SGP

Circuit Breakers

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Introduction

During the operation of power system, it is often desirable and necessary to switch on or off the various circuits (*e.g.*, trans- mission lines, distributors, generating plants etc.) under both normal and abnormal conditions. In earlier days, this function used to be performed by a switch and a fuse placed in series with the circuit. However, such a means of control pre- sents two disadvantages. Firstly, when a fuse blows out, it takes quite sometime to replace it and restore supply to the customers. Secondly, a fuse cannot successfully interrupt heavy fault cur- rents that result from faults on modern high-volt- age and large capacity circuits. Due to these dis- advantages, the use of switches and fuses is lim- ited to low-voltage and small capacity circuits where frequent operations are not expected *e.g.,* for switching and protection of distribution trans- formers, lighting circuits, branch circuits of dis- tribution lines etc.

With the advancement of power system, the lines and other equipment operate at very high voltages and carry large currents. The arrange- ment of switches along with fuses cannot serve the desired function of swithgear in such high capacity circuits. This necessitates to employ a more dependable means of control such as is obtained by the use of *circuit breakers.* A circuit breaker can make or break a circuit either manually or automatically under all conditions *viz.*, no-load, full-load and short-circuit conditions. This characteristic of the circuit breaker has made it a very useful equipment for switching and protection of various parts of the power system. In this chapter, we shall deal with the various types of circuit breakers and their increasing applications as control devices.

19.1 Circ uit Bre akers

A circuit breaker is a piece of equipment which can

(i) make or break a circuit either manually or by remote control under normal conditions
(ii) break a circuit *automatically* under fault conditions
(iii) make a circuit either manually or by remote control under fault conditions

Thus a circuit breaker incorporates manual (or remote control) as well as automatic control for switching functions. The latter control employs relays and operates only under fault conditions. The mechanism of opening of the circuit breaker under fault conditions has already been briefed in chap- ter 16.

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

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

192 Arc Phenomenon

When a short-circuit occurs, a heavy current flows through the contacts of the *circuit breaker before they are opened by the protective system. At the instant when the contacts begin to separate, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature. The heat produced in the medium between contacts (usually the medium is oil or air) is sufficient to ionise the air or vapourise and ionise the oil. The ionised air or vapour acts as conduc- tor and an arc is struck between the contacts. The p.d. 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 resis- tance. 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.

* Important note. In single phase circuits (*e.g.*, lighting circuits etc.), a switch is located in only one of the two conductors to lamps. However, in power circuits, a circuit interrupting device (*e.g.*, a circuit breaker) is put in each *phase* or conductor. These are sometimes called three-pole circuit breakers. In the discussion that follows, we shall confine ourselves to a single-pole device, it is being understood that three such units will be provided in three-phase installation.

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

193 Prin ciples of Arc Extinction

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

(i) p.d. between the contacts

(ii) ionised particles between contacts Taking these in turn,

(i) When the contacts have a small separation, the p.d. between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that p.d. becomes inadequate to maintain the arc. However, this method is impracticable in high voltage system where a separation of many metres may be required.

(ii) The ionised particles between the contacts tend to maintain the arc. If the arc path is deionised, the arc extinction will be facilitated. This may be achieved by cooling the arc or by bodily removing the ionised particles from the space between the contacts.

194 Metho ds of Ar c Extinc tion

to cause something to stop burning

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

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

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. Consequently, the current is inter- rupted or the arc is extinguished. The principal disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in d.c. circuit breakers and low-capacity a.c. circuit breakers.

The resistance of the arc may be increased by :

(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. This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

(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. The cross-section of the arc can be reduced by letting the arc pass through a narrow opening or by having smaller area of contacts.

(iv) *Splitting the arc.* The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthen- ing and cooling. The arc may be split by introducing some conducting plates between the contacts.

2. Low resistance or Current zero 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 extin- guishes naturally and is prevented from restriking inspite of the rising voltage across the contacts. All modern high power a.c. circuit breakers employ this method for arc extinction.

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

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

(a) causing the ionised particles in the space between contacts to recombine into neutral molecules.

(b) sweeping the ionised particles away and replacing them by un-ionised particles

Therefore, the real problem in a.c. arc interruption is to rapidly deionise the medium between contacts as soon as the current becomes zero so that the rising contact voltage or restriking voltage cannot breakdown the space between contacts. The de-ionisation of the medium 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) *high pressure.* If the pressure in the vicinity of the arc is increased, the density of the particles constituting the discharge also increases. The increased density of particles causes higher rate of de-ionisation and consequently the dielectric strength of the medium between contacts is increased.

(iii) *cooling.* Natural combination of ionised particles takes place more rapidly if they are al- lowed to cool. Therefore, dielectric strength of the medium between the contacts can be increased by cooling the arc.

(iv) *blast effect.* If the ionised particles between the contacts are swept away and replaced by un- ionised 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.

19.5 Im p ortant Terms

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

(i) Arc Voltage. *It is the voltage that appears across the contacts of the circuit breaker during the arcing period.*

As soon as the contacts of the circuit breaker separate, an arc is formed. The voltage that appears across the contacts during arcing period is called the arc voltage. Its value is low except for the
*period the fault current is at or near zero current point. At current zero, the arc voltage rises rapidly to peak value and this peak voltage tends to maintain the current flow in the form of arc.

(ii) Restriking voltage. *It is the transient voltage that appears across the contacts at or near current zero during arcing period.*

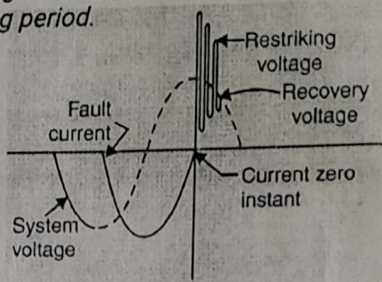


Fig. 19.1

At current zero, a high-frequency transient voltage ap- pears across the contacts and is caused by the rapid distribu- tion of energy between the magnetic and electric fields associ- ated with the plant and transmission lines of the system. This transient voltage is known as restriking voltage (Fig. 19.1). The current interruption in the circuit depends upon this volt- age. If the restriking voltage rises more rapidly than the di- electric strength of the medium between the contacts, the arc will persist for another half-cycle. On the other hand, if the dielectric strength of the medium builds up more rapidly than
the restriking voltage, the arc fails to restrike and the current will be interrupted.

(iii) Recovery voltage. *It is the normal frequency (50 Hz) r.m.s. voltage that appears across the contacts of the circuit breaker after final arc extinction. It is approximately equal to the system voltage.*

* The power system contains an appreciable amount of inductance. At the instant of current zero point, the fault currrent lags behind the arc voltage by 90°. Obviously, the arc voltge must have a peak value at this instant.

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

19.6 Classific ation of Circ uit Bre akers

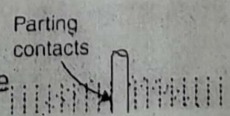
There are several ways of classifying the circuit breakers. However, the most general way of classi- fication is on the basis of medium used for arc extinction. The medium used for arc extinction is usually oil, air, sulphur hexafluoride (SF_6) or vacuum. Accordingly, circuit breakers may be classi- fied into :

(i) *Oil circuit breakers* which employ some insulating oil (*e.g.*, transformer oil) for arc extinction.
(ii) *Air-blast circuit breakers* in which high pressure air-blast is used for extinguishing the arc.
(iii) *Sulphur hexafluroide circuit breakers* in which sulphur hexafluoride (SF_6) gas is used for arc extinction.
(iv) *Vacuum circuit breakers* in which vacuum is used for arc extinction.

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

19.7 Oil Circ uit Bre akers

In such circuit breakers, some insulating oil



(*e.g.*, trans- former oil) is used as an arc quenching medium. The con- tacts 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 *hy- drogen at high pressure. The hydrogen gas occupies a volume about one thousand times that of the oil decom- posed. The oil is, therefore, pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc re- gion and adjacent portions of the contacts (See Fig. 19.2). The arc extinction is facilitated mainly by two processes.

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

Advantages. The advantages of oil as an arc quenching medium are :

(i) It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.

* Mainly hydrogen gas is produced as a result of oil decomposition. However, a small percentage of meth- ane, ethylene and acetylene is also generated.

† Important. The reader may note that arc itself is employed for its extinction. Therefore, it should not be regarded as an unfortunate manifestation. It must also be realised that in the absence of the arc, the current flowing in the circuit would be interrupted instantaneously, and due to the rapid collapse of associated magnetic field, very high voltages would be induced which would severely stress the insulation on the system. On the other hand, the arc permits the circuit interruption to take place at some current zero and thus without inducing potentials of dangerous values.

(ii) It acts as an insulator and permits smaller clearance between live conductors and earthed components.

(iii) The surrounding oil presents cooling surface in close proximity to the arc.

Disadvantages. The disadvantages of oil as an arc quenching medium are :

(i) It is inflammable and there is a risk of a fire.

(ii) It may form an explosive mixture with air

(iii) The arcing products (*e.g.*, carbon) remain in the oil and its quality deteriorates with succes- sive operations. This necessitates periodic checking and replacement of oil.

19.8 Typ es of Oil Circ uit Bre akers

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

(i) *Bulk oil circuit breakers* which use a large quantity of oil. The oil has to serve two purposes. Firstly, it extinguishes the arc during opening of contacts and secondly, it insulates the cur- rent conducting parts from one another and from the earthed tank. Such circuit breakers may be classified into :

(*a*) Plain break oil circuit breakers (*b*) Arc control oil circuit breakers.

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

(ii) *Low oil circuit breakers* which use minimum amount of oil. In such circuit breakers, oil is used *only* for arc extinction; the current conducting parts are insulated by air or porcelain or organic insulating material.

19.9 Plain Bre ak Oil Circ uit Bre akers

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

The plain-break oil circuit breaker is the earliest type from which all other circuit breakers have developed. It has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather-tight earthed tank containing oil upto 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. Fig. 19.3 shows a *double break plain oil circuit breaker. It is called a double break because it provides two breaks in series.

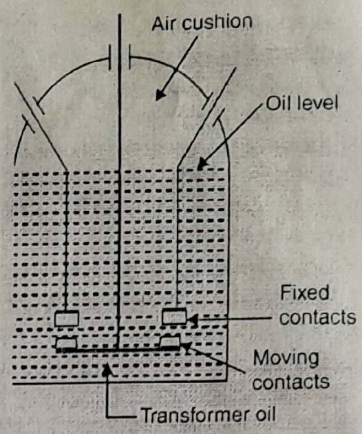


Fig. 19.3

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 :

* This type of construction increases the effective speed of arc lengthening and permits to divide the tran- sient re-striking voltage over two breaks so that only half appears across each.

(i) The hydrogen gas bubble generated around the arc cools the arc column and aids the de- ionisation 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 result of these actions is that at some critical gap length, the arc is extinguished and the circuit current is interrupted.

Disadvantages

(i) There is no special control over the arc other than the increase in length by separating the moving contacts. Therefore, for successful interruption, long arc length is necessary.

(ii) These breakers have long and inconsistent arcing times.

(iii) These breakers do not permit high speed interruption.

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

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19.10 Arc Control Oil Circ uit Bre akers

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

(i) *Self-blast oil circuit breakers*— in which arc control is provided by internal means *i.e.* the arc itself is employed for its own extinction efficiently.

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

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

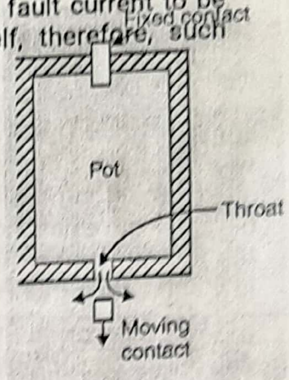


Fig. 19.4

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

(a) Plain explosion pot. It is a rigid cylinder of insulating material and encloses the fixed and moving contacts (See Fig. 19.4). The moving contact is a cylindrical rod passing through a restricted opening (called throat) at the bottom. When a fault occurs, the contacts get separated and an arc is struck between them. The heat of the arc decomposes oil into a gas at very high pressure in the pot. This high pressure forces the oil and

† At relatively high voltages, the size of such a breaker assumes unduly large proportions due to the necessity of very long gap between the contacts for successful arc extinction.

gas through and round the arc to extinguish it. If the final arc extinction does not take place while the moving contact is still within the pot, it occurs immediately after the moving contact leaves the pot. It is because emergence of the moving contact from the pot is followed by a violent rush of gas and oil through the throat producing rapid extinction.

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

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

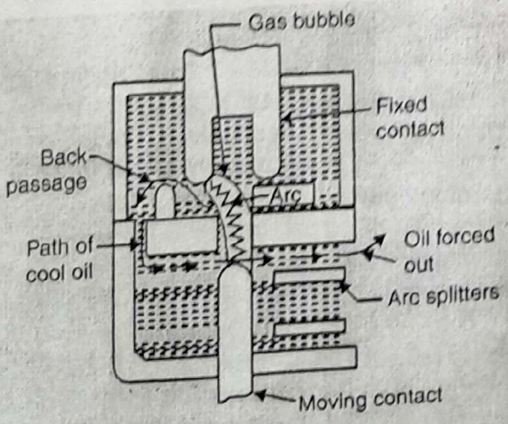


Fig. 19.5

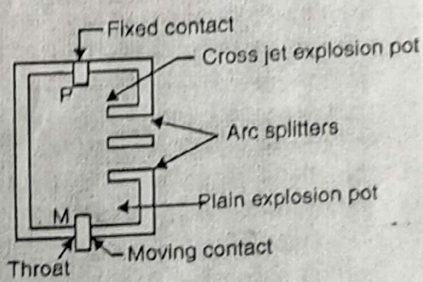


Fig. 19.6

therefore, driven sideways into the "arc splitters" which increase the arc length, causing arc extinction.

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

(c) Self-compensated explosion pot. This type of pot is essentially a combination of plain explosion pot and cross jet explosion pot. Therefore, it can interrupt low as well as heavy short circuit currents with reasonable accuracy.

Fig. 19.6 shows the schematic diagram of self-compensated explosion pot. It consists of two chambers, the upper chamber is the cross-jet explosion pot with two arc splitter ducts while the lower one is the plain explosion pot. When the short-circuit current is heavy, the rate of generation of gas is very high and the device behaves as a cross-jet explosion pot. The arc extinction takes place when the moving contact uncovers the first or second arc splitter duct. However, on low short-circuit currents, the rate of gas generation is small and the tip of the moving contact has the time to reach the lower chamber. During this time, the gas builds up sufficient pressure as there is very little leakage through

* Since the jet of oil is forced at right angles to the arc path, this type of pot is referred to as cross-jet explosion pot.

† The rate at which oil moves into the path of arc is a function of gas pressure. The gas pressure depends upon the value of fault current. Lower the fault current, lesser the gas pressure generated and vice-versa.

arc splitter ducts due to the obstruction offered by the arc path and right angle bends. When the moving contact comes out of the throat, the arc is extinguished by plain pot action.

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

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

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

Advantages

(a) Since oil pressure developed is independent of the fault current to be interrupted, the perfor- mance at low currents is more consistent than with self-blast oil circuit breakers.

(b) The quantity of oil required is reduced considerably.

19.11 Low Oil Circ uit Bre akers

In the bulk oil circuit breakers discussed so far, the oil has to perform two functions. Firstly, it acts as an arc quenching medium and secondly, it insulates the live parts from earth. It has been found that only a small percentage of oil is actually used for arc extinction while the major part is utilised for insulation purposes. For this reason, the quantity of oil in bulk oil circuit breakers reaches a very high figure as the system voltage increases. This not only increases the expenses, tank size and weight of the breaker but it also increases the fire risk and maintenance problems.

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

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

(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 insula- tion 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

Construction
operation

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

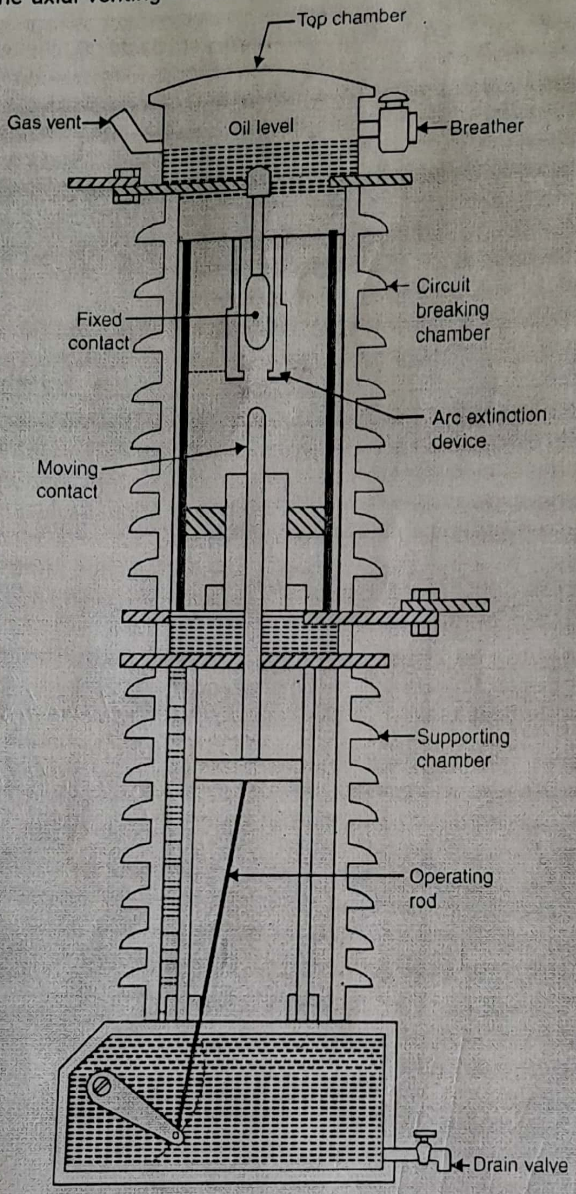


Fig. 19.7 Low-oil Circuit Breaker

radial venting helps in the interruption of heavy currents.

(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. The top chamber is also provided with a separator which prevents any loss of oil by centrifugal action caused by circuit breaker operation during fault conditions.

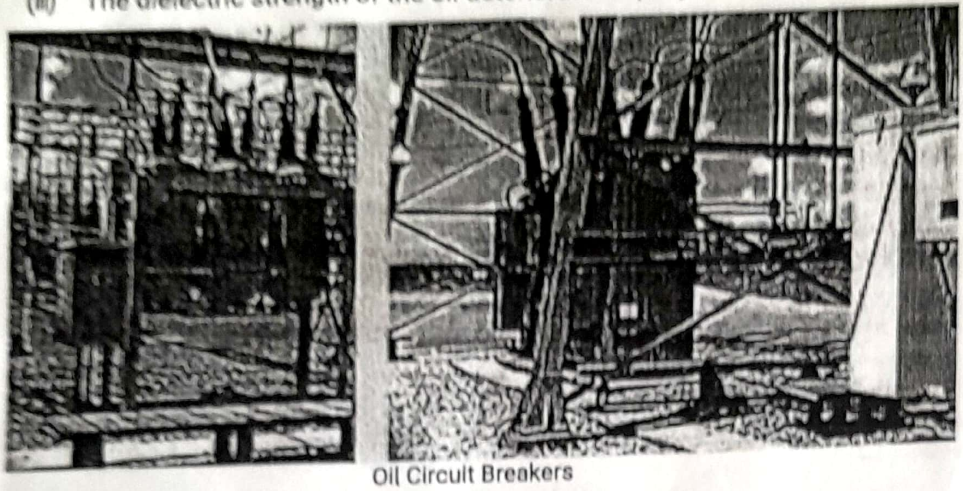
Operation. Under normal operating conditions, the moving contact remains engaged with the upper fixed contact. When a fault occurs, the moving contact is pulled down by the tripping springs and an arc is struck. The arc energy vaporises the oil and produces gases under high pressure. This action constrains 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. A low oil circuit breaker has the following advantages over a bulk oil circuit breaker:

(i) It requires lesser quantity of oil.
(ii) It requires smaller space.
(iii) There is reduced risk of fire.
(iv) Maintenance problems are reduced.

