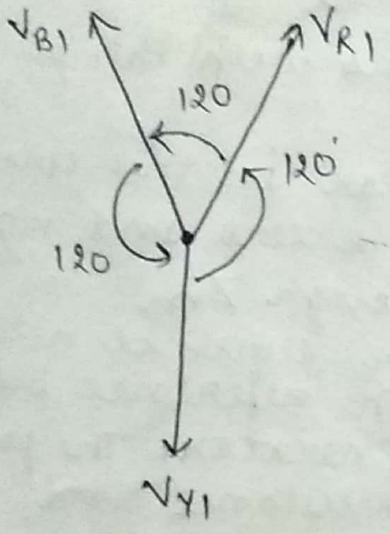
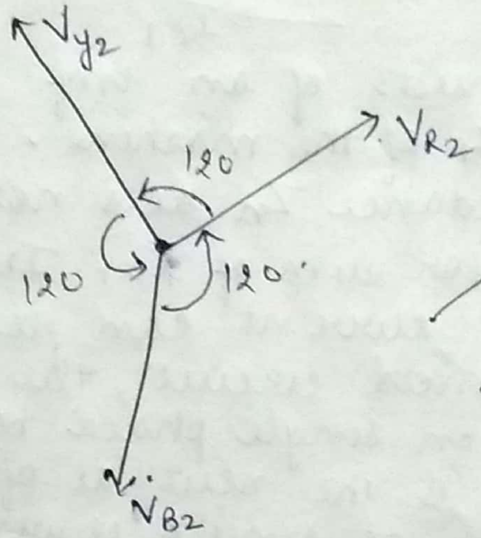
★ Method of symmetrical components

It is used to simplify fault analysis by converting a three phase unbalanced system into two sets of balanced phasors and a set of single phase phasors or symmetrical components. These set of phasors are positive, negative and zero sequence.



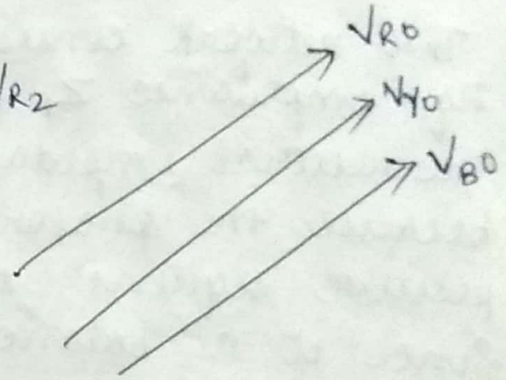
+ve Sequence

Set of three phasors equal in magnitude, displaced from each other by 120° in phase and having the same phase sequence as the original phasors



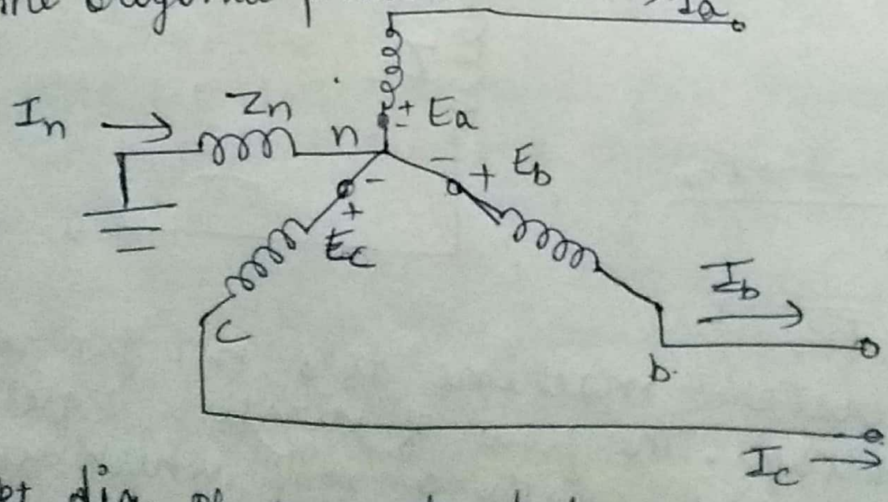
-ve sequence

~~Havin so~~ Equal in magnitude and 120° in phase but having opp. phase sequence to that of the original phasors

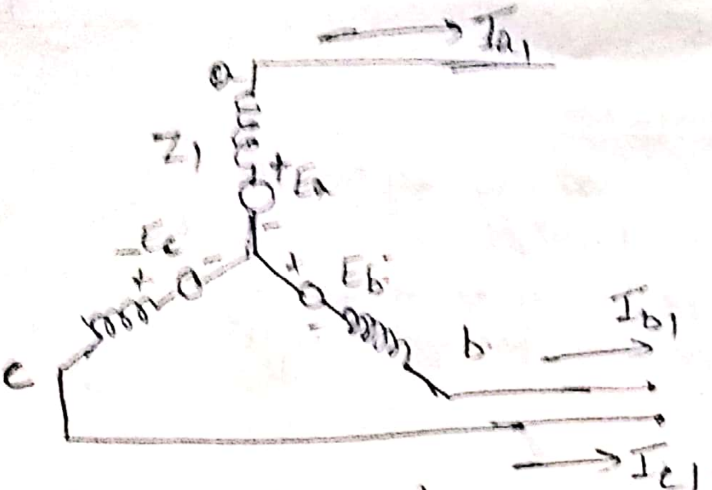


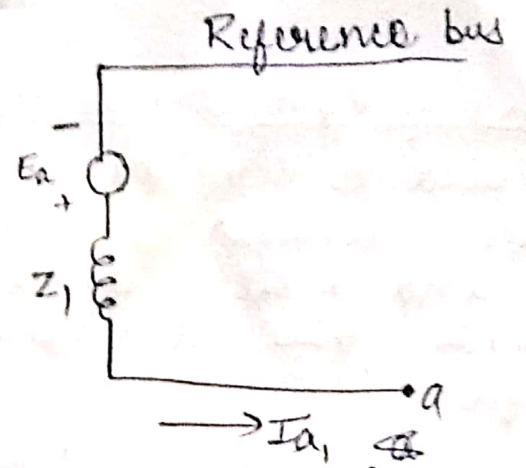
Zero sequence

Set of three phasors equal in magnitude and all in phase (with no mutual phase displacement)



Ckt dig. of an unloaded generator grounded through impedance Z_n

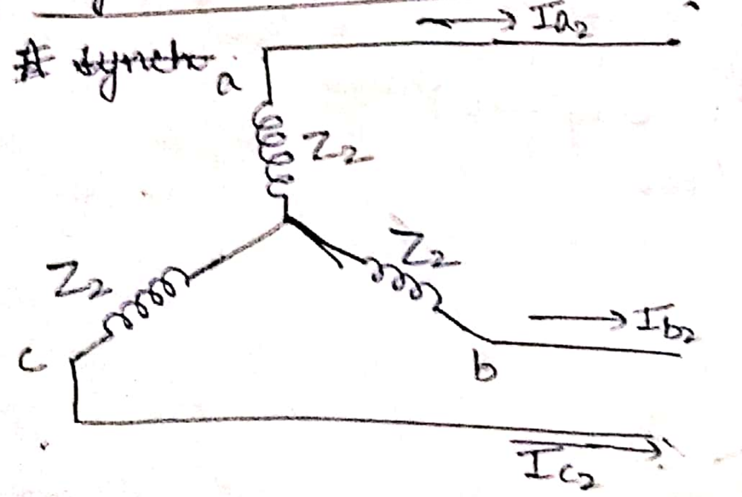


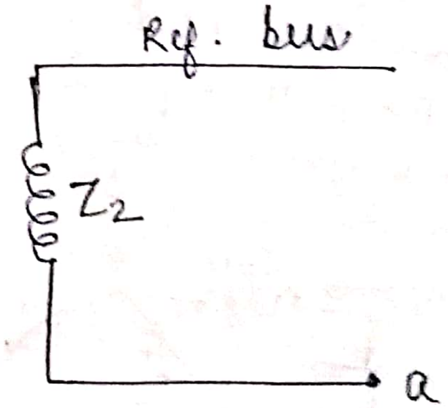


This network consists of an emf in series with the positive seq. impedance Z_1 of the machine.
The neutral impedance Z_n does not appear in this circuit because the phasor sum of I_{a_1}, I_{b_1} & I_{c_1} is zero and no positive sequence current can flow through Z_n.
Since it is balanced circuit, the positive sequence network can be drawn on single phase basis. The reference bus for this network is the neutral of the generator. The positive sequence impedance Z_1 consists of winding resistance and direct axis reactance.

$$V_{a_1} = E_a - Z_1 I_{a_1}$$

Negative sequence network





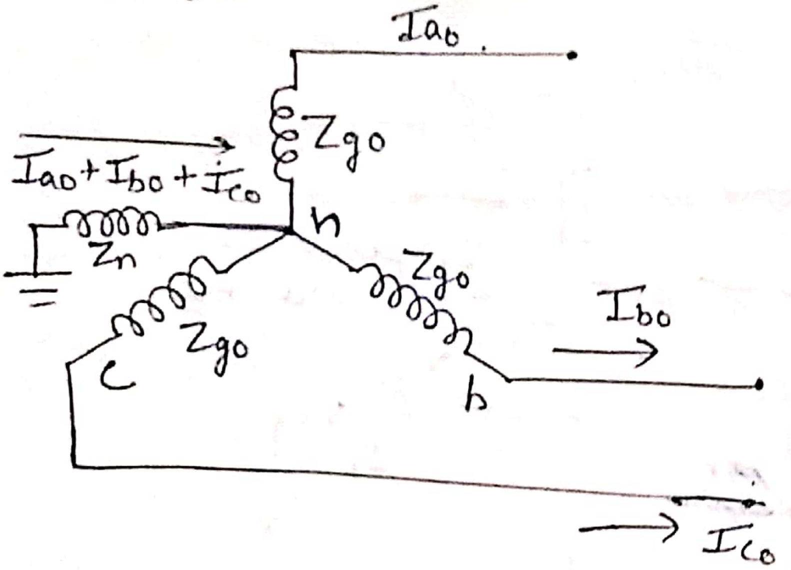
A synchronous ~~generator~~ machine does not generate any -ve sequence voltage. The flow of negative sequence currents in the stator wdgs creates an mmf which rotates at synchronous speed in a direction opposite to the direction of rotor i.e. at twice the synchronous speed w.r.t. to rotor. Thus the negative sequence mmf moves alternately past the direct and quadrature axis and sets up a varying armature reaction effect.

