to the average restraining current is a fixed percentage. This is why it is known as percentage-differential relay. The relay is also called the biased-differential relay because the restraining coil is also called a biased coil as it provides additional flux.

The percentage or biased differential relay has a rising pick-up characteristic. So with the increase of magnitude of through current, the relay is restrained against mal-operation.

Figure 3.61 shows the comparison of a simple overcurrent relay with a percentage-differential relay under such conditions. An overcurrent relay having the same minimum pick-up as a percentage-differential relay would operate undesirably when the differential current merely exceeded the value X, while there would be no tendency for the percentage-differential relay to operate.

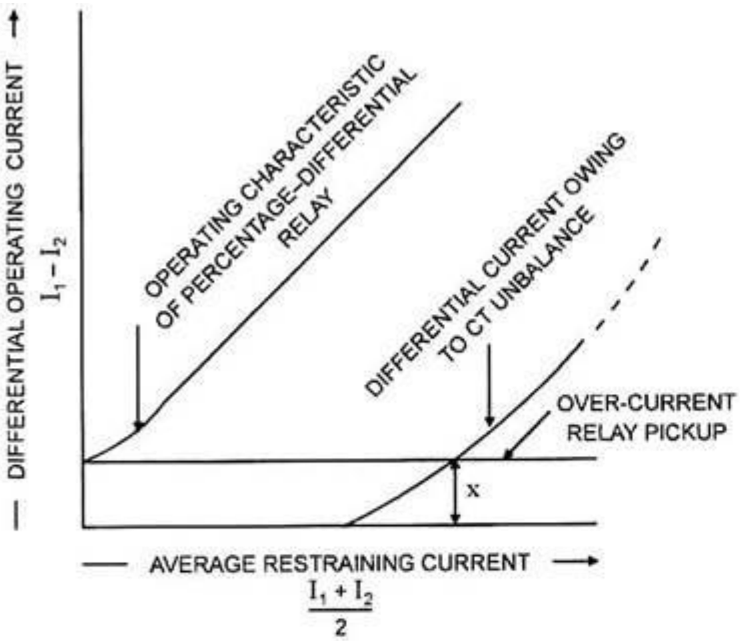


Fig. 3.61

Three-Terminal System-Application of a Percentage-Differential Relay:

Percentage-differential relay protection can be applied to the system elements having more than two terminals, as in the three-terminal application shown in Fig. 3.62. Each of the three restraining coils has the same number of turns, and each coil develops a torque independently of others. Their torques is added arithmetically.

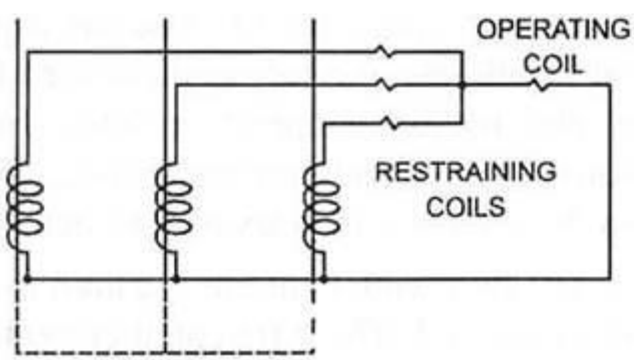


Fig. 3.62. *Three-Terminal System—Application of Percentage-Differential Relay*

The percent slope characteristic for such a relay will vary with the distribution of currents between the three restraining coils. Percentage-differential relays are generally instantaneous or high speed. Time delay is not required for selectivity because the percentage-differential characteristic makes these relays immune to the effects of transients when the relays are properly applied.

Induction Type Biased Differential Relay:

In the simplest electromagnetic form the relay is shown in Fig. 3.63. Such a relay consists of a pivoted disc free to rotate in the air gaps of two electromagnets, a portion of each pole of which is fitted with a copper shading ring. This ring can be moved further into, or out of the pole.

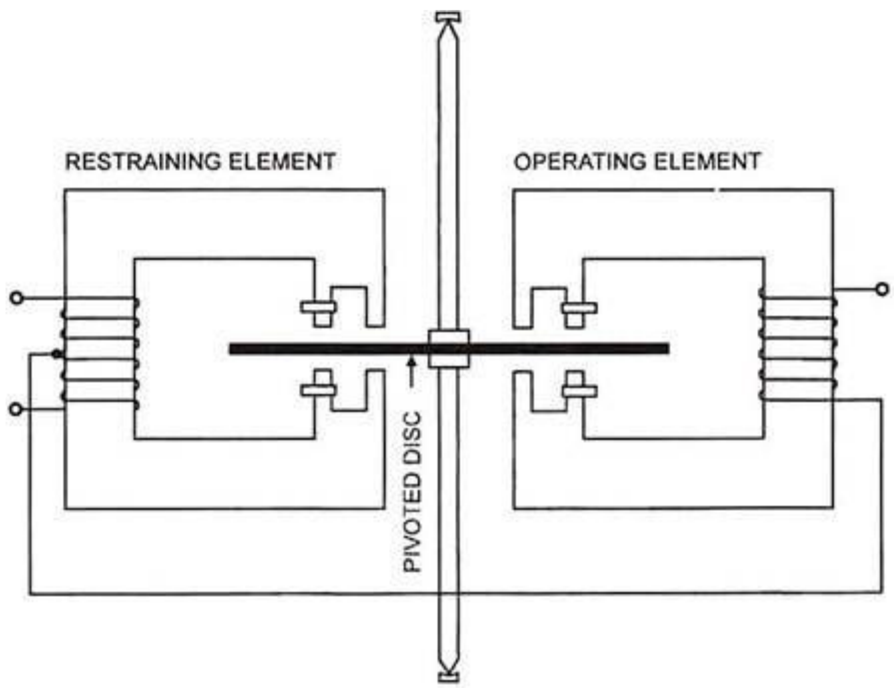


Fig. 3.63. *Induction Type Biased Differential Relay*

The disc experiences two torques—one due to the operating element and the other due to restraining element. If the shading rings were in the same position on each element, the resulting torque experienced by the disc would be zero. But if the shading rings of restraining element were moved further into the iron core, the torque exerted by the restraint element will exceed than that of the operating element.

The advantages of such a relay over the beam type are:
(i) The induction element is not susceptible to operation due to transients and

(ii) A slight time delay can be obtained and the biasing feature can be finally adjusted merely by changing the position of the shading rings on either or both elements.

3. Voltage Balance Differential Relay:
The differential relays are known as current balance relays. Such relays are convenient where both ends of the protected element are close together e.g., with generator or transformer protection but do not suit for the protection of feeders. If such relays are used for feeder protection of several km length, the secondary emfs of the CTs would be required to circulate about 1 or 5 A at full load or several times the current during external fault conditions, round a pilot loop of fairly high impedance. Such a burden is impracticable for any economic design of CT. Another class of relays is the voltage balance differential relays, which are preferred for the feeder protection.

In this arrangement, two similar current transformers are connected at either end of the system element under protection (such as a feeder) by means of pilot wires. The relays are connected in series with the pilot wires, one at each end. The relative polarity of the CTs is such that there is no current through the relay under normal operating conditions and through fault conditions. The CTs used in such protection should be such that they should induce voltages in the secondary linearly with respect to the current. Since the magnitude of fault current is very large, in order that the voltage should be a linear function of such large currents the CTs should be air-cored.

When a fault occurs in the protected zone, the currents in the two primaries will differ from one another and so voltages induced in the secondaries of the CTs will differ and circulating current will flow through the operating coils of the relays. Thus the trip circuit will be closed and the circuit breaker will open.

To provide for capacity currents, the relays employed may be overcurrent type which should operate only when the difference of the currents on both sides exceeds certain value.

In this system no restraining coil or balancing resistance or overload coil is required.

Though this method is more reliable than current balance or circulating current system but has great disadvantage that CTs do not carry current so acts as open circuited and inserts high impedance in the circuit. This method may be employed for protection of feeders, alternators and transformers. For use on transformers, the turn-ratio of power transformers must be kept in view.

TOPIC – 6

PROTECTION OF ELECTRICAL POWER EQUIPMENT AND LINES

Protection of Alternators:

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

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

1. **Failure of prime-mover**
2. **Failure of field**
3. **Overcurrent**
4. **Overspeed**
5. **Overvoltage**
6. **Unbalanced loading**
7. **Stator winding faults**

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

- **In case of turbo-alternator sets, failure of steam supply may cause inverted running. If the steam supply is gradually**

restored, the alternator will pick up load without disturbing the system. If the steam failure is likely to be prolonged, the machine can be safely isolated by the control room attendant since this condition is relatively harmless. Therefore, automatic protection is not required.

- **In case of hydro-generator sets, Protection of Alternators against inverted running is achieved by providing mechanical devices on the water-wheel. When the water flow drops to an insufficient rate to maintain the electrical output, the alternator is disconnected from the Therefore, in this case also electrical protection is not necessary.**
- **Diesel engine driven alternators, when running inverted, draw a considerable amount of power from the supply system and it is a usual practice to provide Protection of Alternators against motoring in order to avoid damage due to possible mechanical seizure. This is achieved by applying reverse power relays to the alternators which *isolate the latter during their motoring action. It is essential that the reverse power relays have time-delay in operation in order to prevent inadvertent tripping during system disturbances caused by faulty synchronizing and phase swinging.**

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

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

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

4. Overspeed: The chief cause of overspeed 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 overspeed occurs.

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

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

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

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

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

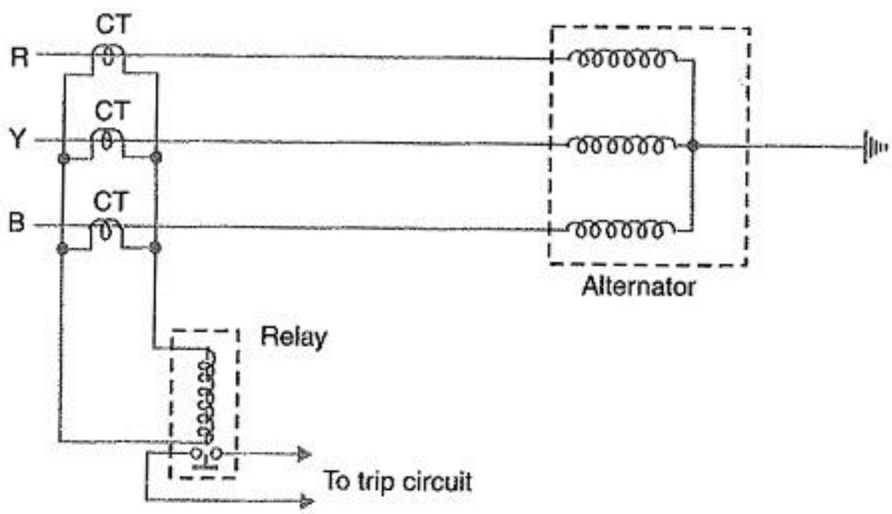


Fig. 22.1

Fig. 22.1 shows the schematic arrangement for the Protection of Alternators against unbalanced loading. The scheme comprises three line current transformers, one mounted in each phase, having their secondaries connected in parallel. A relay is connected in parallel across the transformer secondaries. Under normal operating conditions, equal currents flow through the different phases of the alternator and their algebraic sum is zero. Therefore, the sum of the currents flowing in the secondaries is also zero and no current flows through the operating coil of the relay. However, if unbalancing occurs, the currents induced in in the secondaries will be different and the resultant of these currents will flow through the relay. The operation of the relay will trip the circuit breaker to disconnect the alternator from the system.

