Chapter (2)

2.1 Air break circuit breaker

2. 1. 1. Air-break Circuit-breaker

The air at atmospheric pressure is used as an arc extinguishing medium in Air-Break Circuit-Breakers. This circuit breaker employs the high resistance interruption principle. the arc is rapidly lengthened by means of the arc runners and arc chutes and the resistance of the arc is increased by cooling, lengthening and splitting the arc. The arc resistance increases to such an extent that the voltage drop across the arc becomes more than the supply voltage and the arc gets extinguished. Magnetic field is utilized for lengthening the arc in high voltage air-break circuit-breakers.

Air-break circuit breakers are used in D.C. circuit and a.c. circuits up to 12KV.

The air-break circuit breakers are generally indoor type and installed on vertical panels or indoor draw-out type switchgear.

A.C. air circuit breakers are widely used in indoor medium voltage and low voltage switchgear. Typical reference values of ratings of air-break circuit breaker are:

460 V, 400-3500 A, 40-75 KA
3.3 KV, 400-3500 A, 13.1-31.5 KA
6.6 KV, 400-2400 A, 13.1-20 KA

2. 1. 2. Construction of Air-break Circuit-breaker

In the air-break circuit-breaker the contact separation and arc extinction takes place in air at atmospheric pressure. As the contacts are opened, arc is drawn between them. The arc core is a conducting 'path' of plasma. The surrounding medium contains ionized air. By cooling the arc, the diameter of arc core is reduced. The arc is extinguished by lengthening the arc, cooling the arc and splitting the arc. The arc resistance is increased to such an extent that the system voltage cannot maintain the arc and the arc get extinguished. This type of breaker is used for medium and low voltages.

There are two sets of contacts : Main contacts (1) and Arcing contacts (2). Main contacts conduct the current in closed position of the breaker. They have low contact resistance and are silver plated. The arcing contacts (2) are hard, heat resistance and are usually of copper alloy. While opening the contacts, the main contacts dislodge first. The current is shifted to the arcing contacts. The arcing contacts dislodge later and arc is drawn between them (3). This arc is forced upwards by the electromagnetic forces and thermal action. The arc ends travel along the arc Runners (Arcing horns). The arc moves upwards and is split by arc splitter plates (arc chutes) (5) as shown by the arrow (4). The arc extinguished by lengthening, cooling, splitting etc. In some breakers the arc is drawn in the direction of the splitter by magnetic field.

Furthermore, air-break circuit-breaker have been developed with current limiting feature, magnetic blow-up of arc, etc. Air break a.c. circuit breakers are widely used for industrial switchgear, auxiliary switchgear in generation station. Air break principle employing lengthening of arc, arc runners, magnetic blow-ups are used for d.c. circuit breaker up to 15 KV.

2. 1. 3. Air-break Circuit-breaker (Miniature and Molded-Case C.B)

These are used extensively in low voltage domestic, commercial and industrial applications. They replace conventional fuses and combine the features of a good HRC fuse and a good switch.

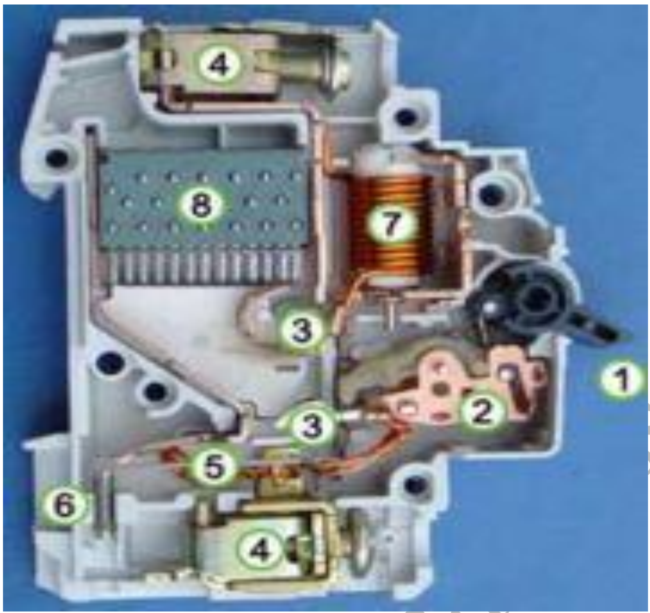


Fig.2.1 The internal details of a 10 ampere European DIN rail mounted thermal-magnetic circuit breaker

For normal operation, it is used as a switch. During over loads or faults, it automatically trips off. The tripping mechanism is actuated by magnetic (part 7) and thermal sensing devices (part5) provide within the MVB.

Tripping mechanism and the terminal contacts (part4) are assembled in a molded case, molded out of thermosetting powders. They ensure high mechanical strength, high dielectric strength and virtually no ageing. The current carrying parts (part3) are made out of electrolytic copper or silver alloy depending upon the rating of the breaker. All other metal parts are of non-ferrous, non rusting type. Sufficient cross section for the current carrying parts is provided to ensure low temperature rise even under high ambient temperature environment. The arc chute (part8) has a special construction which increase the length of the arc by the magnetic field created by the arc itself and the arc chute is so placed in the breaker that the hot gases may not come in contact with any of the important parts of the breaker.

The breakers have unit construction whereby multiple pole breakers can be made by assemble of single pole breakers.

Figure contents:

1. Actuator lever - used to manually trip and reset the circuit breaker. Also indicates the status of the circuit breaker (On or off /tripped). Most breakers are designed so they can still trip even if the lever is held or locked in the on position. This is sometimes referred to as "free trip" or "position trip" operation.
2. Actuator mechanism - forces the contacts together or apart.
3. Contacts - Allow current to flow when touching and break the flow of current when moved apart.

4. Terminals
5. Bimetallic strip
6. Calibration screw - Allows the manufacture to precisely adjust the trip current of the device after assembly.
7. Solenoid
8. Arc divider / extinguished

Typical Rating of MCB:

Current Rating: 5, 10, 15, 20, 30, 40, 50, 60 Amp.
Also, 0.5, 0.75, 1, 2, 2.5, 3, 3.5, 6, 7.5, 8, 10, 12, 25, 35, 45, 55 Amp.
Voltage Rating: 240 V/415 V AC; 50 V/11 V DC
Breaking Capacity: AC: 3 KA at 415 V
DC: 3 KA at 50 V (non-inductive),
1 KA at 110 V (non-inductive).

Typical Examples for AC MCB

MCB DOM (6, 10, 16, 20, 25, 32, 40, 50, 63A) 4.5kA – 1, 2, 3, 4 poles
MCB iK60 (6, 10, 16, 20, 25, 32, 40, 50, 63A) 6kA – 1, 2, 3 poles
MCB iC60N (2, 3, 6, 10, 16, 20, 25, 32, 40, 50, 63A) 10kA – 1, 2, 3, 4 poles
MCB iC60H (6, 10, 16, 20, 25, 32, 40, 50, 63A) 15kA – 1, 2, 3, 4 poles
MCB iC60L (10, 16, 20, 25, 32, 40, 50, 63A) 15, 20, 25kA – 1, 2, 3, 4 poles
MCB C120N (80, 100, 125A) 10kA – 1, 2, 3, 4 poles
MCB C120H (80, 100, 125A) 15kA – 1, 2, 3, 4 poles

Typical Examples for DC MCB

MCB C60H (1, 2, 3, 4, 5, 6, 10, 13, 15, 16, 20, 25, 30, 32, 40, 50, 63A) 10kA – 1, 2 poles

Typical Examples for AC MCCB

MCCB EZC100F (15, 20, 25, 30, 40, 50, 60, 75, 80, 100A) 10kA – 1, 2, 3, 4 poles
MCCB EZC100N (15, 20, 25, 30, 40, 50, 60, 75, 80, 100A) 18kA – 1, 2, 3, 4 poles
MCCB EZC100H (15, 20, 25, 30, 40, 50, 60, 75, 80, 100A) 30kA – 1, 2, 3, 4 poles
MCCB EZC250N (100, 125, 150, 160, 175, 200, 225, 250A) 25kA – 3, 4 poles
MCCB EZC250H (100, 125, 150, 160, 175, 200, 225, 250A) 36kA – 3, 4 poles
MCCB EZC400N (250, 300, 320, 350, 400A) 36kA – 3, 4 poles
MCCB EZC400H (250, 300, 320, 350, 400A) 50kA – 3, 4 poles

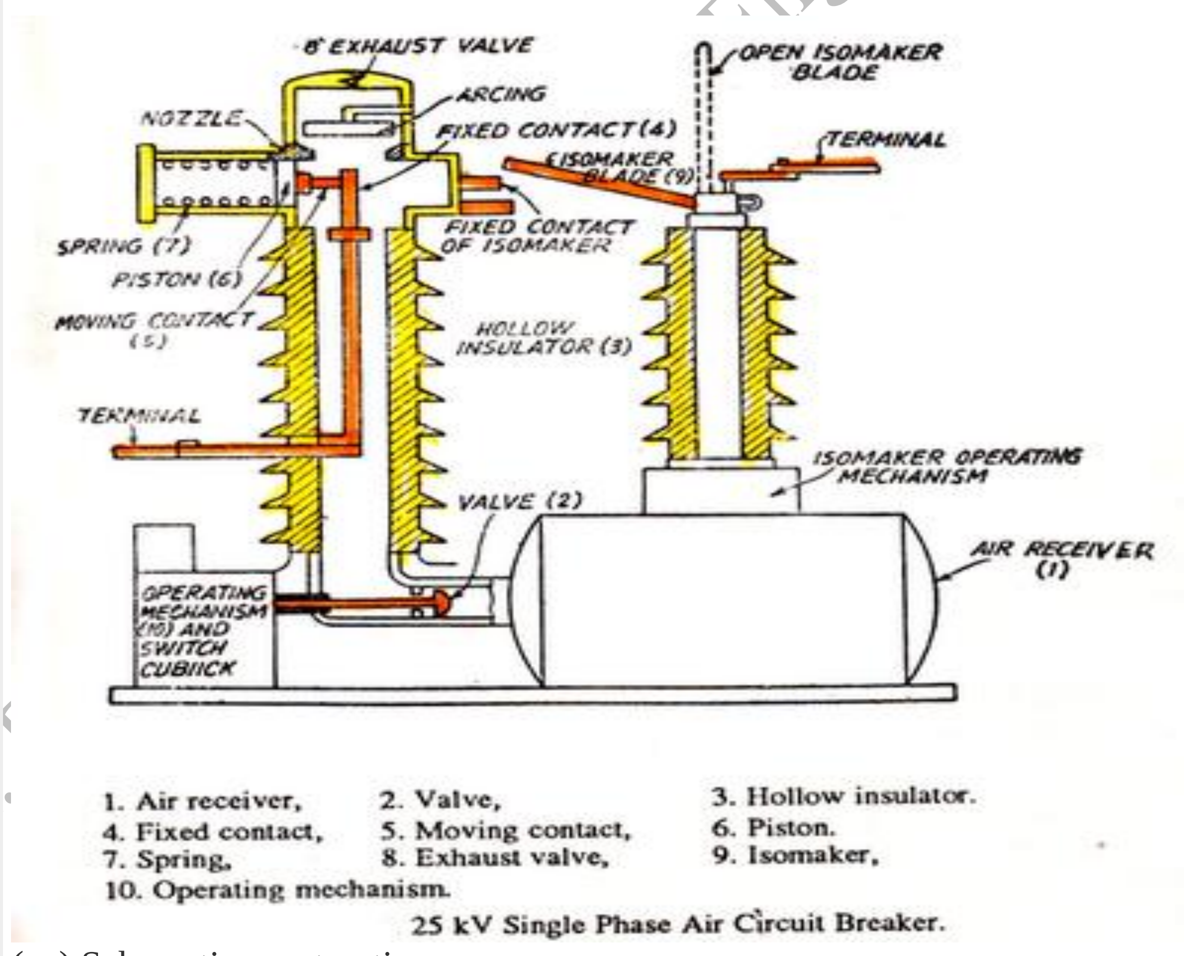
2.2. Air-Blast Circuit-Breaker

2.2.1 Introduction

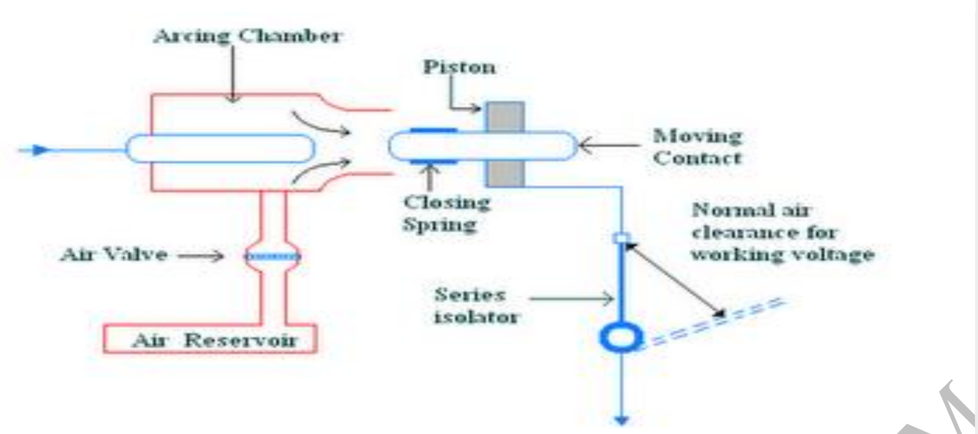
Air blast circuit breakers are used today from 11 to 1100 KV, for various application. They offer several advantages such as faster operations, suitability for related operation, auto-reclosure, unit type multi-break construction, simple, assembly, modest maintenance, etc. A compressor plant is necessary to maintain high air pressure in the receiver. Air-blast circuit breakers operate repeatedly. Air-blast circuit breakers are used for interconnected lines and important lines when rapid operation is desired.

2.2.2 Construction of Air-Blast Circuit-Breaker

In air blast circuit breaker (also called compressed air circuit breaker) high pressure air is forced on the arc through a nozzle at the instant of contact separation. The ionized medium between the contacts is blown away by the blast of the air. After the arc extinction the chamber is filled with high pressure air, which prevents restrike. In some low capacity circuit breakers, the isolator is an integral part of the circuit breaker. The circuit breaker opens and immediately after that the isolator opens, to provide addition gap. In EHV circuit of today, isolators are generally independently mounted (Fig. 2.2).



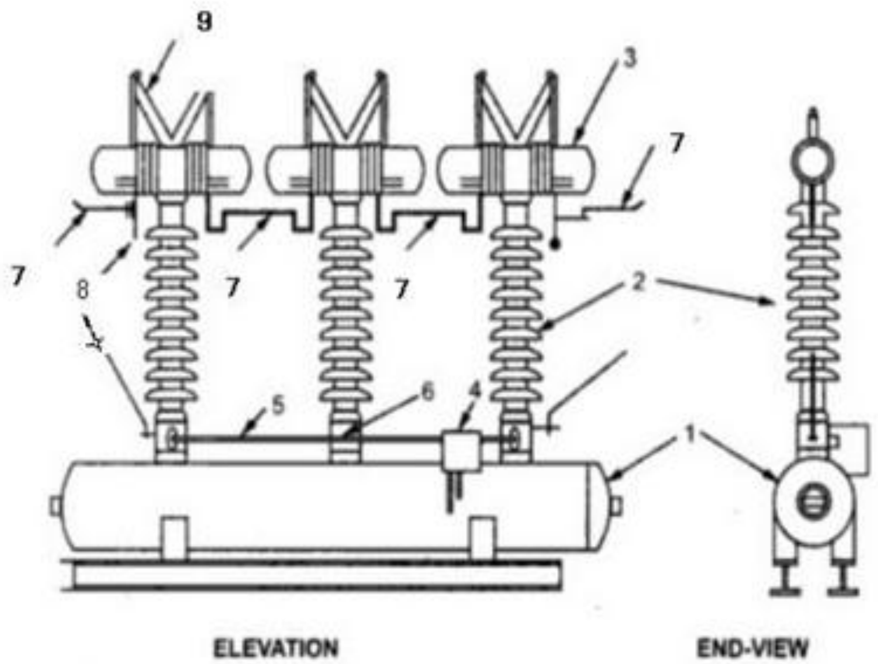
(a) Schematic construction



(b) Principle

Figure 2.2 Air blast circuit breaker isolator connection

Figure 2.3 shows one pole of the EHV air blast circuit breaker. In the complete assembly there are three identical poles.



1. Tank air reservoir
2. Hollow insulator assembly
3. Double arc extinction chamber
4. Pneumatic operation mechanism
5. Operation rod
6. Pneumatic valve
7. Connection for current
8. Arcing horns
9. Resistance switching unit

Figure 2.3 One pole of an extra high voltage air blast circuit breaker

Description: High pressure air between 20 to kgf/cm^2, is is stored in the air reservoir (item 1 in Fig. 2.3). Air is taken from compressed air system. Three hollow insulator columns (item 2) are mounted on the resrvoir with valves (6) at their base. The double arc extinguishing chambers (3) are mounted on the top of the hollow insulator chambers. The current carrying parts (7) connect the three arc extinction chambers to each other in series and the pole to the neighboring equipment. Since there exist a very high voltage between the conductor and the air reservoir, the entire arc extinction chamber assembly is mounted on insulators.
The details of the double arc extinction chambers (3) are shown in Fig. 2.4. Since there three double arc extinction poles in series, there are six breakers per pole. Each arc extinction chamber (Fig. 2.4) consists of one twin fixed contact. There are two moving contacts which are shown in the closing process. The moving contacts can move axially so as to open or close. Its position open or close depends on air pressure and spring pressure.