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

(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.
(iii) The dielectric strength of the oil deteriorates rapidly due to high degree of carbonisation.



Oil Circuit Breakers

19.12 Maintenance of Oil Circuit Breakers

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

(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 or reconditioned. The oil in good condition should withstand 30 kV for one minute in a standard oil testing cup with 4 mm gap between electrodes.
(iii) Check the insulation for possible damage. Clean the surface and remove carbon deposits with a strong and dry fabric.
(iv) Check the oil level.
(v) Check closing and tripping mechanism.

19.13 Air-Blast Circuit Breakers

These breakers employ a high pressure *air-blast as an arc quenching medium. The contacts are opened in a flow of air-blast established by the opening of blast valve. The air-blast cools the arc and sweeps away the arcing products to the atomsphere. This rapidly increases the dielectric strength of the medium between contacts and prevents from re-establishing the arc. Consequently, the arc is extinguished and flow of current is interrupted.

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

(i) The risk of fire is eliminated.
(ii) The arcing products are completely removed by the blast whereas the oil deteriorates with successive operations; the expense of regular oil replacement is avoided.
(iii) 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.
(iv) The arcing time is very small due to the rapid build up of dielectric strength between con- tacts. Therefore, the arc energy is only a fraction of that in oil circuit breakers, thus resulting in less burning of contacts.
(v) Due to lesser arc energy, air-blast circuit breakers are very suitable for

conditions where frequent operation is required.

(vi) The energy supplied for arc extinction is obtained from high pressure air and is independent of the current to be interrupted.

Disadvantages. The use of air as the arc quenching medium offers the following disadvantges :

(i) The air has relatively inferior arc extinguishing properties.

(ii) The air-blast circuit breakers are very sensitive to the variations in the rate of rise of restrik- ing voltage.

(iii) Considerable maintenance is required for the compressor plant which supplies the air-blast. The air blast circuit breakers are finding wide applications in high voltage installations. Major-
ity of the circuit breakers for voltages beyond 110 kV are of this type.

19.14 Typ es of Air-Blast Circ uit Bre akers

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

(i) *Axial-blast type* in which the air-blast is directed along the arc path as shown in Fig. 19.8(*i*).

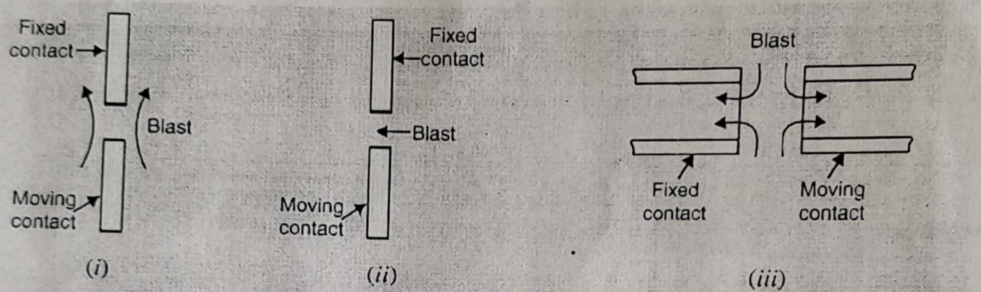


Fig. 19.8

* Other gases such as nitrogen, carbon dioxide and hyrdogen can also be used. The circuit breaking proper- ties of nitrogen are about similar to air and there is no added advantage of using it. Carbon dioxide tends to freeze and hydrogen gas is very costly. Therefore, air is used as the circuit breaking medium.

(ii) *Cross-blast type* in which the air-blast is directed at right angles to the arc path as shown in Fig. 19.8 (*ii*).

(iii) *Radial-blast type* in which the air-blast is directed radially as shown in Fig. 19.8 (*iii*).

(i) Axial-blast air circuit breaker. Fig 19.9 shows the essential components of a typical axial- blast air circuit breaker. The fixed and moving contacts are held in the closed position by spring pressure under normal conditions. The air reservoir is connected to the arcing cham- ber through an air valve. This valve remains closed under normal conditions but opens

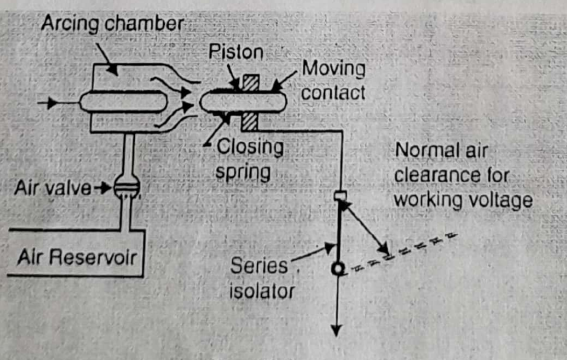


Fig. 19.9

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. At the same time, high pressure air blast flows along the arc and takes away the ionised gases along with it. Consequently, the arc is extinguished and current flow is interrupted.

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

(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. Fig. 19.10 shows the essential parts of a typical cross-blast air circuit breaker. When the moving contact is withdrawn, an arc is struck between the fixed and moving contacts. The high pressure cross-blast forces the arc into a chute con - sisting 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.

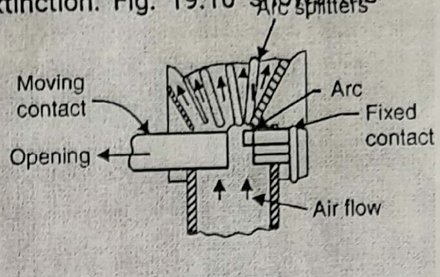


Fig. 19.10

Since blast pressure is same for all currents, the inefficiency at low currents is eliminated. The final gap for interruption is great enough to give normal insulation clearance so that a series isolating switch is not necessary.

19.15 Sulphur Hexaflourid e (SF_6) Circ uit Bre akers

In such circuit breakers, sulphur hexaflouride (SF_6) gas is used as the arc quenching medium. The SF_6 is an electro-negative gas and has a strong tendency to absorb free electrons. The contacts of the breaker are opened in a high pressure flow of SF_6 gas and an arc is struck between them. The conducting free electrons in the arc are rapidly captured by the gas to form relatively immobile negative ions. This loss of conducting electrons in the arc quickly builds up enough insulation strength

to extinguish the arc. The SF_6 circuit breakers have been found to be very effective for high power and high voltage service.

Construction. Fig. 19.11 shows the parts of a typical SF_6 circuit breaker. It consists of fixed and moving contacts enclosed in a chamber (called arc interruption chamber) containing SF_6 gas. This chamber is connected to SF_6 gas reservior. When the contacts of breaker are opened, the valve mechanism permits a high pressure SF_6 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 SF_6 gas to let out through these holes after flowing along and across the arc. The tips of fixed contact, moving contact and arcing horn are coated with copper-tungsten arc resistant material. Since SF_6 gas is costly, it is reconditioned and reclaimed by suitable auxiliary sytem after each operation of the breaker.

Working. In the closed position of the breaker, the contacts remain surrounded by SF_6 gas at a pressure of about 2·8 kg/cm^2. When the breaker operates, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronised with the opening of a valve which permits SF_6 gas at 14 kg/cm^2 pressure from the reservoir to the arc interrup- tion chamber. The high pressure flow of SF_6 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 be- tween the contacts quickly builds up high dielectric strength and causes the extinction of the arc. After the breaker operation (*i.e.*, after arc extinction), the valve is closed by the action of a set of springs.

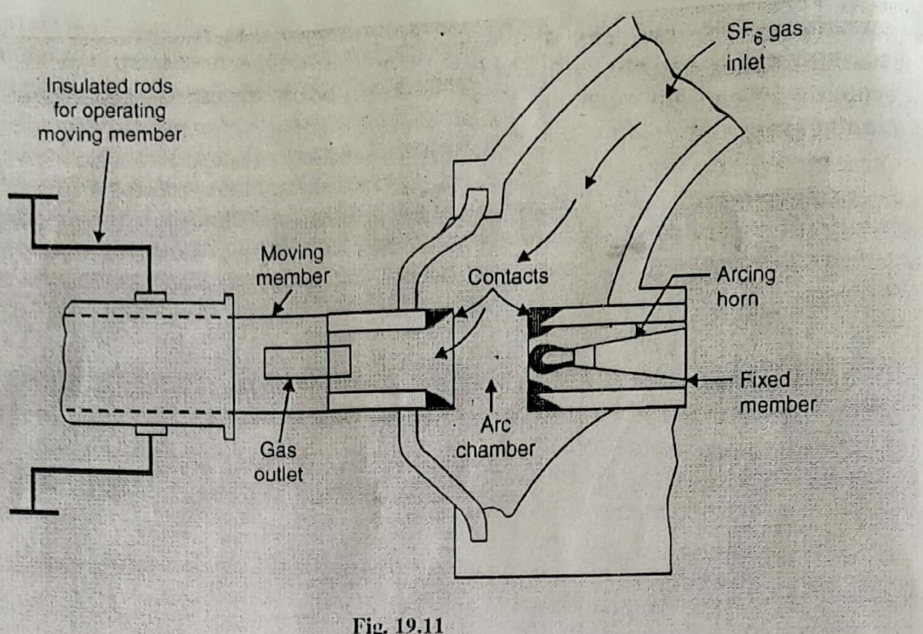


Fig. 19.11

Advantages. Due to the superior arc quenching properties of SF_6 gas, the SF_6 circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below :

(i) Due to the superior arc quenching property of SF_6, such circuit breakers have very short arcing time.

(ii) Since the dielectric strength of SF_6 gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.

(iii) The SF_6 circuit breaker gives noiselss operation due to its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker.

(iv) The closed gas enclosure keeps the interior dry so that there is no moisture problem.

(v) There is no risk of fire in such breakers because SF_6 gas is non-inflammable.

(vi) There are no carbon deposits so that tracking and insulation problems are eliminated.

(vii) The SF_6 breakers have low maintenance cost, light foundation requirements and minimum auxiliary equipment.

(viii) Since SF_6 breakers are totally enclosed and sealed from atmosphere, they are particularly suitable where explosion hazard exists *e.g.*, coal mines.

Disadvantages

(i) SF_6 breakers are costly due to the high cost of SF_6.

(ii) Since SF_6 gas has to be reconditioned after every operation of the breaker, additional equip- ment is requried for this purpose.

Applications. A typical SF_6 circuit breaker consists of interrupter units each capable of dealing with currents upto 60 kA and voltages in the range of 50—80 kV. A number of units are connected in series according to the system voltage. SF_6 circuit breakers have been developed for voltages 115 kV to 230 kV, power ratings 10 MVA to 20 MVA and interrupting time less than 3 cycles.

19.16 Va cuum Circuit Bre akers (VCB)

In such breakers, vacuum (degree of vacuum being in the range from 10^{-7} to 10^{-5} torr) is used as the arc quenching medium. Since vacuum offers the highest insulating strength, it has far superior arc quenching properties than any other medium. For example, when contacts of a breaker are opened in vacuum, the interruption occurs at first current zero with dielectric strength between the contacts building up at a rate thousands of times higher than that obtained with other circuit breakers.

Principle. The production of arc in a vacuum circuit breaker and its extinction can be explained as follows : When the contacts of the breaker are opened in vacuum (10^{-7} to 10^{-5} torr), an arc is produced between the contacts by the ionisation of metal vapours of contacts*. However, the arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc rapidly condense on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength. The reader may note the salient feature of vacuum as an arc quenching medium. As soon as the arc is produced in vacuum, it is quickly extinguished due to the fast rate of recovery of dielectric strength in vacuum.

Construction. Fig. 19.12 shows the parts of a typical vacuum circuit breaker. It

vacuum chamber. The movable member is connected to the control mechanism

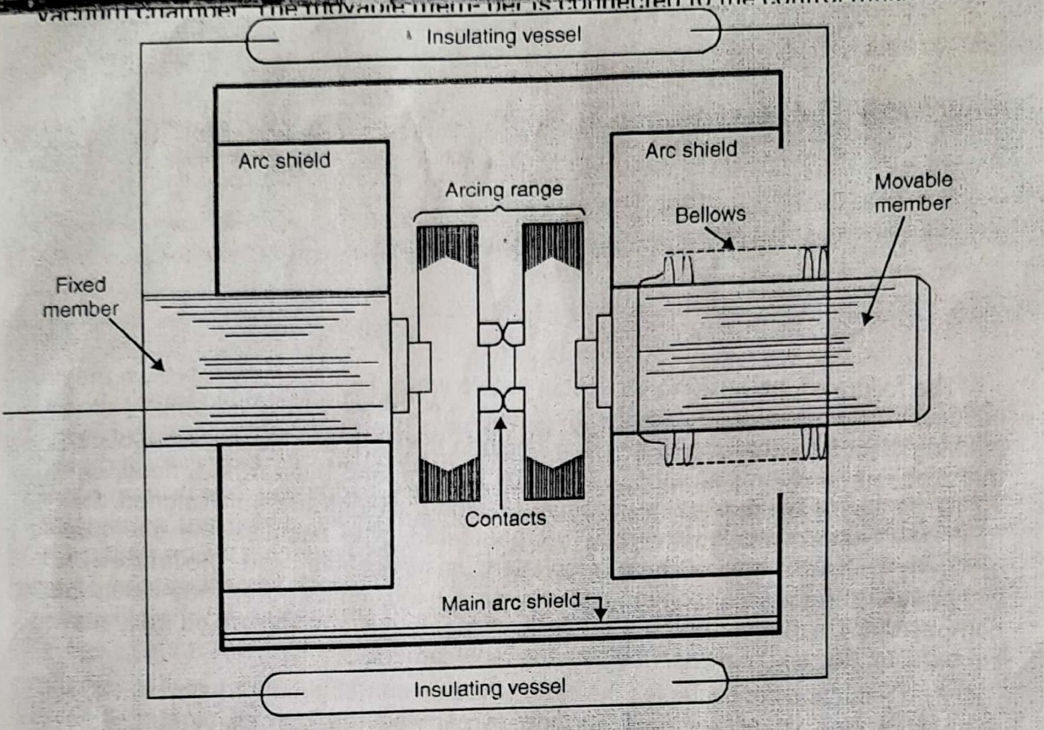


Fig. 19.12

Advantages. Vacuum circuit breakers have the following 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.

(iv) They can interrupt any fault current. The outstanding feature of a VCB is that it can break any heavy fault current perfectly just before the contacts reach the definite open position.

(v) They require little maintenance and are quiet in operation.

(vi) They can successfully withstand lightning surges.

(vii) They have low arc energy.

(viii) They have low inertia and hence require smaller power for control mechanism.

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

19.17 Switchgear Components

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

(i) Bushings (ii) Circuit breaker contacts

(iii) Instrument transformers (iv) Bus-bars and conductors

(i) Bushings. When a high voltage conductor passes through a metal sheet or frame which is at earth potential, the necessary insulation is provided in the form of bushing. The primary function of the bushing is to prevent electrical breakdown between the enclosed conductor and the surrounding earthed metal work. Fig. 19.13 (*i*) shows the use of bushing for a plain-break oil circuit breaker. The high voltage conductor passes through the bushing made of some insulating material (*e.g.*, porcelain, steatite). Although there are several types of bushing (*e.g.*, condenser type, oil filled etc.), they perfom the same function of insulating the conductor from earthed tank.

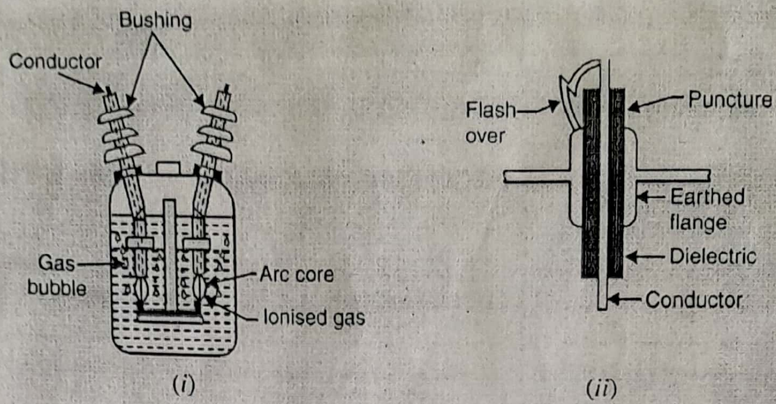


Fig. 19.13

The failure of the bushing can occur in two ways. Firstly, the breakdown may be caused by *puncture i.e.*, dielectric failure of the insulating material of the bushing. Secondly, the breakdown may occur in the form of a *flash-over* between the exposed conductor at either end of the bushing and the earthed metal. Fig. 19.13 (*ii*) illustrates these two possibilities. The bushings are so designed that flash-over takes place before they get punctured. It is because the puncture generally renders the bushing insulation unserviceable and incapable of withstanding the normal voltage. On the other hand, a flash-over may result in comparatively harmless burning of the surface of the bushing which can then continue to give adequate service pending replacement.

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

(a) *Tulip type contacts.* Fig. 19.14 (*i*) shows the Tulip type contact. It consists of moving contact which moves inside the fixed contacts. At contact separation, the arc is generally established between the tips of the fixed contacts and the tip of the moving contact as shown in Fig. 19.14 (*ii*). The advantage of this type of contact is that arcing is confined

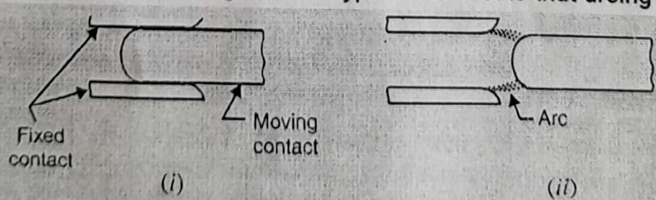


Fig. 19.14

to the regions which are not in contact in the fully engaged position.

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

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

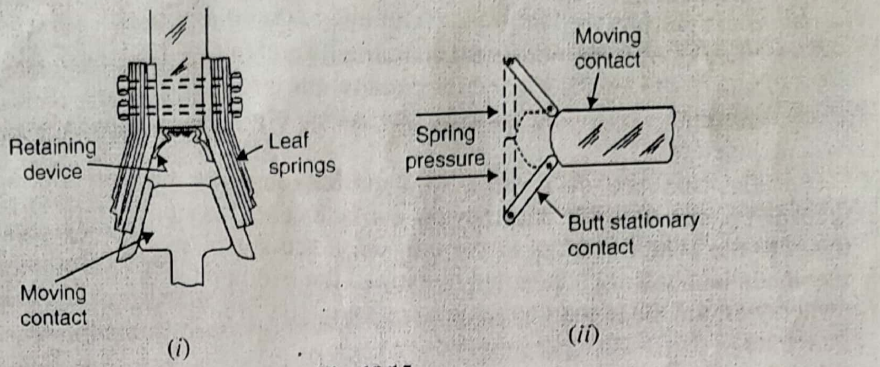


Fig. 19.15

higher short- circuit rating.

(iii) Instrument transformers. In a modern power system, the circuits operate at very high voltages and carry current of thousands of amperes. The measuring instruments and protective de- vices cannot work satisfactorily if mounted directly on the power lines. This difficulty is overcome by installing instrument transformers on the power lines. The function of these instrument transform- ers is to transform voltages or currents in the power lines to values which are convenient for the operation of measuring instruments and relays. There are two types of instrument transformers *viz.*

(a) Current transformer (C.T.)

