SWITCH GEAR AND PROTECTION

LECTURE NOTE

DEPT OF ELECTRICAL ENGG.

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CIRCUIT BREAKER

INTRODUCTION:

During the operation of power system, it is often desirable and necessary to switch on or off the various circuit under normal and abnormal conditions. In earlier days this function is used to performed by switches and fuse placed in series with the circuit. How ever such a means of control posses two advantages:

a. When fuse blows it takes quite some time to replace it and restore supply to the customer.

b. Fuse can't successfully interrupt high fault current.

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

With the advancement of power system, the lines and other equipment operate at very high voltage and carry large currents. The arrangement of switches along with fuse can't serve the desired function of switchgear.

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

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 circuit breaker essentially consists of a moving part and fixed contact called electrodes. Under normal operating condition these contacts remain closed and will not open automatically unit and unless the system become faulty. These contacts can operate manually and automatically when-ever it is desired.
When fault occurs in any part of the systems the trip coil become energised and moving contacts are pulls apart from fixed contact, thus opens up 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 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.

Operating principle:

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

a. 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.

b. 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.

c. Therefore, the main problem in a circuit breaker is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

Arc Phenomenon:

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

a. The potential difference between contacts are quite small and it is sufficient to maintain arc.

b. The arc provides a low resistance path and consequently the current in the circuit remains UN interrupted so long as the arc persists.

c. During the arcing period, the current flowing between the contacts depends upon the arc resistance. The greater the arc resistance, the smaller the current that flows between the contacts.

The arc resistance depends upon the following factors:

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

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

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

Principles of Arc Extinction:

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

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

- When the contacts have a small separation, the Potential difference between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that Potential difference becomes inadequate to maintain the arc. However, this method is impracticable in high voltage system where a separation of many meters may be required.

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

Methods of Arc Extinction (or) Interruption:

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

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

High resistance method:

In this method, arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc. Consequently, the current is interrupted or the arc is extinguished.

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

The resistance of the arc may be increased by:

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

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

3. **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.
4. **Splitting the arc**: The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthening and cooling. The arc may be split by introducing some conducting plates between the contacts.

Low resistance or Current zero method:

In this method is employed for arc extinction in a.c. circuits only. In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally and is prevented from restriking in spite of the rising voltage across the contacts. All Modern high power a.c. circuit breakers employ this method for arc extinction.

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

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

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

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

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

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

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

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

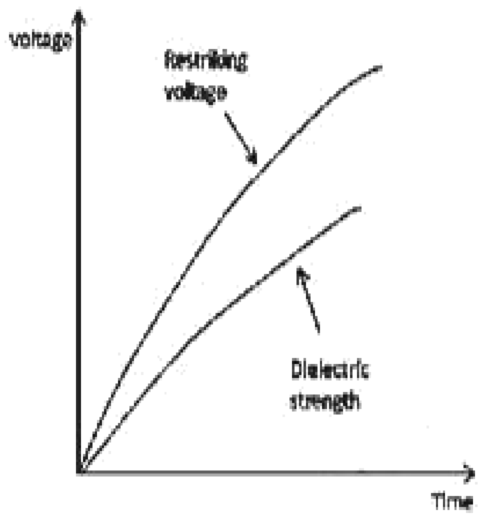
4. **Blast effect:** If the ionized particles between the contacts are swept away and replaced by UN ionized particles, the dielectric strength of the medium can be increased considerably. This may be achieved by a gas blast directed along the discharge or by forcing oil into the contact space.

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

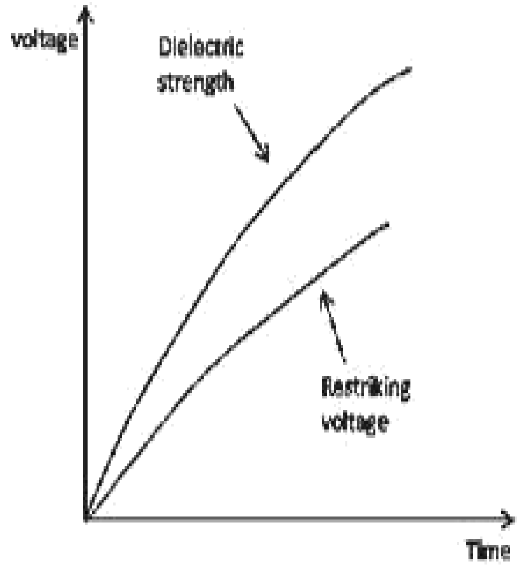
1. Recovery rate theory (Slepain's Theory)
2. Energy balance theory (Cassie's Theory)

Recovery rate theory (Slepain's Theory):

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



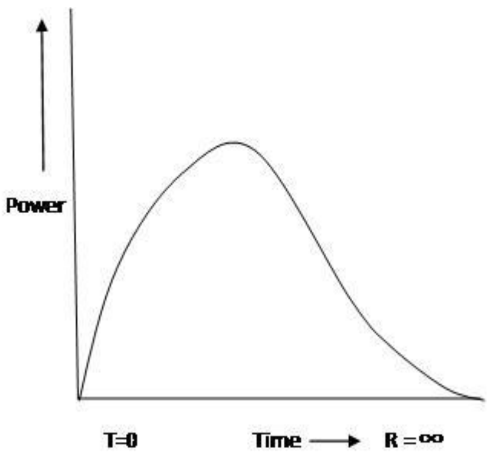
(a) Arc Extinguishes



(b) Arc Persists

Energy balance theory (Cassie's Theory):

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



Important Terms:

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

1. **Arc Voltage:**

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

2. **Restriking voltage:**

It is the transient voltage that appears across the contacts at or near current zero during arcing period. At current zero, a high-frequency transient voltage appears across the contacts and is caused by the rapid distribution of energy between the magnetic and electric fields associated with the plant and transmission lines of the system. This transient voltage is known as restriking voltage (Fig. 19.1).

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

3. **Recovery voltage:**

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

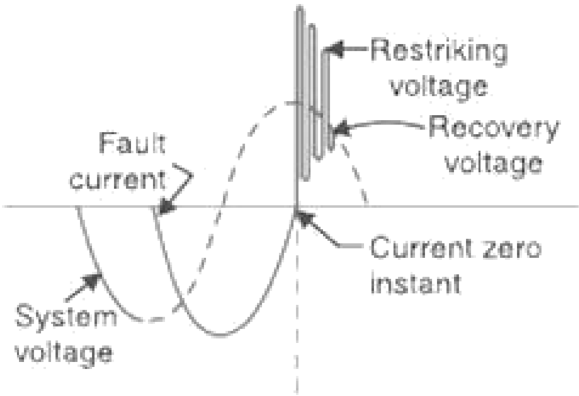
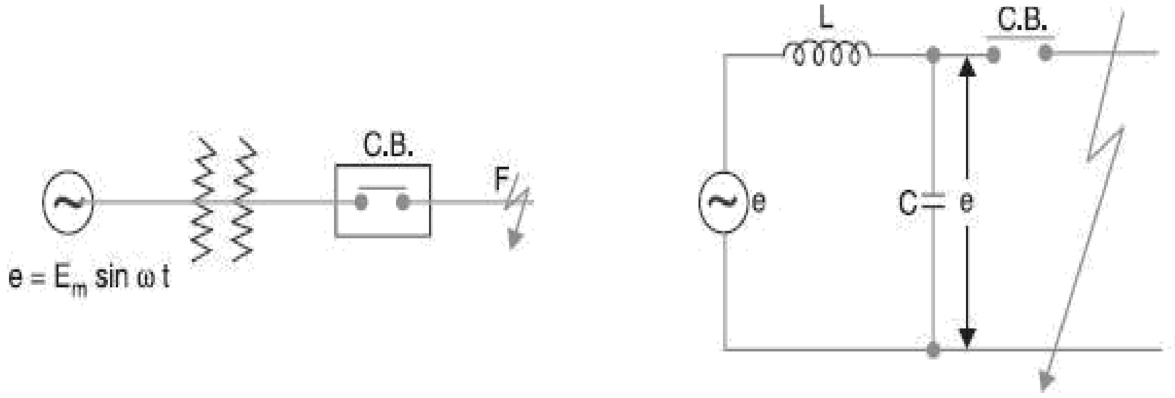


Fig. 19.1

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

Expression for Restriking voltage and RRRV:

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



(*i*) (*ii*)

Fig. 19.17

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

Rate of rise of re-striking voltage:

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

Consider the opening of a circuit breaker under fault conditions Shown in simplified form in Fig. 19.17 (ii) above. Before current interruption, the capacitance C is short-circuited by the fault and the short-circuit current through the breaker is limited by Inductance L of the system only. Consequently, the short-circuit current will lag the voltage by 90º as shown in Fig. 19.18, where I Represents the short-circuit current and ea represents the arc voltage. It may be seen that in this condition, the *entire generator voltage appears across inductance L.

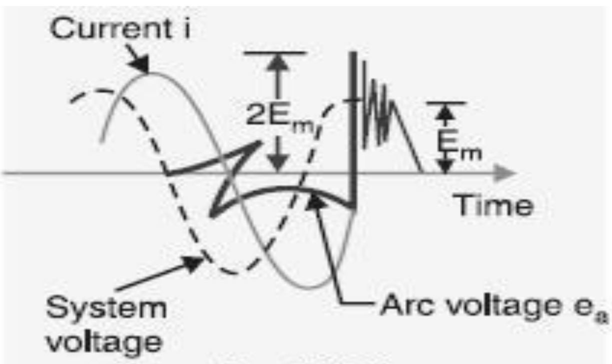


Fig. 19.18

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

This L - C combination forms an oscillatory circuit and produces a transient of frequency: $f_n = \frac{1}{2\pi LC}$

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

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

$v_c(t)=E(1-\cos w_n t)$ or $v_c(t)=E(1-\cos \frac{1}{\,} t)$ = Restriking voltage

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

The rate of rise of restriking voltage (RRRV) = — $(1 - \cos w_n t)$

$= w_n E \sin w_n t$

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

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

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

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

1. Recovery voltage
2. Natural frequency of oscillations

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

Current chopping:

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

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

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

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

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

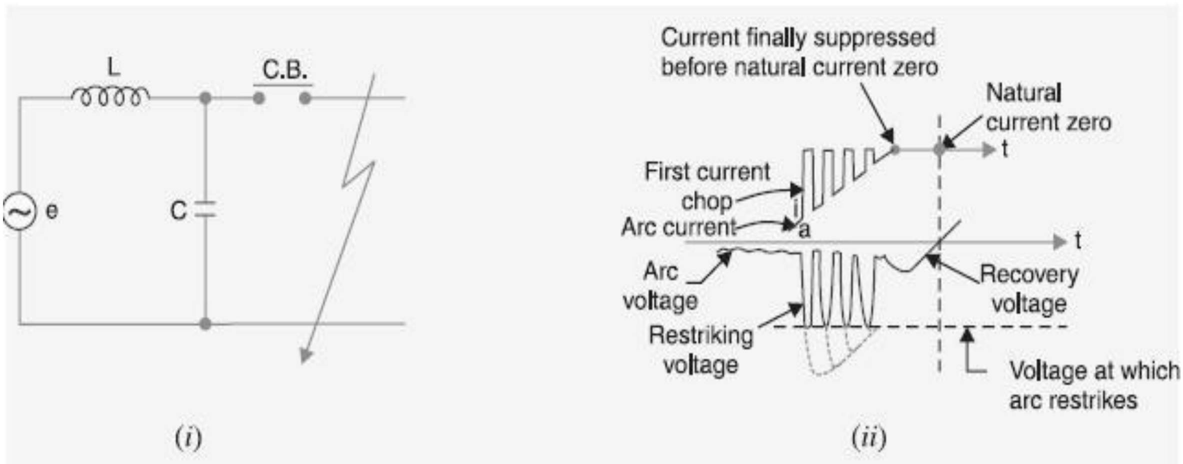


Fig. 19.19

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

Capacitive current breaking:

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

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

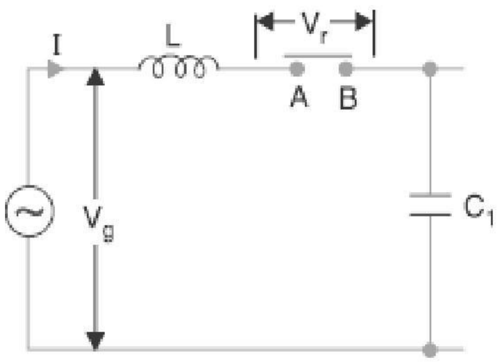


Fig. 19.20

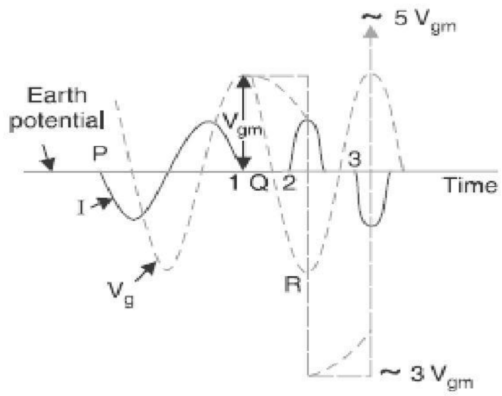


Fig. 19.21

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

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

Resistance Switching:

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

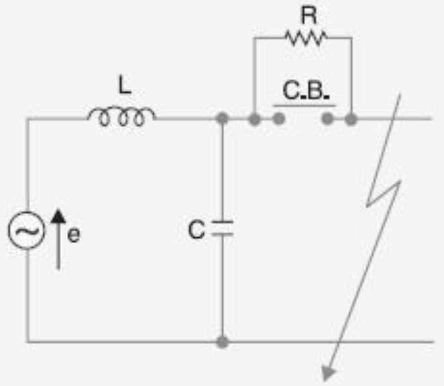


Fig. 19.22

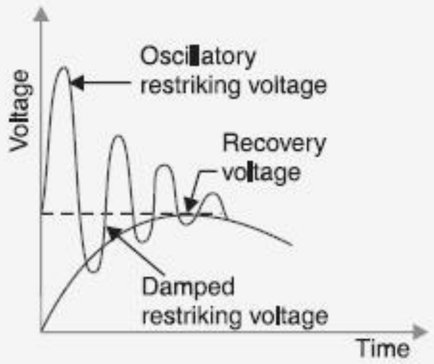


Fig. 19.23

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

The voltage equation is given by

$$L\frac{di}{dt} + \frac{1}{C}\int i_C \, dt = E \quad \text{and} \quad i = i_c + i_R$$

Therefore, the above equation become

$$L\frac{d(i_c + i_R)}{dt} + v_c = E$$

or

$$L\frac{di_c}{dt} + L\frac{di_R}{dt} + v_c = E$$

$$i_c = \frac{dq}{dt} = \frac{d(Cv_c)}{dt}$$

Therefore,

$$\frac{di_c}{dt} = \frac{d^2(Cv_c)}{dt^2} = C\frac{d^2v_c}{dt^2}$$

$$\frac{di_R}{dt} = \frac{d(v_c/R)}{dt} = \frac{1}{R}\frac{dv_c}{dt}$$

Substituting these values in the main equation, we get

$$LC\frac{d^2v_c}{dt^2} + \frac{L}{R}\frac{dv_c}{dt} + v_c = E$$

Taking Laplace Transform, we get

$$LCS^2v_c(S) + \frac{L}{R}S\,v_c(S) + v_c(S) = \frac{E}{S}$$

Other terms are zero, as $v_c = 0$ at $t = 0$

or

$$LCv_c(S)\left[S^2 + \frac{1}{RC}S + \frac{1}{LC}\right] = \frac{E}{S}$$

or

$$v_c(S) = \frac{E}{SLC\left[S^2 + \frac{1}{RC}S + \frac{1}{LC}\right]}$$

For no transient oscillation, all the roots of the equation should be real. One root is zero, i.e. $S = 0$ which is real. For the other two roots to be real, the roots of the quadratic equation in the denominator should be real. For this, the following condition should be satisfied.

$$\left[\left(\frac{1}{2RC}\right)^2 - \frac{1}{LC}\right] \geq 0 \quad \text{or} \quad \frac{1}{4R^2C^2} \geq \frac{1}{LC}$$

or

$$\frac{4}{LC} \leq \frac{1}{R^2C^2} \quad \text{or} \quad R^2 \leq \frac{LC}{4C^2}$$

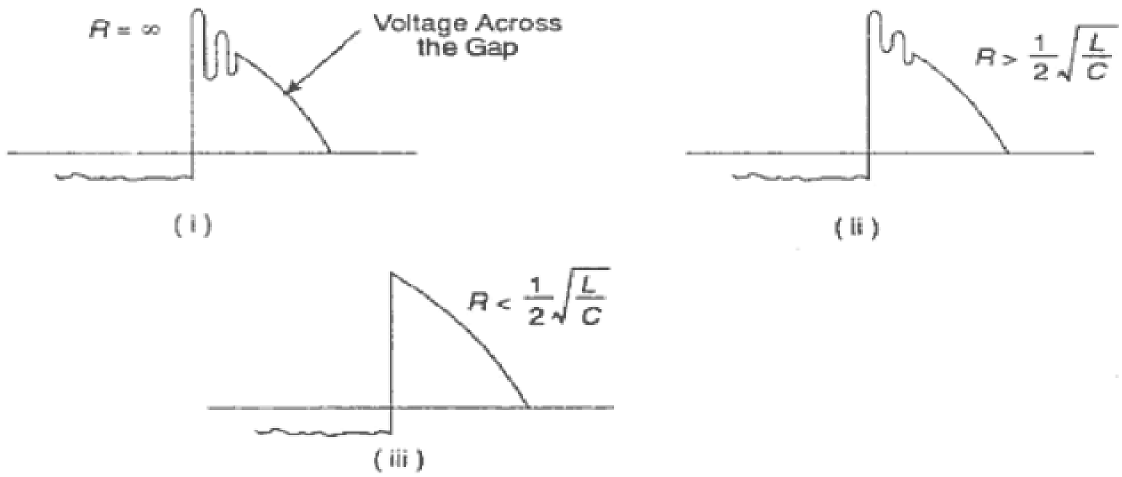


FIGURE 9.9 Transient oscillations for different values of R

or $$R^2 \leq \frac{1}{4} \cdot \frac{L}{C} \quad \text{or} \quad R \leq \frac{1}{2}\sqrt{\frac{L}{C}}$$

Therefore, if the value of the resistance connected across the contacts of the circuit breaker is equal to or less than $\frac{1}{2}\sqrt{L/C}$ there will be no transient oscillation. If $R > \frac{1}{2}\sqrt{L/C}$, there will be oscillation. $R = \frac{1}{2}\sqrt{L/C}$ is known as critical resistance. Figure 9.9 shows the transient conditions for three different values of R.

The shunt resistor also helps in limiting the oscillatory growth of re-striking voltage. It can be proved mathematically that natural frequency of oscillations (or) the frequency of damped oscillation of the circuit shown in Fig. 19.22 is given by:

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

The effect of shunt resistance R is to prevent the oscillatory growth of re-striking voltage and cause it to grow exponentially up to recovery voltage. This is being most effective when the value of R is so chosen that the circuit is critically damped. The value of R required for critical damping is 0.5 . Fig. 19.23 shows the oscillatory growth and exponential growth when the circuit is critically damped.

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

1. To reduce the rate of rise of re-striking voltage and the peak value of re-striking voltage.
2. To reduce the voltage surges due to current chopping and capacitive current breaking.
3. To ensure even sharing of re-striking voltage transient across the various breaks in multi break circuit breakers.

It may be noted that value of resistance required to perform each function is usually different. However, it is often necessary to compromise and make one resistor do more than one of these functions.