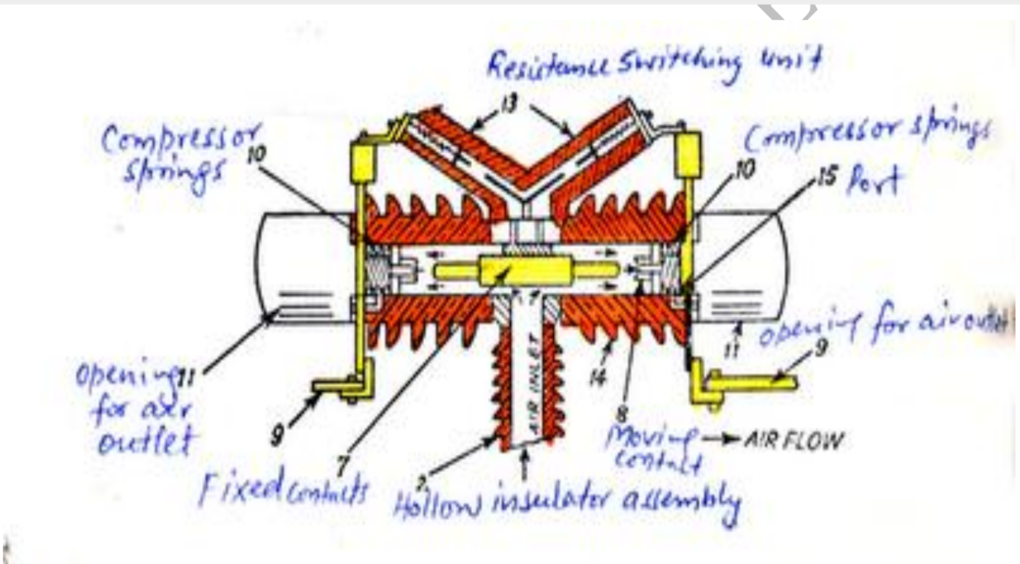


Figure 2.4 Extra high voltage air blast circuit breaker

The operation mechanism (item 4 in Fig. 2.3) operates the rods (item 5) when it gets a pneumatic or electrical signal. The valves (6) open so as to send the high pressure air in the hollow of the insulator. The high pressure air rapidly enters the double arc extinction chamber. As the air enters into the arc extinction chamber the pressure on the moving contacts becomes more than spring pressure and contacts open.
The contacts travel through a short distance against the spring pressure. At the end of contacts travel the part for outgoing air is closed by the moving contacts and the entire arc extinction chamber is filled with high pressure air, as the air is not allowed to go out. However, during the arcing period the air goes out through the openings and takes away the ionized air of arc.
While closing, the valve (6) is turned so as to close connection between the hollow of the insulator and the reservoir. The valve lets the air from the hollow insulator to the atmosphere. As a result the pressure of air in the arc extinction chamber (3) is dropped

down to the atmospheric pressure and the moving contacts close over the fixed contacts by virtue of the spring pressure. the opening is fast because the air takes a negligible time to travel from the reservoir to the moving contact. The arc is extinguished within a cycle. Therefore, air blast circuit breaker is very fast in breaking the current.
Closing is also fast because the pressure in the arc extinction chamber drops immediately as the value (6) operates and the contacts close by virtue of the spring pressure.
The construction described below applies to air-blast circuit-breakers for EHV applications, for voltages above 145 KV. For voltages of 420 KV and more, the construction is modified by adding required number of arc interrupting chambers in series.
Air blast circuit breaker requires an auxiliary compressed air system.
Air blast circuit breakers for 12 KV are generally having a different type of construction.
Air blast circuit breakers are preferred for furnace duty and traction systems are not satisfactory for such duties.

Typical ratings of Air Blast Circuit Breaker are:

- 12 KV, 40 KA
- 22 KV, 40KA
- 145 KV, 40 KA, 3 cycles
- 245 KV, 40 KA, 50 KA, 2.5 cycles
- 420 KV, 40 KA, 50 KA, 63.5 KA, 2 cycles

The grading capacitors are connected across the interrupter unit for the equal distribution of voltage between the units. Closing resistors (Fig. 2.5) are connected across the interrupter units for limiting the over voltages during closing operation. Opening resistors are connected across the interrupter units to make the circuit breakers restrike free.

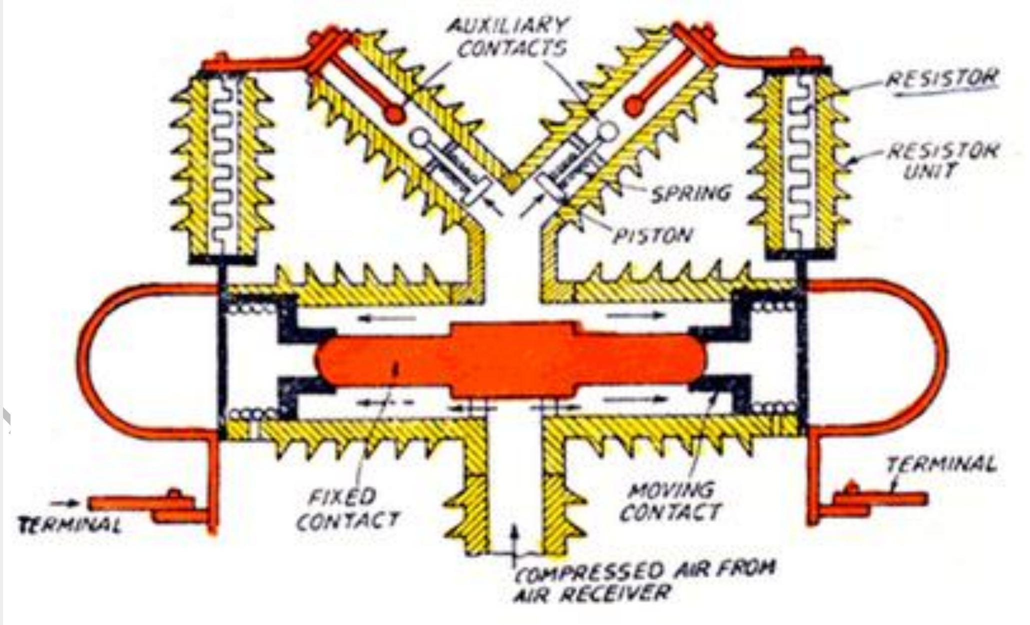
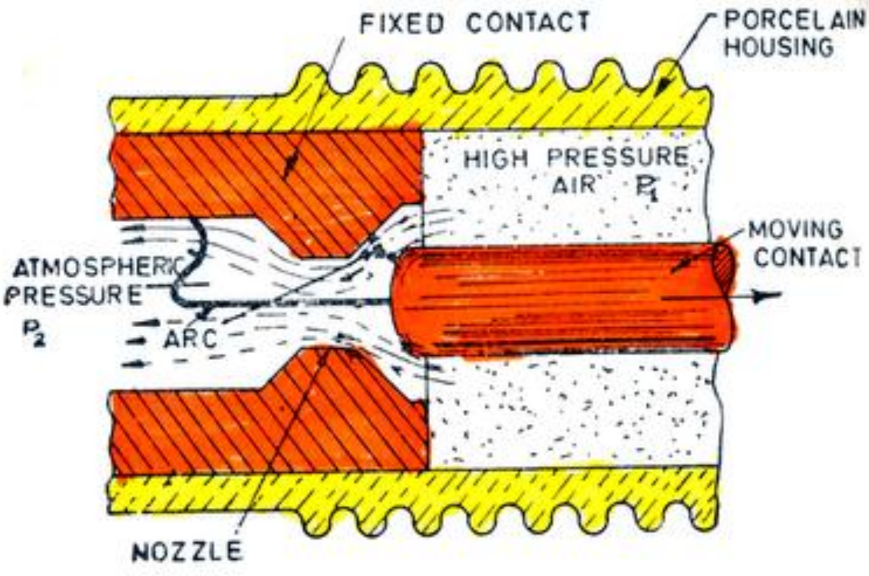


Figure 2.5 Configuration of switching resistor

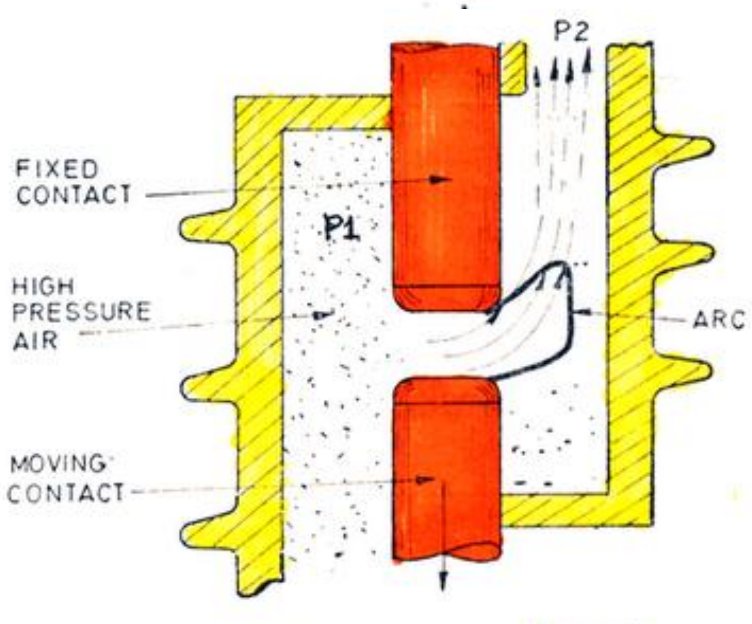
2.2.3 Principle of Arc Quenching in Air Blast Circuit Breaker

The air blast circuit breaker needs an auxiliary compressed air system which supplies air to the air receiver of the breaker. For opening operation, the air is admitted in the arc extinction chamber. It pushes away the moving contacts against spring pressure. In doing so, the contacts are separated and the air blast takes away the ionized gases along with it and assists s arc extinction. After few cycles the arc is extinguished by the air blast and the arc extinction chamber is filled with high pressure air (30kgf/cm^2). The high pressure air has higher dielectric strength than that of atmospheric pressure. Hence a small contact gap of a few centimeters is enough.

The flow of air around contacts is guided by the nozzle shaped contacts. It may be axial, across or a suitable combination {Fig. 2.6(a), (b)}.



(a) Axial flow.



(b) Cross flow in ABCB—(Not used).

Figure 2.6 Flow of air around contacts in air blast circuit breaker

In the axial blast type air flow Fig. 2.6 (a) the flow air is longitudinal, along the arc. In axial blast type air flow, the air flows from high pressure reservoir to the atmospheric pressure through a convergent divergent nozzle. The difference in pressure and the design of nozzle is such that as the air expands into the low pressure zone, it attains almost supersonic velocity. The mass flow of air through the nozzle is governed by the parameters like pressure ratio, area of throat, nozzle throat diameter and is influenced by the diameter of the arc itself.

The air flowing at high speed axially along the arc causes removal of heat from the periphery of the arc and the diameter of the arc reduces to a low value at current zero. At this instant the arc is interrupted and the contact space is flushed with fresh air flowing through the nozzle.

The flow of fresh air through the contact space ensures removal of hot gases and rapid building up of the dielectric strength.

The principle of cross blast illustrated in Fig. 2.6 (b) is used only in the circuit breaker of relatively low rating such as 12 KV, 500 MVA.

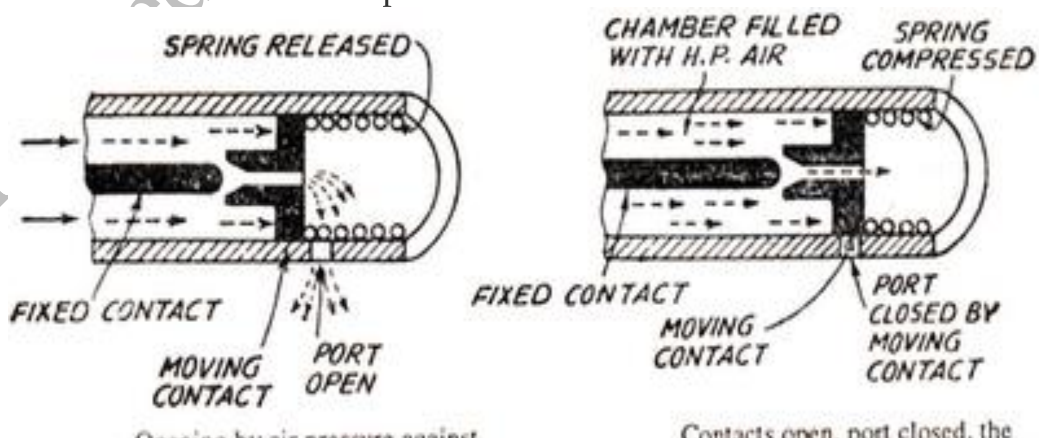
The experience has shown that in the cross blast flow, the air flows around the arc and the diameter of arc is likely to remain stable for higher values of current.

During the period of arc extinction, the air continues to flow through the nozzle to the atmosphere. The mass flow rate can be increased by increasing the pressure system. The increase in the mass flow results in increased breaking capacity.

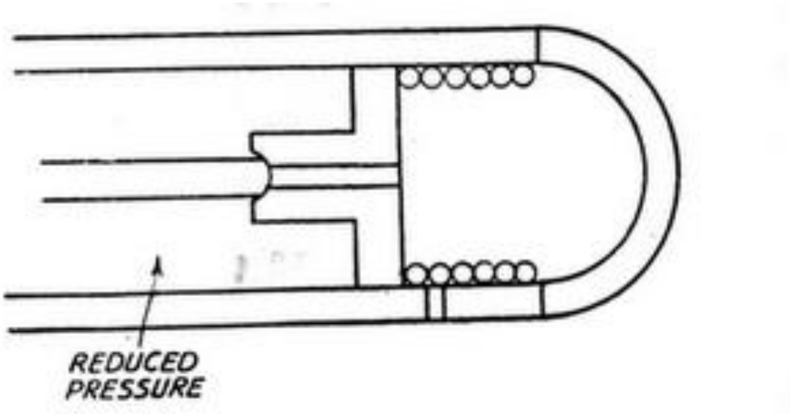
After the brief duration of air flow, the interrupter is filled with high pressure air. The dielectric strength of air increases with pressure. Hence the fresh high pressure air in the contact space is capable of withstanding the transient recovery voltage.

After the arc extinction the interrupter chamber is filled with high pressure air. For closing operation, the air from this chamber is let out to the atmosphere. Thereby the pressure on the moving contacts from one side is reduced and the moving contacts close rapidly by the spring pressure (Fig. 2.7).

The air blast circuit breakers come under the class external extinguishing energy type. The energy supplied for arc extinction is obtained from high pressure air and is independent of current to be interrupted.



(a) Sequence of operation in ABCB.



(b) Contact close by spring pressure against reduced air pressure.

Figure 2.7 Principle of Operation in ABCB

2.2.4 Merits and Demerits of Air Blast Circuit Breaker

Merits of Air Blast Circuit Breaker:

1. Can be used at high pressure.
2. Reliable operation due to external source of extinguishing energy.
3. Free from decomposition.
4. Clean, non-inflammable.
5. Air is freely available everywhere.
6. Fresh medium is used every time. Hence the breaker can be repeatedly operated, if designed for such duty.
7. At high pressure the small contact travel is enough.
8. The same are serves purpose of moving the contact and arc extinction.
9. High speed of operation. The compressed air moves very fast and brings about the opening operation. The arcing time is also short. Hence total breaking time is short operation mechanism of air blast circuit breaker are pneumatic. The arcing time is almost exactly 0.01 second, i.e 1/2 cycle plus another 1/2 cycle for operation the contacts. Hence breaker speed of the order of 2 cycles can be achieved. This makes the circuit breaker suitable for important lines because high speed opening and auto-reclosure can improve system stability.
10. Rapid auto-reclosure The circuit breaker can be given rapid auto-reclosure feature. The manufacturer gives such a provision at additional cost. The ABCB is easy to reclose because the reclosure is by spring pressure against reduced air pressure.
11. Clean service. No need of maintenance as of oil
12. Unit type construction gives advantage in design, manufacturer and testing
13. Very high breaking capacities and service voltage can be obtained by connection more number of units in series. Hence for all extra high voltage and high breaking capacities of today air-blast circuit breakers are used, e.g. 420 KV, 63.5 KA, 2 cycles

14. Suitability for repeated operation, The fresh air is used every time. Hence the breaker can be used for repeated operation if designed for duty. This is not the case with oil circuit breaker.

Demerits of Air Blast Circuit Breaker:

1. Complex design of arc extinction chambers and operating mechanisms, problems for switching over voltages are reduced by reclosing resistors.
2. Auxiliary high pressure air system is necessary. The cost can be justified if there several breakers in the switching yard. For single breakers the cost of auxiliary compressed air system would be too high.

