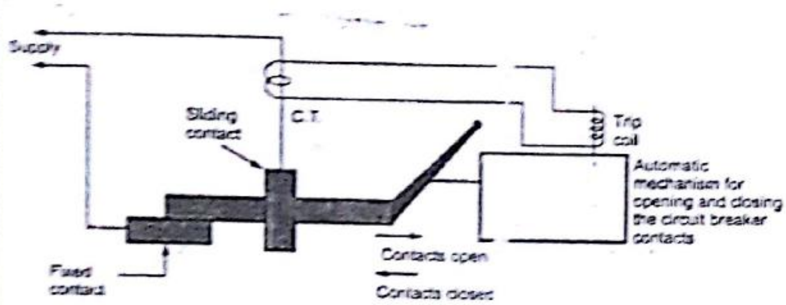
UNIT- V Circuit Breakers

Fault clearing process - classification of circuit breakers - construction and operation of circuit breakers - oil minimum circuit breakers - Air blast circuit breaker - vaccum circuit breaker - SF6 circuit breaker - circuit breaker ratings - circuit breaker testing - Intelligent breaker - Digital optical instrument transformers (DOIT)

Basic action of a circuit Breaker (or) Fault clearing process:-



* It consists of two contacts 1. Fixed & 2. Moving.
* A handle is attached at the end of the moving contact & it can be operated manually or automatically.
* The automatic operation needs a separate mechanism which consists of a trip coil & it is energised by the secondary of the current transformer. The terminals of circuit breaker is connected to supply.
* under normal working condition, the emf produced in secondary winding of current transformer is not sufficiently high to energize the trip coil.
* under abnormal or Faulty working condition, the high current in primary of current transformer induces sufficiently high emf in the secondary winding of CT so that trip coil is energized. This will start moving the contacts.
* This action will not be instantaneous as there is always a time lag between the energization of the trip circuit & the actual opening of the contacts.
* As the contacts are separated, the circuit is not interrupted at once, it leads to formation of arc & it leads to production of large amount of heat which may damage the system or the breaker. So extinguish the arc becomes necessary as early as possible in minimum time.
* The time interval which is between the energization of the trip coil to the instant of contact separation is called the opening time. It is dependent on Fault current level.

* The time interval from the contact separation to the extinction of arc is called arcing time. It depends not only on fault current but also on availability of voltage for maintenance of arc & mechanism used for extinction of arc.

Requirements of a circuit Breaker:-

1. The normal working current & the short circuit current must be safely interrupted by the circuit breaker.
2. The faulty section of the system must be isolated by circuit breaker as quickly as possible keeping minimum delay.
3. It should not operate with flow of overcurrent during healthy conditions.
4. The faulty circuit only must be isolated without affecting the healthy one.

classification of circuit Breakers:-

It is made on the basis of insulating medium employed in the circuit breakers to extinguish the arc.

1. oil circuit breakers
2. Air Blast circuit breakers
3. sulphur Hexaflouride (SF_6) circuit breakers
4. Vaccum circuit breakers.

oil circuit Breakers

Advantages:-

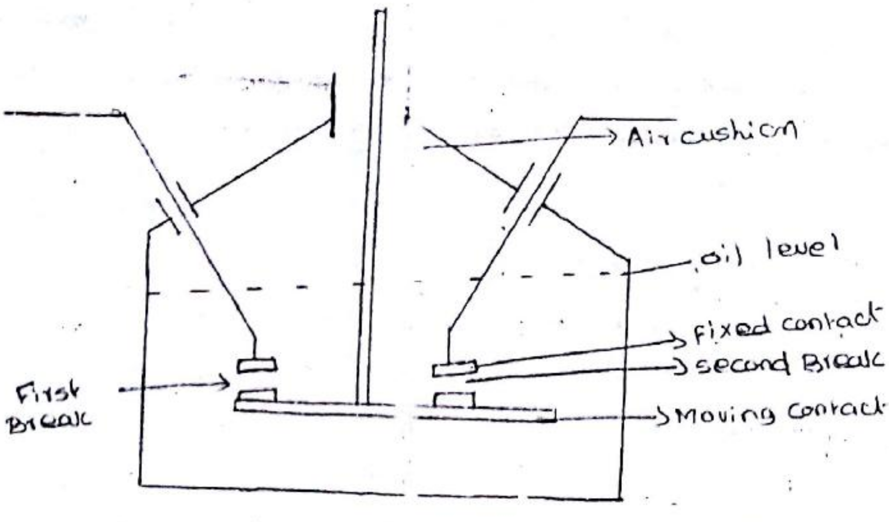
* Mineral oil has better insulating properties than air.
* oil has also good cooling property.
* In circuit breakers when arc is formed, it decomposes oil into gases. Hence the arc energy is absorbed in decomposing the oil.

