

Lecture Notes on SWITCH GEAR AND PROTECTIVE DEVICE



**6TH SEMESTER DIPLOMA (EE)
SUBJECT CODE: TH-2**



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Definition of following important terms.

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Induction type directional over current relay.

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CHAPTER-1

INTRODUCTION TO SWITCHGEAR

Switchgear

- A switchgear essentially consists of switching and protecting devices such as switches, fuses, circuit breakers, relays etc.
- During normal operation, switchgear permits to switch on or off generators, transmission lines, distributors and other electrical equipment.
- when a failure (e.g. short circuit) occurs on any part of power system, a heavy current flows through the equipment, threatening damage to the equipment and interruption of service to the customers.
- So the apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as switchgear.

Essential Features Of Switchgear

- (i) Complete reliability.
 - switchgear is added to the power system to improve the reliability. When fault occurs on any part of the power system, the switchgear must operate to isolate the faulty section from the remainder circuit.
- (ii) Absolutely certain discrimination.
 - When fault occurs on any section of the power system, the switchgear must be able to discriminate between the faulty section and the healthy section.
- (iii) Quick operation.
 - When fault occurs on any part of the power system, the switchgear must operate quickly so that no damage is done to generators, transformers and other equipment.
- (iv) Provision for manual control.
 - In case the electrical (or electronics) control fails, the necessary operation can be carried out through manual control.

Switchgear Equipments

It includes switches, fuses, circuit breakers, relays and other equipment.

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. The switches may be classified into (i) air switches (ii) oil switches.

(i) Air-break switch.

- It is an air switch and is designed to open a circuit under load.

(ii) Isolator or disconnecting switch.

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

(iii) Oil switches.

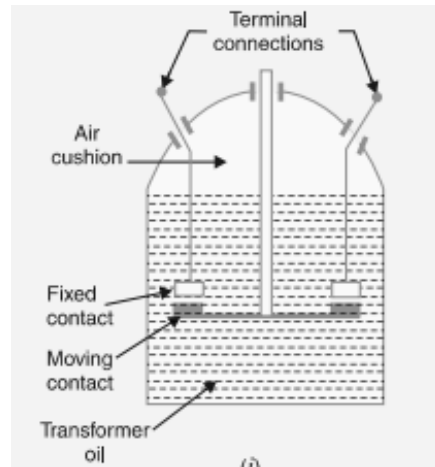
- The contacts of such switches are opened under oil, usually transformer oil.

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.

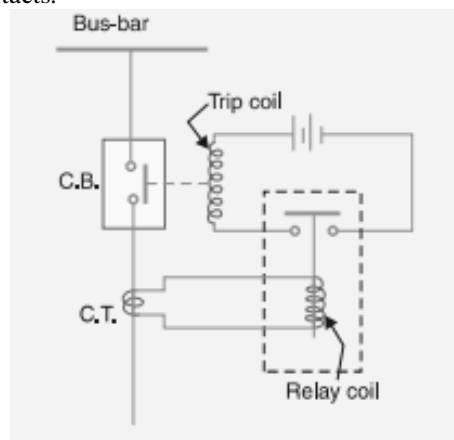
3. Circuit breakers.

- 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.



4. Relays.

- A relay is a device which detects the fault and supplies information to the breaker for circuit interruption. It can be divided into three parts
- (i) The primary winding of a current transformer (C.T.) which is connected in series with the circuit to be protected. The primary winding often consists of the main conductor itself.
- (ii) The second circuit is the secondary winding of C.T. connected to the relay operating coil.
- (iii) The third circuit is the tripping circuit which consists of a source of supply, trip coil of circuit breaker and the relay stationary contacts.

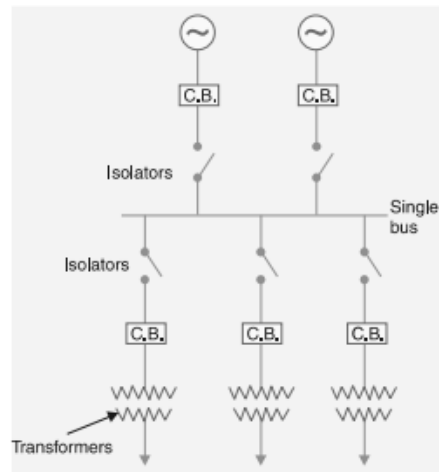


Bus-bar Arrangement

- When a number of generators or feeders operating at the same voltage have to be directly connected electrically, bus-bars are used as the common electrical component.
- Bus-bars are copper rods or thin walled tubes and operate at constant voltage.

(1) Single Bus-bar System.

- The single busbar system has the simplest design and is used for power stations. It is also used in small outdoor stations having relatively few outgoing or incoming feeders and lines.
- The generators, outgoing lines and transformers are connected to the bus-bar. Each generator and feeder is controlled by a circuit breaker.
- The isolators permit to isolate generators, feeders and circuit breakers from the bus-bar for maintenance.



Advantages-

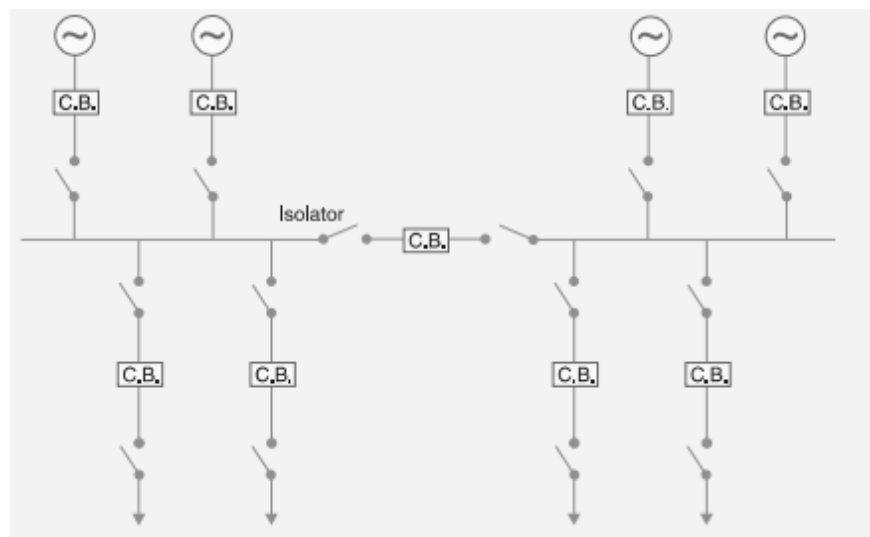
- (i) low initial cost,
- (ii) less maintenance and simple operation.

Disadvantages.

- (i) The bus-bar cannot be cleaned, repaired or tested without de-energising the whole system.
- (ii) If a fault occurs on the bus-bar itself, there is complete interruption of supply.

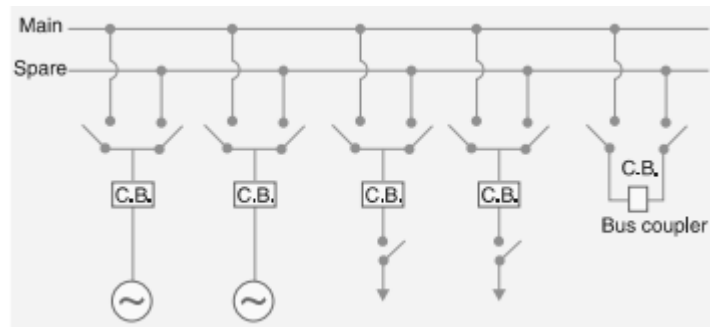
(2) Single bus-bar system with Sectionalisation.

- The bus-bar divided into two sections connected by a circuit breaker and isolators. Three principal advantages are claimed for this arrangement.
- Firstly, if a fault occurs on any section of the bus-bar, that section can be isolated without affecting the supply to other sections.
- Secondly, if a fault occurs on any feeder, the fault current is much lower than with unsectionalised bus-bar. This permits the use of circuit breakers of lower capacity in the feeders.
- Thirdly, repairs and maintenance of any section of the bus-bar can be carried out by de-energising that section only, eliminating the possibility of complete shut-down.



(3) Duplicate bus-bar system.

- Such a system consists of two bus-bars a “main bus-bar” and a “spare” 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 isolators.



Advantages

- (i) If repair and maintenance it to be carried on the main bus, the supply need not be interrupted as the entire load can be transferred to the spare bus.
- (ii) The testing of feeder circuit breakers can be done by putting them on spare bus-bar, thus keeping the main bus-bar undisturbed.

switchgear Accommodation

Depending upon the voltage to be handled, switchgear may be broadly classified into (i) outdoor type (ii) indoor type

(i) Outdoor type.

- For voltages beyond 66 kV, switchgear equipment is installed outdoor. It is because for such voltages, the clearances between conductors and the space required for switches, circuit breakers, transformers and others equipment become so great.

(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 through the circuit. This is called short-circuit current.

Causes of short-circuit. It may be caused due to internal and external effects.

- Internal effects are caused by breakdown of equipment or transmission lines, from deterioration of insulation in a generator, transformer and ageing of insulation, inadequate design or improper installation.
- External effects causing short circuit include insulation failure due to lightning surges, overloading of equipment causing excessive heating; mechanical damage by public

Fault On Power System

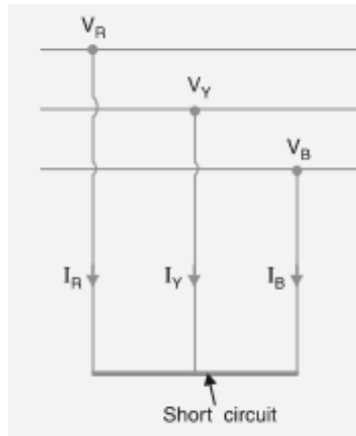
- A fault occurs when two or more conductors that normally operate with a potential difference come in contact with each other. the faults in a 3-phase system can be classified into two main categories.
- Symmetrical faults. That fault which gives rise to symmetrical fault currents (equal faults currents with 120° displacement) is called a symmetrical fault. ex-LLL fault
- Unsymmetrical faults. Those faults which give rise to unsymmetrical currents (unequal line currents with unequal displacement) are called unsymmetrical faults. ex-LG,LLG,LL fault

CHAPTER 2

SYMMETRICAL FAULT CALCULATIONS

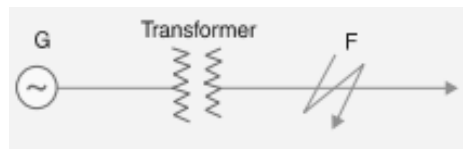
Symmetrical Fault

- 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 shortcircuit condition



Limitation Of Fault Current

- When a short circuit occurs at any point in a system, the short-circuit current is limited by the impedance of the system up to the point of fault.