Switchgear Components:

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

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

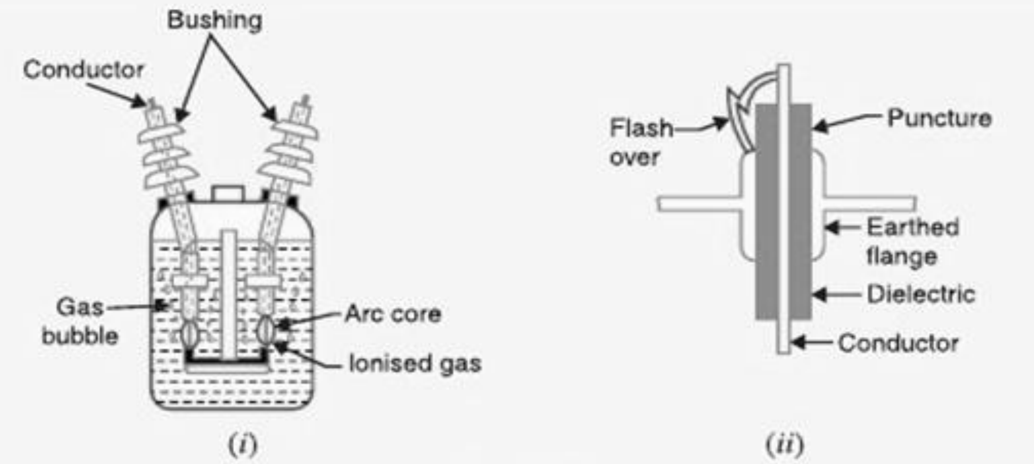


Fig. 19.13

Bushings:

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

Circuit breaker contacts:

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

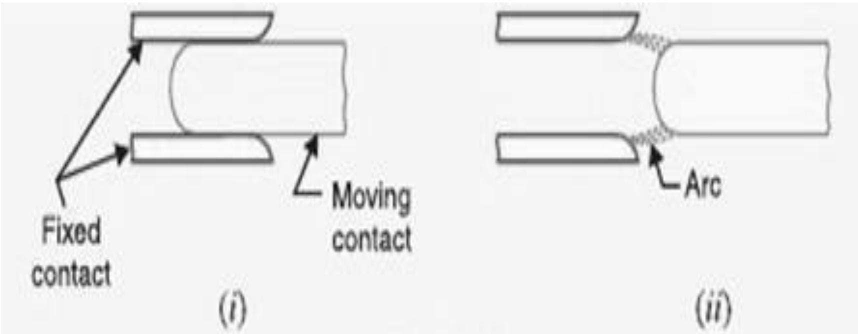


Fig. 19.14

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

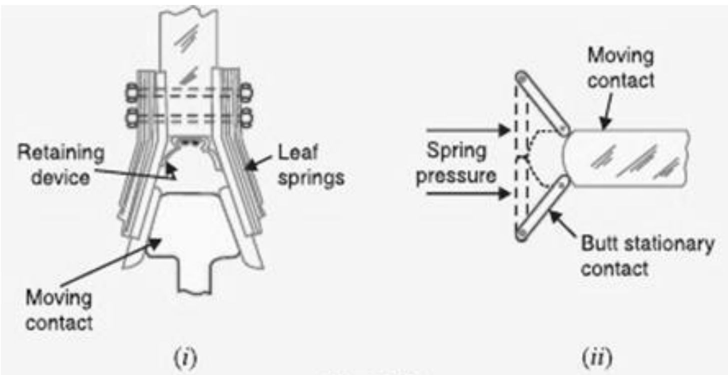


Fig. 19.15

(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. Secondly, there is no grip force so that this type of contact is especially suitable for higher short circuit rating.

Instrument transformers:

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

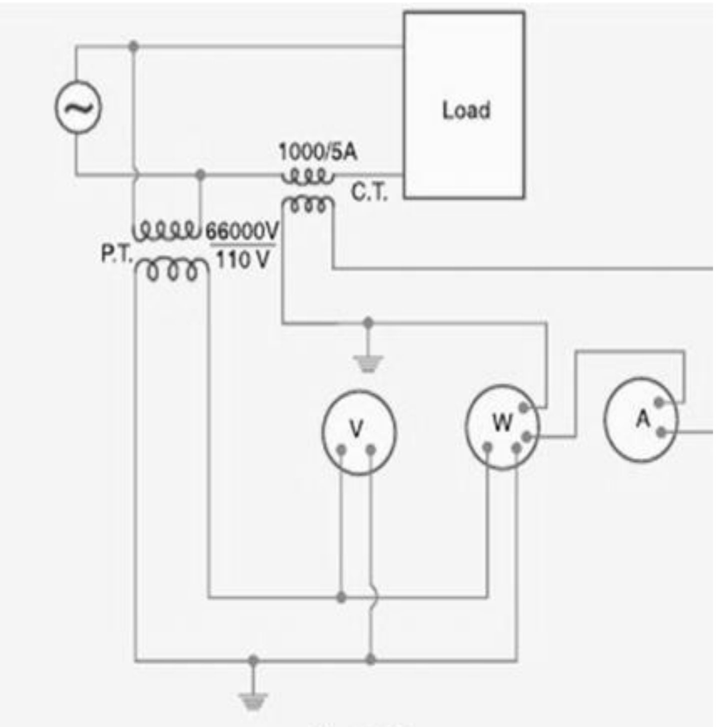


Fig. 19.16

There are two types of instrument transformers viz.

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

The primary of current transformer is connected in the power line. The secondary winding provides for the instruments and relays a current which is a constant fraction of the current in the line similarly, a potential transformer is connected with its primary in the power line. The secondary provides for the instruments and relays a voltage which is a known fraction of the line voltage. Fig. 19.16 shows the use of instrument transformers. The *potential transformer rated 66,000/110V provides a voltage supply for the potential coils of voltmeter and wattmeter. The current transformer rated 1000/5 A supplies current to the current coils of wattmeter and ammeter.

The use of instrument transformers permits the following advantages:

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

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

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

Circuit Breaker Ratings:

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

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

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

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

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

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

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

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

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

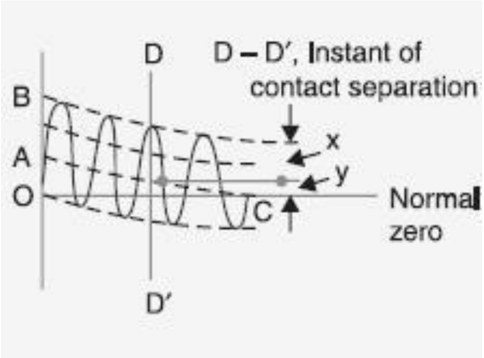


Fig. 19.24

x = maximum value of a.c. component

y = d.c. component

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

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

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

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

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

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

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

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

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

Making capacity:

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

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

It may be noted that the definition is concerned with the first cycle of current wave on closing the circuit breaker. This is because the maximum value of fault current possibly occurs in the first cycle only when maximum asymmetry occurs in any phase of the breaker. In other words, the making current is equal to the maximum value of asymmetrical current. To find this value, we must multiply symmetrical breaking current by $\sqrt{2}$ to convert this from r.m.s. to peak, and then by 1·8 to include the ―doubling effect‖ of maximum asymmetry. The total multiplication factor becomes $\sqrt{2} \times 1 \cdot 8 = 2 \cdot 55$.

Making capacity =2·55 X Symmetrical breaking capacity

Short-time rating:

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

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

The oil circuit breakers have a specified limit of 3 seconds when the ratio of symmetrical breaking current to the rated normal current does not exceed 40. However, if this ratio is more than 40, then the specified limit is 1 second.

Normal current rating:

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

Circuit Breaker

Classification of Circuit Breakers:

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

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

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

Oil Circuit Breakers:

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

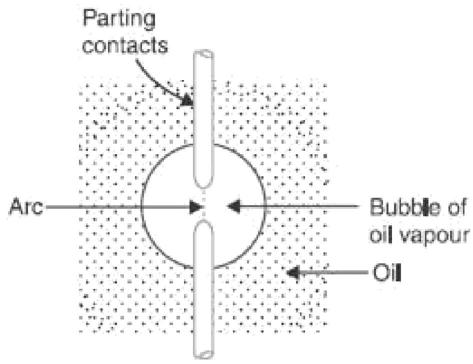


Fig. 19.2

The advantages of oil as an arc quenching medium are:

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

The disadvantages of oil as an arc quenching medium are:

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

Types of Oil Circuit Breakers:

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

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

Bulk oil circuit breakers:

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

1. Plain break oil circuit breakers

2. Arc control oil circuit breakers.

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

Plain Break Oil Circuit Breakers:

A plain-break oil circuit breaker involves the simple process of separating the contacts under the whole of the oil in the tank. There is no special system for arc control other than the increase in length caused by the separation of contacts. The arc extinction occurs when a certain critical gap between the contacts is reached. The plain- break oil circuit breaker is the earliest type from which all other circuit breakers have developed. It has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather-tight earthed tank containing oil up to a certain level and an air cushion above the oil level. The air cushion provides sufficient room to allow for the reception of the arc gases without the generation of unsafe pressure in the dome of the circuit breaker. It also absorbs the 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.

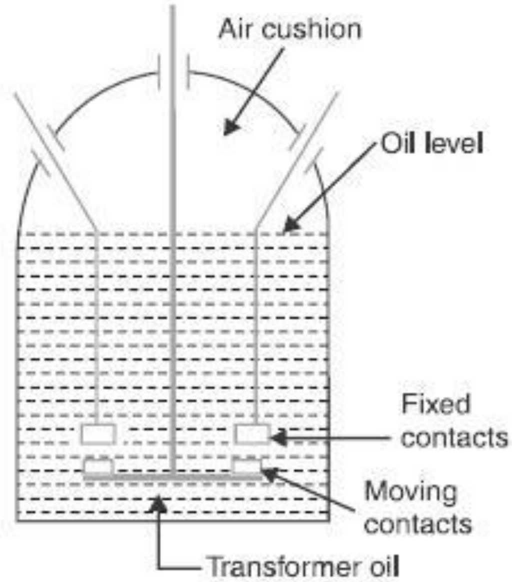


Fig. 19.3

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 vaporizes the oil mainly into hydrogen gas.

The arc extinction is facilitated by the following processes:

- The hydrogen gas bubble generated around the arc cools the arc column and aids the deionization of the medium between the contacts.
- The gas sets up turbulence in the oil and helps in eliminating the arcing products from the arc path.
- 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:

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

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

Arc Control Oil Circuit Breakers:

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

There are two types of such breakers, namely:

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

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

Self-blast oil circuit breakers:

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

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

Plain explosion pot:

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

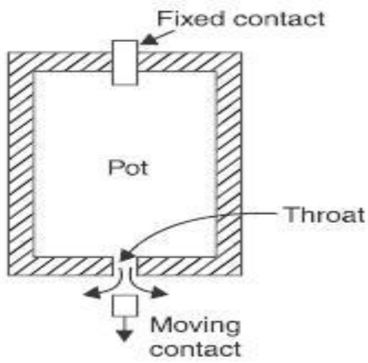


Fig. 19.4

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

Cross jet explosion pot:

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

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

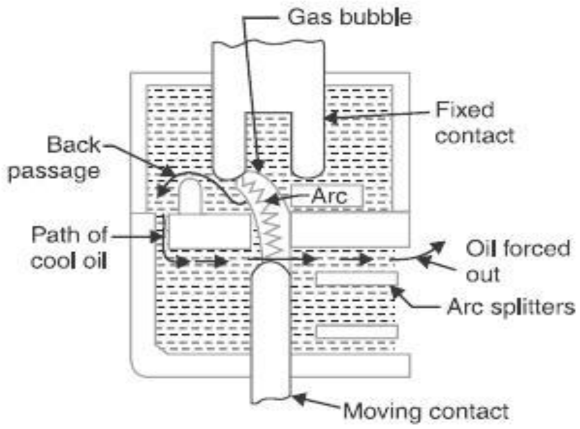


Fig. 19.5

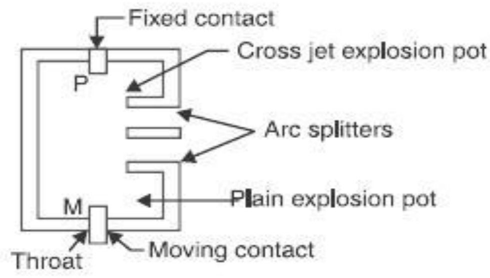


Fig. 19.6

Self-compensated explosion pot:

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

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

Forced-blast oil circuit breakers:

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

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

Advantages:

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

2. The quantity of oil required is reduced considerably.

Low Oil Circuit Breakers:

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

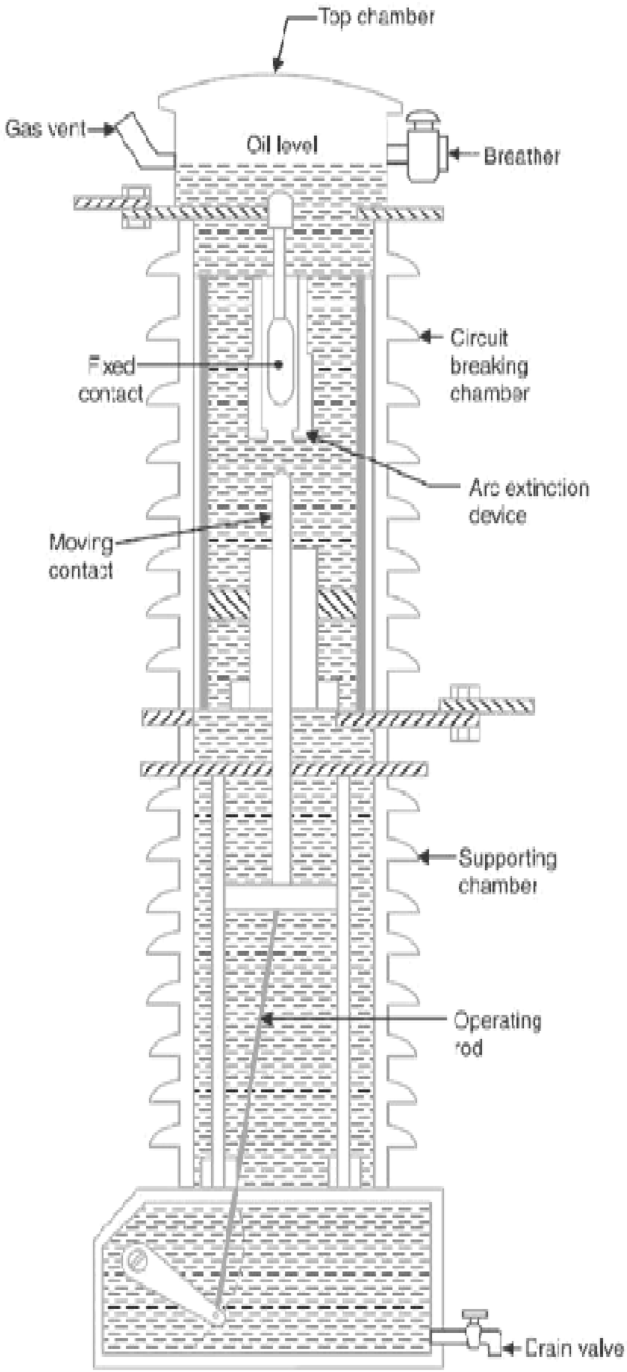


Fig. 19.7 Low-oil Circuit Breaker

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

Construction:

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

Supporting chamber:

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

Circuit-breaking chamber:

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

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

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

Top chamber:

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

Operation:

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

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

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

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

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

Maintenance of Oil Circuit Breakers:

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

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

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

Air-Blast Circuit Breakers:

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

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

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

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

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

Types of Air-Blast Circuit Breakers:

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

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

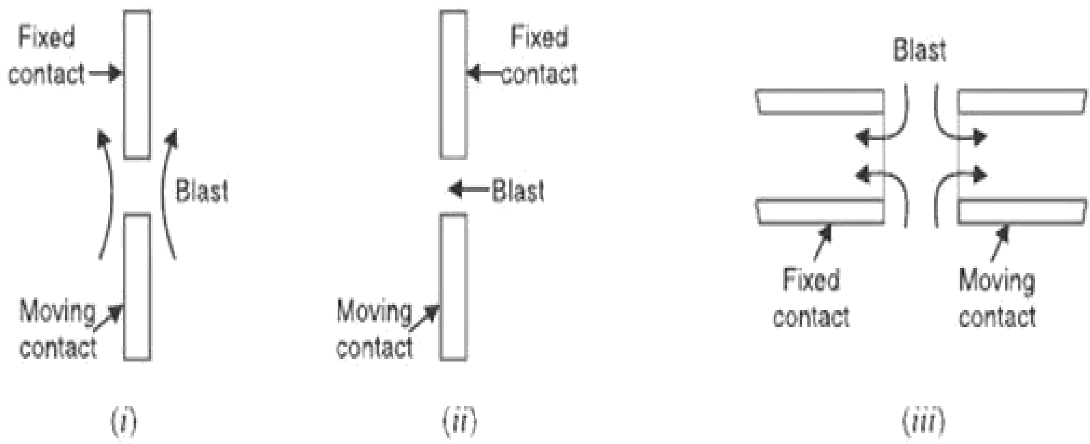


Fig. 19.8

Axial-blast air circuit breaker:

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

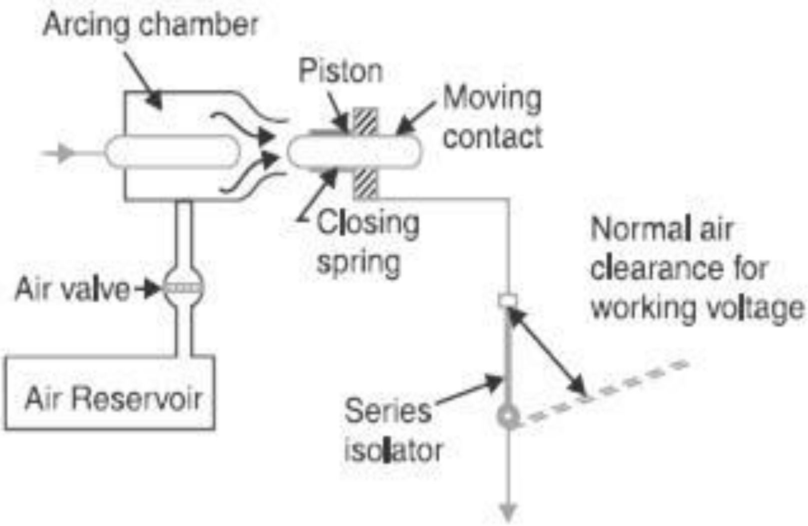


Fig. 19.9

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

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

Cross-blast air breaker:

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

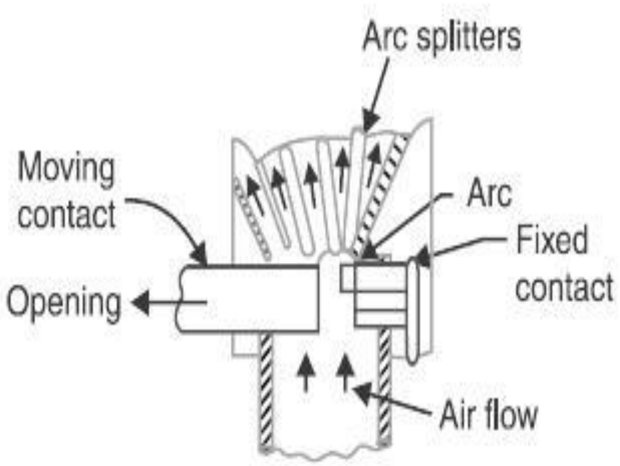


Fig. 19.10

Sulphur Hexafluoride (SF6) Circuit Breakers:

