UNIT V

CIRCUIT BREAKERS

5.1 **Rating of Circuit Breaker**

The **rating of a circuit breaker** includes,

1) Rated short circuit breaking current.
2) Rated short circuit making current.
3) Rated operating sequence of circuit breaker.
4) Rated short time current.

Short circuit breaking current of circuit breaker

This is the maximum short circuit current which a circuit breaker can withstand before it. Finally cleared by opening its contacts. When a short circuit flows through a circuit breaker, there would be thermal and mechanical stresses in the current carrying parts of the breaker. If the contact area and cross-section of the conducting parts of the circuit breaker are not sufficiently large, there may be a chance of permanent damage in insulation as well as conducting parts of the CB. The short circuit current has a certain value at the instant of contact separation. The breaking current refers to value of current at the instant of the contact separation. The rated values of transient recovery voltage are specified for various rated voltage of circuit breakers. For specified conditions of rated TRV and rated power frequency recovery voltage, a circuit breaker has a certain limit of breaking current. This limit is determined by conducting short circuit type tests on the circuit breaker. The waveforms of short circuit current are obtained during the breaking test. The evaluation of the breaking current is explained in Fig. 3. The breaking current is expressed by two values. The r.m.s values of a.c. components are expressed in KA. the standard values being 8, 10, 12.5, 16, 20, 25, 31.5, 40, 45, 63, 80 and 100KA. The earlier practice was to express the rated breaking capacity of a circuit breaker in terms of MVA given as follows Rated Breaking MVA capacity = $\sqrt{3}$ x KV x KA Where MVA = Breaking capacity of a circuit breaker kV KV = Rated voltage KA = Rated breaking current.

This practice of specifying the breaking capacity in terms of MVA is convenient while calculating the fault levels. However, as per the revised standards, the breaking capacity is expressed in KA for specified conditions of TRV and this method takes into account both breaking current and TRV. The breaking capacity can be both symmetrical and asymmetrical in nature. In asymmetrical breaking capacity the DC component of the current is added. While selecting the circuit breaker for a particular location in the power system the fault level at that location is determined. The rated breaking current can then be selected from standard range.

Rated short circuit making capacity

The short circuit making capacity of circuit breaker is expressed in peak value not in rms value like breaking capacity.It may so happen that circuit breaker may close on an existing fault. In such cases the current increase to the maximum value at the peak of first current loop. The circuit breaker should be able to close without hesitation as contact touch. The circuit breaker should be able to withstand the high mechanical forces during such a closure. These capabilities are proved by carrying out making current test. The rated short circuit making current of a circuit breaker is the peak value of first current loop of short circuit current (I pk)Which the circuit breaker is capable of making at its rated voltage. The rated short circuit making current should be least 2.5 times the r.m.s. value of a.c. component of rated breaking current . Rated making current = 1.8 x √2 x Rated short circuit breaking = 2.5 x Rated short circuit breaking current In the above equation the factor √2 convert the r.m.s value to peak value. Factor 1.8 takes into account the doubling effect of short circuit current with consideration to slight drop in current during the first quarter cycle .

Rated operating sequence or duty cycle of circuit breaker

This is mechanical duty requirement of circuit breaker operating mechanism. The sequence of rated operating duty of a circuit breaker has been specified as O – t – CO – t" – CO Where O indicates opening operation of the CB. CO represents closing operation immediately followed by an opening operation without any intentional time delay. t" is time between two operations which is necessary to restore the initial conditions and / or to prevent undue heating of conducting parts of circuit breaker. t = 0.3 sec for circuit breaker intended for first auto re closing duty, if not otherwise specified. Suppose rated duty circle of a circuit breaker is 0 – 0.3 sec – CO – 3 min – CO. This means, an opening operation of circuit breaker is followed by a closing operation after a time interval of 0.3 sec, then the circuit breaker again opens without any intentional time delay. After this opening operation the CB is again closed after 3 minutes and then instantly trips without any intentional time delay.

Rated short time current

This is the current limit which a circuit breaker can carry safely for certain specific time without any damage.