- if a fault 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 fault.

Percentage Reactance

- The reactance of generators, transformers, reactors etc. is usually expressed in percentage reactance to permit rapid short circuit calculations.
- It is the percentage of the total phase-voltage dropped in the circuit when full-load current is flowing i.e.

$$\%X = \frac{IX}{V} \times 100$$

I = full-load current

V = phase voltage

X = reactance in ohms per phase

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

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

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

Percentage Reactance And Base KVA

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

Short Circuit KVA

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

Let

V = normal phase voltage in volts

I = full-load current in amperes at base kVA

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

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

\therefore Short-circuit kVA for 3-phase circuit

$$= \frac{3 V I_{sc}}{1000}$$

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

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

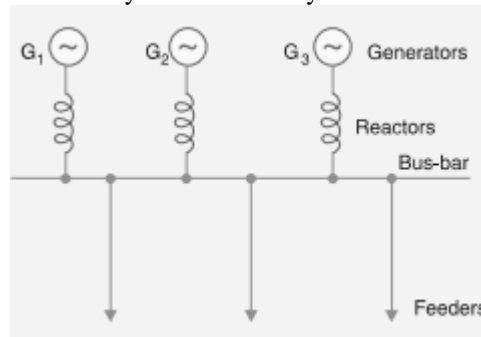
Reactor Control Of Short Circuit Current

- 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.

Location Of Reactors

(1) Generator reactors.

- When the reactors are connected in series with each generator, they are known as generator reactors .
- 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.

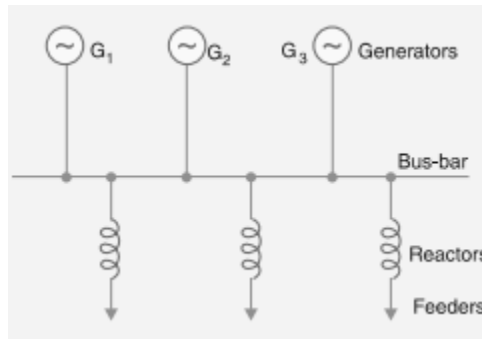


Disadvantages

- (i) There is a constant voltage drop and power loss in the reactors even during normal operation.
- (ii) 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.

(2) Feeder reactors.

- When the reactors are connected in series with each feeder, they are known as feeder reactors. Two principal advantages are claimed for feeder reactors.
- 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 localised.



Disadvantages

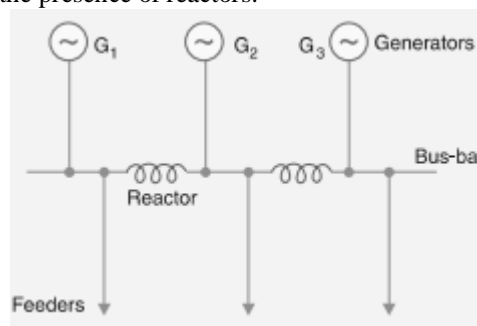
- (i) There is a constant power loss and voltage drop in the reactors even during normal operation.
- (iii) If the number of generators is increased, the size of feeder reactors will have to be increased to keep the short-circuit currents within the ratings of the feeder circuit breakers

(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 reactors even during normal operation.
- This disadvantage can be overcome by locating the reactors in the bus-bars by Ring system and Tie-Bar system.

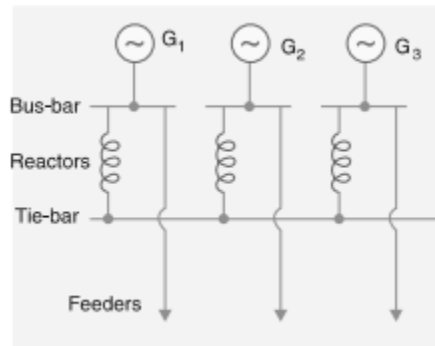
(i) Ring system.

- In this system, bus-bar is divided into sections and these sections are connected through reactors. 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.
- 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 reactors.



(ii) Tie-Bar system.

- Advantage of tiebar system is that additional generators may be connected to the system without requiring changes in the existing reactors.
- Disadvantage that it requires an additional bus-bar i.e. the tie-bar.



CHAPTER-3

FUSE

Fuse

- A **fuse** 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.

Characteristics Of Fuse Element

- (i) low melting point e.g., tin, lead.
- (ii) high conductivity e.g., silver, copper.
- (iii) free from deterioration due to oxidation e.g., silver.
- (iv) low cost e.g., lead, tin, copper.

Fuse Element Material

- The most commonly used materials for fuse element are lead, tin, copper, zinc and silver.
- For small currents upto 10 A, tin or an alloy of lead and tin (lead 37%, tin 63%) is used for making the fuse element.
- For larger currents, copper or silver is employed.

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

- (i) It is comparatively free from oxidation.
- (ii) It does not deteriorate when used in dry air.
- (iii) 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.
- (iv) The conductivity of silver is very high.

Important Term Of Fuse

(i) Current rating of fuse element.

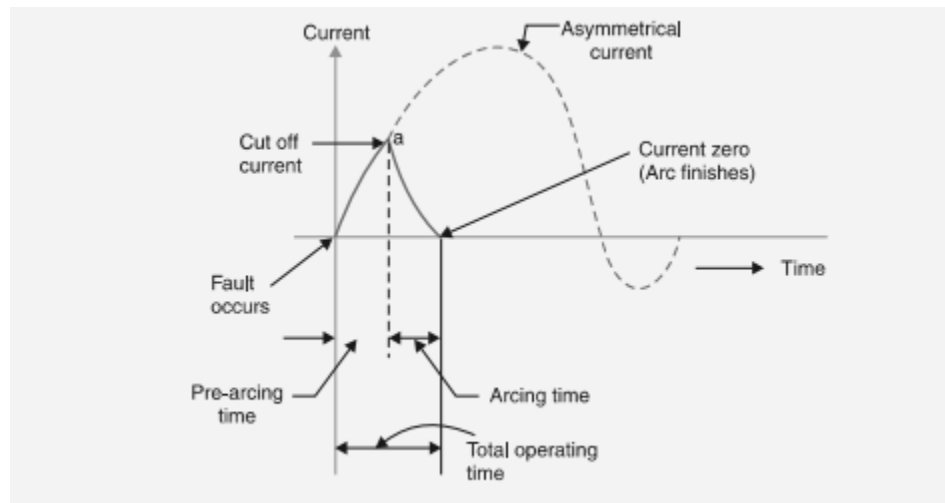
- It is the current which the fuse element can normally carry without overheating or melting. It depends upon the temperature rise of the contacts of the fuse holder, fuse material and the surroundings of the fuse.

(ii) Fusing current.

- It is the minimum current at which the fuse element melts and thus disconnects the circuit protected by it.

(iii) Fusing factor.

- It is the ratio of minimum fusing current to the current rating of the fuse element. 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.

**(iv) Prospective Current.**

- The r.m.s. value of the first loop of fault current is known as prospective current. 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.

(v) Cut-off current.

- It is the maximum value of fault current actually reached before the fuse melts.

(vi) Pre-arcing time.

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

(vii) Arcing time.

- This is the time between the end of pre-arcing time and the instant when the arc is extinguished.

(viii) Total operating time.

- It is the sum of pre-arcing and arcing times.

(ix) 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.

Types of Fuse

The fuses may be classified into two types:

- (i) Low voltages fuses
- (ii) High voltage fuses

(I) Low Voltage Fuses

Low voltage fuses can be subdivided into two classes again

- (1) semi-enclosed rewirable fuse
- (2) high rupturing capacity (H.R.C.) cartridge fuse.

1. Semi-enclosed rewirable fuse / Kit Kat fuse.

- Rewirable fuse is used where low values of fault current are to be interrupted.

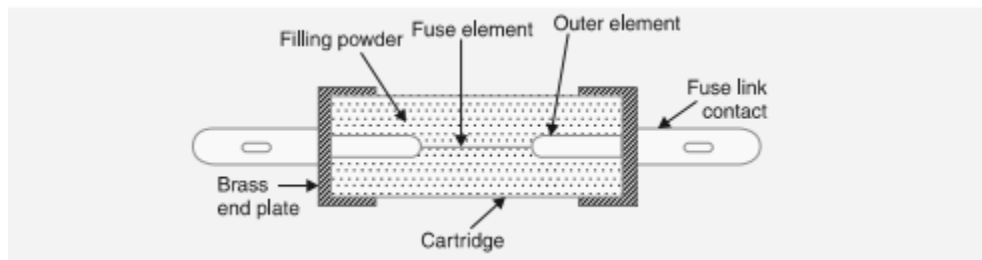
- It consists of a base and a fuse carrier.
- The base is of porcelain and carries the fixed contacts to which the incoming and outgoing phase wires are connected.
- The fuse carrier is also of porcelain and holds the fuse element (tinned copper wire) between its terminals. The fuse carrier can be inserted in or taken out of the base when desired.
- When a fault occurs, the fuse element is blown out and the circuit is interrupted. The fuse carrier is taken out and the blown out fuse element is replaced by the new one.

Disadvantages

- (i) This type of fuse has a low-breaking capacity and hence cannot be used in circuits of high fault level.
- (iii) The fuse element is subjected to deterioration due to oxidation through the continuous heating up of the element.