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

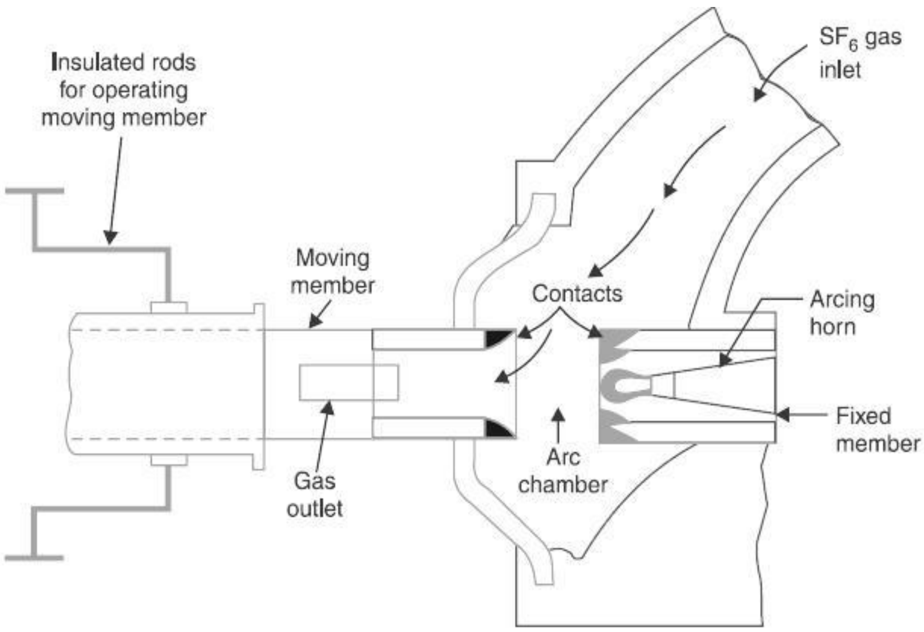


Fig. 19.11

Construction:

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

Working:

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

Advantages:

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

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

Disadvantages:

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

Applications:

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

Vacuum Circuit Breakers (VC B):

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

Principle:

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

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

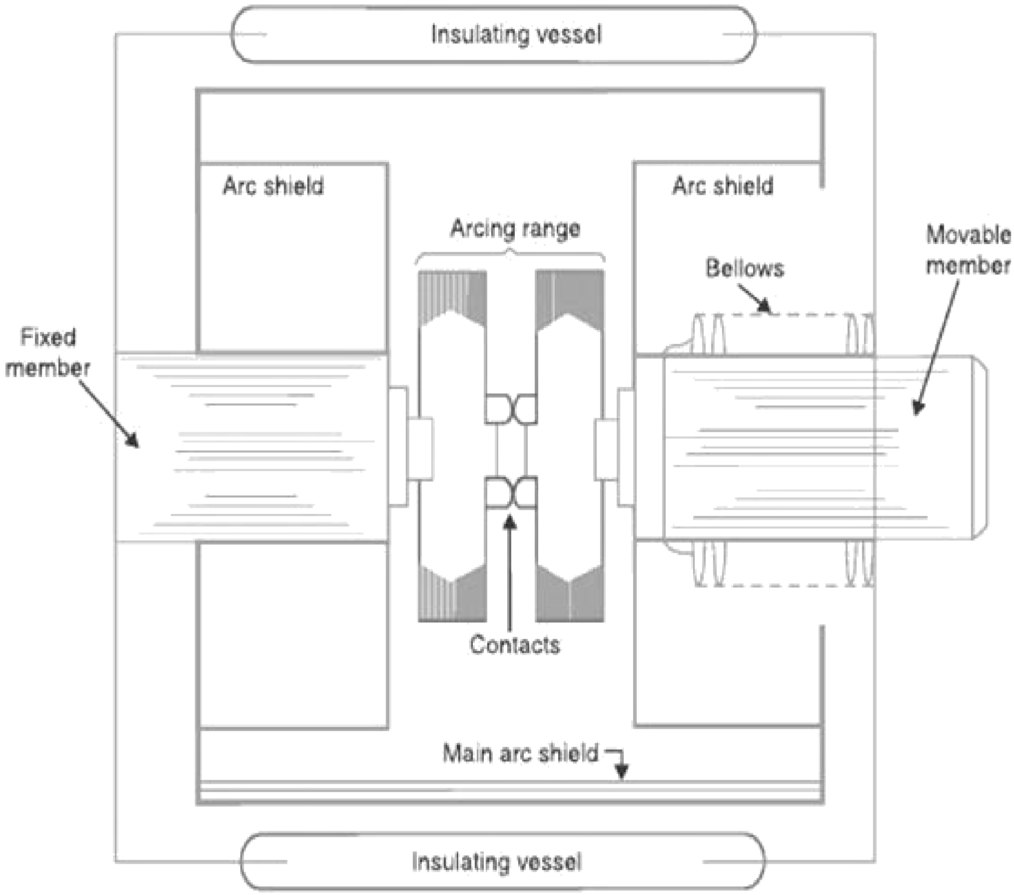


Fig. 19.12

Construction:

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

Working:

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

Vacuum circuit breakers have the following advantages:

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

Applications:

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

ALTERNATOR PROTECTION

1.PROTECTION OF ALTERNATOR

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

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

i failure of prime-mover
ii failure of field
iii overcurrent
iv overspeed
v overvoltage
vii unbalanced loading
vi stator winding faults

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

(a) In case of turbo-alternator sets, failure of steam supply may cause inverted running. If the steam supply is gradually restored, the alternator will pick up load without disturbing the system. If the steam failure is likely to be prolonged, the machine can be safely isolated by the control room attendant since this condition is relatively harmless. Therefore, automatic protection is not required.

(b) In case of hydro-generator sets, protection against inverted running is achieved by providing mechanical devices on the water-wheel. When the water flow drops to an insufficient rate to maintain the electrical output, the alternator is disconnected from the system. Therefore, in this case also electrical protection is not necessary.

(c) Diesel engine driven alternators, when running inverted, draw a considerable amount of power from the supply system and it is a usual practice to provide protection against motoring in order to avoid damage due to possible mechanical seizure. This is achieved by applying reverse power relays to the alternators which isolate the latter during their motoring action. It is essential that the reverse power relays have time-delay in operation in order to prevent inadvertent tripping during system disturbances caused by faulty synchronising and phase swinging.

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

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

(a) The modern tendency is to design alternators with very high values of internal impedance so that they will stand a complete short-circuit at their terminals for sufficient time without serious overheating. On the occurrence of an overload, the alternators can be disconnected manually.

(b) The disadvantage of using overload protection for alternators is that such a protection might disconnect the alternators from the power plant bus on account of some momentary troubles outside the plant and, therefore, interfere with the continuity of electric service.

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

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

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

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

a. trip the main circuit breaker to disconnect the faulty alternator from the system

b. disconnect the alternator field circuit

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

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

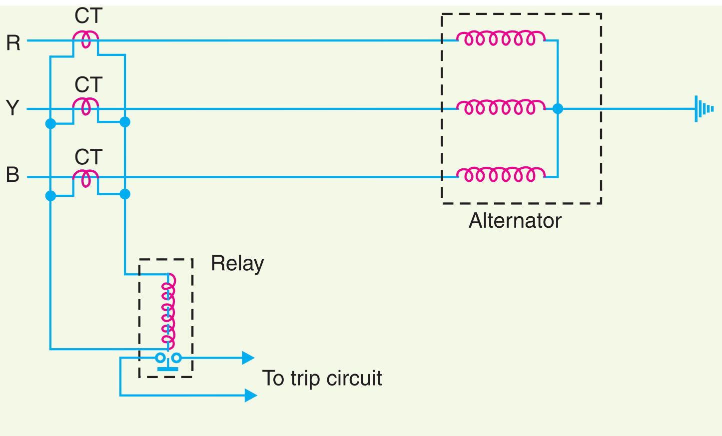


Fig. 22.1

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

a. fault between phase and ground

(b) fault between phases

(c) inter-turn fault involving turns of the same phase winding

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

2.Differential protection of Alternator

The most common system used for the protection of stator winding faults employs circulating-current principle (Refer back to Art. 21.18). In this scheme of protection, currents at the two ends of the protected section are compared. Under normal operating conditions, these currents are equal but may become unequal on the occurrence of a fault in the protected section. The difference of the currents under fault conditions is arranged to pass through the operating coil of the relay. The relay then closes its contacts to isolate protected section from the system. This form of protection is also known as **merz-price circulating current scheme**

Schematic arrangement Fig. 22.2 shows the schematic arrangement of current differential protection for a 3-phase alternator. Identical current transformer pairs CT_1 and CT_2 are placed on either side of each phase of the stator windings. The secondaries of each set of current transformers are connected in star ; the two neutral points and the corresponding terminals of the two star groups being connected together by means of a four-core pilot cable. Thus there is an independent path for the currents circulating in each pair of current transformers and the corresponding pilot *P*.

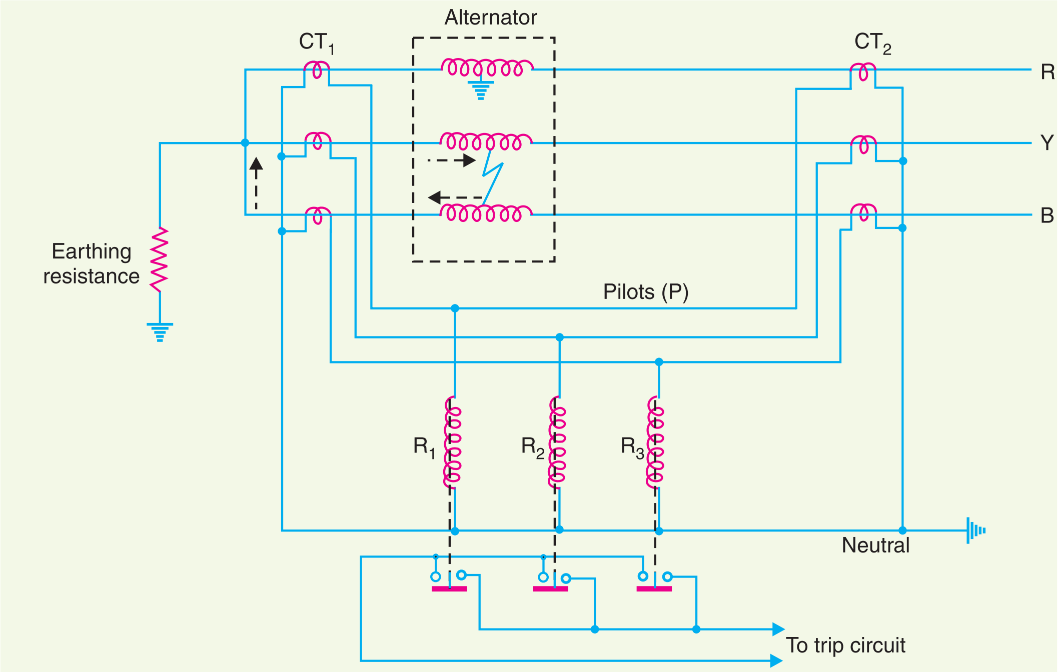


Fig. 22.2

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

Operation Referring to Fig. 22.2, it is clear that the relays are connected in shunt across each circulating path. Therefore, the circuit of Fig. 22.2 can be shown in a simpler form in Fig. 22.3. Under normal operating conditions, the current at both ends of each winding will be equal and hence the currents in the secondaries of two CTs connected in any phase will also be equal. Therefore, there is balanced circulating current in the pilot wires and no current flows through the operating coils (R_1, R_2 and R_3) of the relays. When an earth-fault or phase-to-phase fault occurs, this condition no longer holds good and the differential current flowing through the relay circuit operates the relay to trip the circuit breaker.

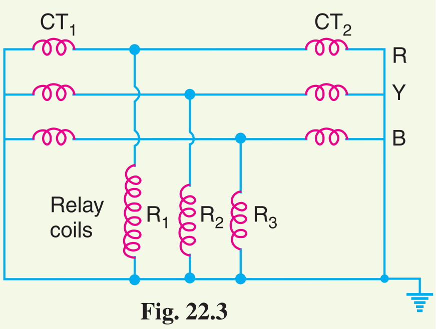


Fig. 22.3

(i) Suppose an earth fault occurs on phase R due to breakdown of its insulation to earth as shown in Fig. 22.2. The current in the affected phase winding will flow through the core and frame of the machine to earth, the circuit being completed through the neutral earthing resistance. The currents in the secondaries of the two CTs in phase R will become unequal and the difference of the two currents will flow through the corresponding relay coil (*i.e.* R_1), returning via the neutral pilot. Consequently, the relay operates to trip the circuit breaker.

(ii) Imagine that now a short-circuit fault occurs between the phases Y and B as shown in Fig. 22.2. The short-circuit current circulates *via* the neutral end connection through the two windings and through the fault as shown by the dotted arrows. The currents in the secondaries of two CTs in each affected phase will become unequal and the differential current will flow through the operating coils of the relays (*i.e.* R_2 and R_3) connected in these phases. The relay then closes its contacts to trip the circuit breaker.

It may be noted that the relay circuit is so arranged that its energising causes **(i)** opening of the breaker connecting the alternator to the bus-bars and **(ii)** opening of the field circuit of the alternator.

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

Limitations The two circuits for alternator protection shown above have their own limitations. It is a general practice to use neutral earthing resistance in order to limit the destructive effects of earth-fault currents. In such a situation, it is impossible to protect whole of the stator windings of a star-connected alternator during earth-faults. When an earth-fault occurs near the neutral point, there

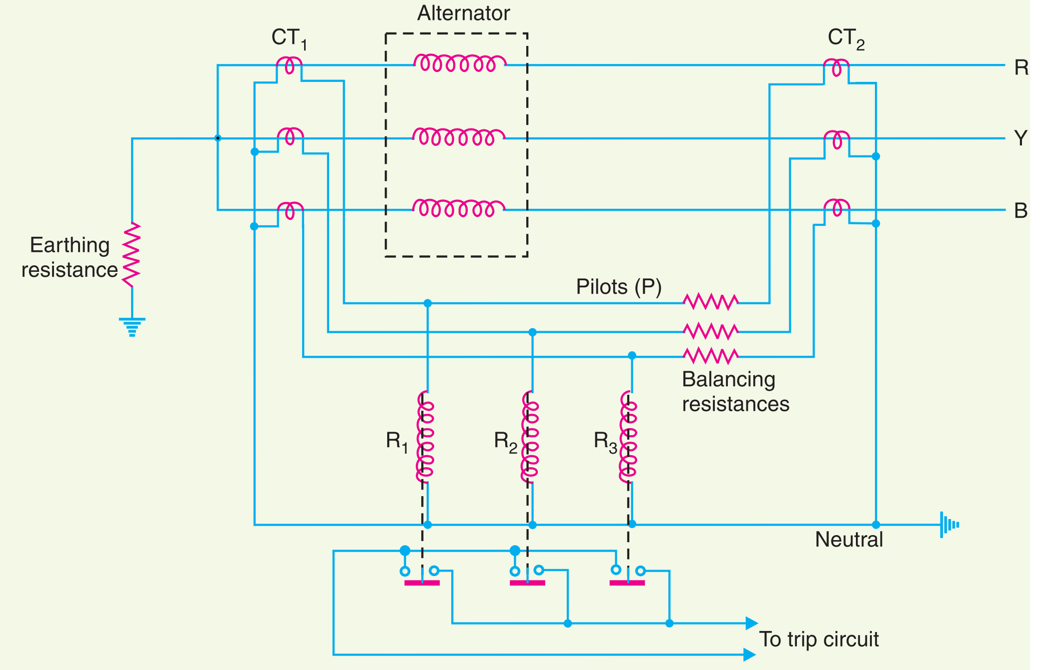


Fig. 22.4

may be insufficient voltage across the short-circuited portion to drive the necessary current round the fault circuit to operate the relay. The magnitude of unprotected zone depends upon the value of earthing resistance and relay setting.

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

3. Modified differential protection of alternator

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

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

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

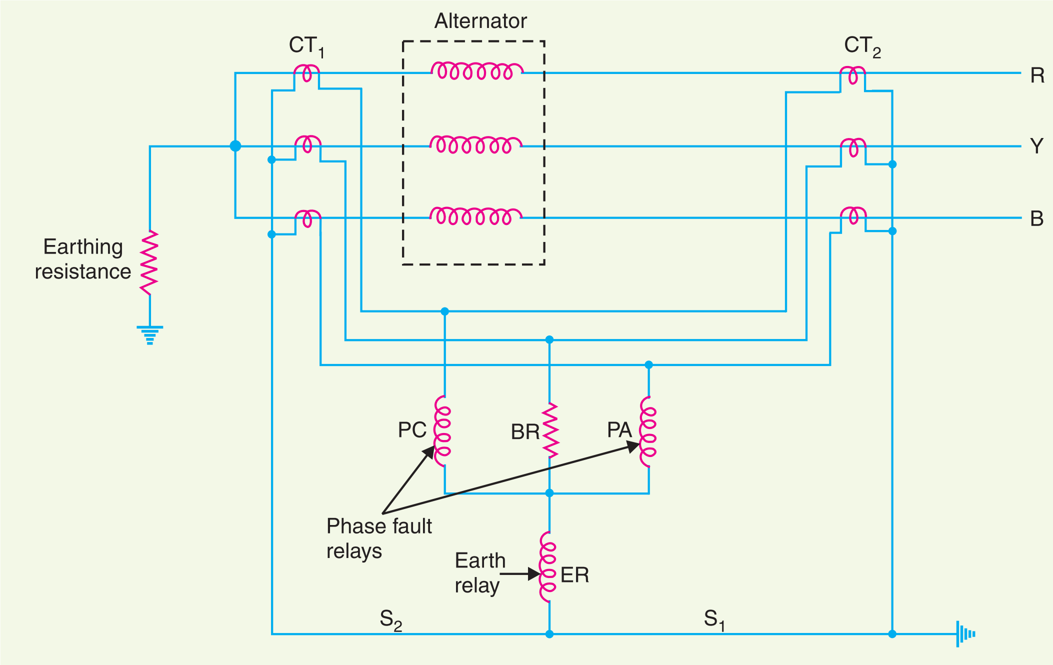


Fig. 22.5

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

4.Balanced earth fault protection

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

Schematic arrangement Fig. 22.6 shows the schematic arrangement of a balanced earth-fault protection for a 3-phase alternator. It consists of three line current transformers, one mounted in each phase, having their secondaries connected in parallel with that of a single current transformer in the conductor joining the star point of the alternator to earth. A relay is connected across the transformers secondaries. The protection against earth faults is limited to the region between the neutral and the line current transformers.

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

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

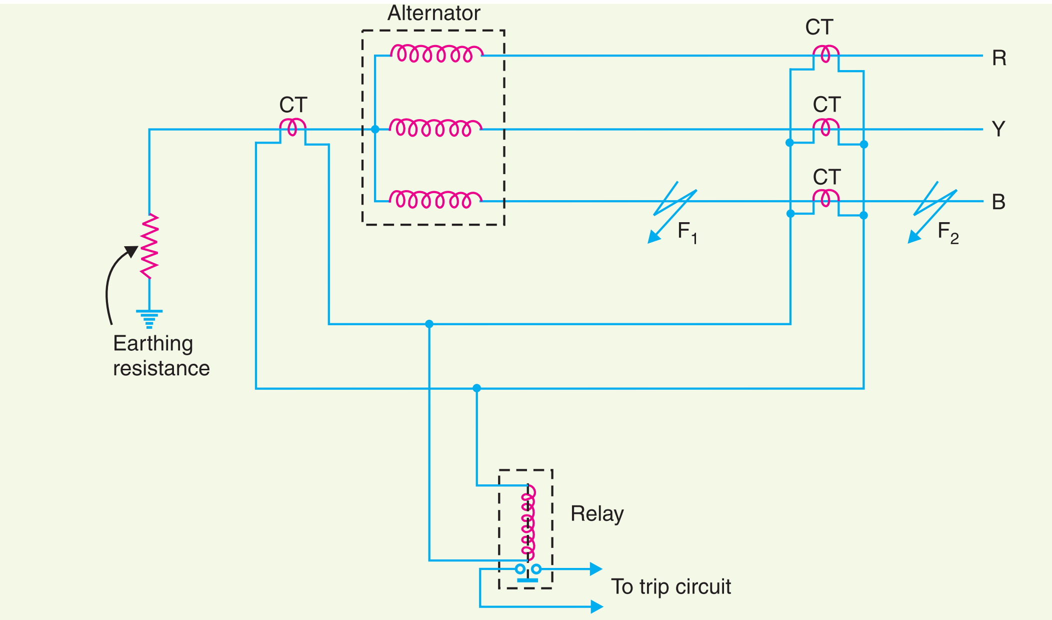


Fig. 22.6

current flows through the relay. When an earth-fault occurs at F_1 or within the protected zone, these currents are no longer equal and the differential current flows through the operating coil of the relay. The relay then closes its contacts to disconnect the alternator from the system.