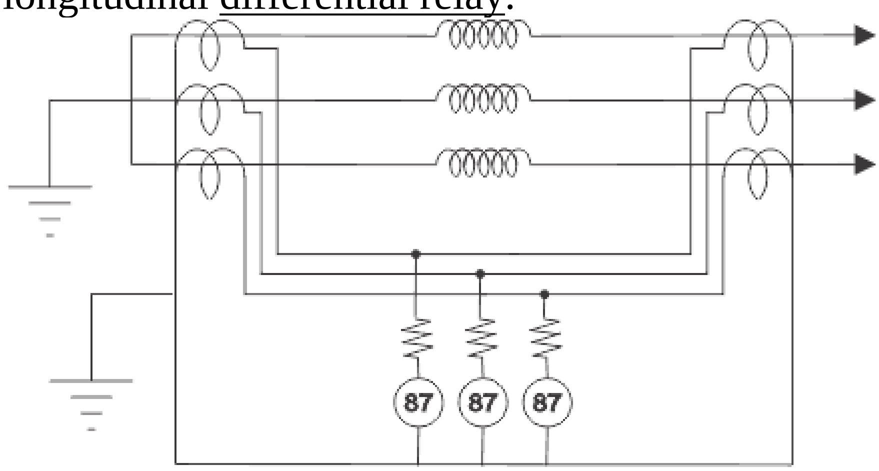
7. Stator winding faults: These faults occur mainly due to the insulation failure of the stator windings. The main types of stator winding faults, in order of importance are :

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

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

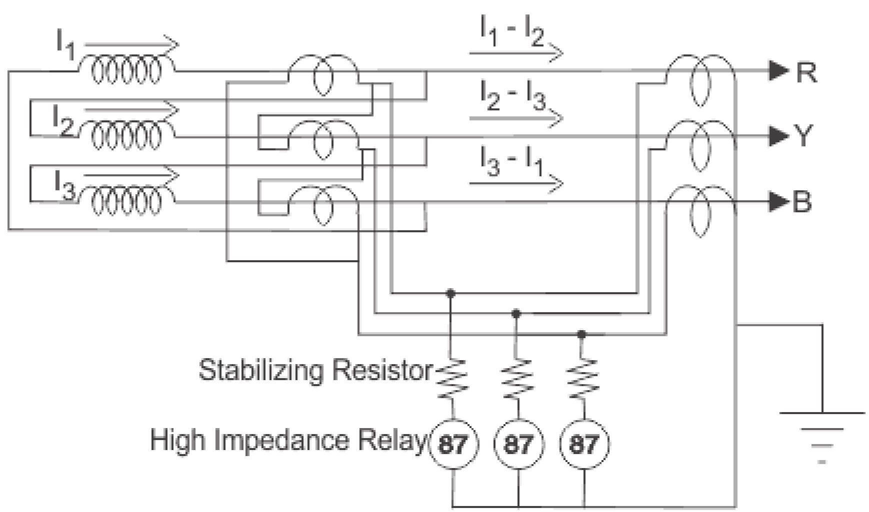
DIFFERENTIAL PROTECTION OF ALTERNATORS :

Any internal fault inside the stator winding is cleared by mainly **differential protection scheme of the generator** or alternator. The differential protection is provided in the generator by using longitudinal differential relay.



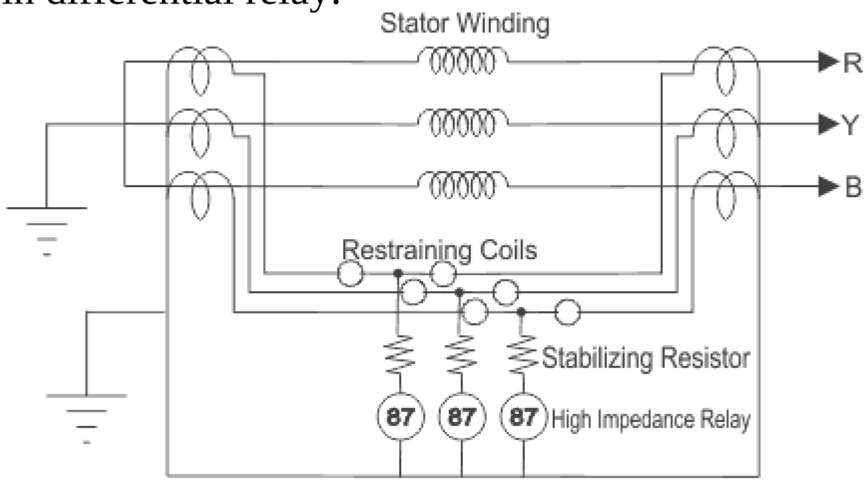
Generally instantaneous attracted armature type relays are used for this purpose because all they have high speed operation and also they are free from being affected by any AC transient of the power circuit.

There are two sets of current transformers, one CT is connected to the line side of the generator and other is connected to the neutral side of the generator in each phase. It is needless to say that the characteristics of all current transformers installed against each phase must be matched. If there is any major mismatched in the current transformer's characteristics of both sides of the generator, there may be high chance of malfunctioning of differential relay during the fault external to the stator winding and also may be during normal operating conditions of the generator. To ensure that the relay does not operate for the faults external to the operated zone of the protection scheme, a stabilizing resistor is fitted in series with the relay operating oil. It also ensures that if one set of CT has been saturated, there will be no possibility of malfunctioning of the differential relay.



It is always preferable to use dedicated current transformers for differential protection purpose because common current transformers may cause unequal secondary loading for other functionalities imposed on them. It is also always preferable to use all current transformers for **differential protection of generators** or alternators should be of same characteristics. But practically there may be some difference in characteristics of the current transformers installed at line side to those installed in neutral side of the generator.

These mismatches cause spill current to flow through the relay operating coil. To avoid the effect of spill current, percentage biasing is introduced in differential relay.



The percentage biased differential relay comprises two restraint coils and one operating coil per phase. In the relay, the torque produced by operating coil tends to close the relay contacts for instantaneous tripping of circuit breakers but at the same time the torque produced by the restraint coils prevents to close the relay contacts as restraint coils torque is directed opposite of the operating coil torque. Hence during through fault the differential relay would not be operated because the setting of the relay is increased by restraint coils and also it prevents malfunctioning of relay due to spill current. But during internal fault in the winding of the stator, the torque produced by restraint coils is ineffective and the relay closes its contact when setting current flows through the operating coil.

Differential current pickup setting/bias setting of the relay is adopted based on the maximum percentage of allowable mismatch adding some safety margin.

The spill current level for the relay is to just operate it; is experienced as a percentage of the through fault current causing it. This percentage is defined as bias setting of the relay.

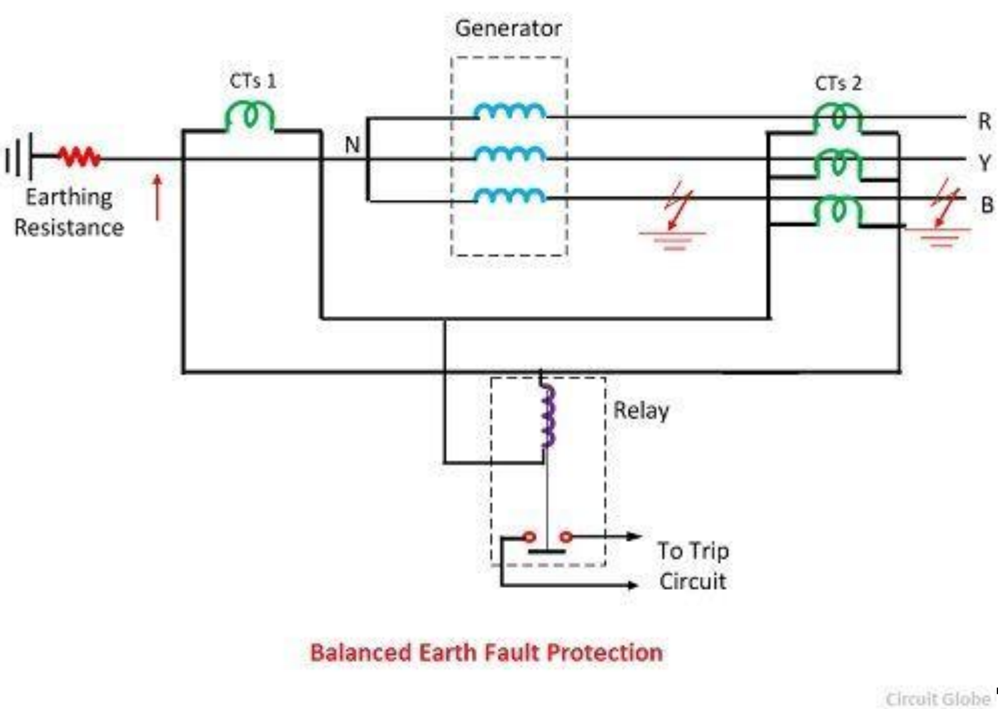
$$Hence,\ percentage\ bias = \frac{spill\ current\ for\ relay\ operation}{through\ fault\ current\ causing\ it} \times 100\%$$

Balanced Earth Fault Protection :

The balanced earth fault protection scheme is mainly used for protection of small generator where differential and self-balanced protection systems are not applicable. In a small generator, the neutral end of the three phase windings is connected internally to a single terminal. So the neutral end is not available, and protection against earth fault is provided by using the balanced earth protection scheme. Such scheme does not provide protection against phase-to-phase fault until and unless they develop into earth faults.

Connection of Balanced Earth Fault Protection Scheme

In this scheme, the current transformers are mounted on each phase. Their secondary is connected in parallel with that of CT mounted on a conductor joining the star point of the generator to earth. A relay is connected across the secondaries of the CTs.



The balanced protection schemes provide protection against earth fault in the limited region between the neutral and line CTs (current transformers). It provides protection against the stator winding of the earth fault in the stator and does not operate in case of an external earth fault. This scheme is also called restricted earth fault protection scheme. Such type of protection is provided in the large generator as an additional protection scheme.

Working of Balanced Earth Fault Protection Scheme

When the generator is in a normal operating condition the sum of the currents flow in the secondary of the current transformers is zero and the current flow into secondary to neutral is also zero. Thus the relay remains de-energized. When the fault occurs in the protected zone (left of the line) the fault current flow through the primary of current transformers and the corresponding secondary current flow through the relay which trips the circuit breaker.

When the fault develops external of the protective zone (right of the current transformer) the sum of the currents at the terminal of the generator is exactly equal to the current in the neutral connection. Hence, no current flows through the relay operating coil.

Drawback of Balanced Earth Protection Scheme

If the fault occurs near the neutral terminal or when grounding of the neutral is connected through a resistance or a distributing transformer then the magnitude of the fault current flow through the secondary of current transformer becomes small. This current is less than the pick-up current of the relay. Thus, the relay remains inoperative, and the fault current continues to persist in the generator winding which is highly undesirable

PROTECTION SYSTEMS FOR TRANSFORMER :

Transformers are one of the most critical and expensive components of any distribution system. It is an enclosed static device usually drenched in oil, and hence faults occurring to it are limited. But the effect of a rare fault can be very dangerous for the transformer, and the long lead time for repair and replacement of transformers makes things even worse. Hence **power transformers protection** becomes very crucial.

Faults occurring on a transformer are mainly divided into two types, which are, **external faults and internal faults**, to avoid any danger to the transformer, an external fault is cleared by a complex relay system within the shortest possible time. The internal faults are mainly based on sensors and measurement systems.

- Transformers within the range of 500 KVA fall under (Category I & II), so those are protected using fuses, but to protect transformers up to 1000 kVA (distribution transformers for 11kV and 33kV) Medium Voltage circuit breakers are usually used.
- For transformers 10 MVA and above, which falls under (Category III & IV), differential relays had to be used to protect them.

Additionally, mechanical relays such as **Buchholtz relays,** and **sudden pressure relays** are widely applied for transformer protection. In addition to these relays, thermal overload protection is often implemented to extend a transformer's lifetime rather than for detecting faults.

Common Types of Transformer Protection

1. Overheating protection
2. Overcurrent protection
3. Differential Protection of Transformer
4. Earth Fault Protection (Restricted)
5. Buchholz (Gas Detection) Relay
6. Over-fluxing protection

Overheating Protection in Transformers

Transformers overheat due to the overloads and short circuit conditions. The allowable overload and the corresponding duration are dependent on the type of transformer and class of insulation used for the transformer.

Higher loads can be maintained for a very short amount of time if it is for a very long, it can damage the insulation due to **temperature rise above an assumed maximum temperature.** The temperature in the oil-cooled transformer is considered maximum when its 95*C, beyond which the life expectancy of the transformer decreases and it has detrimental effects in the insulation of the wire. That is why overheating protection becomes essential.

Large transformers have **oil or winding** temperature detection devices, which measure **oil or winding** temperature, typically there are two ways of measurement, one is referred to **hot-spot measurement** and second is referred to as **top-oil measurement,** the below image shows a typical thermometer with a temperature control box from reinhausen used to measure the temperature of a liquid insulated conservative type of transformer.