Disadvantages:-

1. It is inflammable & may pose a fire hazard.
2. It has the possibility of forming explosive mixture with air & production of carbon particles in the oil due to heating reduces the dielectric strength.

plain break oil circuit Breakers:-

* There is a fixed & moving contact immersed in oil.
* The metal tank is strong, weather tight & earthed.
* when contacts separate there is a severe arc which decomposes the oil into gases.



* The gas obtained from the oil is mainly hydrogen.
* The volume of gases produced is about one thousand times that of the oil decomposed.
* Hence the oil is pushed away from arc & the gaseous medium surrounds the arc.

The arc quencing factors are

1. Elongation of the arc.
2. Formation of gaseous medium between contacts which has a high heat conductivity & high dielectric strength.
3. Turbulent motion of the oil resulting from the gases passing through it.

* A large gaseous pressure is developed because a large amount of energy is dissipated within the tank. Therefore the tank of the circuit breaker is made strong to withstand such a large pressure.
* when gas is formed around the arc, the oil is displaced.
* To accomodate the displaced oil, an air cushion between the oil surface & the tank is essential. The air cushion also absorbs the mechanical shock produced due to upward oil movement.
* A vent will be in the tank cover for the gas outlet.
* A sufficient level of oil above the contacts is required to provide substantial oil pressure at the arc.
* certain gap between the contacts must be created before the arc interruption. To achieve this, the speed of the break should be as high as possible.
* The two breaks in series provide rapid arc elongation without the need for a specially fast contact. The double break also provides ample gas distance before arc interruption.
* But this arrangement has the disadvantage of unequal voltage distribution across the breaks.

* To equalise the voltage distribution across the breaks, nonlinear resistors are connected across each break.

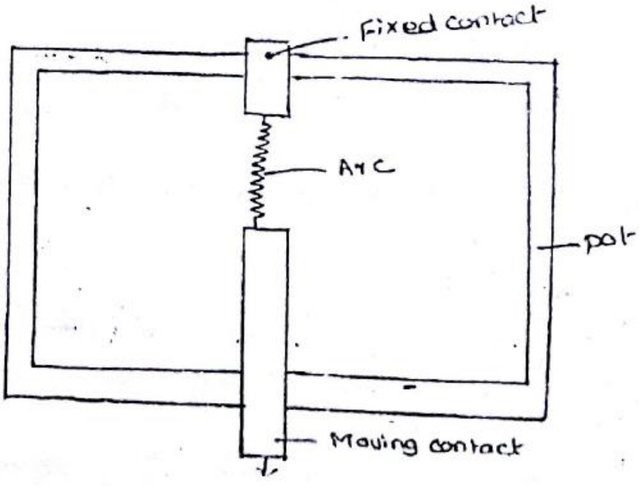
* It is employed for breaking of low currents at comparatively lower voltages. They are used on low voltage dc circuits & on low voltage ac distribution circuits.

* Their size becomes unduly large for higher voltages.
* They require large amount of transformer oil.
* They are not suitable for autoreclosing.
* Their speed is slow.
* They can be used upto 11kV with an interrupting capacity upto 250MVA.