2. High-Rupturing capacity (H.R.C.) cartridge fuse.

- It consists of a heat resisting ceramic body having metal end-caps to which is welded silver current carrying element.
- The space within the body surrounding the element is completely packed with a filling powder.
- The filling material may be chalk, plaster of paris, quartz or marble dust and acts as an arc quenching and cooling medium.



- Under normal load conditions, the fuse element is at a temperature below its melting point. Therefore, it carries the normal current without overheating.
- When a fault occurs, the current increases and the fuse element melts before the fault current reaches its first peak. The heat produced in the process vapourises the melted silver element.
- The chemical reaction between the silver vapour and the filling powder results in the formation of a high resistance substance which helps in quenching the arc.

Advantages

- (i) They are capable of clearing high as well as low fault currents.
- (ii) They do not deteriorate with age.
- (iii) They have high speed of operation.
- (iv) They provide reliable discrimination.
- (v) They require no maintenance.

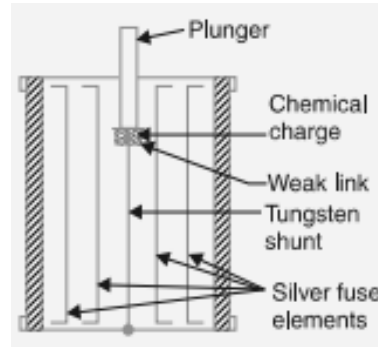
Disadvantages

- (i) They have to be replaced after each operation.

3. H.R.C. fuse with tripping device.

- Sometime H.R.C. cartridge fuse is provided with a tripping device. When the fuse blows out under fault conditions, the tripping device causes the circuit breaker to operate.
- The body of the fuse is of ceramic material with a metallic cap rigidly fixed at each end.

- These are connected by a number of silver fuse elements. At one end is a plunger which under fault conditions hits the tripping mechanism of the circuit breaker and causes it to operate.
- The plunger is electrically connected through a fusible link, chemical charge and a tungsten wire to the other end of the cap as shown.



- When a fault occurs, the silver fuse elements are the first to be blown out and then current is transferred to the tungsten wire. The weak link in series with the tungsten wire gets fused and causes the chemical charge to be detonated. This forces the plunger outward to operate the circuit breaker. The travel of the plunger is so set that it is not ejected from the fuse body under fault conditions.

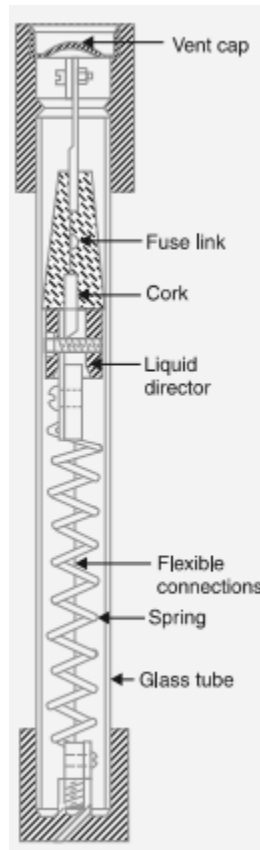
Advantages.

- (i) In case of a single phase fault on a three-phase system, the plunger operates the tripping mechanism of circuit breaker to open all the three phases and thus prevents “single phasing”.
- (ii) The effects of full short circuit current need not be considered in the choice of circuit breaker. This permits the use of a relatively inexpensive circuit breaker.

(ii) High Voltage Fuses

(1) Liquid type.

- It consists of a glass tube filled with carbon tetrachloride solution and sealed at both ends with brass caps.
- The fuse wire is sealed at one end of the tube and the other end of the wire is held by a strong phosphor bronze spiral spring fixed at the other end of the glass tube.
- When the current exceeds the prescribed limit, the fuse wire is blown out. As the fuse melts, the spring retracts part of it through a baffle (or liquid director) and draws it well into the liquid.
- The small quantity of gas generated at the point of fusion forces some part of liquid into the passage through baffle and there it effectively extinguishes the arc.



Current Carrying Capacity Of A Fuse Element

- The current carrying capacity of a fuse element mainly depends on the metal used and the cross sectional area but is affected also by the length, the state of surface and the surroundings of the fuse.
- When the fuse element attains steady temperature,
Heat produced per sec = Heat lost per second by convection, radiation and conduction

$$\text{or} \quad I^2 R = \text{Constant} \times \text{Effective surface area}$$

$$\text{or} \quad I^2 \left(\rho \frac{l}{a} \right) = \text{constant} \times d \times l$$

$$\text{where} \quad \begin{aligned} d &= \text{diameter of fuse element} \\ l &= \text{length of fuse element} \end{aligned}$$

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

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

$$\text{or} \quad I^2 \propto d^3 \quad \dots(i)$$

Expression (i) is known as ordinary *fuse law*.

Difference Between Fuse And Circuit Breaker

| S. No. | Particular | Fuse | Circuit breaker |
|--------|--------------------------|--|---|
| 1. | <i>Function</i> | It performs both detection and interruption functions. | It performs interruption function only. The detection of fault is made by relay system. |
| 2. | <i>Operation</i> | Inherently completely automatic. | Requires elaborate equipment (<i>i.e.</i> relays) for automatic action. |
| 3. | <i>Breaking capacity</i> | Small | Very large |
| 4. | <i>Operating time</i> | Very small (0.002 sec or so) | Comparatively large (0.1 to 0.2 sec) |
| 5. | <i>Replacement</i> | Requires replacement after every operation. | No replacement after operation. |

CHAPTER 4

CIRCUIT BREAKER

Circuit Breaker & Operating Principle

- A circuit breaker can make or break a circuit either manually or automatically under all conditions (no-load, full-load and short-circuit conditions)
- A circuit breaker essentially consists of fixed and moving contacts, called electrodes.
- Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty.
- When a fault occurs on any part of the system, the trip coils of the circuit breaker get energised and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

Arc Phenomenon

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

(i) Degree of ionisation

- The arc resistance increases with the decrease in the number of ionised particles between the contacts.

(ii) Length of the arc

- The arc resistance increases with the length of the arc i.e., separation of contacts.

(iii) Cross-section of arc

- The arc resistance increases with the decrease in area of X-section of the arc.

Methods of Arc Extinction

There are two methods of extinguishing the arc in circuit breakers

1. High Resistance Method

In this method, arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc. The principal disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in d.c. circuit breakers and low-capacity a.c. circuit breakers.

The resistance of the arc may be increased by :

(i) Lengthening the arc.

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

(ii) Cooling the arc.

Cooling helps in the deionisation of the medium between the contacts.

(iii) Reducing X-section of the arc.

If the area of X-section of the arc is reduced, the voltage necessary to maintain the arc is increased. In other words, the resistance of the arc path is increased.

(iv) Splitting the arc.

The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series.

2. Low Resistance Method

This method is employed for arc extinction in a.c. circuits only. In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally and is prevented from restriking inspite of the rising voltage across the contacts.

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

(i) lengthening of the gap

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

(ii) cooling

- Dielectric strength of the medium between the contacts can be increased by cooling the arc.

(iii) blast effect

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

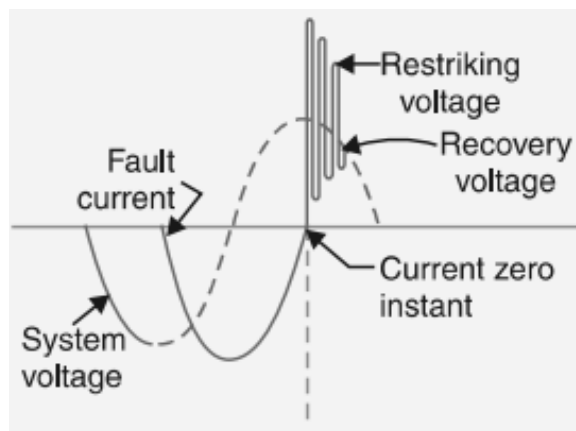
Important Terms

(i) Arc Voltage.

- It is the voltage that appears across the contacts of the circuit breaker during the arcing period is called the arc voltage.

(ii) Restriking voltage.

- It is the transient voltage that appears across the contacts at or near current zero during arcing period.



- At current zero, a high-frequency transient voltage appears across the contacts and is caused by the rapid distribution of energy between the magnetic and electric fields associated with the plant and transmission lines of the system. This transient voltage is known as restriking voltage.

(iii) Recovery voltage

- It is the normal frequency r.m.s. voltage that appears across the contacts of the circuit breaker after final arc extinction. It is approximately equal to the system voltage.

Classification Of Circuit Breaker

The classification is based on the medium used for arc extinction. The medium used for arc extinction is usually oil, air, sulphur hexafluoride (SF₆) and vacuum.

(i) Oil circuit breakers

- Oil is used for extinguishing the arc. (transformer oil)

(ii) Air-blast circuit breakers

- High pressure air-blast is used for extinguishing the arc.

(iii) Sulphur hexafluoride circuit breakers

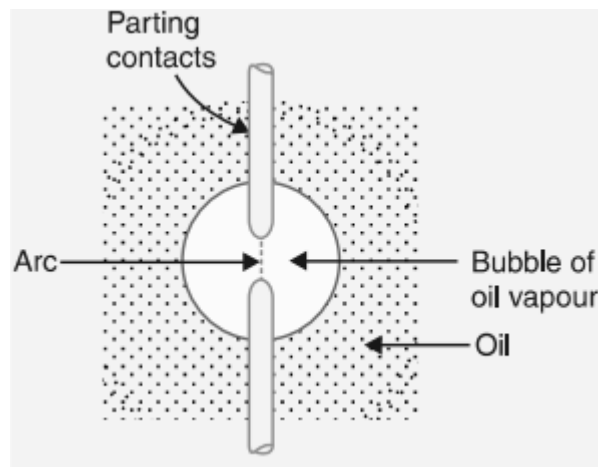
- Sulphur hexafluoride (SF₆) gas is used for arc extinction.

(iv) Vacuum circuit breakers

- Vacuum is used for arc extinction.