The circuit breakers do not clear the short circuit current as soon as any fault occurs in the system. There always some intentional and an intentional time delays present between the instant of occurrence of fault and instant of clearing the fault by CB. This delay is present because of time of operation of protection relays, time of operation of circuit breaker and also there may be some intentional time delay imposed in relay for proper coordination of power system protection. Hence, after fault, a circuit breaker has to carry the short circuit for certain time. The summation of all time delays should not be more than 3 seconds, hence a circuit breaker should be capable of carrying a maximum fault current for at least this short period of time. The short circuit current may have two major affects inside a circuit breaker.

1. Because of the high electric current, there may be high thermal stress in the insulation and conducting parts of CB.

2. The high short circuit current, produces significant mechanical stresses in differentcurrent carrying parts of the circuit breaker.

A circuit breaker is designed to withstand these stresses. But no circuit breaker has to carry a short circuit current not more than a short period depending upon the coordination of protection. So it is sufficient to make CB capable of withstanding affects of short circuit current for a specified short period.

The rated short time current of a circuit breaker is at least equal to rated short circuit breaking current of the circuit breaker.

Rated voltage of circuit breaker

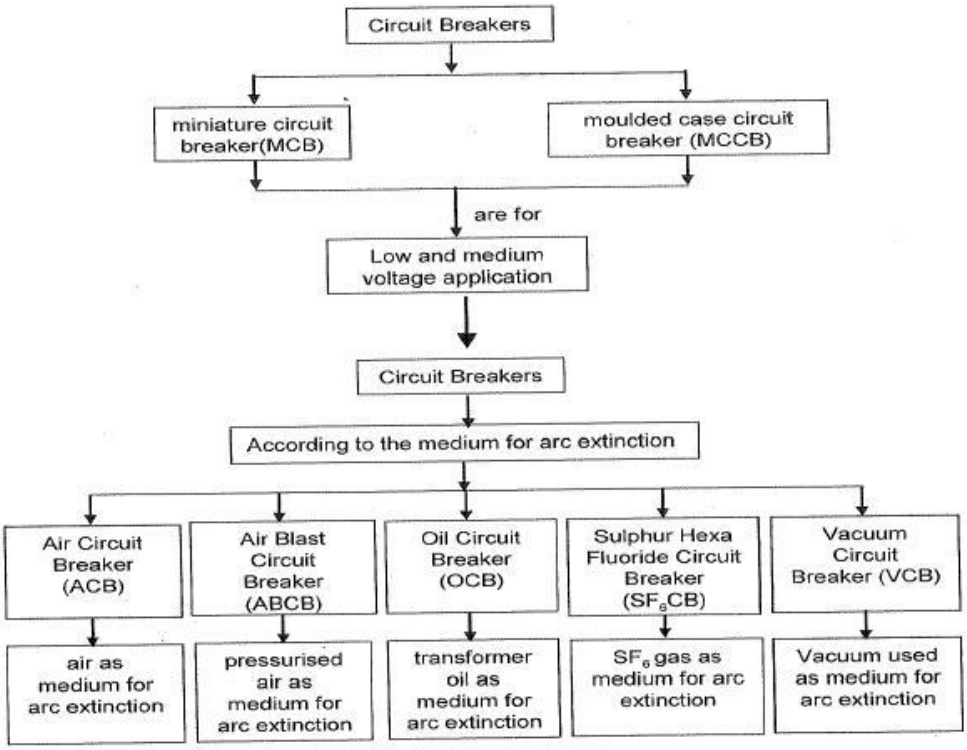
Rated voltage of circuit breaker depends upon its insulation system. For below 400 KV system, the circuit breaker is designed to withstand 10% above the normal system voltage. For above or equal 400 KV system the insulation of circuit breaker should be capable of withstanding 5% above the normal system voltage. That means, rated voltage of circuit breaker corresponds to the highest system voltage. This is because during no load or small load condition the voltage level of power system is allowed rise up to highest voltage rating of the system. A circuit breaker is also subject to two other high voltage condition.

1) Sudden disconnection of huge load for any other cause, the voltage imposed on the CB and also between the contacts when the CB is open, may be very high compared to higher system voltage. This voltage may be of power frequency but does not stay for very long period as this high voltage situation must be cleared by protective switchgear. But a circuit breaker may have to withstand this power frequency over voltage, during its normal life span.