The box has a **dial gauge** which indicates the **temperature of the transformer** (which is the black needle) and the red needle indicates the **alarm set point.** If the black needle surpasses the red needle, the device will activate an alarm.

If we look down, we can see four arrows through which we can configure the device to act as an **alarm or trip** or they can be used to **start or stop pumps or cooling fans**.

As you can see in the picture, the **thermometer** is mounted on the top of the transformer tank above the core and the winding, it's so done because the highest temperature is going to be at the center of the tank because of the core and the windings. This temperature is known as the **top oil temperature.** This temperature gives us an estimate of the **Hot-spot Temperature** of the transformer core. Present-day **fiber optic cables** are used within the low voltage winding to accurately measure the temperature of the transformer. That is how overheating protection is implemented.

Overcurrent Protection in Transformer

The overcurrent protection system is one of the earliest developed protection systems out there, the graded overcurrent system was developed to guard against overcurrent conditions. power distributors utilize this method to detect faults with the help of the IDMT relays. that is, the relays having:

1. Inverse characteristic, and
2. Minimum time of operation.

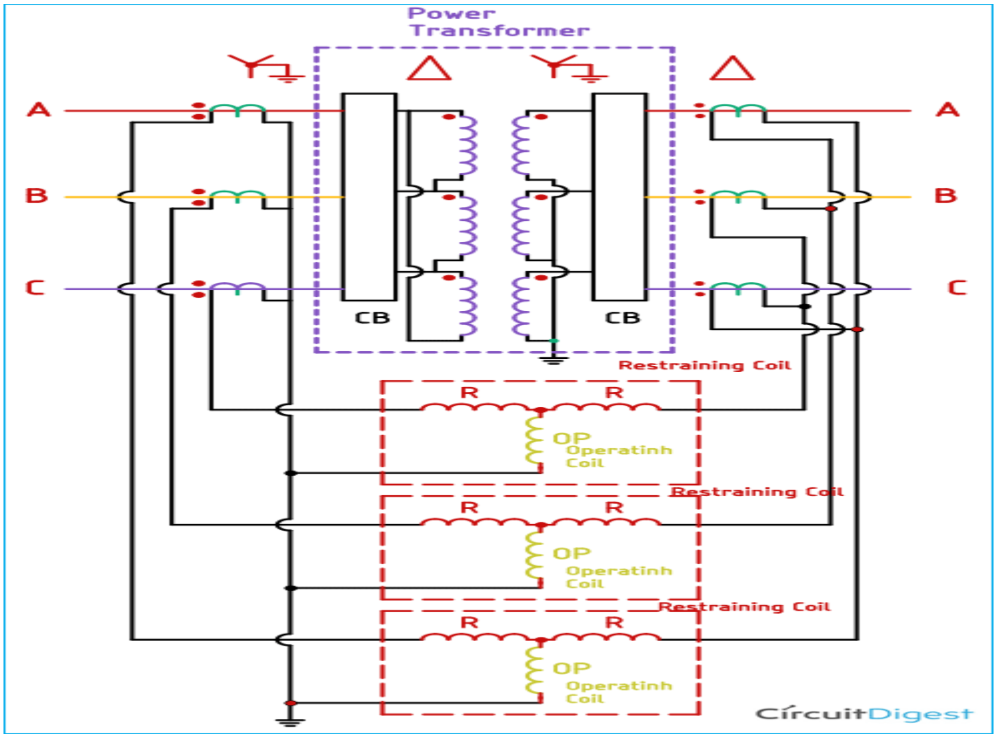
The capabilities of the IDMT relay is restricted. These sorts of relays have to be set 150% to 200% of the max rated current, otherwise, the relays will operate for emergency overload conditions. Therefore, these relays provide minor protection for faults inside the transformer tank.

Differential Protection of Transformer

The Percentage Biased Current Differential Protection is used to **protect power transformers** and it is one of the most common **transformer protection schemes** that provide the best overall protection. These types of protection are used for transformers of rating exceeding 2 MVA.

The transformer is star connected on one side and delta connected the other side. The CTs on the star side are delta-connected and those on the delta-connected side are star-connected. The neutral of both the transformers are grounded.

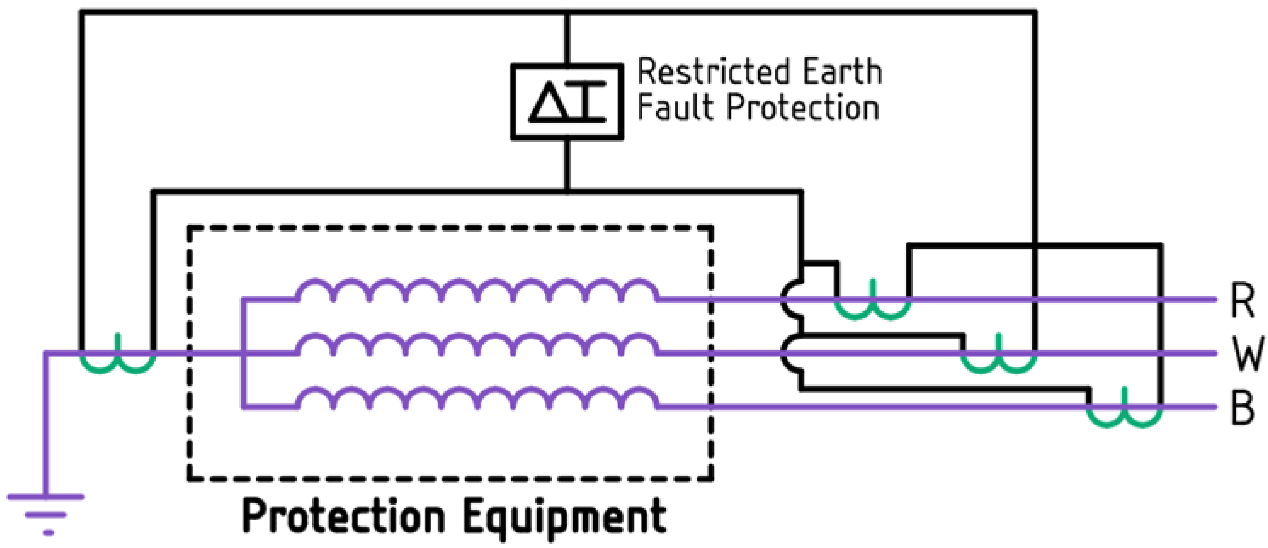
The transformer has two coils, one is the **operating coil** and the other is the **restraining coil**. As the name implies, the restraining-coil is used to produce the restraining force, and the operating-coil is used to produce the operating force. The restraining-coil is connected with the secondary winding of the current transformers, and the operating coil is connected in between the equipotential point of the CT.



Transformer Differential Protection Working:

Normally, the operating coil carries no current as the current is matched on both sides of the power transformers, when an internal fault occurs in the windings, the balance is altered and the operating coils of the **differential relay** start producing differential current among the two sides of the transformer. Thus, the relay trips the circuit breakers and protects the main transformer.

Restricted Earth Fault Protection



A very high fault current can flow when a fault occurs at the transformer bushing. In that case, the fault needs to be cleared as soon as possible. The reach of a particular protection device should be only limited to the zone of the transformer, which means if any ground fault occurs in a different location, the relay allocated for that zone should get triggered, and other relays should stay the same. So, that is why the relay is named **Restricted** earth fault protection relay.

In the above picture, the **Protection Equipment** is on the protected side of the transformer. Let's assume this is the primary side, and let's also assume there is a ground fault on the secondary side of the transformer. Now, if there is a fault on the ground side, because of the ground fault, a **Zero Sequence Component** will be there, and that will circulate only on the secondary side. And it will not be reflected in the primary side of the transformer.

This relay has three phases, if a fault occurs, they will have three components, the **positive sequence components, the negative sequence components, and the zero sequence components**. Because the positive sequins components are displaced by 120*, so at any instant, the sum of all the currents will flow through the protection relay. So, the sum of their currents will be equal to zero, as they are displaced by 120*. Similar is the case for the negative sequence components.

Now let us assume a fault condition occurs. That fault will be detected by the CTs as it has a zero-sequence component and the current starts flowing through the protection relay, when that happens, the relay will trip and protect the transformer.

Buchholz (Gas Detection) Relay

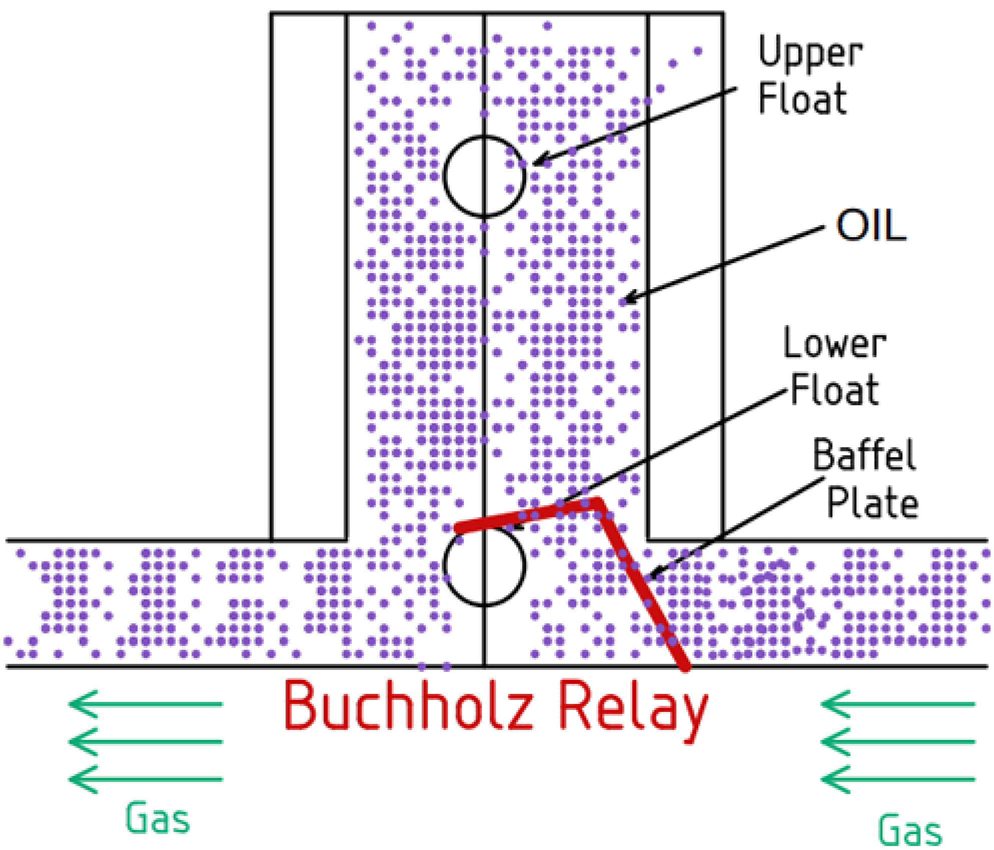
The **Buchholtz relay** is fitted in between the main transformer unit and the conservator tank when a fault occurs within the transformer, it detects the resolved gas with the help of a float switch.

If you look closely, you can see an arrow, gas flows out from the main tank to the conservator tank, normally there should not be any gas in the transformer itself. Most of the gas is referred to as dissolved gas and nine different types of gasses can be produced depending on the fault condition. There are two valves at the top of this relay, these valves are used to reduce the gas build-up, and it's also used to take out a gas sample.

When a fault condition occurs, we have sparks between the windings, or in between windings and the core. These small electrical discharges in the windings will heat the insulating oil, and the oil will break down, thus it produces gases, the severity of the breakdown, detects which glasses are created.