Oil Circuit Breaker

- Insulating oil is used as an arc quenching medium.
- The contacts are opened under oil and an arc is struck between them.
- The heat of the arc evaporates the surrounding oil and dissociates it into a substantial volume of gaseous *hydrogen at high pressure.
- The hydrogen gas occupies a volume about one thousand times that of the oil decomposed. The oil is pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region and adjacent portions of the contacts



The arc extinction is facilitated mainly by two processes.

- ❖ The hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionisation of the medium between the contacts.
- ❖ The gas sets up turbulence in the oil and forces it into the space between contacts, thus eliminating the arcing products from the arc path. The result is that arc is extinguished and circuit current interrupted.

Advantages

- (i) It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.
- (ii) It acts as an insulator and permits smaller clearance between live conductors and earthed components.

Disadvantages

- (i) It is inflammable and there is a risk of a fire.
- (iii) The arcing products like carbon remain in the oil and its quality deteriorates with successive operations. This necessitates periodic checking and replacement of oil.

Types Of Oil Circuit Breaker**(i) Bulk oil circuit breakers**

A large quantity of oil is used for arc quenching.

The oil has to serve two purposes.

- It extinguishes the arc during opening of contacts
- It insulates the current conducting parts from one another and from the earthed tank.
- it again classified in to two types
 - (a) Plain break oil circuit breakers
 - (b) Arc control oil circuit breakers.

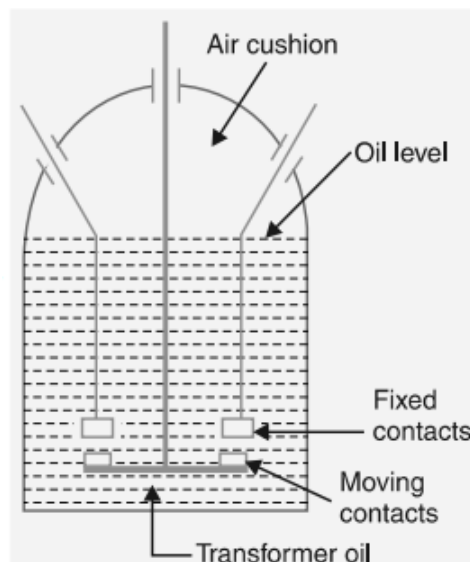
(ii) Low oil circuit breakers

A small quantity of oil is used for arc quenching.

- The oil is only use for arc extinction and the current conducting parts are insulated by air or porcelain or organic insulating material.

Plain-Break Oil Circuit Breaker

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



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

The arc extinction is facilitated by the following processes :

- (i) The hydrogen gas bubble generated around the arc cools the arc column and aids the deionisation of the medium between the contacts.
- (ii) The gas sets up turbulence in the oil and helps in eliminating the arcing products from the arc path.
- (iii) As the arc lengthens due to the separating contacts, the dielectric strength of the medium is increased. the arc is extinguished and the circuit current is interrupted.

Disadvantages

- (i) These breakers have long and inconsistent arcing times.
- (ii) These breakers do not permit high speed interruption.

Low oil circuit breakers

Construction

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

(i) Supporting chamber.

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

(ii) Circuit-breaking chamber.

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

- (a) upper and lower fixed contacts
- (b) moving contact
- (c) turbulator

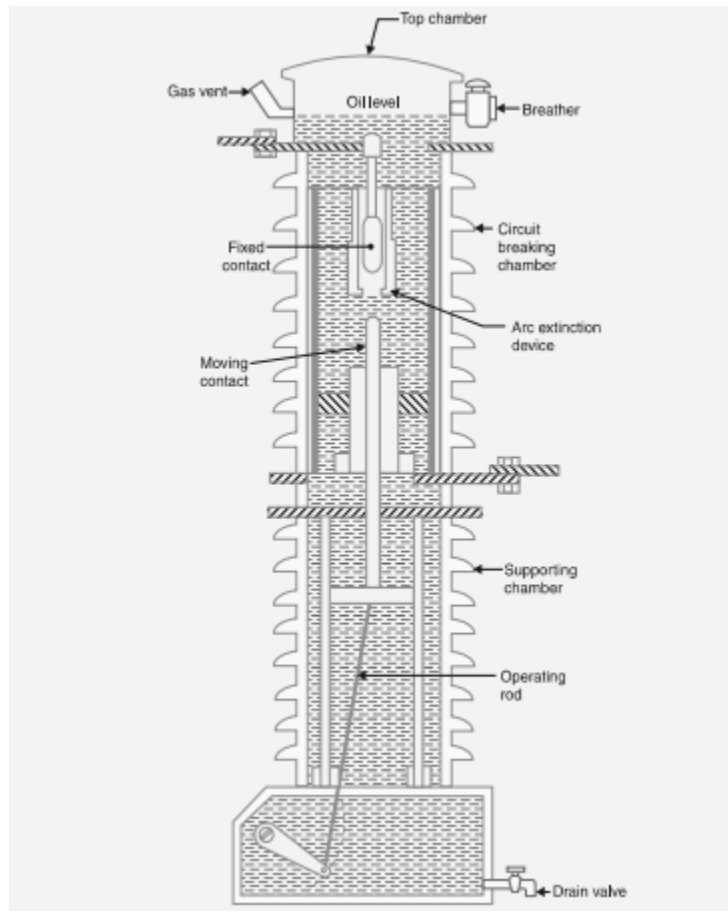
(iii) Top chamber.

It is a metal chamber and is mouted on the circuit-breaking chamber. It provides expansion space for the oil in the circuit breaking compartment.

Operation

- Under normal operating conditions, the moving contact remains engaged with the upper fixed contact.

- When a fault occurs, the moving contact is pulled down by the tripping springs and an arc is struck.
- The arc energy vaporises the oil and produces gases under high pressure. This action constrains the oil to pass through a central hole in the moving contact and results in forcing series of oil through the respective passages of the turbulator. The process of turbulation is orderly one in which the sections of the arc are successively quenched by the effect of separate streams of oil moving across each section in turn and bearing away its gases.

**Advantages**

- (i) It requires lesser quantity of oil.
- (ii) It requires smaller space.

Disadvantages.

- (i) Due to smaller quantity of oil, the degree of carbonisation is increased.
- (ii) There is a difficulty of removing the gases from the contact space in time.

Maintenance Of Oil Circuit Breaker

- (i) Check the current carrying parts and arcing contacts. If the burning is severe, the contacts should be replaced.
- (ii) Check the dielectric strength of the oil. If the oil is badly discoloured, it should be changed

- (iii) Check the oil level.
- (iv) Check closing and tripping mechanism.

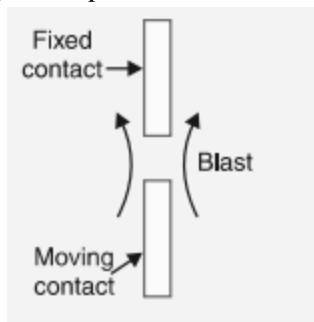
Air Blast Circuit Breaker

A high pressure air-blast is used for an arc quenching medium. The contacts are opened in a flow of air-blast established by the opening of blast valve. The air-blast cools the arc and sweeps away the arcing products to the atmosphere and Consequently the arc is extinguished and flow of current is interrupted.

Types Of Air Blast Circuit Breaker

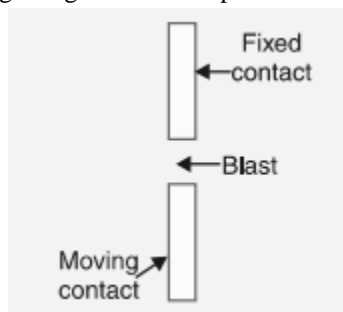
(i) Axial-blast type

- The air-blast is directed along the arc path



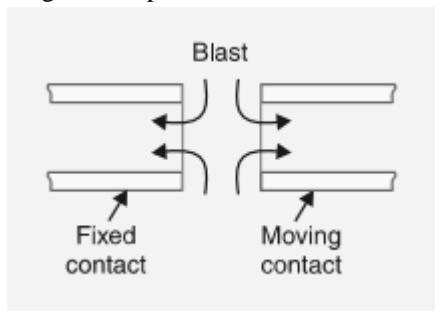
(ii) Cross-blast type

- The air-blast is directed at right angles to the arc path



(iii) Radial-blast type

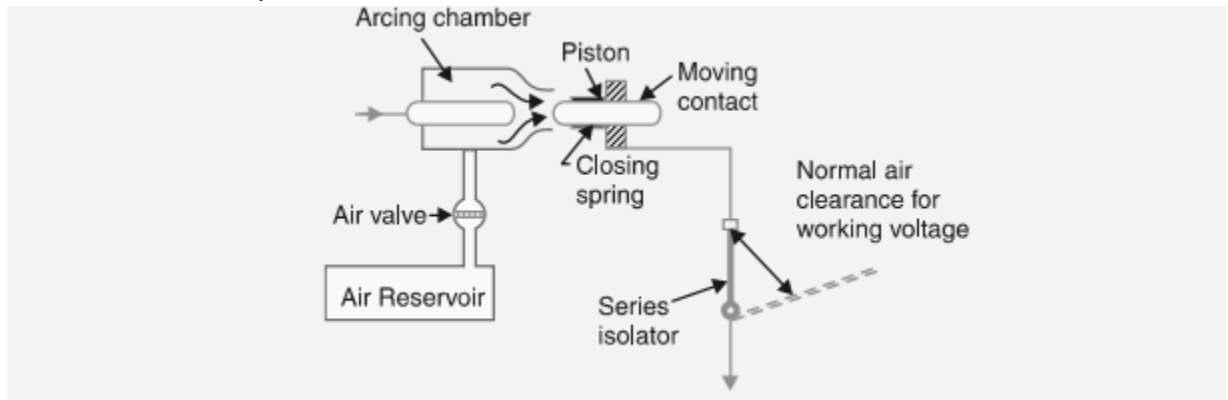
The air-blast is directed radially along the arc path



(i) Axial-blast air circuit breaker

- The fixed and moving contacts are held in the closed position by spring pressure under normal conditions.