The Circuit Breaker must be rated for power frequencies withstand voltage for a specific time only. Generally the time is 60 seconds. Making power frequency withstand capacity, more than 60 second is not economical and not practically desired as all the abnormal situations of electrical power system are definitely cleared within much smaller period than 60 seconds.

2) Like other apparatuses connected to power system, a circuit breaker may have also to face lightening impulse and switching impulses during its life span.

The insulation system of CB has to withstand these impulse voltage waveform. So a circuit breaker is designed to withstand this impulse peaky voltage for microsecond range only.



5.2 Air blast circuit breaker

This type of circuit breakers, is those kind of circuit breaker which operates in air at atmospheric pressure. After development of oil circuit breaker, the medium voltage air circuit breaker (ACB) is replaced completely by oil circuit breaker in different countries. But in countries like France and Italy, ACBs are still preferable choice up to voltage 15 KV. It is also good choice to avoid the risk of oil fire, in case of oil circuit breaker. In America ACBs were exclusively used for the system up to 15 KV until the development of new vacuum and SF6 circuit breakers.

Working principle of air circuit breaker(ACB)

The working principle of this breaker is rather different from those in any other types of circuit breakers. The main aim of all kind of circuit breaker is to prevent the reestablishment of arcing after current zero by creating a situation where in the contact gap will withstand the system recovery voltage. The air circuit breaker does the same but in different manner. For interrupting arc it creates an arc voltage in excess of the supply voltage. Arc voltage is defined as the minimum voltage required maintaining the arc. This circuit breaker increases the arc voltage by mainly three different ways,

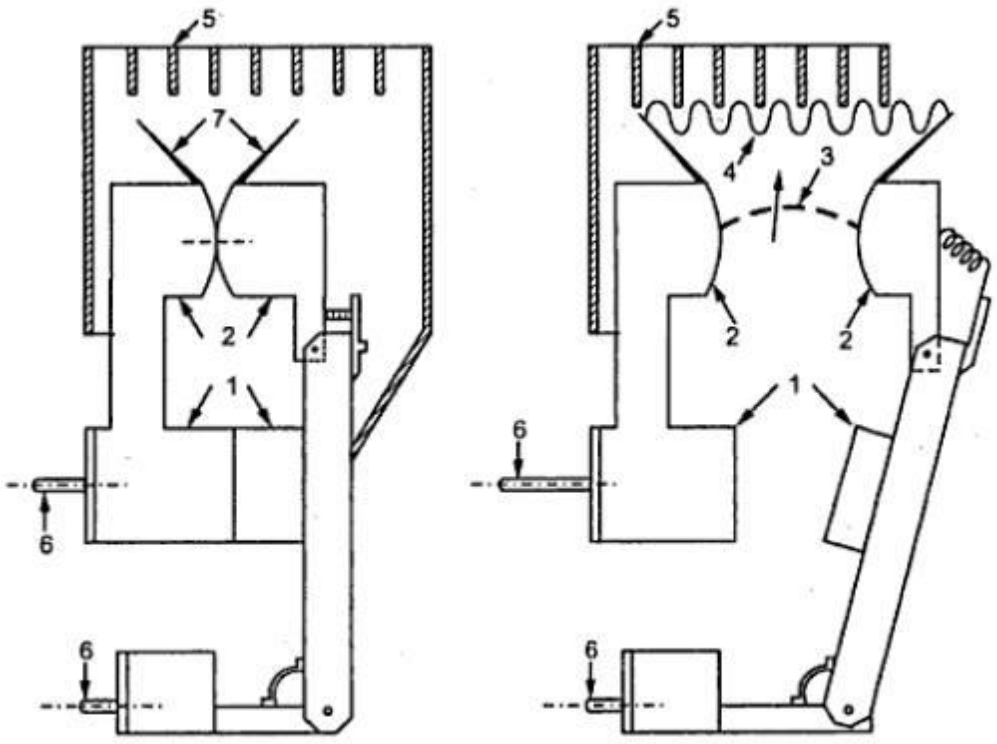
1. It may increase the arc voltage by cooling the arc plasma. As the temperature of arc plasma is decreased, the mobility of the particle in arc plasma is reduced, hence more voltage gradient is required to maintain the arc.