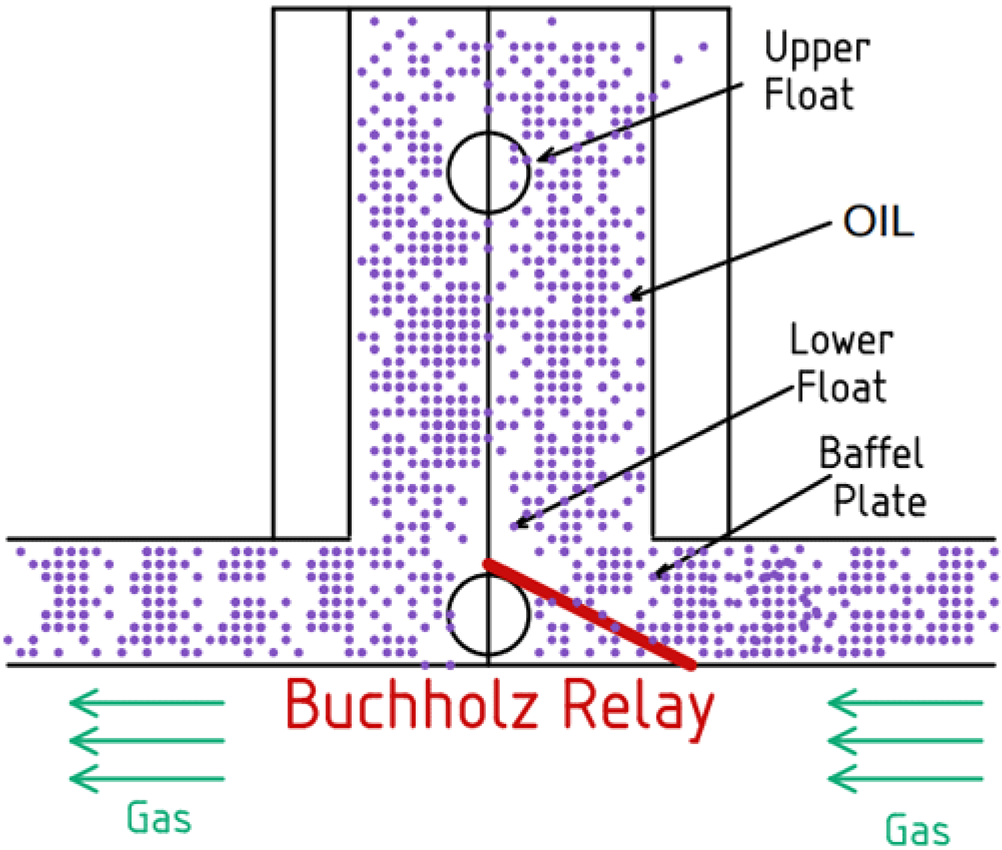
A large energy discharge will have a production of acetylene, and as you may know, acetylene takes a lot of energy to be produced. And you should always remember that any type of fault will produce gases, by analyzing the amount of gas, we can find the severity of the fault.

How Buchholz (Gas Detection) Relay Works?

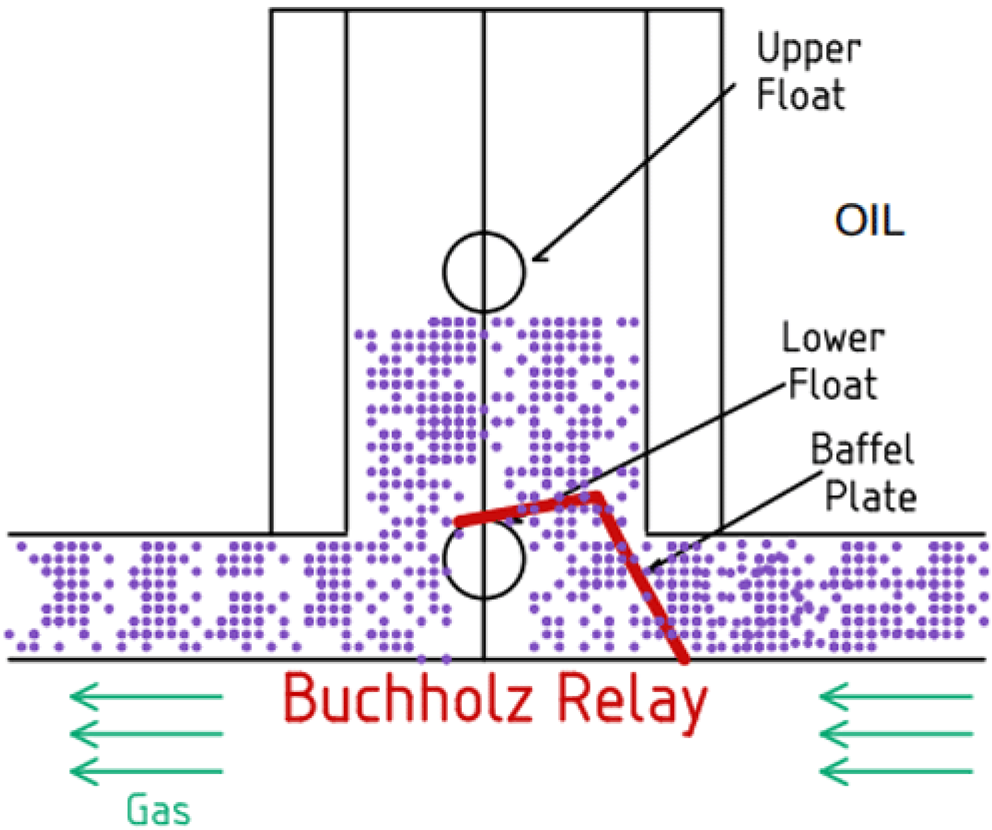


As you can see from the image, we have two floats: an upper float and a lower float, also we have a baffle plate that is pushing down the lower float.

When a large electrical fault occurs, it produces a lot of gas than the gas flows through the pipe, which shifts the baffle plate and that forces the lower floated down, now we have a combination, the upper float is up and the lower float is down and the baffle plate has tilted. This combination indicates that a massive fault has occurred. which shuts down the transformer and it also generates an alarm. The image below shows exactly that,

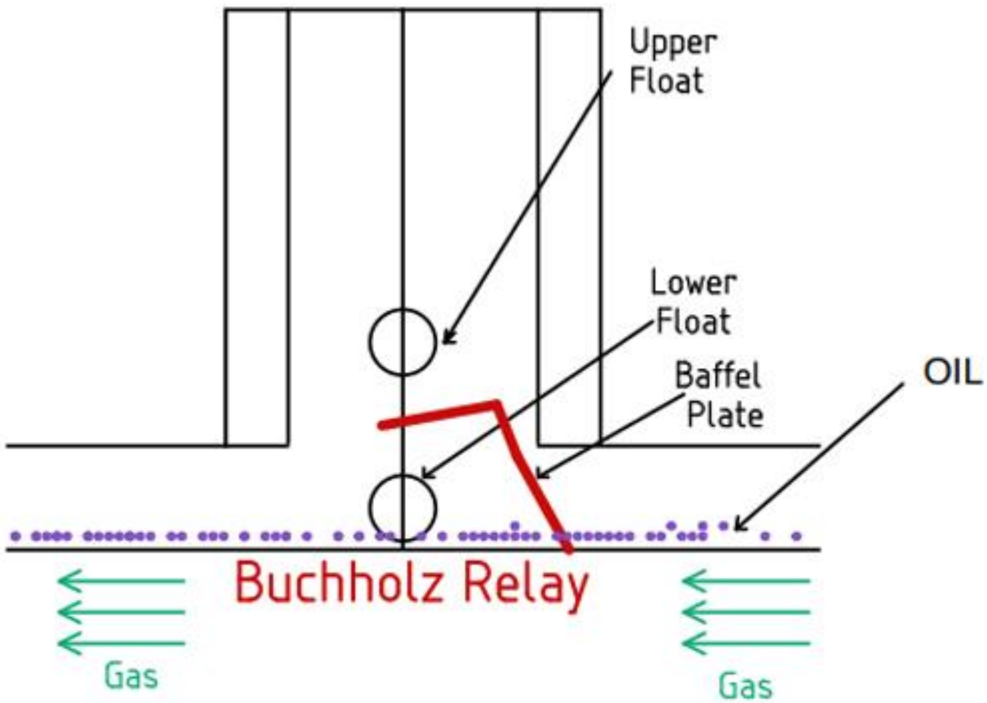


But this is not the only scenario where this relay can be useful, imagine a situation where inside the transformer there is a **minor arcking** that is happening, these arks are producing a small amount of gas, this gas produces a pressure inside the relay and the upper float gets down displacing the oil inside it, now the relay generates an alarm in this situation, the upper float is down, the lower float is unchanged and the baffle plate is unchanged if this configuration is detected, we can be sure that we have a slow accumulation of gas. The image below shows exactly that,



Now we know we have a fault, and we will bleed out some of the gas using the valve above the relay and analyze the gas to find out the exact reason for this gas build-up.

This relay can also detect conditions where the insulating oil level falls due to leaks in the transformer chassis, in that condition, the upper float drops, the lower float drops, and the baffle plate stays in the same position. In this condition, we get a different alarm. The below image shows the working.



With these three methods, the Buchholz relay detects faults.

Over-fluxing Protection

A transformer is designed to operate at a fixed flux level exceed that flux level and the core gets saturated, the saturation of the core causes heating in the core that quickly follows through the other parts of the transformer that leads to overheating of components, thus over flux protection becomes necessary, as it protects the transformer core. Over-flux situations can occur because of overvoltage or a reduction in system frequency.

To protect the transformer from over-fluxing, the **over-fluxing relay** is used. The over-fluxing relay measures the ratio of Voltage / Frequency to calculate the flux density in the core. A rapid increase in the voltage due to transients in the power system can cause over fluxing but transients die down fast, therefore, the instantaneous tripping of the transformer is undesirable.

The flux density is directly proportional to the ratio of **voltage to frequency(V/f)** and the instrument should detect the ration if the value of this ratio becomes greater than unity, this is done by a microcontroller-based relay which measures the voltage and the frequency in real-time, then it calculates the rate and compares it with the pre-calculated values. The relay is programmed for an inverse definite minimum time (**IDMT characteristics**). But the setting can be done manually if that is a requirement. In this way, the purpose will be served without compromising the over-flux protections. Now, we see how important it is to prevent the tripping of the transformer from over-fluxing.

Bus-Bar Protection:

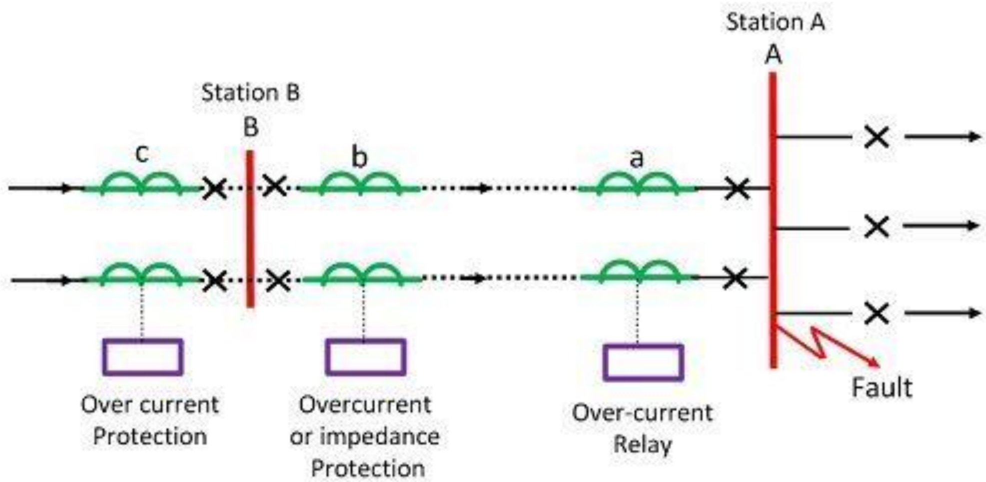
When the fault occurs on the bus bars whole of the supply is interrupted, and all the healthy feeders are disconnected. The majority of the faults is single phase in nature, and these faults are temporary. The bus zone fault occurs because of various reasons likes failure of support insulators, failure of circuit breakers, foreign object accidentally falling across the bus bar, etc., For removing the bus fault, all the circuits connecting to the faulty section needs to be open.

The most commonly used schemes for bus zone protection are:

- Backup protection
- Differential Overcurrent Protection
  - Circulating current protection
  - Voltage Overvoltage Protection
- Frame leakage protection.

Backup protection for Bus-Bars :

This is the simple way of protecting the bus-bar from the fault. The fault occurs on the bus-bar because of the supplying system. So the backup protection is provided to the supply system. The figure below shows the simple arrangement for the protection of bus-bar. The bus A is protected by the distance protection of the bus B. If the fault occurs on A, then the B will operate. The operating times of the relay will be 0.4 seconds.