5.Stator inter-turn protection

Merz-price circulating-current system protects against phase-to-ground and phase-to-phase faults. It does not protect against turn-to-turn fault on the same phase winding of the stator. It is because the current that this type of fault produces flows in a local circuit between the turns involved and does not create a difference between the currents entering and leaving the winding at its two ends where current transformers are applied. However, it is usually considered unnecessary to provide protection for inter-turn faults because they invariably develop into earth-faults.

In single turn generator (*e.g.* large steam-turbine generators), there is no necessity of protection against inter-turn faults. However, inter-turn protection is provided for multi-turn generators such as hydro-electric generators. These generators have double-winding armatures (*i.e.* each phase wind-

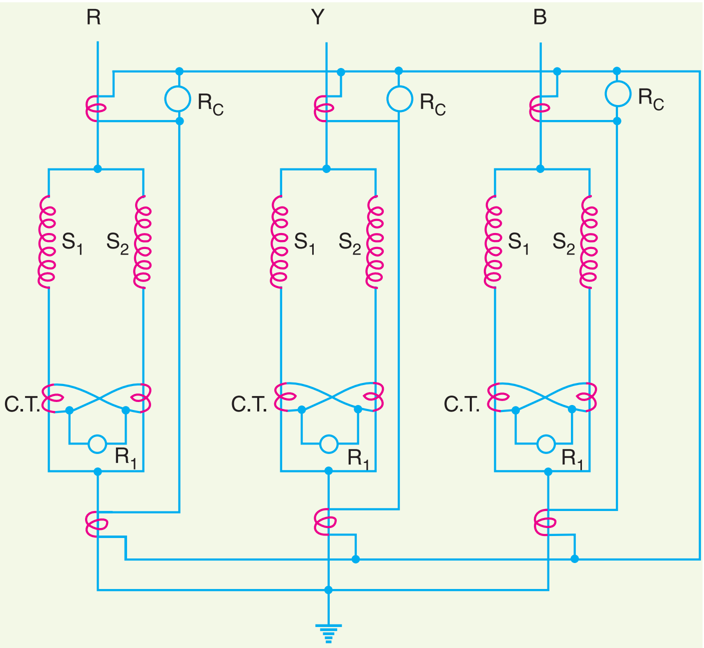


Fig. 22.7

ing is divided into two halves) owing to the very heavy currents which they have to carry. Advantage may be taken of this necessity to protect inter-turn faults on the same winding. Fig. 22.7 shows the schematic arrangement of circulating-current and inter-turn protection of a 3-phase double wound generator. The relays R_C provide protection against phase-to-ground and phase-to-phase faults whereas relays R_1 provide protection against inter-turn faults.

Fig. 22.8 shows the duplicate stator windings S_1 and S_2 of one phase only with a provision against inter-turn faults. Two current transformers are connected on the circulating-current principle. Under normal conditions, the currents in the stator windings S_1 and S_2 are equal and so will be the currents in the secondaries of the two CTs. The secondary current round the loop then is the same at all points and no current flows through the relay R_1. If a short-circuit develops between adjacent turns, say on S_1, the currents in the stator windings S_1 and S_2 will no longer be equal. Therefore, unequal currents will be induced in the secondaries of CTs and the difference of these two currents flows through the relay R_1. The relay then closes its contacts to clear the generator from the system.

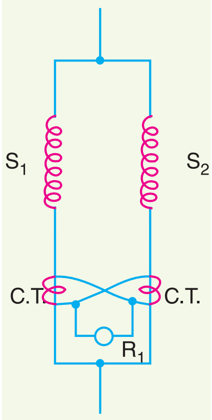


Fig. 22.8

TRANSFORMER PROTECTION

1.Protection of transformer

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

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

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

(i) open circuits

(ii) overheating

(iii) winding short-circuits *e.g.* earth-faults, phase-to-phase faults and inter-turn faults.

An open circuit in one phase of a 3-phase transformer may cause undesirable heating. In practice, relay protection is not provided against open circuits because this condition is relatively harmless. On the occurrence of such a fault, the transformer can be disconnected manually from the system.

Overheating of the transformer is usually caused by sustained overloads or short-circuits and very occasionally by the failure of the cooling system. The relay protection is also not provided against this contingency and thermal accessories are generally used to sound an alarm or control the banks of fans.

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

2.Protection scheme of alterntor

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

(i) Buchholz relay providing protection against all kinds of incipient faults *i.e.* slow-developing faults such as insulation failure of windings, core heating, fall of oil level due to leaky joints etc.

(ii) Earth-fault relay providing protection against earth-faults only.

(iii) Over current realy providing protection mainly against phase-to-phase faults and overloading.

(iv) Differential system (or circulating-current system) providing protection against both earth and phase faults.

The complete protection of transformer usually requires the combination of these systems. Choice of a particular combination of systems may depend upon several factors such as **(a)** size of the transformer **(b)** type of cooling **(c)** location of transformer in the network **(d)** nature of load supplied and **(e)** importance of service for which transformer is required. In the following sections, above systems of protection will be discussed in detail.

BUCHHOLZ RELAY

It is a gas-actuated relay installed in oil immersed transformers for protection against all kinds of faults. Named after its inventor, Buchholz, it is used to give an alarm in case of incipient (*i.e.* slow-developing) faults in the transformer and to disconnect the transformer from the supply in the event of severe internal faults. It is usually installed in the pipe connecting the conservator to the main tank as shown in Fig. 22.11. It is a universal practice to use Buchholz relays on all such oil immersed transformers having ratings in excess of 750 kVA.

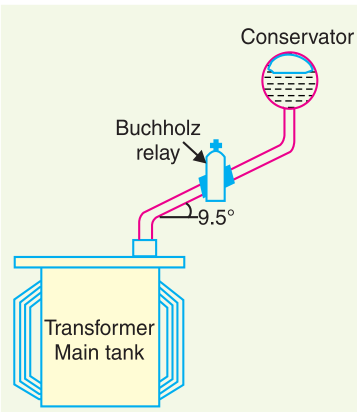


Fig. 22.11

Buchholz Relay

Construction Fig. 22.12 shows the constructional details of a Buchholz relay. It takes the form of a domed vessel placed in the connecting pipe between the main tank and the conservator. The device has two elements. The upper element consists of a mercury type switch attached to a float. The lower element contains a mercury switch mounted on a hinged type flap located in the direct path of the flow of oil from the transformer to the conservator. The upper element closes an alarm circuit during incipient faults whereas the lower element is arranged to trip the circuit breaker in case of severe internal faults.

Operation The operation of Buchholz relay is as follows :

In case of incipient faults within the transformer, the heat due to fault causes the decomposition of some transformer oil in the main tank. The products of decomposition contain more than 70% of hydrogen gas. The hydrogen gas being light tries to go into the conserva-

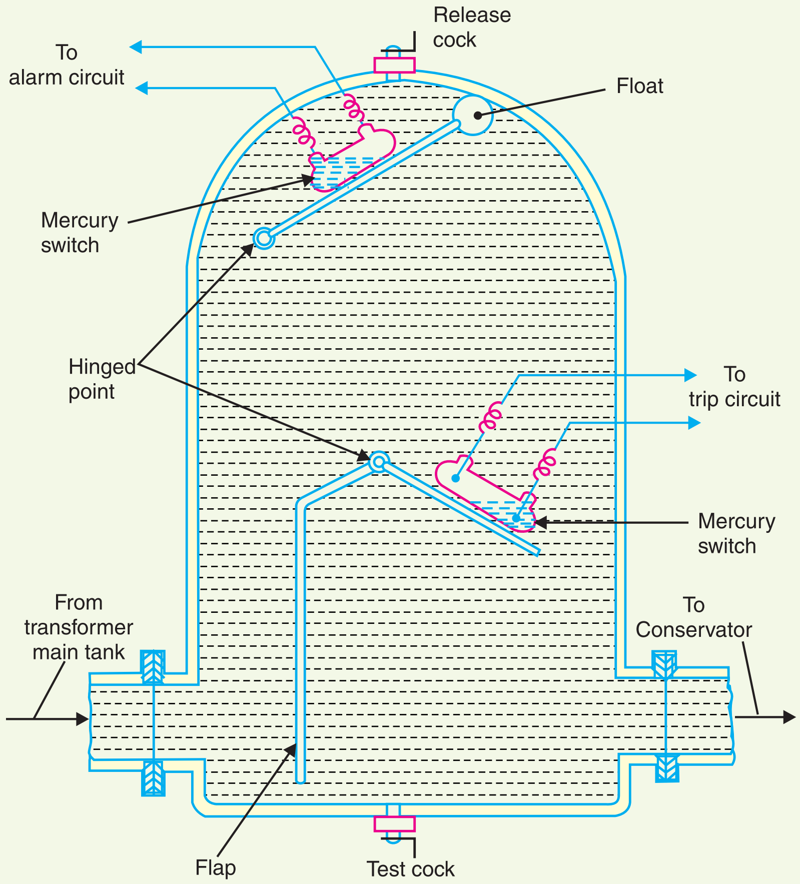


Fig. 22.12

tor and in the process gets entrapped in the upper part of relay chamber. When a predetermined amount of gas gets accumulated, it exerts sufficient pressure on the float to cause it to tilt and close the contacts of mercury switch attached to it. This completes the alarm circuit to sound an *alarm.

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

Advantages

It is the simplest form of transformer protection.

It detects the incipient faults at a stage much earlier than is possible with other forms of protection.

Disadvantages

It can only be used with oil immersed transformers equipped with conservator tanks.

The device can detect only faults below oil level in the transformer. Therefore, separate protection is needed for connecting cables.

EARTH-FAULT OR EARTH LEAKAGE PROTECTION

An earth-fault usually involves a partial breakdown of winding insulation to earth. The resulting leakage current is considerably less than the 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 these circumstances, it is profitable to employ earth-fault relays in order to ensure the disconnection of earth-fault or leak in the early stage. An earth-fault relay is essentially an overcurrent relay of low setting and operates as soon as an earth-fault or leak develops. One method of protection against earth-faults in a transformer is the core balance current transformer shown in Fig. 22.13.

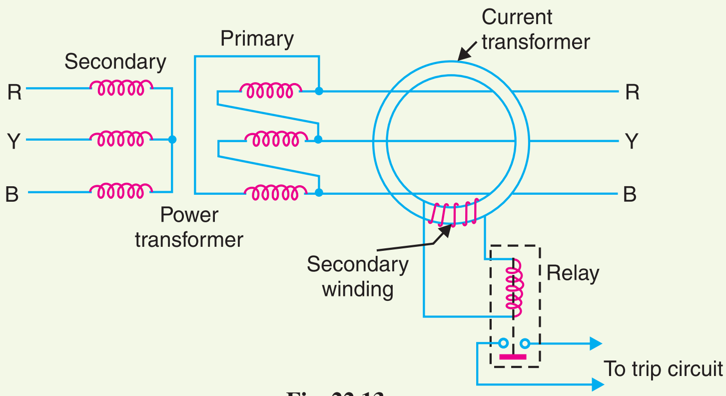


Fig. 22.13

The three leads of the primary winding of power transformer are taken through the core of a current transformer which carries a single secondary winding. The operating coil of a relay is connected to this secondary. Under normal conditions (*i.e.* no fault to earth), the vector sum of the three phase currents is zero and there is no resultant flux in the core of current transformer no matter how much the load is out of balance. Consequently, no current flows through the relay and it remains inoperative. However, on the occurrence of an earth-fault, the vector sum of three phase currents is no longer zero. The resultant current sets up flux in the core of the C.T. which induces e.m.f. in the secondary winding. This energises the relay to trip the circuit breaker and disconnect the faulty transformer from the system.

Earth Leakage Relay

COMBINED LEAKAGE AND OVERLOAD PROTECTION

The core-balance protection described above suffers from the drawback that it cannot provide protection against overloads. If a fault or leakage occurs between phases, the core-balance relay will not operate. It is a usual practice to provide combined leakage and overload protection for transformers. The earth relay has low current setting and operates under earth or leakage faults only. The overload relays have high current setting and are arranged to operate against faults between the phases.

Fig. 22.14 shows the schematic arrangement of combined leakage and overload protection. In this system of protection, two overload relays and one leakage or earth relay are connected as shown. The two overload relays are sufficient to protect against phase-to-phase faults. The trip contacts of overload relays and earth-fault relay are connected in parallel. Therefore, with the energising of either overload relay or earth relay, the circuit breaker will be tripped.

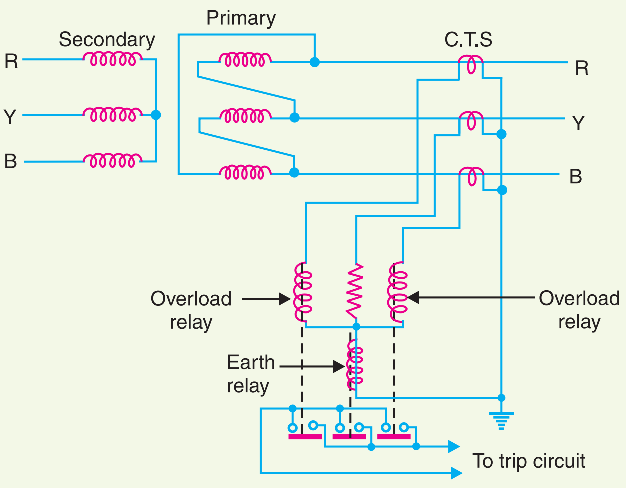


Fig. 22.14

APPLYING CIRCULATING CURRENT-SCHEME TO TRANSFORMER

Merz-Price circulating -current principle is commonly used for the protection of power transformers against earth and phase faults. The system as applied to transformers is fundamentally the same as that for generators but with certain complicating features not encountered in the generator application. The complicating features and their remedial measures are briefed below :

(I) In a power transformer, currents in the primary and secondary are to be compared. As these two currents are usually different, therefore, the use of identical transformers (of same turn ratio) will give differential current and operate the relay even under no load conditions.

The difference in the magnitude of currents in the primary and secondary of power transformer is compensated by different turn ratios of CTs. If T is the turn-ratio of power transformer, then turn-ratio of CTs on the *l.v.* side is made T times that of the CTs on the *h.v.* side. Fulfilled this condition, the secondaries of the two CTs will carry identical currents under normal load conditions. Consequently, no differential current will flow through the relay and it remains inoperative.

(II) There is usually a phase difference between the primary and secondary currents of a 3-phase power transformer. Even if CTs of the proper turn-ratio are used, a differential current may flow through the relay under normal conditions and cause relay operation.

The correction for phase difference is effected by appropriate connections of CTs. The CTs on one side of the power transformer are connected in such a way that the resultant currents fed into the pilot wires are displaced in phase from the individual phase currents in the same direction as, and by an angle equal to, the phase shift between the power-transformers primary and secondary currents. The table below shows the type of connections to be employed for CTs in order to compensate for the phase difference in the primary and secondary currents of power transformer.

S. No.	Power transformer connections		Current transformer connections	
	Primary	**Secondary**	**Primary**	**Secondary**
1	Star with neutral earthed	Delta	Delta	Star
2	Delta	Delta	Star	Star
3	Star	Star with neutral earthed	Delta	Delta
4	Delta	Star with neutral earthed	Star	Delta

Thus referring to the above table, for a delta/star power transformer, the CTs on the delta side must be connected in star and those on the star side in delta.

(III) Most transformers have means for tap changing which makes this problem even more difficult. Tap changing will cause differential current to flow through the relay even under normal operating conditions.

The above difficulty is overcome by adjusting the turn-ratio of CTs on the side of the power transformer provided with taps.

(IV) Another complicating factor in transformer protection is the magnetising in-rush current. Under normal load conditions, the magnetising current is very small. However, when a transformer is energised after it has been taken out of service, the magnetising or in-rush current can be extremely high for a short period. Since magnetising current represents a current going into the transformer without a corresponding current leaving, it appears as a fault current to differential relay and may cause relay operation.

In order to overcome above difficulty, differential relays are set to operate at a relatively high degree of unbalance. This method decreases the sensitivity of the relays. In practice, advantage is taken of the fact that the initial in-rush currents contain prominent second-harmonic component. Hence, it is possible to design a scheme employing second-harmonic bias features, which, being tuned to second-harmonic frequency only, exercise restrain during energising to prevent maloperation.

While applying circulating current principle for protection of transformers, above precautions are necessary in order to avoid inadvertent relay operation.

CIRCULATING CURRENT SCHEME FOR TRANSFORMER

Fig. 22.15 shows Merz-Price circulating-current scheme for the protection of a 3-phase delta/delta power transformer against phase-to-ground and phase-to-phase faults. Note that *CT*s on the two sides of the transformer are connected in star. This compensates for the phase difference between the power transformer primary and secondary. The *CT*s on the two sides are connected by pilot wires and one relay is used for each pair of *CT*s.

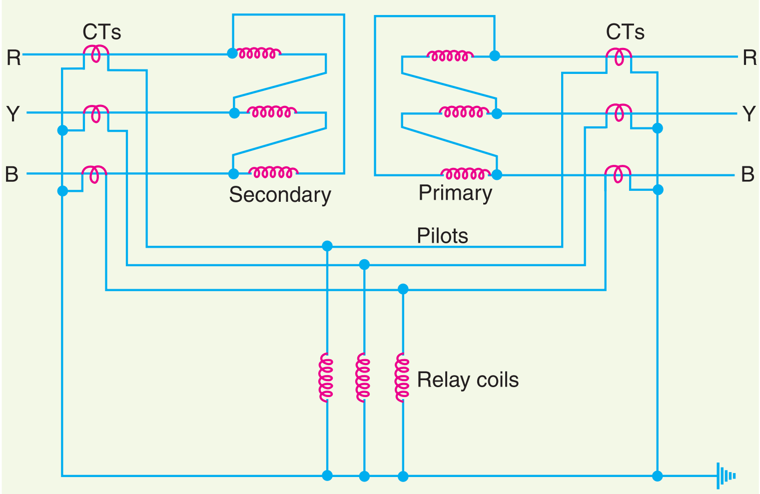


Fig. 22.15

During normal operating conditions, the secondaries of *CT*s carry identical currents. Therefore, the currents entering and leaving the pilot wires at both ends are the same and no current flows through the relays. If a ground or phase-to-phase fault occurs, the currents in the secondaries of *CT*s will no longer be the same and the differential current flowing through the relay circuit will clear the breaker on both sides of the transformer. The-protected zone is limited to the region between *CT*s on the high-voltage side and the *CT*s on the low-voltage side of the power transformer.