Self generated pressure oil circuit Breaker:

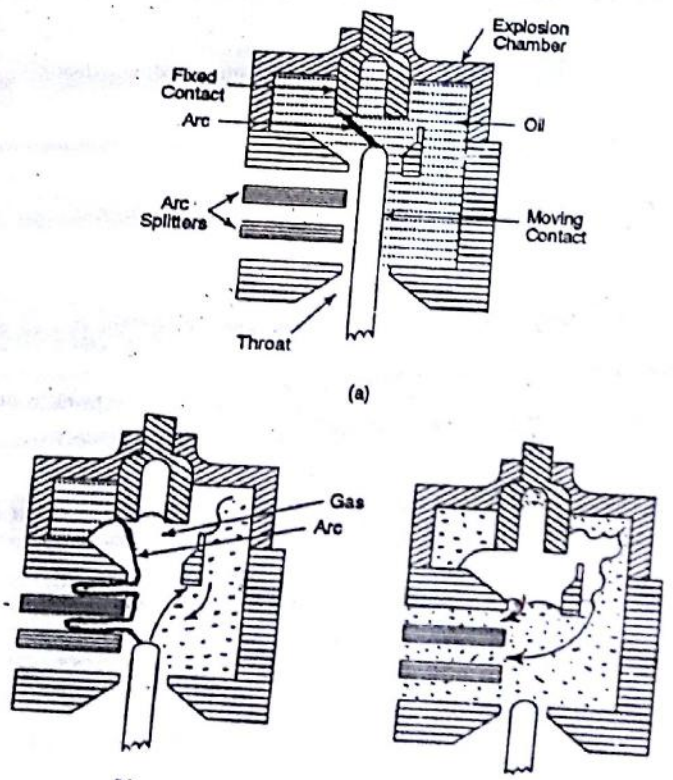
* In this, arc energy is utilised to generate a high pressure in a chamber known as explosion pot or pressure chamber or arc controlling device.
* The contacts are enclosed within the pot. The pot is made of insulating material & it is placed in the tank.
* Such breakers have high interrupting capacity.
* The arcing time is reduced.
* Since the pressure is developed by the arc itself, it depends upon the magnitude of the current.
* Therefore pressure will be low at low currents & high at high values of the current.
* This creates a problem in designing a suitable explosion pot.
* At low currents, pressure generated should be sufficient to extinguish the arc. At heavy currents, the pressure should not be too high so as to burst the pot.

a) plain Explosion pot :-



* when the moving contacts separate, a severe arc is formed.
* The oil is decomposed & gas is produced.
* It generates a high pressure within the pot because there is a close fitting throat at the lower end of the pot.
* The high pressure developed causes turbulent flow of streams of the gas into the arc resulting in arc extinction.
* If the arc extinction does not occur within the pot, it occurs immediately after the moving contact leaves the pot, due to the high velocity axial blast of the gas which is released through the throat.
* since the arc extinction in the plain explosion pot is performed axially, it is also known as an axial extinction pot.
* This type of pot is not suitable for breaking of heavy currents.
* The pot may burst due to very high pressure.
* At low currents, the arcing time is more.
* Hence this type is suitable for the interruption of medium range.

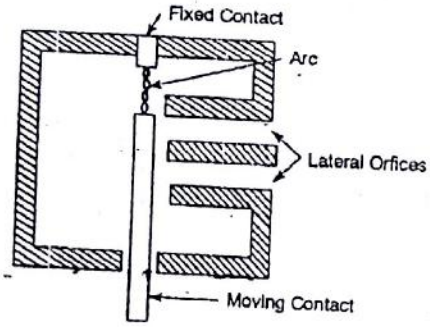
2. cross Jet explosion pot:-



Cross-jet explosion pot

* It is suitable for high current interruptions.
* Arc splitters are used to obtain an increased arc length for a given amount of contact travel.
* Arc which is formed due to separation of contacts is pushed into the arc splitters & finally it is extinguished.
* In this type of pot, the oil blast is across the arc & hence it is known as cross-jet explosion pot.