2. It may increase the arc voltage by lengthening the arc path. As the length of arc path is increased, the resistance of the path is increased, and hence to maintain the same arc current more voltage is required to be applied across the arc path. That means arc voltage is increased.
3. Splitting up the arc into a number of series arcs also increases the arc voltage.

The *first objective* is usually achieved by forcing the arc into contact with as large an area as possible of insulating material. Every air circuit breaker is fitted with a chamber surrounding the contact. This chamber is called „arc chute". The arc is driven into it. If inside of the arc chute is suitably shaped, and if the arc can conform to the shape, the arc chute wall will help to achieve cooling. This type of arc chute should be made from some kind of refractory material

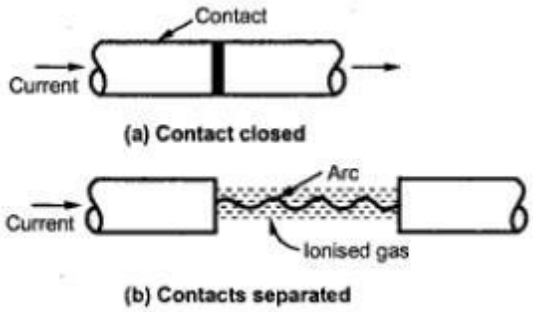
The *second objective* that is lengthening the arc path is achieved concurrently with the first objective. If the inner walls of the arc chute is shaped in such a way that the arc is not only forced into close proximity with it but also driven into a serpentine channel projected on the arc chute wall. The lengthening of the arc path increases the arc resistance.

The *third objective* is achieved by using metal arc slitter inside the arc chute. The main arc chute is divided into numbers of small compartments by using metallic separation plates. These metallic separation plates are actually the arc splitters and each of the small compartments behaves as individual mini arc chute. In this system the initial arc is split into a number of series arcs, each of which will have its own mini arc chute.



(I) Contact closed (II) Contacts open

1. Main contacts 4. Arcsplitterplates
2. Arcing contacts 5.Current carrying terminals
3. Arc rifling in the direction of the arrow 6. Arc runners Arc getting split



In the air reservoir there is a high pressure air stored between 20 to 30 kg/cm2. And that air is taken from compressed air system. On the reservoir there are three hollow insulator columns mounted with valves at their base. On the top of the hollow insulator chambers there are double arc extinguishing chambers mounted. The current carrying parts 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. Since there are three double arc extinction poles in series, there are six breakers per pole. Each arc extinction chamber consists of one twin fixed contact. There are two moving contacts. The moving contacts can move axially so as to open or close. Its opening or closing mechanism depends on spring pressure and air pressure.

The operation mechanism operates the rods when it gets a pneumatic or electrical signal. The valves 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 it causes the contacts to be 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 While closing, the valve 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 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 operates and the contacts close by virtue of the spring pressure.

Advantages:

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

Disadvantages:

- Considerable maintenance is required for the compressor plant which supplies the air blast.
- Air blast circuit breakers are very sensitive to the variations in the rate of restriking voltage.
- Air blast circuit breakers are finding wide applications in high voltage installations.Majority of circuit breakers for voltages beyond 110 kV are of this type.

5.3 Oil circuit breakers

Types Of Oil Circuit Breakers

Oil circuit breakers can be classified into following types:

1) Bulk oil circuit breakers

which use a large quantity of oil. In this circuit breaker the oil serves two purposes. Firstly it extinguishes the arc during opening of contacts and secondly it insulates the current conducting parts from one another and from the earthed tank. Such circuit breakers are classified into:

- Plain oil circuit breakers
- Arc control circuit breakers

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

2) Low oil circuit breakers,

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

Construction

There are two chambers in a low oil circuit breaker; the oil in each chamber is separated from each other. The main advantage of this is that low oil is required and oil in second chamber won‘t get polluted. Upper chamber is called the circuit breaker chamber and lower one is called the supporting chamber. Circuit breaking chamber consists of moving contact and fixed contact. Moving contact is connected with a piston it‘s just for the movement of the contact and no pressure build due to its motion. There are two vents on fixed contact they are axial vent for small current produced in oil due to heating of arc and radial vents for large currents. The whole device is covered using Bakelite paper and porcelain for protection. Vents are placed in a tabulator.