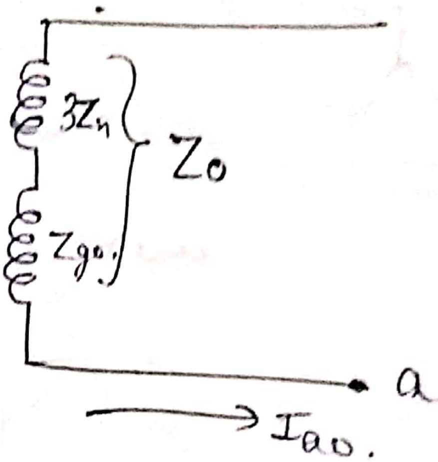
Therefore, $X_2 = \frac{1}{2}[X_d'' + X_q'']$

$V_{a_2} = -Z_2 I_2$

Zero sequence network

No zero sequence voltage is induced in a synchronous machine.





The flow of zero sequence currents in the stator wdgs produces three mmfs which in time phase. If each phase winding produced a sinusoidal space mmf, then with the rotor removed, the flux at a point on the axis of the stator due to zero sequence current would be zero at every instant. When the flux in the air gap or the leakage flux around slots or end connections is considered, no point in these regions is equidistant from all the three-phase wdgs of the stator. ~~The~~.

The zero sequence currents flow through the neutral impedance Z_n. The current flowing through this impedance Z_n is $3I_{a0}$

~~3+~~ The zero sequence voltage drop $-3 I_{a0} Z_n - I_{a0} Z_{g0}$. Since the current in the zero sequence network is I_{a0} this network must have an impedance of $3Z_n + Z_{g0}$. Thus,

$$Z_0 = 3Z_n + Z_{g0}.$$

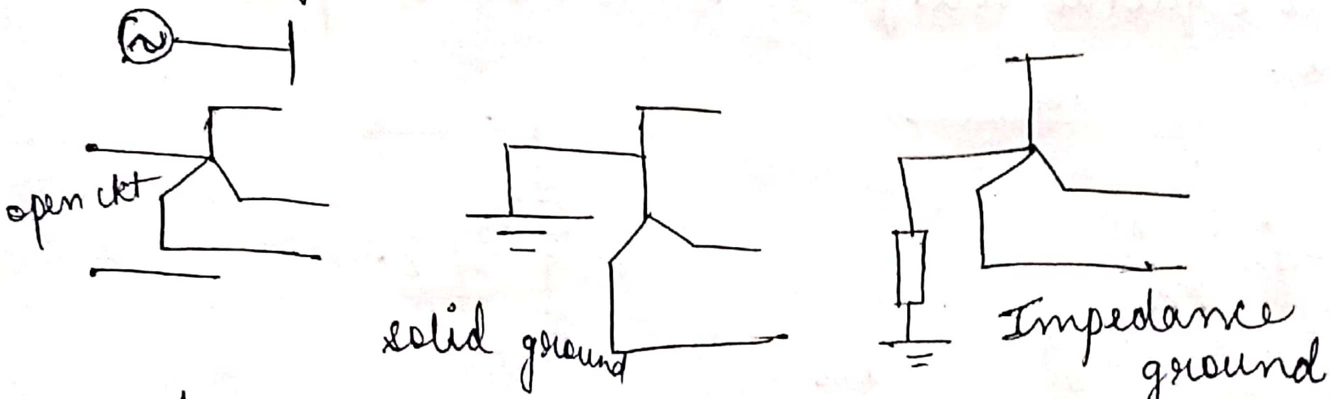
W.r.t. to ref. bus,

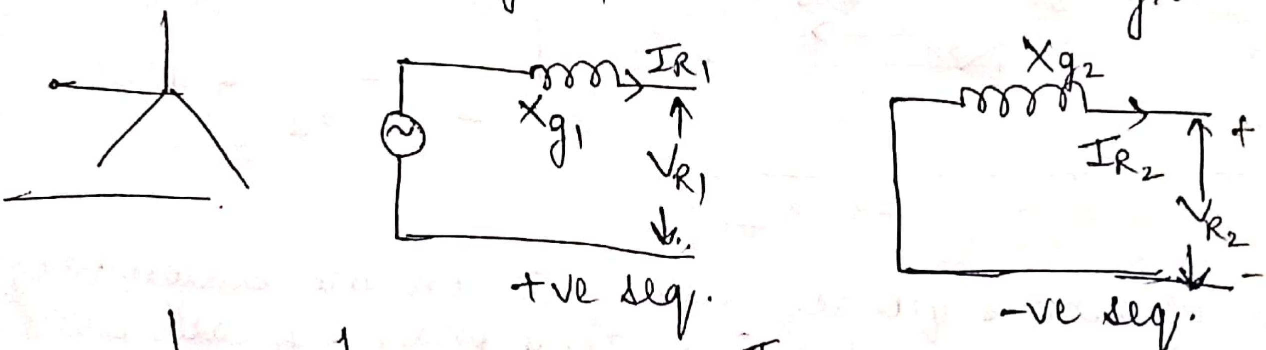
$$V_{a0} = -I_{a0} Z_0$$

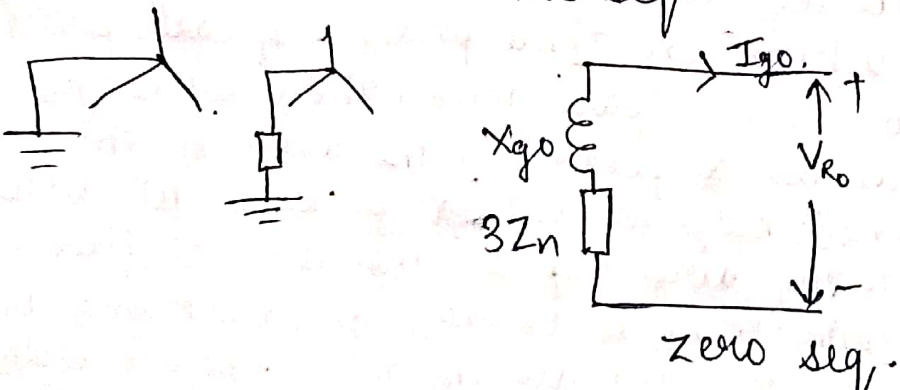
★ Sequence representation of the element :-

1.) Generator – The emf will induced only and only in case of +ve sequence.

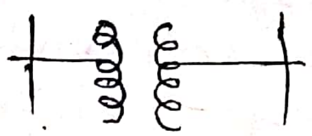
There will be no induced emf in case of -ve sequence & zero sequence diagram.



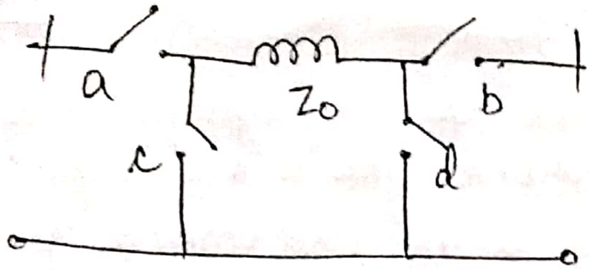




2.) Transformer

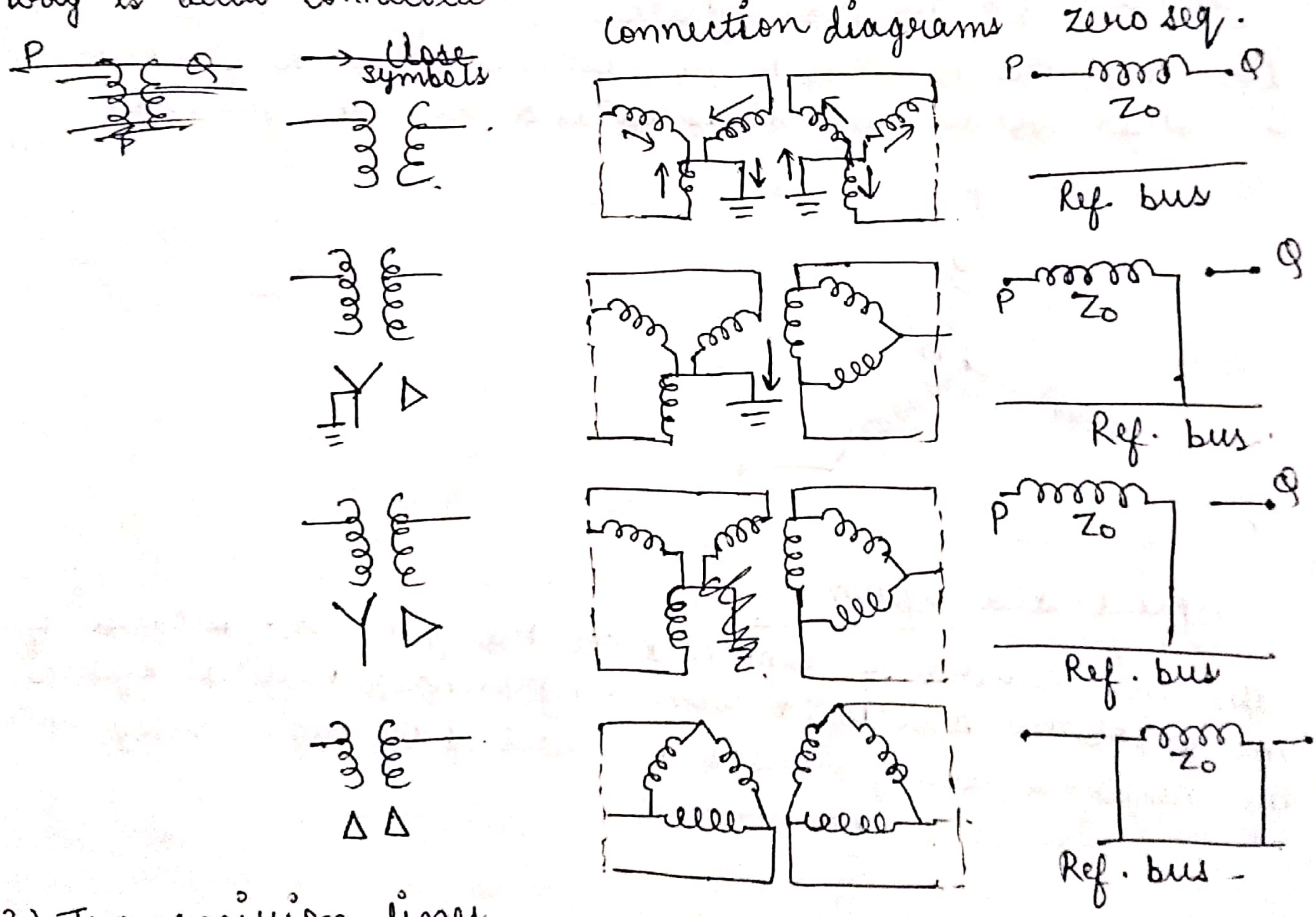


The x'-mer will be represented as a series reactance in case of +ve & -ve sequence diagram, whatever be the type of wdg and neutral position.