2.2.5 Maintenance aspects

Maintenance of ABCB is comparatively easier than that of tank type oil circuit breaker and minimum oil circuit breaker. This is because there is no oil, which needs regular testing and purification. Secondly, the units can be easily disassembled, checked and reassembled. The assembly of various units is similar and easy. The operating mechanism can be easily dismantled and reassembled.

The major problem in air blast installation is the leakage from compressed air system and from the pipe connection. The leakage takes place from the threaded joints or from mating parts joined by means of nut-bolts

2.3. Bulk Oil and Minimum Oil Circuit Breaker

Such circuit breakers utilize dielectric oil (transformer oil) for arc extinction. In bulk oil circuit breakers, the contacts are separated inside steel filled with dielectric oil. In minimum oil circuit breakers, the contacts are separated in insulation housing (interrupter) filled with dielectric oil.

The oil in oil circuit breakers (OCBs) serves two purposes. It insulates between the phases and between the phases and the ground, and it provides the medium for the extinguishing of the arc. When electric arc is drawn under oil, the arc vaporizes the oil and creates a large bubble that surrounds the arc. The gas inside the bubble is around 80% hydrogen, which impairs ionization. The decomposition of oil into gas requires energy that comes from the heat generated by the arc. The oil surrounding the bubble conducts the heat away from the arc and thus also contributes to deionization of the arc.

Main disadvantage of the oil circuit breakers is the flammability of the oil, and the maintenance necessary to keep the oil in good condition) i.e. changing and purifying the oil).

Bulk oil circuit breaker (tank type circuit breakers) is becoming obsolete and has been described here in brief.

Minimum oil circuit breakers have the following demerits:

- Short contact life.
- Frequent maintenance.
- Possibility of explosion.
- Larger arcing time for small current.
- Prone to restrike

They are being superseded by SF6 circuit breakers in all ranges.

2.3.1 Tank type or Bulk Oil Circuit Breaker (BOCB)(now obsolete)

Bulk oil circuit breakers are enclosed in metal-grounded weatherproof tanks that are referred to as dead tanks. The tank type circuit breakers have 3 separate tanks for 72.5 KV and above (Fig. 2.8a). For 36 KV and below, single tank construction, phase barriers were provided between phases.

The contact separation takes place in steel tanks filled with oil. The gases formed, due to the heat of the arc, expand and set the turbulent flow in the oil. The arc was drawn directly inside of the container tank without any additional arc extinguishing but the one provided by the gas bubble surrounding the arc. Plain break breakers were superseded by arc controlled oil breakers.

To assist arc extinction process, arc control devices were fitted to the contact assembly. These were semi-enclosed chamber of dielectric materials. The purpose of the arc control devices is to improve operating capacity, speed up the extinction of arc, and decrease pressure on the tank. The performance of oil circuit breaker depended on the effectiveness of the arc control devices.

(a) 115 KV circuit breaker

(b) 66 KV circuit breaker

Figure 2.8 Types of bulk oil circuit breaker

The breakers incorporate arc control is called arc control circuit breakers. These are two types of such breakers:

1. **Self blast oil circuit breakers -** in which arc control is provided by internal means i.e. are itself facilitates its own extinction efficiency.
2. **Forced blast oil circuit breakers -** in which arc control is provided by mechanical means external to the circuit breaker.

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

The pressure chamber is relatively cheap and gives reduced final arc extinction gap length and arcing time as against the plain oil breaker. Different types of explosion pots are described below:

a) **Plain explosion pot** –

It is a rigid cylinder of insulating material and encloses the fixed and moving contacts as shown in Fig. 2.9. The moving contact is a cylindrical rod passing through a restricted opening called throat at the bottom. When fault occurs the contacts get separated and 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 around the arc to extinguish it.

If the arc extinction will not take place when the moving contact is still within the pot, it occurs immediately after the moving contact leaves the pot. It is because, emergence of moving contact will be followed by violent rush of gas and oil through the throat production rapid extinction.

Limitation of this type of pot is that it cannot be used for very low or very high fault currents. With low fault currents the pressure developed is small, thereby increasing the arcing time. And with high fault currents, the gas is produced so rapidly that the plot may burst due to high pressure. So this pot is used on moderate short circuit currents only when rate of gas evolution is moderate.

b) **Cross jet explosion pot** –

Figure 2.10 shows the cross jet pot which is made of insulating material and has channels on one side that acts as arc splitters. The arc splitter helps in increasing the arc length, thus facilitating arc extinction. When fault occurs, the moving contact of the circuit breaker begins to separate and arc is 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 used for interrupting heavy fault currents. For low fault currents the gas pressure is small and consequently the pot does not give a satisfactory operation.

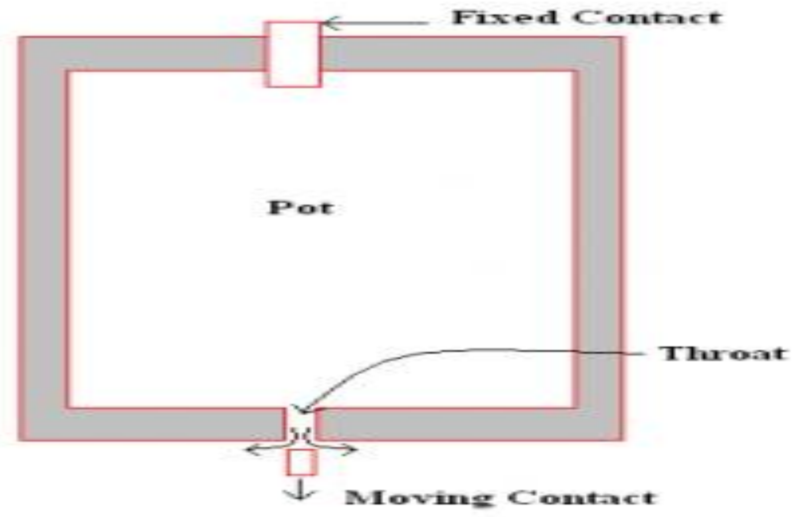


Figure 2.9 Plain explosion pot principle

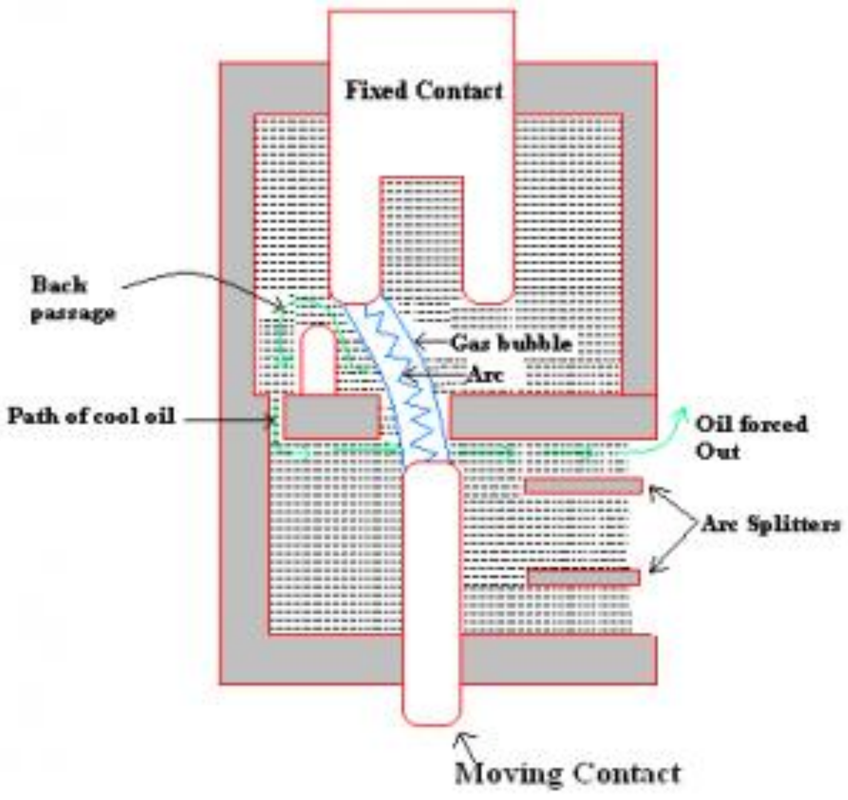


Figure 2.10 Principle of cross jet explosion pot

c) **Self compensated explosion pot** –

This pot is a combination of plain explosion pot and cross jet explosion pot. So it can interrupt low as well as heavy short circuit currents. Figure 2.11 shows the self compensated explosion pot.

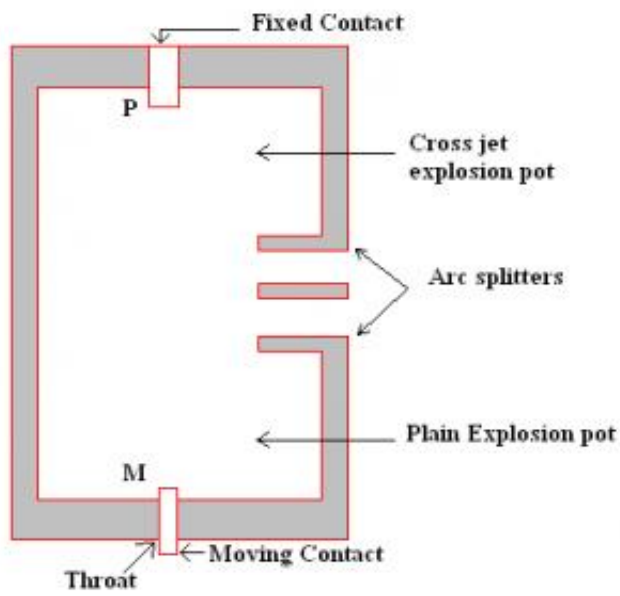


Figure 2.11 self compensated explosion pot

Forced Blast Oil Circuit Breaker

In this type of circuit breaker there is a piston attached to a moving contact. When fault occurs the moving contact moves and hence the piston associated with it also moves producing pressure inside the oil chamber. So the oil gets movement or turbulates and quenching the arc.

The arc control devices can be classified into two groups: cross-blast and axial blast interrupters (Fig. 2.12).

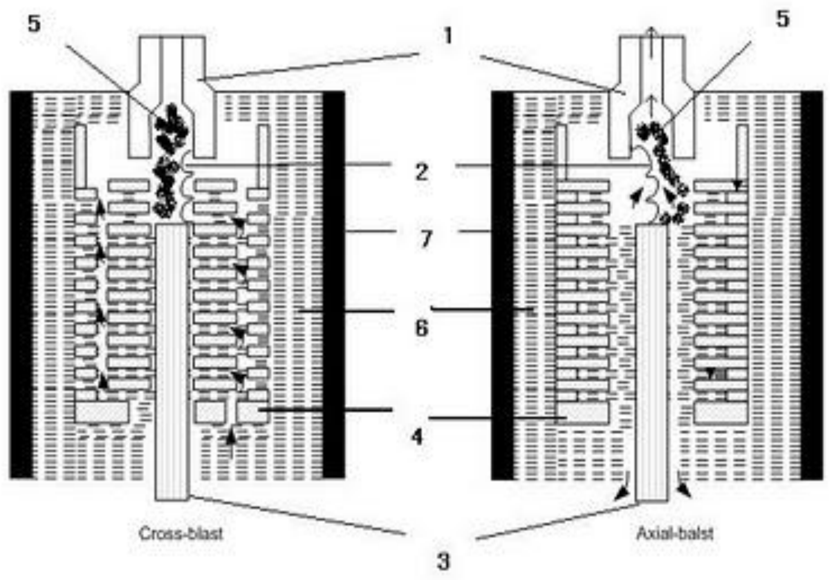


Figure 2.12 Classification of arc control devices

Figure contents:
1- Fixed contact assembly 2- Arc 3- Moving contact with tungsten-copper tip
4- Fiber reinforced tube 5- Gas evolved by decomposition of oil 6- Dielectric oil
7- Outer enclosure (Porcelain or Fiber Reinforced Epoxy)

In cross blast interrupters, the arc is drawn in front several lateral vents. The gas formed by the arc causes high pressure inside the arc control device. The arc is forced into the lateral vents in the pot, which increases the length of the arc and shortens the interruption time. The axial blast interrupters use similar principle as the cross blast interrupters. However, the axial design has a better dispersion of the gas from the interrupter.

Figure 2.13 illustrates a typical 69 KV breaker of 2500 MVA breaking capacity. All three phases are installed in the same tank. The tank is made of steel and is grounded. This type of breaker arrangement is called the dead tank construction. The moving contact of each phase of the circuit breaker is mounted on a lift rod of insulating material. There are two breaks per phase during the breaker opening. The arc control pots are fitted over the fixed contacts. Resistors parallel to the breaker contacts may be installed alongside the arc control pots. It is customary and convenient for this type of breakers to mount current transformers in the breaker bushings.

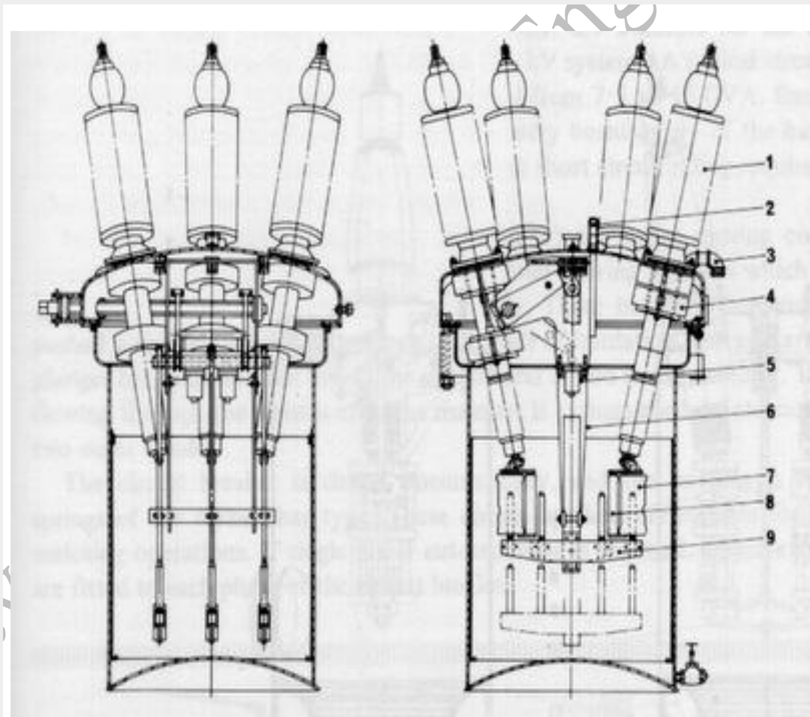


Figure 2.13 dead tank oil circuit breaker

Figure contents:

1	bushing	6	plunger guide
2	oil level indicator	7	arc control device
3	vent	8	resistors
4	current transformer	9	plunger bar
5	dashpot		

The practical limit for the bulk oil breakers is 275 KV. Figure 2.14 shows 220 KV one phase dead tank circuit breaker.

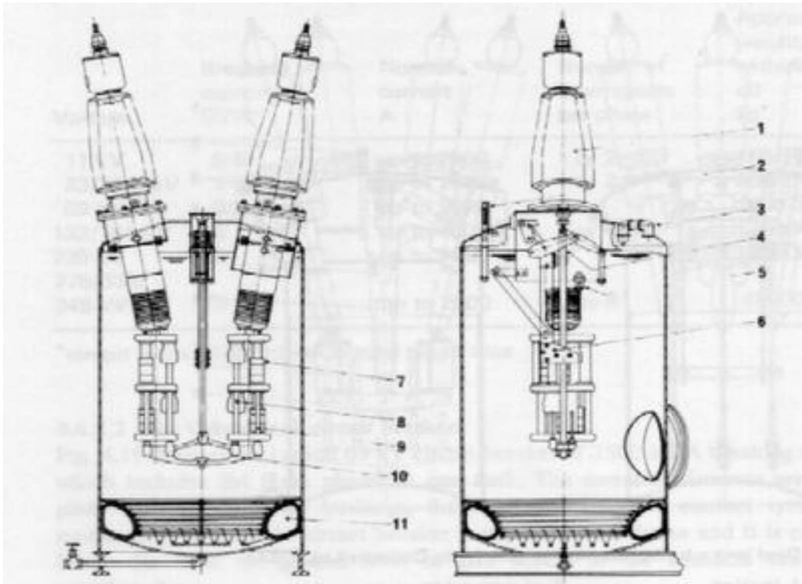


Figure 2.14 Single phase tank oil circuit breaker

Figure content:

1	bushing	7	arc control unit
2	oil level indicator	8	parallel contact
3	vent	9	resistor
4	linear linkage	10	plunger bar
5	dashpot	11	impulse cushion
6	guide block		

The oil circuit breakers are usually installed on concrete foundations at the ground level. During interruption of heavy fault currents the breakers tend to move. To minimize the damage to the breakers, breakers with very high interrupting capacity have an impulse cushion is provided at the bottom of the breakers. The cushion filled with an inert gas, for example nitrogen.