(b) Potential transformer (P.T.)

The primary of current transformer is connected in the power line. The secondary winding provides for the instruments and relays a current which is a constant fraction of the current in the line.

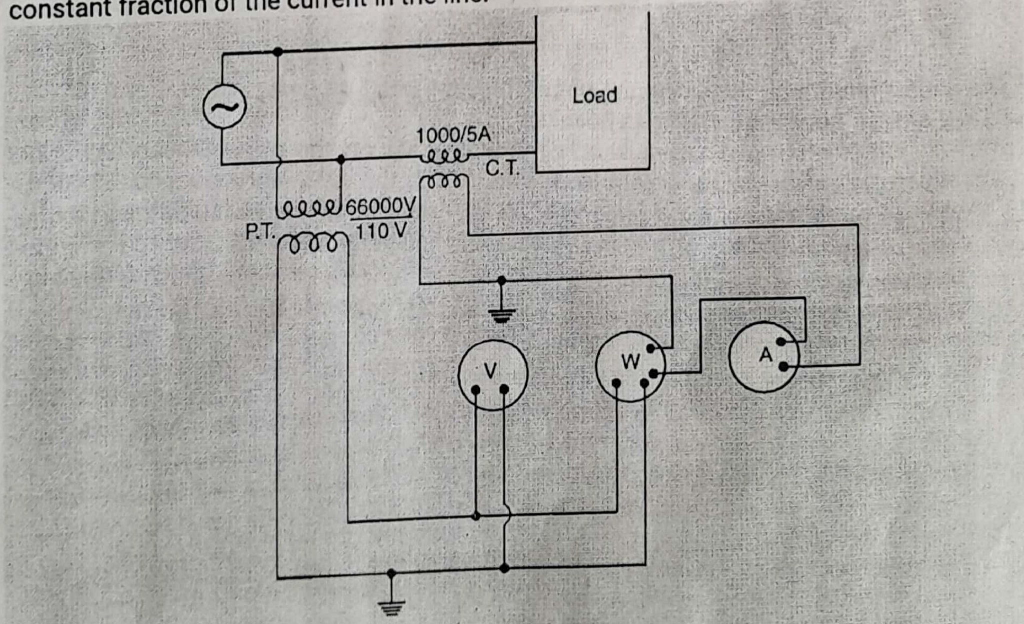


Fig. 19.16

Unit - ..   S. Sabiha   Anjana

Circuit Breakers are classified according to medium for arc extinction into :-

(1) Oil circuit breaker which uses transformer oil for arc extinction

(2) Air blast C.B which uses Pressurized air as mediam for arc extinction.

(3) SF_6 C.B; which uses SF_6 gas for arc extinction.

(4) Vacuum C.B in which Vacuum is used for arc extinction. where due to Vacuum, rate of arc extinction is high

1) Oil circuit Breaker :-

This uses oil as arc quenching medium. The contacts of the C.B are separated in the oil

There are three types of oil C.B :-

(i) C.B using large quantity of oil (or) Bulk oil C.B

(ii) C.B using minimum quantity of oil called minimum oil C.B.

(iii) Plain-break oil C.B.

(a) Plain Break oil C.B :-

It Consists of a strong metal tank earthed containing oil upto certain level and air cushion above the oil level. Both the fixed and moving contacts are immersed in oil.

When the contacts are separated, an arc is struck b/w the contacts with Production of large amount of heat. This will increase the temperature to near about 5000°k which will vapourize the oil into gases.

In this decomposition 70% Hydrogen with small percentages of i.e., 20% Acetylene, 8% Ethane and 5% methane gases are released.

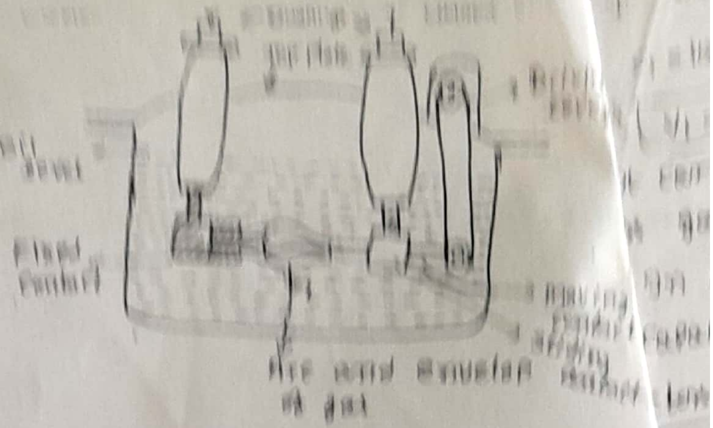
A very small amount oil decomposes in to large bubbles. These bubbles of gas which prevent restriking of the arc after the current reaches zero point of the cycle.
(or)
When distance b/w fixed contact and moving contact reaches at critical value, the arc gets extinguished at current zero.

There are two types of Plain-break oil C.B :-

(a) Single break oil C.B (b) Double break oil C.B.

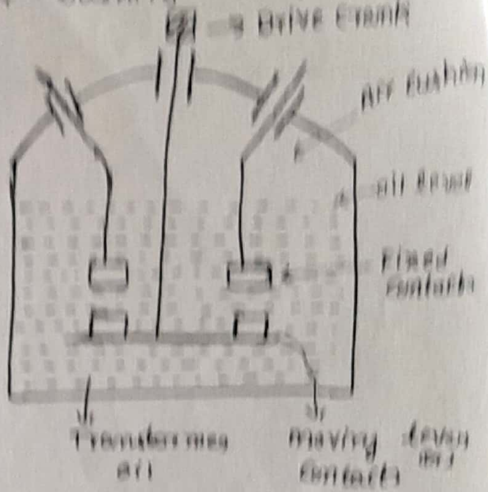
Single Break oil C.B :-

Principle is same.
The in & out of the current is through the terminal bushings.
There is only one arc which is struck b/w fixed & moving contact.
The current breaks at one bushing and the moving contact is supported by the other bushing through sliding contact.

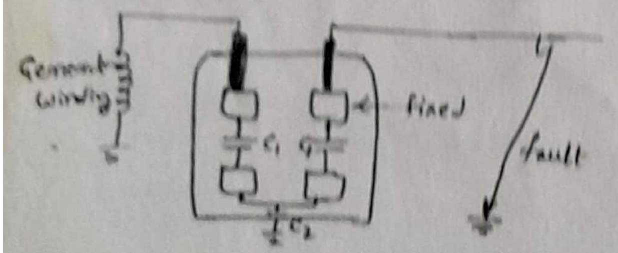


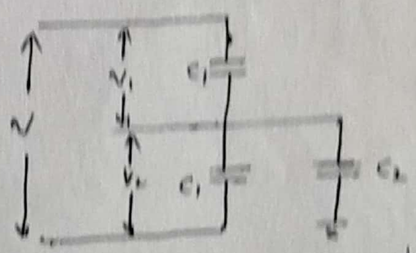
(b) Double Break oil C.B :-

The principle of this type of C.B is shown in fig.



There are two fixed contacts associated with terminal bushing which makes contact with moving contacts during normal condition.
The lever containing the moving contacts can be operated with the help of crank.
When the contacts are separated, two arcs are formed. Thus there are two breaks in series. This can achieve rapid arc lengthening which eliminates the need for a specially fast moving contact speed.
But this introduces unequal voltage distribution across the breaks with uneven sharing of total interrupting duty.
When such a breaker interrupts an earth fault, the recovery voltage is not equally divided between the two breaks.
Consider the equivalent electrical circuit





Equivalent circuit.

where
C_1 = capacitance b/w fixed & moving contacts.
C_2 = " " moving contact and earth.

I be the fault current $V_1 = \frac{I}{\omega C_1}$ Volt ; $V_2 = \frac{I}{\omega(C_1+C_2)}$

$C_1 = 10\,pF$ & $C_2 = 40\,pF$, then $\frac{V_1}{V_2} = \frac{C_1 + C_2}{C_1} = \frac{10+40}{10} = \frac{50}{10} = 5$

$V_1 = 5 V_2$

It can be seen that about 83% of the system voltage appears across gap and only 17% appears across moving contact and earth.

In order to equalize the voltage across the gaps, high resistance capacitors are connected across them.

Factors affecting Performance of Plane break oil C.B :-

i) Critical length of the break
ii) Speed of the contact movement.
iii) The head of oil above the contacts.
iv) The clearance b/w the live contacts and the earthed pressurized tank.

Advantages :-

(i) The arc energy is easily absorbed by the oil due to its decomposition.
(ii) The gases formed due to oil, has good cooling properties.
(iii) The oil used acts as a insulator.
(iv) After current zero a flow of cool oil in the contact space which is having dielectric strength.

Dis advantages :-

(i) There is no special control over the arc other than the increase in length by separating the moving contacts.
Hence large arc length is required for faithful interruption.
(ii) These breakers do not permit high speed interruption, So arcing times are long.

Applications :- These C.B are suitable upto 150 MVA, 11 kV capacity.

(B) Bulk oil C.B (or) Controlled break oil C.B :- (arc control C.B)

In this type large amount of oil is used. Oil serves the additional purposes like insulation and cooling.

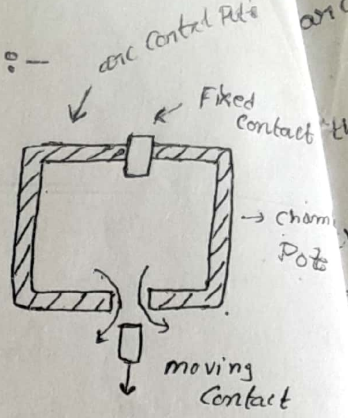
Also it is not suitable for high speed interruption i.e., they cannot be used for auto reclosing.

(i) Self generated pressure oil C.B.
(ii) Forced Blast oil C.B.

These breakers are used up to 33 kV.

Self Generated Pressure oil C.B:-

(a) ~~Plane~~ Plain Explosion Pot (or) Axial blast Pot :-



It consists of a rigid cylinder made up (or) Strong Shell of a insulating material.

The moving contact is a cylindrical rod which pass (vertically) through a small opening called throat.

Whenever fault occurs, contact will start separating, arc is formed.

Heat contained in the arc causes the decomposition of the oil into gases at very high pressure in the pot. This high pressure forces the oil and gas around the arc to extinguish it.

If final arc interruption does not take place, then the moving contact is moved away from the pot; it allows a high velocity axial blast of gas to release through the throat producing rapid arc extinction.

As the arc extinction takes place axially, it is called axial blast type C.B.

Draw back:- It cannot be used for very high (or) very low fault currents.

At low fault current, pressure developed is small thus arcing time is increased.

At high fault, high pressure developed there is possibility of bursting the explosion pot or chamber.

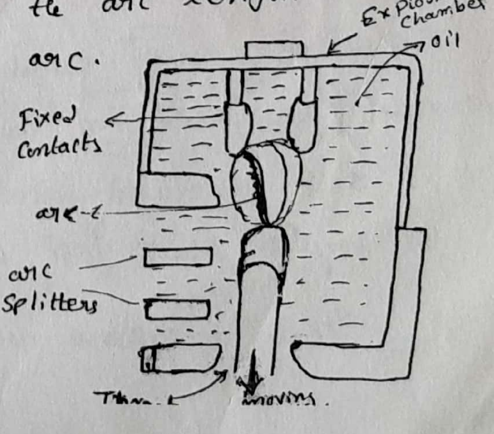
(b) Cross Jet Explosion Pot (or) Cross blast type :-

It is modification of plain explosion pot. It has 4 stages.

It consists of cylinder made up of insulating material.

There are channels on one side which act as arc splitters.

The use of arc splitters is to increase the arc length which will assist arc extinction by lengthening the arc.



In 1st stage, the moving contacts has separated, & arc is formed.

While in 4th stage final arc extinction takes place where moving contacts is out of the throat.

arc is struck initially at the top of Pot, the gas formed
pressure on the oil when the moving contacts moved away
the arc splitter ducts, fresh oil is forced across the Path of
Then the arc is passed through the arc splitters due to
ch its length increases which causes arc extinction.

Forced Blast oil C.B :- (or) Externally generated Pressure (or) Impulse type oil C.B

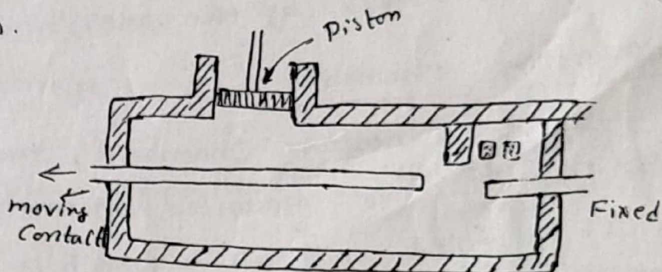
In self blast oil C.B, the Pressure was developed due to arc, to force the oil across the arc Path.

Dis adv is long arcing time.

It is over comed by force blast oil C.B, the Pressure is supplied from some external source.

This can be achieved by Piston cylinder arrangement. The movement of Piston is coupled mechanically to moving contacts. This enables high speed interruption.

When a fault occurs, contacts get separated and an arc is struck. The Piston forces a jet of oil towards the contact gap which will extinguish the arc.



Even at low fault currents, Pressure is developed which is independent of current to be interrupted.

Ⓒ **Low oil (or) minimum oil C.B :-** It is also known as the "Live-tank type oil C.B."

Dis adv in Bulk oil C.B :-

→ If system volt increases, then the quantity of oil required is also increased
→ So it gives additional cost, about 5000 litres in 220kV system
→ increases risk of fire and causes maintenance Problems.
→ Also a very small amount of oil is used for arc extinction and remaining Portion is for insulation and cooling.
→ It has a leakage Property by which appearance is not clean.

Keeping in view of the above said disadvantages minimum oil C.B is designed.

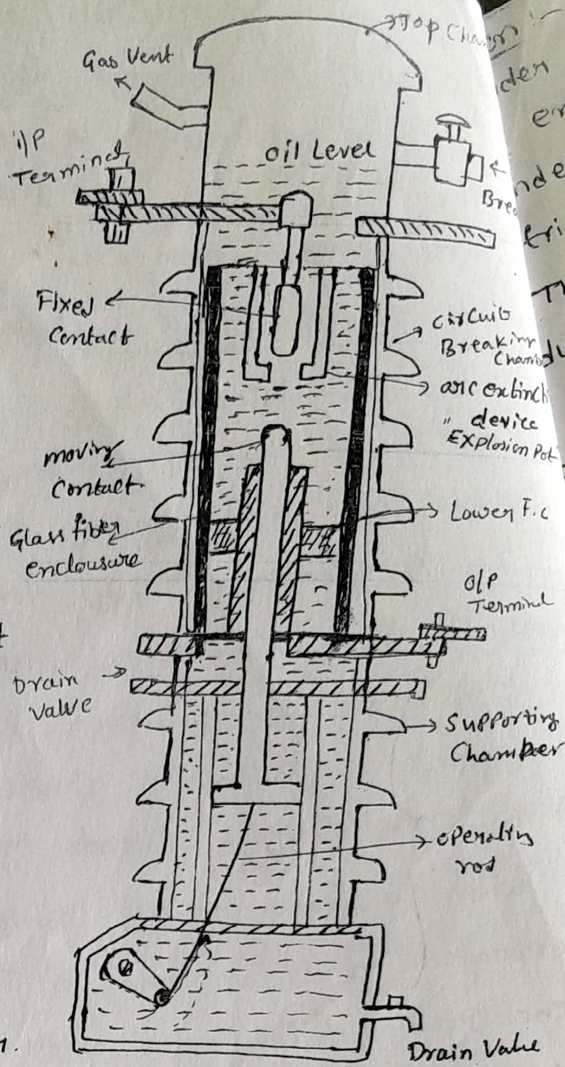
In this much amount oil should be used for arc extinction, and the remaining oil used for insulation. ~~& cooling~~

Construction:-

It consists of two separate compartments which are filled with the oil.

Upper chamber is circuit breaking chamber.
Lower " " supporting chamber.

These two chambers are separated by partition, to prevent mixing of oil with each other.



This arrangement has two advantages:-

(1) Circuit breaking chamber requires a small volume of oil which is just sufficient for arc extinction.

(2) Small amount of oil is to be replaced as the oil in supporting chamber does not get contaminated by the arc.

Supporting chamber:-

It is a bottom chamber, made up of Porcelain & mounted on metal chamber.

It is filled with oil which is separated from the oil in circuit breaking chamber. The oil inside it, is employed for insulation.

Circuit Breaking Chamber:-

It is a Porcelain enclosure which is mounted on the top of supporting chamber. It is filled with oil and consists of (i) upper and lower fixed contacts (ii) moving contacts (iii) Turbulator.

The moving contact is hallow. It consists of a cylinder which moves down over a fixed Piston.

The Turbulator forms an arc control device and it has both axial and radial vents.

The axial venting ensures the interruption of low currents whereas radial venting ensures the " " high " .

Top Chamber:- It provides expansion space for the oil present in circuit breaking chamber.

It also contains a separator which avoids loss of oil by centrifugal action caused by circuit breaker operation during fault condition.

Operation :-

Under normal Conditions, the moving contacts and fixed contacts engaged Position.

Under abnormal Conditions, the moving Contacts are Pulled down by tripping springs. An arc is struck between b/w them.

The energy of the arc causes vapourisation of oil. This will produce gases at high Pressure.

This action Prevents the oil to Pass through central hole in the moving contact & results in forcing series of oil through the Passages to the turbulator. Thus arc is quenched.

Maintenance of Oil C.B:-

(i) Check the Current Carrying Parts i.e Contacts. If they are burnt replace them.

(ii) Check the dielectric strength of oil. If its Colour is changed then it should be changed (or) reconditioned.

(iii) Check the insulation for any damage.

(iv) Oil level should be checked.

(v) The Closing and tripping mechanism should be checked.

Advantages:-

(i) The quantity of oil required is small.

(ii) The space required is reduced.

(iii) The risk of fire is reduced. (iv) It has highest breaking Capacity.

Dis advantages:-

(i) Due to smaller quantity of oil, the degree of Carbonisation is increased.

(ii) The gases are difficult to remove from the Contact space in time.

(iii) The dielectric strength of the oil deterorates rapidly as degree of carbonisation is high.

These breakers are used up to maximum up to 132 kV.

Air Blast Circuit Breakers :-

Gaseous dielectrics are having more spread velocity than liquid spread velocity, therefore these are used for operating voltages beyound 132KV.

In this type of C.B the compressed air is used for the arc extinction. Hence it is called Compressed air C.B

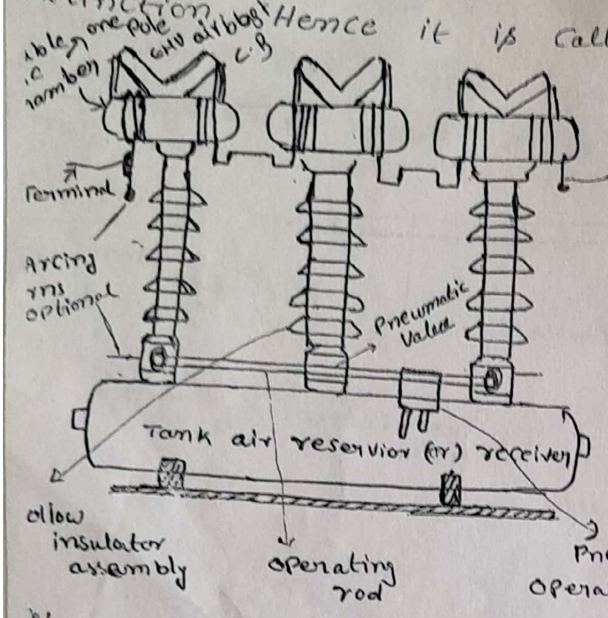


fig:- One Pole Extra high Volt air blast C.B.