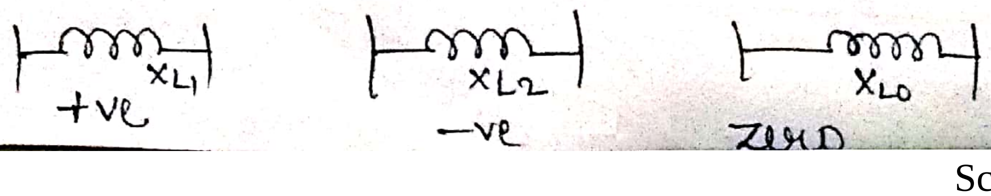
~~The~~ zero seq. diagram

The zero seq. diagram of a transformer is represented as a switch.
The series switch a & b will be closed when the x'mer wdg is star connected with neutral ground.
The shunt switch c & d will be closed when the x'mer wdg is delta connected.



3.) Transmission lines

The zero sequence reactance of lines is about 2 to 4 times the positive sequence reactance. The mag. field due to the flow of zero sequence currents is very different from the mag. field due to +ve sequence currents.



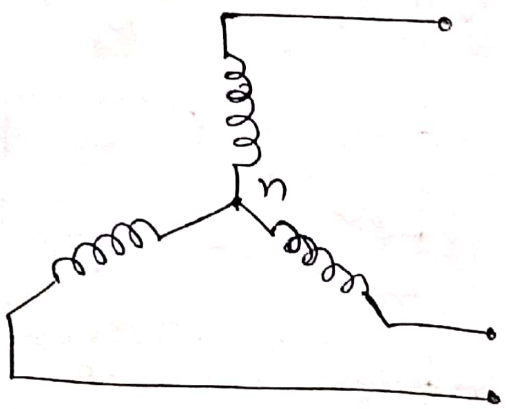
★ Neutral grounding

In this, the neutral of the system or rotating system or transformer is connected to the ground. This is an important aspect of power system design because the performance of the system regarding s/c, stability, protection etc. is greatly affected by the condition of the neutral. A 3-ϕ system can be operated in two possible ways -

1.) With ungrounded neutral
2.) With a ground neutral

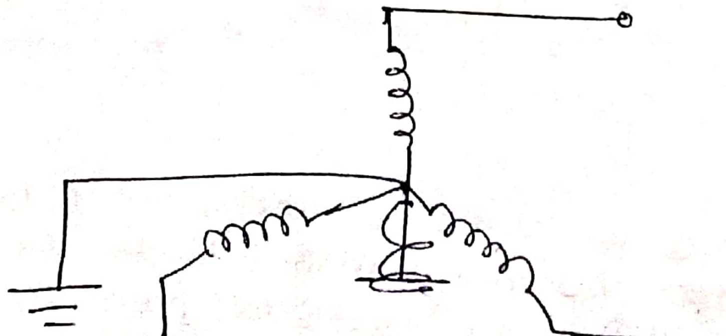
Ungrounded neutral system -

In this, the neutral is not connected to the ground. In other words neutral is isolated from the ground.



Grounded system -

In this neutral is connected to the ground. Because of the problems associated with ungrounded neutral systems, the neutrals are grounded in most of the high - voltage systems



Advantages of neutral grounding –

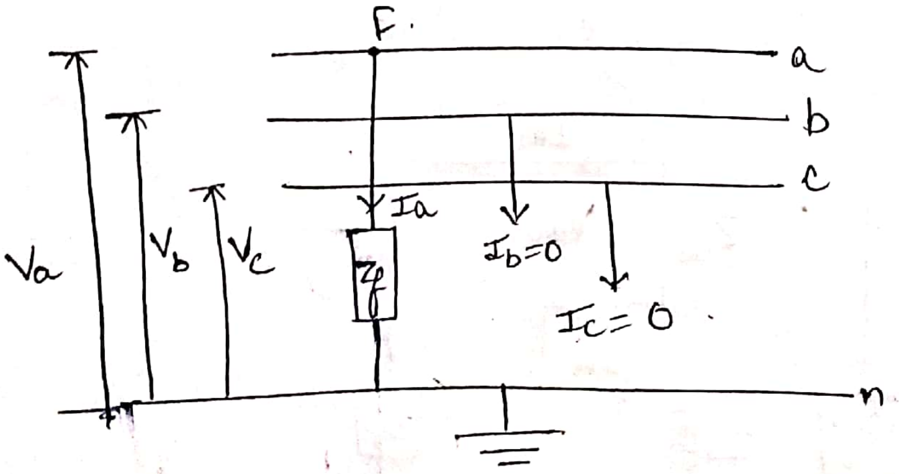
1. Voltages of phases are limited to the line to ground voltages.
2.) Surge voltage due to arcing grounds is eliminated.
3.) The overvoltages due to lightening discharged to ground.
4.) It provides greater safety to personnel and equipment.
5.) It provides improved service reliability.

Method of Neutral grounding –

1.) Solid grounding
2.) Resistance grounding
3.) Reactance grounding
4.) Peterson – coil " "

★ Unsymmetrical faults

Single line to Ground fault –



Suppose 'a' is connected to the ground at fault Point 'F'.
Fault impedance $= Z_f$.
Since only phase 'a' is connected to ground at the fault, phase 'b' and 'c' are O/C and carries no current.

$$I_b = 0 \;,\; I_c = 0$$

The voltage at the fault point F is $V_a = I_a Z_f$

~~$I_{a0} =$~~

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix}$$

$$I_{a0} = I_{a1} = I_{a2} = \frac{1}{3} I_a \quad \text{—— (1)}$$

~~$V_{a0} = E_{a0} - Z_{a0} I_{a0}$~~

~~$V_{a1} = E_{a1} - Z_{a1} I_{a1}$~~

~~$V_{a2} = E_{a2} - Z_{a2} I_{a2}$~~

~~E_{a0}, E_{a1} & E_{a2} are the sequence voltages of phase a.~~

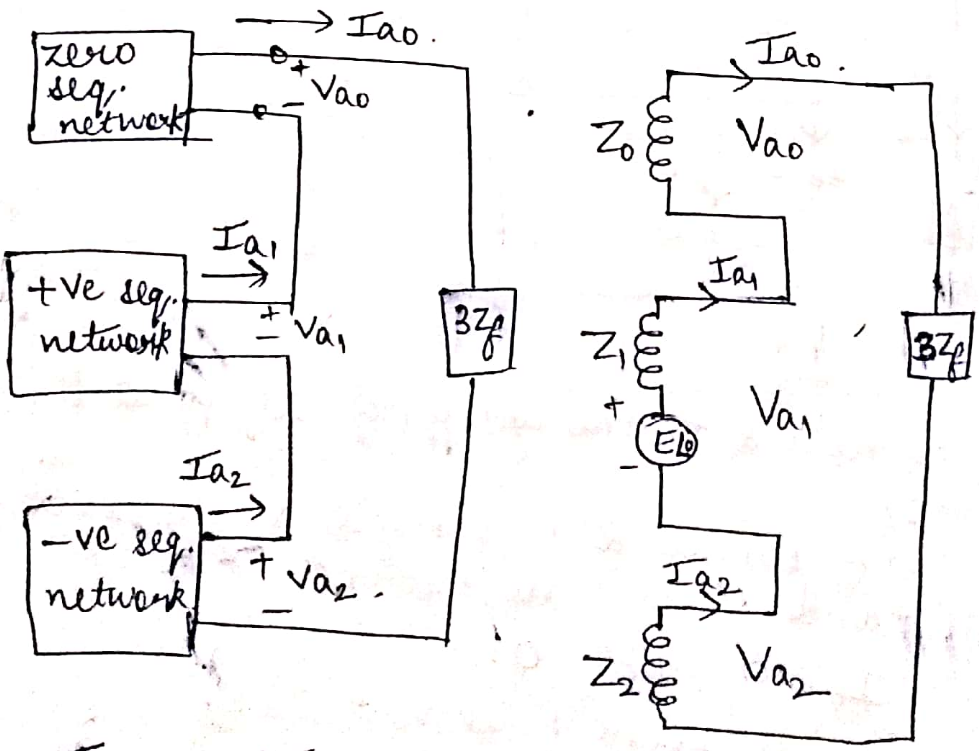
$$V_a = I_a Z_f \quad \text{—— (2)}$$

From eq^n (1) & (2)

$$3 I_{a1} = I_a$$

$$V_a = 3 I_{a1} Z_f$$

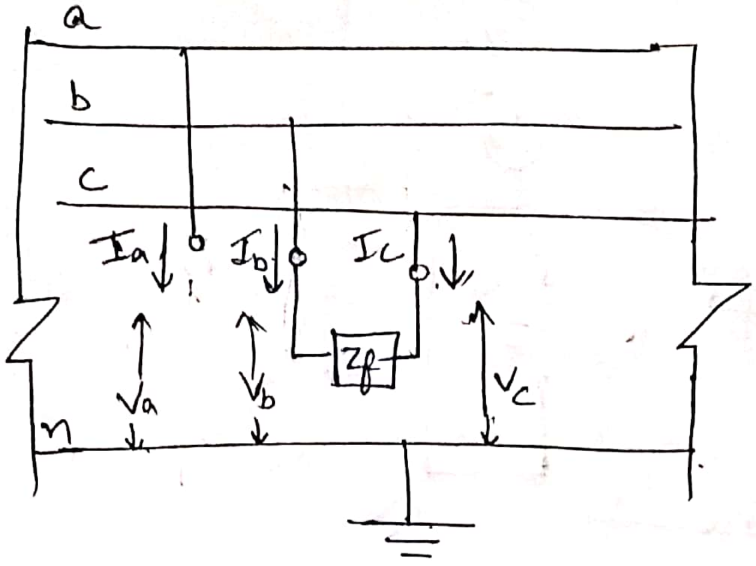
$$I_{a1} = \frac{V_a}{3 Z_f}$$



$$I_{a0} = I_{a1} = I_{a2} = \frac{E}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

$$I_a = I_{a0} = I_{a1} = I_{a2} = \frac{3E}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

Line to line fault



$I_a = 0$

$I_b = -I_c$

$V_b = V_c + Z_f I_b$

The sequence currents at the fault point –

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} 0 \\ I_b \\ -I_b \end{bmatrix}$$