The bus-bar protection system has few disadvantages likes the protection system is slow. Such system is mainly used for the protection of the transmission lines. But as the protection system is very economical, thereby it is also used for the bus-bar protection.

This protective scheme is not used for small switchgear system. The backup protection system has many disadvantages likes delayed in action, disconnections of more circuits for two or more transmission line requires etc.

Frame Leakage Or Fault-Bus Protection

This method insulates the bus-supporting structure and its switchgear from the ground, interconnecting all the framework, circuit breakers tanks, etc. and provided a single ground tank connection through a CT that feeds an overcurrent relay. The overcurrent relay controls a multi-contact auxiliary relay that trips the breakers of all circuits connected to the bus.

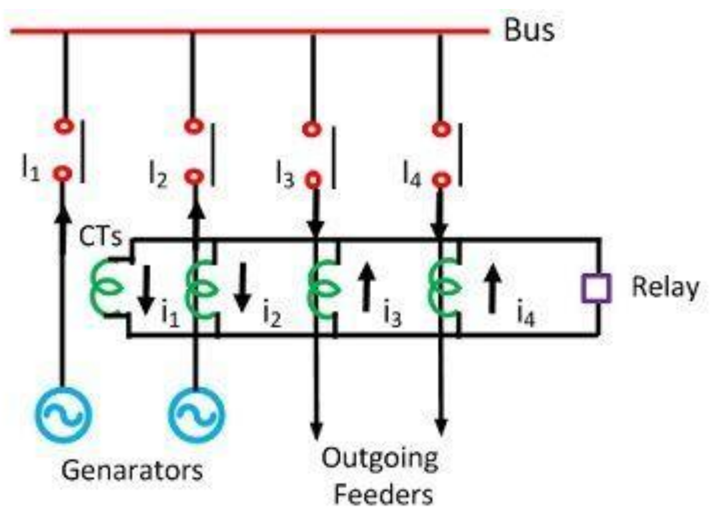
In such type of protection, the only metal supporting structure or fault-bus is grounded through a CT, secondary of which is connected to an overcurrent relay. Under normal operating condition, the relay remains inoperative, but fault involving a connection between a conductor and the ground supporting structure will result in current flow to ground through the fault bus, causing the relay to operate. The operation of the relay will trip all the breakers connecting equipment to the bus.

Differential Over Current Protection

Current Differential Protection

The current differential protection scheme works on the principle of the circulating current which states that the current enters into the bus-bar is equal to the current leaving the bus-bar. The sum of the incoming and outgoing junction is equal to zero. If the sum of current is not equal to zero, then the fault occurs in the system. The differential protection scheme is used both for the protection of the phase-to-phase fault and for the ground fault.

Schematic diagram of bus differential protection relay is shown in the figure below. The current transformers are placed on both the incoming and the outgoing end of the bus-bar. The secondary terminals of the current transformer are parallel connected to each other.



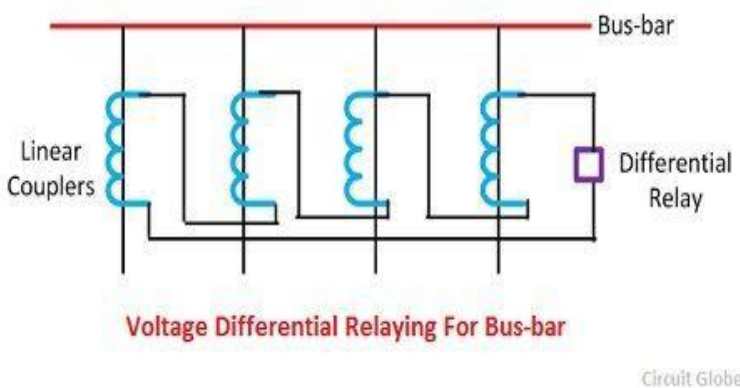
Schematic Diagram of Bus Differential Protection

 The summation current of the current transformer flows through the operating coil of the relay. The current flows through the relay coils indicates the short circuit current present on the secondary of the CTs. Thus, the relay sends the signal to the circuit breakers to open the contacts.

The drawback of such types of the scheme is that the iron cored current transformer causes the fault operation of the relay at the time of the external fault.

Voltage Differential Protection Relay

In this scheme, the coreless CTs are used. The linear couplers are used for increases the number of turns on the secondary sides of the CTs. The secondary relays connected in series with the help of the pilot wires. The relay coil is also connected in series with the second terminal.



When the system is free from fault or external fault occurs on the system, the sum of secondary current of CTs becomes zero. On the occurrence of the internal fault, the fault current flows the differential relay. The relay becomes operative and gives command to the circuit breaker to open their contacts. Thus, protects the system from damage.

PROTECTION OF TRANSMISSION LINE :

There are several protective schemes for transmission lines and may be grouped into two groups viz.,1. non-unit type and 2.unit type.

The non-unit type of protection includes time-graded overcurrent protection, current-graded overcurrent protection, and distance protection, while the unit type protection includes pilot-wire differential protection, carrier-current protection based on phase comparison method etc.

Separate protection systems are necessary for ground faults because ground faults are more frequent on overhead transmission lines than phase fault, and ground fault current is different from phase fault current in magnitude.

Differential Pilot Wire Protection:

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

1. **Merz-Price voltage balance system**

2. **Translay scheme**

1. Men-Price voltage balance system: Fig. 23.8 shows the single line diagram of MerzPrice voltage balance system for the protection of a 3-phase line. Identical current transformers are placed in each phase at both ends of the line. The pair of CTs in each line is connected in series with a relay in such a way that under, normal conditions, their secondary voltages are equal and in opposition i.e. they balance each other.

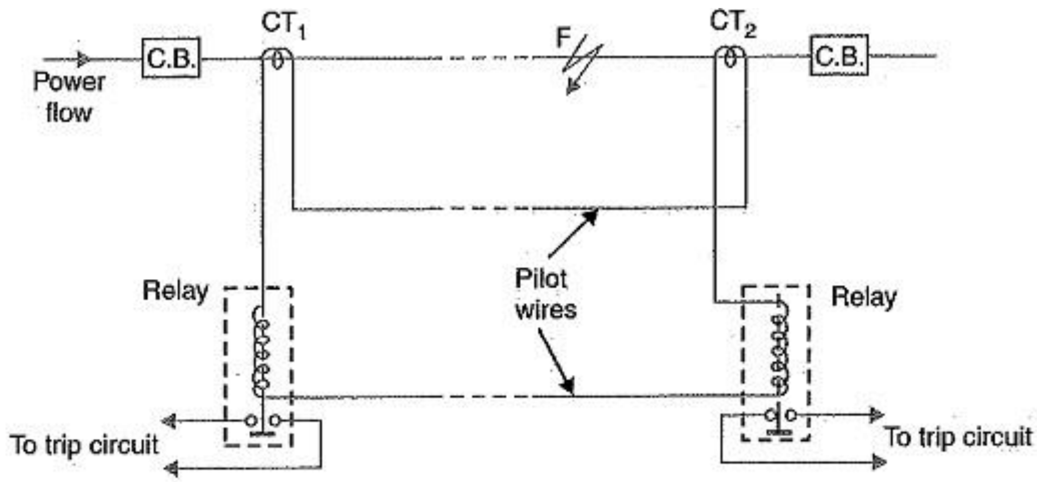


Fig. 23.8

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

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

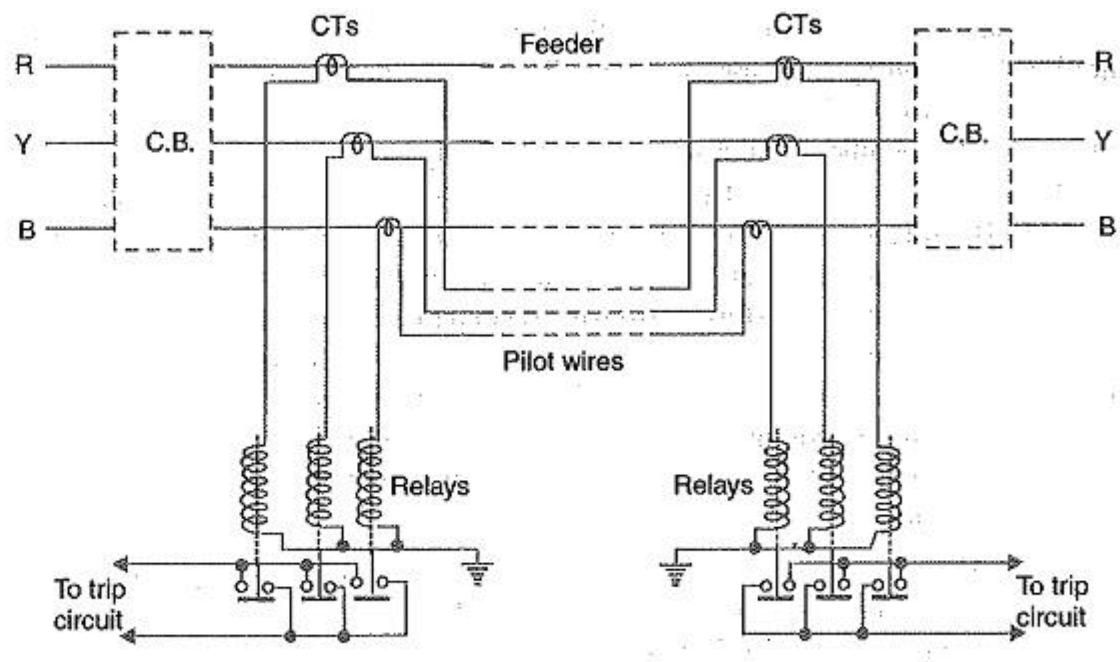


Fig. 23.9

Advantages of Differential Pilot Wire Protection:

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

Disadvantages of Differential Pilot Wire Protection:

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

- **This system cannot be used for line voltages beyond 33 kV because of constructional difficulties in matching the current transformers.**

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.

Feeder Protection :

Overcurrent Earth Fault Protection:

Overcurrent Earth Fault Protection – Earth-fault protection can be provided with normal overcurrent relays, if the minimum earth-fault current is sufficient in magnitude. The magnitude of earth-fault current is usually low compared to the phase-fault currents because the fault impedance is much higher for earth-faults than for phase-faults. It also depends On the type of neutral earthing, i.e. whether solidly earthed, insulated or earthed through some resistance or reactance. Whatever the case may be the earth-fault current will be small compared to the phase-fault currents in magnitude.

The relay thus connected for earth-fault protection is different from the ones provided for phase-faults. It has the peculiarity that it is set independent of load current and thus settings below normal load current can be achieved. Hence earth-fault relays are set at low settings between 30% and 70% but low values of current settings impose a higher burden on the relay with rated current in the primary of the CT. It will be seen that unless the earth-fault current is limited or special CTs are used to provide a higher output, time/current grading of earth-fault relays is not practicable.

Fortunately the grading of earth-fault relays, unlike overcurrent phase relays, is normally limited to one system voltage due to general use of delta/star step down transformer, as the earth-fault in one section does not draw ground current from other parts. This simply means that an earth-fault on one side of the transformer will not be seen by the earth-fault relays on the other side and hence the grading between the relays on the different voltage systems is not required.

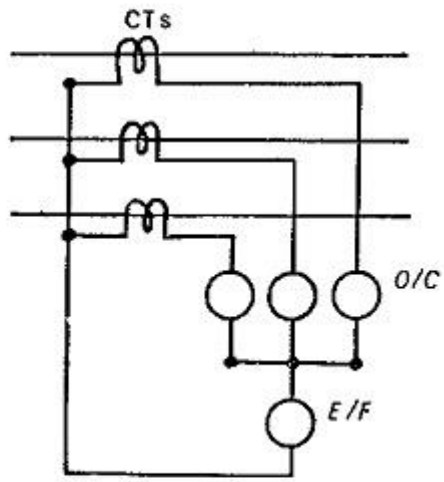


FIGURE 5.8 Location of phase relays and *E/F* relays. *O/C*—Overcurrent relays (phase relays); *E/F*—Earth-fault relay.

Overcurrent Earth Fault Protection can be provided with only one overcurrent relay connected in the residual circuit or across the zero phase sequence filter. A current will flow through the relay winding only when a fault involving earth occurs. Figure (5.8) shows the location of the earth-fault relay along with the phase relays.