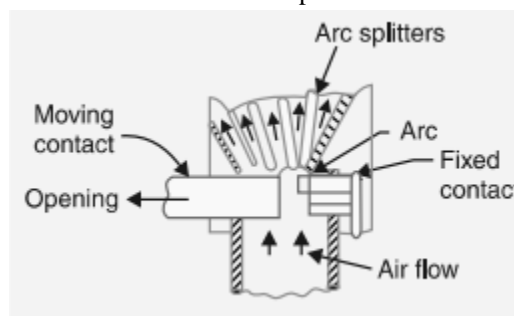
- The air reservoir is connected to the arcing chamber through an air valve. This valve remains closed under normal conditions but opens automatically by the tripping impulse when a fault occurs on the system.



- When a fault occurs, the tripping impulse causes opening of the air valve which connects the circuit breaker reservoir to the arcing chamber.
- The high pressure air entering the arcing chamber pushes away the moving contact against spring pressure.
- The moving contact is separated and an arc is struck. Consequently the arc is extinguished and current flow is interrupted.

(ii) Cross-blast air breaker.

- In this type of circuit breaker an air-blast is directed at right angles to the arc.
- The cross-blast lengthens and forces the arc into a suitable chute for arc extinction.
- When the moving contact is withdrawn, an arc is struck between the fixed and moving contacts.
- The high pressure cross-blast forces the arc into a chute consisting of arc splitters and baffles. The splitters serve to increase the length of the arc and baffles give improved cooling. The result is that arc is extinguished and flow of current is interrupted.



Advantages & Disadvantages of Air Blast Circuit Breaker

Advantages

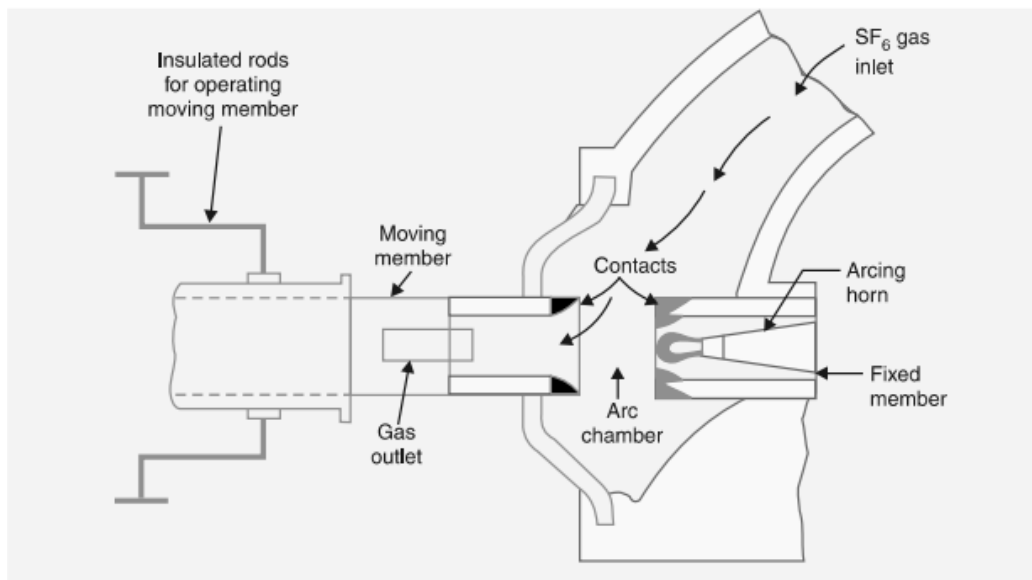
- The risk of fire is eliminated.
- The arcing products are completely removed by the blast
- The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small. This reduces the size of the device.

Disadvantages

- Maintenance is required for the compressor plant.

Sulphur Hexafluoride (Sf6) Circuit Breaker

- In such circuit breakers, sulphur hexafluoride (SF₆) gas is used as the arc quenching medium.
- It consists of fixed and moving contacts enclosed in a chamber (called arc interruption chamber) containing SF₆ gas. This chamber is connected to SF₆ gas reservoir.
- When the contacts of breaker are opened, the valve mechanism permits a high pressure SF₆ gas from the reservoir to flow towards the arc interruption chamber.
- The fixed contact is a hollow cylindrical current carrying contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides to permit the SF₆ gas to let out through these holes after flowing along and across the arc.
- The tips of fixed contact, moving contact and arcing horn are coated with copper-tungsten arc resistant material.



Operation

- When a fault occurs the contacts of the breaker are opened in a high pressure flow of SF₆ gas and an arc is struck between them.
- The high pressure flow of SF₆ rapidly absorbs the free electrons in the arc path to form immobile negative ions which are ineffective as charge carriers.
- The result is that the medium between the contacts quickly builds up high dielectric strength and causes the extinction of the arc.

Advantages

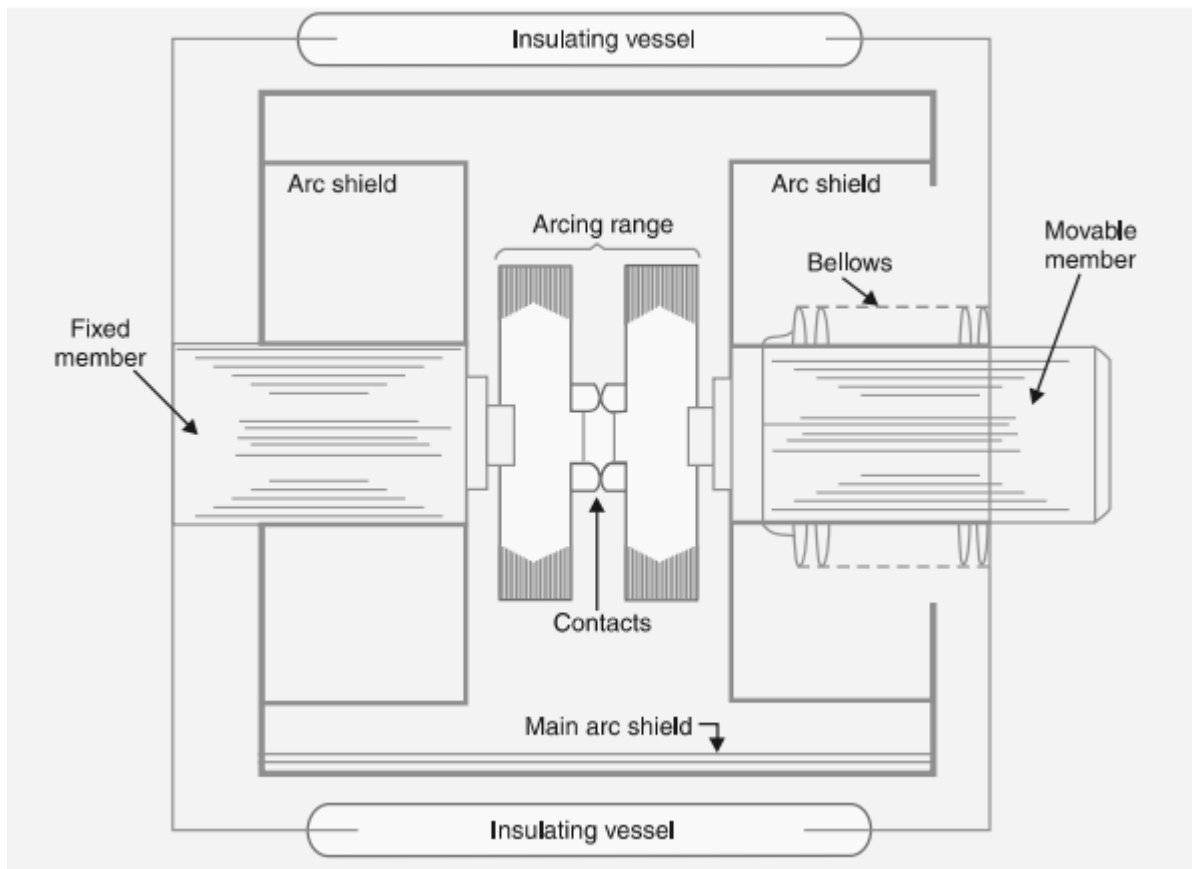
- (i) Due to the superior arc quenching property of SF₆, such circuit breakers have very short arcing time.
- (ii) Since the dielectric strength of SF₆ gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.
- (iii) The SF₆ circuit breaker gives noiseless operation due to its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker.

Disadvantages

- (i) SF₆ breakers are costly due to the high cost of SF₆.

Vacuum Circuit Breaker

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

**Operation**

- When the breaker operates the moving contact separates from the fixed contact and an arc is struck between the contacts.
- The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in a short time and seized by the surfaces of moving and fixed members and shields.
- Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker occurs with a short contact separation (0.625 cm).

Advantages

- (i) They are compact, reliable and have longer life.

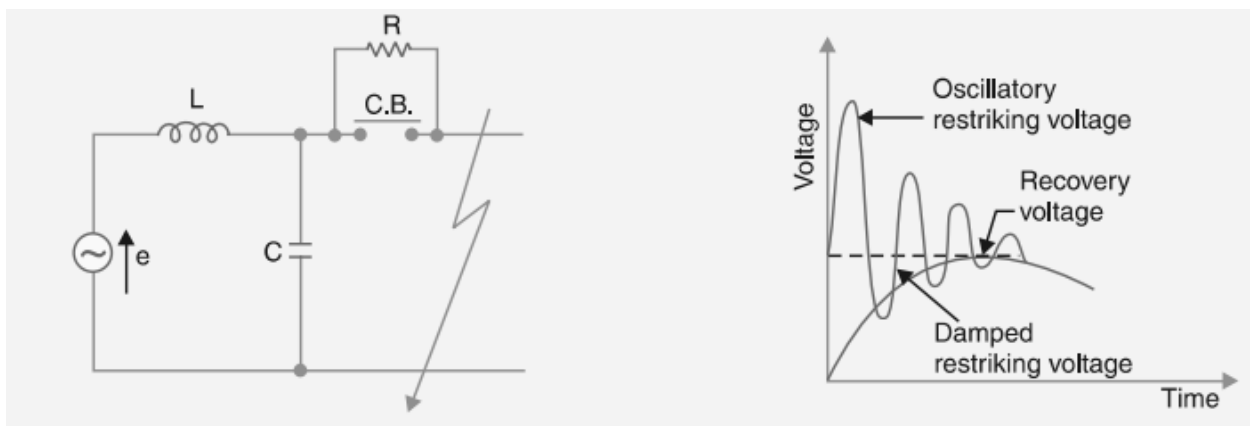
- (ii) There are no fire hazards.
- (iii) There is no generation of gas during and after operation.