$I_{a0} = 0$

$I_{a2} = a^2 I_b - a I_b$

$I_{a1} = a I_b - a^2 I_b$

$I_{a2} = -I_{a1}$

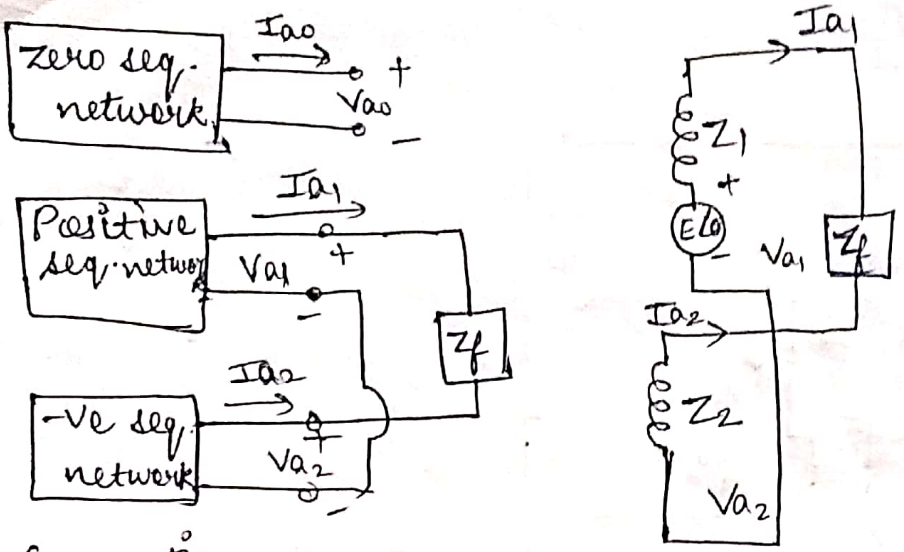
$(V_{a0} + a^2 V_{a1} + a V_{a2}) = V_{a0} + a V_{a1} + \cancel{a V_{a2}}\ a^2 V_{a2} + Z_f (I_{a0} + a^2 I_{a1} + a I_{a2})$

$\because I_{a0} = 0, \quad V_{a0} = 0$

$(a^2 - a) V_{a1} = (a^2 - a) V_{a2} + (a^2 - a) I_{a1} Z_f$

$V_{a1} = V_{a2} + I_{a1} Z_f$

$\longrightarrow$

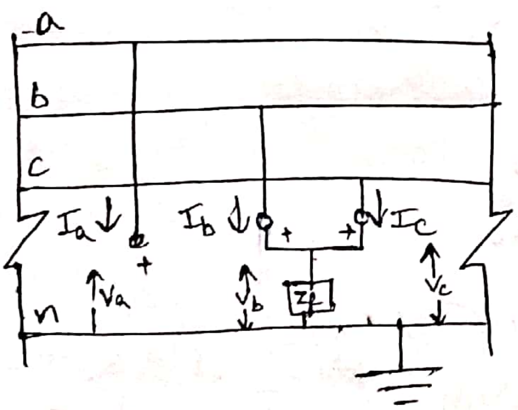


Connection ~~of sequence~~ network for LL Fault

$$I_{a1} = \frac{E}{Z_1 + Z_2 + Z_f}$$

~~$I_b = I_c = I_a$~~ $$I_b = \frac{-j\sqrt{3}E}{Z_1 + Z_2 + Z_f}$$

Double line to Ground Fault



$I_a = 0$ —— (1)

$V_b = V_c = (I_b + I_c) Z_f$ —— (2)

$I_{a0} + I_{a1} + I_{a2} = 0$ [∵ From eq^n (1)]

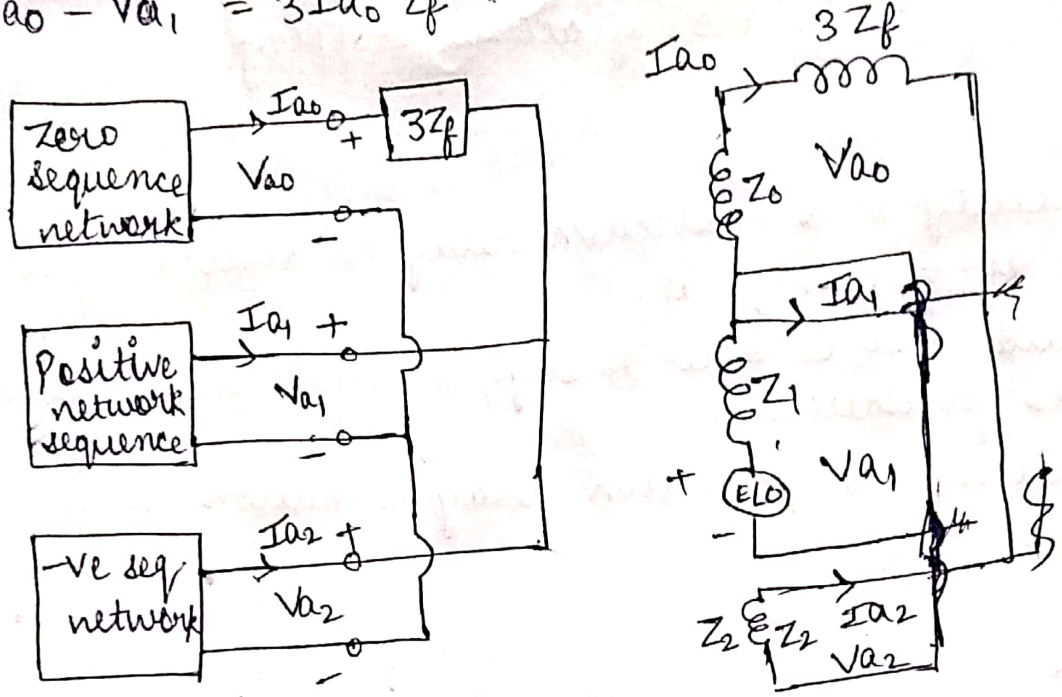
$V_{a0} + a^2 V_{a1} + a V_{a2} =$ ~~5~~ $V_{a0} + a V_{a1} + a^2 V_{a2}$ [∵ From eq^n (2)]

$V_{a1} = V_{a2}$

$V_{a0} + a^2 V_{a1} + a V_{a2} =$ ~~V_{a0}~~ $(I_{a0} + a^2 I_{a1} + a I_{a2} + I_{a0} + a I_{a1} + a^2 I_{a2}) Z_f$

$V_{a0} + a^2 V_{a1} + a V_{a1} = ($~~$I_{a0}$~~ $2 I_{a0} + I_{a1}(a^2 + a) + I_{a2}(a^2 + a)] Z_f$

$V_{a0} - V_{a1} = 3 I_{a0} Z_f$



Connections of sequence networks for ~~Double~~ LLG

★ Attributes of protection schemes : (Circuit Breakers + Protection relays)

1.) Dependability -

a.) A protection relays is said to be dependable if it trips (cut off) only when there is fault current.

b.) It can be measured in terms of the 'certainity' of its tripping only when it has to trip.

c.) It can be improved by improving its ~~sensability~~ sensitivity.

d.) % Dependability = $\frac{\text{No. of correct trippings}}{\text{Total no. of desired trippings}} \times 100$

2.) Security -

a.) This is a property of protection relay that characterizes fault trippings.

b.) If a relay trips when there is no fault current, then it is said to be insecure.

c.) It is the parameter that suggests how accurately a particular protection relay is working.

d.) % security = $\frac{\text{(No. of correct trippings} \times 100)}{\text{Total no. of actual trippings}}$

3.) Selectivity

a.) It is the ability of a protection relay to accurately locate the fault and ~~as i~~ classify it.

b.) A relay should also be able to suggest whether or not the fault is in its jurisdiction.

c.) This jurisdiction of a protection relay is known as its protection zone.

4.) Reliability

a.) This is the quality of the relay that determines its ability of not failing ever.

b.) This quality can be achieved by redundancy.

c.) % Reliability = $\frac{\text{No. of correct trippings} \times 100}{\text{No. of desired trippings + No. of incorrect trips}}$

5.) Fast operation

A protective relay should be fast enough to isolate the faulty element of the ~~equipme~~ system as quickly as possible to minimize damage to the equipments and maintain system's stability.

★ Backup Protection -

It provides the backup to the main protection whenever it fails in operation or its cut for repairs. The backup protection is essential for the proper working of the electrical system. The backup protection is the second line of defence which isolates the faulty section of the system in case the main protection fail to function properly. The failure of the primary protection occurs because of the failure of the DC supply circuit, current or voltage supply to relay circuit or because of the circuit breaker.

The backup protection may be provided either on the same circuit breaker which would be normally opened by the main protection or in different circuit breakers. Sometimes for simplification, the backup protection has a low sensitivity and operated over a limited backup zone.

→ Breaking current

14.9 CLASSIFICATION OF CIRCUIT BREAKERS

Circuit breakers can be classified using the different criteria such as, intended voltage application, location of installation, their external design characteristics, insulating medium used for arc quenching, etc.

14.9.1 Classification Based on Voltage

Circuit breakers can be classified into the following categories depending on the intended voltage application.

(i) Low Voltage Circuit Breaker (less than 1 kV)

(ii) Medium Voltage Circuit Breaker (1 kV to 52 kV)

(iii) High Voltage Circuit Breakers (66 kV to 220 kV)

(iv) Extra High Voltage (EHV) Circuit Breaker (300 kV to 765 kV)

(v) Ultra High Voltage (UHV) Circuit Breaker (above 765 kV)

Fixed contact

14.9.2 Classification Based on Location

Circuit breakers based on their location are classified as

(i) Indoor type

(ii) Outdoor type

Low and medium voltage switchgears, and high voltage Gas Insulated Switchgears (GIS) are categorised as Indoor Switchgears, whereas the Switchgears which have air as an external insulating medium, i.e. Air-Insulated Switchgear (AIS), are categorised as outdoor Switchgears.

14.9.3 Classification Based on External Design

Circuit breakers can be classified into following categories depending on their external design.

(i) Dead tank type

(ii) Live-tank type

This clascification is for outdoor circuit breakers from the point of view of their physical structural design.

14.9.4 Classification Based on Medium Used for Arc Quenching

Out of the various ways of classification of circuit breakers, the general way and the most important method of classification is on the basis of medium used for insulating and arc quenching. Depending on the arc quenching medium employed, the following are important types of circuit breakers

(i) Air-break circuit breakers:

(ii) Oil circuit breakers

(iii) Air blast circuit breakers

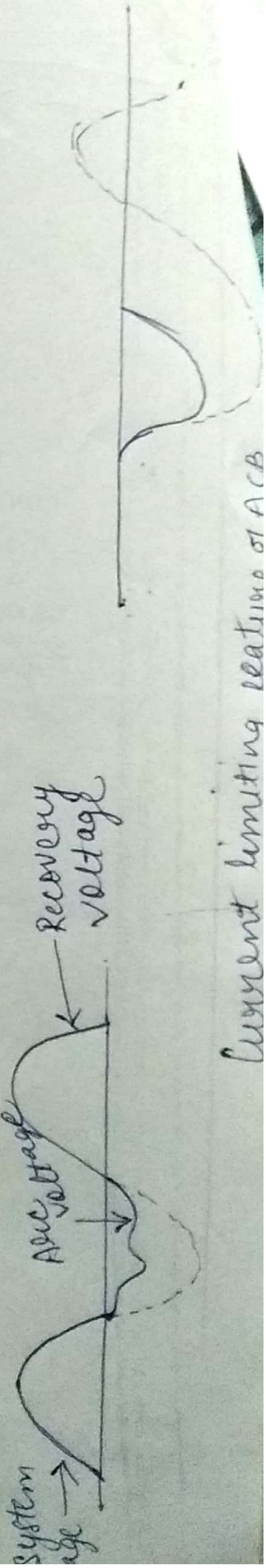
(iv) Sulphur hexafluoride (SF_6) circuit breakers

(v) Vacuum circuit breakers

The development of circuit breakers outlined above has taken place chronologically in order to meet two important requirements of the power system which has progressively grown in size. Firstly, higher and higher fault currents need to be interrupted, i.e., breakers need to have larger and larger breaking capacity. Secondly, the fault interruption time needs to be smaller and smaller for maintaining system stability.