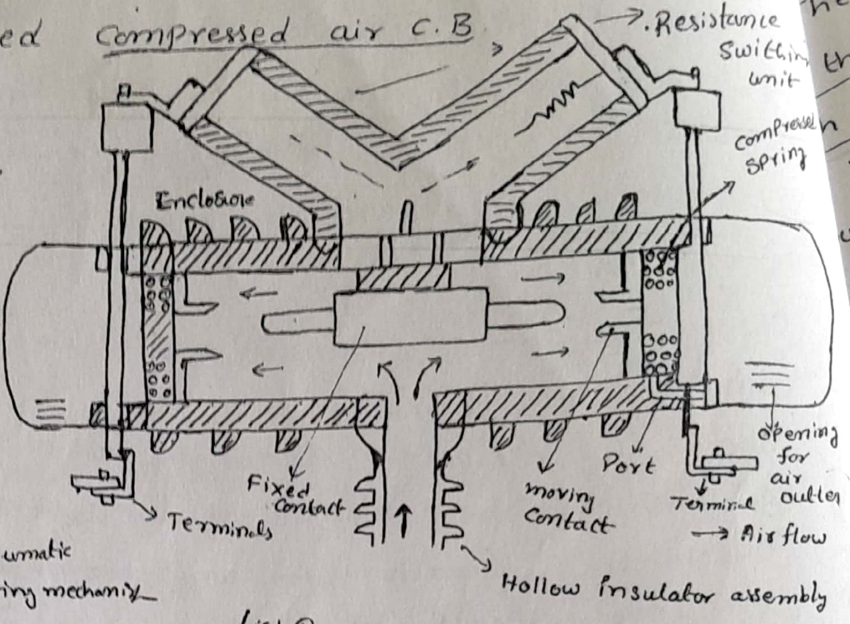


fig:-(b) Double arc extinction chamber.

On this reservoir there are 3 hollow insulator columns. On the top of each insulator there is double arc extinction chamber.

For each C.B Pole there are six breaks as there are three double arc extinction Poles in series.

Each arc extinction Chamber consists of 2 fixed and two moving contacts. These Contacts can move axially so as to open or close. The Position depends on air Pressure & Spring Pressure.

The operating rod is operated by the opening mechanism. This will lead to flow of high Pressure air by opening the valve.

This high Pressure air enters the double arc extinction chamber rapidly.

Due to the flow of air the Pressure on moving contacts increases than spring Pressure and then contacts open.

Due to the motion of moving contacts the Port for outgoing air is closed & the whole arc extinction chamber is filled with high Pressure air.

But during the arcing Period the air Passes through the openings and takes away ionized air of arc.

this air flows from high pressure reservior to the atmosphere a nozzle, whose design makes air to expand in the low pressure.

e high speed air flowing axially along the arc will cause oval of heat from the periphery of the arc.

The diameter of arc reduces to a low value at current zero. this instant of the arc interruption the contact space is filled th the fresh air.

This will make possible to remove the hot gases and fast building up of the dielectric strength of the medium. Thus the arc is extinguished.

These breakers requires resistance switching for obtaining sufficient resistance.

These breakers are used up to operating voltage of 400kV.

→ In this C.B, pressure generated in the arc extinction chamber is independent of arc current. The air pressure in this type of C.B is constant which is sufficient enough to break the rated breaking current.

For low values of current, the arcing time does not change since air pressure is independent of arc current.

For breaking low current, high pressure air will be required. Due to this the current gets chopped before reaching natural zero. This will give rise to high restriking voltage and the contact space is not likely to break down.

Therefore these high voltages must be allowed to discharge, order to avoid break down of insulation of circuit breaker.

Thus resistance switching is commonly employed.

- The air reservoir in the air blast C.B contains air of pressure of the order of 20 - 30 kg force / cm^2

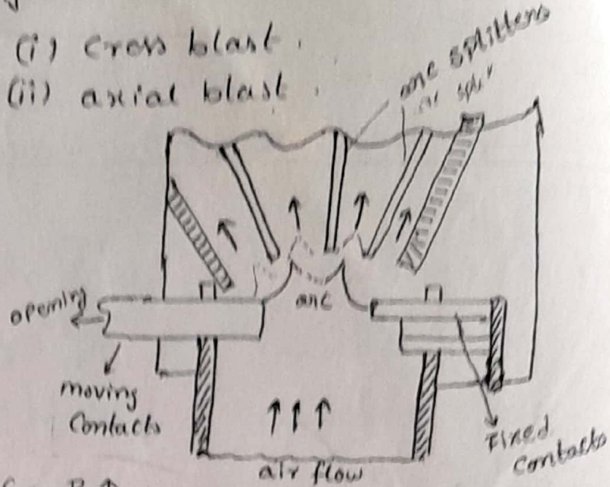
In case of making operation, the valve is turned which connects hollow column of insulator and the reservoir.

The air is passed to the atmosphere due to which pressure of air in the chamber is dropped to atmospheric pressure and closing of moving contacts is achieved against spring pressure.

During opening operation, the blast of air will take ionized gases with it and helps in extinguishing the arc.

There are two major types :- (i) Cross blast.
(ii) axial blast.

(i) <u>Cross Blast type</u>:-



The moving contacts is near to the arc splitter.

The air blast forces the arc on to the arc splitter plates.

These plates will lengthen the arc. R ↑.

Depending up on the breaking capacity of the breaker, the size and no. of plates are decided.

The moving contact consists of flat copper silver faced blade. The fixed contact is mounted at the base between the two insulating blocks.

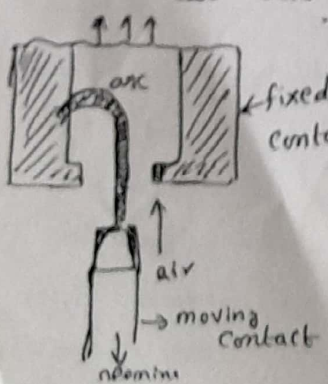
Resistance switching is not required, as sufficient resistance is automatically introduced in the arc to control the restriking transient.

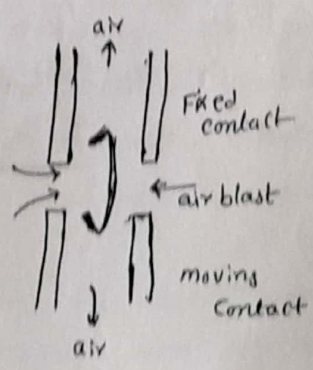
The cross blast are commonly used in indoor C.B of medium high voltage of up to 220kV.

(ii) <u>Axial blast Type</u>:-

In this type of blast of air is along the line of arc.

There are two sub types (a) single blast (b) double blast type. (or) Radial blast type.





...ages:-

ure
Closing

o fire hazards are Possible

High Speed Operation is achieved, because of Short gap needed for interruption.

The time for arc Persists is short.

As arc duration is short and consistent, the amount of heat released is less and the contact points are burnt to less extent.

The C.B uses compressed air, which gives fresh air for each operation. The arc energy at each operation is less than that compared with oil C.B. So it is used for frequent operation

(6) maintenance free.

(7) Stability of the system can be maintained.

Dis advantages:-

(1) It is used for frequent operation, it is necessary to have a compressor with sufficient capacity of high pressure air

(2) There is a possibility of air leakages at the pipe fittings.

(3) It is very sensitive to restricking voltages. Thus current chopping may occur which may be avoided by employing resistance switching.

Applications:-

It is Preferred for arc furnace duty, traction system. Because they are suitable for repeated duty.

This Air Blast C.B is used in range of 132 kV to 400 kV with breaking capacities up to 7000 MVA.

Vaccum Circuit Breaker :-

In this, Vacuum is used as the arc quenching medium. The Pressure below about 10^{-5} mm of mercury are Considered to be high vacuum.

1 mm of Hg = 1 torr ; 10^{-3} mm of Hg = 1 micron = 10^{-3} torr

Vacuum is superior medium than any other arc quenching medium since it offers highest insulating strength.

Vacuum arc :-

It is different from the general class of low and high Pressure arcs.

In the vacuum arc, the neutral atoms, ions & electrons do not come from the surrounding medium in which the arc is drawn, but they are obtained (or) emitted from the electrodes themselves by evaporating its surface material.

As the current carrying contacts are separated, cathode spots are formed depending upon the current to be interrupted.

For low currents a highly mobile cathode spot is formed and for large currents a multiple no. of cathode spots are formed.

These spots constitute the main source of vapour in the arc.

The process involved in drawing the arc will be due to high electric field b/w contacts (or) resistive heating produced at the point of operation.

The cathode surfaces, normally are not perfectly smooth but have many micro projections.

When the contacts are separating, the current flowing in the circuit will be concentrated in these projections as they form the last point of contacts.

Due to their small area of cross-section, the projections will suffer explosive evaporation by resistive heating (hot spot is created because of high current density) at the instant of contact separation and supply sufficient quantity of vapour for the arc formation.

i.e., under the occurance of fault due to higher fault

l, certain hot spots are developed at the tips of the
l (due to irregularity of surface).
rom these hot spots metallic fumes are liberated.
e metallic fumes (e⁻, ions, molecules) acts as path finders for arc to struck
n the arc is struck. This is called vacuum arc.
since the e's emission occurs only at the cathode spots (hot spots)
nd not from the entire surface of the cathode, the vacuum arc
also known as cold cathode arc.

In cold cathode the emission of e⁻'s could be due to:-
(i) field emission (ii) Thermionic emission (iii) Both
(iv) secondary emission by positive ion bombardment
(v) " " " Photons (vi) Pinch effect.

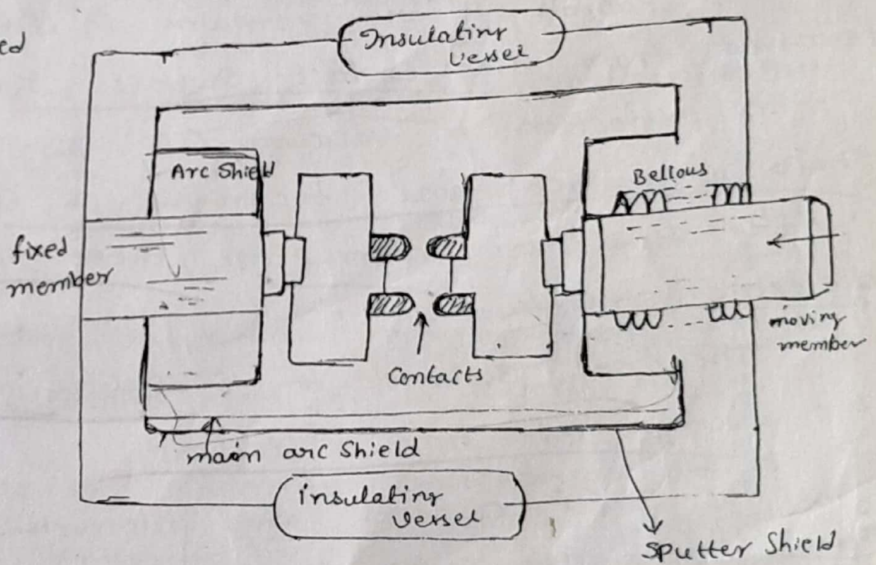
Construction:-

It consists of vacuum chamber in which fixed & moving contact and arc shield are mounted.

The movable member is connected to the control mechanism by stainless steel bellows.

The bellows permit the sealed contruction of the interrupter.

They are covered by protective shield.



The ~~outer~~ sputter shield is provided in between the contacts and the envelops in order to prevent the metal vapour reaching the envelope as it reduces the breakdown stength b/w the contacts. Also called main arc shield. This is generally made of stainless steel.

The outer insulating vessel is made up of glass (or) ceramics, because the glass envelop makes it easy to examine from outside, the state of the contacts after the breaker has interrupted the current.

when the contacts are separated due to abnormal conditions, arc is struck b/w contacts. The arc is produced due to ionisation of metal ions & depends very much on material of contacts.

It contains +ve ions liberated from contact material. The vapour density depends on the current in the arcing.

When current decreases, the rate of vapour release decreases, and after current zero, the medium regains its dielectric strength if vapour density is reduced.

When current to be interrupted is very small in vacuum by separating the contacts under high vacuum, the arc has several parallel paths. The total current is divided into many parallel arcs which repell each other and spreads over contact surface. This is called diffused arc which can be interrupted easily.

At high currents, arc gets concentrated on a small region. It causes rapid vapourisation of the contact surface. The interruption of arc is possible if arc remains in diffused state. If it is quickly removed from the contact surface, the arc will be restriked.

Arc extinction in vacuum C.B is greatly influenced by material, shape of contact and technique of condensing metal vapour.

After final arc interruption, there is rapid building up of dielectric strength.

They are suitable for capacitor switching as it reduces the average life time of the arc.

The small currents are interrupted before natural current zero which may cause chopping, which depends upon the vapour pressure and the electron emission property of the contact material.

A high vapour pressure and low thermal conductivity metals are more desirable ~~from~~ to limit the current chopping, where as low vapour pressure metals are more desirable from the arc extinction point of view.

Materials having high boiling & melting points have low vapour pressure at high temperatures but are poor conductors.

are as metals having low boiling and melting Points have
vapour Pressure at high temperatures, low electron functions and good thermal and electrical Conductivities.

Therefore to get these properties in one single material, composites of two or more metals have to be made.

Ex:- Copper - bismuth, Silver - bismuth, Silver - lead (Tin), Copper - lead (Tin) are some of the alloys used as Contact materials.

Advantages:-

(1) they are Compact In size and have longer life.
(2) There are no fire hazards
(3) There is no generation of gas during and after operation.
(4) There is no restriction on interruption of fault Current.
(5) less maintainance
(6) They can withstand successfully with lightning surges.
(7) They have low arc energy.
(8) Small Power is required for control mechanism.

Dis advantage:-

-- There is erosion of material from electrodes & evolution of gases from the electrodes during arcing.

- Severe Current Chopping because of low Pressure.

Applications:-

They are employed for outdoor installations ranging from 22 kV to 66 kV. with limited rating ranging from 60 to 100 MVA.

However by making use of Capacitor switching, the rating is extended up to 300 kV.

These breakers are used for getting 1^{st} swing Stability.

Unit - III Electro magnetic Relays

S. Sabiha

Relay :- A relay is an automatic device which senses an abnorm Condition in an electric circuit and closes its contacts. These contacts in turn close the C.B trip coil circuit, there by it opens the C.B and the faulty part of the electric circuit is disconnect from the rest of the healthy circuit.

The Protection provided by the protective relaying equipment can be categorised in two two types as :-

(1) Primary relaying equipment

(2) Back up " "

Primary relaying is the first line of defence and is responsible to protect all the power system elements from all the types of faults.

where as back-up protection relaying works only when the primary relaying equipment fails. which means back-up relaying is inherently slow in action.

Primary relaying may fail because of failure of any of the following :-

ⓐ Failure in C.B ⓑ Failure in protective relay

ⓒ " " tripping circuit ⓓ " " D.C tripping voltage

ⓔ loss of voltage or current supply to the relay.

The systems which are provided both primary and secondary relays are called non-unit type of protection system.

The system with only primary relays are called unit type of protection systems.

Secondary relay is called back up relay (or) master relay.

When the primary protection is made inoperative for the maintenance purpose, the back up protection acts like a main protection.

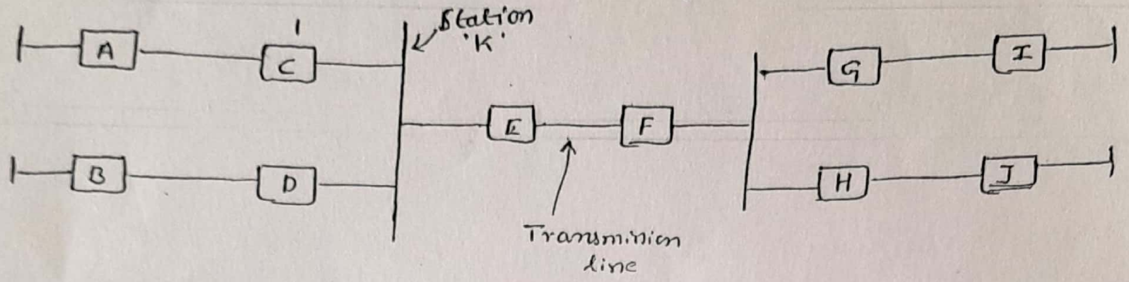
The arrangement of back up protection scheme should be such that the failure in main protection should not cause the failure in back up protection as well.

This is satisfied if back up relaying & Primary relaying not have anything common.

Hence generally back up Protection is located at different Stations from the Primary Protection.

Concept of Back up relaying:-

Consider the back up relaying employed for the transmission line section EF as shown in fig.



The relays C, D, G & H are Primary relays, while A, I and J are the back up relays.

Normally back up relays are tripped if Primary relay fails. So if the Primary relay 'E' fails to trip, then backup relays A and B get tripped. The back up relays and associated back up relaying equipments are Physically apart from the faulty equipment.

The back up relays A and B provide backup Protection for fault at station 'k'.

The back up relays A & F Provide the back up Protection for the faults in the line DB.

When back up relay operates, the larger part of the System is disconnected.

The important requirement of back up relaying is that it must operate with Sufficient time delay so that the Primary relaying is given a chance to operate.

When fault occurs, both the type of relays start relaying operation but Primary is expected to trip first and back up will then reset.

methods of Back up Protection :-

(1) Relay Backup Protection :- In this scheme, a single breaker is used by both Primary as well as backup Protection but the two Protective systems are different.

(2) Breaker Backup Protection:-

In this method, separate breakers are Provided for Primary and backup Protection. Both the types of breakers are at the same station

(3) Remote Backup Protection :- In this method, seperate breakers are Provided for primary and back up Protection. The two type of breakers are at the different stations and are completely isolated and independent of each other.

(4) centrally Co-ordinated Back up Protection :-

In this method, Primary Protection is at various Stations There is a central control room, and back up protection for all the stations is at central control room.

Central control continuously inspects the load flow and frequ in the system.

If any element of any Part of the system fails, load flow gets affected which is sensed by the control room.

Nature and Causes of faults :-

Any fault in electrical apparatus is nothing but the defect in its electrical circuit which makes current Path directed from its intended Path.

When a fault occurs on a system, the voltages of the three Phases become unblanced. As the fault currents are large, the apparatus may get damaged.

Equipment	% of total fault
Over head lines	50%
Switch gear	15%
Transformer	12%
Cables	10%
Control equipment	3%
CT's & PT's	2%

Type of fault ~~in OHT lines~~	% occurance
L-G	85%
L-L	8%
L-L-G	5%
L-L-L	≤ 2%

Essential Qualities of Protective system Relays :-

(1) **Reliability** :- It is the ability of the relay system to ope[rate] under predetermined conditions.

It must operate when it is required.

There are various components which go into operation before relay operates.

Therefore every component and circuit which is involved in operation of the relay plays an important role; for example, lack of suitable current & voltage transformers may result in unreliable operation.

The reliability of a protection system depends on the reliability of various components like C.B, relays, C.T's, P.T's, cables, trip circuits etc.

The proper maintenance also plays an important role in impro[ving] the reliability of operation of the system.

The statistical data and records give good idea about the reliability of the protective system.

This can be achieved by the factors like,

(i) Simplicity and Robustness in construction
(ii) high contact pressure (iii) Dust free enclosures
(iv) good contact material (v) good work-man ship
(vi) Careful maintenance. (vii) Prevention of contact contamination

(2) **Selectivity and Discrimination** :-

It is the ability of relay mechanism to identify or select the part of the power system which is under trouble and to disconnect that faulty part without affecting the rest of the healt[hy] part of system.