Figure 2.15 illustrates the tank type oil circuit breaker, in open position, with the arc is not yet extinguished

<u>The major disadvantages of tank type circuit breakers are:</u>

1. Large quantity of oil is necessary in oil circuit breakers though only a small quantity is necessary for arc extinction.
2. The entire oil in the tank is likely to get deteriorated due to sludge formation in proximity of the arc. Then the entire oil needs replacement.
3. The tanks are too big, at 36 KV and above, and the tank type oil circuit breaker loses its simplicity,

The above causes led to the development of minimum oil circuit breakers. As the name itself signifies, the minimum oil circuit breaker requires less oil. The arc extinction medium is dielectric oil, the same as that used in tank type circuit breakers. There is no steel tank but the arc extinction takes place in a porcelain containers.

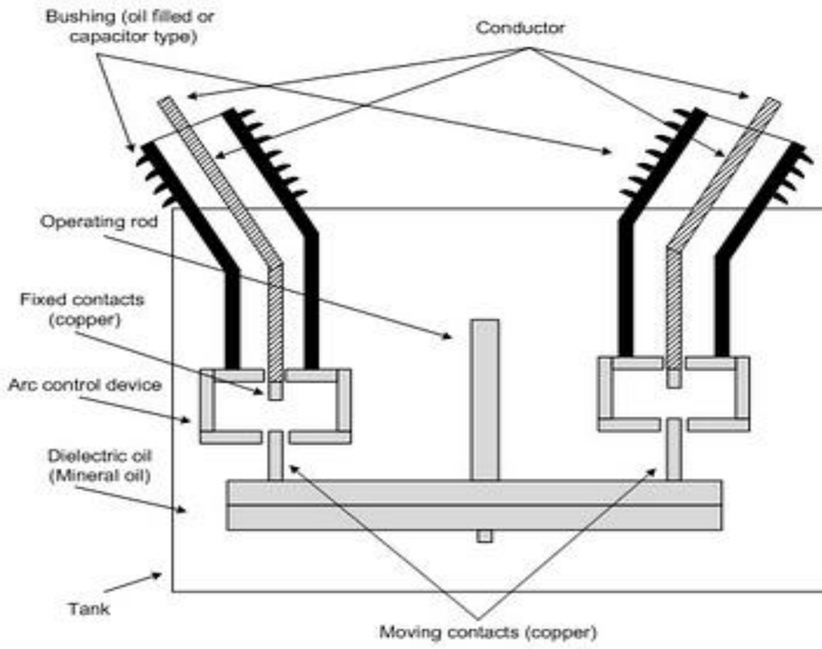


Figure 2.15 Schematic diagram of bulk oil circuit breaker

Summary

In Bulk Oil Circuit Breaker oil serves a two-fold purpose, i.e., as means of extinguishing the arc and also for providing insulation between the live parts and the metallic tank.
This is the oldest amongst the three types having been developed towards close of the nineteenth century. In its simplest form the process of separating the current carrying contacts was carried out under oil with no special control over the resulting arc other than the increase in length caused by the moving contacts.
As the power systems began to develop resulting in higher voltages and higher fault levels, plain break type breaker could no longer keep pace with the requirements.
Various methods of controlling the breaking process were investigated and developed. This led to the development of controlled break oil Circuit Breaker. This employed pressure chamber and is still widely used because it is relatively cheap to make and gives greatly improved performance in terms of final extinction, gap length and arcing time, as against the plain break oil Circuit Breaker. Various designs exist according to the preferences and requirements of individual manufacturers and designations such as 'Cross Jet Type', 'Explosion Pot' and 'Baffle pot', etc.
Many oil Circuit Breakers feature special arc control devices most of which are based on the simple pressure chamber principle but incorporate certain modifications aimed at improving the breaking capacity. Depending on the working principle of these special pressure chambers the breakers are designated as: impulse oil Circuit Breakers deigns grid breakers, breakers with double arc pressure chambers and axial jet pressure chamber oil Circuit Breakers.

2.3.2 Minimum Oil Circuit Breaker (MOCB)

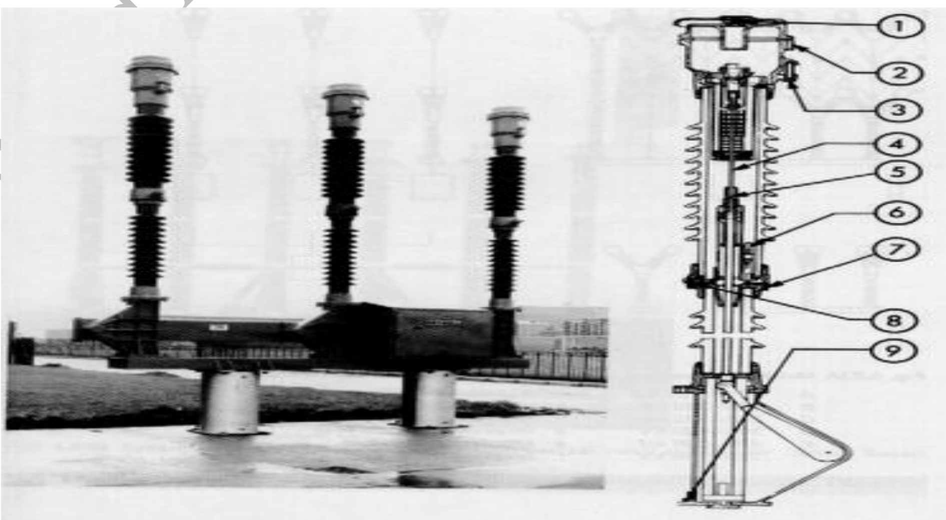
This type is also known as poor oil or small oil circuit breaker. In the bulk oil circuit breakers, the oil serves as both arcs extinguishing medium and main insulation. The minimum oil circuit breakers were developed to reduce the oil volume only to amount needed for extinguishing the arc - about 10% of bulk oil amount. The arc control for the minimum oil breakers is based on the same principle as the arc control devices of the bulk oil breakers. To improve breaker performance, oil is injected into the arc.

In MOCB, The current interruption takes place inside "interrupter". The enclosure of the interrupter is made of insulating material, like porcelain. Hence, the clearance between the line and the enclosure can be reduced and lesser quantity of oil would be required for internal insulation.

The interrupter containers of the minimum oil circuit breakers are insulated from the ground. This is usually referred to as live tank construction. For high voltage (above 132 KV), the interrupter are arranged in series. It essential to ensure that each interrupter carries its share of the duty. Care must be taken that all breaks occur simultaneously, and that the restriking voltage is divided equally across the breaks during the interrupting process. The thermal voltage division depends on stray capacitances between the contacts and the ground, and therefore is in very uneven. This is corrected by connecting capacitances or resistors in parallel with the interrupting heads. Figure 2.16 shows a three phase minimum oil circuit breaker along with cross-section through a single phase.

One pole of a 3-pole outdoor MOCB is illustrated in Fig. 2.17 in some details. There are two chambers separated from each other but both are filled with oil. The upper chamber is the arc extinction chamber. The oil from this chamber does not mix with that in the lower chamber. Lower chamber acts like a dielectric support.

Arc extinction device is fitted to the upper fixed contact. The lower fixed contact is ring shaped. The moving contact makes a sliding contact with the lower fixed contacts. A resin bounded fiber glass cylinder encloses the contact assembly. This cylinder is also filled with oil. Porcelain cylinder encloses the fiber glass cylinder. Other provisions are similar to the bulk oil circuit breaker.



(a) Three phase circuit breaker (b) Cross section through a single phase

Figure 2.16 Minimum oil circuit breaker

Figure contents:

1 vent valve
2 terminal pad
3 oil level indicator
4 moving contact
5 lower fixed contact
6 separating piston
7 terminal pad
8 upper drain valve
9 lower drain valve

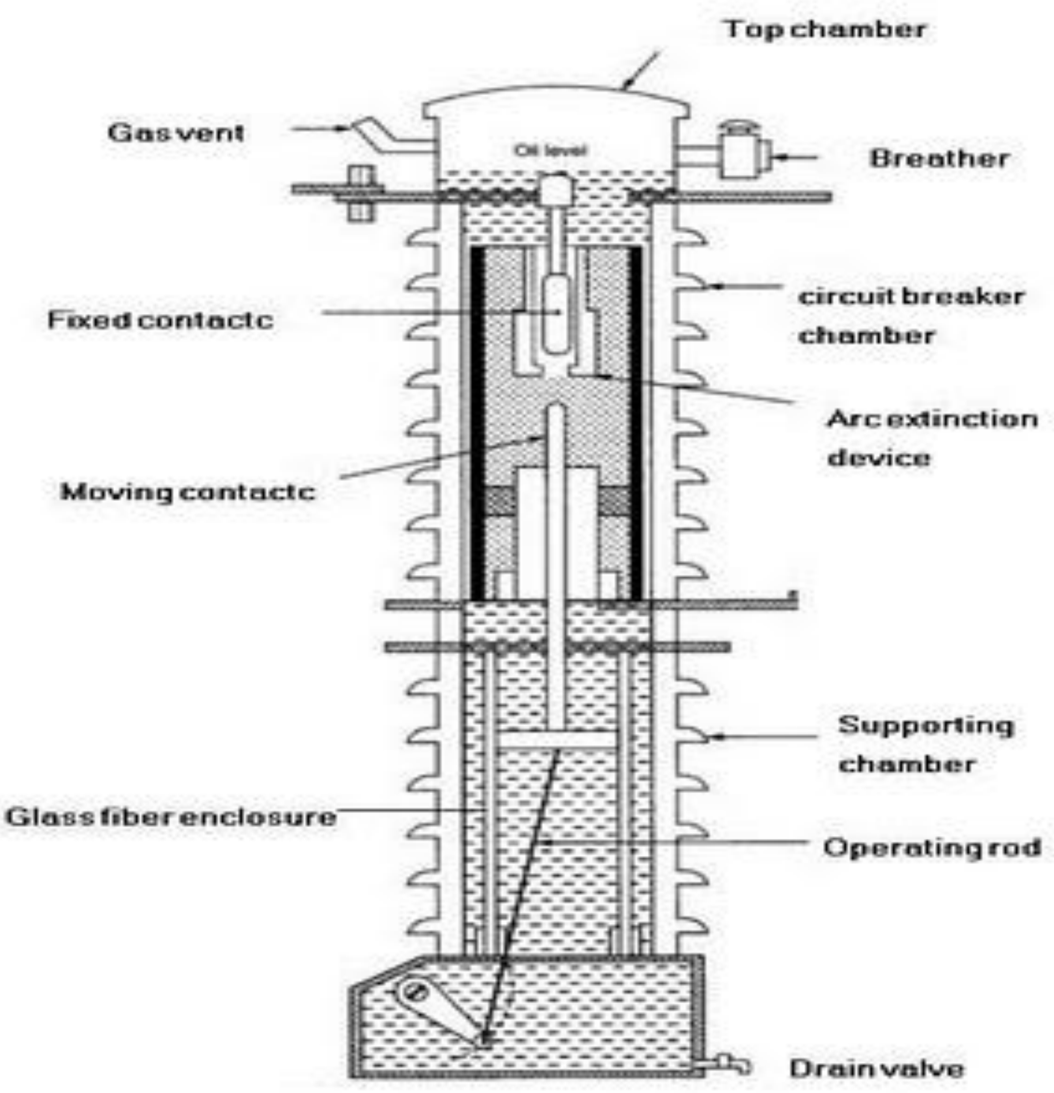


Figure 2.17 Simplified diagram of an outdoor minimum oil circuit breaker pole, with one interrupter per pole

To illustrate the principle of working, the sectional view of working portion of 170 KV 3500 MVA, breaker of M/s Delle france is shown in Fig. 2.18 The most important part of the breaker is its extinguishing chamber. This takes the form of an insulating cylinder containing oil, in the exist of which moves the contact rod within which breaking occurs.

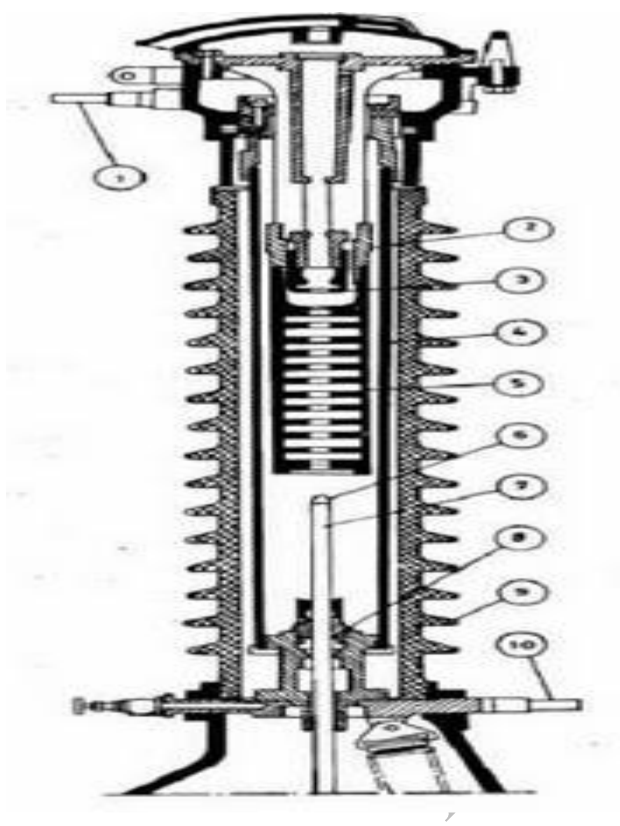


Figure 2.18 Cross sectional view of working portion of 170 KV 3500 MVA breaker of M/S delle france.

The arcing chamber is supported at its base by a casing enclosing a mechanism whose function is to move the contact rod according to the impulses given by the control mechanism. In the on position, the current flow from the upper current terminal (1) to the contact finger (2) follows the movable contact rod (7) and reaches the current terminal (10) across the lower contact fingers (8). At the beginning of the stroke and before breaking, the contact rod strongly pulled downwards by the tripping springs, starts a high speed opening motion. Then, an arc strikes between the contact rod tips (6) and the stationary arcing ring (3), protecting the upper contact fingers.

At this moment gases escape without hindrance towards top of the apparatus, the contact rod rapidly reaches a very high linear speed; it moves the arc downwards and forces it to enter the explosion pot (5) where it is maintained rectilinear and is elongated in a direction opposite to the release of gases towards fresh oil. Since the arc is as short as possible the arc voltage is minimized and the energy dissipated is reduced. Still, since the gases can no longer develop freely, they generate a considerable pressure in the explosion pot (5), thus producing a violent upward axial blast of oil vapor, exhausting the highly ionized gaseous mass. The optimum distance is thus obtained, the jet of oil causes the dielectric strength to be rapidly increased, and at the following current zero, the arc is impeded from restricting and the breaking is thus achieved.

The explosion pot (5) is intended to withstand high pressures. It is partitioned into several components by means of discs whose function is to retain a certain quantity if fresh oil while the first break is proceeding; this allows a second break to occur with complete safety at the full short circuit breaker.

The low oil content circuit breakers require separate current transformers of wound type. Still at all voltages from 33 KV and above the costs of these breakers inclusive of current transformers favorably with that of the bulk oil breakers.

Disadvantage of Oil Circuit Breakers

1. The decomposed products of dielectric oil are inflammable and explosive. If the oil circuit breaker is unable to break the fault current, the pressure in the tank may rise above safe limit and explosion may occur. This does not happen in SF6, ABCB, and vacuum C.B.
2. The oil absorbs moisture readily. The dielectric strength reduces by carbonizations which occur during arcing. The oil needs replacement after a certain breaker operations. It needs regular maintenance.
3. Oil is not a suitable medium for breakers which have to operate repeatedly. Breakers used for furnaces, railways, industrial loads etc., operate frequently. Oil circuit breakers are unsuitable because oil gets deteriorated.
4. The oil leakage, losses, replacement and purification is often troublesome. Hence oil circuit breakers involve more maintenance.