c) Self compensated explosion pot:-



* It is a combination of a cross-jet explosion pot & a plain-explosion pot.
* It's upper portion is a cross-explosion pot & the lower portion is a plain explosion pot.
* On heavy currents the rate of gas generation is very high & consequently the pressure produced is also very high.
* The arc extinction takes place when the first or second lateral orifice of the arc splitter is uncovered by the moving contact.
* The pot operates as a cross-jet explosion pot.
* When current is low, the pressure is also low in the begining, so the arc is not extinguished when the tip of the moving contact is in the upper portion of the pot.
* By the time, the moving contact reaches the orifice at the bottom of the pot, sufficient pressure is developed.
* The arc is extinguished when the tip of the moving contacts comes out of the throat.
* The arc is extinguished by the plain explosion pot action. Thus it is seen that the pot is suitable for low as well as high current interruptions.

d) Double Break oil circuit Breaker:-

* To obtain high speed arc interruption, particularly at low currents various improved designs of the explosion pot have been presented.
* Double break oil circuit breaker is also one of them.
* It employs an intermediate contact between the fixed & moving contacts.

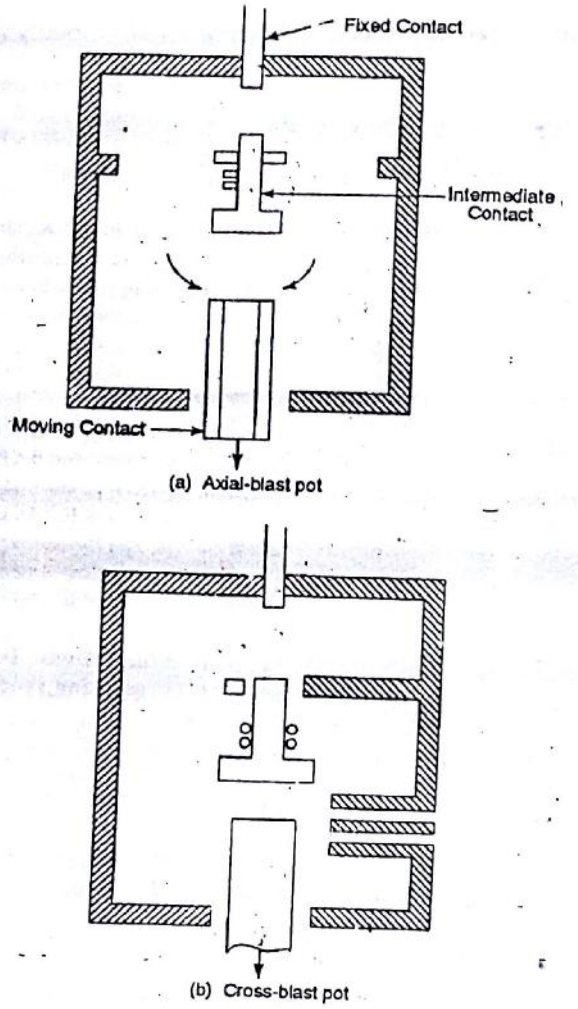


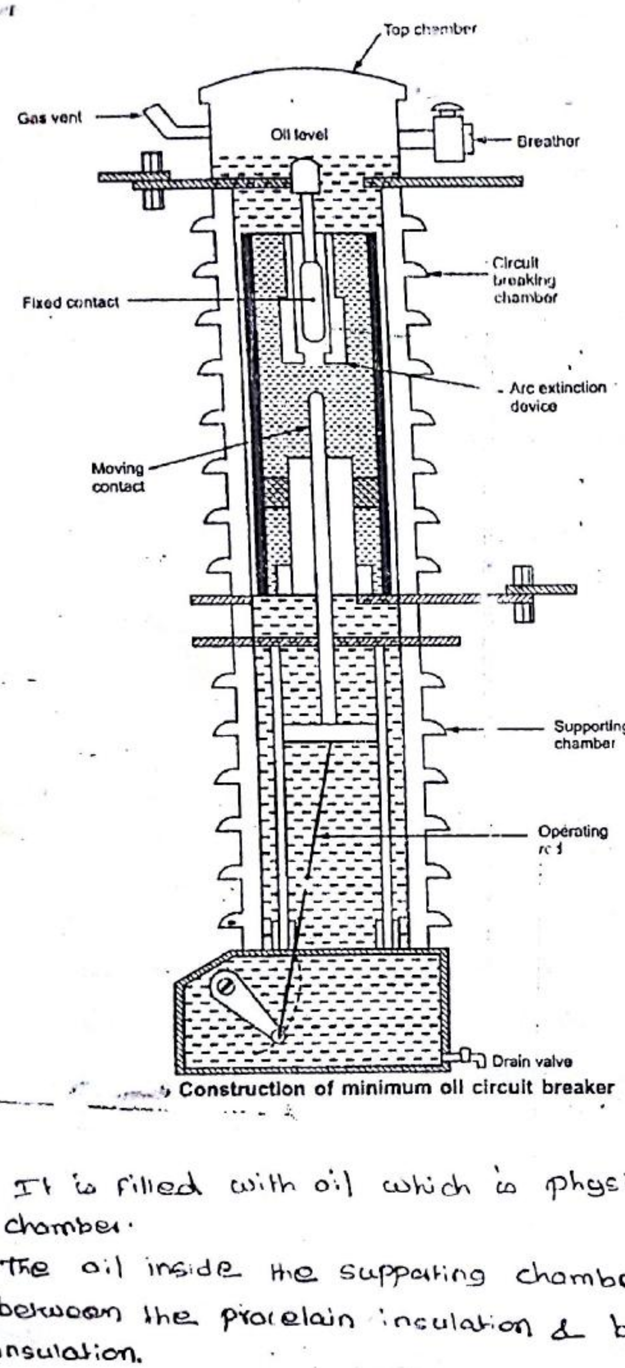
FIGURE 9.17 Double break oil circuit breakers

* When moving contacts separates, the intermediate contact also follows it.
* First the arc appears between the fixed contact & the inter-mediate contact.
* Soon after the intermediate contact stops, a second arc appears between the inter-mediate contact & the moving contact.
* The second arc is extinguished quickly by employing gas pressure & oil momentum developed the first arc.

Bulk oil & Minimum oil circuit Breakers:-

* With increase in system voltage, the quantity of oil in bulk oil circuit breakers also increases. It gives additional expenses, increases the risk of fire & causes maintenance problem.
* This will make necessary the design of a type of circuit breakers which requires a low volume of oil.
* The oil serves two purposes.
  1. It acts as arc quenching medium (10%)
  2. It insulates live parts from earth (90%)