Operation

Under normal operating conditions, the moving contacts remain engaged with the upper fixed contact. When a fault occurs, the moving contact is pulled down by the tripping springs and an arc is struck. The arc vaporizes oil and produces gases under high pressure. This action constrains the oil to pass through a central hole in the moving contact and results in forcing series of oil through the respective passages of the turbulator.The process of tabulation is orderly one, in which the sections of arc are successively quenched by the effect of separate streams of oil, moving across each section in turn and bearing away its gases

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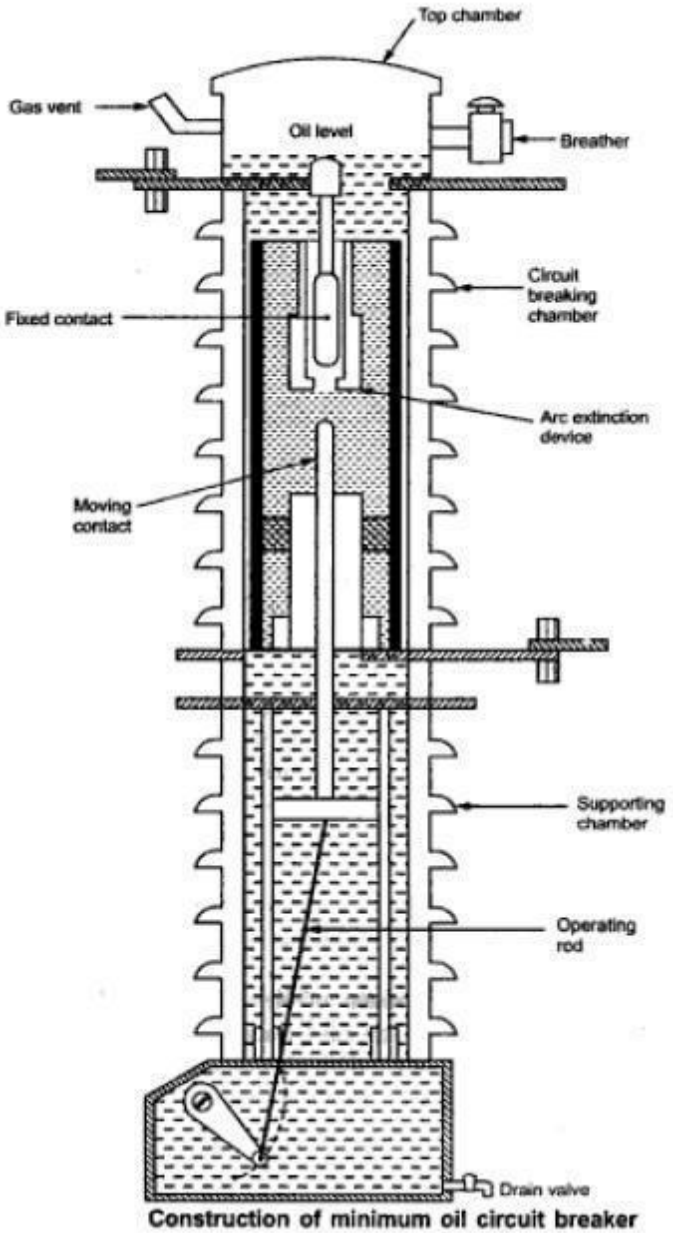
Advantages

A low oil circuit breaker has following advantages compared to bulk oil circuit breaker

- It requires lesser quantity of oil
- It requires smaller space
- There is reduced risk of fire
- Maintenance problems are reduced

Disadvantages

- Low oil circuit breaker has following disadvantages compared to bulk oil circuit breaker
- Due to smaller quantity of oil, the degree of carbonization is increased
- There is a difficulty of removing the gases from the contact space in time
- The dielectric strength of oil deteriorates rapidly due to high degree of carbonization.