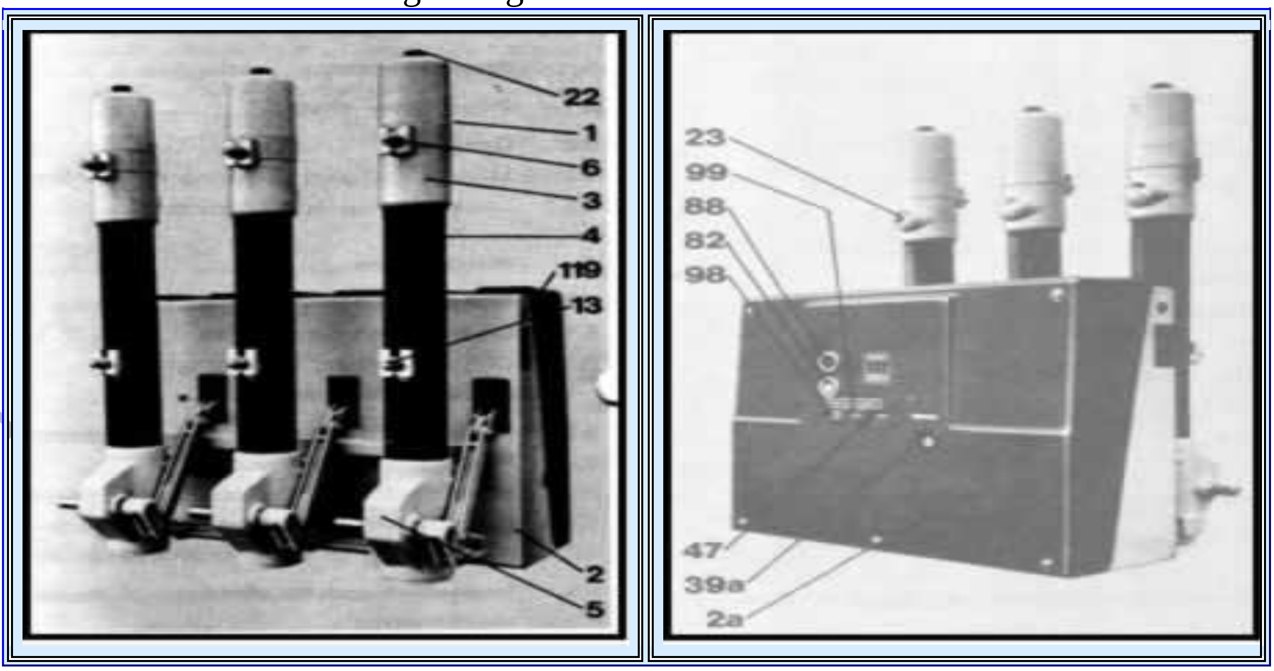
The small oil volume breakers have distinct advantage over the air blast breakers under the following conditions:

1 - Kilometric faults.

This is because the oil Circuit Breakers are much less sensitive to the natural frequency of the restricting voltage.

2. Disconnection of Transformers on load.

The current chopping phenomenon which causes over voltages, before natural zero, is not serious in this class of breakers as the arc extinguishing Energy is always proportional to the broken current. Restricting voltage**.**



1 – Circuit Breaker pole
2 – Mechanism housing
2a – cover of mechanism housing
3 – Pole head
4 – Pole cylinder
5 – Crank housing
6 – Upper main terminal
13 – Bottom main terminal
22 – Vent housing
23 – 0il level indicator
39a – square on charging shaft
47 – Spring condition indicator
82 – off push - button
88 – on push – button
98 – Circuit Breaker indicator
99 – Operation counter
119 – Lifting hole for transport

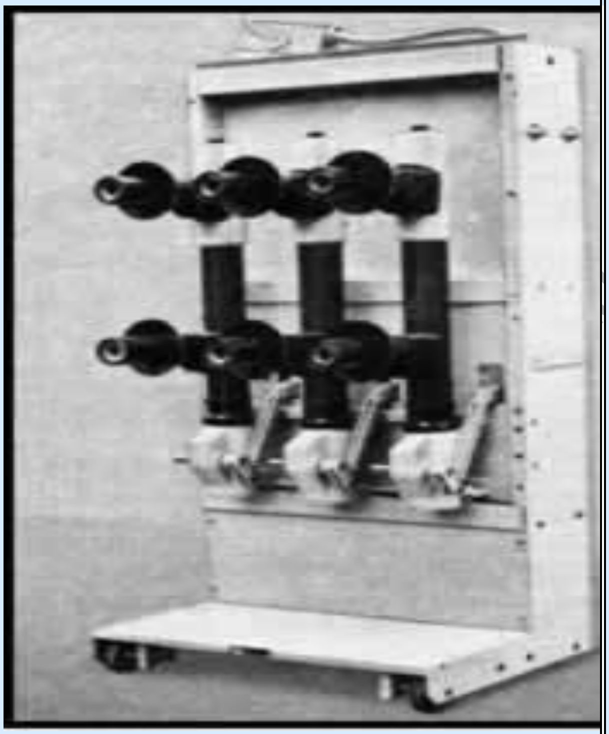


Fig. 2.19 Small Oil Volume Breaker type OD4 makes BBC

Summary

As the system voltages and fault levels increased the Bulk Oil Breakers required huge quantities of insulating oil and became unwieldy in size and weight. This added enormously to the cost of a power system. Simultaneously improvements were made in the technique of ceramics. The function of oil as insulating medium in the Bulk Oil Breakers was transferred to the porcelain containers.

Only a small quantity of oil was used to perform its functions as arc quenching medium. This led to the development of small oil volume or low oil content breakers in the continent of Europe. Like the Bulk Oil Breakers these have also since then passed through many stages of development with varying designs of the arcing chambers. Today the small oil volume breakers are available for voltages up to 36 kV and the fault levels associated therewith. Contrary to the operation of the impulse type Circuit Breaker, such as air blast Circuit Breaker, in which arc extinction and dielectric recovery are affected by means of an external quenching medium, the process of arc extinction in the small *oil* volume Circuit Breaker is of internal thermo- dynamic origin.

During the tripping operation an arc strikes in oil between the moving contact and the fixed contacts. This arc is elongated vertically in the explosion pot until the distance traveled is sufficient to withstand the voltage between contacts.

The increase in internal pressure due to the Splitting up and vaporization of oil by the arc creates a rapid movement of the extinguishing medium round the arc this self-quenching effect causes a rapid cooling of the ionized column along its whole Length due to partition of the explosion pot and the dielectric recovery is sufficiently rapid. To prevent the arc restricting after a natural Passage Through zero. The electric arc itself has, therefore, supplied the necessary energy for its own extinction. There are now numerous manufacturers of small oil volume Breakers However, to illustrate the principles of working, the sectional view of working portion of 170 kV 3500 MVA.

In addition there are certain other advantages which may be summed up as under:

1) Light and reduced size rendering transport
2) Simple construction making erection easy.
3) Quick and simple maintenance.

One of the limitations put forward against this class of breakers is frequent maintenance, owing to reduced quantity of oil and consequent liability to quick carbonization, on circuits susceptible to frequent trappings because of too many faults.

Interruptions on lines carried on pin insulators are rather too many on account of poor workmanship, inadequate and improper maintenance. However, for this reason alone, it may not be worthwhile to reject these breakers unless the difference in cost with Bulk Oil Breakers is meager. For this very reason doubt was expressed about the ability of these breakers for rapid reclosing duty. However, low oil content breakers have been designed and constructed for rapid reclosing duties by established makers of this class of breakers. Rated breaking capacities in general are covered securely by a circuit breaking of any design but, depending on the arc extinguishing principles employed, difficulties are sometimes encountered in performing certain specific duties.

The situations where the small oil volume breakers are, presently, considered at disadvantage are:

1) Switch unloaded lines.
2) Evolving faults.
3) Out of phase disconnection.

2.4 Vacuum circuit breaker

2.4.1 History

In 1972 Professor Sorensen and his assistants at the California Institute of technology achieve significant in the research on switching of currents in a vacuum. The developed theoretical knowledge greatly preceded the level of current technology and couldn't offer a simple and reliable piece of equipment to register micro-leaks and to control the level of vacuum in the chambers. Problem such as copper contacts' tendency to form cold welds in vacuum and generation of over voltages due to premature arc extinction of the refractory contacts could not be resolved. The above mentioned technical problems led to the stagnation of vacuum switching technology development.

Almost twenty years passed before vacuum technology saw a new shift in its development. In the middle of 1950's a technical breakthrough took place in the development of semiconductors, which allowed developing an industrial method of cleaning gas from copper contacts. The invention of sensitive mass spectrometers allowed registering even the smallest leaks in vacuum chambers. Based on fundamental and applied research, construction bureaus manufactured and successfully tested a whole line of vacuum arc extinction chambers. Figure 2.20 show one of the first vacuum chambers.

Figure 2.20 On of the first vacuum chambers with wolfram contacts with a diameter of 1.25 cm, contact spacing of 0.63 mm, nominal current 2000 Amp

As a result of implementation of current achievements, it became possible to create a test vacuum arc extinction chamber (AEC) that successfully performed approximately 90 current breaking operations in the 10-40 KV voltage which was impossible for oil circuit breakers. The research of switching current in vacuum became interesting in Russia in the 1960's. It was at this time that GE introduced the first commercial series of vacuum circuit breakers. It is necessary to state that in the 60's only two countries, Russia and the USA possessed the required technology to manufacture AECs. The specific technologies were the manufacture of oxygen free copper, creation of metal ceramic alloys and the manufacture of metal alloys with a coefficient of heat expansion analogical to glass ceramics.

2.4.2 The theory of Current Switching in Vacuum

If contacts carrying current disconnect, an electric arc is created between them, which supports a high conductivity of the space between the contacts and allow the current leaking between the contacts as if were still closed (Fig. 2.21). This causes the element between the contacts to heat a temperature high enough to disconnect (break-up) its molecules and ionizes the space. The existence of an electric arc is characterized by the quasi-equilibrium state, when the arc voltage self regulates at a level sufficient to maintain the conductivity of the formed plasma, where the diameter of the arc column shrinks or expands depending on the changes of the value of the passing current.

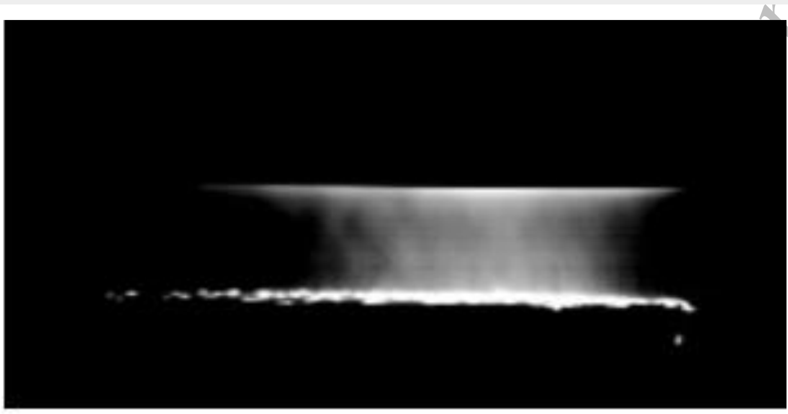


Figure 2.21 Photograph of an electric arc in the space between the contacts at 15-20 k Amp current1

The energy produced at this moment goes into the surrounding environment due to thermal conductivity, convection and radiation. This energy balance must be destroyed if the arc is to be suppressed and current is to be disconnected. When the current reaches natural zero, the energy stops coming from the network. By intensively cooling the space between the contacts at this moment, it is possible to break the arc, disturb the space conductivity and restore its electric stability and by doing this to accomplish the disconnection.

Figure 2.22 Photograph of an arc looking as a braid

2.4.3 Construction of Vacuum Circuit Breaker

The vacuum circuit breaker comprises one or more sealed vacuum interrupter units per pole (Fig. 2.23). The moving contact in the interrupter is connected to insulating operating rod linked with the opening mechanism. The contact travel is of the order of a few millimeters only. The movement of the contacts within the sealed interrupter unit is permitted by metal-bellows.

Vacuum circuit breakers can be classified in the following two categories:

- Vacuum interrupters installed in indoor switchgear and kiosks rated up to 36 KV (Fig. 2.24).
- Vacuum circuit breakers suitable for outdoor installation and having two or more interrupters in series per pole (Fig. 2.25).

The structural configuration of the circuit breakers of two categories mentioned above is quite different as it can be seen, though the basic interrupter unit is base on same principle of operation.

The multi-unit vacuum circuit breakers rated 72.5 KV and above have been developed and installed in England and U.A.S. However, they are not very popular and are not likely to be preferred to other types of circuit breakers.

For voltage up to 36 KV, vacuum circuit breakers employing a single interrupter unit have become extremely popular for metal enclosed switchgear, arc furnace installation, switchgear in generating stations and industrial applications.

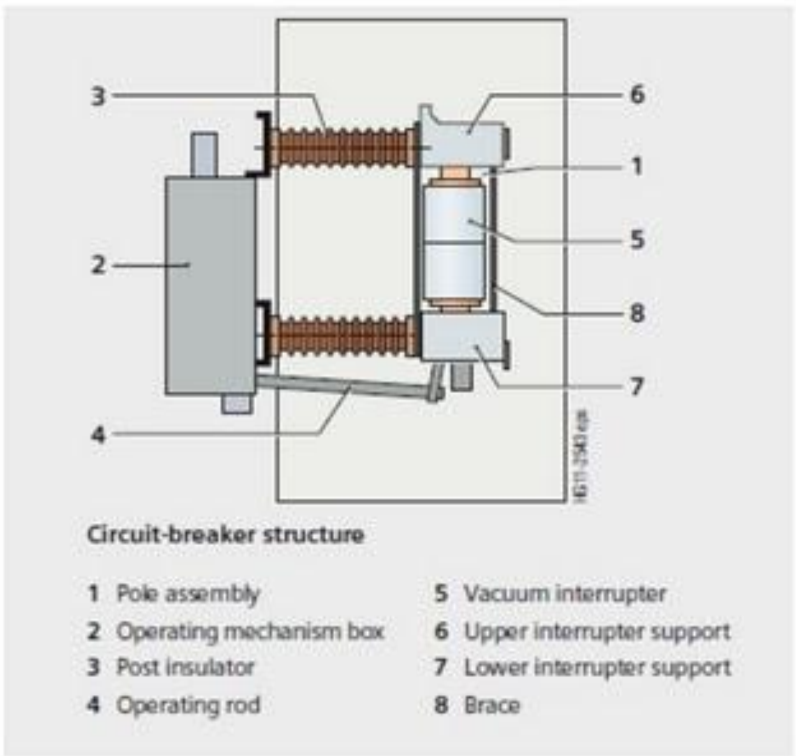


Figure 2.23 Construction of vacuum circuit breaker1

Figure 2.24 12kv indoor vacuum circuit breaker

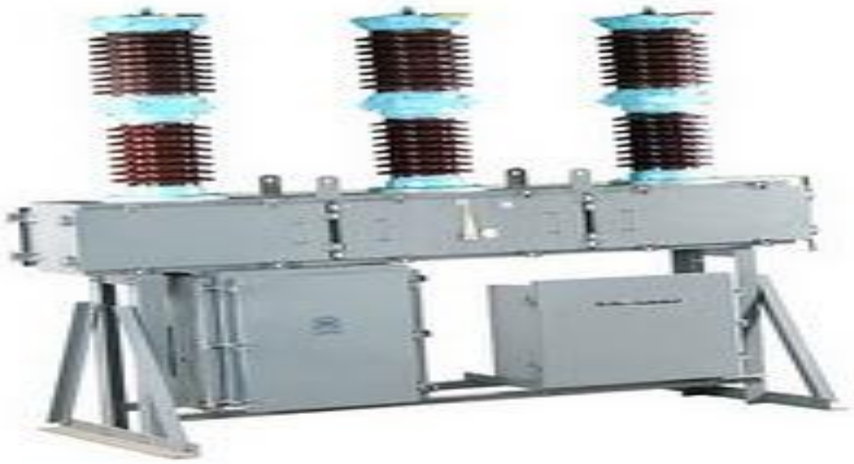


Figure 2.25 12KV outdoor vacuum circuit breaker

The construction of the vacuum chamber is relatively simple. As it can be seen in Fig. 2.26, it consists of a pair of contacts (4; 5), one of which is mobile (5), enclosed in a vacuum dense shield, soldered to ceramic or glass isolators (3; 7), upper and lower metal covers (2; 8) and a metal screen (6).The movement of the mobile contact in relation to the immobile one is provided by means of using a bellows element (9). Chamber outputs (1; 10) serve to connect it to the main current circuit of the breaker. It is necessary to state that only special metals that are vacuum dense and cleaned of dissolved gases are used in vacuum chamber shield manufacturing: copper and special alloys as well as special ceramic composition (usually it is 50%-50% copper-chrome) that provides high breaking capacity, low deterioration and resistance to the appearance of welding points on the surface of the contacts.