* A low or minimum oil C.B uses a smaller container having oil which is just enough for arc extinction.
* The container of oil is supported on porcelain insulators, so proper insulation is obtained.
* It requires less space than bulk oil type. This is an important consideration in large installations.

* The quenching of arc is done in same way as in bulk oil C.B. The usage of suitable arc control devices further facilitate the arc extinction.



Construction of minimum oil circuit breaker

Construction:-

* It consists of two separate compartments which are separated from each other. Both these compartments are filled with oil.

* upper chamber - circuit breaking chamber.

* lower chamber - supporting chamber.

* The two chambers are separated by a partition & oil from both the chambers are prevented from mixing with each other.

This type of arrangement has two advantages:

1. C.B chamber requires small volume of oil which is just sufficient for arc extinction.
2. small amount of oil is to be replaced as the oil in the supporting chamber does not get contaminated by the arc.

1. Supporting chamber:-

* It is a bottom chamber which is made up of procelain & mounted on metal chamber.

* It is filled with oil which is physically separated from the oil in C.B chamber.
* The oil inside the supporting chamber & the annular space formed between the procelain insulation & backelised paper is employed for insulation.

2. Circuit Breaking chamber:-

It is a procelain enclosure which is mounted on the top of the supporting compartment. It is also filled with oil & consists of following parts.

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

* The moving contact is hollow. It consists of a cylinder which moves down over a fixed piston.
* The turbulator forms an arc control device & it has both axial & radial vents.
* The axial venting ensures the interruption of low currents whereas radial venting ensures interruption of heavy currents.

3. Top chamber:-

* It is a metal chamber mounted on the top of circuit breaking chamber.
* It provides expansion space for the oil present in circuit breaking chamber.
* It also contains a separator which avoids loss of oil by centrifugal action caused by circuit breaker operation during fault conditions.