Switchgear Components

- (i) Bushings.
- (ii) Circuit breaker contacts.
- (iii) Instrument transformers.
- (iv) Bus-bars and conductors.

Resistance Switching

- The excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R connected across the circuit breaker contacts. This is known as resistance switching.



- when a fault occurs, the contacts of the circuit breaker are opened and an arc is struck between the contacts.
- The contacts are shunted by resistance R, a part of arc current flows through this resistance. This results in the decrease of arc current and an increase in the rate of de-ionisation of the arc path. Consequently, the arc resistance is increased and the arc is extinguished and circuit current is interrupted.
- The shunt resistor also helps in limiting the oscillatory growth of re-striking voltage. It can be proved mathematically that natural frequency of oscillations of the circuit

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

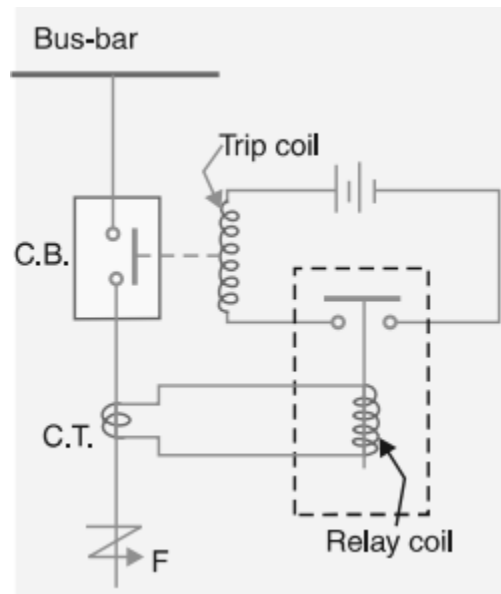
- The resistors across breaker contacts may be used to perform the following functions
 - (i) To reduce the rate of rise of re-striking voltage and the peak value of re-striking voltage.
 - (ii) To reduce the voltage surges due to current chopping and capacitive current breaking

CHAPTER -5

PROTECTIVE RELAY

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 relays detect the abnormal conditions in the electrical circuits by constantly measuring the electrical quantities which are different under normal and fault conditions.



The relay circuit connections can be divided into three parts

- (i) First part is the primary winding of a current transformer (C.T.) which is connected in series with the line to be protected.
- (ii) Second part consists of secondary winding of C.T. and the relay operating coil.
- (iii) 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 Requirement Of Protective Relay

- (i) selectivity
- (ii) speed

- (iii) sensitivity
- (iv) reliability
- (v) simplicity
- (vi) economy

Basic Relay

Relay work on the following two main operating principles

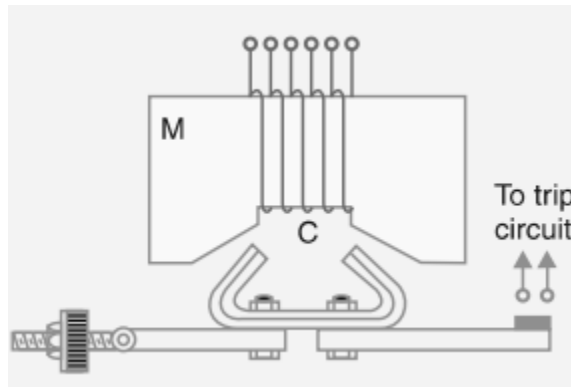
- (i) Electromagnetic attraction
- (ii) Electromagnetic induction

(i) Electromagnetic attraction

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

(i) Attracted armature type relay

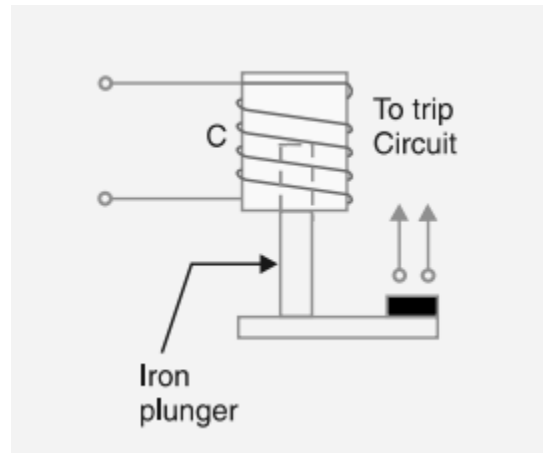
- It consists of a laminated electromagnet M carrying a coil C and a pivoted laminated armature.
- The armature is balanced by a counterweight and carries a pair of spring contact fingers at its free end.
- Under normal operating conditions, the current through the relay coil C is such that counterweight holds the armature in the normal position.



- when a short-circuit occurs, the current through the relay coil increases sufficiently and the relay armature is attracted upwards.
- The contacts on the relay armature bridge a pair of stationary contacts attached to the relay frame. This completes the trip circuit which results in the opening of the circuit breaker and the disconnection of the faulty circuit.

(ii) Solenoid type relay

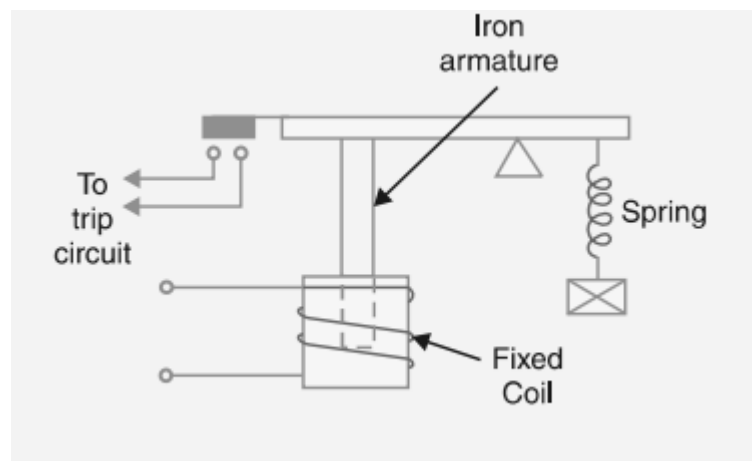
- It consists of a solenoid and movable iron plunger arrangement.
- Under normal operating conditions, the current through the relay coil C is such that it holds the plunger by gravity or spring in the normal position.



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

(iii) Balanced beam type relay

- It consists of an iron armature fastened to a balance beam.
- Under normal operating conditions the current through the relay coil is such that the beam is held in the horizontal position by the spring.
- when a fault occurs the current through the relay coil becomes greater than the pickup value and the beam is attracted to close the trip circuit. This causes the opening of the circuit breaker to isolate the faulty circuit.



Induction Relays

- Electromagnetic induction relays operate on the principle of induction motor and are widely used for protective relaying purposes involving a.c. quantities.
- An induction relay essentially consists of a pivoted aluminium disc placed in two alternating magnetic fields of the same frequency but displaced in time and space.
- The torque is produced in the disc by the interaction of one of the magnetic fields with the currents induced in the disc by the other.

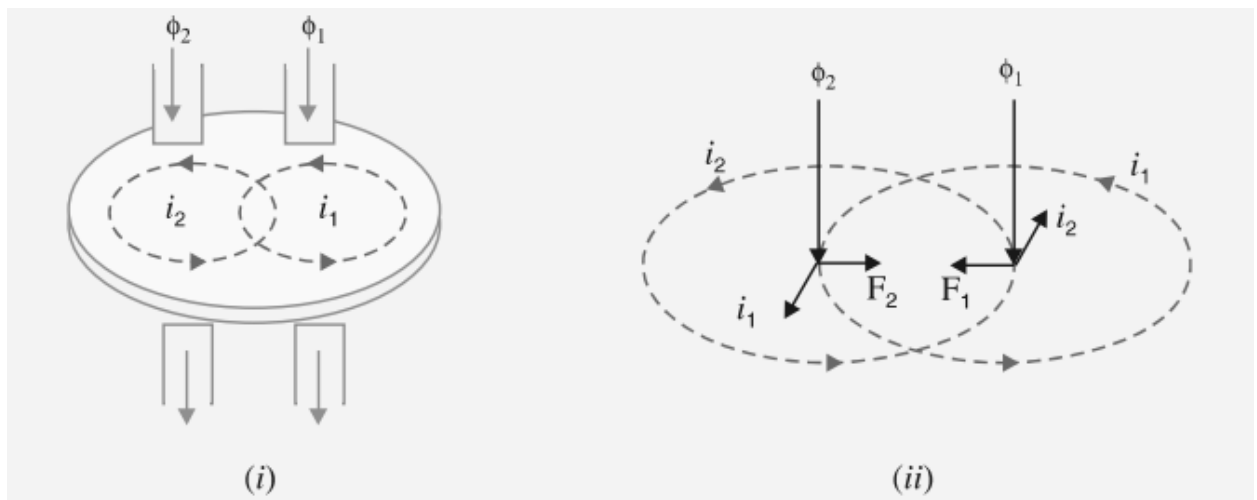
- The production of torque in an induction relay shown in figure (i). The two a.c. fluxes ϕ_2 and ϕ_1 differing in phase by an angle induce e.m.f.s' in the disc and cause the circulation of eddy currents i_2 and i_1 respectively.
- These currents lag behind their respective fluxes by 90°. shown in figure (ii).
- let

$$\phi_1 = \phi_{1max} \sin \omega t$$

$$\phi_2 = \phi_{2max} \sin (\omega t + \alpha)$$

- where ϕ_1 and ϕ_2 are the instantaneous values of fluxes and ϕ_2 leads ϕ_1 by an angle α . Assuming that the paths in which the rotor currents flow have negligible self-inductance, the rotor currents will be in phase with their voltages.

$$i_1 \propto \frac{d\phi_1}{dt} \propto \frac{d}{dt} (\phi_{1max} \sin \omega t)$$



$$\propto \phi_{1max} \cos \omega t$$

and

$$i_2 \propto \frac{d\phi_2}{dt} \propto \phi_{2max} \cos (\omega t + \alpha)$$

Now,

$$F_1 \propto \phi_1 i_2 \quad \text{and} \quad F_2 \propto \phi_2 i_1$$

The two forces are in opposition are shown in figure (ii).