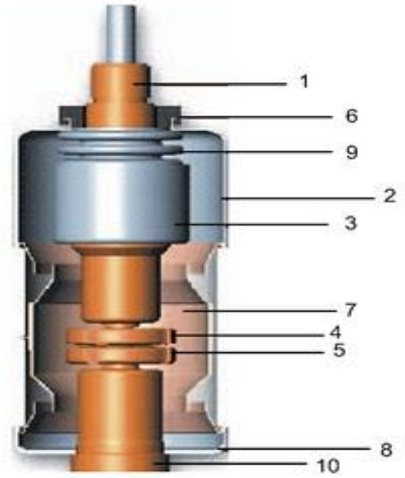
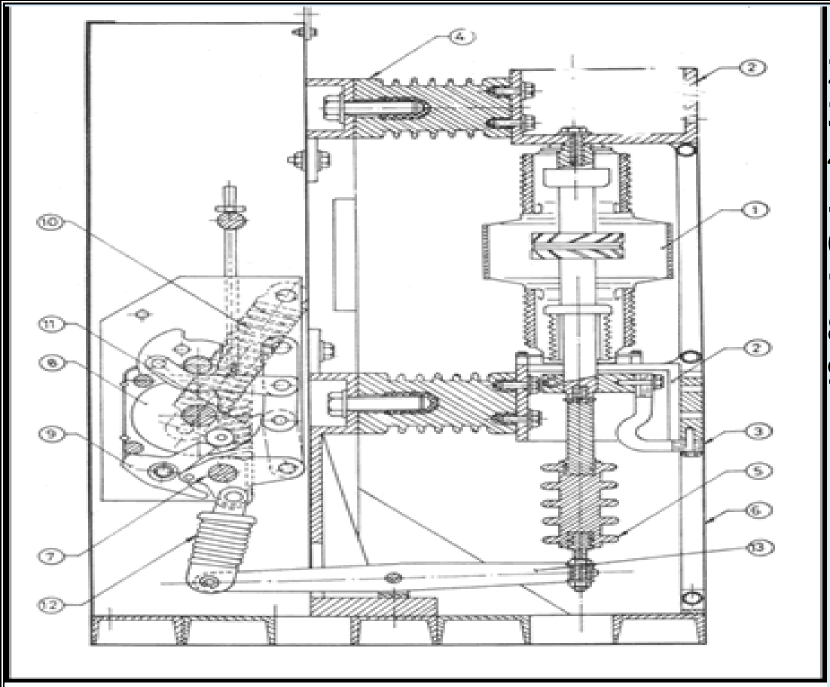


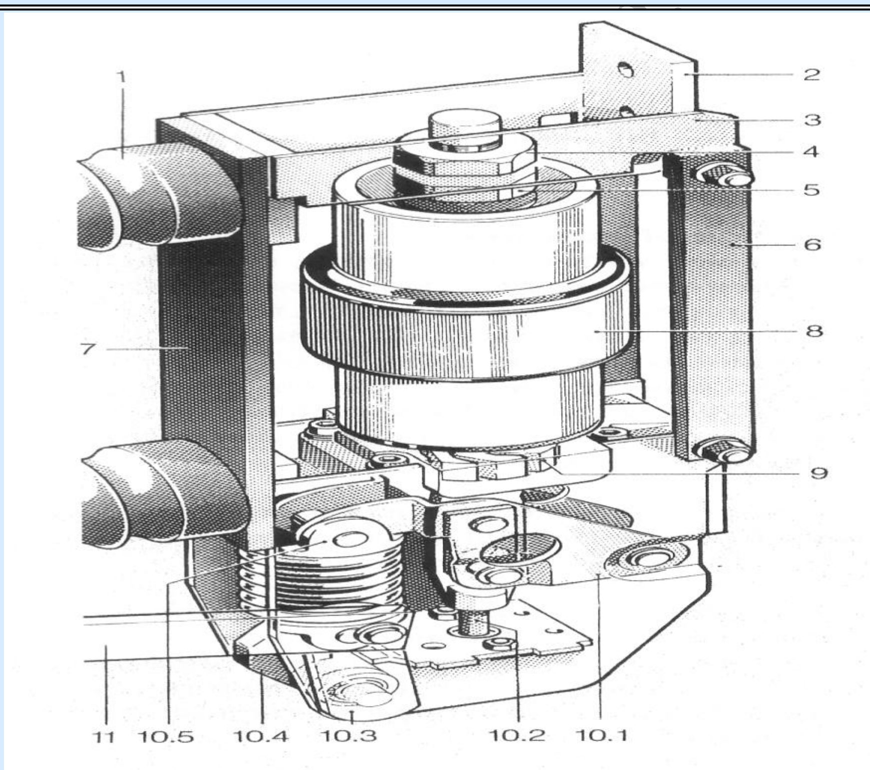
Figure 2.26 Construction of vacuum interruption chamber

Cylindrical ceramic insulators together with the vacuum space when the contacts are open provide insulation between the chamber outputs when the circuit breaker is in the opened position. To prevent metal steam condensation on the surface of the ceramic insulators, which causes damage to the electric strength of the insulators, a metal screen (Fig. 2.27) is used that "intercepts" and absorb metal steam formed during the switching. By doing this it prolongs the durability of the chamber (electrical endurance). The level of vacuum in the modern arc extinction chambers equals 10^{-7} -10^{-6} Pa, which provides the durability resources for the chambers for their entire term of use because the necessary insulation parameters of the vacuum space are reached at 10^{-3} Pa. Experience shows that during the process of switching, the level of vacuum slightly rises due to the condensed metal steam absorbing the residual gases.

Figure 2.27 Model of contact system AEC



1 - Vacuum Interrupter
2 - Terminal
3 - Flexible connection .
4 - Support insulators.
5 - Operating rod.
6 - Tie bar.
7 - Common operating shifts .
8 - operating corn .
9 - Locking cam.
10 - Making spring .
11 - Breaking spring.
12 - Loading spring.
13 - Main link.



1- cast resin post insulator 2- upper connection 3- upper contact support
4- 5- fastening nuts 6- Rear pull strap 7- Front pull strap
8- vacuum Switching chamber 9- contact Switch with toroidal contact
Lower contact support Consisting of :-
10.1 transmission lever 10.2 burn-off indicator 10.3 actuation crank
10.4 actuation lever 10.5 telescope rod with contact spring
11 hook stick

Fig. 2.28 Construction of the Switch pole type VA, VXC

2.4.4 Merits of Vacuum Circuit Breakers

The vacuum switchgear has been successfully developed and is gaining rapid popularity. The vacuum switches are likely to be popular for wide range of applications. These switches devices have several merits such as:

1. VCB is self contained and does not need filling of gas or oil. They do not need auxiliary air system, oil handling system, etc. No need for periodic refilling.
2. No emission of gases, pollution free.
3. Modest maintenance of the breaker, no maintenance of interrupters. Hence economical over long period.
4. Breakers form a unit which can be installed at any required orientation. Breaker unit is compact and self contained.
5. Non-explosive
6. Silent operation.
7. Large number of operation on load, or short circuit. Suitable for repeated duty.
8. Long life of the order of several hundred operations on rated normal current.
9. Constant dielectric. There are no gas decomposition products in vacuum and the hermetically sealed vacuum interrupter keeps out all environmental effect.
10. Constant contact resistance. In vacuum, the contacts cannot be oxidized, a fact which ensures that their very small resistance is maintained through their life.
11. High total current switched. Since contact piece erosion is small, rated normal interrupted current is up to 30.000 times; and rated short circuit breaking current is on the average of a hundred times.

The above reasons, together with the economic advantages offered, have boosted acceptance of the vacuum arc quenching principle.

2.4.5 Demerits of Vacuum Circuit Breakers

1. The vacuum interrupter is more expensive than the interrupter devices in other types of interrupters and its cost is affected by production volume. It is uneconomical to manufacturer vacuum interrupters in small quantities.
2. Rated voltage of single interrupter is limited until very recently to about $36\sqrt{3} = 20$ KV above 36 KV, two interrupters are required to be connected in series. This makes the breaker uneconomical for voltage rated above 36 KV.
3. Vacuum interrupters required high technology for production.
4. In the event of loss of vacuum, due to transient damage or failure, the entire interrupter is rendered useless. It cannot be required at site.
5. For interrupter low magnetizing currents, in certain range, additional surge suppressors are required in parallel with phase of a VCB.

2.5 Sulphur Hexafluoride (SF6) Circuit Breaker and SF6 Insulated Metal clad switchgear

2.5.1 Introduction

Sulpher hexafluoride (SF6) is an inert, heavy gas having good dielectric and arc extinguishing properties. The dielectric strength of the gas increases with pressure and is more than that of dielectric oil at pressure of 3 kgf/cm^2 . This gas is now being very widely used in electrical equipment like high voltage metal enclosed cables; high voltage metal clad switchgear, capacitors, circuit breakers, current transformers, bushings, etc. This gas liquefies at certain low temperatures, the liquefaction temperature increases with pressure. This gas is commercially manufactured in many countries and is now being extensively used by electrical industry in Europe, U.S.A. and Japan.

Several types of SF6 circuit breakers have been developed by various manufacturers in the world, for rated voltage from 3.6 to 760 KV. However, at present they are generally preferred for voltages above 72.5 KV.

SF6 gas insulated metal clad switchgear comprises factory assembled metal clad, substation equipment like circuit breakers, isolators, earthing switches, bus bars, etc. These are filled with SF6 gas. Such sub-stations are compact and are being favored in densely populated urban areas.

Sulphur hexafluoride gas is prepared by burning coarsely crushed roll sulphur in the fluorine gas, in a steel box, provided with staggered horizontal shelves, each bearing about 4 kg of sulphur. The steel box is made gas-tight. The gas thus obtained contains other fluoride such as S_2F_{10} , SF_4 and must be purified further. SF6 gas is generally supplied by chemical firms. The cost of gas is low if manufactured on a large scale.

The gas is transported in liquid from in cylinders. Before filling the gas, the circuit breaker is evacuated to the pressure of about 4 mm of mercury so as to remove the moisture and air. The gas is then filled in the circuit breaker. The gas can be reclaimed by the gas-handling unit.

There are two types of SF6 circuit breakers:

1. **Single pressure puffer type SF6 circuit**
   In which the entire circuit breaker is filled with SF6 gas at single pressure (4 to 6 kgf/cm^2). The pressure and gas flow, required for arc extinction, is obtained by piston action.
2. **Double pressure type SF6 circuit breaker**
   In which the gas from high pressure system is released into low pressure system over the arc during the arc quenching process. This type has been superseded by puffer type.

2.5.2 Properties of SF6 Gas

Sulphur hexafluoride (SF6) gas has good dielectric and arc extinguishing properties. The dielectric strength of the gas increases with pressure and is more than that of the dielectric oil at high pressures. SF6 is now very widely used in electrical equipments like high voltage metal enclosed cables, high voltage metal clad switchgear, capacitors, circuit breakers, current transformers, high voltage bushing, etc.

Sulphur hexafluoride gas is of low cost if manufactured on a large scale. It is transported in liquid from cylinders. Before filling the gas, the circuit breaker is evacuated to the pressure of about 4mm of mercury so as to remove the moisture and air. The gas is then filled in the C.B.

Physical properties of SF6 gas

- **Liquefaction of SF6 Gas**

The gas starts liquefying at certain low temperatures. The temperature of liquefaction depends on pressure. At 15 kgf/cm^2 the gas starts liquefying at *10* ° C . Hence this gas is not suitable for pressure above 15 kgf/cm^2

The temperature at which the SF6 gas changes to liquid state depends on the pressure. With higher pressure, the temperature increases. To avoid the liquefaction of SF6 gas. The temperature of SF6 should be maintained above certain value. For atmospheric pressure, SF6 gas starts liquefying at a temperature of about *10* ° C. Hence thermostatically controlled heaters are provided, which maintain the gas temperature above about *16* ° C in case of high pressure system.

- **Heat Transferability**

The heat transferability of SF6 gas is 2 to 2.5 times that of air at same pressure. Hence for the equal conductor size, the current carrying capacity is relatively more.

- **Enthalpy**

Heat content property at temperature below *6000* ° K is much higher than nitrogen. This assists cooling of arc space after current zero, due to continuous removal of heat from the contact space by the surrounding gas.

- **Low arc time constant**

The time constant of the medium is defined as "the time between current zero and the instant the conductance of contact space reaches zero value". Due to the electro negativity of SF6 gas the arc time constant of SF6 gas is very low and the rate of dielectric strength is high. Hence SF6 circuit breakers are suitable for switching condition. involving high rate of rise of TRV.

Chemical properties of SF6 Gas

1. Stable up to *500* ° C.
2. Inert. The chemical inertness of this gas is advantageous in switchgear. The life of metallic part, contacts is longer in SF6 gas. The components do not get oxidized or deteriorated. Hence the maintenance requirements are reduced. Moisture is very harmful to the properties of the gas. In the presence of moisture, hydrogen fluoride is formed during arcing which can attack the metallic and insulating parts in the circuit breaker.
3. Electronegative gas.
4. Does not react with structural material up to *500* ° C.
5. Products of decomposition. During arc extinction process SF6 is broken down to some extent intoSF_4, SF_2. The products of decomposition recombine upon cooling to form the original gas. The remainder is removed by filters containing activated alumina (AL_2O_3) Loss factor is small. The products of decomposition are toxic and attack certain structural materials.

6. The metallic fluorides are good dielectric materials hence are safe for electrical equipment.
7. Moisture content in the gas, due to influx from outside, present a various problems in SF6 circuit breakers. Several failures have been reported recently due to this cause.

<u>Dielectric properties of SF6 Gas</u>

1. Dielectric strength of SF6 gas atmospheric pressure is 2.35 times that of air, it is 30% less than of dielectric oil used in oil circuit breakers.
2. At higher pressure the dielectric strength of the gas increases. At pressure about 3 kgf/cm^2 the dielectric strength of SF6 gas is more than that of dielectric oil. This property permits smaller clearance and small size of equipments for the same KV.
3. The breakdown voltage in SF6 gas depends on several aspects such as electrode configuration, roughness of electrodes, distribution of electric field, vicinity of insulating supports, moisture, wave shape etc. Other parameters remaining constant, the breakdown voltage in SF6 increases with pressure. The gas follows paschen's law which states that "in uniformly distributed electric field, the breakdown voltage (V_b) in a gas is directly proportional to the product of gas pressure (p) and electrod gap (d)" $V_b \propto pd$
4. With the non uniform field, the breakdown voltage versus pressure curve does not follow the paschent's law strictly. The breakdown voltage increases with pressure. However after about 2.5 kgf/cm^2 it starts reducing and then rises again. The pressure at which the breakdown voltage starts reducing is called 'Critical pressure'. The dielectric strength at pressure between 2-3 kgf/cm^2 is high. Hence this pressure range preferred in SF6 insulated metal enclosed switchgear. However, in circuit breaker compartment, the pressure of the order of is kgf/cm^2 preferred for arc quenching process.
5. Rough electrode surface reduces the breakdown voltage with rough surface the ionization starts earlier near the sharp points on conductors. Hence conductor surfaces should be smooth
6. The conductors in SF6 insulating equipment are supported on epoxy or porcelain insulators. The flashover invariably takes place along the surface of the support insulators. The breakdown can occur at extremely low values if the insulators supports are covered by moisture and conducting dust. Hence the insulators should be extremely clean and should have anti-tracking properties.
7. The breakdown is initiated at sharp edges of conducting parts and parts having maximum stress concentration. The limiting value of breakdown stress is of the order of 20 P KV/cm for pure SF6 and P is pressure of gas in kgf/cm^2 . Good stress distribution is very important in SF6 insulated equipment.
8. The breakdown value depends on the wave-shape characterized by peak value, wave front, wave-tall, polarity in case of impulse wave. Voltage withstand value reduces with increase in steepness and increase in duration of the wave. Negative polarity is generally more severe than positive.

9. SF6 gas maintains high dielectric strength even when diluted by air (Nitrogen). 30% SF6 + 70 % of air, by volume, has a dielectric strength twice that of air (at the same pressure). Below 30% by volume, the dielectric strength reduces quickly.

2.5.3 Arc Extinction in SF6 Circuit Breaker

High voltage circuit breaker with SF6 gas as the insulation and quenching medium have been in use throughout the world for more than 30 years. This gas is particularly suitable because of its high dielectric strength and thermal conductivity.

The current interruption process in a high voltage circuit breaker is a complex matter due to simultaneous interaction of several phenomena. When the circuit breaker contacts separate, an electric arc will be established, and current will continue to flow through the arc. Interruption will take place at an instant when the alternating current reaches zero.

When a circuit breaker is tripped in order to interrupt a short circuit current, the contact parting can start anywhere in the current loop. After the contacts have parted mechanically, the current will flow between the contacts through an electric arc, which consists of a core of extremely hot gas with a temperature of 5,000 to 20.000 K. This column of gas is fully ionized (plasma) and has an electrical conductivity comparable to that of carbon. When the current approaches zero, the arc diameter will decrease. with the cross section approximately proportional to the current. In the vicinity of zero passage of current, the gas has been cooled down to around 2.000 K and will no longer be ionized plasma, nor will it be electrically conducting.

Two physical requirements (regimes) are involved:

- Thermal regime: The hot arc channel has to be cooled down to a temperature low enough that it ceases to be electrically conducting.
- Dielectric regime: After the arc extinction, the insulating medium between the contacts must withstand the rapidly increasing recovery voltage. This recovery voltage has a transient component (transient recovery voltage, TRV) caused by the system when current is interrupted.

If either of these two requirements is not met, the current will continue to flow for another half cycle, until the next current zero is reached. It is quite normal for a circuit breaker to interrupt the short circuit current at the second or even third current zero after contact separation.

Thermal regime

The thermal regime is especially critical at short line fault interruption. The circuit parameters directly affecting this regime are the rate of decrease of the current to be interrupted (di/dt) and the initial rate of rise of the transient recovery voltage (dv/dt) immediately after current zero. The higher the values of either of these two parameters, the more severe the interruption is. A high value of (di/dt) results a hot arc with a large amount of stored energy at current zero, which makes interruption more difficult. High values of (dv/dt) will result in an increase of the energy to the post arc current.

These exists certain inertia in the electrical conductivity of the arc. When the current approaches zero, these is still a certain amount of electrical conductivity left in the arc path. This gives rise to what is called a "post-arc current". With amplitude up to a few A.

Whether or not interruption is going to by successful is determined by a race between the cooling effect and the energy input in the arc path by the transient recovery voltage. When the scales of the energy balance tip in favor of the energy input the circuit breaker will fail thermally. The thermal interruption regime for SF6 circuit breakers corresponds to the period of time starting some µs before current zero, until extinguishing of the post arc current, a few µs after current zero.