The Discrimination quality of the protective system is the ability to distinguish between normal condition and abnorma[l] condition and also between abnormal condition with in protective zone and else where.

Selectivity is achieved in two ways :-
(i) unit system of protection.
(ii) non-unit system of protection.

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Unit System of Protection means the one, which the Protection responds only to faults with in its own zone and does not make note of the conditions elsewhere,

eg:- the differential Protection of transformers & generators. Here the Protection scheme will work only if the fault is in the T/ or generator respectively.

Non-unit system of Protection is one in which the selectivi is obtained by grading the time (or) current settings of the relays at different locations, all of which may respond to a fault.

If the Protective system is not selective then it operates for the faults beyond its Protective Zones and unnecessary the large part of the system gets isolated. This causes a lot of inconvenience to the supplier and users.

(3) Speed and time :-

A Protective relay must disconnect the faulty system as fast as Possible.

If the faulty system is not disconnected for a long time the

(i) The device carrying fault currents may get damaged

(ii) The failure leads to the reduction in system voltage. Such low voltage may affect the motors & generators running on the consumer side.

(iii) If fault persists for long time, then subsequently other faul may get generated.

The total time required b/w the instant of fault and the final arc interruption in C.B is called fault clearing time.

fault clearing time = Relay time + C.B time.

Relay time is the time b/w the instant of fault occurrence and the instant of closure of relay contacts.

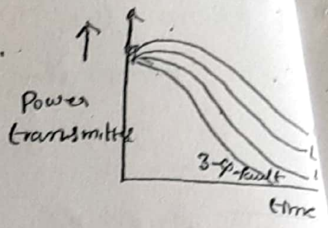
C.B time is the time taken by C.B to operate to open the contacts and to extinguish the arc completely.

The fault clearing time should be as small as possible to have high speed of operation of the Protective System.

Though the small fault clearing time is preferred, in practice certain Basic time lag is provided, because (1)

(1) To have clear discrimination b/w Primary & backup Protec.

(2) To prevent unnecessary operation of relays under the condit. Such as transients, Starting Inrush of current etc.



curve: the Power that can be transmitted as a function of fault clearing time for various types of faults.

④ **Sensitivity :-**

It is the ability of the relay system to operate with low value of actuating quantity.

It indicates minimum value of fault current at which the Protection starts operating in the Protective zone. i.e Protective relay must be more sensitive.

The relay sensitivity is the function of minimum volt-am input to the relay coil necessary to cause its operation.

Eg:- 1VA I/P relay is more sensitive than 5VA input relay.

$$K_S = \frac{I_S}{I_o}$$

where K_S = Sensitivity factor

I_S = minimum S/C current in the zone

I_o = " operating " for the Protect

Simplicity :-

The Protective system should be as simple as possible, so that it can be easily maintained.

The Simplicity & reliability are closely related to each other.

The Simpler systems are always more reliable.

Economical :-

It is necessary that the cost of the system should be with in the limits.

Basic terms and definations:-

(1) **Protective Relay:-** It is an electrical relay, which closes its contacts when an actuating quantity reaches a certain preset value. Due to closing of contacts, relay initiates a trip ckt of C.B (or) an alarm circuit.

(2) **Pick up level (or) Set value:-**

It is the minimum value of an actuating quantity at which relay starts operating.

actuating quantity → is current the relay coil.

(3) **Pick up:-** A relay is said to be picked up when it moves from 'OFF' position to 'ON' position.

(4) **Reset level:- (or) Drop out:-**

It is the maximum value of actuating quantity that can keep the relaying under off conditions.
(or)
A relay is said to reset, when it comes back to original position. The value of an actuating quantity current or voltage below which the relay resets is called reset value

(5) **Reset time:-**

It is the time elapsed b/w the instants of current becomes less than ~~reaches~~ the reset level and the closer of breaker contacts.

(6) **Primary Relays:-** The relays which are connected directly in the circuit to be protected.

(7) **Secondary Relays:-** The relays which are connected in the circuit to be protected through C.T's & P.T's.

(8) **Operating time:- (or) Pick up time:-**

It is the time which elapses between the instant when the actuating quantity exceeds the pick up value to the instant when the relay contacts opera..

⑨ **Reach:-** This term is mostly used in connection with distance relays.
A distance relay operates whenever the impedance seen by the relay is other than the prespecified value.
This impedance (or) corresponding distance is known as the reach of the relay.

⑩ **over Reach:-**

The tendency of the relay to operate at impedances larger than its setting is known as over Reach.

$Z > Z_L$; where Z_L = Set Valve, Prespecified value

$Z = \frac{V}{I}$

This relay is used for over voltage protection.

⑪ **Under Reach:-**

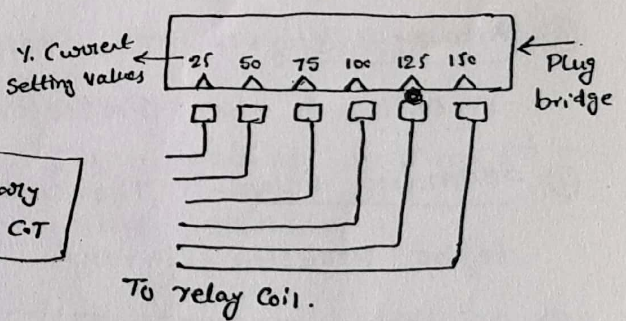
This relay operates for the condition $Z < Z_L$.
This is used for over current protection.

⑫ **Current Setting:-**

The Pick up value of current can be adjusted to the required level in the relays which is called current setting of that relay.

It is achieved by use of tappings on the relay coil, which are brought out to a plug bridge as shown in fig.

The tap values are expressed in terms of percentage full load rating of C.T.



∴ Pickup Current = % Current Setting X Rated secondary Current of C.T

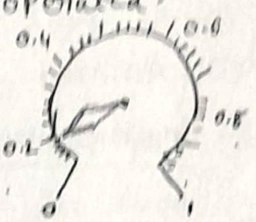
⑬ **Plug setting multiplier (P.S.M):-**

It is the ratio between fault current in the relay coil & the ~~Plug~~ Pickup Current.

$$P.S.M = \frac{\text{fault Current in relay Coil}}{\text{Pick up current}}$$

$$P.S.M = \frac{\text{fault Current in relay Coil}}{\text{\% Current Setting} \times \text{Rated Secondary current of C.T}}$$

(14) <u>Time Setting multiplier</u>:- Similar to Current setting, It is also a set value of time for which the relay has to operated.

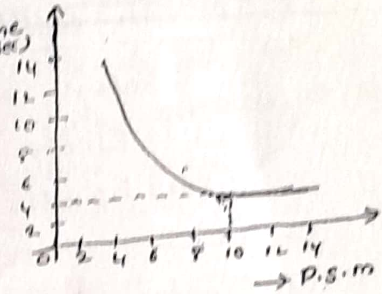


The value of time-setting multiplier along with the time obtained from time/p.s.m curve decides the actual time of operation of the relay.

Time-Setting multiplier

∴ Actual time of operation = time in sec × time-setting multiplier

(15) <u>Time / P.S.m Curve</u>:- The curve showing relation between time and Plug-setting multiplier is provided which is called time/p.s.m curve.



For Low values of over currents the operating time varies inversely with current.

But as current increases & approaches upto 20 times its rated value then the time becomes almost constant.

This type of characteristics is necessary to ensure discrimination on very high fault currents flowing through healthy part of the system.

(16) <u>Protective Systems</u>:- The Combination of C.B, trip ckt's, C.T and other protective relaying equipments is called protective system.

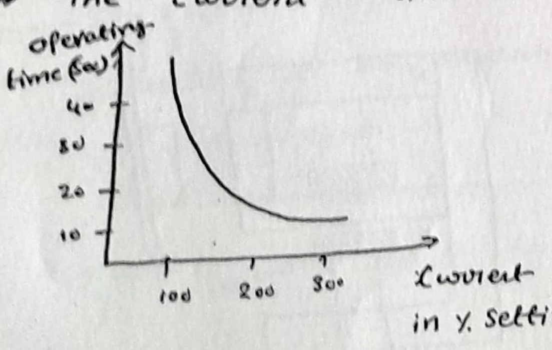
(17) <u>Protective Scheme</u>:-

The combination of various protective systems covering a particular protective zone for a particular equipment is called protective scheme.

<u>For Ex</u>:- a generator may be provided with protective systems like over current, differential, earth fault etc.

The combination of all these systems is called generator protective schemes.

→ The current - time characteristics is <u>hyperbolic</u>.



Classification of Relays :- 3 types

ⓐ As Per location ⓑ As Per time of operation
ⓒ As Per construction.

ⓐ **As Per Location :-** Unit type of Protection System
Non-unit " " "

ⓑ **As Per time of operation :-**
→ Instantaneous relay :-
→ Inverse time lag type
→ Definite time lag type

ⓒ **As Per Construction :-**

Relays are Classified in two 4 types :-
(i) Electro magnetic relays (ii) Thermal relays
(iii) Static relays (iv) micro Processor based relays.

Ⓐ Electro magnetic Attraction Relays :-

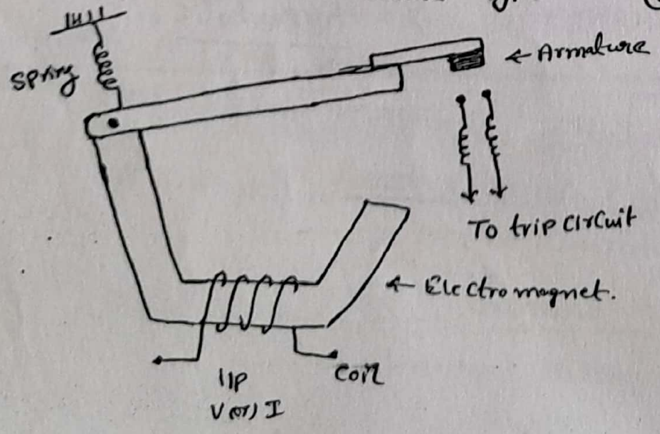
This relays will works on the Principle of electromagnetic attraction or induction.

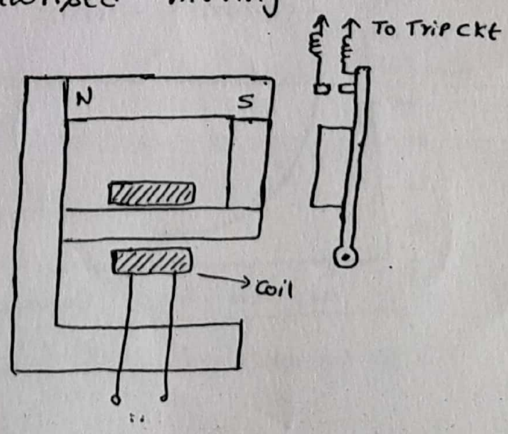
When operating Current becomes large, the magnetic field Produced by an electromagnet is high that it attracts the armat or Plunger, making contact with the trip circuit.

Various types of Electromagnetic attraction type relays are :-
(1) Attracted armature type relay.
(2) Solenoid and Plunger type relay.

(1) Attracted armature type Relay :-

There are two types of Structures available for attracted armature type relay
ⓐ Hinged armature type ⓑ Polarised moving iron type.





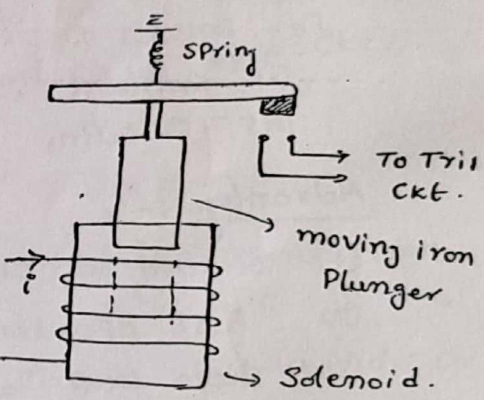
In attracted armature type, there exists a laminated electro-mag which carries a coil.

The coil is energized by the operating quantity which is proporti to the circuit voltage or current. Then core gets magnetized.

The armature or a moving iron is designed in such a way that, under normal operating currents, the magnetizing force produced by the electro magnet could not able to lift the armature.

When the current through coil increases beyond the limit i.e., prespecified value, the magnetizing force produced by electro-magnet increases, and the armature is lifted up. moved down i.e., due to this it makes contacts with contacts of a trip circuit., which results in an opening of a C.B.

(2) <u>Solenoid and Plunger type relay</u>:-



It consists of a solenoid which is nothing but an electromagnet.

It also consists a moving iron plunger.

Under normal working conditions, the spring holds the plunger in the position such that it cannot make contact with trip circuit contacts.

Under fault conditions, the magnetizing force produced by solenoid increases there by it attracts the plunger inside, the plunger is pulled down.

In this downward movement, the flopp closes the trip circuit contacts. then C.B opens.

The electromagnetic force produced due to operating quantity which is exerted on armature is proportional to the square of flux in the airgap.

Neglecting saturation, force is proportional to square of curre

Hence it is useful for a.c & d.c.

For d.c operation :- In dc, electromagnetic force is constant, when this force exceeds the restraining force, the relay operates.

$F_e = K_1 I^2$ — F_e = electro magnetic force
K_1 = Constant.
I = operating current in a coil

&

$F_r = K_2$ — F_r = Restraining force due to spring including friction

At balance

$$K_1 I^2 = K_2 \Rightarrow \boxed{I = \sqrt{\frac{K_2}{K_1}} = \text{Constant}}$$

This is the current at which relay operates

For a.c operation:-

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

I_m = max value of the operating current

F_e consists of two components
(i) Constant, independent of time
(ii) Pulsating at double the freq of applied voltage.

Advantages:-

(1) It can be used for both ac and dc.
(2) Fast operation & fast reset.
(3) These are almost instantaneous
(4) Simple, reliable & robust.

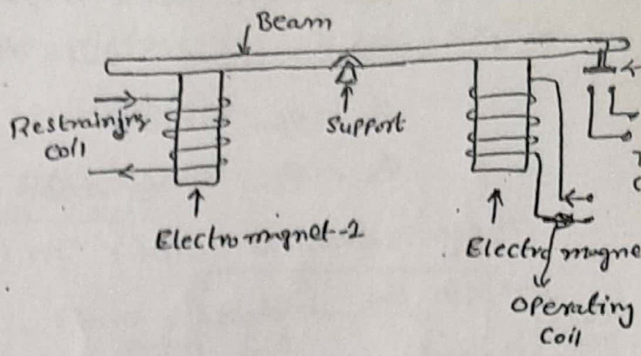
Dis advantages:-

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

Applications:-

(1) Protection for various a.c and d.c equipments.
(2) The over / under current & over/ under volt. Protection of various ac & dc equipments.
(3) In the definite time lag over current & earth fault Protect along with definite time lag over current relay.
(4) For the differential Protection.

(B) Balanced Beam Relay:- It is also a type of attracted armature type relay.



It consists of a beam carrying two electromagnets at its ends.

One electromagnet produces operating torque while the other produces restraining torque.

The beam is supported at the middle.

Under normal operating conditions, the two torques are equal and beam remains horizontal.

When there is a fault, the operating current is high and produces high operating torque. Thus the beam gets deflected more on operating side.

Due to this, armature fitted at end of the beam gets pulled and makes contact with the contacts of trip ckt.

Thus trip ckt operates.

© Induction Relays:-

It operates based on the electromagnetic Induction principle.

∴ These relays used for only a.c circuits but not d.c cir

These type of relays also called magnitude relay.

Based on the construction, the various types of the Induction type relays are,

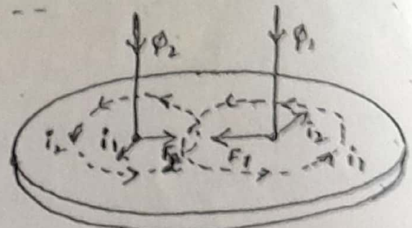
(1) Shaded Pole type.
(2) Watt hour meter type } → Induction disc type.
(3) Induction cup type.

Torque Equation for Induction Type Relays:-

In these relays a metallic disc is allowed to rotate between the two electromagnets.

The alternating currents supplied to two electromagnets produce the two alternating fluxes ϕ_1 and ϕ_2.

These two have same frequency but they have a Phase difference of 'α' between them such that ϕ_2 leads ϕ_1.



$\therefore$ $\phi_1 = \phi_{1m} \sin\omega t$

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

These induces emf's in the rotor.

Due to the induced emf's, the eddy currents i_1 and i_2 are circulated in the disc.

The two eddy currents react with each other to produce a force which acts on the rotor.

Assuming the disc to be non-inductive, these currents will be in phase with their respective voltages.

$\therefore$ The induced eddy currents lag behind the respective fluxes by 90°.

$e_1 \propto \frac{d\phi_1}{dt} \Rightarrow i_1 \propto \frac{d\phi_1}{dt} \propto \frac{d(\phi_{1m}\sin\omega t)}{dt} \propto \phi_{1m}\cos\omega t$

$e_2 \propto \frac{d\phi_2}{dt} \Rightarrow i_2 = \frac{d\phi_2}{dt} \propto \frac{d(\phi_{2m}\sin(\omega t+\alpha))}{dt} \propto \phi_{2m}\cos(\omega t+\alpha)$

The forces are produced due to the interaction of ϕ_1 with i_2 and ϕ_2 with i_1

$\therefore$ $F_1 \propto \phi_1 i_2$ and $F_2 \propto \phi_2 i_1$

The directions of F_1 and F_2 can be obtained by Flemings left hand rule.

These two forces are acting in the opposite directions & hence net force

$F \propto F_2 - F_1$

$F \propto \phi_2 i_1 - \phi_1 i_2$

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

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

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

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

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

$$\boxed{F \propto \phi_1 \phi_2 \sin\alpha}$$

Protection of Transformers

S. Sabiha kutty

The Power T/F is a major and very important equipment in a Power system.

It requires highly reliable Protective devices.

The Choice of Protection for any Power-T/F depends upon a no of factors, such as its size, importance and whether it has no-load or off-load tap changer.

The following Information is necessary while selecting the Protection scheme for a Power T/F.

1. Particulars of transformer
   - ⓐ KVA rating ⓑ Voltage ratio
   - ⓒ Connections of windings ⓓ Percentage reactance
   - ⓔ Neutral Point earthing, Value of resistance
   - ⓕ whether indoor or outdoor, dry or oil filled
   - ⓖ with or without Conservator ⓗ type of T/F's
   - ⓘ type of Cooling
2. Length and Cross-section of Connecting leads b/w CT's and relay Panel.
3. Fault level at Power T/F terminals.

The faults in T/F Can be Caused by failure of insulating materials due to dust, moisture, Voids weakening of winding due to external short-Circuits.

Protective equipment for transformer Protection includes gas relays which give an alarm on incipient faults, differential System of Protection which gives Protection on Phase to Phase faults, Phase to ground faults, Other Protective relays, & Surge arresters used against high Voltage Surges.

Types of faults Encountered in T/F's :-

(a) Internal faults

(b) External faults

Internal faults

The Primary Protection of T/F's is meant for the internal faults. These are 2 types :-

(i) Short circuits in the transformer winding and Connections

These are electrical faults of serious nature and are likely to cause immediate damage. Such faults are detectable at the winding terminals by unbalances in voltage or current.

This type of faults include line to ground or line to line and interturn faults on H.V and L.V windings. These are due to failure of insulation due to temperature rise (or) deterioration of transformer oil.

(ii) Incipient faults :-

Initially, such faults are of minor nature but slowly might develop into major faults.