Operation:-

* under normal operating conditions, the moving contact & fixed contacts are in engaged position.
* During abnormal conditions the moving contact is pulled down by the tripping springs.
* with the separation of contacts, an arc is struck between them.
* the energy in the arc causes vapourisation of oil. This will produce gases at high pressure.
* This action prevents the oil to pass through central hole in the moving contact & results in forcing series of oil through the passages of the turbulator.
* The process of turbulation is one in which sections of the arc is successively quenched by the effect of separate streams of oil moving across each section.

Maintanance of oil circuit Breakers:-

* The maintenance of oil circuit breakers consists of checking of contacts & dielectric strength of the oil.
* After fault has been interrupted by C.B, fault current flows for short time or load currents for several times, it's contacts may be burnt due to arcing.
* Also there may be some loss of dielectric strength of oil due to carbonisation & this will reduce rupturing capacity of the breaker.
* Thus periodic checking of C B's is essential after regular interval of 3 or 6 months.

Following points should be kept in mind while checking.

1. check the current carrying parts. If they are burnt, replace them.
2. check the dielectric strength of oil. If its colour is changed then it should be changed or reconditioned. The oil in good condition withstands 30kV for one minute with 4mm gap between electrodes.
3. check the insulation for any damage. clean the surface with removal of carbon deposites with strong & dry fabric.
4. The oil level should be checked.
5. The closing & tripping mechanism should be checked.

Advantages:-

1. The quantity of oil required is small.
2. The space requirement is reduced.
3. The risk of fire is reduced.

Disadvantages:-

1. Due to smaller quantity of oil, the degree of carbonisation is increased.
2. The gases are difficult to remove from the contact space in time.
3. The dielectric strength of the oil deteriorates rapidly as degree of carbonisation is high.

Applications:-

It is now available for all voltages & for the highest breaking capacity, hence preferred in most of the protection schemes.

Air Blast circuit Breaker:-

* In air blast C.B's, compressed air at a pressure of 20-30 kg/cm^2 is employed as an arc quenching medium.
* Air blast circuit breakers are suitable for operating voltages of 132kV & above.
* They have also been used on 11kV - 33kV range for certain applications.
* At present SF6 C.B's are preferred for 132kV & above.
* Vacuum C.B's are preferred for 11kV - 33kV range.
* Therefore the air blast circuit breakers are becoming obsolete.

Advantages:-

1. cheapness, & free availability of the interrupting medium, chemical stability & inertness of air.

2. High speed operation.
3. Elimination of Fire hazard.
4. Short & consistent arcing time & therefore, less burning of contacts.
5. Less maintenance.
6. suitability for Frequent operation.
7. Facility for high speed reclosure.

Disadvantages:-

1. An air compressor plant has to be installed & maintained.
2. upon arc interruption, the air blast C.B produces a high level noise when air is discharged to the open atmosphere. In residental areas, Silencers need to be provided to reduce the noise level to an acceptable level.
3. Problem of current chopping.
4. problem of restriking voltage.

* Switching resistors & equalising capacitors are generally connected across the interrupters.
* The switching resistors reduce transient overvoltages & help arc Interruption.
* Capacitors are employed to equalise the voltage across the breaks.
* The NO of breaks depend on the system voltage.

eg: breaks
2 for 66kV
2 to 4 For 132kV
2 to 6 For 220kV ...

Breaking capacities :- 5000 MVA at 66kV
10,000 MVA at 132kV
20,000 MVA at 220kV ...

C.B's For higher interrupting capacity have also been designed For 1000kV & 1100kV systems.

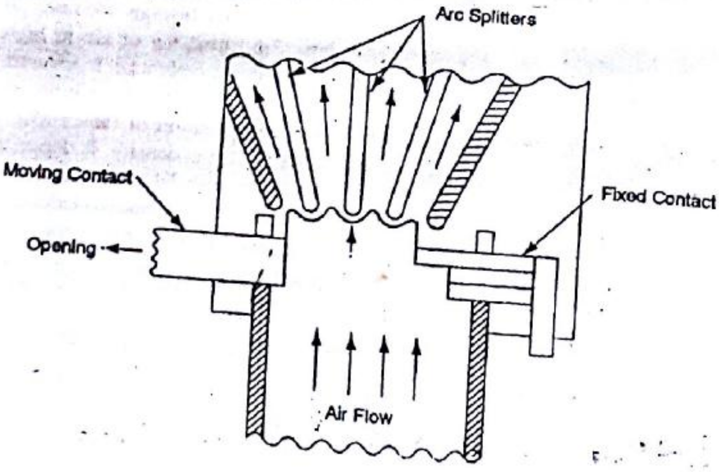
Applications:-

They are preferred for arc Furnace duty & traction system because they are suitable for repeated duty.