When both overcurrent and earth-fault protection are required using IDMT relays it is usual to provide two phase relays instead of three phase relays with one earth-fault relay from economic considerations (Fig. (5.9)).

If all the CTs were ideal, under normal operating conditions and interphase faults no current would flow through the earth-fault relay. However, when commercially identical CTs are used some current would flow through the relay. This is due to difference in errors and in amounts of residual magnetism. This current is called unbalance current or false residual current which is in the range of 0.01 to 0.1A at rated primary current and many times larger when heavy phase-fault currents flow.

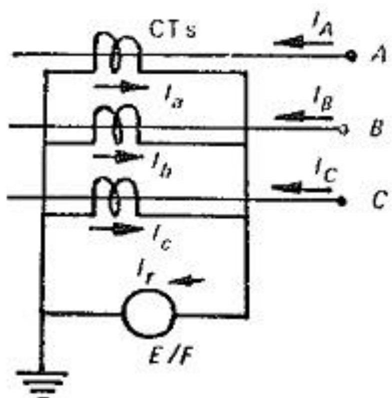


FIGURE 5.10 Principle scheme of *E/F* protection

Figure (5.10) illustrates the principle of earth-fault protection. Obviously during normal operation and also for three-phase and line-to-line faults, the current passing through the relay is equal to zero:

When a single or double earth-fault occurs, the zero sequence current flows through the relay. Now from the equivalent circuit of the CT we have

where

Is = secondary current

I′p = primary current referred to secondary

I′e = exciting current referred to secondary

Ip = primary current

Ie = exciting current

n=secondary to primary turn ratio

Accordingly we can write

Equation (5.7) shows that earth-fault relay responds to zero sequence current and the value of the pickup of earth-fault relay has to be selected against the maximum value of false residual current only.

TOPIC - 7

PROTECTION AGAINST OVER VOLTAGE AND LIGHTNING

Voltage Surge or Transient Voltage:

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

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

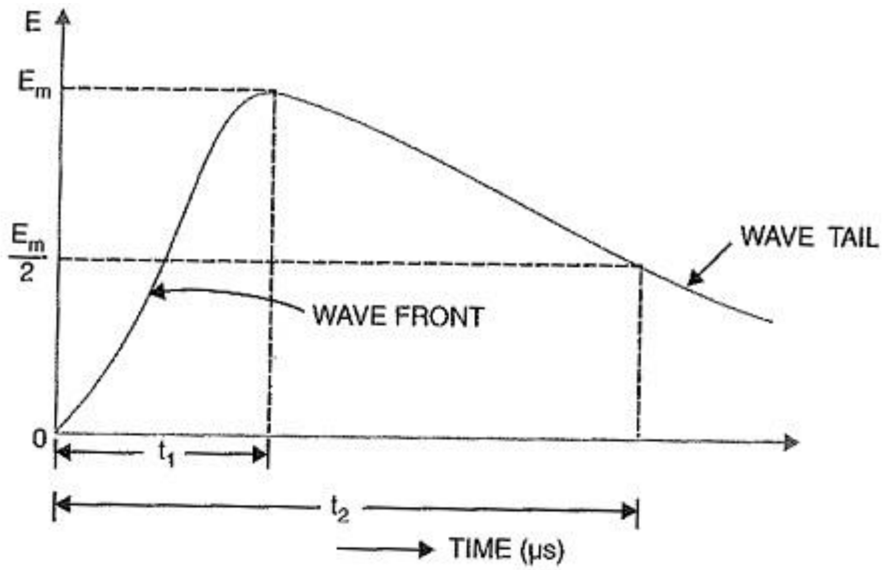


Fig. 24.1

Fig. 24.1 shows the wave-form of a typical lightning surge. The voltage build-up is taken along y-axis and the time along x-axis. It may be seen that lightning introduces a steep-fronted wave. The steeper the wave front, the more rapid is the build-up of voltage at any point in the network. In most of the cases, this build-up is comparatively rapid, being of the order of 1-5 μs. Voltage Surge are generally specified in terms of rise time t_1 and the time t_2 to decay to half of the peak value. For example, a 1/50 μs surge is one which reaches its maximum value in 1μs and decays to half of its peak value is 50 μs.

Causes of Overvoltages:

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

1. Internal causes

1. **Switching surges**
2. **Insulation failure**
3. **Arcing ground**
4. **Resonance**

2. External causes

1. **lightning**

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

Internal Causes of Overvoltages:

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

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

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

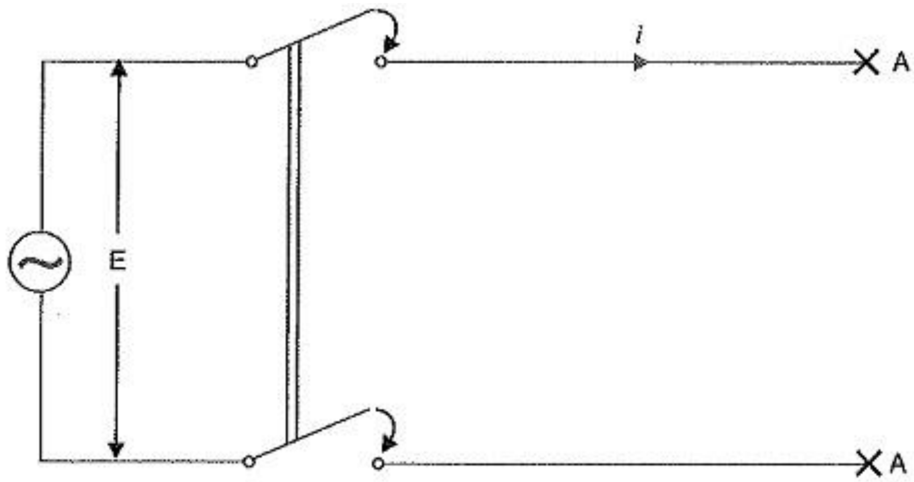


Fig. 24.2

When the unloaded line is connected to the voltage source, a voltage wave is set up which travels along the line. On reaching the terminal point A, it is reflected back to the supply end without change of sign. This causes voltage doubling i.e. voltage on the line becomes twice the normal value. If $E_{r.m.s.}$ is the supply Voltage Surge, then instantaneous voltage which the line will have to withstand will be $2\sqrt{2}$ E This overvoltage is of temporary nature. It is because the line losses attenuate the wave and in a very short time, the line settles down to its normal supply voltage E. Similarly, if an unloaded line is switched of the line will attain a voltage of $2\sqrt{2}$ E for a moment before settling down to the normal value.

(ii) Case of a loaded line: Overvoltages will also be produced during the switching operations of a loaded line. Suppose a loaded line is suddenly interrupted. This will set up a voltage of 2 $Z_n i$ across the break (i.e. switch) where i is the instantaneous value of current at the time of opening of line and Z_n is the natural impedance of the line. For example, suppose the line having Z_n=1000Ω carries a current of 100 A (r.m.s.) and the break occurs at the moment when current is maximum. The voltage across the breaker (i.e. switch) = $2\sqrt{2}$ x 100 x 1000/1000 = 282.8 kV. If V_m is the peak value of voltage in kV, the maximum voltage to which the line may be subjected is = (V_m + 282.8) kV.

(iii) Current chopping: Current chopping results in the production of high voltage transients across the contacts of the air blast circuit breaker.

It is briefly discussed Unlike oil circuit breakers, which are independent for the effectiveness on the magnitude of the current being interrupted, air-blast circuit breakers retain the same extinguishing power irrespective of the magnitude of this current. When breaking low currents (e.g. transformer magnetizing current) with air-blast breaker, the powerful de-ionizing effect of air-blast causes the current to fall abruptly to zero well before the natural current zero is reached. This phenomenon is called current chopping and produces high transient voltage across the breaker contacts. Overvoltages due to current chopping are prevented by resistance switching.

2. Insulation failure: The most common case of insulation failure in a power system is the grounding of conductor (i.e. insulation failure between line and earth) which may cause overvoltages in the system. This is illustrated in Fig. 24.3.

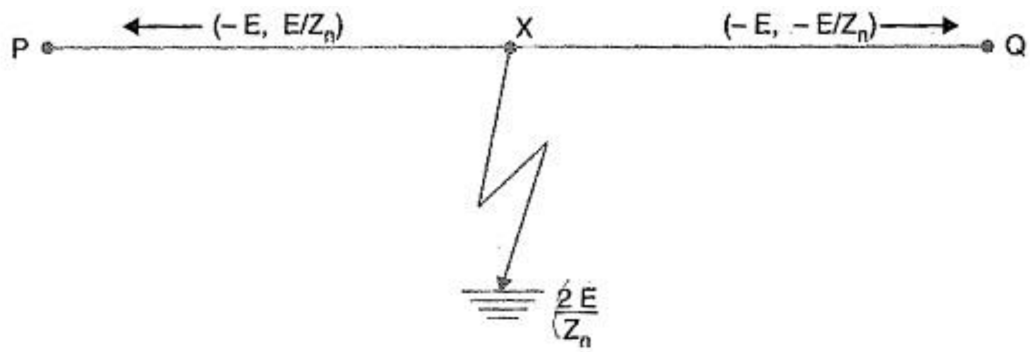


Fig. 24.3

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

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

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

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

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

Lightning:

Lightning is one of those natural events which catches people's imagination with its obvious violence and the destructive power attributed to it.
Thunder and lightning was believed to the expression of the wrath of the gods.
Lightning fascinates and frightens us. The considerable damage it causes to property and its unfortunate victims plainly demonstrate that the imaginary is based on a phenomenon that is very real and can be fairly well explained, but cannot be combated. Only modest attempts can be made to control its effects and the consequences.
Lightning can be likened to a disruptive electrical discharge due to the dielectric breakdown of the air between the clouds or between the

clouds and the ground. Certain clouds (cumulo- nimbus) create meteorological conditions that are favourable to the accumulation of electrostatic charges.

Breakdown, which is visible in the form of the lightning flash, itself has a very complex phenomenology (precursor, leader stroke, return discharge, etc.).
It is accompanied by a sound wave, thunder, caused by the sudden expansion of the air which is overheated by the electric arc.

When lightning reaches the earth, it generally does so directly on natural elements (trees, hills, water, etc.) but also occasionally on structures, buildings, pylons and other man-made structures.

A distinction that leads to the division into two separate types of effect:
- Those described as “direct" which are due to the circulation of the intense current (several tens of thousands of amperes) which heats materials and causes considerable damage (calcination, fire, dislocation or even collapse)
- Associated, “indirect" effects which produce overvoltages by conduction, induction or increasing the earth potential.

Protection must be provided against these indirect effects in electrical installations which, besides their sensitive, not to say strategic, role have also become more fragile due to their increasing numbers, size and the corollary use of electronics.

Types of lightning strokes:

There are three primary types of lightning, defined by what is at the "ends" of a flash channel.

- Intracloud (IC), which occurs within a single thundercloud unit
- Cloud to cloud (CC) or intercloud, which starts and ends between two different "functional" thundercloud units

- Cloud to ground (CG), that primarily originates in the thundercloud and terminates on an Earth surface, but may also occur in the reverse direction, that is ground to cloud

There are variations of each type, such as "positive" versus "negative" CG flashes, that have different physical characteristics common to each which can be measured. Different common names used to describe a particular lightning event may be attributed to the same or different events.

Cloud to ground (CG)

Cloud to ground lightning

Cloud-to-ground (CG) lightning is a lightning discharge between a thundercloud and the ground. It is initiated by a stepped leader moving down from the cloud, which is met by a streamer moving up from the ground.

CG is the least common, but best understood of all types of lightning. It is easier to study scientifically, because it terminates on a physical object, namely the Earth, and lends itself to being measured by instruments on the ground. Of the three primary types of lightning, it poses the greatest threat to life and property since it terminates or "strikes" the Earth. The overall discharge, termed a flash, is composed of a number of processes such as preliminary breakdown, stepped leaders, connecting leaders, return strokes, dart leaders and subsequent return strokes.

Positive and negative lightning

Cloud-to-ground (CG) lightning is either positive or negative, as defined by the direction of the conventional electric current from cloud to ground. Most CG lightning is negative, meaning that a negative charge is transferred to ground and electrons travel downward along the lightning channel. The reverse happens in a positive CG flash, where electrons travel upward along the lightning channel and a positive charge is transferred to the ground. Positive lightning is less common than negative lightning, and on average makes up less than 5% of all lightning strikes.