Construction of minimum oil circuit breaker

5.4 SF6 circuit breaker.

At this point we are aware that the medium in which arc extinction of the circuit breaker takes place greatly influences the important characteristics and life of the circuit breaker. the working of a vacuum circuit breaker was illustrated. We already know that the use of vacuum circuit breaker is mainly restricted to system voltage below 38 kV. The characteristics of vacuum as medium and cost of the vacuum CB does not makes it suitable for voltage exceeding 38 kV. In the past for higher transmission voltage Oil Circuit Breaker (OCB) and Air Blast Circuit Breaker (ABCB) were used. These days for higher transmission voltage levels SF6 Circuit Breakers are largely used. OCB and ABCB have almost become obsolete. In fact in many installations SF6 CB is used for lower voltages like 11 kV, 6 kV etc.. i)sulphur Hexafluoride symbolically written as SF6 is a gas which satisfy the requirements of an ideal arc interrupting medium. So SF6 is extensively used these days as an arc interrupting medium in circuit breakers ranging from 3 kv upto 765 kv class. In addition to this SF6 is used in many electrical equipments for insulation. Here first we discuss in brief, some of the essential properties of SF6 which is the reason of it's extensive use in circuit breakers

SF6 gas has high dielectric strength which is the most important quality of a material for use in electrical equipments and in particular for breaker it is one of the most desired properties. Moreover it has high Rate of Rise of dielectric strength after arc extinction.

This characteristics is very much sought for a circuit breaker to avoid restriking.

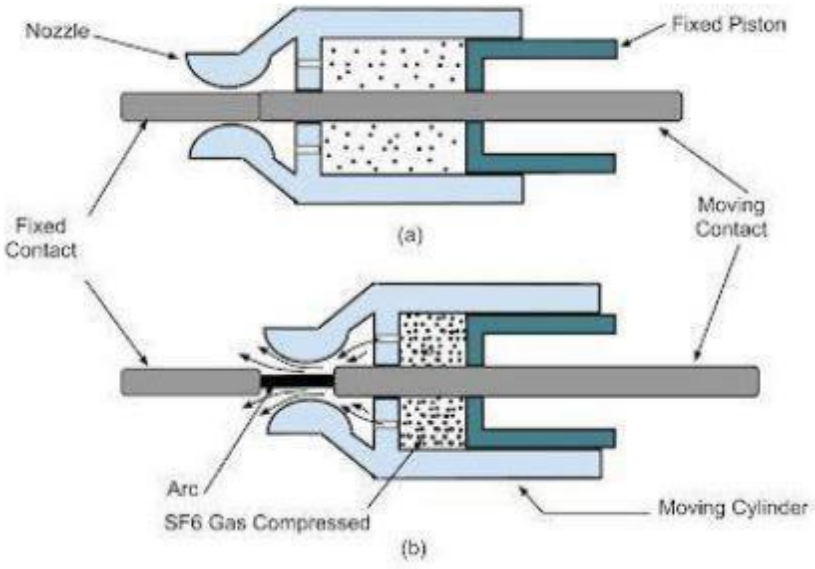
- SF6 is colour less, odour less and non toxic gas.
- SF6 is an inert gas. So in normal operating condition the metallic parts in contact with the gas are not corroded. This ensures the life of the breaker and reduces the need for maintenance.
- SF6 has high thermal conductivity which means the heat dissipation capacity is more. This implies greater current carrying capacity when surrounded by SF6 .
- The gas is quite stable. However it disintegrates to other fluorides of Sulphur in the presence of arc. but after the extinction of the arc the SF6 gas is reformed from the decomposition.
- SF6 being non-flammable so there is no risk of fire hazard and explosion.

A sulfur hexafluoride circuit breaker uses contacts surrounded by sulfur hexafluoride gas to quench the arc. They are most often used for transmission-level voltages and may be incorporated into compact gas-insulated switchgear. In cold climates, supplemental heating or de-rating of the circuit breakers may be required due to liquefaction of the SF6 gas.