SWITCH GEAR AND PROTECTION (SGPD)

Introduction to switch Gear

1. State any four functions of protective relaying.

- To disconnect the abnormally operating part so as to avoid the damage within effective operation of the rest of the system.
- To prevent the subsequent faults arising due to the primary fault.
- To disconnect the faulty part as quickly as possible so as to minimize the damage to the faulty part itself.
- To improve system performance, reliability and service continuity.

2. What is protective zone?

A protective zone is a separate zone which is established around each element of power system remains unprotected. The area of a power system which remains unprotected such that any fault occurring in that area would not be cleared at all is called dead spot or blind spot of a power system.

3. List the basic requirements or essential qualities of protective relaying.

(i)Reliability
(ii) selectivity and discrimination
(iii) speed and time
(iv)sensitivity
(v) stability
(vi) adequateness
(vii) simplicity and economy.

4. what is backup protection?

The protection which comes in to the play when the primary protection fails is called backup protection. When the primary protection is made inoperative for the maintenance purpose then backup protection acts like main protection.

5. Define pickup value.

Pickup value: it is the minimum value of an actuating quantity at which relay starts operating. In most of the relays actuating quantity is current in the relay coil and pickup value of current is indicated along with the relay.

6. Fill in the blanks by inserting appropriate words.

(i) A fuse is a .... device. Ans : (protective)
(ii) A circuit breaker is a .... device. . Ans : (circuit interrupting)
(iii) An isolator is designed to open a circuit under .... Ans : (no load)
(iv) When a switch is opened, ... is produced. Ans : (arc)
(v) Under normal operating conditions, the contacts of the circuit breaker remain .... Ans : (closed)
(vi) Under fault conditions, ... supplies information to the circuit breaker to open. Ans : (relay)
(vii) If a fault occurs on the bus itself in a single bus-bar system, then there is complete .... Ans : (shut down)
(viii) The sectionalised bus-bar system gives .... fault current than that of unsectionalised bus-bar. Ans : (lower)
(ix) For greater flexibility, ... bus-bar system is used. Ans : (duplicate)
(x) The outdoor type switchgear is generally used for voltages beyond .... kV. Ans : (66)

7. **Write down essential features of switch-gear.**
   - Complete reliability
   - Absolutely certain discrimination
   - Quick operation
   - Provision for manual control
   - Provision for instruments
8. **What is protective relay?**

   A relay is a device which detects the fault and supplies information to the breaker for circuit interruption. It can be divided into three parts.

   (i) The primary winding of a current transformer (C.T.) which is connected in series with the circuit to be protected. The primary winding often consists of the main conductor itself.

   (ii) The second circuit is the secondary winding of C.T. connected to the relay operating coil.

   (iii) The third circuit is the tripping circuit which consists of a source of supply, trip coil of circuit breaker and the relay stationary contacts

CHAPTER -2 (FAULT CALCULATION)

1. What are the different types of faults in a power system?

   Symmetrical faults: the fault which gives rise to equal fault currents in all the lines with displacement of 120° between them. The example is line to line fault i.e. shorting of all three lines.

   Unsymmetrical faults: The fault which gives rise to unequal fault currents in all the lines with unequal displacement between them. The example is line ground, line to line, line to line to ground faults.

2. **It is the percentage of the total phase-voltage dropped in the circuit when full-load current is flowing i.e.,**

   %X = (IX /V)×100

   Where

   I = full-load current

   V = phase voltage

   X = reactance in ohms per phase
3. **What is the advantages of percentage reactance compared to omhic reactance ?**

   advantage of using percentage reactance instead of ohmic reactance in short-circuit calculations. Percentage reactance values remain unchanged as they are referred through transformers, unlike ohmic reactances which become multiplied or divided by the square of transformation ratio. This makes the procedure simple and permits quick calculations.
4. **What are the disadvantages of generator reactors ?**

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

   (ii) If a bus-bar or feeder fault occurs close to the bus-bar, the voltage at the bus-bar will be reduced to a low value, thereby causing the generators to fall out of step.

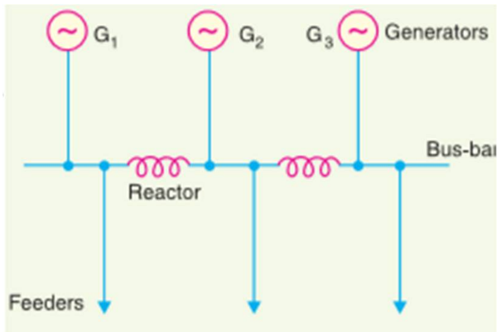
   (iii) If a fault occurs on any feeder, the continuity of supply to other is likely to be affected.
5. Give example of unsymmetrical faults

   (a) Single line-to-ground fault

   (b) (b) Line-to-line fault

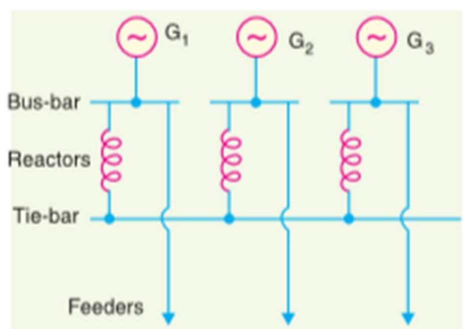
   (c) (c) Double line-to-ground fault
6. What is ring main system ?

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



7. What is tie bus bar ?

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



8. Fill in the blanks by inserting appropriate words.

(i) When a short-circuit occurs, a .... current flows through the system. Ans: (heavy)

(ii) The most serious result of a major uncleared short-circuit fault is the .... Ans: (fire)

(iii) When all the three phases are short-circuited, it gives rise to .... currents.
Ans: (symmetrical fault)

(iv) The rating of a circuit breaker is generally determined on the basis of .... short circuit currents. Ans: (symmetrical)

(v) The most common type of fault in overhead lines is .... Ans: (phase-to-ground fault)

(vi) The .... short-circuit fault gives very heavy duty on the circuit breaker.
Ans: (3-phase)

(vii) If the % age reactance upto the fault point is 20%, then short-circuit current will be .... times the full-load current. Ans(5)

(viii) A 1000 kVA transformer with 5% reactance will have a reactance of .... at 2000 kVA base. Ans(10%)

(ix) Short-circuit kVA is obtained by multiplying the base kVA by .... Ans(100/% X)

(x) Reactors are used at various points in the power system to .... Ans(limit short-circuit current)

9.What is the harmful effect of short circuit ?

The heavy current due to short-circuit causes excessive heating which may result in fire or explosion. Sometimes short-circuit takes the form of an arc and causes considerable damage to the system. ... The low voltage created by the fault has a very harmful effect on the service rendered by the power system.

10. What is the importance of base kVA in short-circuit calculations ?

Generally, the various equipments used in the power system have different kVA ratings. Therefore, it is necessary to find the percentage reactances of all the elements on a common kVA rating. This common kVA rating is known as base kVA. The value of this base kVA is quite unimportant and may be : (i) equal to that of the largest plant (ii) equal to the total plant capacity (iii) any arbitrary value The conversion can be effected by using the following relation :

% age reactance at base kVA = (Base kVA /Rated kVA) × % age reactance at rated kVA

11. What is the importance of short-circuit calculations?

A Short Circuit Analysis will help to ensure that personnel and equipment are protected by establishing proper interrupting ratings of protective devices (circuit breaker and fuses). If an electrical fault exceeds the interrupting rating of the protective device, the consequences can be devastating.

Circuit Breaker

Q1. A thermal protection switch provides protection against what?

a. Overload
b. Temperature.
c. Short circuit.
d. Over voltage

ANSWER: a. Overload

Q2. Which of the following circuit breakers is used for the railway electrification?

a. Air blast circuit breaker
b. SF_6 circuit breaker
c. Bulk oil circuit breaker
d. Minimum oil circuit breaker

ANSWER: a. Air blast circuit breaker

Q3. Which circuit breaker is preferred to be installed in extra high voltage ac system?

a. Bulk oil type circuit breaker
b. Air blast circuit breaker
c. SF_6 circuit breaker
d. Vacuum circuit breaker

ANSWER: c. SF_6 circuit breaker

Q4. Which among these circuit breakers produce the least arc energy?
a. Plain oil
b. Minimum oil
c. Air blast
d. Air break
ANSWER: c. Air blast
Q5. The rating of the circuit breaker is usually determined on the basis of _____________ fault.
a. Symmetrical.
b. Line to line
c. Single line to ground
d. Double line to ground
ANSWER: a. Symmetrical.
Q6. Which of the following circuit breakers has the lowest operating voltage?
a. SF_6 circuit breaker
b. Air break
c. Air blast
d. Minimum oil circuit breaker
ANSWER: b. Air break
Q7. Which of the following circuit breakers is highly reliable and has a least maintenance?
a. Oil circuit breakers
b. Air blast
c. Vacuum circuit breakers
d. SF_6 circuit breakers
ANSWER: d. SF_6 circuit breakers
Q8. Circuit breakers usually operate under
a. Steady short circuit current
b. Sub transient state of short circuit current
c. Transient state of short circuit current
d. None of these
ANSWER: b. Sub transient state of short circuit current
9.What is a Circuit Breaker?
Circuit Breaker is a mechanical device designed to close or open contact members, thus closing or opening an electrical circuit under the normal or abnormal conditions.
10.How does a Circuit Breaker different from Switch?
Switch is just a device when can be able to open and close the circuit during normal operation. Whereas on the other hand circuit breaker has the ability to open and close the contacts during abnormal or fault conditions. Thus circuit breaker has the potential to break and make heavy short circuit currents. Auto-reclosures in the circuit beaker has the ability to re-close after certain designed duration to verify whether the short circuit was cleared.
11.What is meant by making capacity of the circuit breaker?
The making capacity of the circuit breaker when closed on a short circuit is the peak value of the maximum current wave (including dc component) in the first cycle of the current after the circuit is closed by the circuit breaker.
12.Why current chopping is not common in oil circuit breakers?
Current chopping is not common in oil circuit breakers because in most of the oil circuit breakers the arc extinguishing power is proportional to the magnitude of current to be interrupted.
13.Name the materials used for the contacts of vacuum circuit breakers?
Copper-Bismuth, Copper-lead, Copper-tellurium, Silver-bismuth, Silver-lead and Silver-tellurium are some of the alloys employed as contact materials in the vacuum circuit breakers.

14.**Why current chopping considered as serious drawback in a circuit breaker?**
The current chopping is considered as serious drawback because it sets up high voltage transient across the breaker contacts.
15.For EHV applications which type of circuit breaker is mostly preferred?
For Exta High Voltage (EHV) applications SF6 gas insulated switchgear is preferred.
16.What are the duties of Circuit Breakers?
Some of the duties of the circuit breakers are listed below:

- Interruption of small inductive currents
- Switching of unloaded transmission lines and unloaded cables
- Switching of capacitor banks and reactors
- Interruption of terminal faults
- Interruption of short line faults
- Asynchronous switching

16. What is re-sticking voltage ?

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 re-striking voltage.

17. What factors arc resistance depends ?

(i) Degree of ionisation— the arc resistance increases with the decrease in the number of ionised particles between the contacts.
(ii) Length of the arc— the arc resistance increases with the length of the arc i.e., separation of contacts
(iii) Cross-section of arc— the arc resistance increases with the decrease in area of X-section of the Arc

18. What factors are responsible for the maintenance of arc between the contacts ?

(i) p.d. between the contacts
(ii) ionised particles between contacts
Explanation:
(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.
19. How we can deionize the medium in circuit breaker ?
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 allowed 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 unionised particles, the dielectric strength of the medium can be increased considerably. This may be achieved by a gas blast directed along the discharge or by forcing oil into the contact space.

(20) What is recovery voltage ?

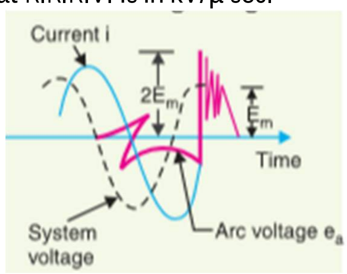
It is the normal frequency (50 Hz) r.m.s. voltage that appears across the contacts of the circuit breaker after final arc extinction. It is approximately equal to the system voltage.

(21) What is current chopping ?

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

(22) What is RRRV ?

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



Before current interruption, the capacitance C is short-circuited by the fault and the short-circuit current through the breaker is limited by inductance L of the system only. Consequently, the short-circuit current will lag the voltage by 90º.where i represents the short-circuit current and ea represents the arc volt age. It may be seen that in this condition, the entire generator voltage appears across inductance L. When the contacts are opened and the arc finally extinguishes at some current zero, the generator voltage e is suddenly applied to the inductance and capacitance in series. This L–C combination forms an oscillatory circuit and produces a transient of frequency :

fn =1/2Πsqrt(LC)

which appears across the capacitor C and hence across the contacts of the circuit breaker. This transient voltage, as already noted, is known as re-striking voltage and may reach an instantaneous peak value twice the peak phase-neutral voltage i.e. 2 Em. The system losses cause the oscillations to decay fairly rapidly but the initial overshoot increases the possibility of re-striking the arc. It is the rate of rise of re-striking voltage (R.R.R.V.) which decides whether the arc will re-strike or not. If R.R.R.V. is greater than the rate of rise of dielectric strength between the contacts, the arc will re-strike. However, the arc will fail to re-strike if R.R.R.V. is less than the rate of increase of dielectric strength between the contacts of the breaker.

23. What is breaking capacity. of circuit breaker?

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

24. What is making capacity. of circuit breaker?

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

Making capacity =2·55 × Symmetrical breaking capacity

25. What is resistance switching ?

current chopping in case of capacitive current breaking etc. give rise to severe voltage oscillations. These excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R connected across the circuit breaker contacts. This is known as resistance switching.

FUSE

1. **What is a fuse ?**

   A fuse is a short piece of metal, inserted in the circuit, which melts when excessive current flows through it and thus breaks the circuit.

2. **Explain advantage of fuse.**

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

3. Write down desirable characteristic of fuse

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

4.Why present trend is to use silver in fuse despite its high cost ?

(i) It is comparatively free from oxidation.
(ii) It does not deteriorate when used in dry air.
(iii) The coefficient of expansion of silver is so small that no critical fatigue occurs. Therefore, the fuse element can carry the rated current continuously for a long time.
(iv) The conductivity of silver is very high. Therefore, for a given rating of fuse element, the mass of silver metal required is smaller than that of other materials. This minimises the problem of clearing the mass of vapourised material set free on fusion and thus permits fast operating speed.
(v) Due to comparatively low specific heat, silver fusible elements can be raised from normal temperature to vapourisation quicker than other fusible elements. Moreover, the resistance of silver increases abruptly as the melting temperature is reached, thus making the transition from melting to vapourisation almost instantaneous. Consequently, operation becomes very much faster at higher currents.
(vi) Silver vapourises at a temperature much lower than the one at which its vapour will readily ionise. Therefore, when an arc is formed through the vapourised portion of the element, the arc path has high resistance. As a result, short-circuit current is quickly interrupted.

5. Current rating of fuse element.

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

6. What is Fusing current ?

It is the minimum current at which the fuse element melts and thus disconnects the circuit protected by it. Obviously, its value will be more than the current rating of the fuse element.

7.What is fusing factor?

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

8.What is prospective current ?

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

PROTECTIVE RELAY

1.what are the fundamental requirements of protective relay?

(i) selectivity (ii) speed (iii) sensitivity (iv) reliability (v) simplicity (vi) economy

2.what is zone of protection ?

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

3.what is instantaneous relay ?

Instantaneous relay. An instantaneous relay is one in which no intentional time delay is provided. In this case, the relay contacts are closed immediately after current in the relay coil exceeds the minimum calibrated value.

4.What is inverse time relay?

An inverse-time relay is one in which the operating time is approximately inversely proportional to the magnitude of the actuating quantity. At values of current less than pickup, the relay never operates. At higher values, the time of operation of the relay decreases steadily with the increase of current.

5.What is current setting ?

It is often desirable to adjust the pick-up current to any required value. This is known as current setting and is usually achieved by the use of tappings on the relay operating coil.

6.What is P.S.M ?

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

7.What is T.S.M ?

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

8.Write down functional relay type.

(i) Induction type overcurrent relays (ii) Induction type reverse power relays (iii) Distance relays (iv) Differential relays (v) Translay scheme

9.what is differential relay?

A differential relay is one that operates when the phasor difference of two or more similar electrical quantities exceeds a pre-determined value.

10 What is back up protection ?

It is the second line of defence in case of failure of the primary protection. It is designed to operate with sufficient time delay so that primary relaying will be given enough time to function if it is able to.

11. Fill in the blanks by inserting appropriate words

(i) A relay performs the function of .... Ans: (fault)

(ii) The relay operating coil is supplied through .... Ans: (instrument transformers)

(iii) A 1 VA relay is .... sensitive than a 3 VA relay. Ans: (more)

(iv) The minimum relay coil current at which the relay operates is called............... Ans(pick-up value)

(v) Induction relays .... be used with d.c. quantities. Ans: (cannot)

(vi) Back-up protection functions when .... Ans: (primary protection fails)

PROTECTION OF TRANSFORMER AND ALTERNATORS

1.Write down different faults in alternator.

(i) failure of prime-mover (ii) failure of field (iii) overcurrent (iv) overspeed (v) overvoltage (vi) unbalanced loading (vii) stator winding faults

2.What is inverted running of alternator?

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

3.What is merz-price protection scheme?

In this scheme of protection, currents at the two ends of the protected section are compared. Under normal operating conditions, these currents are equal but may become unequal on the occurrence of a fault in the protected section. The difference of the currents under fault conditions is arranged to pass through the operating coil of the relay. The relay then closes its contacts to isolate protected section from the system. This form of protection is also known as Merz-Price circulating current scheme.

4.Why modified differential protection is needed for alternator ?

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

5.What are common transformer faults?

(i) open circuits (ii) overheating (iii) winding short-circuits e.g. earth-faults, phase-to-phase faults and inter-turn faults

6.What is incipient fault ?

slow-developing faults such as insulation failure of windings, core heating, fall of oil level due to leaky joints etc.

7.What is Buchholz relay?

Buchholz relay is a gas-actuated relay installed in oil immersed transformers for protection against all kinds of incipient faults.

8.Fill in the blanks by inserting appropriate words/figures.

(i) The most commonly used system for the protection of generator is ....
Ans(circulating-current system)
(ii) Automatic protection is generally .... provided for field failure of an alternator. Ans(not)
(iii) The chief cause of overspeed in an alternator is the .... Ans(sudden loss of load)
(iv) Earth relays have .... current settings. Ans(lower)
(v) Buchholz relay is installed between .... and conservator. Ans(main tank)
(vi) Buchholz relays can only be used with oil immersed transformers equipped with .... Ans(conservator)
vii) For the protection of a delta/star power transformers, the CTs on delta side must be connected in .... and those on the star side in .... Ans (star, delta)
(viii) Overload protection is generally not provided for .... Ans(alternators)
(ix) Buchholz relay is a .... relay. Ans(gas actuated)
(x) Automatic protection is generally not provided for .... transformer. Ans(small distribution)

9. **Fill in the blanks by inserting appropriate words/figures.**

(i) Buchholz relay can detect faults .... oil level in the transformer. Ans(below)
(ii) The most important stator winding fault of an alternator is .... fault. Ans(earth)
(iii) Balanced earth-fault protection is generally provided for ....generators. Ans(small-size)
(iv) An earth-fault current is generally .... than short-circuit current. Ans(less)
(v) Merz-Price circulating current principle is more suitable for .... than .... Ans(Generator , Transformer)

BUS-BARS AND LINE PROTECTION

1.What are different methods of line protection?

The common methods of line protection are :

(i) Time-graded overcurrent protection

(ii) Differential protection

(iii) (iii) Distance protection

2.What is radial feeder?

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

3.What is ring-main system?

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

4.what is summation transformer?

A summation transformer is a device that reproduces the polyphase line currents as a single-phase quantity.