A *bolt from the blue* lightning strike which appears to initiate from the clear, but turbulent sky above the anvil cloud and drive a bolt of plasma through the cloud directly to the ground. They are commonly referred to as positive flashes despite the fact that they are usually negative in polarity.

There are six different mechanisms theorized to result in the formation of downward positive lightning.

- Vertical wind shear displacing the upper positive charge region of a thundercloud, exposing it to the ground below.
- The loss of lower charge regions in the dissipating stage of a thunderstorm, leaving the primary positive charge region.
- A complex arrangement of charge regions in a thundercloud, effectively resulting in an *inverted dipole* or *inverted tripole* in which the main negative charge region is above the main positive charge region instead of beneath it.
- An unusually large lower positive charge region in the thundercloud.
- Cutoff of an extended negative leader from its origin which creates a new bidirectional leader in which the positive end strikes the ground, commonly seen in anvil-crawler spider flashes.
- The initiation of a downward positive branch from an intracloud lightning flash.

Contrary to popular belief, positive lightning flashes do *not* necessarily originate from the anvil or the upper positive charge region and strike a rain-free area outside of the thunderstorm. This belief is based on the outdated idea that lightning leaders are unipolar in nature and originating from their respective charge region.

Positive lightning strikes tend to be much more intense than their negative counterparts. An average bolt of negative lightning carries an electric current of 30,000 amperes (30 kA), and transfers 15 coulombs of electric charge and 1 gigajoule of energy. Large bolts of negative lightning can carry up to 120 kA and 350 C. The average positive ground flash has roughly double the peak current of a typical negative flash, and can produce peak currents up to 400 kA and charges of several hundred coulombs. Furthermore, positive ground flashes with high peak currents are commonly followed by long continuing currents, a correlation not seen in negative ground flashes.

As a result of their greater power, as well as lack of warning, positive lightning strikes are considerably more dangerous. Due to the aforementioned tendency for positive ground flashes to produce both high peak currents and long continuing current, they are capable of heating surfaces to much higher levels which increases the likelihood of a fire being ignited.

Positive lightning has also been shown to trigger the occurrence of upward lightning flashes from the tops of tall structures and is largely responsible for the initiation of sprites several tens of kilometers above ground level. Positive lightning tends to occur more frequently in winter storms, as with thundersnow, during intense tornadoes and in the dissipation stage of a thunderstorm. Huge quantities of extremely low frequency (ELF) and very low frequency (VLF) radio waves are also generated,

A unique form of cloud-to-ground lightning exists where lightning appears to exit from the cumulonimbus cloud and propagate a considerable distance through clear air before veering towards, and striking, the ground. For this reason, they are known as "bolts from the blue". Despite the popular misconception that these are positive lightning strikes due to them seemingly originating from the positive charge region, observations have shown that these are in fact negative flashes. They begin as intracloud flashes within the cloud, the negative leader then exits the cloud from the positive charge region before propagating through clear air and striking the ground some distance away.

Cloud to cloud (CC) and intra-cloud (IC)

Branching of cloud to cloud lightning, New Delhi, India

Multiple paths of cloud-to-cloud lightning, Swifts Creek, Australia.

Cloud-to-cloud lightning, Victoria, Australia.

Cloud-to-cloud lightning seen in Gresham, Oregon.

Lightning discharges may occur between areas of cloud without contacting the ground. When it occurs between two separate clouds it is known as *inter-cloud lightning*, and when it occurs between areas of differing electric potential within a single cloud it is known as *intra-cloud lightning*. Intra-cloud lightning is the most frequently occurring type.

Intra-cloud lightning most commonly occurs between the upper anvil portion and lower reaches of a given thunderstorm. This lightning can sometimes be observed at great distances at night as so-called "sheet lightning". In such instances, the observer may see only a flash of light without hearing any thunder.

Anvil Crawler over Lake Wright Patman south of Redwater, Texas on the backside of a large area of rain associated with a cold-front

Another term used for cloud–cloud or cloud–cloud–ground lightning is "Anvil Crawler", due to the habit of charge, typically originating beneath or within the anvil and scrambling through the upper cloud layers of a thunderstorm, often generating dramatic multiple branch strokes. These are usually seen as a thunderstorm passes over the observer or begins to decay. The most vivid crawler behavior occurs in well developed thunderstorms that feature extensive rear anvil shearing.

Lightning Arrester

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

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

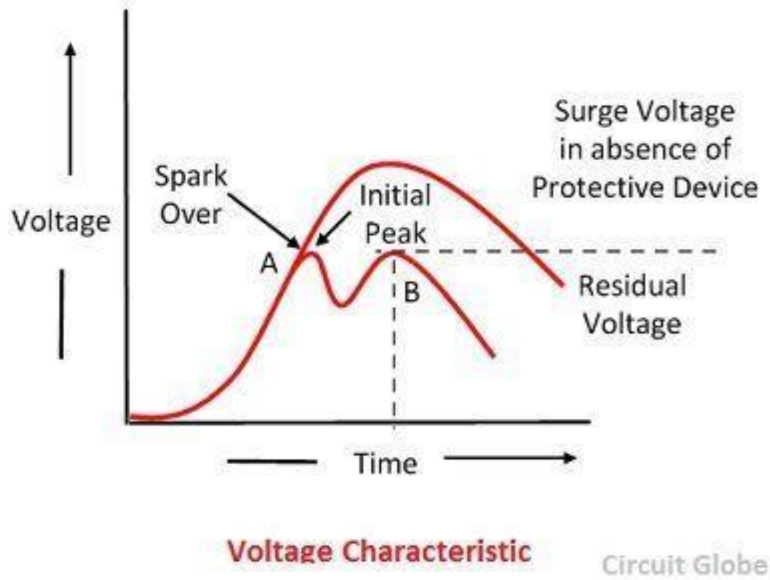
1. The high peak or crest voltage of the surge may cause flash-over in the internal winding thereby spoil the winding insulation.
2. The steep wave fronts of the surges may cause external flashover between the terminal of the transformer.
3. The highest peak voltage of the surge may cause external flashover,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

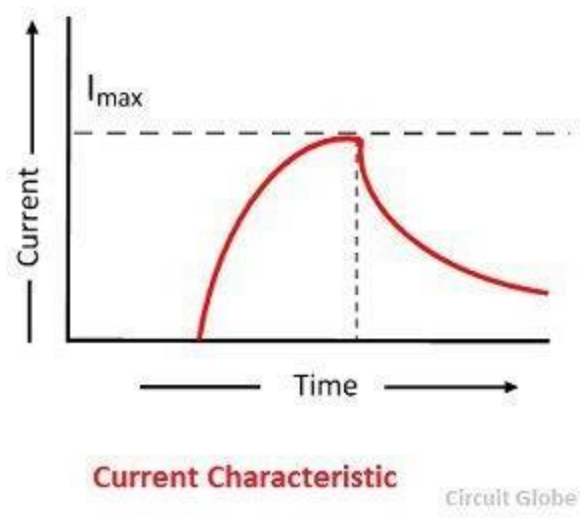
Working of Lightning Arrester

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

The lightning arrester provides a path of low impedance only when the travelling surge reaches the surge diverter, neither before it nor after it.

The insulation of the equipment can be protected if the shape of the voltage and current at the diverter terminal is similar to the shape shown below.





An ideal lightning arrester should have the following characteristics;

1. It should not draw any current during normal operating condition, i.e., it sparks-over voltage must be above the normal or abnormal power frequency that may occur in the system.
2. Any transient abnormal voltage above the breakdown value must cause it to break down as quickly as possible so that it may provide a conducting path to ground.
3. When the breakdown has taken place, it should be capable of

carrying the resulting discharge current without getting damaged itself and without the voltage across it exceeding the breakdown value.

4. The power frequency current following the breakdown must be interrupted as soon as the transient voltage has fallen below the breakdown value.

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

Location of Lightning Arrester

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

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

Types of Lightning Arresters

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

These types are;

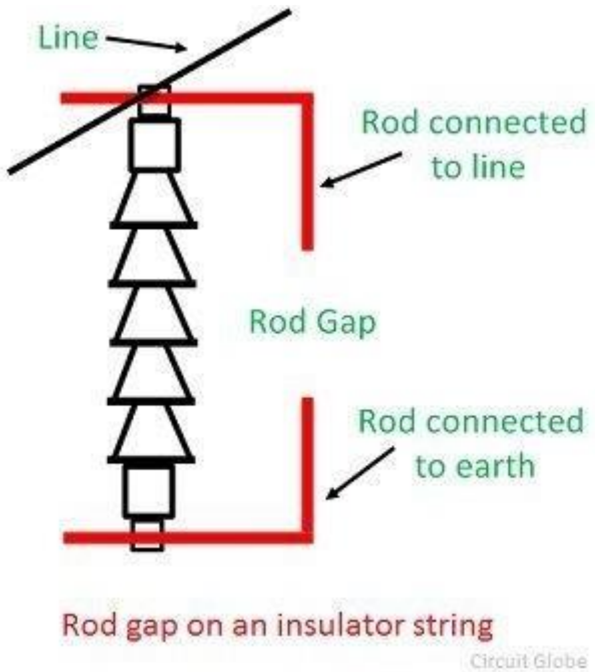
1. Rod Gap Arrester
2. Horn Gap Arrester
3. Valve Type Lightning

Arresters Their types are

explained below in details.

1. **Rod Gap Arrester**

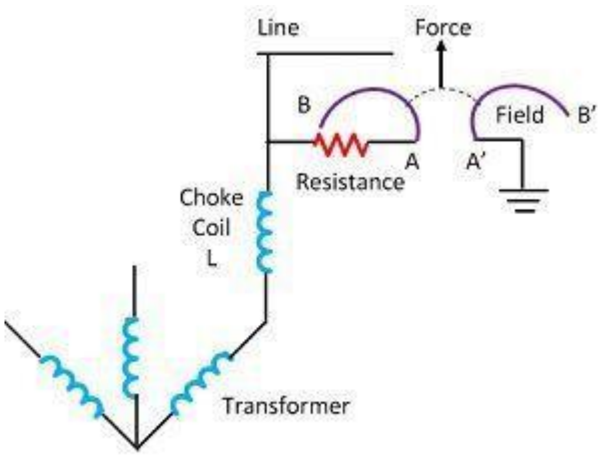
It is one of the simplest forms of the arrester. In such type of arrester, there is an air gap betweenthe ends of two rods. The one end of the arrester is connected to the line and the second end of the rod is connected to the ground. The gap setting of the arrester should be such that it should break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

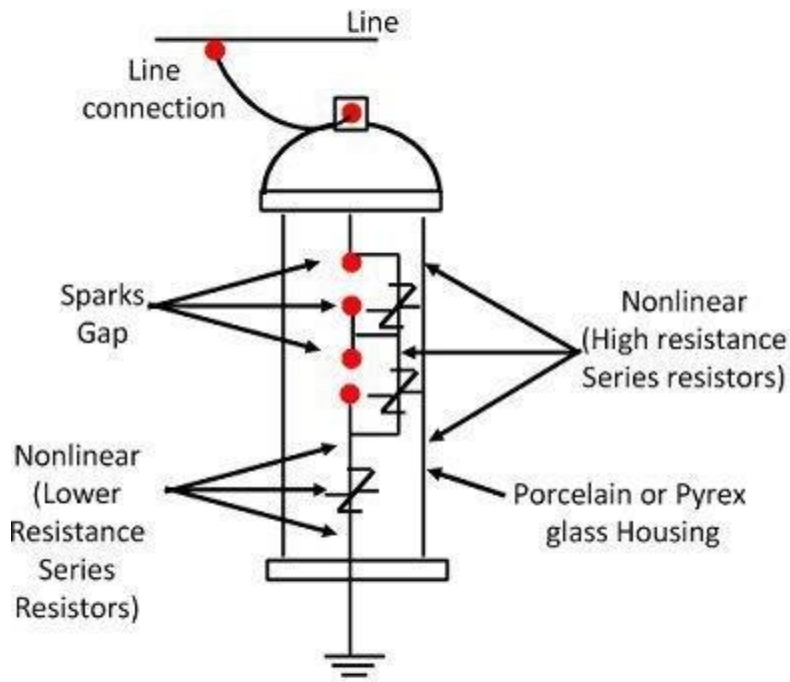
It consists of two horns shaded piece of metal separated by a small air gap and connected in shunt between each conductor and earth. The distance between the two electrodes is such that thenormal voltage between the line and earth is insufficient to jump the gap. But the abnormal high voltage will break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



Horn Gap With Choke Coil and Resistance

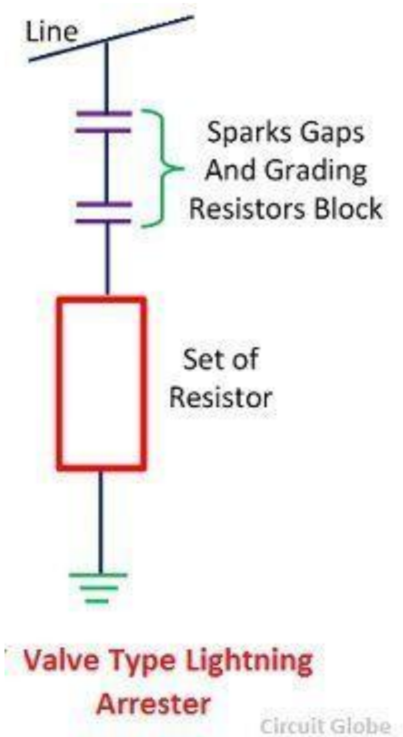
3. Valve Type Lightning Arrester

Such type of resistor is called nonlinear diverter. It essentially consists a divided spark gap inseries 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 resistorof high ohmic value is connected in parallel.