An air-blast C.B may be either of the Following two types.

1. Cross blast circuit breakers
2. Axial blast circuit breakers.

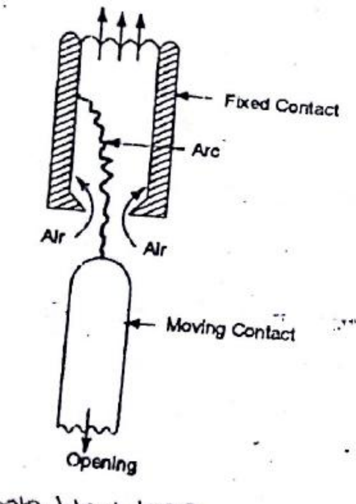
1. cross - blast circuit breakers:-



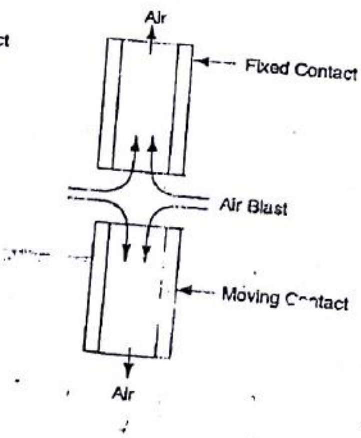
* In this, a high pressure blast of air is directed perpendicularly to the arc for its interruption.
* The arc is forced into a suitable chute.
* sufficient lengthening of the arc is obtained resulting in the introduction of appreciable resistance in the arc itself.

* Therfore resistance switching is not common in this type of C.B's.
* cross blast C.B's are suitable for interrupting high currents (upto 100kA) at comparatively low voltages. (to be continued in next page)

2. Axial blast circuit Breakers:-



Single blast type axial blast C.B



Double blast type (or radial blast type) axial blast C.B.

* In this, a high pressure blast of air is directed longitudinally, (ie) in line with the arc.
* Axial blast C.B's are suitable for EHV & super high voltage application.
* This is because interrupting chambers can be fully enclosed in procelain tubes.
* Resistance switching is employed to reduce the transient overvoltages.
* Air blast C.B's have also been commissioned for 1100kV system.

* In this type, air flows from high pressure reservoir to the atmosphere through a nozzle, whose design makes air to expand in the low pressure zone.
* It will attain high velocity.
* The high speed air flowing axially along the arc will cause removal of heat from the periphery of the arc.