5.Fill in the blanks by inserting appropriate words/figures

(i) Differential protection scheme for longer lines is .... costly. Ans(very)

(ii) The bus-bar zone, for the purpose of protection, includes .... , ... and ....
Ans(bus-bars, isolating switches, circuit breakers)

(iii)The two most commonly used schemes for bus-bar protection are ...., and ....
Ans(differential protection, fault bus protection)

(iv)The probability of faults occurring on the lines is much more due to their .... and ....
Ans(greater length, exposure to atmospheric conditions)

(v)In time-graded overcurrent protection, ... discrimination is incorporated. Ans(time)

6 Fill in the blanks by inserting appropriate words/figures

(i) The parallel feeders .... be protected by non-directional overcurrent relays alone.
Ans(cannot)

(ii) The Translay scheme is essentially a .... balance system. Ans(voltage)

(iv) A summation transformer is a device that reproduces the polyphase line currents as a .... phase quantity.Ans (single)

(v) The ideal scheme of protection for lines is .... protection. Ans(differential)

(vi) Accurate matching of current transformers is .... in Merz-Price voltage balance system. Ans(essential)

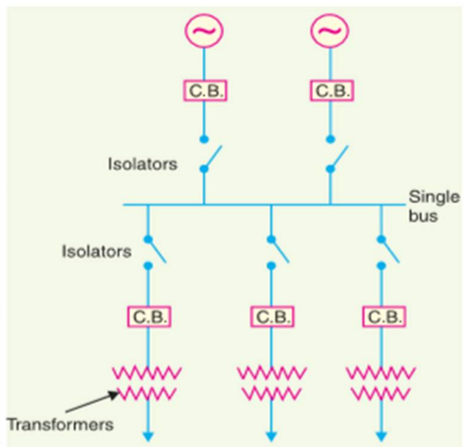
SWITCH GEAR AND PROTECTION (SGPD)

Chapter -1 Introduction to switch Gear

1. Discuss the different types of bus-bar arrangements

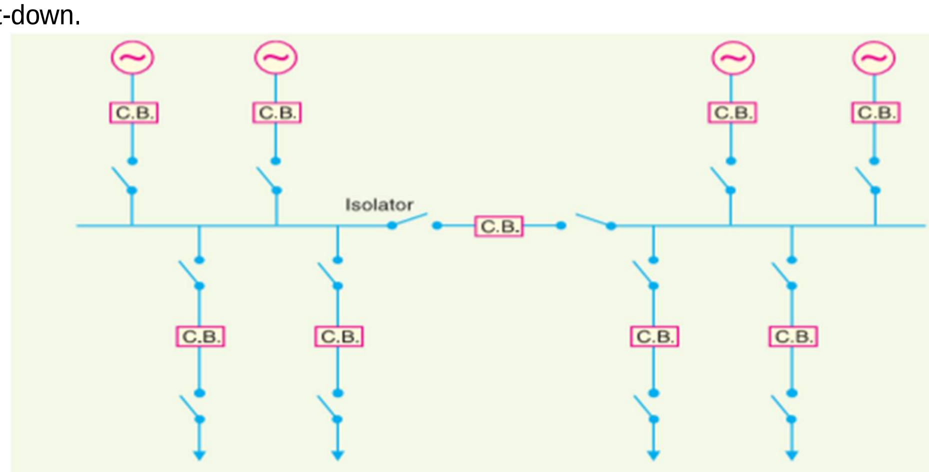
(1) Single Bus-bar System:

The single bus bar system has the simplest design and is used for power stations. It is also used in small outdoor stations having relatively few outgoing or incoming feeders and lines. The generators, outgoing lines and transformers are connected to the bus-bar. Each generator and feeder is controlled by a circuit breaker. The isolators permit to isolate generators, feeders and circuit breakers from the bus-bar for maintenance. The chief advantages of this type of arrangement are low initial cost, less maintenance and simple operation.



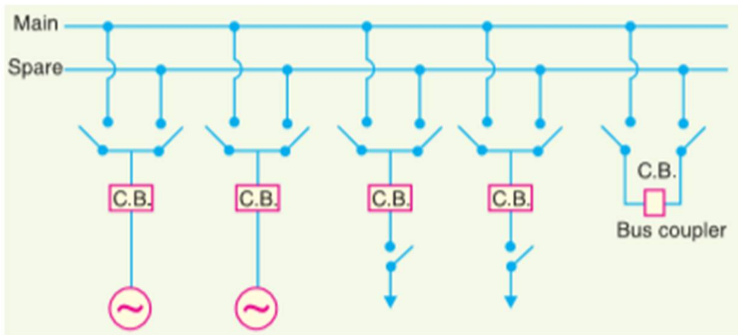
(2) Single bus-bar system with Sectionalisation:

In large generating stations where several units are installed, it is a common practice to sectionalise the bus so that fault on any section of the bus-bar will not cause complete shut down. Figure shows the bus-bar divided into two sections connected by a circuit breaker and isolators. Three principal advantages are claimed for this arrangement. Firstly, if a fault occurs on any section of the bus-bar, that section can be isolated without affecting the supply to other sections. Secondly, if a fault occurs on any feeder, the fault current is much lower than with un-sectionalised bus-bar. This permits the use of circuit breakers of lower capacity in the feeders. Thirdly, repairs and maintenance of any section of the bus-bar can be carried out by de-energising that section only, eliminating the possibility of complete shut-down.



3. Duplicate bus-bar system.

In large stations, it is important that breakdowns and maintenance should interfere as little as possible with continuity of supply. In order to achieve this objective, duplicate bus-bar system is used in important stations. Such a system consists of two bus-bars, a "main bus-bar'' and a "spare" bus-bar. Each generator and feeder may be connected to either bus-bar with the help of bus coupler which consists of a circuit breaker and isolators. In the scheme shown in Fig. 16.4, service is interrupted during switch over from one bus to another. However, if it were desired to switch a circuit from one to another without interruption of service, there would have to be two circuit breakers per circuit. Such an arrangement will be too expensive.



2. Describe essential features of switch-gear .

The essential features of switchgear are :

(i) **Complete reliability:** With the continued trend of interconnection and the increasing capacity of generating stations, the need for a reliable switchgear has become of paramount importance. This is not surprising because switchgear is added to the power system to improve the reliability. When fault occurs on any part of the power system, the switchgear must operate to isolate the faulty section from the remainder circuit.

(ii) **Absolutely certain discrimination:** When fault occurs on any section of the power system, the switchgear must be able to discriminate between the faulty section and the healthy section. It should isolate the faulty section from the system without affecting the healthy section. This will ensure continuity of supply.

(iii) **Quick operation:** When fault occurs on any part of the power system, the switchgear must operate quickly so that no damage is done to generators, transformers and other equipment by the short-circuit currents. If fault is not cleared by switchgear quickly, it is likely to spread into healthy parts, thus endangering complete shut down of the system.

(iv) **Provision for manual control:** A switchgear must have provision for manual control. In case the electrical (or electronics) control fails, the necessary operation can be carried out through manual control.

(v) **Provision for instruments:** There must be provision for instruments which may be required. These may be in the form of ammeter or voltmeter on the unit itself or the necessary current and voltage transformers for connecting to the main switchboard or a separate instrument panel.

CHAPTER -2 (FAULT CALCULATION)

1. Prove that %X=(KVA)X / 10(KV)^2

$$X = \frac{(\%X)\,V}{100I} = \frac{(\%X)\,V \times V}{100 \times VI} = \frac{(\%X)\left(\frac{V}{1000}\right)\left(\frac{V}{1000}\right) \times 1000}{100 \times \left(\frac{V}{1000}\right) \times I} = \frac{(\%X)\,(\text{kV})^2 \times 10}{\text{kVA}}$$

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

2.What is a reactor ? Explain its advantages.

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

Advantages

(i) Reactors limit the flow of short-circuit current and thus protect the equipment from overheating as well as from failure due to destructive mechanical forces.

(ii) (ii) Troubles are localised or isolated at the point where they originate without communicating their disturbing effects to other parts of the power system. This increases the chances of continuity of supply.

(iii) (iii) They permit the installation of circuit breakers of lower rating.

3. A 3-phase, 20 MVA, 10 kV alternator has internal reactance of 5% and negligible resistance. Find the external reactance per phase to be connected in series with the alternator so that steady current on short-circuit does not exceed 8 times the full load current.

Full-load current, $I = \frac{20 \times 10^6}{\sqrt{3} \times 10 \times 10^3} = 1154{\cdot}7\text{ A}$

Voltage per phase, $V = \frac{10 \times 10^3}{\sqrt{3}} = \frac{10{,}000}{\sqrt{3}}$ volts

As the short-circuit current is to be 8 times the full-load current,

∴ Total percentage reactance required

$$= \frac{\text{Full-load current}}{\text{Short-circuit current}} \times 100$$

$$= \left(\frac{1}{8}\right) \times 100 = 12{\cdot}5\ \%$$

∴ External percentage reactance required

$$= 12{\cdot}5 - 5 = 7{\cdot}5\%$$

Let $X\,\Omega$ be the per phase external reactance required.

Now, percentage reactance $= \frac{I\,X}{V} \times 100$

$$7{\cdot}5 = \frac{1154 \cdot 7X}{\frac{10{,}000}{\sqrt{3}}} \times 100$$

∴ $$X = \frac{7 \cdot 5 \times 10000}{\sqrt{3} \times 100 \times 1154 \cdot 7} = \mathbf{0{\cdot}375\ \Omega}$$

4. Write down the procedure for calculation of symmetrical fault KVA.

The procedure for the solution of such faults involves the following steps :

(i) Draw a single line diagram of the complete network indicating the rating, voltage and percentage reactance of each element of the network.

(ii) Choose a numerically convenient value of base kVA and convert all percentage reactances to this base value.

(iii) Corresponding to the single line diagram of the network, draw the reactance diagram showing one phase of the system and the neutral. Indicate the % reactances on the base kVA in the reactance diagram. The transformer in the system should be represented by a reactance in series.

(iv) Find the total % reactance of the network upto the point of fault. Let it be X%. (v) Find the full-load current corresponding to the selected base kVA and the normal system voltage at the fault point. Let it be I.

(v) Then various short-circuit calculations are :
Short-circuit current, ISC = I × 100 %X
Short-circuit kVA = Base kVA × 100 %X

8. What are the different types of faults in a power system?

Symmetrical faults: the fault which gives rise to equal fault currents in all the lines with displacement of 120° between them. The example is line to line fault i.e. shorting of all three lines.

Unsymmetrical faults: The fault which gives rise to unequal fault currents in all the lines with unequal displacement between them. The example is line ground, line to line, line to line to ground faults.

9. What are the causes of faults in a power system?

The various causes are failure of insulation of conductor at one or more places, conducting objects comes in contact with the live part of the system, mechanical failure, excessive internal and external stress, over voltages due to switching surges, lightning strokes, heavy winds and storms, falling of trees on the lines, accidents of vehicles with the towers or poles, perching of birds on the lines, accidental short circuits due to snakes, kites, strings etc.

10. What are the various methods of earthing in substations?

2. Solid or effective grounding
3. Resistance grounding
4. Reactance grounding
5. Resonant grounding

11. Why earth wire is provided in overhead transmission lines?

- To protect the line conductors from direct lightning strokes.
- To reduce the line outages
- To reduce the interference on neighbouring installations.

12. What is the difference between a short circuit and an overload.

When there is a short circuit, the impedance at the fault point is almost zero and the voltage at the fault point is zero. The short circuit current is very high. While an overload means the load is higher than the rated load which is specified as the safe load. Thus the current is also higher than the safe load. The overload does not causes damage instantly but if persists for long time, can cause damage to the system.

Circuit Breaker

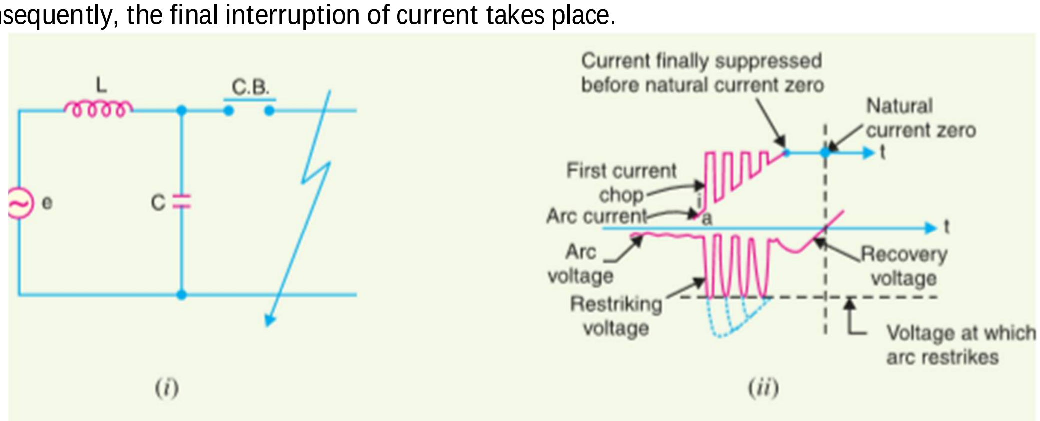
1.Explain current chopping phenomenon in case of air circuit breaker.

Current chopping. It is the phenomenon of current interruption before the natural current zero is reached. Current chopping **mainly occurs in air-blast circuit breakers because they retain the same extinguishing power irrespective of the magnitude of the current to be interrupted. When breaking low currents (e.g., transformer magnetising current) with such breakers, the powerful de-ionising effect of air-blast causes the current to fall abruptly to zero well before the natural current zero is reached. This phenomenon is known as current chopping and results in the production of high voltage transient across the contacts of the circuit breaker as discussed below : Consider again Fig. 19.17 (ii) repeated as Fig. 19.19 (i). Suppose the arc current is i when it is chopped down to zero value as shown by point a in Fig. 19.19 (ii). As the chop occurs at current i, therefore, the energy stored in inductance is L i2/2. This energy will be transferred to the capacitance C, charging the latter to a prospective voltage e given by :

$$(½)Li^2 = (½) CV^2$$

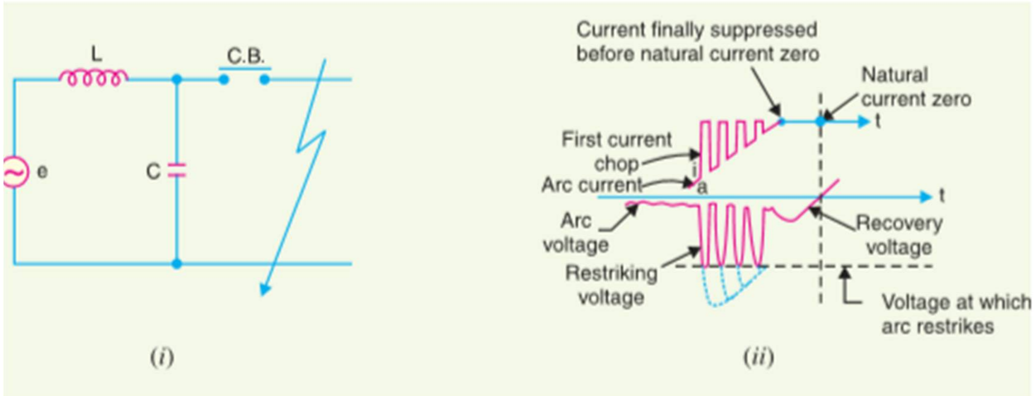
$$e = i\ \mathrm{Sqrt}(L/C) \text{ volts} \quad ...(i)$$

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



2. Explain Capacitive current breaking in case of circuit breaker .

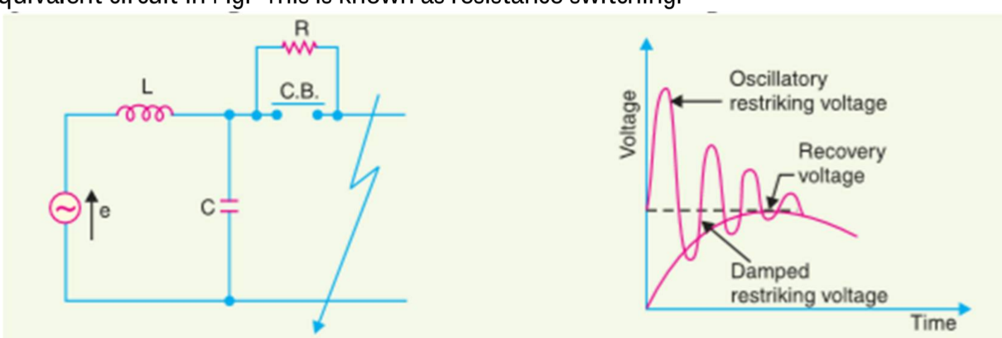
Another cause of excessive voltage surges in the circuit breakers is the interruption of capacitive currents. Examples of such instances are opening of an unloaded long transmission line, disconnecting a capacitor bank used for power factor improvement etc. Consider the simple equivalent circuit of an unloaded transmission line shown in Fig1. Such a line, although unloaded in the normal sense, will actually carry a capacitive current I on account of appreciable amount of capacitance C between the line and the earth. Let us suppose that the line is opened by the circuit breaker at the instant when line capacitive current is zero [point 1 in fig 2]. At this instant, the generator voltage Vg will be maximum (i.e., Vgm) lagging behind the current by 90º. The opening of the line leaves a standing charge on it (i.e., end B of the line) and the capacitor C1 is



charged to Vgm. However, the generator end of the line (i.e., end A of the line) continues its normal sinusoidal variations. The voltage Vr across the circuit breaker will be the difference between the voltages on the respective sides. Its initial value is zero (point 1) and increases slowly in the beginning. But half a cycle later [point R in Fig. 19.21], the potential of the circuit breaker contact 'A' becomes maximum negative which causes the voltage across the breaker (Vr) to become 2 Vgm. This voltage may be sufficient to restrike the arc. The two previously separated parts of the circuit will now be joined by an arc of very low resistance. The line capacitance discharges at once to reduce the voltage across the circuit breaker, thus setting up high frequency transient. The peak value of the initial transient will be twice the voltage at that instant i.e., − 4 Vgm. This will cause the transmission voltage to swing to − 4 Vgm to + Vgm i.e., − 3Vgm.

3. Explain Resistance switching in circuit breaker .

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



Referring to Fig, when a fault occurs, the contacts of the circuit breaker are opened and an arc is struck between the contacts. Since the contacts are shunted by resistance R, a part of arc current flows through this resistance. This results in the decrease of arc current and an increase in the rate of de-ionisation of the arc path. Consequently, the arc resistance is increased. The increased arc resistance leads to a further increase in current through shunt resistance. This process continues until the arc current becomes so small that it fails to maintain the arc. Now, the arc is extinguished and circuit current is interrupted. The shunt resistor also helps in limiting the oscillatory growth of re-striking voltage. It can be proved mathematically that natural frequency of oscillations of the circuit shown in Fig. 19.22 is given by :

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

The effect of shunt resistance R is to prevent the oscillatory growth of re-striking voltage and cause it to grow exponentially upto recovery voltage. This is being most effective when the value of R is so chosen that the circuit is critically damped. The value of R required for critical damping is 0·5sqrt(L/C). Fig shows the oscillatory growth and exponential growth when the circuit is critically damped. To sum up, resistors across breaker contacts may be used to perform one or more of the following functions :

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

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

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

6. Explain working principle of SF6 circuit breaker .

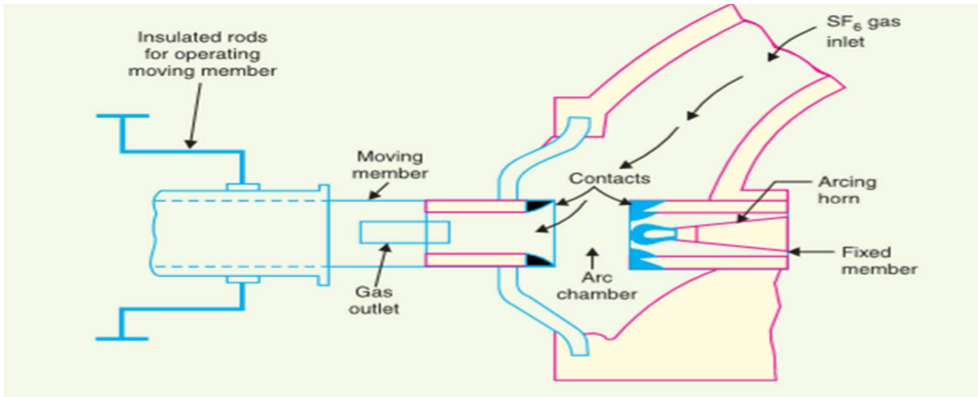
In such circuit breakers, sulphur hexaflouride (SF6) gas is used as the arc quenching medium. The SF6 is an electro-negative gas and has a strong tendency to absorb free electrons. The contacts of the breaker are opened in a high pressure flow of SF6 gas and an arc is struck between them. The conducting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

Construction.