14.10 AIR-BREAK CIRCUIT BREAKERS

Air-break circuit breakers are quite suitable for high current interruption at low voltage. In this type of a circuit breaker, air at atmospheric pressure is used as an arc extinguishing medium. Figure 14.14 shows an air-break circuit breaker. It employs two pairs of contacts—main contacts and arcing contacts. The main contacts carry current when the breaker is in closed position. They have low contact resistance. When contacts are opened, the main contacts separate first, the arcing contacts still remain closed. Therefore, the current is shifted from the main contacts to the arcing contacts. The arcing contacts separate later on and the arc is drawn between them.



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In air-break circuit breakers, the principle of high resistance is employed for arc interruption. The arc resistance is increased by lengthening, splitting and cooling the arc. The arc length is rapidly increased employing arc runners and arc chutes. The arc moves upward by both electromagnetic and thermal effects. It moves along the arc runner and then it is forced into a chute. It is split by arc splitters. A blow-out coil is employed to provide magnetic field to speed up arc movement and to direct the arc into arc splitters. The blow-out coil is not connected in the circuit permanently. It comes in the circuit by the arc automatically during the breaking process. The arc interruption is assisted by current zero in case of ac air break circuit breakers. High resistance is obtained near current zero.

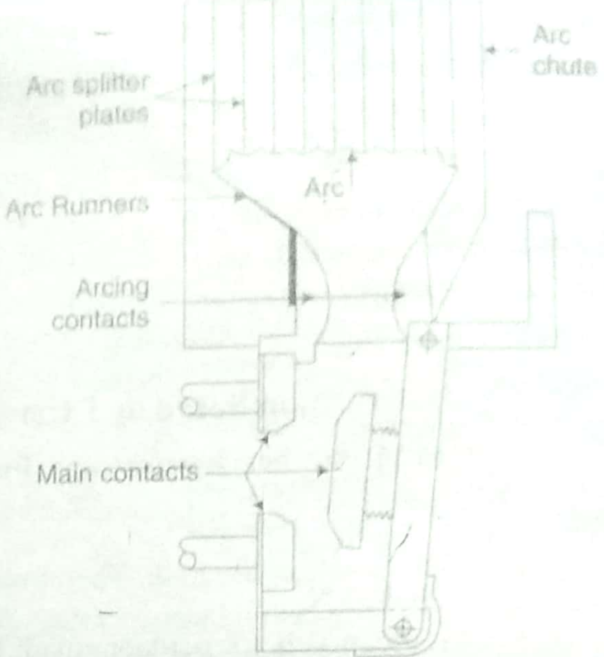

Fig. 14.14 *Air-break circuit breaker*

AC air-break circuit breakers are available in the voltage range 400 to 12 kV. They are widely used in low and medium voltage system. They are extensively used with electric furnaces, with large motors requiring frequent starting, in a place where chances of fire hazard exist, etc. Air-break circuit breakers are also used in dc circuit up to 12 kV.

14.11 OIL CIRCUIT BREAKERS

Mineral oil has better insulating properties than air. Due to this very reason it is employed in many electrical equipment including circuit breakers. Oil has also good cooling property. In a circuit breaker when arc is formed, it decomposes oil into gases. Hence, the arc energy is absorbed in decomposing the oil. The main disadvantage of oil is that it is inflammable and may pose a fire hazard. Other disadvantages included the possibility of forming explosive mixture with air and the production of carbon particles in the oil due to heating, which reduces its dielectric strength. Hence, oil circuit breakers are not suitable for heavy current interruption at low voltages due to carbonisation of oil. There are various types of oil circuit breakers developed for use in different situations. Some important types are discussed below.

14.11.1 Plain-break Oil Circuit Breakers

In a plain-break oil circuit breaker there is a fixed and a moving contact immersed in oil. The metal tank is strong, weather tight and earthed. Figure 14.15 shows a double break plain oil circuit breaker. When contacts separate there is a severe arc which decomposes the oil into gases. The gas obtained from the oil is mainly hydrogen. The volume of gases produced is about one thousand times that of the oil decomposed. Hence, the oil is pushed away from arc and the gaseous medium surrounds the arc

The arc quenching factors are as follows.

(i) Elongation of the arc.

(ii) Formation of gaseous medium in between the fixed and moving contacts. This has a high heat conductivity and high dielectric strength.

(iii) Turbulent motion of the oil, resulting from the gases passing through it.

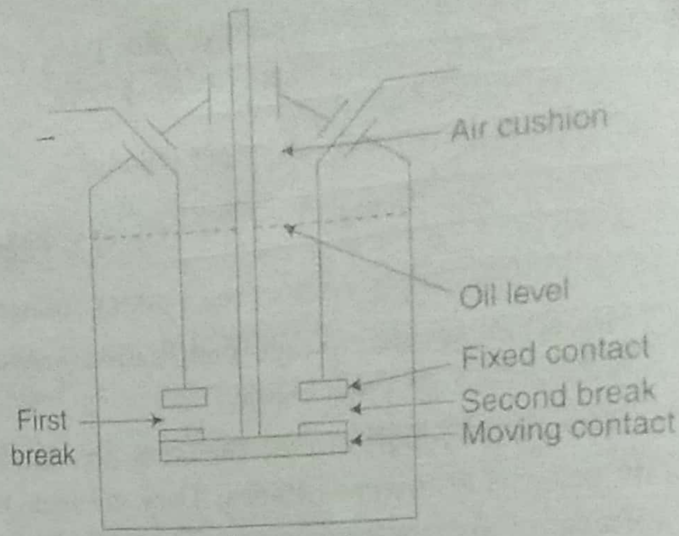

Fig. 14.15 *Plain-break oil circuit breaker*

A large gaseous pressure is developed because a large amount of energy is dissipated within the tank. Therefore, the tank of the circuit breaker is made strong to withstand such a large pressure. When gas is formed around the arc, the oil is displaced. To accommodate the displaced oil, an air cushion between the oil surface and the tank is essential. The air cushion also absorbs the mechanical shock produced due to upward oil movement. It is necessary to provide some form of vent fitted in the tank cover for the gas outlet. A sufficient level of oil above the contacts is required to provide substantial oil pressure at the arc.

Certain gap between the contacts must be created before the arc interruption occurs. To achieve this, the speed of the break should be as high as possible. The two breaks in series provide rapid arc elongation without the need for a specially fast contact. The double break also provides ample gap distance before arc interruption. But this arrangement has the disadvantage of unequal voltage distribution across the breaks.

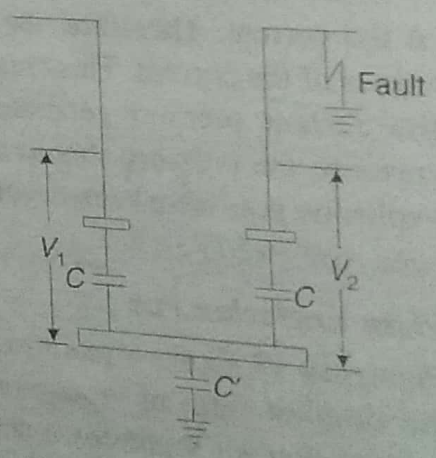

Fig. 14.16 *Voltage distribution across breaks*

Figure 14.16 shows voltage distribution across breaks. C is the capacitance between the fixed contact and moving contact, C' is the capacitance between the moving contact and earth. V_1 is the voltage across the first contact and V_2 across the second contact. Suppose the fault current is i. The voltages V_1 and V_2 will be expressed as follows.

$$V_1 = \frac{i}{wC} \quad (14.20) \quad \text{and} \quad V_2 = \frac{i}{w(C + C')} \quad (14.21)$$

The capacitance between the moving contact and earth C' is in parallel with C, the capacitance of the second break.

$$\frac{V_1}{V_2} = \frac{C + C'}{C} \quad (14.22)$$

Taking $C = 8$ pF and $C' = 16$ pF, we get

$$\frac{V_1}{V_2} = \frac{C + C'}{C} = \frac{8 + 16}{8} = \frac{24}{8} = 3$$

$$\frac{V_1 + V_2}{V_2} = \frac{3+1}{1} = 4$$

$$V_1 + V_2 = V = \text{system voltage}$$

$$V_2 = 25\% \text{ of the system voltage}$$

$$V_1 = 75\% \text{ of the system voltage}$$

To equalise the voltage distribution across the breaks, non-linear resistors are connected across each break.

The plain-break circuit breakers are employed for breaking of low current at comparatively lower voltages. They are used on low voltage dc circuits and on low voltage ac distribution circuits. Their size becomes unduly large for higher voltages. Also, they require large amount of transformer oil. They are not suitable for autoreclosing. Their speed is slow. They can be used up to 11 kV with an interrupting capacity up to 250 MVA.

14.11.2 Self-generated Pressure Oil Circuit-breaker

In this type of circuit-breakers, arc energy is utilised to generate a high pressure in a chamber known as explosion pot or pressure chamber or arc controlling device. The contacts are enclosed within the pot. The pot is made of insulating material and it is placed in the tank. Such breakers have high interrupting capacity. The arcing time is reduced.

Since the pressure is developed by the arc itself, it depends upon the magnitude of the current. Therefore, the pressure will be low at low current and high at high values of the current. This creates a problem in designing a suitable explosion pot. At low current, pressure generated should be sufficient to extinguish the arc. At heavy currents, the pressure should not be too high so as to burst the pot. Various types of explosion pots have been developed to suit various requirements. A few of them have been discussed below.