Net force F at the instant considered is

$$\begin{aligned} |F| &\propto F_2 - F_1 \\ &\propto \phi_2 i_1 - \phi_1 i_2 \\ &\propto \phi_{2max} \sin (\omega t + \alpha) \phi_{1max} \cos \omega t - \phi_{1max} \sin \omega t \phi_{2max} \cos (\omega t + \alpha) \\ &\propto \phi_{1max} \phi_{2max} [\sin (\omega t + \alpha) \cos \omega t - \sin \omega t \cos (\omega t + \alpha)] \\ &\propto \phi_{1max} \phi_{2max} \sin \alpha \\ &\propto \phi_1 \phi_2 \sin \alpha \quad \dots(i) \end{aligned}$$

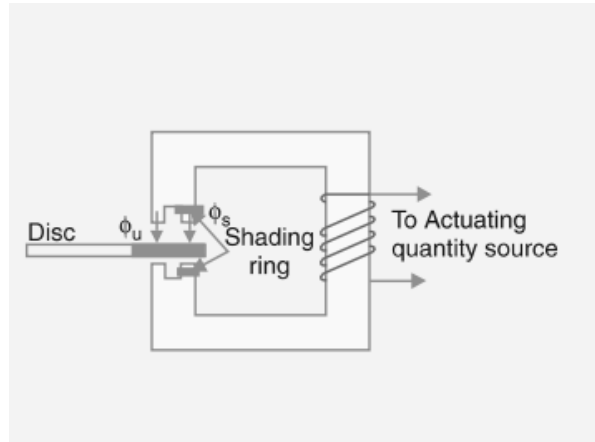
where ϕ_1 and ϕ_2 are the r.m.s. values of the fluxes.

The following three types of structures are commonly used for obtaining the phase difference in the fluxes and hence the operating torque in induction relays :

- (i) shaded-pole structure
- (ii) watt-hour-meter or double winding structure
- (iii) induction cup structure

(i) Shaded-pole structure

- It consists of a pivoted aluminium disc free to rotate in the air-gap of an electromagnet. One half of each pole of the magnet is surrounded by a copper band known as shading ring.

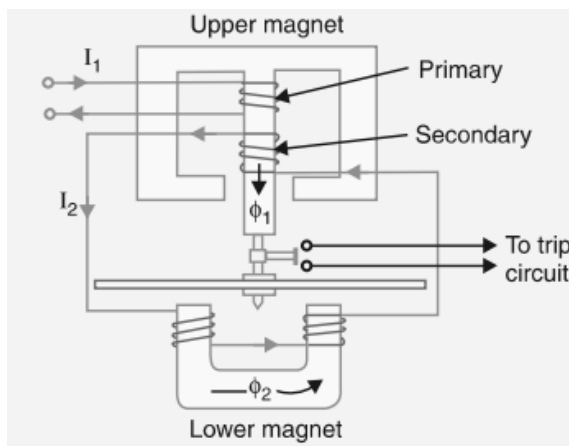


- The alternating flux ϕ_s in the shaded portion of the poles will, owing to the reaction of the current induced in the ring, lag behind the flux ϕ_u in the unshaded portion by an angle α .
- These two a.c. fluxes differing in phase will produce the necessary torque to rotate the disc.
- The driving torque $T \propto \phi_s \phi_u \sin \alpha$
- Assuming the fluxes ϕ_s and ϕ_u to be proportional to the current I in the relay coil,

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

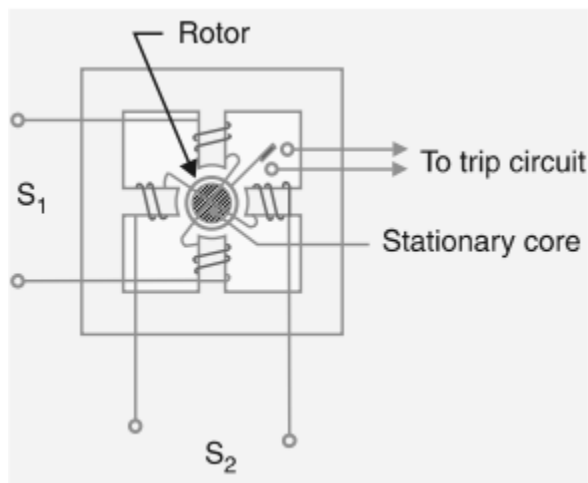
(ii) Watthour-meter structure

- It consists of a pivoted aluminium disc arranged to rotate freely between the poles of two electromagnets.
- The upper electromagnet carries two windings that is the primary and the secondary winding.
- The primary winding carries the relay current I_1 while the secondary winding is connected to the winding of the lower magnet.
- The primary current induces e.m.f. in the secondary and so circulates a current I_2 in it.
- The flux ϕ_2 induced in the lower magnet by the current in the secondary winding of the upper magnet will lag behind ϕ_1 by an angle α .
- The two fluxes ϕ_1 and ϕ_2 differing in phase by will produce a driving torque on the disc proportional to $\phi_1 \phi_2 \sin \alpha$.



(iii) Induction cup structure

- It is like an induction motor except that the rotor iron is stationary, only the rotor conductor portion being free to rotate.
- The moving element is a hollow cylindrical rotor which turns on its axis. The rotating field is produced by two pairs of coils wound on four poles as shown.
- The rotating field induces currents in the cup to provide the necessary driving torque. If ϕ_1 and ϕ_2 represent the fluxes produced by the respective pairs of poles, then torque produced is proportional to $\phi_1\phi_2 \sin \alpha$ where α is the phase difference between the two fluxes.



- A control spring and the back stop for closing of the contacts carried on an arm are attached to the spindle of the cup to prevent the continuous rotation.
- Induction cup structures are more efficient torque producers than either the shaded-pole or the watt-hour meter structures.

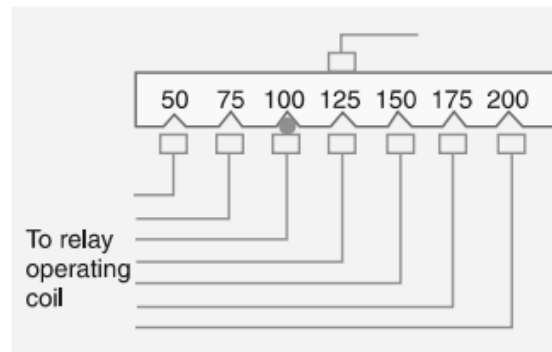
Important Terms

(i) Pick-up current

- It is the minimum current in the relay coil at which the relay starts to operate. So long as the current in the relay is less than the pick-up value, the relay does not operate.

(ii) Current setting

- To adjust the pick-up current to any required value. The current setting is required
- **Pick-up current = Rated secondary current of C.T. Current setting**

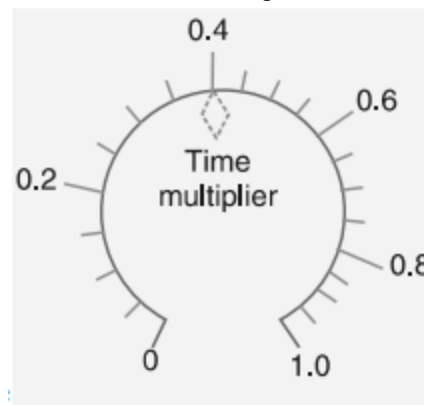


(iii) Plug-setting multiplier (P.S.M.)

- It is the ratio of fault current in relay coil to the pick-up current.

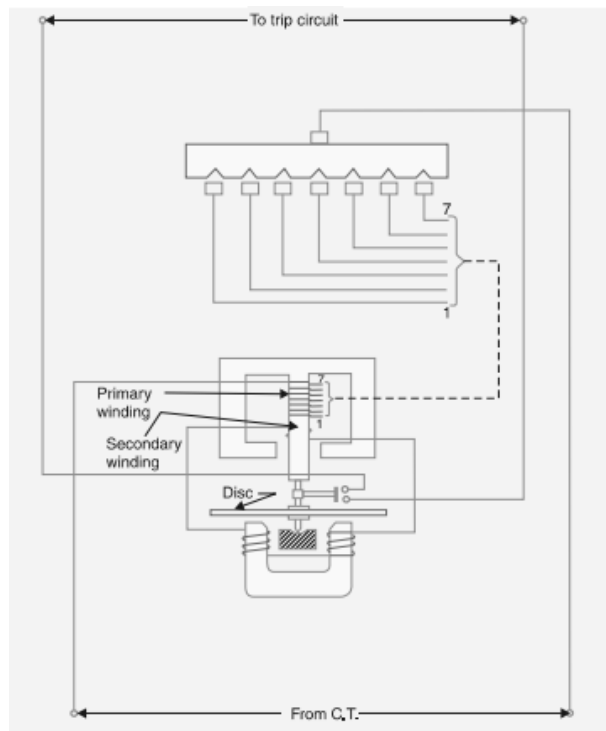
(iv) Time-setting multiplier

A relay is generally provided with control to adjust the time of operation. This adjustment is known as time-setting multiplier. The time-setting dial is calibrated from 0 to 1 in steps of 0.05 sec.



Induction Type Overcurrent Relay (Non-directional)

- These relays are used on a.c. circuits only and can operate for fault current flow in either direction.
- 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 and giving the desired current setting.
- The secondary winding is energised by induction from primary and is connected in series with the winding on the lower magnet. The controlling torque is provided by a spiral spring. The spindle of the disc carries a moving contact which bridges two fixed contacts (connected to trip circuit) when the disc rotates through a pre-set angle.
- This angle can be adjusted to any value between 0° and 360°. By adjusting this angle, the travel of the moving contact can be adjusted and hence the relay can be given any desired time setting..