Dielectric regime

When the circuit breaker has successfully passed the thermal regime, the transient recovery voltage (TRV) between the contacts rises rapidly and will reach a high value. For example, in a single unit 245 KV circuit breaker, the contact gap may be stressed by 400 KV or more 70 to 200 µs after the current zero.

In the dielectric regime the extinguishing/ isolating medium is longer electrically conducting, but it still has a much higher temperature than the ambient. This reduces the voltage withstand capacity of the contact gap. The stress on the circuit breaker depends on the rate of rise and the amplitude of the TRV.

The withstand capability of the contact gap must always higher than the transient recovery voltage otherwise a dielectric re-ignition will occur (dielectric failure). This requires an extremely high dielectric withstand capability of the gas, which is still rather hot and therefore has low density.

The arc extinction process, in SF6 CB, is different from that in air blast CB. During the arcing period, SF6 gas is blown axially along the arc. The gas removes from the arc by axial convection and radial dissipation. As a result, the arc diameter reduces during the decreasing mode of the current wave. The diameter becomes small during current zero and the arc is extinguished.

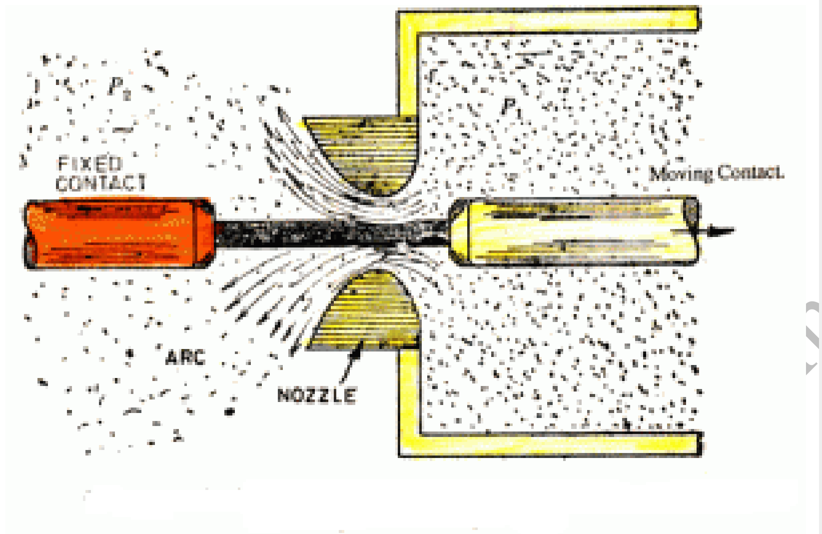
Due to its electro negativity and low arc time constant, the SF6 gas regains its dielectric strength rapidly after the final current zero, the rate of rise of dielectric strength is very high and the time constant is very small.

The arc extinguishing properties of SF6 gas was pointed out in 1953. The research pointed out that SF6 is a remarkable medium for arc extinction. The arc extinguishing properties are improved by moderate rates of forced gas flow through the arc space.

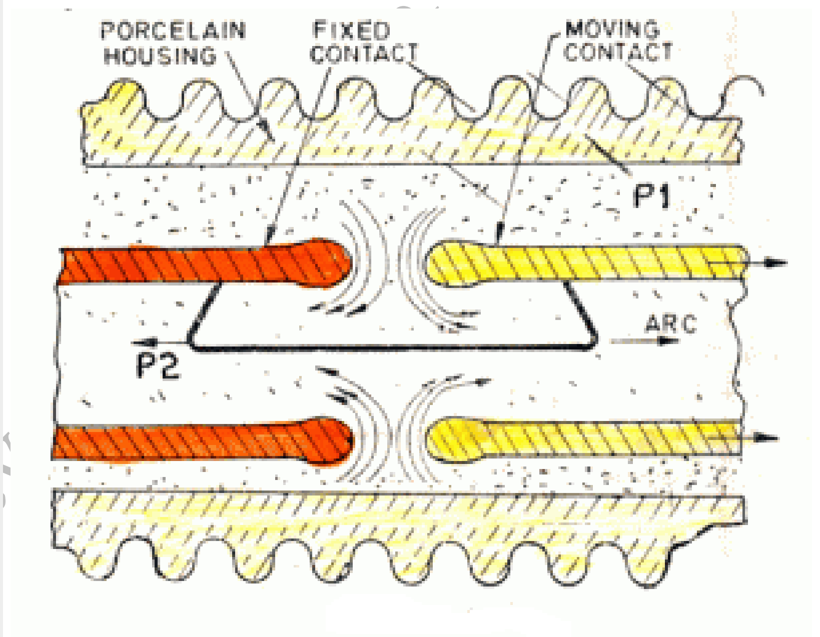
Plain break contacts drawn apart, (AC arcs), in SF6 can interrupt about 100 times more current than in air at given voltage.

The basic requirement in arc extinction is not primarily the dielectric strength, but high rate of recovery of dielectric strength. In SF6 gas, the electrons get attached with molecules to become ions. Thereby, the dielectric strength is quickly regained. Problems connected with current chopping are therefore minimized.

In SF6 CB, The gas is made to flow from a high pressure zone to a low pressure zone through a convergent-divergent nozzle. The mass flow is a function of the nozzle-throat diameter, the pressure ratio, and the time of flow. The nozzle is located such that the flow of gas covers the arc. The gas flow attains almost supersonic speed in the divergent portion of the nozzle. Thereby the gas takes away the heat from the periphery of the arc, causing reduction in the diameter of the arc. Finally, the arc diameter becomes almost zero at current zero and the arc is extinguished. The arc space is filled with fresh SF6gas and the dielectric strength of the contact space is rapidly recovered due to the electro-negativity of the gas. The single flow pattern (Fig. 2.29a) and double flow pattern (Fig. 2.29b) are used for arc extinguishing in single-pressure puffer type and double-pressure type SF6 circuit breakers.



(a) Single axial flow pattern



(b) Double axial flow pattern

Figure 2.29 Arc extinction in gas flow circuit breakers (Gas flows from high pressure to low pressure)

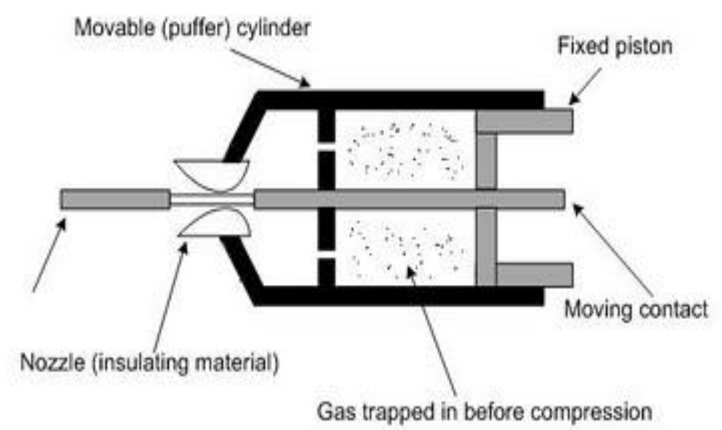
<u>Single pressure puffer type circuit breaker, with single flow quenching medium</u>

- When breaker is fully closed, the pressure in the puffer cylinder is equal to that outside the cylinder.
- During opening stroke, puffer cylinder and moving contact tube start moving.

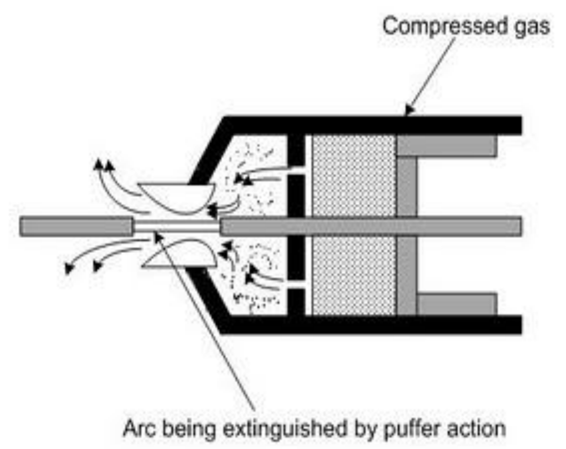
- Gas gets compressed within puffer cylinder.
- After a certain travel, contact separates and arc is drawn.
- However, compressed gas flows from higher pressure to lower pressure through the nozzle.

2.5.4 Single Pressure Puffer Type SF6 Circuit Breaker

This type of circuit breakers employs the principle of puffer action, illustrated above. Figure 2.30(a) illustrates the fully closed position of the cylinder.



(a)



(b)

Figure 2.30 Puffer action principles

- The moving cylinder is coupled with the movable conductor against the fixed piston, and there is a relative movement between the moving cylinder and the fixed piston.

- The gas is compressed in the cavity.
- This trapped gas is released through the nozzle, during arc extinction process.
- During the travel, of the moving contact and the movable cylinder, the gas puffs over the arc and reduces the arc diameter by axial convection and radial dissipation.
- At current zero, the arc diameter becomes too small and the arc gets extinguished
- The puffing action continues for some time, even after the arc extinction, and the contact space is filled with cool, fresh gas.

Figure 2.31 illustrates the configuration of a 245 KV/420 KV single-pressure SF6 circuit breaker. The two interrupters are mounted on the hollow support insulators. The operation mechanism, installed at the base of the insulators, is linked with the movable contact in the interrupter, by means of insulating operating rod and a link mechanism.

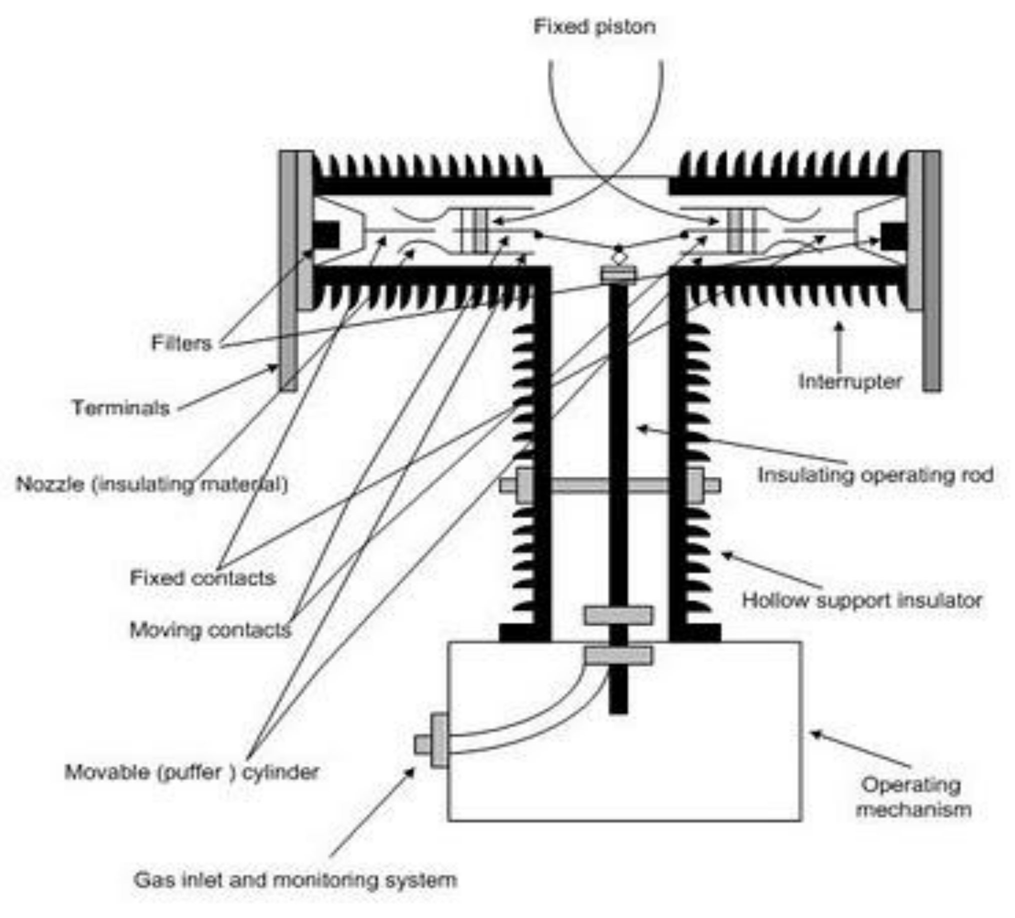


Figure 2.31 One pole of 245 KV puffer type SF6 circuit breaker

The circuit breaker is filled with SF6 gas at a pressure of about 5 kgf/cm^2. During the opening operation, the operating rod is pulled downwards by the operating mechanism. The link mechanism converts the vertical motion into horizontal motion. The contact and the movable cylinder, in the interrupter, are moved against the fixed position.

Break-time up to 3 cycles can be achieved by puffer principle described above. For achieving 2 cycle break-time, differential position is used, in which the puffer cylinder and piston move in opposite directions, thus reducing total stroke and time of travel.

2.5.5 Merits of SF6 Circuit Breaker

1. Outdoor EHV SF6 CB has less number of interrupters per pole than ABCB and MOCB. It is simple, less costly, maintenance free compact.
2. The gas is non-inflammable and chemically stable. The decomposition product is not explosive. Hence there is no danger of fire or explosions.
3. Same gas is re-circulated in the circuit. Hence requirement of SF6 gas is small in the long run. No replacement is required for at least five years.
4. Ample overload margin. For the same size of conductors, the current carrying ability of SF6 CB is about 1.5 times that of ABCB because of superior heat transferability of SF6 gas.
5. The breaker is silent and does not sound, like ABCB, during operation.
6. The sealed construction avoids the contamination by moisture, dust, sand, etc.
7. No cost for compressed air system as in ABCB.
8. Maintenance required is minimum. The breaker may need maintenance once in four to ten years.
9. Ability to interrupt low and high fault currents, magnetizing currents, capacitive currents, without excessive over voltage. Sf6 gas CB can perform the various duties like clearing short line faults, opening unloaded transmission lines, capacitor switching, transformers, reactor switching. etc. much smoothly
10. Excellent insulating, arc extinguishing, physical and chemical properties of SF6 gas is the greatest advantages of SF6 breakers.
11. No frequent contact replacement. Contact corrosion is very small due to inertness of SF6 gas. Hence, contacts do not suffer oxidation.
12. No over voltage problems. Due to particular properties of SF6 gas, the arc is extinguished at natural current zero without current chopping and associated over voltage originating in circuit breakers
13. Simplicity of the interrupter chamber which does not need an auxiliary chamber for breaking.
14. Autonomy provided by the puffer technique.
15. The possibility to obtain the highest performances, up to 36 KA, with a reduced number of interrupting chambers.
16. Short break time of 2 to 2.5 cycles.
17. High electrical endurance, allowing at least 25 years of operation without reconditioning.
18. Possible compact solutions when used for GIS or hybrid switchgear.
19. Integrated closing resistors or synchronized operations to reduce switching over voltages.
20. Reliability and availability.
21. Low noise level.

2.5.6 Some Demerits of SF6 Circuit Breaker

1. Sealing problems arise due to the type of construction used. Special materials are necessary in construction. Imperfect joints lead to leakage of gas.
2. Arced SF6 gas is poisonous and should not be inhaled or let-out.
3. Influx of moisture in the system is very dangerous to SF6 gas circuit breakers.
4. The double pressure SF6 CB is relatively costly.
5. The internal parts should be cleaned thoroughly during periodic maintenance, under clean, dry environment.
6. Special facilities are needed for transporting the gas, transferring the gas, and maintaining the quality of the gas. The deterioration of quality of the gas affects the reliability of the SF6 circuit breaker.

Summary of Merits of SF6 GIS

Safe	Operating personnel are protected by the earthed metal enclosures
Reliable	The complete enclosure of all live parts guards against any Impairment of the insulation system.
Space saving	SF6 Switchgear installations take up only 1/10 of the space Required for conventional installations.
Economical	High flexibility and application versatility provide novel, and economic overall concepts.
Maintenance free	An extremely careful selection of materials. an expedient design and a high standard of manufacturing quality assure Long service life with practically no maintenance requirement.
Low weight	Low weight due to aluminum enclosure, correspondingly Low cost foundations and buildings.
Shop assembled	Quick site assembly ensured by extensive preassembly and Testing of complete feeders or large units in the factory.