Plain Explosion Pot

Figure 14.17 shows a plain explosion pot. This is the simplest form of an explosion pot. When the moving contact separates a severs arc is formed. The oil is decomposed and gas is produced. It generates a high pressure within the pot because there is a close fitting throat at the lower end of the pot. The high pressure developed causes turbulent flow of streams of the gas into the arc resulting in arc-extinction. If the arc extinction does not occur within the pot, it occurs immediately after the moving contact leaves the pot, due to the high velocity axial blast of the gas which is released through the throat. Since the arc extinction in the plain explosion pot is performed axially, it is also known as an axial extinction pot. This type of a pot is not suitable for breaking of heavy currents. The pot may burst due to very

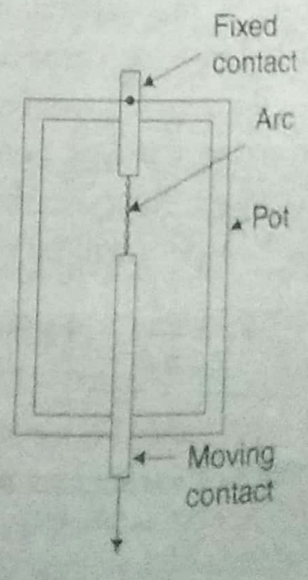

Fig. 14.17 Plain explosion pot

large pressure. At low currents, the arcing time is more. Hence, this type of an explosion pot is suitable for the interruption of currents of medium range.

Cross-jet Explosion Pot

Figure 14.18 shows a cross-jet explosion pot. It is suitable for high current interruptions. Arc splitters are used to obtain an increased arc length for a given amount of contact travel. When the moving contact is separated from the fixed contact, an arc is formed, as shown in Fig. 14.18(a). The arc is pushed into the arc splitters as shown in Fig. 14.18(b), and finally it is extinguished, as in Fig. 14.18(c). In this type of a pot, the oil blast is across the arc and hence it is known as a cross-jet explosion pot.

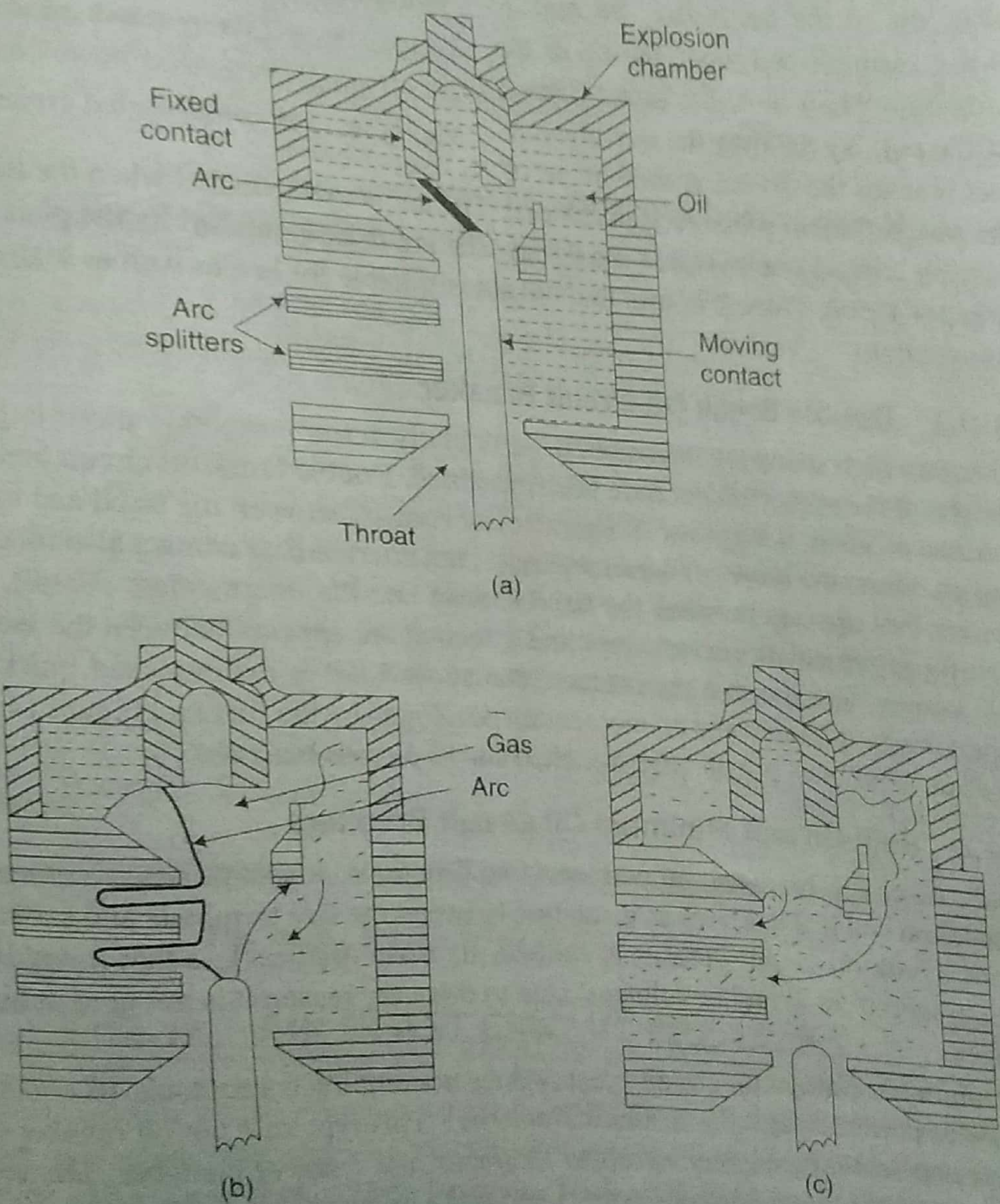

Fig. 14.18 *Cross-jet explosion pot*

Self-compensated Explosion Pot

This type of a pot is a combination of a cross-jet explosion pot and a plain explosion pot. Figure 14.19 shows a self-compensated explosion pot. Its upper portion is a cross-explosion pot, and the lower portion a plain explosion pot. On heavy currents the rate of gas generation is very high and consequently, the pressure produced is also very high. The arc extinction takes place when the first or second lateral orifice of the arc splitter is uncovered by the moving contact. The pot operates as a cross-jet explosion pot. When the current is low, the pressure is also low in the beginning. So the arc is not extinguished when the tip of the moving contact is in the upper portion of the pot. By the time the moving contact reaches the orifice at the bottom of the pot, sufficient pressure is developed. The arc is extinguished when the tip of the moving contact comes out of the throat. The arc is extinguished by the plain explosion pot action. Thus, it is seen that the pot is suitable for low as well as high current interruptions.

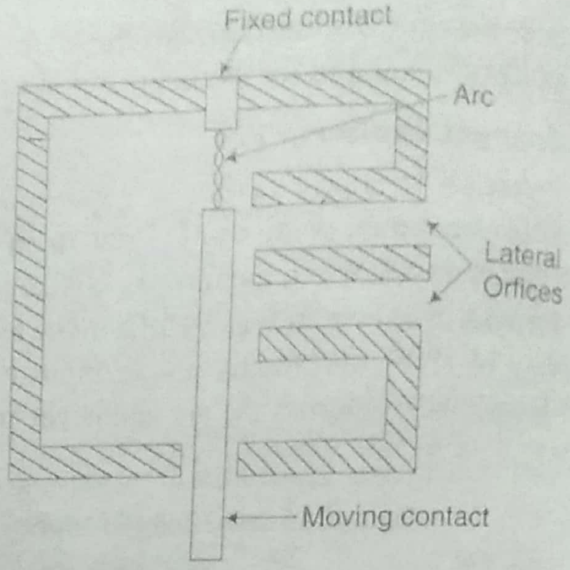

Fig. 14.19 *Self-compensated explosion pot*

14.11.3 Double Break Oil Circuit Breaker

To obtain high speed arc interruption, particularly at low currents, various improved designs of the explosion pot have been presented. Double break oil circuit breaker is also one of them. It employs an intermediate contact between the fixed and moving contact. When the moving contact separates, the intermediate contact also follows it. The arc first appears between the fixed contact and the intermediate contact. Soon after, the intermediate contact stops and a second arc appears between the intermediate contact and the moving contact. The second arc is extinguished quickly by employing gas pressure and oil momentum developed by the first arc. Figure 14.20(a) shows an axial blast pot and Fig. 14.20(b) shows a cross blast pot.

14.11.4 Bulk Oil and Minimum Oil Circuit Breakers

In bulk oil circuit breakers, oil performs two functions. It acts as an arc extinguishing medium and it also serves as insulation between the live terminals and earth. The tank of a bulk oil circuit breaker is earthed. Its main drawback is that it requires a huge amount of oil at higher voltages. Due to this very reason it is not used at higher voltages.

A minimum content oil circuit breaker does not employ a steel tank. Its container is made of porcelain or other insulating material. This type of a circuit breaker consists of two sections, namely an upper chamber and a lower chamber. The upper chamber contains an arc control device, fixed and a moving contact. The lower chamber acts as an insulating support and it contains the operating mechanism. These two chambers are filled with oil but they are physically separated form each other. The arc control device is placed in a resin bounded glass fiber cylinder (or backelised paper encloser). This cylinder is also filled with oil. The fiber glass cylinder is then placed in a porcelain cylinder. The annular space between the fiber-glass cylinder and the porcelain insulator is also filled with oil.

Minimum oil circuit breakers are available in the voltage range of ... to 420 kV. Nowadays they are superseded by SF_6 circuit breakers.

One of the important advantages that the bulk oil circuit breaker has over both the low content oil circuit breakers and air blast circuit breakers is that the protective current transformers can be accommodated on the bushings instead of being supplied as a separated piece of apparatus.

The number of interrupter units contained in a tank depends upon the fault current to be interrupted, and the system voltage. Up to 11 kV voltage, the minimum oil circuit breakers generally employ a single interrupter per phase. The typical figures for higher voltages are, two per phase at 132 kV, and six per phase at 275 kV. Each interrupter has a provision of resistance switching (a typical value being 1200 Ω, linear wire wound resistor) to damp restriking voltage.