Such faults are not detectable at the winding terminals by unbalance in voltage or current and hence, the Protective devices meant to operate under short circuit conditions are not capable of detecting this type of faults.

Such faults include Poor electrical connections, small sparking, Core faults, failure of the coolant, regulator faults and bad load sharing b/w transformers.

External faults :-

External faults are "Through faults" which occurs beyond protected zone of the T/F, but fed through the T/F. Through faults are not detected by the differential protection. If the through faults persists for long period of time, the T/F may get subjected to the thermal and mechanical stresses which can damage the T/F.

The over current relays with zero sequence protection and negative sequence protection are used to give protection against through faults.

Such a protection acts as a back-up protection

Gas Actuated Devices :-

During internal faults below oil level, the heat of arc causes decomposition of oil. The gases formed by decomposition are gathered in the air cushion and the conservator of the transformer.

The rate of gas generation depends upon fault current & arc voltage.

The following devices are used for detecting these faults

(a) Pressure relief & Pressure relay
(b) rate of rise of Pressure relay (c) gas accumulator relay (Buchholz relay)

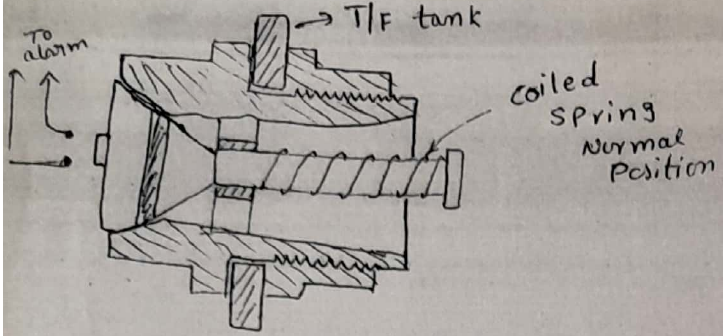
(a) Pressure Relief & Pressure relay :-

It is mounted on T/F tank. It releases gas pressure to the atmosphere during.

- high over load. Peaks
- Prolonged over loads
- arcing faults with in oil

The Pressure relief Value is spring loaded and has a seal-seal. when the Pressure inside the tank increases above a Certain Value, the force on movable sub-assembly exceeds the spring force and the Valve operates

The alarm contacts are closed. After release of pressure the may be manually reset.



(b) <u>Rate of Rise of Pressure Relay</u> :-

Rate of rise of pressure relay does not respond to <u>Static Pressure</u>.

It responds only to rate of rise of pressure resulting from internal arcing.

The main pressure sensing element is a pressure actuated micro-switch mounted inside a metallic bellows.

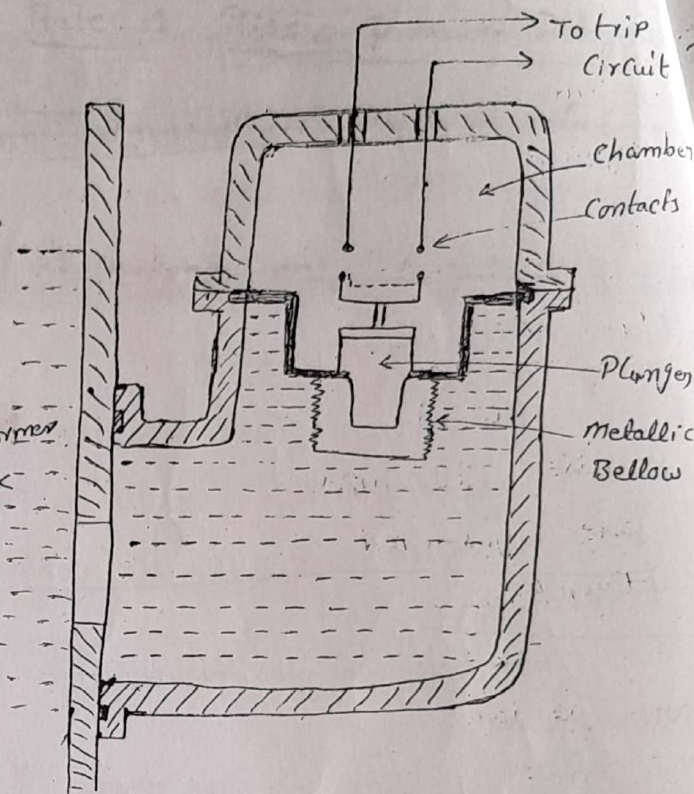


fig:- Rate of rise of Pressure relay.

The static pressure do not squeeze the bellow.

Dynamic pressure squeeze the bellow & operate the micro switch.

Rate of Rise of pressure relay is generally arranged to trip the transformer. It can be mounted on the tank.

Its operation is quicker than the pressure relief valve.

Buchholz Relay :-

It is a "gas actuated relay", used for the Protection ~~of~~ oil immersed transformers against all the types of internal faults.

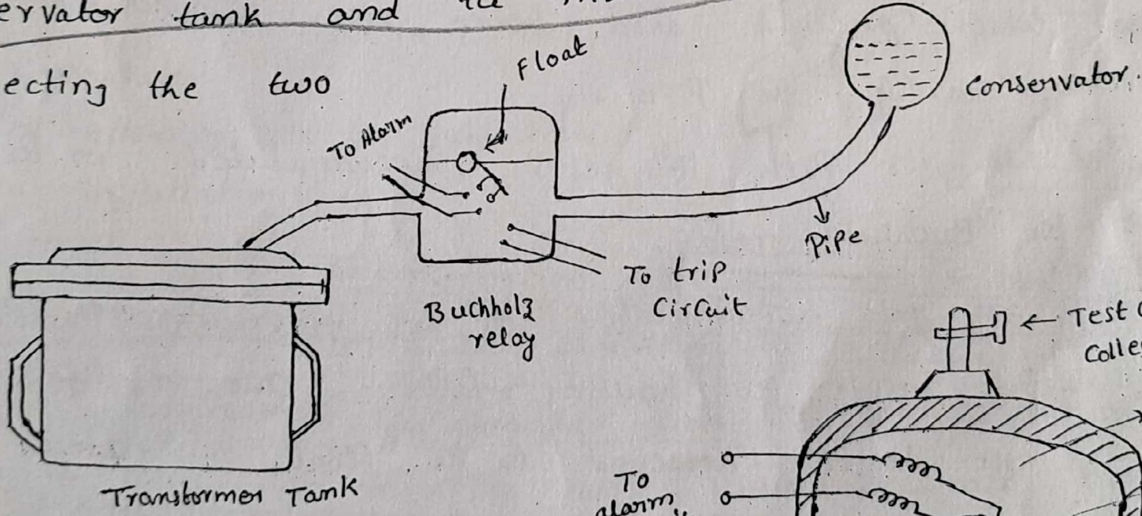
It is practically used for oil immersed T/F's having rating more than 500 KVA.

This relays are not provided for T/F's below 500 KVA from the point of view of economic considerations.

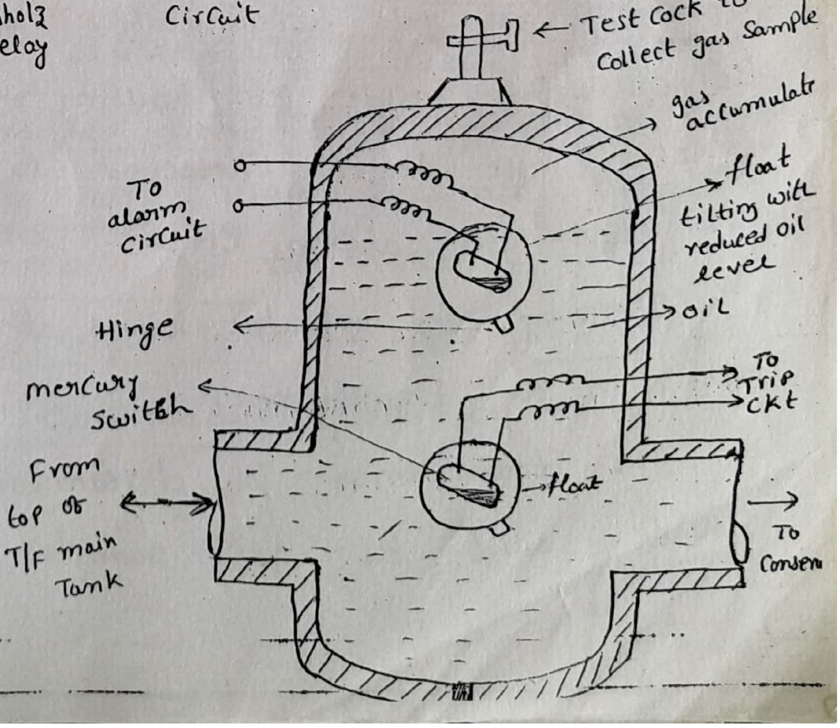
The slow developing faults called incipient faults in the T/F tank below oil level operate Buchholz relay which gives an alarm.

If the faults are severe it disconnects the transformer from the supply.

Such relay can only be fitted to the T/F's equipped with conservator tanks as it is installed in between the conservator tank and the main tank i.e., in the pipe connecting the two



Buchholz Relay ⇒



Construction :-

It consists of two hinged floats in the metallic chamber located in the Pipe connection b/t the Conservator and the T/F tank.

One of the float is near the top of the chamber and actuates the mercury switch connected to the external alarm circuit.

The other float is opposite to the orifice of the Pipe to the transformer and actuates the mercury Switch connected to the tripping circuit.

Operation :-

There are many types of internal faults such as insulation fault, core heating, bad switch contacts, faulty joints etc, which can occur.

When the faults occur, oil in the tank decomposes, generating the gases. The 70% component of such gases in hydrogen which is light and hence rises upwards towards conservator through the Pipe.

But in its Path it gets accumulated in the upper Part of the Buchholz relay.

When gas gets accumulated in the upper Part of housing, the oil level inside the housing falls. Due to this the mercury type switch attached to the float is tilted and so closes the alarm circuit and rings the bell.

There by the operator knows that there is some incipient fault in the transformer.

The transformer is disconnected at the earliest Possible and the gas sample is tested.

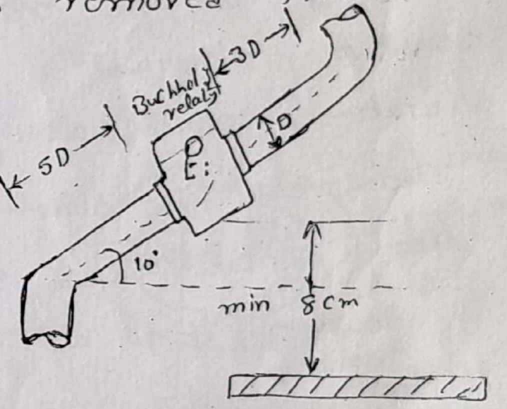
in the testing of gas provides clue regarding the type of fault is started developing in the transformer.

Hence T/F can be disconnected before fault grows into serious one.

A release cock is provided at the top of the chamber so that after operation the pressure in the chamber can be released and the gas emitted to allow the chamber to refil with oil.

When a severe fault occurs such as internal short circuit b/w phases, earth fault inside the tank etc. occurs then large volume of gas is evolved so that the lower float containing a mercury switch mounted on a hinged type flat is tilted and the trip coil is energized.

There after the transformer is removed from the service.



A Buchholz relay is installed in the pipe connecting the T/F tank and conservator.

The following are the guide lines for the installation.

- The angle of inclination of the axis of the pipe with horizontal plane should be between 10 to 11°.
- The length of the straight run of the section of the pipe b/w the relay and the T/F tank should be more than 5D (D is the internal diameter of the connecting pipe).
- The length of the straight run of pipe after the Buchholz relay upto the conservator should be more than 3D.

Advantages:

(1) It is the simplest Protection in case of transformer.

(2) Normally a Protective relay does not indicate the appearance of the fault. It operates when fault occurs.

But Buchholz relay gives an indication of the fault at very early stage, by anticipating the fault and operates the alarm circuit.

Thus T/F can be taken out of service before any type of serious damage occurs.

Limitations:-

(1) These relays can be used only for oil immersed T/F's having conservators.

(2) Only faults below oil level are detected.

(3) Setting of the mercury switches can not be kept too sensitive otherwise the relay can operate due to bubbles, vibration, earthquakes mechanical shocks etc.

(4) The relay is slow to operate having minimum operating time of 0.1 sec & average time of 0.2 seconds.

However, it is an excellent relay to bring to notice incipient faults.

Applications:-

The following types of T/F faults can be protected by the Buchholz relay and are indicated by alarm:-

(a) Local over heating

(b) Entrance of air bubbles in oil

(c) Core bolt insulation failure.

(d) Short circuited laminations.

(e) Loss of oil and reduction in oil level due to leakage.

(f) Bad and loose electrical contacts.

(g) Short circuit b/w Phases

(h) Bushing Puncture

(i) winding earth faults.

ction against over heating (or) Temperature rise :-

The overheating of the T/F is basically of sustained loads and short circuits.

The permissible overload and the corresponding duration dependent on the type of T/F & class of insulation used the T/F.

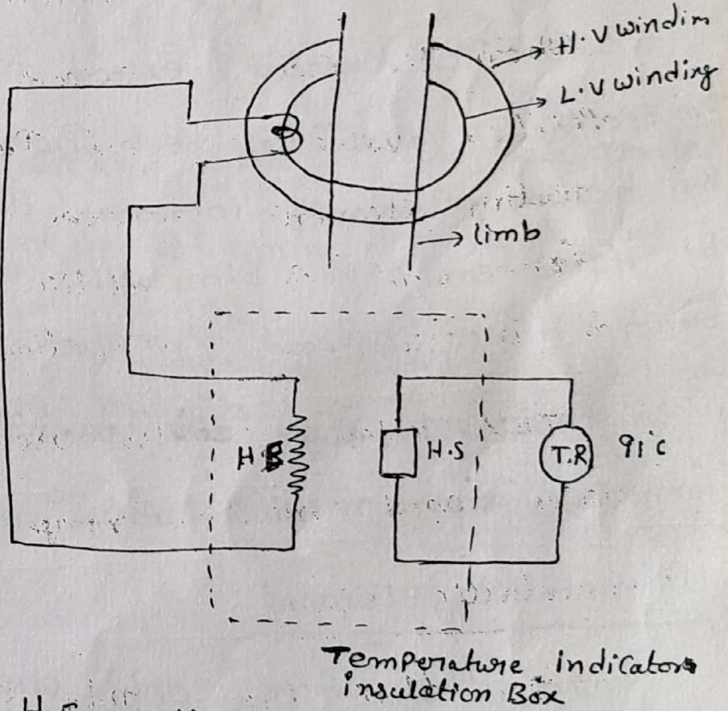
Similarly the failure of the cooling system and core faults, though rare, is another possible cause of overheating.

Generally the thermal overload relays and temperature relays, sounding alarm are used to provide protection against overheating.

The maximum allowable temperature inside the T/F is 91°c

Excess in temperature can be measured by thermal method.

In this method a C.T is connected to L.V winding from there, the terminals are brought out and these are connected to heating element.



This heating element produces the heat which is analogus to heat developed inside the Transformer.

H.E = Heating element.
H.S = Heating sensor.
T.R = Thermal Relay.

Near by heating element a heat sensor is kept which will gives the measure of this heat as temperature.

If this heat exceeds 91°c the thermal relay gets operated.

The heating element and heat sensor both are kept this Temperature insulation box.

Thermal Relays:-

These relays will work on the Principle of Electro-Thermo effect i.e., Production of heat by the execution of electric current, & this heat is considered as Pick up level for the re...

There are mainly 3 types:-

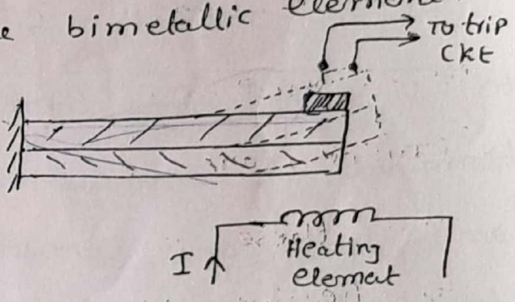
(i) Bimetallic element (ii) unimetallic element
(iii) Thermo Couple.

(i) Bimetallic element:-

It is the combination of two metal strips having different linear Coefficient of expansions.

This relay is initially designed with normal operating currents, the heat Produced by heating element will not Produce any bending movement in the bimetallic element.

When the current exceeds the Pre specified value the heat Produced by heating element increases there by free end of bimetallic element bends in the upward direction as shown in the figure.

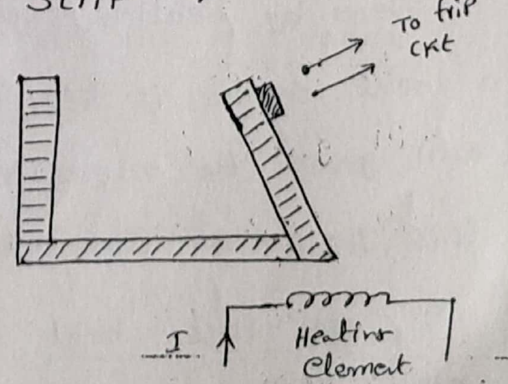


This relay is also used for the Protection of ovens, furnaces and medium range motors.

Unimetallic element:-

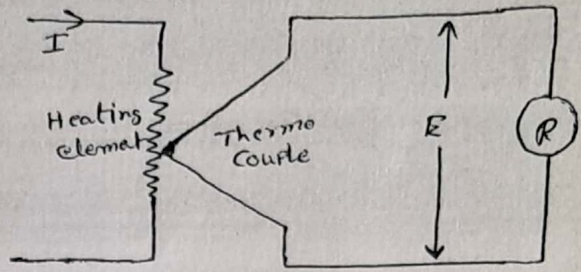
In this type only one metal strip is used.

When current exceeds the Prespecified value the heat Produced by heating element becomes excess there by metal strip tend to expand.



ctro- Thermo Couple :-
electric
the re

It is a combination of two dissimilar metals having Property of generating emf by grossping temperature.



The figure shows the basic form of thermo-couple type of relay

The electrical quantity is Passed through heating element then the heating element will produce proportional heat, by grasping this heat Thermo-couple will generate an emf

$$E = a(\Delta T) + b(\Delta T)^2$$

a = 40 to 50 $\mu V/^{o}C$;

b = few tenths of a ; $\Delta T = T_1 \sim T_2$ (temp diffe)

If this emf crosses the Pickup Value relay gets operated.

The relay is set at a Pickup of emf Produced for normal operating currents

This relay is used for the Protection of alternator at generating stations, Transformers,

$E = a(\Delta T) + b(\Delta T)^2$

Overfluxing Protection :-

The flux density in transformer core is Proportional to ratio of voltage to frequency i.e., $B \propto V/f$.

The Power transformers are designed to work with certain value of flux density in the Core.

The Power transformers are designed to withstand $(V_n/f_n \times 1.1)$ Continuously, where V_n is normal highest r.m.s voltage and f_n is standard frequency.

The Capability for V/f for higher values is limited to a few minutes

$\frac{V/f}{V_n/f_n}$	1.1	1.2	1.25	1.3	1.4
Duration of withstand limit (minutes)	Continuous	2	1	0.5	0

In the generator transformer unit, if full excitation is applied before generator reaches its synchronous speed then due to high V/f the overfluxing of the core may result.

Higher Core flux means more core loss and overheating of the Core.

Also the saturation of magnetic circuit is also the Probable cause for the overfluxing operation.

The V/f relay called volts/hertz relay is Provided to give the Protection against overfluxing operation.

The V/f relay is Provided in the automatic voltage regulator of generator.

This relay does not allow exciting current to flow till the generator reaches to a synchronous speed and runs to produce voltage of proper frequency.