Advantages:

- Due to superior arc quenching property of sf6 , such breakers have very short arcing time

- Dielectric strength of sf6 gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.
- Gives noiseless operation due to its closed gas circuit
- Closed gas enclosure keeps the interior dry so that there is no moisture problem
- There is no risk of fire as sf6 is non-inflammable
- There are no carbon deposits
- Low maintenance cost, light foundation requirements and minimum auxiliary equipment
- sf6 breakers are totally enclosed and sealed from atmosphere, they are particularly suitable where explosion hazard exists



Disadvantages:

- sf6 breakers are costly due to high cost of sf6
- sf6 gas has to be reconditioned after every operation of the breaker, additional equipment is required for this purpose

CONSTRUCTION, PRINCIPLE OF OPERATION

The construction and working principles of SF6 circuit breaker varies from manufacturer to manufacturer. In the past double pressure type of SF6 breakers were used. Now these are obsolete. Another type of SF6 breaker design is the self blast type, which is usually used for medium transmission voltage. The Puffer type SF6 breakers of single pressure type are the most favored types prevalent in power industry. Here the working principle of Puffer type breaker is illustrated (Fig-A)

As illustrated in the figure the breaker has a cylinder and piston arrangement. Here the piston is fixed but the cylinder is movable. The cylinder is tied to the moving contact so that for opening the breaker the cylinder along with the moving contact moves away from the fixed contact (Fig-A(b)). But due to the presence of fixed piston the SF6 gas inside the cylinder is compressed. The compressed SFe gas flows through the nozzle and over the electric arc in axial direction. Due to heat convection and radiation the arc radius reduces gradually and the arc is finally extinguished at current zero.

The dielectric strength of the medium between the separated contacts increases rapidly and restored quickly as fresh SF6 gas fills the space. While arc quenching, small quantity of SF6 gas is broken down to some other fluorides of sulphur which mostly recombine to form SF6 again. A filter is also suitably placed in the interrupter to absorb the remaining decomposed byproduct.

The gas pressure inside the cylinder is maintained at around 5 kgf per sq. cm. At higher pressure the dielectric strength of the gas increases. But at higher pressure the SF6 gas liquify at higher temperature which is undesired. So heater is required to be arranged for automatic control of the temperature for circuit breakers where higher pressure is utilised. If the SF6 gas will liquify then it loses the ability to quench the arc. Like vacuum breaker, SF6 breakers are also available in modular design form so that two modules connected in series can be used for higher voltage levels. SF6 breakers are available as both live tank and dead tank types. In Fig-B above a live tank outdoor type 400 kV SF6 breaker is shown.