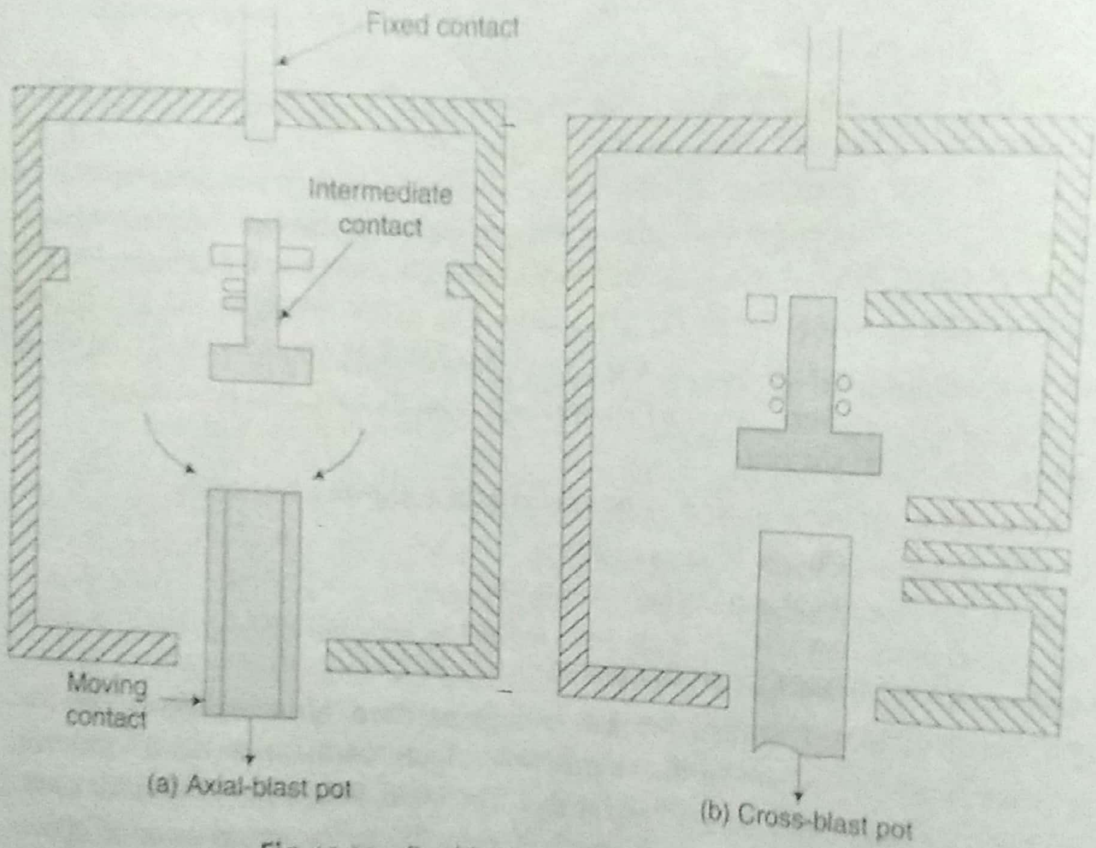

Fig. 14.20 *Double break oil circuit breakers*

14.12 AIR BLAST CIRCUIT BREAKERS

In air blast circuit breakers, compressed air at a pressure of 20–30 kg/cm^2 is employed as an arc quenching medium. Air blast circuit breakers are suitable for operating voltage of 132 kV and above. They have also been used in 11 kV–33 kV range for certain applications. At present, SF_6 circuit breakers are preferred for 132 kV and above. Vacuum circuit breakers are preferred for 11 kV–33 kV range. Therefore, the air blast circuit breakers are becoming obsolete. Not famous

The advantages of air blast circuit breakers over oil circuit breakers are:

(i) Cheapness and free availability of the interrupting medium, chemical stability and inertness of air

(ii) High speed operation

(iii) Elimination of fire hazard

(iv) Short and consistent arcing time and therefore, less burning of contacts

(v) Less maintenance

(vi) Suitability for frequent operation

(vii) Facility for high speed reclosure

The disadvantages of an air blast circuit breaker are as follows

(i) An air compressor plant has to be installed and maintained

(ii) Upon arc interruption the air blast circuit breaker produces a high-level noise when air is discharged to the open atmosphere. In residential areas, silencers need to be provided to reduce the noise level to an acceptable level

(iii) Problem of current chopping

(iv) Problem of restriking voltage

Switching resistors and equalising capacitors are generally connected across the interrupters. The switching resistors reduce transient overvoltages and help arc interruption. Capacitors are employed to equalise the voltage across the breaks. The number of breaks depends upon the system voltage. For example, there are 2 for 66 kV, 2 to 4 for 132 kV, 2 to 6 for 220 kV, 4 to 12 for 400 kV, 8 to 12 for 750 kV. The breaking capacities are, 5000 MVA at 66 kV, 10,000 MVA at 132 kV, 20,000 MVA at 220 kV; 35000 MVA at 400 kV, 40,000 MVA at 500 kV; 60,000 MVA at 750 kV. Circuit breakers for higher interrupting capacity have also been designed for 1000 kV and 1100 kV systems.

An air-blast circuit breaker may be either of the following two types.

(i) Cross-blast Circuit Breakers

(ii) Axial-blast Circuit Breakers

14.12.1 Cross-blast Circuit Breakers

In a cross-blast type circuit breaker, a high-pressure blast of air is directed perpendicularly to the arc for its interruption. Figure 14.21(a) shows a schematic diagram of a cross-blast type circuit breaker. The arc is forced into a suitable chute. Sufficient lengthening of the arc is obtained, resulting in the introduction of appreciable resistance in the arc itself. Therefore, resistance switching is not common in this type of circuit breakers. Cross-blast circuit breakers are suitable for interrupting high current (up to 100 kA) at comparatively lower voltages.

14.12.2 Axial-blast Circuit Breakers

In an axial-blast type circuit breaker, a high-pressure blast of air is directed longitudinally, i.e. in line with the arc. Figure 14.21(b) and (c) show axial-blast type circuit breakers. Figure 14.2.1(b) shows a single blast type. Whereas Fig. 14.21(c) shows a double blast type or radial blast type. Axial blast circuit breakers are suitable for EHV and super high voltage application. This is because interrupting chambers can be fully enclosed in porcelain tubes. Resistance switching is employed to reduce the transient overvoltages. The number of breaks depends upon the system voltage, for example, 4 at 220 kV and 8 at 750 kV. Air-blast circuit breakers have also been commissioned for 1100 kV system.

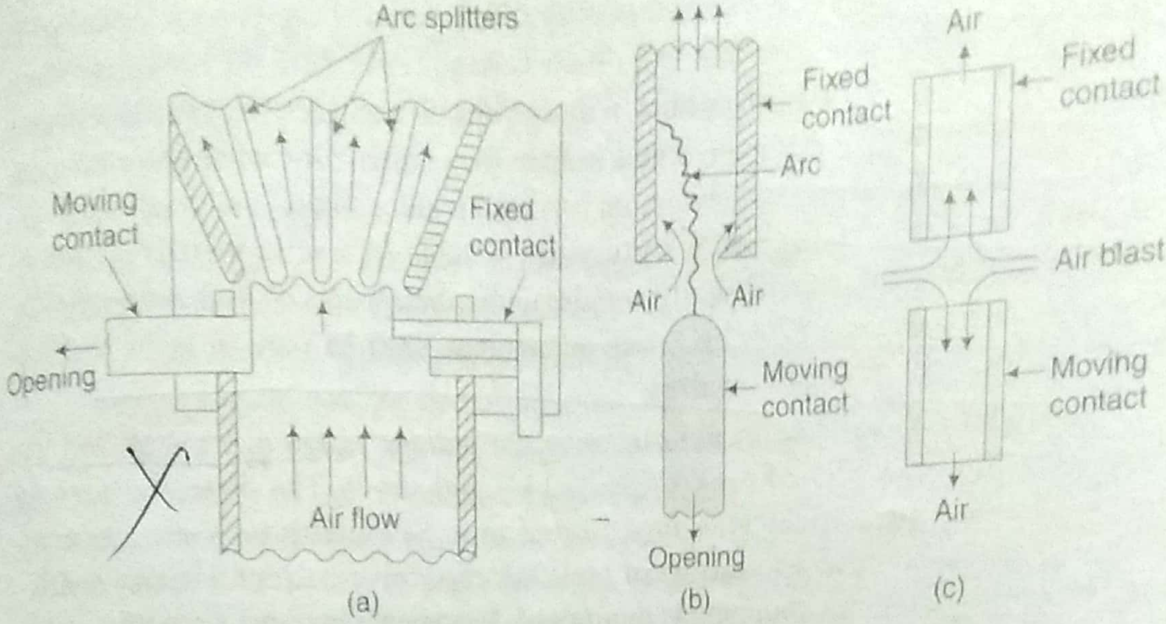

Fig. 14.21 (a) Cross-blast circuit breaker (b) Single blast type axial-blast circuit breaker (c) Double blast type (or radial-blast type) axial-blast circuit breaker

14.13 SF_6 CIRCUIT BREAKERS

Sulphur hexafluoride (SF_6) has good dielectric strength and excellent arc quenching property. It is an inert, nontoxic, nonflammable and heavy gas. At atmospheric pressure, its dielectric strength is about 2.35 times that of air. At 3 atmospheric pressure its dielectric strength is more than that of transformer oil, It is an electronegative gas, i.e. it has high affinity for electrons. When a free electron comes in collision with a neutral gas molecule, the electron is absorbed by the neutral gas molecule and a negative ion is formed. As the negative ions so formed are heavy they do not attain sufficient energy to contribute to ionisation of the gas. This property gives a good dielectric property. Besides good dielectric strength, the gas has an excellent property of recombination after the removal of the source which energizes the arc. This gives an excellent arc quenching property. The gas has also an excellent heat transfer property. Its thermal time constant is about 1000 times shorter than that of air.

Under normal conditions, SF_6 is chemically inert and it does not attack metals or glass. However, it decomposes to SF_4, SF_2, S_2, F_2, S and F at temperatures of the order of 1000°C. After arc extinction, the products of decomposition recombine in a short time, within about 1 microsecond. In the presence of moisture, the decomposition products can attack contacts, metal parts and rubber sealings in SF_6 circuit breakers. Therefore, the gas in the breaker must be moisture-free. To absorb decomposition products, a mixture soda lime (NaOH + CaO) and activated alumina can be placed in the arcing chamber.

One major disadvantage of SF_6 is its condensation at low temperature. The temperature at which SF_6 changes to liquid depends on the pressure. At 15 atm. pressure, the gas liquefies at a temperature of about 10°C. Hence, SF_6 breakers are equipped with thermostatically controlled heaters wherever such low ambient temperatures are encountered.

SF_6 gas because of its excellent insulating and arc-quenching properties has revolutionized the design of high and extra high voltage (EHV) circuit breakers. These properties of SF_6 has made it possible to design circuit breakers with smaller overall dimensions, shorter contact gaps, which help in the construction of outdoor breakers with fewer interrupters, and evolution of metalclad (metal enclosed) SF_6 gas insulated switchgear (GIS). SF_6 is particularly suitable for use in metalclad switchgear which is becoming increasingly popular under the aspects of high compatibility with the environment. SF_6 offers many advantages such as compactness and less maintenance of EHV circuit breakers.

SF_6 circuit breakers are manufactured in the voltage range 3.3 kV to 765 kV. However, they are preferred for votlages 132 kV and above. The dielectric strength of SF_6 gas increases rapidly after final current zero. SF_6 circuit breakers can withstand severe RRRV and are capable of breaking capacitive current without restriking. Problems of current chopping is minimised. Electrical clearances are very much reduced due to high dielectric strength of SF_6.