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 thegrounded resistance. The impulse voltage is mainly concentrated on the upper spark gap whichin spark over cause the complete arrester to spark over to.

SURGE ABSORBER :

Types of Surge Absorber:

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

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

Although both surge diverter and surge absorber eliminate the surge, the manner in which it is done is different in the two devices. The surge diverter diverts the surge to earth but the surge absorber absorbs the surge energy.

Different Types of Surge Absorber are

1. **Condenser or Capacitor Surge Absorber**
2. **Inductor and Resistance Surge Absorber**
3. **Ferranti Surge Absorber**

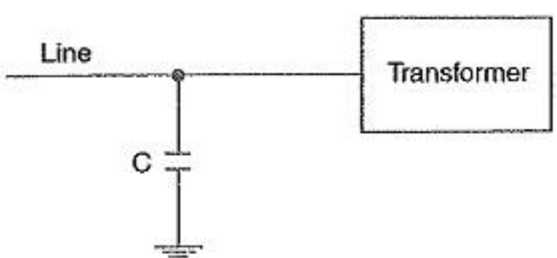


Fig. 24.14

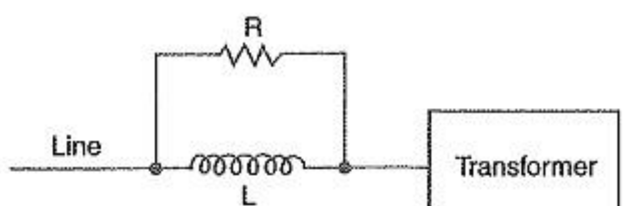


Fig. 24.15

1. Condenser or Capacitor Surge Absorber:

A condenser connected between the line and earth can act as a surge absorber. Fig. 24.14 shows how a capacitor acts as surge absorber to protect the transformer winding. Since the reactance of a condenser is inversely proportional to frequency, it Will be low at high frequency and high at low frequency. Since the surges are of high frequency, the capacitor acts as a short circuit and passes them directly to earth. However, for power frequency, the reactance of the capacitor is very high and practically no current flows to the ground.

2. Inductor and Resistance Surge Absorber :

Another Types of Surge Absorber consists of a parallel combination of choke and resistance connected in series with the line as shown in Fig. 24.15. The choke offers high reactance to surge frequencies ($X_L=2\pi fL$). The surges are, therefore, forced to flow through the resistance R where they are dissipated.

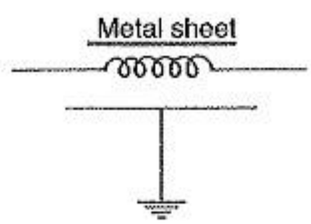


Fig. 24.16

3. Ferranti Surge Absorber :

Fig 24.16 shows the Types of Surge Absorber. It is called Ferranti surge absorber. It consists of an air cored inductor connected in series with the line. The inductor is surrounded by but insulated from an earthed metallic sheet called dissipator. This arrangement is equivalent to a transformer with short-circuited secondary. The inductor forms the primary whereas the dissipator forms the short-circuited secondary. The energy of the surge is used up in the form of heat generated in the dissipator due to transformer action. This type of surge absorber is mainly used for the protection of transformers.

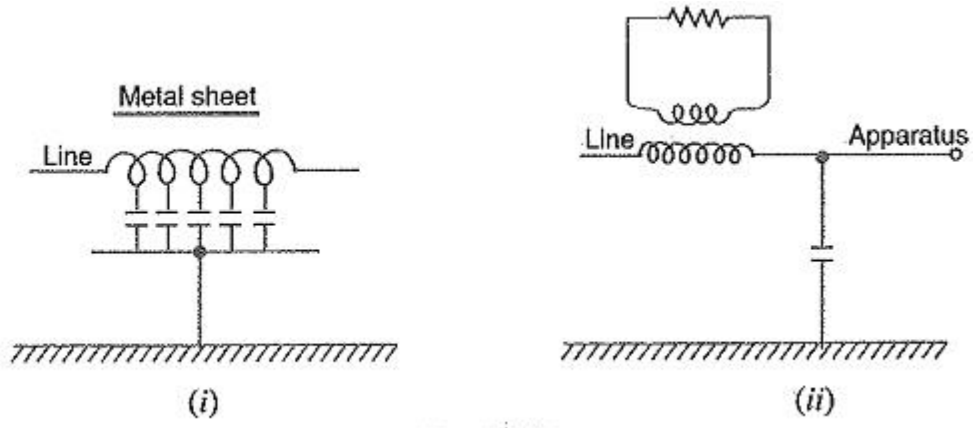


Fig. 24.17

Fig. 24.17 (i) shows the schematic diagram of 66 kV Ferranti surge absorber while Fig. 24.17 (ii) shows its equivalent circuit.

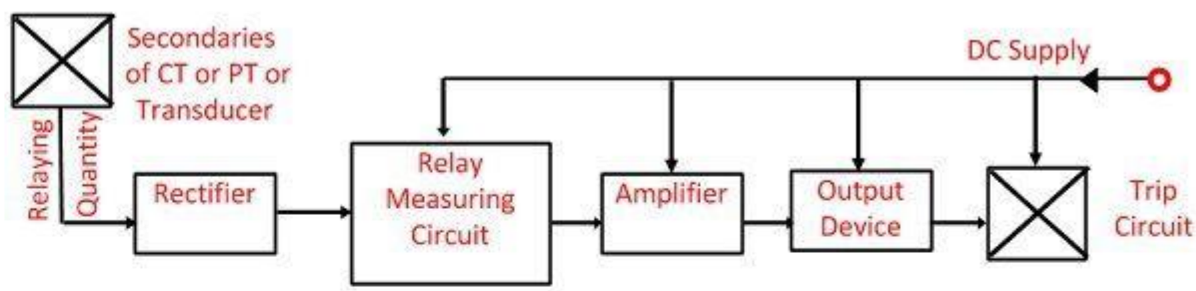
TOPIC – 8

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.

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



Block Diagram of Static Relay

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

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

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

Advantages of Static Relay

The following are the benefits of static relays.

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

Limitations of Static Relay

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

- The static relay is more costly as compared to the electromagnetic relay.
- The construction of the relay is easily affected by the surrounding interference.

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

OVERCURRENT 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.

Working Principle of Over Current Relay

In an **over current relay**, there would be essentially a current coil. When normal current flows through this coil, the magnetic effect generated by the coil is not sufficient to move the moving element of the relay, as in this condition the restraining force is greater than deflecting force. But when the current through the coil increases, the magnetic effect increases, and after a 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 overcurrent relays** but basic **working principle of overcurrent relay** is more or less same for all.

Types of Over Current Relay

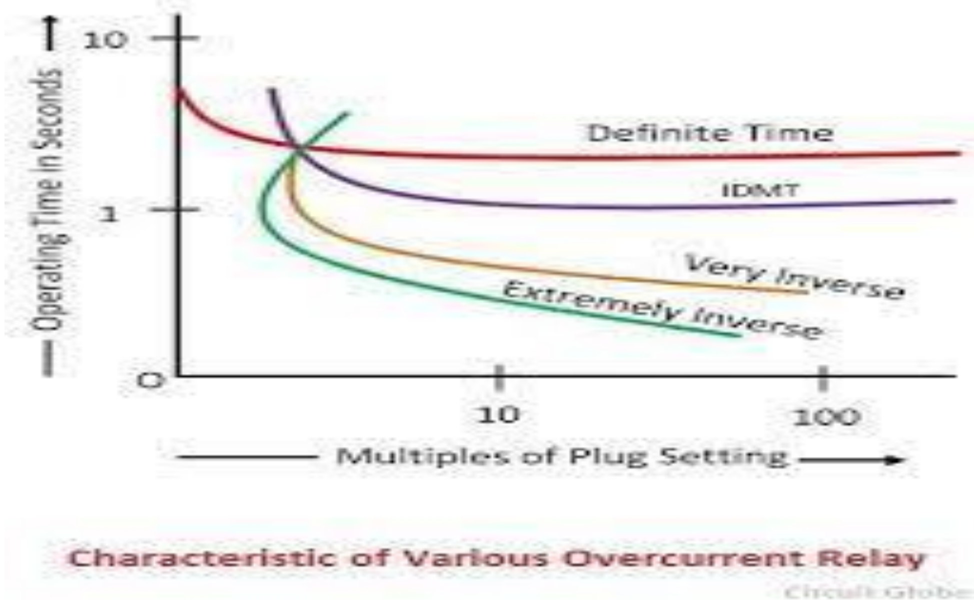
Depending upon time of operation, there are various **types of Over Current relays**, such as,

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

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

Instantaneous Over Current Relay

Construction and working principle of **instantaneous over current relay** is quite simple.
Here generally a magnetic core is wound by a current coil. A piece of iron is so fitted by hinge support and restraining spring in the relay, that when there is not sufficient current in the coil, the NO contacts remain open. When the current in the coil crosses a preset value, the attractive force becomes enough to pull the iron piece towards the magnetic core, and consequently, the no contacts get closed.
We refer the pre-set value of current in the relay coil as pickup setting current. This relay is referred as instantaneous **over current relay**, as ideally, the relay operates as soon as the current in the coil gets higher than pick upsetting current. There is no intentional time delay applied. But there is always an inherent time delay which we cannot avoid practically. In practice, the operating time of an instantaneous relay is of the order of a few milliseconds.



Characteristic of Various Overcurrent Relay

Definite Time Over Current Relay

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

Inverse Time Over Current Relay

Inverse time is a natural character of any induction type rotating device. Here, the speed of rotation of rotating part of the device is faster if the input current is more. In other words, time of operation inversely varies with input current. This natural characteristic of electromechanical induction disc relay is very suitable for overcurrent protection. If the fault is severe, it will clear the fault faster. Although time inverse characteristic is inherent to electromechanical induction disc relay, the same characteristic can be achieved in microprocessor-based relay also by proper programming.

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

Ideal inverse time characteristics cannot be achieved, in an overcurrent relay. As the current in the system increases, the secondary current of the current transformer is increased proportionally. The secondary current enters the relay current coil. But when the CT becomes saturated, there would not be a further proportional increase of CT secondary current with increased system current. From this phenomenon, it is clear that from trick value to certain range of faulty level, an inverse time relay shows specific inverse characteristic. But after this level of fault, the CT becomes saturated and relay current does not increase further with increasing faulty level of the system. As the relay current does not increase further, there would not be any further reduction in time of operation in the relay. We define this time as the minimum time of operation. Hence, the characteristic is inverse in the initial part, which tends to a definite minimum operating time as the current becomes very high. That is why the relay is referred as **inverse definite minimum time over current relay** or simply **IDMT relay**.