SF6 Gas Insulated Switchgear (GIs)

Types of Bays SF6 Gas Insulated Switchgear.
1 – Feeder Bay. خلية مغذى
2 – Transformer Bay. خلية محول
3 – Bus section Bay. طولى خلية رابط قضبان
4 – Bus coupler Bay. عرضى خلية رابط قضبان

Component of SF6 Gas Insulated Feeder bay

1 – High Speed Earth Switche (Line Earth Switch). مغذى سكينة تأريض
2 – Isolator for Voltage Transformer. محول جهد سكينة
3 – Voltage Transformer. محول جهد
4 – Line Isolator. (Disconnector Switch) سكينة عزل المغذى
5 – Maintenance Earth Switches. سكينة تأريض
6 – CT's For Bus-Bar protection. محول تيار لحماية البسبار
7 – Circuit Breaker. قاطع الدائرة
8 – CT's For Line protection and metering. القياس محول تيار المغذى و أجهزة
9 – Maintenance Earth Switches. سكينة تأريض
10 – Bus-Bar Isolator سكينة عزل البسبار

Component of SF6 Gas Insulated Transformer bay

1 – Bus-Bar Isolator. (Disconnector Switch) سكينة عزل قضيب التوزيع
2 – Maintenance Earth Switches. تأريض سكينة
3 – CT's For Transformer protection. لأجهزة وقاية المحول محول تيار
4 – Circuit Breaker. قاطع الدائرة
5 – CT's for Bus-Bar protection and metering. محول تيار لحماية البسبار و أجهزة القياس
6 – Maintenance Earth Switches. سكينة تأريض
7 – Transformer Isolator. المحول سكينة عزل
8 – Maintenance Earth Switches. (Transformer E.S) سكينة تأريض المحول

Component of SF6 Gas Insulated Bus section bay

1 – Bus-Bar Isolator. (Disconnector Switch) سكينة عزل البسبار
2 – Maintenance Earth Switches. سكينة تأريض
3 – CT's For Bus-Bar protection and metering. محول تيار لحماية البسبار و أجهزة القياس
4 – Circuit Breaker. قاطع الدائرة
5 – Maintenance Earth Switches. تأريض سكينة

Component of SF6 Gas Insulated Bus coupler bay

1 – Bus-Bar Isolator. (Disconnector Switch) سكينة عزل البسبار
2 – Maintenance Earth Switches. تأريض سكينة
3 – CT's For Bus-Bar protection and metering. محول تيار لحماية البسبار و أجهزة القياس
4 – Circuit Breaker. قاطع الدائرة
6 – Maintenance Earth Switches. سكينة تأريض
7 – Bus-Bar Isolator. سكينة عزل البسبار

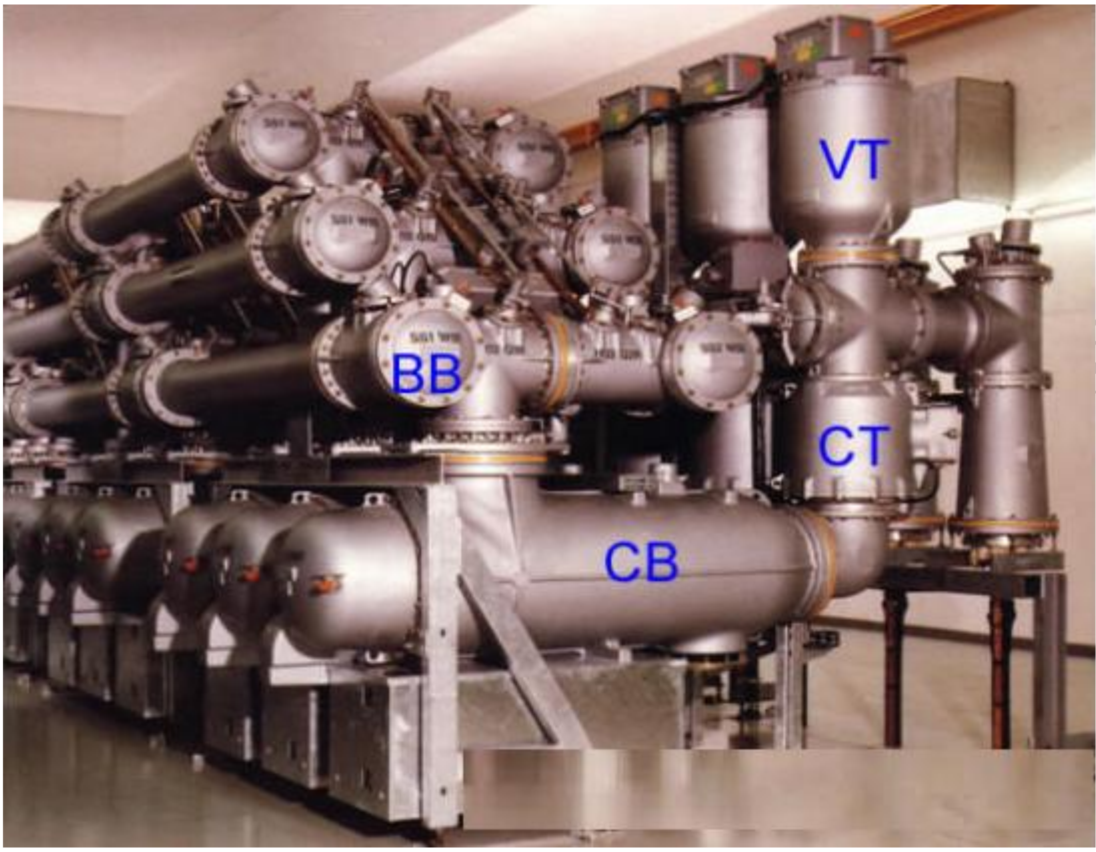


Fig. 2.32 High voltage Gas Insulated Switch gear - Type Double Bus-Bar

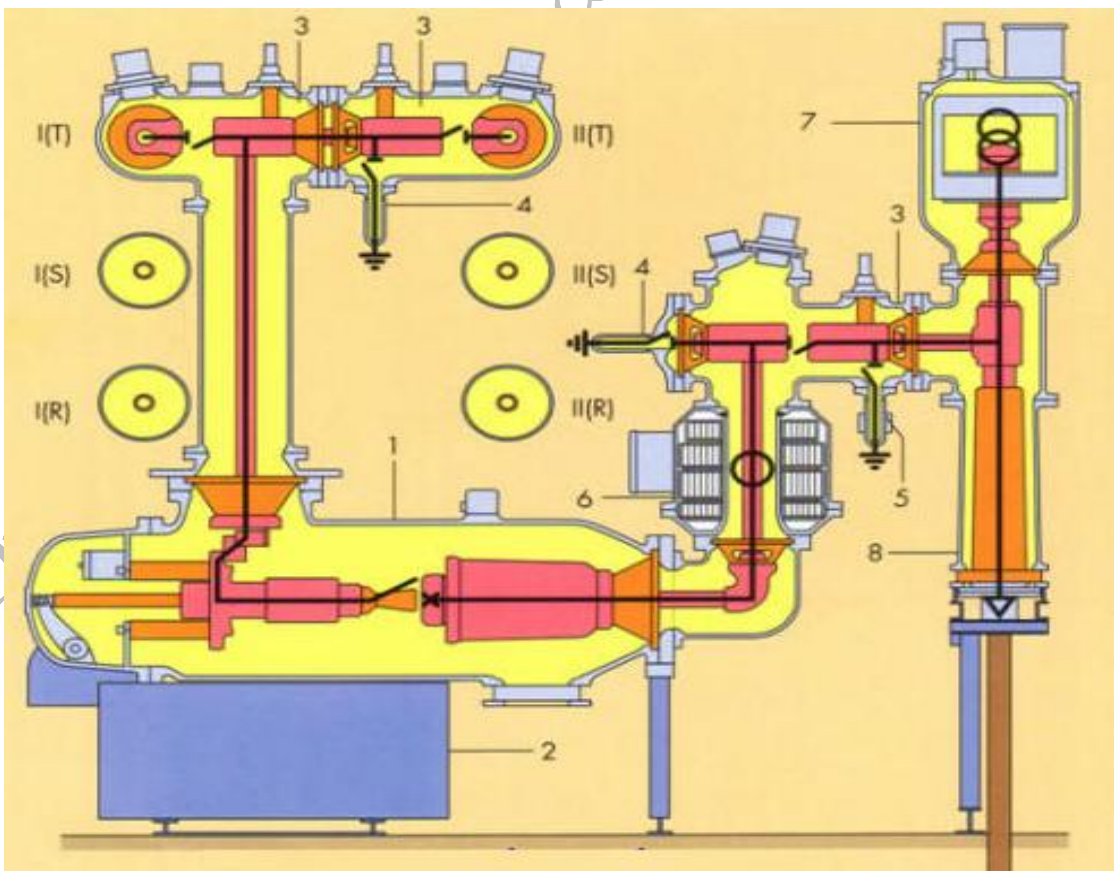


Fig. 2.33 Single line diagram High voltage Gas Insulated Switch gear - Type Double Bus-Bar

1 – Circuit Breaker.
2 – Spring Mechanism.
3 – Disconnected.
4 – Slow Earthing Switch
5 – Make Proof Earthing Switch.
6 – Current Transformer.
7 – Voltage Transformer.
8 – HV cable connection.

The various modules of GIS are factory assembled and are filled with SF6 gas at a pressure of about 3 kg/cm^2. Thereafter, they a taken to site for final assembly. Such substations are compact and can be installed conveniently on any floor of a multi-storied building or in an underground substation.

As the units are factory assembled, the installation time is substantially reduced. Such installations are preferred in cosmopolitan cities, industrial townships, etc., where cost of land is very high and higher cost of SF6 insulated Switchgear (GIs) is justified by saving due to reduction in floor area requirement.

They are also preferred in heavily polluted areas where dust, chemical fumes and salt layers can cause frequent flashovers in conventional outdoor air-insulated substations

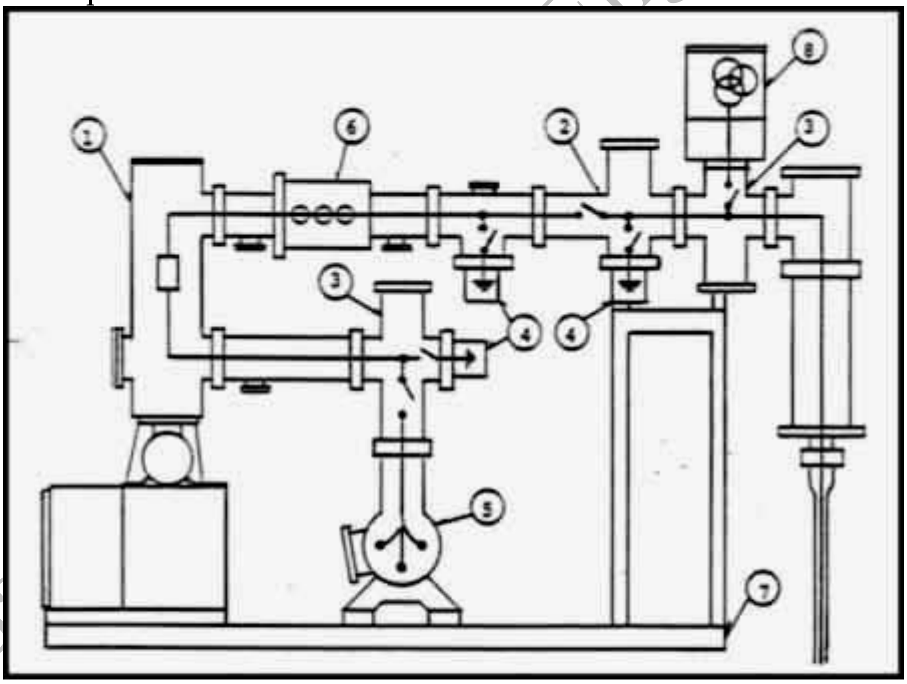


Fig. 2.34 GIS bay single Bus-Bar

1- Circuit Breaker
2- Disconnector Switch (GL-Type)
3- Disconnector Switch (GR-Type)
4- Earthing Switch (GRE-Type)
5- 3-ph. Bus-Bar.
6- Current Transformer.
7- Base.
8- Voltage Transformer.

The SF6 Gas Insulated Substations (GIs) contains the same Components as in the conventional outdoor substations. All the live parts are enclosed in metal housings filled with SF6 gas. The live parts and supported on at resin insulators.
Some of the insulators are designed as barriers between neighboring modules such that the gas does not pass through them.
The entire installation is sub-divided into compartments which are gas tight with respect to each other. Thereby the gas monitoring system of each compartment can be independent and simpler.
The enclosures are of non-magnetic material such as aluminum or stainless steel and are earthed. Static O-seals placed between machined flanges provide the gas tightness. The O-rings are placed in the grooves' such that after assembly, the O-rings are squeezed by about 20 %. Quality of material and dimension of grooves and O-seals are important to ensure gas-tight performance.
The GIs has gas-monitoring system. The gas density in each compartment is monitored. If pressure drops slightly, the gas is automatically tapped up with further gas leakage, the low-pressure alarm is sounded or automatic tripping or lock-out occurs

Advantages of GIs and Application Aspects:

- **1- Compactness.**

The space occupied by SF6 installation is only about 8 to 10 % of that a conventional outdoor
substation. High cost is partly compensated by saving in cost of space. A typical 420/525 kV SF6 GIs
requires only 920 m^2 site area against 30.000 m^2 for a conventional air insulated substation.

- **2 - Choice of Mounting Site.**

Modular SF6 GIS can be tailor made to Suit the particular site requirements.
This results is saving of otherwise Expensive civil-foundation work. SF6 GIS can be suitably mounted indoor
on any floor or basement and SF6 Insulated Cables (GIC) can be taken through walls and terminated
through SF6 bushing or power cables.

- **3 - Reduced Installation Time.**

The principle of building block construction (modular construction) reduces the installation time to a few weeks. Each conventional substation requires several months for installation.
In SF6 substations, the time-consuming high cost galvanized steel structures are eliminated. Heavy foundations for galvanized steel structures,
Equipment support structures etc are eliminated. This results in economy and reduced project execution time. Modules are factory assembled, tested and dispatched with nominal SF6 gas. Site erection time is reduced to final assembly of modules.

- **4 - Protection from pollution.**

The external moisture. Atmospheric Pollution, snow dust etc. have little influence on SF6 insulated substation. However, to facilitate installation and maintenance, the substations are generally housed inside a small building.

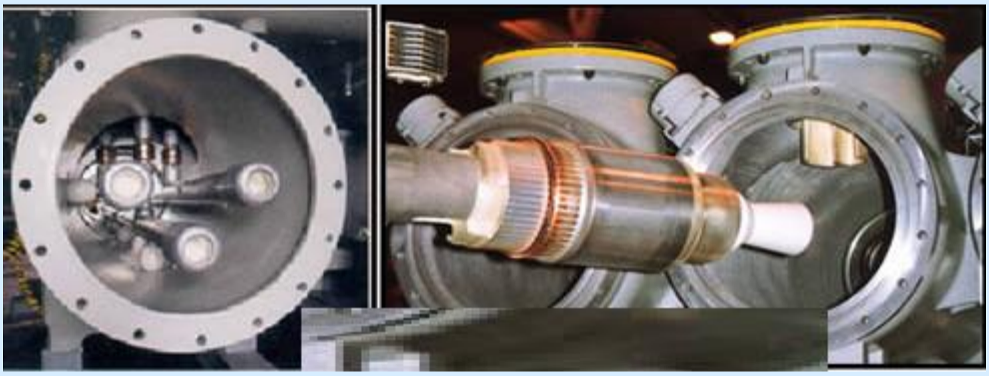
5- Increased Safety.

As the enclosures are at earth potential there is no possibility of accidental contact by service personnel to live parts.

6 - Explosion-proof and Fire-proof installation.

Oil Circuit Breakers and oil filled equipment are prone to explosion. SF6 breakers and SF6 filled equipment are explosion proof and fire-proof..

Alternatives of Enclosures, Single three phase and three single enclosures



Three phase Single Enclosures	Three phase and three single enclosures

The following alternatives are available to the designers for configuration of GIs.

1. Separate enclosure for each phase. This alternative was used for Components and Bus-Bars in early GIs. Now it is used only for EHV and UHV, GIS. The GIS above 420 kV are generally with separate enclosure for each phase.
2. Separate enclosure for components and a common single enclosure For three phase enclosure for Bus-Bars. This alternative is more widely used now for all GIS
3. Common single enclosure for all three phases for components and For Bus-Bars. The per cent trend is to use single three phase modules for Components and Bus-Bars for all GIS. The GIS developed during 1980’s are with this philosophy.

MCB (Miniature Circuit Breaker) — rated current not more than 100 A. Trip characteristics normally not adjustable. Thermal or thermal-magnetic operation.

MCCB (Molded Case Circuit Breaker)—rated current up to 1000 A. Thermal or thermal-magnetic operation. Trip current may be adjustable.

Air circuit breaker—Rated current up to 10,000 A. Trip characteristics often fully adjustable including configurable trip thresholds and delays. Usually electronically controlled, though some models are microprocessor controlled. Often used for main power distribution in large industrial plant, where the breakers are arranged in draw-out enclosures for ease of maintenance.

Vacuum circuit breaker — with rated current up to 3000 A, these breakers interrupts the current by creating and extinguishing the arc in a vacuum container. These can only be practically applied for voltages up to about 35,000 V, which corresponds roughly to the medium-voltage range of power systems. Vacuum circuit breakers tend to have longer life expectancies between overhaul than do air circuit breakers.

Sulfur hexafluoride -High-voltage circuit-breakers have greatly changed since they were first introduced about 40 years ago, and several interrupting principles have been developed that have contributed successively to a large reduction of the operating energy. These breakers are available for indoor or outdoor applications, the latter being in the form of breaker poles housed in ceramic insulators mounted on a structure. Current interruption in a high-voltage circuit-breaker is obtained by separating two contacts in a medium, such as SF6, having excellent dielectric and arc quenching properties. After contact separation, current is carried through an arc and is interrupted when this arc is cooled by a gas blast of sufficient intensity.