14.13.1 Properties of SF_6 Gas

The properties of SF_6 gas can be divided as

(i) Physical properties

(ii) Chemical properties

(iii) Electrical properties

1. Physical Properties of SF_6 Gas

The physical properties of SF_6 gas are as follows:

(i) It is a colourless, odourless, non-toxic and non-inflammable gas.

(ii) Pure gas is not harmful to health.

(iii) It is in gas state at normal temperature and pressure.

(iv) It is heavy gas having density 5 times that of air at 20°C and atmospheric pressure.

(v) The gas starts liquifying at certain low temperatures. The temperature of liquification depends on pressure. At 15 atm. pressure, the gas liquifies at a temperature of about 10°C.

(vi) It has an excellent heat transfer property. The heat transfer capability of SF_6 is 2 to 2.5 times that of air at same pressure.

(vii) The heat content property is much higher than air. This property of SF_6 assists cooling of arc space after current zero.

2. Chemical Properties of SF_6 Gas

(i) It is chemically stable at atmospheric pressure and at temperatures up to 500°C.

(ii) It is a chemically inert gas.

The property of chemical inertness of this gas is advantageous in switchgear. Because of this property, it has exceptionally low reactivity and does not attack metals, glass, plastics, etc. The life of contacts and other metallic parts is longer in SF_6 gas. The components do not get oxidised or deteriorated. Hence the maintenance requirements are reduced.

14.13.3 Types of SF_6 Circuit Breakers

The following are two principal types of SF_6 circuit breakers:

(i) Double Pressure Type SF_6 Circuit Breaker This type of circuit breaker employs a double pressure system in which the gas from a high-pressure compartment is released into the low-pressure compartment through a nozzle during the arc extinction process. This type of SF_6 circuit breaker has become obsolete.

Figure 14.24(a) shows a puffer-type breaker in closed position. The moving cylinder and the moving contact are coupled together. When the contacts separate and the moving cylinder moves, the trapped gas is compressed. The trapped gas is released through a nozzle and flows axially to quench the arc as shown in Fig. 14.24(b). There are two types of tank designs. Live tank design and dead tank design. In live tank design, interrupters are supported on porcelain insulators. In the dead tank design, interrupters are placed in SF_6 filled-tank which is at earth potential. Live tank design is preferred for outdoor substations.

A number of interrupters (connected in series) on insulating supports are employed for EHV systems up to 765 kV. Two interrupters are used in a 420 kV system. Breaking time of 2 to 3 cycles can be achieved. In the circuit breaker the steady pressure of the gas is kept at 5 kg/cm^2. The gas pressure in the interrupter compartment increases rapidly to a level much above its steady value to quench the arc.

14.13.4 Advantages of SF_6 Circuit Breakers

(i) Low gas velocities and pressures employed in the SF_6 circuit breakers prevent current chopping and capacitive currents are interrupted without restriking.

(ii) These circuit breakers are compact. and have smaller overall dimensions and shorter contact gaps. They have less number of interrupters and require less mantenance.

(iii) Since the gas is non-inflammable, and chemically stable and the products of decomposition are not explosive, there is no danger of fire or explosion.

(iv) Since the same gas is recirculated in the circuit, the requirement of SF_6 gas is small.

(v) The operation of the circuit breaker is noiseless because there is no exhaust to atmosphere as in case of air blast circuit breakers

(vi) Because of excellent arc quenching properties of SF_6, the arcing time is very short and hence the contact erosion is less. The contacts can be run at higher temperatures without deterioration.

(vii) Because of inertness of the SF_6 gas, the contact corrosion is very small. Hence contacts do not suffer oxidation.

(viii) The sealed construction of the circuit breaker avoids the contamination by moisture, dust, sand etc. Hence the performance of the circuit breaker is not affected by the atmospheric conditions.

(ix) Tracking or insulation breakdown is eliminated, because there are no carbon deposits following an arcing inside the system.

(x) Because of the excellent insulating properties of the SF_6, contact gap is drastically reduced.

(xi) As these circuit breakers are totally enclosed and sealed from atmosphere, they are particularly suitable for use in such environments where explosion hazards exist.

14.13.5 Disadvantages of SF_6 Circuit Breakers

(i) Problems of perfect sealing. There may be leakage of SF_6 gas because of imperfect joints.

(ii) SF_6 gas is suffocating to some extent. In case of leakage in the breaker tank, SF_6 gas may lead to suffocation of the operating personnel.

(iii) Arced SF_6 gas is poisonous and should not be inhaled or let out.

(iv) Influx of moisture in the breaker is very harmful to SF_6 circuit breaker. There are several cases of failures because of it.

(v) There is necessity of mechanism of higher energy level for puffer-types SF_6 circuit breakers. Lower speeds due to friction, misalignment can cause failure of the breaker.

(vi) Internal parts should be cleaned thoroughly during periodic maintenance under clean and dry environment.

(vii) Special facilities are required for transporting the gas, transferring the gas and maintaining the quality of the gas. The performance and reliability of the SF_6 circuit breaker is affected due to deterioration of quality of the gas.

14.14 VACUUM CIRCUIT BREAKERS

The dielectric strength and arc interrupting ability of high vacuum is superior to those of porcelain, oil, air and SF_6 at atmospheric pressure. SF_6 at 7 atm. pressure and air at 25 atm. pressure have dielectric strengths higher than that of high vacuum. The pressure of 10^{-5} mm of mercury and below is considered to be high vacuum. Low pressures are generally measured in terms of torr; 1 torr being equal to 1 mm of mercury. It has now become possible to achieve pressures as low as 10^{-8} torr.

When contacts separate in a gas, arc is formed due to the ionised molecules of the gas. The mean free path of the gas molecules is small and the ionisation process multiplies the number of electrons to form an electron avalanche. In high vacuum, of the order of 10^{-5} mm of mercury, the mean free path of the residual gas molecules becomes very large. It is of the order of a few metres. Therefore, when contacts are separated by a few mm in high vacuum, an electron travels in the gap without collision. The formation of arc in high vacuum is not possible due to the formation of electron avalanche. In vacuum arc electrons and ions do not come from the medium in which the arc is drawn but they come from the electrodes due to the evaporation of their surface material. The breakdown strenght is independent of gas density. It depends only on the gap length and surface condition and the material of the electrode. The breakdown strength of highly polished and thoroughly degassed electrodes is higher. Copper-bismuth, silver-bismuth, silver-lead and copper-lead are good materials for making contacts of the breaker.

When contacts are separated in high vacuum, an arc is drawn between them. The arc does not take place on the entire surface of the contacts but only on a few spots. The contact surface is not perfectly smooth. It has certain microprojections. At the time of contact separation, these projections form the last points of separation. The current flows through these points of separation resulting in the formation of a few hot spots. These hot spots emit electrons and act as cathode spots. In addition to thermal emission, electrons emission may be due to field emission and secondary emission.

Figure 14.25 shows the schematic diagram of a vacuum circuit breaker. Its enclosure is made of insulating material such as glass, porcelain or glass fibre reinforced plastic. The vapour condensing shield is made of synthetic resin. This shield is provided to prevent the metal vapour reaching the insulating envelope. As the interrupter has a sealed construction a stainless metallic bellows is used to allow the movement of the lower contact. One of its ends is welded to the moving contact. Its other end is welded to the lower end flange. Its contacts have large disc-shaped faces. These faces contain spiral segments so that the arc current produces axial magnetic field. This geometry helps the arc to move over the contact surface. The movement of arc over the contact surface minimises metal evaporation, and hence erosion of the contact due to arc. Two metal end flanges are provided. They support the fixed contact, outer insulating enclosure, vapour condensing shield and the metallic bellows. The sealing technique is similar to that used in electronic valves.

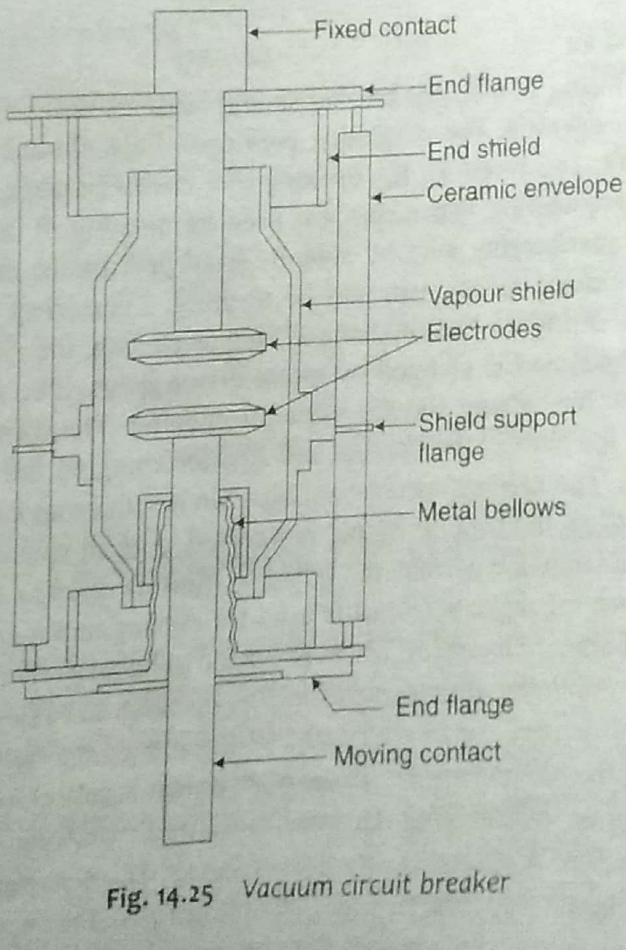

Fig. 14.25 *Vacuum circuit breaker*

The vacuum circuit breaker is very simple in construction compared to other types of circuit breaker. The contact separation is about 1 cm which is adequate for current interruption in vacuum. As the breaker is very compact, power required to close and open its contacts is much less compared to other types of breaker. It is capable of interrupting capacitive and small inductive currents, without producing excessive transient overvotlages. Vacuum circuit breakers have other advantages like suitability for repeated operations, least maintenance, silent operation, long life, high speed of dielectric recovery, less weight of moving parts, etc. The vapour emission depends on the arc current. In ac, when the current decreases, vapour emission decreases. Near current zero, the rate of vapour emission tends to zero. Immediately after current zero, the remaining vapour condenses and the dielectric strength increases rapidly. At current zero, cathode spots extinguish within 10^{-8} second. The rate of dielectric recovery is many times higher than that obtained in other types of circuit breakers. Its typical value may be as high as 20 kV/μs.

Vacuum circuit breakers have now become popular for voltage ratings up to 36 k[V]. Up to 36 kV they employ a single interrupter.

14.15 OPERATING MECHANISM

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