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

Working:

In the closed position of the breaker, the contacts remain surrounded by SF6 gas at a pressure of about 2·8 kg/cm2. 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 SF6 gas at 14 kg/cm2 pressure from the reservoir to the arc interruption chamber. The high pressure flow of SF6 rapidly absorbs the free electrons in the arc path to form immobile negative ions which are ineffective as charge carriers. The result is that the medium between the contacts quickly builds up high dielectric strength and causes the extinction of the arc. After the breaker operation (i.e., after arc extinction), the valve is closed by the action of a set of springs.



7. Explain working principle of vaccum circuit breaker .

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:

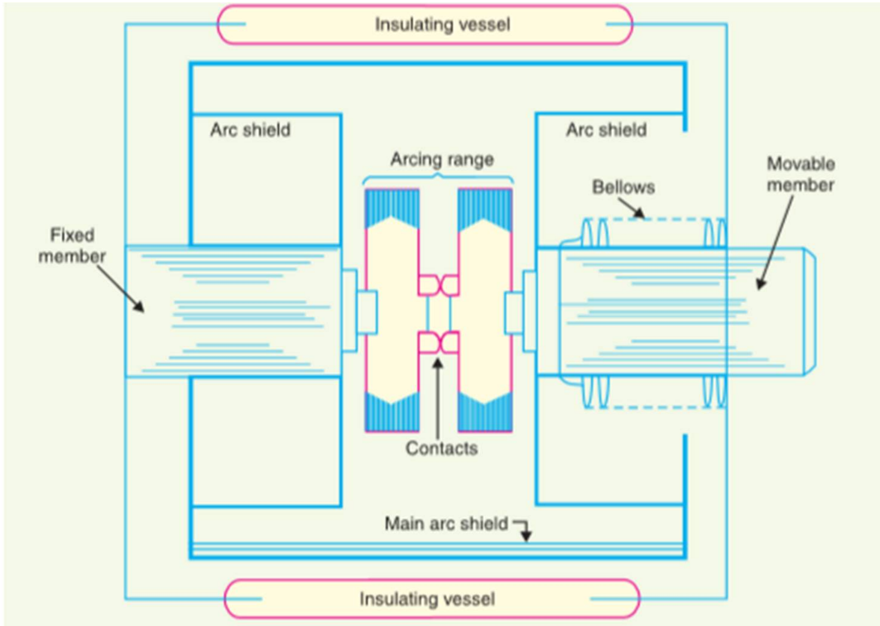
The production of arc in a vacuum circuit breaker and its extinction can be explained as follows : When the contacts of the breaker are opened in vacuum (10−7 to 10−5 torr), an arc is produced between the contacts by the ionisation of metal vapours of contacts*. However, the arc is quickly extinguished 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. shows the parts of a typical vacuum circuit breaker. It consists of fixed contact, moving contact and arc shield mounted inside a vacuum chamber. The movable member is connected to the control mechanism by stainless steel bellows. This enables the permanent sealing of the vacuum chamber so as to eliminate the possibility of leak. A glass vessel or ceramic vessel is used as the outer insulating body. The arc shield prevents the deterioration of the internal dielectric strength by preventing metallic vapours falling on the inside surface of the outer insulating cover.

Working:

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



FUSE

1. **Derive fuse law.**

The current carrying capacity of a fuse element mainly depends on the metal used and the cross-sectional area but is affected also by the length, the state of surface and the surroundings of the fuse. When the fuse element attains steady temperature,

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

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

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

where d = diameter of fuse element

l = length of fuse element

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

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

or $$I^2 \propto d^3 \qquad \ldots(i)$$

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

2. **Explain high voltage fuse**

Some of the high voltage fuses are :

(i) Cartridge type:

This is similar in general construction to the low voltage cartridge type except that special design features are incorporated. Some designs employ fuse elements wound in the form of a helix so as to avoid corona effects at higher voltages. On some designs, there are two fuse elements in parallel ; one of low resistance (silver wire) and the other of high resistance (tungsten wire). Under normal load conditions, the low resistance element carries the normal current. When a fault occurs, the low-resistance element is blown out and the high resistance element reduces the short-circuit current and finally breaks the circuit. High voltage cartridge fuses are used upto 33 kV with breaking capacity of about 8700 A at that voltage. Rating of the order of 200 A at 6·6 kV and 11 kV and 50 A at 33 kV are also available.

(ii) Liquid type.

These fuses are filled with carbon tetrachloride and have the widest range of application to h.v. systems. They may be used for circuits upto about 100 A rated current on systems upto 132 kV and may have breaking capacities of the order of 6100 A. It consists of a glass tube filled with carbon tetrachloride solution and sealed at both ends with brass caps. The fuse wire is sealed at one end of the tube and the other end of the wire is held by a strong phosphor bronze spiral spring fixed at the other end of the glass tube. When the current exceeds the prescribed limit, the fuse wire is blown out. As the fuse melts, the spring retracts part of it through a baffle (or liquid director) and draws it well into the liquid. The small quantity of gas generated at the point of fusion forces some part of liquid into the passage through baffle and there it effectively extinguishes the arc.

(iii) Metal clad fuses.

Metal clad oil-immersed fuses have been developed with the object of providing a substitute for the oil circuit breaker. Such fuses can be used for very high voltage circuits and operate most satisfactorily under short-circuit conditions approaching their rated capacity.

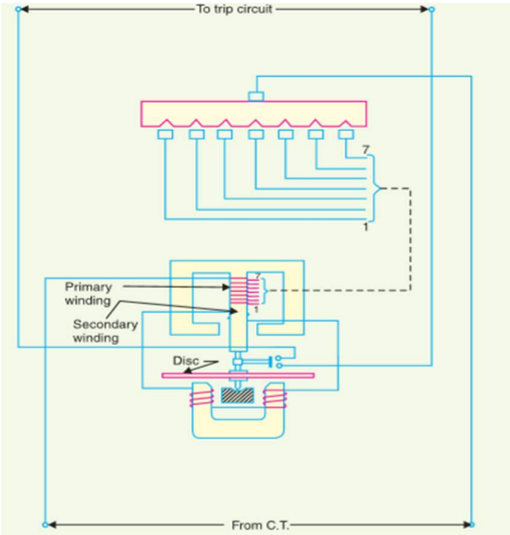
PROTECTIVE RELAY

1.DESCRIBE INDUCTION TYPE OVER-CURRENT RELAY.

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

CONSTRUCTIONAL DETAILS

It consists of a metallic (aluminium) disc which is free to rotate in between the poles of two electromagnets. The upper electromagnet has a primary and a secondary winding. The primary is connected to the secondary of a C.T. in the line to be protected and is tapped at intervals. The tappings are connected to a plug-setting bridge by which the number of active turns on the relay operating coil can be varied, thereby giving the desired current setting. The secondary winding is energised by induction from primary and is connected in series with the winding on the lower magnet. The controlling torque is provided by a spiral spring. The spindle of the disc carries a moving contact which bridges two fixed contacts (connected to trip circuit) when the disc rotates through a pre-set angle. This angle can be adjusted to any value between 0o and 360o. By adjusting this angle, the travel of the moving contact can be adjusted and hence the relay can be given any desired time setting.



OPERATION.

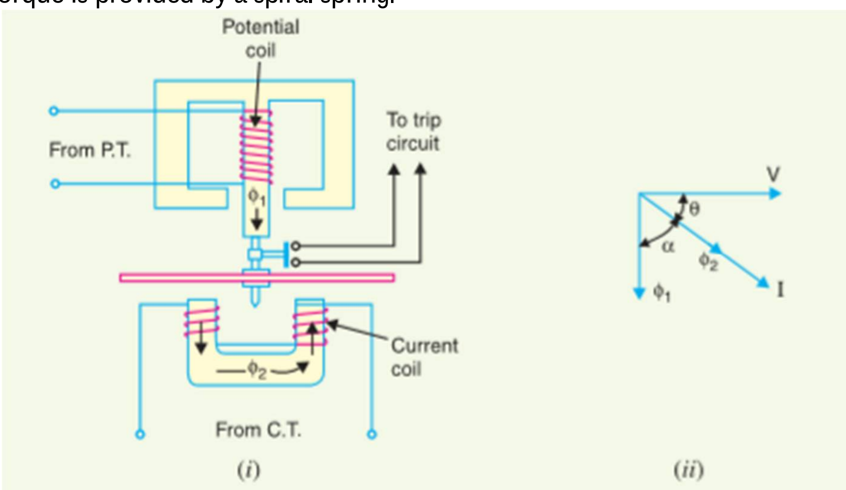
The driving torque on the aluminium disc is set up due to the induction principle This torque is opposed by the restraining torque provided by the spring. Under normal operating conditions, restraining torque is greater than the driving torque produced by the relay coil current. Therefore, the aluminium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

2.DESCRIBE INDUCTION TYPE DIRECTIONAL POWER RELAY.

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

Constructional details.

It consists of an aluminum disc which is free to rotate in between the poles of two electromagnets. The upper electromagnet carries a winding (called potential coil) on the central limb which is connected through a potential transformer (P.T.) to the circuit voltage source. The lower electromagnet has a separate winding (called current coil) connected to the secondary of C.T. in the line to be protected. The current coil is provided with a number of tappings connected to the plugsetting bridge (not shown for clarity). This permits to have any desired current setting. The restraining torque is provided by a spiral spring.



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

Operation.

The flux $\phi 1$ due to current in the potential coil will be nearly 90° lagging behind the applied voltage V. The flux $\phi 2$ due to current coil will be nearly in phase with the operating current I. The interaction of fluxes $\phi 1$ and $\phi 2$ with the eddy currents induced in the disc produces a driving torque given by :

$$T \propto \phi 1 \, \phi 2 \sin \alpha$$

$$\text{Since } \phi 1 \propto V,$$

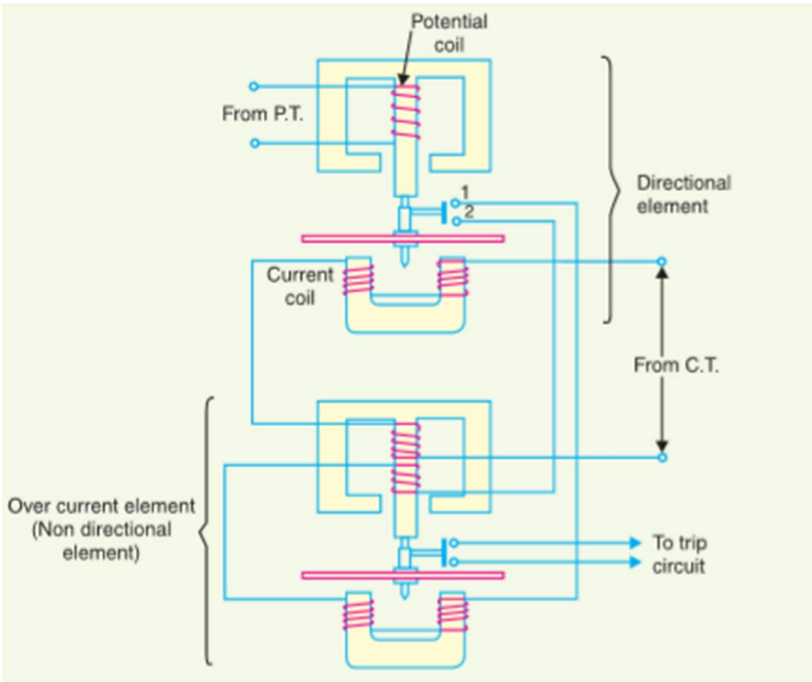
$$\phi 2 \propto I \text{ and } \alpha = 90 - \theta$$

$$\therefore T \propto V I \sin (90 - \theta) \propto V I \cos \theta \propto \text{power in the circuit}$$

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

3.EXPLAIN HOW TO MAKE A NON-DIRECTIONAL OVERCURRENT RELAY TO DIRECTIONAL OVERCURRENT RELAY.

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



Constructional details.

It consists of two relay elements mounted on a common case viz.

(i) directional element and

(ii) (ii) non-directional element.

(i) **DIRECTIONAL ELEMENT**.

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

(ii) **NON-DIRECTIONAL ELEMENT.**

The spindle of the disc of this element carries a moving contact which closes the fixed contacts (trip circuit contacts) after the operation of directional element. It may be noted that plug-setting bridge is also provided in the relay for current setting but has been omitted in the figure for clarity and simplicity. The tappings are provided on the upper magnet of overcurrent element and are connected to the bridge.

OPERATION.

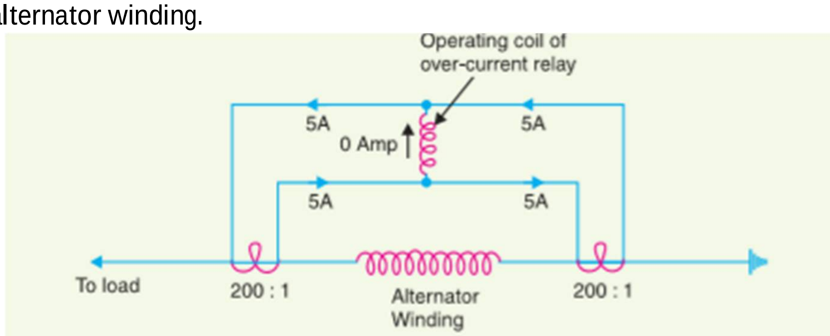
Under normal operating conditions, power flows in the normal direction in the circuit protected by the relay. Therefore, directional power relay (upper element) does not operate, thereby keeping the overcurrent element (lower element) unenergised. However, when a short-circuit occurs, there is a tendency for the current or power to flow in the reverse direction. Should this happen, the disc of the upper element rotates to bridge the fixed contacts 1 and 2. This completes the circuit for overcurrent element. The disc of this element rotates and the moving contact attached to it closes the trip circuit. This operates the circuit breaker which isolates the faulty section. The two relay elements are so arranged that final tripping of the current controlled by them is not made till the following conditions are satisfied : (i) current flows in a direction such as to operate the directional element. (ii) current in the reverse direction exceeds the pre-set value. (iii) excessive current persists for a period corresponding to the time setting of overcurrent element

4.What is differential protection ?

A differential relay is one that operates when the phasor difference of two or more similar electrical quantities exceeds a pre-determined value. Thus a current differential relay is one that compares the current entering a section of the system with the current leaving the section. Under normal operating conditions, the two currents are equal but as soon as a fault occurs, this condition no longer applies. The difference between the incoming and outgoing currents is arranged to flow through the operating coil of the relay. If this differential current is equal to or greater than the pickup value, the relay will operate and open the circuit breaker to isolate the faulty section. It may be noted that almost any type of relay when connected in a particular way can be made to operate as a differential relay. In other words, it is not so much the relay construction as the way the relay is connected in a circuit that makes it a differential relay. There are two fundamental systems of differential or balanced protection viz. (i) Current balance protection (ii) Voltage balance protection

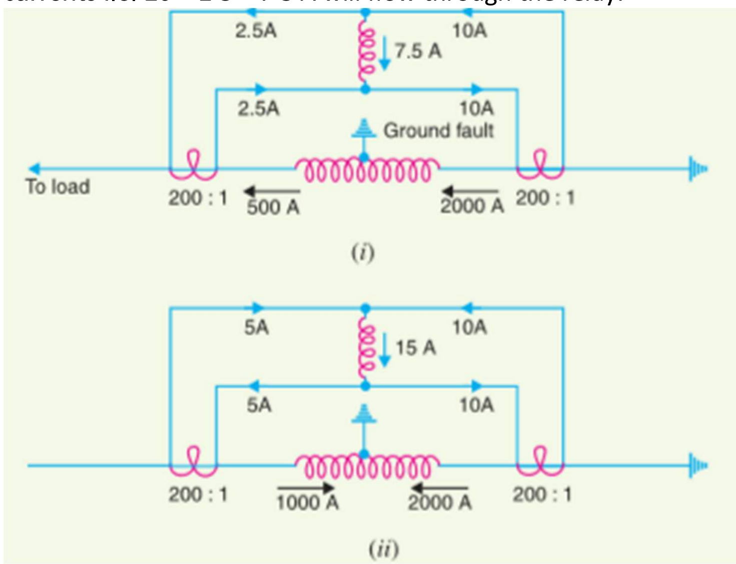
CURRENT DIFFERENTIAL RELAY :

Figure shows an arrangement of an overcurrent relay connected to operate as a differential relay. A pair of identical current transformers are fitted on either end of the section to be protected (alternator winding in this case). The secondaries of CT's are connected in series in such a way that they carry the induced currents in the same direction. The operating coil of the overcurrent relay is connected across the CT secondary circuit. This differential relay compares the current at the two ends of the alternator winding.



Under normal operating conditions, suppose the alternator winding carries a normal current of 1000 A. Then the currents in the two secondaries of CT's are equal .These currents will merely circulate between the two CT's and no current will flow through the differential relay. Therefore, the relay remains inoperative. If a ground fault occurs on the alternator winding as shown in Fig below the two secondary currents will not be equal and the current flows through the operating coil of the relay, causing the relay to operate. The amount of current flow through the relay will depend upon the way the fault is being fed.

(i) If some current (500 A in this case) flows out of one side while a larger current (2000 A) enters the other side as shown in Fig below, then the difference of the CT secondary currents i.e. 10 – 2·5 = 7·5 A will flow through the relay.



(ii) If current flows to the fault from both sides as shown in above, then sum of CT secondary currents i.e. 10 + 5 = 15 A will flow through the relay.

VOLTAGE BALANCE DIFFERENTIAL RELAY

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

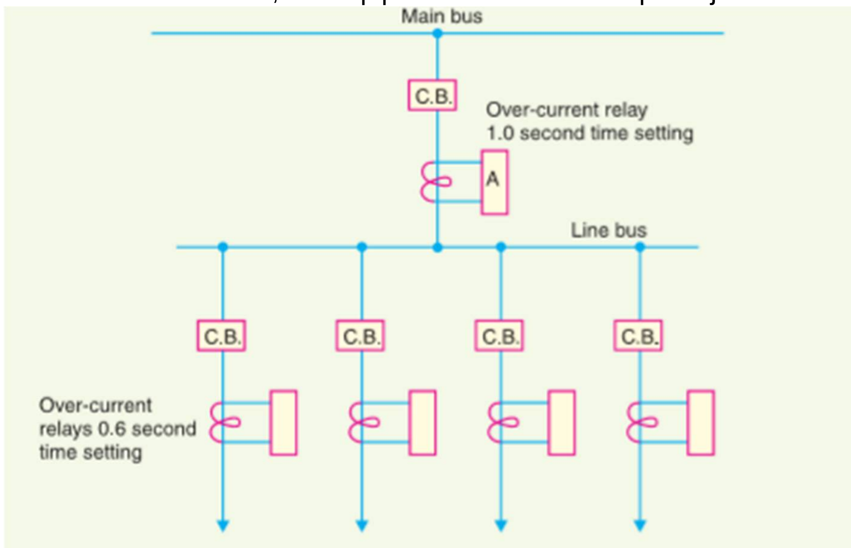
Under healthy conditions, equal currents (I1 = I2) flow in both primary windings. Therefore, the secondary voltages of the two transformers are balanced against each other and no current will flow through the relay operating coil. When a fault occurs in the protected zone, the currents in the two primaries will differ from one another (i.e. I1 ≠ I2) and their secondary voltages will no longer be in balance. This voltage †difference will cause a current to flow through the operating coil of the relay which closes the trip circuit.