The overfluxing relays with enough time lag also can be Provided.

usually 10% of overfluxing can be allowed without da...

If V/f exceeds 1.1, overfluxing Protection operates.

Core-Balance leakage Protection :-

An Earth fault usually involves a Partial breakdown of winding insulation to ground. The resulting leakage current is quite small as compared to Short Circuit Current.

The earth fault may Continue for a long time and cause considerable damage before it ultimately develops into a Short-Circuit and removed from the System.

Under Such Circumstances it is advisable to Provide earth fault Protection in order to ensure that the Earth fault or leak is removed in the early Stages.

An earth-fault relay used for it is essentially an over-current relay of low setting and operates as soon as earth fault or leak develops.

One method of Protection against earth fault in transformers is the "Core-balance leakage Protection"

This System consists of three Primary Conductors surrounded by the magnetic Circuit of a Current transformer.

This has a single secondary winding which is Connected to the relay operating Coil.

Under normal Conditions i.e., when there is no earth fault the instantaneous sum of the Currents in the three Phases is always zero, and there is no resultant flux in the Core of the C.T

Thus no Current flows through the relay operating Coil and trip Circuit remains open.

The overload relays used are high current setting and are arranged to operate against Phase-to-Phase faults while the earth fault relay has low current setting and operates under earth or leakage faults only.

The two overloads relays are sufficient to Protect all the three Phases while the earth fault or leakage fault relay is energized by the resultant currents from all the three CT's in case of leakage fault.

The trip contacts of the over load relays and earth fault or leakage relay are connected in Parallel. So the circuit breaker will trip in the event of energisation of either over load relay or leakage relay.

Thus the Protection against faults and short-circuit either to earth or b/w Phases is achieved.

Open Circuits:-

An open circuit in one of the three Phases of a T/F may cause undesirable heating. In Practice, relay Protection is not Provided against open circuits because this condition is relatively harmless.

In case of such faults, the transformer can be manually disconnected from the system.

Unit-5

Generator Protection

G. Aruna
G.K. Nagalakshmi
M. Anjana

generator is the most important & costly equipment in Power system.

The Protection of generators is very much complex due to the following reasons:-

- It is a large m/c producing high voltages and is connected to bus bars.
- It is accompanied by excitation system, Prime mover, voltage regulator, cooling system etc. Hence it is not a single equipment. The Protection of generator should be co-ordinated with associated equipment.
- It should not be shut off as far as Possible because that would result in Power shortage & emergency.

The following are the various types of faults that can occur on an alternator:

(1) Stator faults:-

It means fault associated with 3-φ armature winding of the generator. These faults are mainly due to the insulation failure of the armature windings.

It includes :- (i) Phase to earth faults
(ii) Phase to Phase faults
(iii) inter-turn involving turns of same phase winding.

(i) Phase to earth faults:-

These faults mainly occurs in the armature slots. The faults are dangerous & can cause severe damage to the expensive machine.

If fault current less than 20A cause negligible burning of core if m/c is tripped quickly.

But if the fault currents are high, severe burning of stator core & may lead damage of laminations & hence need to the requirement of replacing the lamination i.e re-insulation and

& re-building of the core which is very costly & time consuming.

So to avoid the damage due to phase to earth faults, separate, sensitive earth fault protection is necessary for the generator.

(ii) Phase to Phase faults:-

It means short circuit b/w two phase windings. Such faults are uncommon because the insulation used between the coils of different phases in a slot is large i.e., at least twice as large as the insulation b/w one coil & the iron core.

However, a phase-to-earth fault may cause a phase-to-phase fault with in the slots, due to the over heating.

This fault is likely to occur at the end connections of the armature windings, i.e., in the overhanging parts outside the slots.

Such a fault cause severe arcing with high temperature may lead to melting of copper & risk of fire if the insulation is not made of fire-resistant material.

Circulating current biased differential protection gives adequate & fast protection against phase-to-phase faults in the generator zone.

iii) Stator inter-turn faults:-

The coils used in the alternators are generally multi turn coils. So short circuit b/w the turns of one coil may occur which is called an inter-turn fault.

This fault occurs due to current surges which may cause a high voltage ($L\,di/dt$) across the turns at the entrance of the stator winding.

If the stator winding is made up of single-turn coil with only one coil per slot, it is impossible to occur this inter-turn fault.

large m/c's of the order of 50 MVA and more, it is normal Practice to use single turn coils.

But in some countries, multi turn coils are very commonly used, therefore " Stator inter-turn fault Protection (or) Split-Phase protection is used to detect inter-turn faults.

Rotor fault :-

Rotor of an alternator is generally a field winding, it is made up of no. of turns.

So there may be ground faults or short b/w the turns of the field winding, caused by the severe mechanical and thermal stresses acting on the field winding insulation.

The field winding is generally not grounded and hence a single ground fault does not affect the operation of the generator or cause any damage.

However, a single rotor fault to earth increases the stress to the ground in the field when stator transients induce an extra voltage in the field winding.

Thus, the Probability of the occurrance of the second ground fault is increased.

In case second ground fault occurs, a Part of the field winding is byPassed, there by increasing the current through the remaining Portion of the field winding. This causes an unbalance in the airgap fluxes, there by creating an unbalance in the magnetic forces on opposite sides of the rotor.

The unbalancing in magnetic forces makes the rotor shaft eccentric, this causes vibrations.

The unbalanced loading on the generator is responsible to Produce negative sequence currents, which causes a negative sequence component of magnetic field.

It rotates in opposite direction to that of rotor magnetic field.

Due to this field, there is induced emf in the rotor winding, this causes overheating of the rotor.

Rotor earth fault Protection" & rotor temperature indica are the essential and are Provided to large rating generator.

(3) Abnormal Operating Conditions :-

These conditions involve :

(i) Unbalanced loading (ii) failure of Prime mover
(iii) Loss of excitation (iv) over loading (v) over speed
(vi) over voltage

(i) Unbalanced loading :-

The unbalanced loading of the generator results in the circulation of negative sequence currents.

These currents Produce the rotating magnetic field. This rotating magnetic field rotates at the synchronous speed with respect to rotor.

The direction of rotation of this magnetic field is opposite to that of rotor.

Hence effectively the relative speed b/w the two is double the synchronous speed.

Thus the emf gets induced, having double the normal frequency, in the rotor winding i.e of large magnitude.

The eddy current loss $\propto f^2$

& Hysteresis loss $\propto f^{1.6}$

There fore, both the losses increase due to these double frequency induced currents in the rotor

Thus, if the stator carries unbalanced currents, then it the rotor, which is over heated d.c rotor winding as well rotor stampings.

The reasons for the unbalanced load conditions are,

ⓐ Occurrance of unsymmetrical faults near the generating station.

ⓑ The failure of circuit breaker near the generating station

"Negative sequence Protection" is important to prevent dangerous situations due to negative sequence currents.

~~Explore of Parameter~~

The generator can be allowed to run under unbalance loading, depends upon the thermal withstand capacity of the machine, which in turn depends upon the type of cooling system adopted:

The rate of heat generation $\propto I_2^2 R$, while the heat energy is proportional to $I_2^2 R t$, where t = time and I_2 is negative sequence current.

$$I_2^2 R t = k$$

where k is for a particular m/c; safe dissipation energy

Assuming R to be constant & $K = k/R$; we get thermal characteristics of the m/c as $I_2^2 t = K$

$$\therefore \quad t \propto \frac{1}{I^2} \Rightarrow \text{inverse square characteristics}$$

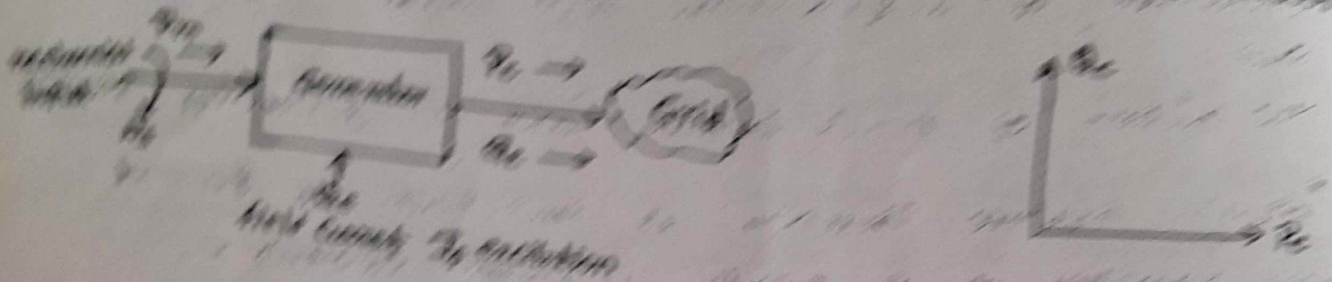
Thus an inverse type of over-current relay, which is fed with negative sequence component of the stator current, gives protection against unbalanced loading of the generator.

Sometimes an auxiliary ~~alarm~~ alarm relay is provided which gives warning when the maximum continuous permissible negative phase sequence current is exceeded.

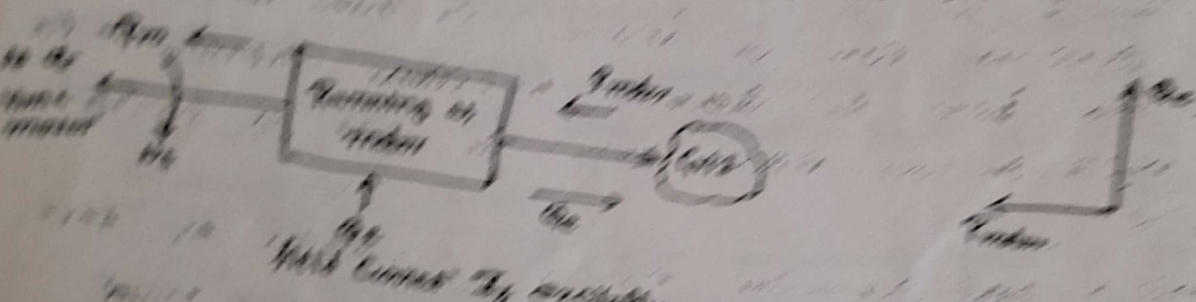
The relay normally used is an IDMT Relay. Due to this, it is called as negative sequence Relay.

(iii) Loss of Prime mover:

In case of loss of prime mover, i.e., loss of steam supply, the machine continues to remain synchronised with the grid, the alternator works as a synchronous motor.



(a) Before loss of Prime mover



(b) Loss of Prime mover

The machine, now draws a small amount of active power from the grid in order to drive the turbine and meet the losses taking place in the machine.

At the same time, the machine supplies reactive power to the grid since its excitation is still intact.

This condition is known as "inverted running".

Running in this mode is not harmful to the generator, but is definitely harmful to a prime mover like a steam turbine.

Normally, loss of steam supply to the turbine causes loss of prime mover, it may cause inverted running, which causes temperature rise & damage to the blades.

Therefore, the loss of Prime mover needs quick detection followed by tripping of generator.

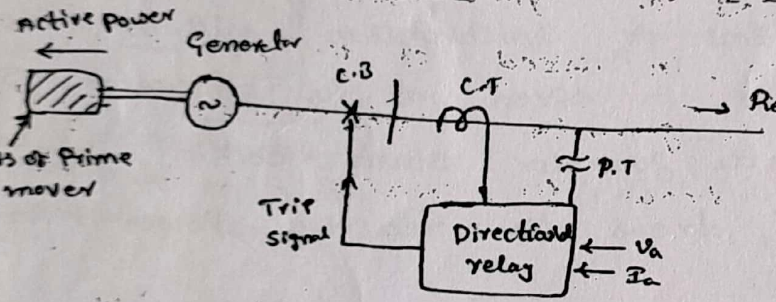
When the Prime mover is lost, generator starts drawing the Power from the grid which is quite small compared to generator rating.

The real Power drawn which is just enough to meet the losses & drive the turbine.

Hence, the magnitude of stator current is smaller than when it was generating, but the stator current undergoes 180° Phase shift. i.e., reverse Power flow.

Thus Protection against inverted running is achieved by applying directional relays to the alternators which isolate during motoring action.

i.e., During inverted running, there is a reversal of Power flow in the stator windings, this causes the operation of "reverse Power relay" i.e., "Directional relay".



(iii) **Loss of Excitation :-**

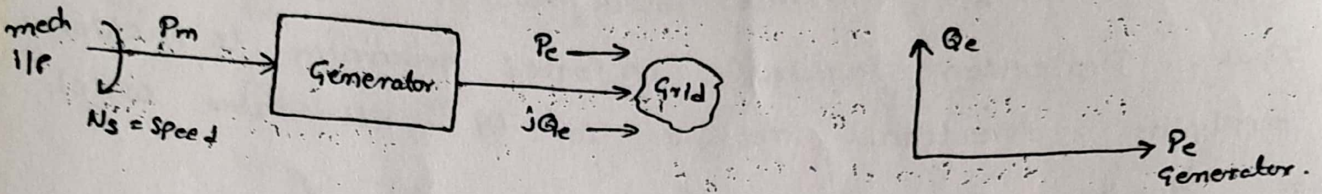
There are several possible causes due to which field excitation may be lost, namely:

- Loss of field to main exciter
- Accidental tripping of the field breaker.
- Short circuit in the field winding
- Poor brush contact in the exciter.
- field circuit breaker failure
- Loss of a.c supply to excitation system.

The generator delivers both real as well as reactive to the grid. The real Power comes from the turbine & the reactive Power is due to the field excitation.

Consider a generator delivering the complex Power, $S = P_e + jQ_e$ to the grid.

Corresponding to real Power P_e, there is the shaft mechanical Power input P_m & corresponding to reactive Power Q_e, there is the field current I_f, as shown in fig@.

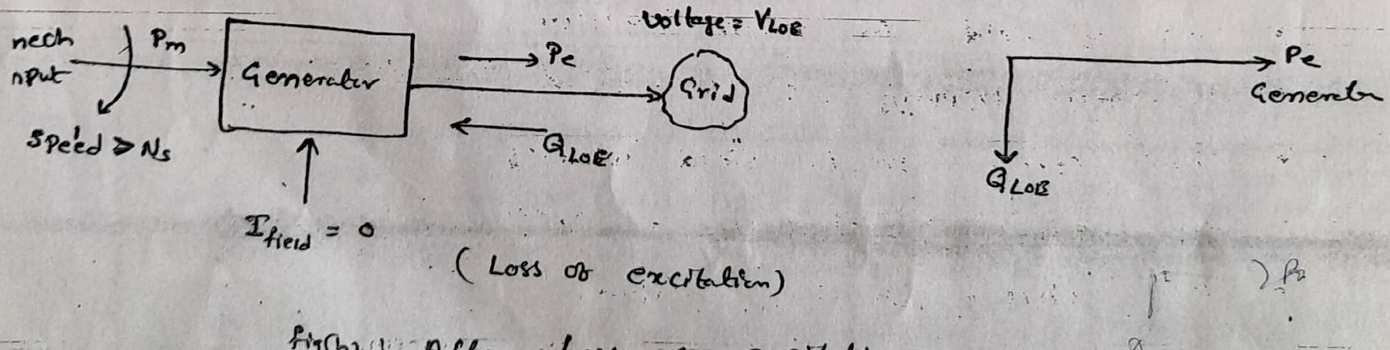


fig@ :- Before loss of excitation.

Now, consider the field excitation is lost while the mechanical input remains same.

which results in loss of synchronism with in a second and this causes increase in speed of the generator. Since Power input is same, the generator starts working as an induction generator, & draws the reactive Power from the bus (or) grid.

The machine starts drawing an exciting current from the system, which is equal to the full load rated value. This leads to the overheating of the stator winding & the rotor body due to induced currents.



(Loss of excitation)

fig(b) :- After Loss of excitation.

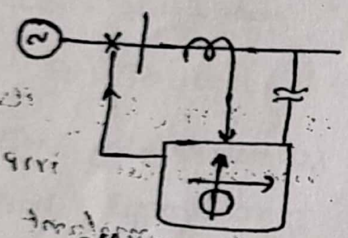
The loss of excitation may also lead to the Pole slipping condition which results in voltage reduction for the output.

The quantity which changes most when a generator loses field excitation is the impedance measured at the stator terminal.

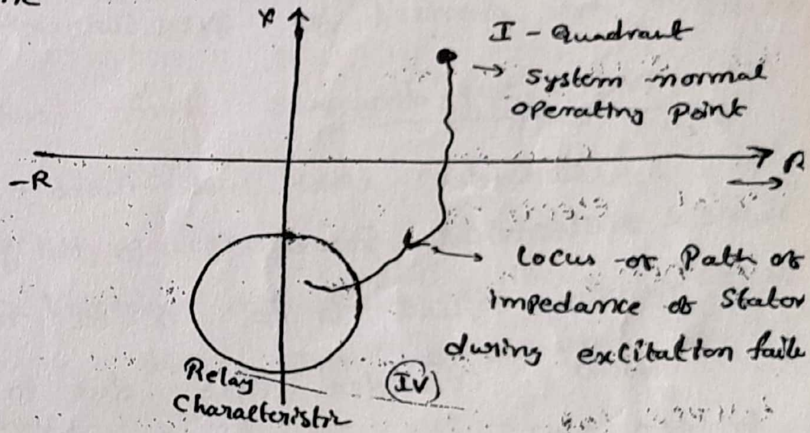
On loss of excitation, the terminal voltage begins to decrease and the current begins to increase, resulting in a decrease of impedance & also a change of P.f.

Thus, loss of excitation can be detected & protected by using offset mho relay located at the generator terminals.

During normal steady state operation, the impedance seen from the stator terminals i.e., the apparent impedance lies in quadrant I, of the R-X plane.



offset mho relay functioning as loss of excitation relay



After the loss of excitation, the apparent impedance enters quadrant IV.

The exact locus of the apparent impedance and the rate at which it is traced out depends upon the initial complex power that was being delivered by the generator.

If the initial power output was high then the locus is traced out quickly.

However, if the initial power was low, then the locus is trace out ~~Slowly~~ Slowly.

As soon as loss of excitation is detected by the relay, an alarm may be sounded & an attempt may be made to see if excitation can be restored.

This relay will trip the field breakers as well as the generator from the system.

(iv) **Over loading :-**

Due to the continuous over loading, the over heating of the stator results. This may increase the winding temperature.

If this temperature rise exceeds certain limit, the insulation of the winding may get damaged.

The degree of over loading decides the effect of temperature rise.

The over current protection is generally set to very high value hence continuous overloads of less value than the setting cannot be sensed by over current protection.

(v) **Over - speeding :-**

Consider that a turbo - alternator is supplying its rated real electrical power Pe to the grid. Its mechanical input Pm is nearly equal to Pe if the machine runs at constant speed.

Now, consider that due to some fault the generator is tripped (or) disconnected from the grid (or) sudden loss of all & major part of load on the alternator.

Thus, Pe becomes zero.

However, the mechanical power input Pm cannot be suddenly reduced to zero.

This would cause the machine to accelerate to dangerously high speeds, if the mechanical input is not quickly reduced by the speed - governing mechanism.

The protection against over speed is obtained by operating the steam valve so as to stop steam input to the turbine.

The speed - governing mechanism or the speed governor of the turbine is basically responsible for detecting this condition e over speeding can also be detected either by an "over-quency relay" (or) by monitoring the output of the tachogenerator mounted on the generator shaft.

Also the reduction in output can be detected using a "watt-metric relay" at the generator terminals which operates instantaneously to close its contacts.

vi) Over Voltage Protection:-

The over voltages are basically due to the over speeding of generator, another reason is the faulty operation of voltage regulators.

Not only the internal over voltages are dangerous but also atmospheric surge voltages which are generated by direct lighting strokes can also reach to the generator.