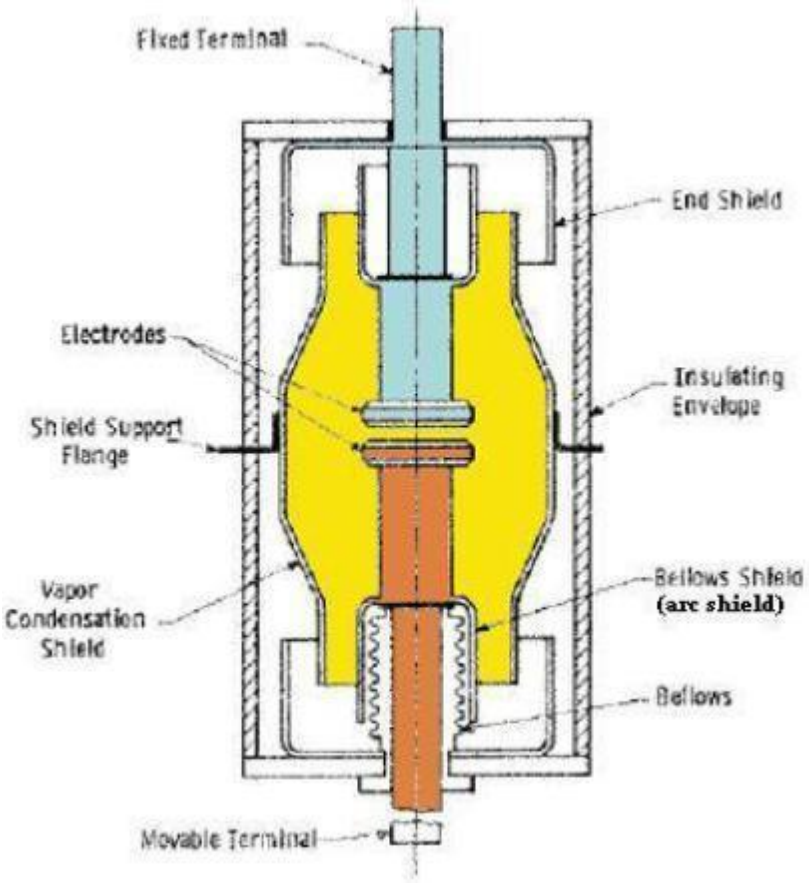
5.5 vacuum circuit breakers

In this breaker, vacuum is being used as the arc quenching medium. Vacuum offers highest insulating strength, it has far superior arc quenching properties than any other medium. When contacts of a breaker are opened in vacuum, the interruption occurs at first current zero with dielectric strength between the contacts building up at a rate thousands of times that obtained with other circuit breakers. **Principle:** When the contacts of the breaker are opened in vacuum (10 -7 to 10 -5 torr), an arc is produced between the contacts by the ionization of metal vapours of contacts. The arc is quickly extinguished because the metallic vapours, electrons, and ions produced during arc condense quickly on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength. As soon as the arc is produced in vacuum, it is quickly extinguished due to the fast rate of recovery of dielectric strength in vacuum

Construction:

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

the internal dielectric strength by preventing metallic vapours falling on the inside surface of the outer insulating cover.



Working:

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

Advantages:

- They are compact, reliable and have longer life.
- There are no fire hazards
- There is no generation of gas during and after operation
- They can interrupt any fault current. The outstanding feature of a VCB is that it can break any heavy fault current perfectly just before the contacts reach the definite open position.
- They require little maintenance and are quiet in operation

- Can withstand lightning surges
- Low arc energy
- Low inertia and hence require smaller power for control mechanism.

Applications:

- For outdoor applications ranging from 22 kV to 66 kV. Suitable for majority of applications in rural area.

5.6 testing of circuit breakers

Primary injection test

For primary injection testing, high current is injected on the primary side of the current transformer. The entire chain – current transformer, conductors, connection points, relay protection and sometimes circuit breakers as well is covered by the test. The system being tested must be taken out of service during primary injection testing. Testing is usually conducted in connection with commissioning. The only way to verify that a direct-acting low voltage circuit breaker operates properly is to inject a high current.

Motion

A high-voltage breaker is designed to interrupt short-circuit current in a controlled manner. This puts great demands on the mechanical performance of all components in the interrupter chamber as well as the operating mechanism. It has to operate at a specific speed in order to build up adequate pressure to allow for cooling stream of air, oil or gas (depending on the type of breaker) to extinguish the arc that is generated after the contact separation until the next zerocrossing. It is important to interrupt the current to prevent a re-strike. This is accomplished by making sure that the contacts move apart far enough from each other before the moving contact has entered the so-called damping zone. The distance throughout which the breaker's electric arc must be extinguished is usually called the arcing zone. From the motion curve, a velocity or acceleration curve can be calculated in order to reveal even marginal changes that may have taken place in the breaker mechanics. The contact travel motion is captured by connecting a travel transducer on the moving part of the operating mechanism. The transducer provides an analogue voltage relative to the movement of the contact. The motion is presented as a curve where distance vs. time allows for further analysis. From the motion curve, a velocity or acceleration curve can be calculated in order to reveal changes in the breaker mechanics that may affect the breakers operation.

Travel

The travel trace indicates the instantaneous position of the circuit beaker contacts during an operation. This gives important information such as total travel, overtravel, rebound, undertravel, contact wipe or penetration of movingcontact or operating-rod position at the time of close or open, and anomalies which are evident from the trace.

Speed

Speed is calculated between two points on this motion curve. The upper point is defined as a distance in length, degrees or percentage of movement from a) the breaker's closed or open position, or b) the contact-closure or contact- separation point. The time that elapses between these two points ranges from 10 to 20 ms, which corresponds to 1-2 zero-crossovers. The lower point is determined based on the upper point. It can either be a distance below the upper point or a time before the upper point. The single most important benefit derived from the instantaneous velocity and acceleration curves is the insight that they provide into the forces involved during the operation of a circuit breaker.

Acceleration

Average acceleration can be calculated from the velocity trace.

Damping

Damping is an important parameter to monitor and test as the stored energy an operating mechanism use to open and close a circuit breaker is considerable. The powerful mechanical stress can easily damage the breaker and/or reduce the breaker's useful life. The damping of opening operations is usually measured as a second speed, but it can also be based on the time that elapses between two points just above the breaker's open position.