5.EXPLAIN TYPES OF PROTECTION IN POWER SYSTEM.

When a fault occurs on any part of electric power system, it must be cleared quickly in order to avoid damage and/or interference with the rest of the system. It is a usual practice to divide the protection scheme into two classes viz. primary protection and back-up protection.

(i) PRIMARY PROTECTION.

It is the protection scheme which is designed to protect the component parts of the power system. Thus referring to Fig below, each line has an overcurrent relay that protects the line. If a fault occurs on any line, it will be cleared by its relay and circuit breaker. This forms the primary or main protection and serves as the first line of defence. The service record of primary relaying is very high with well over ninety percent of all operations being correct. However, sometimes faults are not cleared by primary relay system because of trouble within the relay, wiring system or breaker. Under such conditions, back-up protection does the required job.



(ii)BACK-UP PROTECTION

It is the second line of defence in case of failure of the primary protection. It is designed to operate with sufficient time delay so that primary relaying will be given enough time to function if it is able to. Thus referring to Fig. above relay A provides back-up protection for each of the four lines. If a line fault is not cleared by its relay and breaker, the relay A on the group breaker will operate after a definite time delay and clear the entire group of lines. It is evident that when back-up relaying functions, a larger part is disconnected than when primary relaying functions correctly. Therefore, greater emphasis should be placed on the better maintenance of primary relaying.

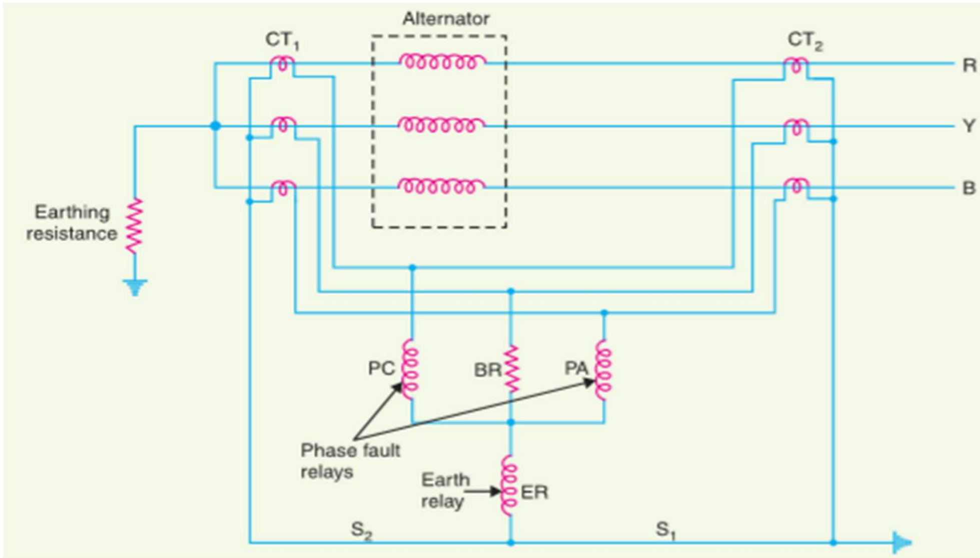
PROTECTION OF ALTERNATORS AND TRANSFORMERS

1.Explain modified differential protection in case of alternator.

If the neutral point of a star-connected alternator is earthed through a high resistance, it will not provide sufficient sensitivity for earth-faults. It is because the high earthing resistance will limit the earth-fault currents to a low value, necessitating relays with low current settings if adequate portion of the generator winding is to be protected. However, too low a relay setting is undesirable for reliable stability on heavy through phase-faults. In order to overcome this difficulty, a modified form of differential protection is used in which the setting of earth faults is reduced without impairing stability. The modified arrangement is shown below. The modifications affect only the relay connections and consist in connecting two relays for phase-fault protection and the third for earth-fault protection only. The two phase elements (PC and PA) and balancing resistance (BR) are connected in star and the earth relay (ER) is connected between this star point and the fourth wire of circulating current pilot-circuit.

OPERATION.

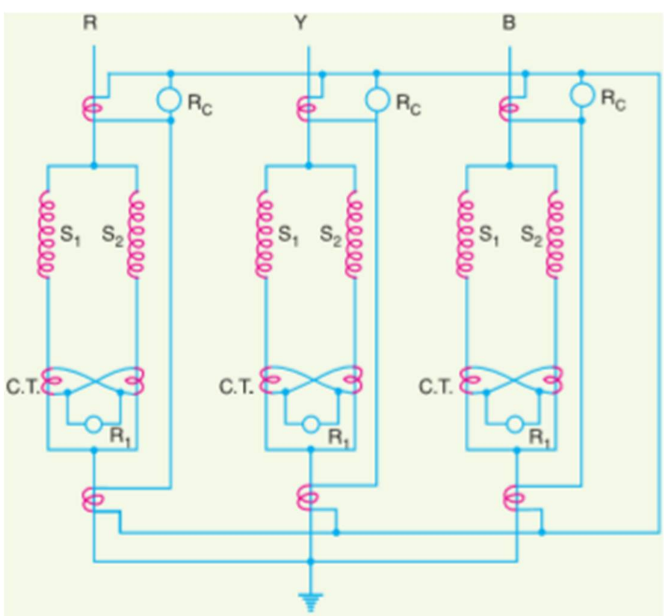
Under normal operating conditions, currents at the two ends of each stator winding will be equal. Therefore, there is a balanced circulating current in the phase pilot wires and no current flows through the operating coils of the relays. Consequently, the relays remain inoperative.



If an earth-fault occurs on any one phase, the out-of-balance secondary current in CTs in that phase will flow through the earth relay ER and via pilot S1 or S2 to the neutral of the current transformers. This will cause the operation of earth relay only. If a fault occurs between two phases, the outof-balance current will circulate round the two transformer secondaries via any two of the coils PA , BR, PC (the pair being decided by the two phases that are faulty) without passing through the earth relay ER. Therefore, only the phase-fault relays will operate.

2.EXPLAIN STARTOR INTER-TURN PROTECTION SCHEME IN CASE OF AN ALTERNATOR.

Merz-price circulating-current system protects against phase-to-ground and phase-to-phase faults. It does not protect against turn-to-turn fault on the same phase winding of the stator. It is because the current that this type of fault produces flows in a local circuit between the turns involved and does not create a difference between the currents entering and leaving the winding at its two ends where current transformers are applied. However, it is usually considered unnecessary to provide protection for inter-turn faults because they invariably develop into earth-faults.



In single turn generator (e.g. large steam-turbine generators), there is no necessity of protection against inter-turn faults. However, inter-turn protection is provided for multi-turn generators such as hydro-electric generators. These generators have double-winding armatures (i.e. each phase winding is divided into two halves) owing to the very heavy currents which they have to carry. Advantage may be taken of this necessity to protect inter-turn faults on the same winding. Fig. above shows the schematic arrangement of circulating-current and inter-turn protection of a 3-phase double wound generator. The relays RC provide protection against phase-to-ground and phase-to-phase faults whereas relays R1 provide protection against inter-turn faults.

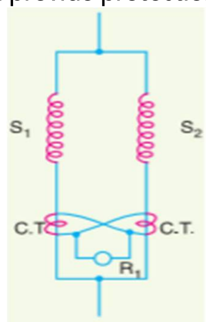


Fig. above shows the duplicate stator windings S1 and S2 of one phase only with a provision against inter-turn faults. Two current transformers are connected on the circulating-current principle. Under normal conditions, the currents in the stator windings S1 and S2 are equal and so will be the currents in the secondaries of the two CTs. The secondary current round the loop then is the same at all points and no current flows through the relay R1. If a short-circuit develops between adjacent turns, say on S1, the currents in the stator windings S1 and S2 will no longer be equal. Therefore, unequal currents will be induced in the secondaries of CTs and the difference of these two currents flows through the relay R1. The relay then closes its contacts to clear the generator from the system.

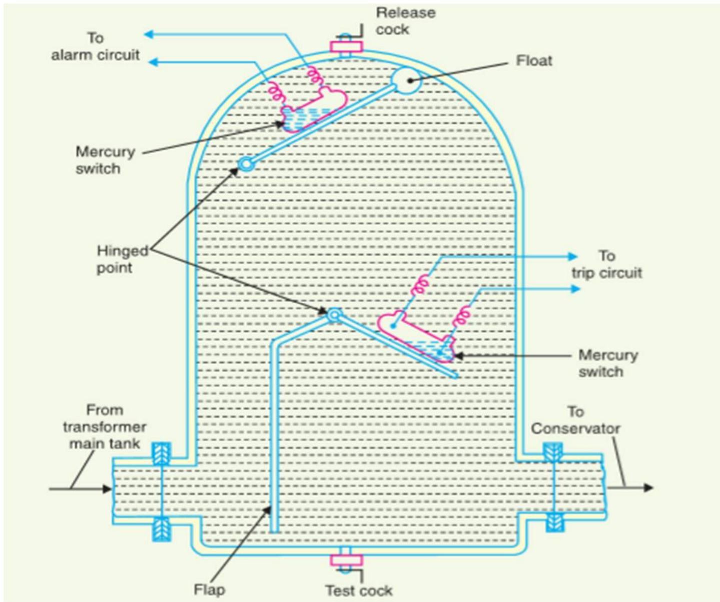
3.EXPLAIN DETAILED OPERATION OF BUCHOLZ RELAY.

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

Construction.

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

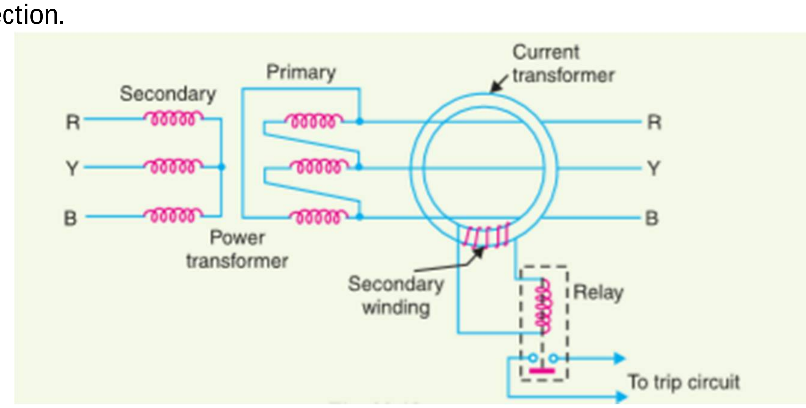
(i) In case of incipient faults within the transformer, the heat due to fault causes the decomposition of some transformer oil in the main tank. The products of decomposition contain more than 70% of hydrogen gas. The hydrogen gas being light tries to go into the conservator and in the process gets entrapped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



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

3.WRITE A SHORT NOTE ON EARTH LEAKAGE PROTECTION.

An earth-fault usually involves a partial breakdown of winding insulation to earth. The resulting leakage current is considerably less than the 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 these circumstances, it is profitable to employ earth-fault relays in order to ensure the disconnection of earth-fault or leak in the early stage. An earth-fault relay is essentially an overcurrent relay of low setting and operates as soon as an earth-fault or leak develops. One method of protection against earth-faults in a transformer is the core-balance leakage protection.



The three leads of the primary winding of power transformer are taken through the core of a current transformer which carries a single secondary winding. The operating coil of a relay is connected to this secondary. Under normal conditions (i.e. no fault to earth), the vector sum of the three phase currents is zero and there is no resultant flux in the core of current transformer no matter how much the load is out of balance. Consequently, no current flows through the relay and it remains inoperative. However, on the occurrence of an earth-fault, the vector sum of three phase currents is no longer zero. The resultant current sets up flux in the core of the C.T. which induces e.m.f. in the secondary winding. This energises the relay to trip the circuit breaker and disconnect the faulty transformer from the system.

PROTECTION OF BUSBAR AND LINES

1.Writedown a short note on bus-bar protection.

Busbars in the generating stations and sub-stations form important link between the incoming and outgoing circuits. If a fault occurs on a busbar, considerable damage and disruption of supply will occur unless some form of quick-acting automaticprotection is provided to isolate the faulty busbar. The busbar zone, for the purpose of protection, includes not only the busbars themselves but also the isolating switches, circuit breakers and the associated connections. In the event of fault on any section of the busbar, all the circuit equipments connected to that section must be tripped out to give complete isolation. The standard of construction for busbars has been very high, with the result that bus faults are extremely rare. However, the possibility of damage and service interruption from even a rare bus fault is so great that more attention is now given to this form of protection. Improved relaying methods have been developed, reducing the possibility of incorrect operation. The two most commonly used schemes for busbar protection are :

(i) Differential protection
(ii) Fault bus protection

(i) Differential protection.

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

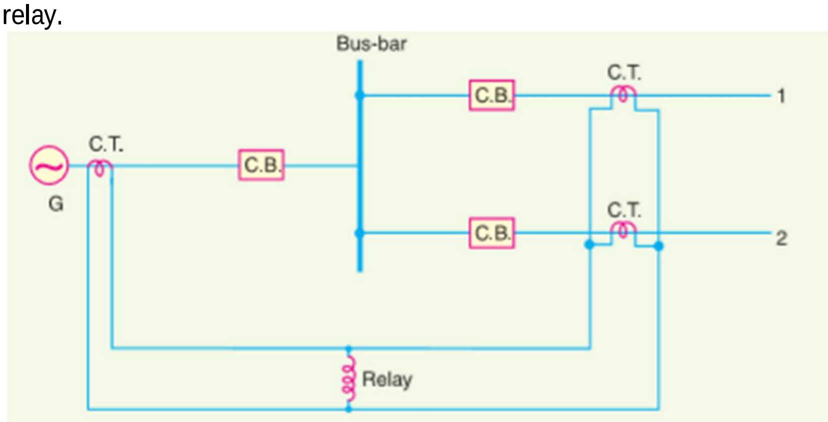
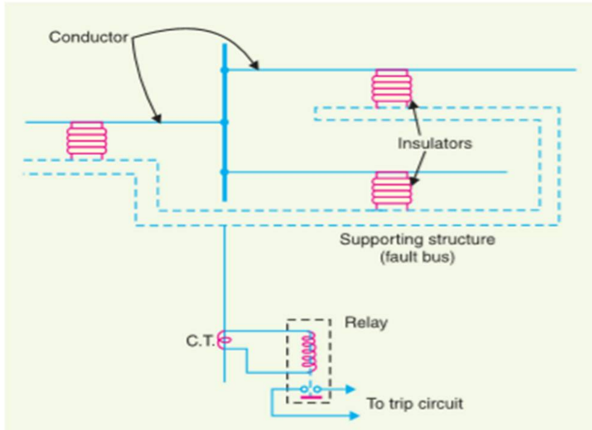


Fig. above shows the single line diagram of current differential scheme for a station busbar. The busbar is fed by a generator and supplies load to two lines. The secondaries of current transformers in the generator lead, in line 1 and in line 2 are all connected in parallel. The protective relay is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

(ii)Fault Bus protection.

It is possible to design a station so that the faults that develop are mostly earth-faults. This can be achieved by providing earthed metal barrier (known as fault bus) surrounding each conductor throughout its entire length in the bus structure. With this arrangement, every fault that might occur must involve a connection between a conductor and an earthed metal part. By directing the flow of earth-fault current, it is possible to detect the faults and determine their location. This type of protection is known as fault bus protection. Fig. below shows the schematic arrangement of fault bus protection. The metal supporting structure or fault bus is earthed through a current transformer. A relay is connected across the secondary of this CT. Under normal operating conditions, there is no current flow from fault bus to ground and the relay remains inoperative. A fault involving a connection between a conductor and earthed supporting structure will result in current flow to ground through the fault bus, causing the relay to operate. The operation of relay will trip all breakers connecting equipment to the bus.



3.EXPLAIN PROTECTION OF TRANSMISSION LINE.

The requirements of line protection are :

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

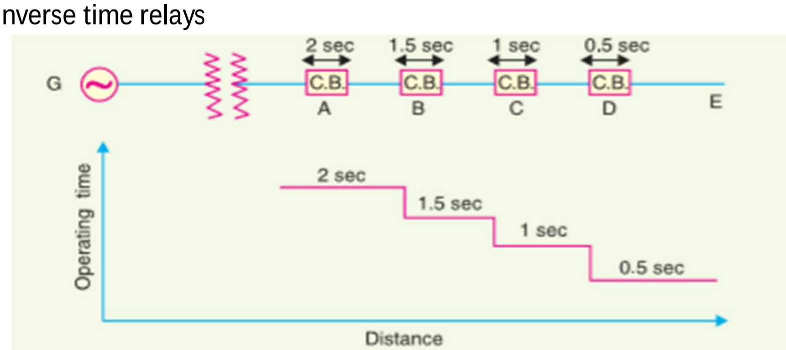
(ii) In case the nearest breaker to the fault fails to open, back-up protection should be provided by the adjacent circuit breakers.

(iii) The relay operating time should be just as short as possible in order to preserve system stability, without unnecessary tripping of circuits. The protection of lines presents a problem quite different from the protection of station apparatus such as generators, transformers and busbars. While differential protection is ideal method for lines, it is much more expensive to use. The two ends of a line may be several kilometres apart and to compare the two currents, a costly pilot-wire circuit is required. This expense may be justified but in general less costly methods are used. The common methods of line protection are :

(i) Time-graded overcurrent protection
(ii) Differential protection
(iii) Distance protection

TIME-GRADED OVERCURRENT PROTECTION

In this scheme of overcurrent protection, time discrimination is incorporated. In other words, the time setting of relays is so graded that in the event of fault, the smallest possible part of the system is isolated. We shall discuss a few important cases. 1. Radial feeder. The main characteristic of a radial system is that power can flow only in one direction, from generator or supply end to the load. It has the disadvantage that continuity of supply cannot be maintained at the receiving end in the event of fault. Time-graded protection of a radial feeder can be achieved by using (i) definite time relays and (ii) inverse time relays



DEFINITE TIME RELAYS.

Fig. aboveshows the overcurrent protection of a radial feeder by definite time relays. The time of operation of each relay is fixed and is independent of the operating current. Thus relay D has an operating time of 0·5 second while for other relays, time delay* is successively increased by 0·5 second. If a fault occurs in the section DE, it will be cleared in 0·5 second by the relay and circuit breaker at D because all other relays have higher operating time. In this way only section DE of the system will be isolated. If the relay at D fails to trip, the relay at C will operate after a time delay of 0·5 second i.e. after 1 second from the occurrence of fault.

DIFFERENTIAL PILOT WIRE PROTECTION:

The differential pilot-wire protection is based on the principle that under normal conditions, the current entering one end of a line is equal to that leaving the other end. As soon as a fault occurs between the two ends, this condition no longer holds and the difference of incoming and outgoing currents is arranged to flow through a relay which operates the circuit breaker to isolate the faulty line. There are several differential protection schemes in use for the lines. However, only the follow ing two schemes will be discussed : 1. Merz-Price voltage balance system 2. Translay scheme

Merz-Price voltage balance system.

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