To protect the generators from surge voltages, the surge arresters & surge capacitors are often used.

At the time of restricking across the contacts of circuit breakers, the transient over voltages get generated. Such surge are called switching surges. & these can be limited by the use of modern circuit breakers.

Another situation, when the transient over voltages are generated, is when the arc's are generated.

During arcing grounds, the transient voltages having amplitudes five times more than the normal line to neutro peak amplitude are generated.

Such transient voltages are dangerous and can be reduced by using resistance earthing.

Merz

- Price Protection of Alternator Stator windings :- (7)

This scheme is also called biased differential Protectio[n] and Percentage differential Protection.

In this method, the currents at the two ends of the Protected section are sensed using current T/F's.

The wires connecting relay coils to the current Transform[er] secondaries are called Pilot wires.

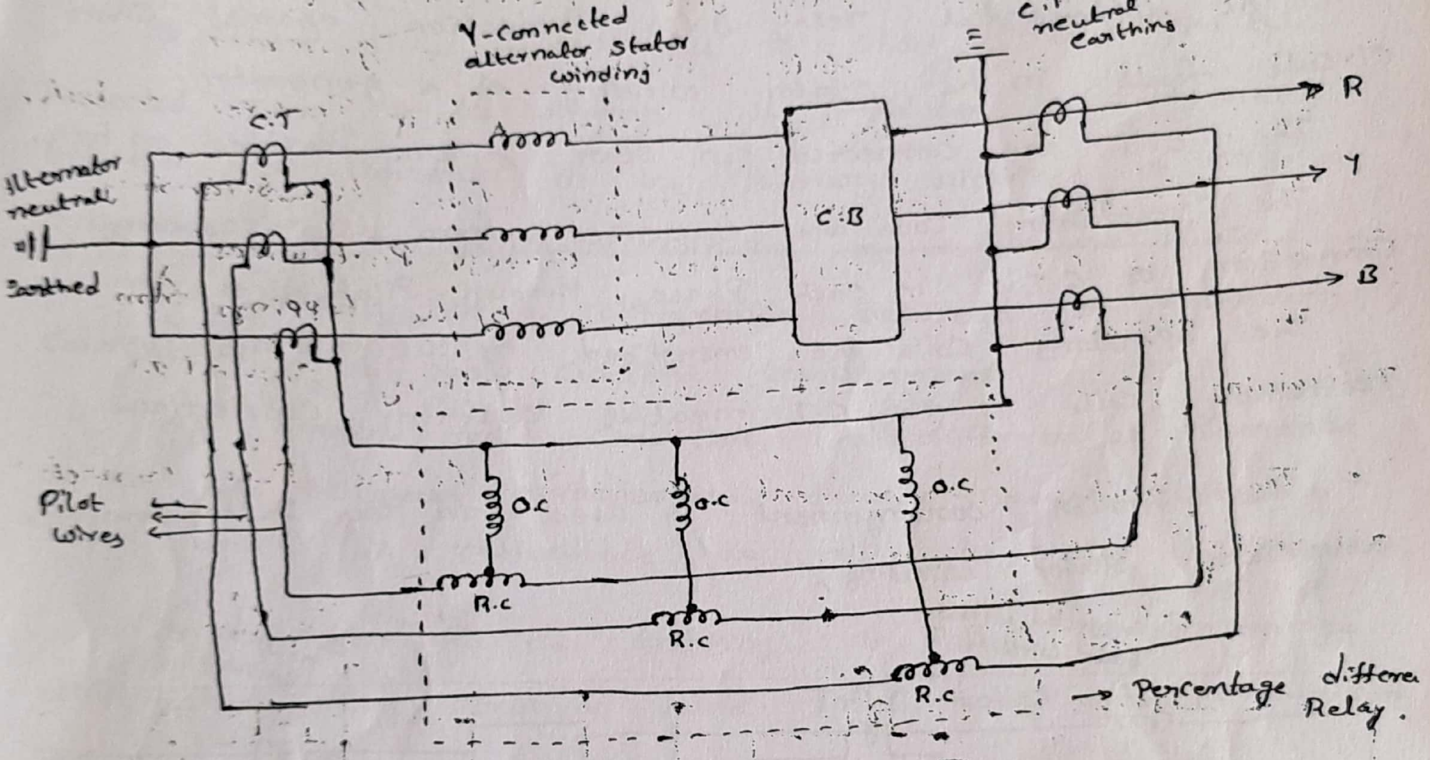


fig:- merz - Price Protection for star connected alternator.

under normal conditions, when there is no fault in the windings, the currents in the Pilot wires fed from C.T secondaries are equal.

The differential current $i_1 - i_2$ through the operating coils of the relay is zero.

Hence the relay is in-operative & system is said to be balanced.

When fault occurs inside the Protected section of the C.T's windings, the differential current $i_1 - i_2$ flows through the operating coils of the relay.

Due to this relay operates. This trips the generator to isolate the faulty section.

Fig shows a schematic arrangement of merz-Price Protection for a star connected alternator.

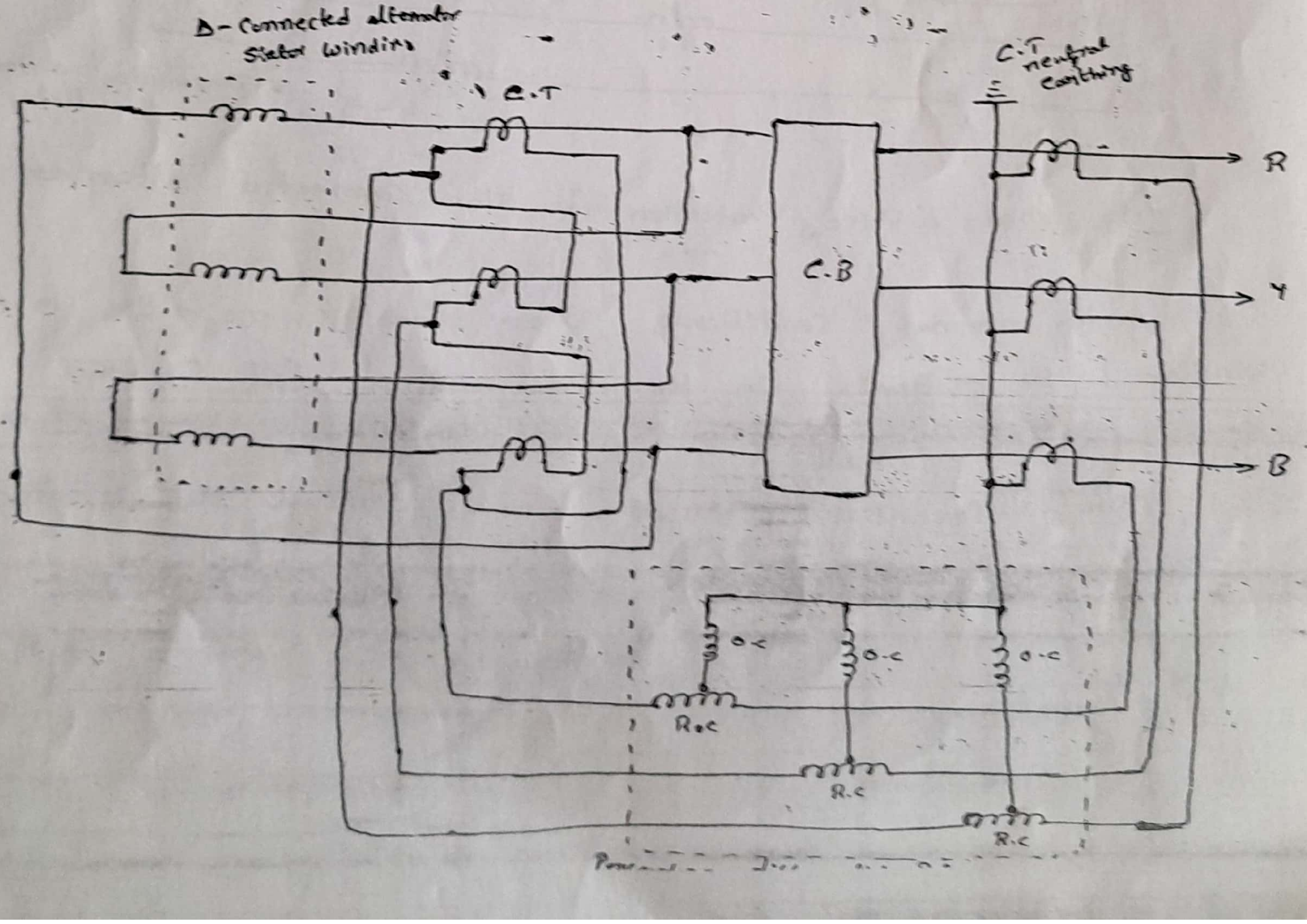
The differential relay gives Protection against short circuit fault in the stator winding of a generator.

The CT's are connected in star & are Provided on both,

The restraining coils are energized from the secondary connection of C.T's in each Phase, through Pilot wires.

The operating coils are energized by the tappings from restraining coils & the C.T neutral earthing connection.

- The similar arrangement is used for the Delta Connected alternator stator winding,



the C.T's on delta connected machine winding side are connected in delta while the C.T's at outgoing side ends are connected in star.

The restraining coils are placed in each Phase, energized by the secondary connections of C.T's while the operating coils are energized from the restraining coil tappings & the C.T neutral earthing.

If there is a fault due to short circuit in the Protected zone of the windings, it Produces a difference between the currents in the Primary windings of C.T's on both sides of the generator winding of the same Phase.

This results in a difference between the secondary currents of the two current transformers.

Thus under fault conditions, a differential currents ~~of the two current transformers~~ flows through operating coils which is responsible to trip the relay & opens C.B.

In addition to the tripping of C.B, the Percentage differential relay trip a hand reset multi contact auxiliary relay.

This auxiliary relay simultaneously initiates the following operations,

(1) Tripping of the main C.B of generator.
(2) Tripping of the field C.B.
(3) " " " neutral C.B if it is Present.
(4) Shut down of the Prime mover.
(5) Operation of alarm, to indicate the occurance of the fault & the operation of the relay the field must be opened immediately otherwise it starts feeding the fault.

When differential relaying is used for the Protection, CTs at both the ends of generator must be of equal ratio and equal accuracy, otherwise wrong operation of the relay may result. The main cause is due to ratio error, unequal secondary burden.

This scheme provides very fast protection to the stator winding against phase-to-phase faults & phase-to-ground faults.

Restricted Earth fault Protection of Generator :-

When the neutral is solidly grounded then the generator gets completely protected against earth faults.

But when neutral is grounded through earth resistance then to limit ground fault currents, but it is not possible to protect the complete winding against earth faults.

The Percentage of winding protected depends on the value of earthing resistance and the relay setting.

If an earth fault occurs near the neutral end of the winding, then the insufficient voltage across the fault drives very low fault current than the pick up current of relay coil. This current is further reduced by the use of neutral grounding.

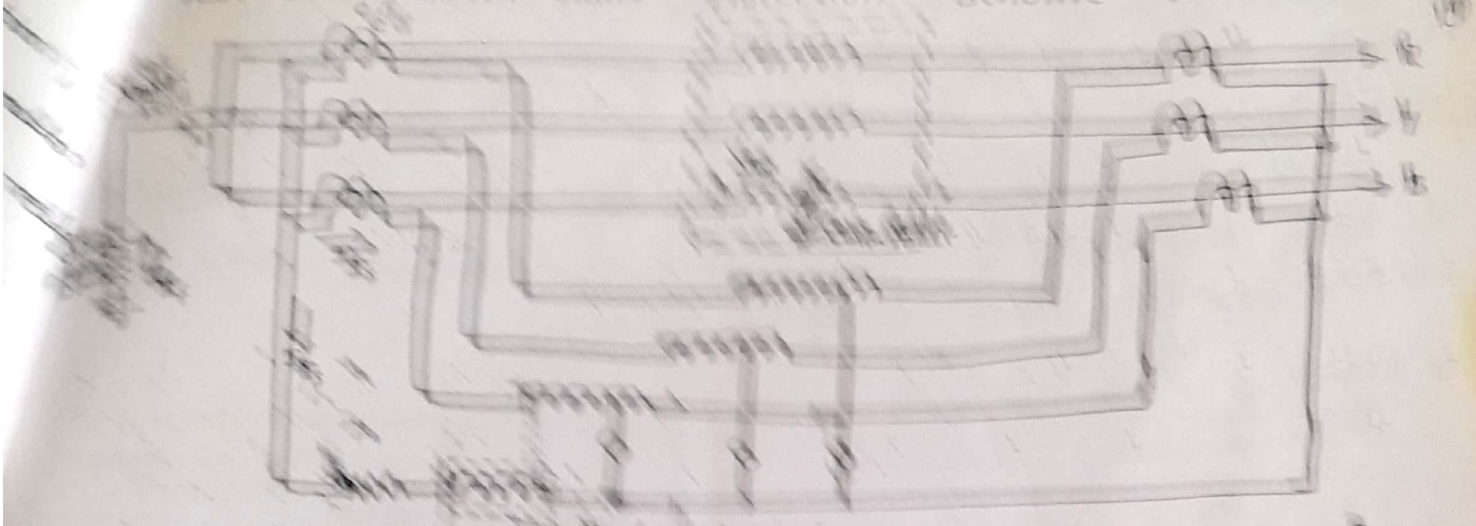
Hence the relay coil remains In-operative.

Thus 15 to 20% winding from the neutral side remains unprotected in this scheme i.e. merz price protection.

Hence it is called Restricted earth fault Protection.

The usual practice is to protect 80 to 85% of the generator winding against ground fault.

Restricted Earth Fault Protection scheme is shown in fig.



Restricted Earth fault relay

Consider the earth fault occurs on phase R due to break down of its insulation to earth, I_F will flow through the core or machine to earth & complete the path through the earthing resistance.

The CT secondary current I_s flows through the operating coil with the restricted earth fault relay coil of the differential protection.

The setting of restricted earth fault relay and setting of overcurrent relay are independent of each other.

Under this secondary current I_s, the relay operates to trip the C.B. The volt V_{an} is sufficient to drive the enough fault current I_F when the fault point 'x' is away from the neutral point.

If the fault point 'x' is nearer to the neutral point then the voltage V_{an} is small and not sufficient to drive enough fault current I_F, & relay cannot operate.

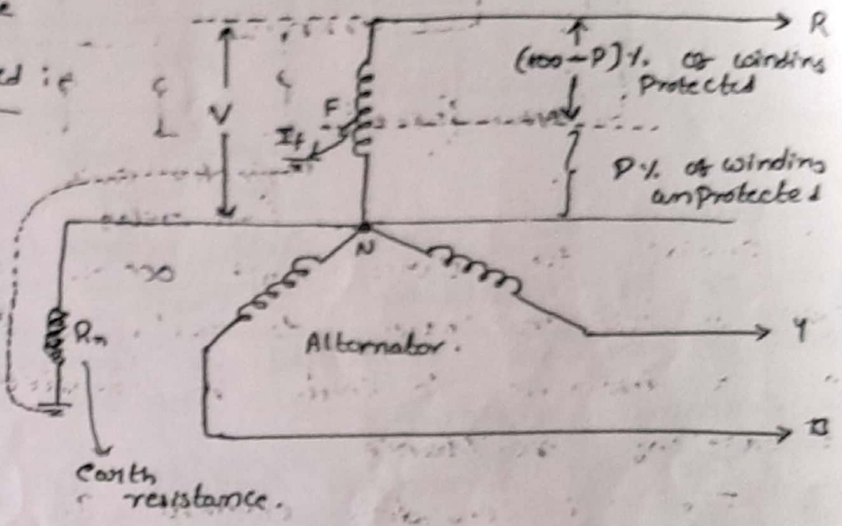
Thus part of the winding from the neutral point remain unprotected.

To overcome this, if relay setting is chosen very low to make it sensitive to low fault currents, then the wrong operation of the relay may result.

Because, if the relay is made too sensitive, it responds during through faults or other faults due to inaccuracies of CT's, saturation of CT's etc.

Hence Practically 15% of winding from the neutral & earth is kept unprotected, Protecting the remaining 85% of the winding against Phase to earth faults.

→ **Effect of Earth Resistance on % of winding unprotected :-**



Consider the earth resistance R_n used to limit earth fault current.

If R_n is very small i.e., neutral is almost solidly grounded, then the fault currents is very high.

But such high fault currents are not desirable, hence small R_n is not Preferred for the large machines.

For low resistance R_n, the value of R_n is selected such that full load current passes through the neutral, for a full line to neutral voltage 'V'.

In medium resistance R_n, the earth fault current is limited to about 200A for full line to neutral voltage 'V', for a 60MW m/c.

In high resistance R_n, the earth fault current is limited to about 10A. This is used for distribution transformers and Generator - transformer units.

Higher the value of R_n, less is the earth fault current & less Percentage of winding gets Protected.

Large Percentage of winding remains unprotected.

(19)

Assuming R_n is earth resistance, and the fault current for earth to ground fault is equal to full load current of the generator, the value of resistance to be inserted in neutral to earth connections is given by $R_n = \frac{V}{I}$

Where V = line to neutral voltage

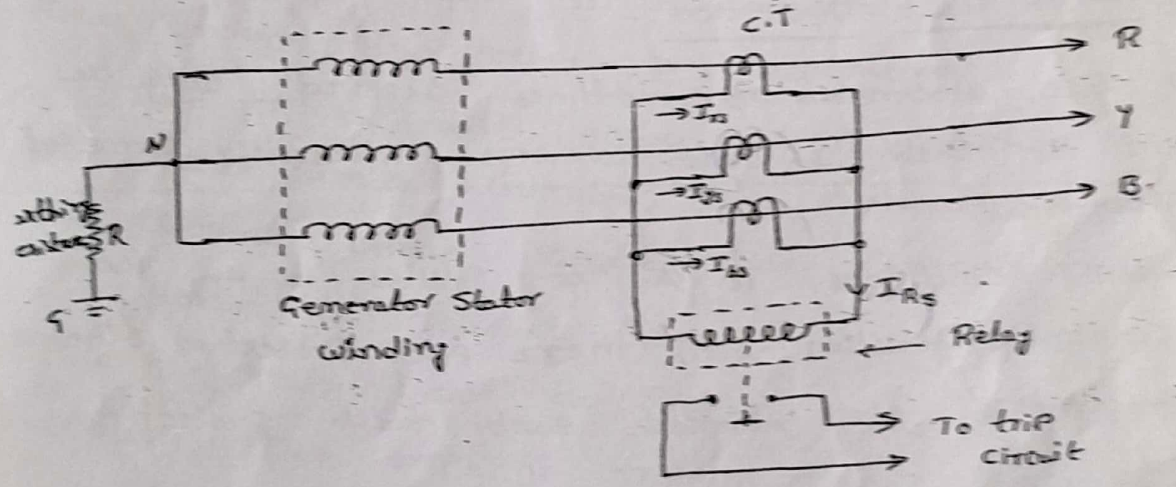
I = full load current of largest m/c

∴ % of winding unprotected $= \frac{R \times I_0}{V} \times 100$

I_0 = minimum operating current in primary of CT.

Unrestricted Earth fault Protection :-

It uses a residually connected earth fault relay. It consists of 3 C.T's, one in each phase. The secondary windings of these C.T's are connected in parallel. The earth fault relay is connected across the secondaries which carries a residual current.



When there is no fault, under normal conditions, vector sum of the three line currents is zero.

So if I_{rs}, I_{ys} and I_{bs} are C.T secondary currents then under normal conditions, we can write

$$\bar{I}_{rs} + \bar{I}_{ys} + \bar{I}_{bs} = 0$$

The sum of the three currents is residual current I_{Rs} which is zero under normal conditions.