Operation

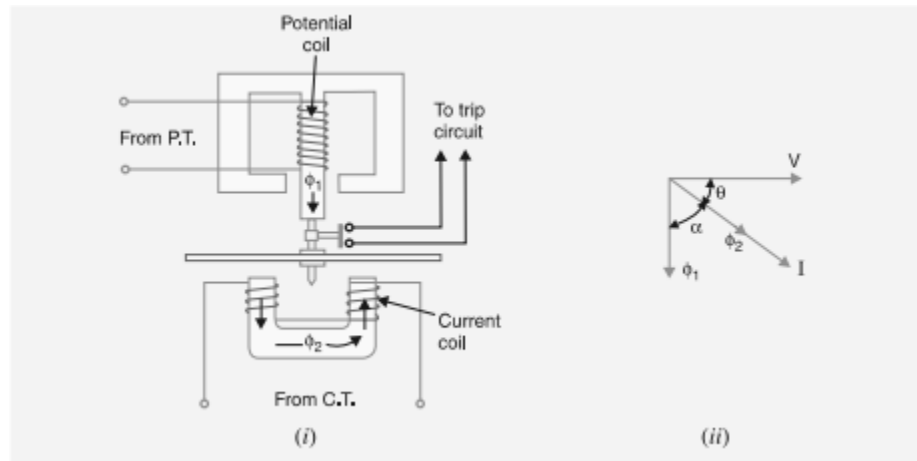
- The driving torque on the aluminum disc is set up due to the induction principle. This torque is opposed by the restraining torque provided by the spring.
- Under normal operating conditions, restraining torque is greater than the driving torque produced by the relay coil current. Therefore, the aluminum disc remains stationary.
- Under fault operating conditions, the current exceeds the pre-set value, the driving torque becomes greater than the restraining torque. then 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 isolates the faulty section.

Induction Type Directional Power Relay

- This type of relay operates when power in the circuit flows in a specific direction.
- 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 tapings connected to the plugsetting bridge (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.

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 .



The interaction of fluxes ϕ_1 and ϕ_2 with the eddy currents induced in the disc produces a driving torque given by :

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

$$\phi_1 \propto V$$

$$\phi_2 \propto I$$

$$\alpha = (90 - \theta)$$

$$T \propto VI \sin(90 - \theta)$$

$$T \propto VI \cos(\theta)$$

Induction Type Directional Overcurrent Relay

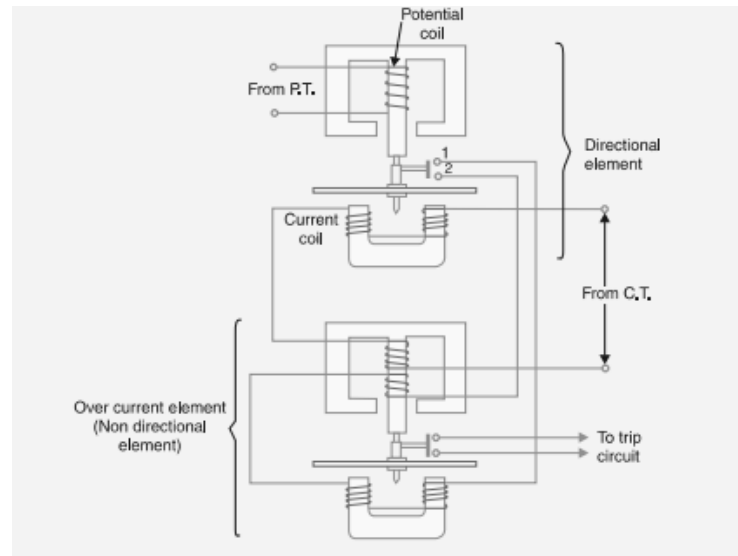
It consists of two relay elements. That is directional element and non-directional element.

(i) Directional element.

- A directional power relay 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.
- It cannot start to operate until its secondary circuit is completed. In other words the directional element must operate first (i.e. contacts 1 and 2 should close) in order to operate the overcurrent element.

(ii) Non-directional element.

- It is an overcurrent element similar in all respects to a non-directional overcurrent relay.
- 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.
- The plug-setting bridge is also provided in the relay for current setting. The tappings are provided on the upper magnet of overcurrent element and are connected to the bridge.



Operation.

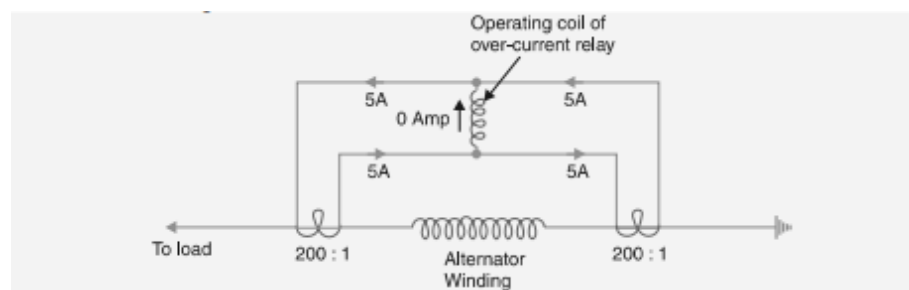
- Under normal operating conditions, power flows in the normal direction in the circuit protected by the relay. So directional power relay (upper element) does not operate by keeping the overcurrent element (lower element) unenergised.
- Under fault operating conditions, there is a tendency for the current or power to flow in the reverse direction. Then 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.

Differential Relay

- A **differential relay** is one that operates when the phasor difference of two or more similar electrical quantities exceeds a pre-determined value.
- Under normal operating conditions, the two currents are equal but as soon as a fault occurs. The difference between the incoming and outgoing currents is arranged to flow through the operating coil of the relay. If this differential current is equal to or greater than the pickup value, the relay will operate and open the circuit breaker to isolate the faulty section.

(i) Current balance protection

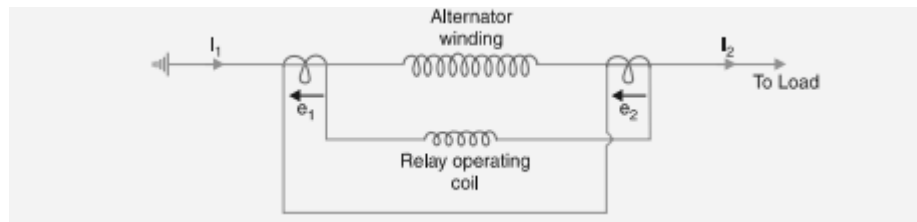
- It consist of a pair of identical current transformers are fitted on either end of the section to be protected.
- The secondaries of CT's are connected in series in such a way that they carry the induced currents in the same direction.
- The operating coil of the overcurrent relay is connected across the CT secondary circuit. This differential relay compares the current at the two ends of the alternator winding.



- Under normal operating conditions, then the currents in the two secondaries of CT's are equal . These currents will circulate between the two CT's and no current will flow through the differential relay.
- If a ground fault occurs on the alternator winding in the below figure (i) then the two secondary currents will not be equal and the current flows through the operating coil of the relay, causing the relay to operate.
- The amount of current flow through the relay will depend upon the fault.

(ii) Voltage balance protection

- In this protection the two similar current transformers are connected at either end of the element to be protected by means of pilot wires.
- The secondaries of current transformers are connected in series with a relay in such a way that under normal conditions, their induced e.m.f.s' are in opposition.



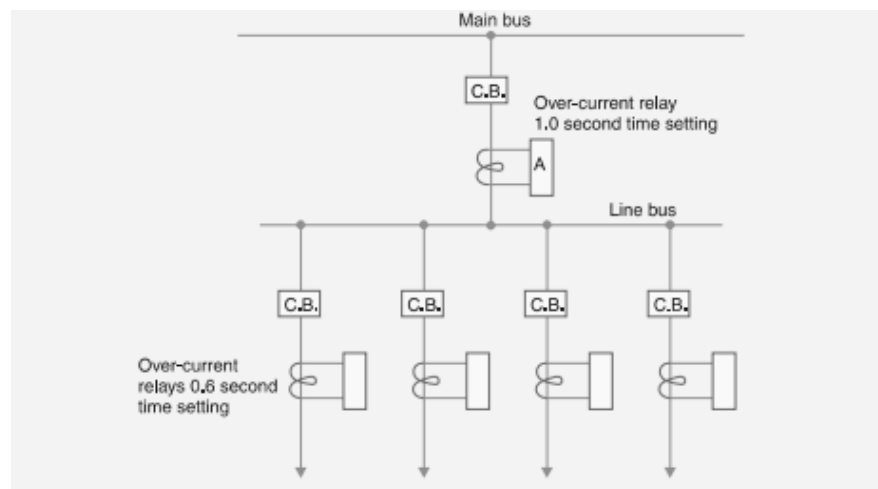
- Under healthy conditions, equal currents ($I_1 = I_2$) flow in both primary windings. So the secondary voltages of the two transformers are balanced against each other and no current will flow through the relay operating coil.
- When a fault occurs in the protected zone, the currents in the two primaries will differ from one another (i.e. $I_1 \neq I_2$) and their secondary voltages will no longer be in balance. This voltage difference will cause a current to flow through the operating coil of the relay which closes the trip circuit.

Types Of Protection

- When a fault occurs on any part of electric power system it must be cleared quickly in order to avoid damage with the rest of the system.
- The protection scheme classified into two types (primary protection and back-up protection).

(i) Primary Protection.

- In each line is an overcurrent relay is connected to protects the line.
- If a fault occurs on any line, it will be cleared by its relay and circuit breaker. This forms the primary or main protection and serves as the first line of defence.



- If the faults are not cleared by primary relay system because of trouble within the relay, wiring system or breaker. Under such conditions, back-up protection does the required job.

(ii) Back-up protection.

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