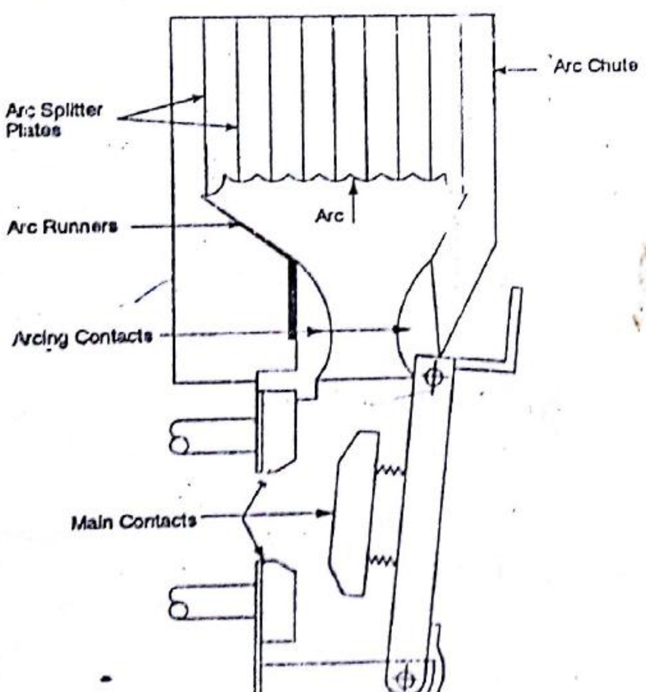
* The diameter of arc reduces to a low value at current zero.
* At this instant of the arc interruption the contact space is filled with the fresh air. This will make possible to remove the hot gases & fast building up of the dielectric strength of the medium.
* During the contact closing, the air from the extinction chamber is allowed to pass to the atmosphere. This will reduce the pressure on the moving contacts & will assist the closing operation.
* In this, the pressure generated in the extinction chamber is independent of arc current, the C.B is said to be of external energy source. The air pressure in this type of C.B is constant which is sufficient enough to break the rated breaking current. In this type, the breaking capacity is fixed by pressure of extinguishing medium.
* For low values of currents, the arcing time does not change appreciably since air pressure is independent of arc current.
* For breaking low current high pressure air will be required. Due to this the current gets chopped before reaching natural zero.
* This will give rise to high restriking voltage & the contact space is not likely to break down.
* Therefore these high voltages must be allowed to discharge to avoid breakdown of insulation of circuit breaker.
* Thus resistance switching is commonly employed in these breakers. Ceramic resistances of non-linear characteristics are used for resistance switching.
* When contacts are opened, the air flows in the arc extinguishing chamber. The separation of main contacts leads to closing of auxiliary contacts which will connect resistance across the arc for a short time. This auxilliary contacts are mounted in inclined V shaped insulators.
* After the arc extinction the pressure on either side of auxilliary contacts is adjusted in such a way that auxilliary contacts open & resistor circuit is interrupted.
* The double blast arrangement is also called radial blast type due to the fact that the blast flows radially into the space between the contacts.

Cross Blast Type:- (contd....)

* The flow of air is across the arc.
* The moving contact is near to the arc splitter assembly.
* The air blast forces the arc on the arc splitter plates.

* These plates will lengthen the arc.
* Depending upon the breaking capacity of the breaker, the size & Number of plates are decided.
* The fixed contact is mounted at the base between the two insulating blocks.
* It consists of a number of silver surfaced spring loaded copper fingers.
* The arcing portion is surfaced with a silver tungsten alloy.
* The moving contact consists of flat copper silver faced blade.
* Resistance switching is not required as sufficient resistance is automatically introduced in the arc to control the restriking voltage.
* This type of breakers are commonly used in indoor C.B's of medium high voltage class.

Air break circuit Breakers:



* Air break C.B's are quite suitable for high current interruption at low voltages.
* In this type, air at atmospheric pressure is used as an arc extinguishing medium.
* It employs two pairs of contacts - main contacts & arcing contacts.
* The main contacts carry current when the breaker is in closed position. They have low contact resistance.
* When contacts are opened, the main contacts separate first, the arcing contacts still remain closed.
* Therefore the current is shifted from the main contacts to the arcing contacts. The arcing contacts separate later on & the arc is drawn between them.
* In air break circuit breakers, the principle of high resistance is employed for arc interruption. The arc resistance is increased by lengthening, splitting & cooling the arc.
* The arc length is rapidly increased employing arc runners & arc chutes. The arc moves upwards by both electromagnetic & thermal effects.

* It moves along the arc runner & then it is forced into a chute. It is split by arc splitters.
* A blow-out coil is employed to provide magnetic field to speed up arc movement, & to direct the arc into arc splitters.
* The blow-out coil is not connected in the circuit permanently. It comes in the circuit by the arc automatically during the breaking process.
* The arc interruption is assisted by current zero in case of ac air break circuit breakers.
* High resistance is obtained near current zero.

Ac air break C.B's are available in the voltage range 400 to 12kV. They are widely used in low & medium voltage system. They are extensively used with electric furnaces with large motors requiring frequent starting, in a place where chances of fire hazard exist etc.,

Air break C.B's are also used in dc circuit upto 12kV.

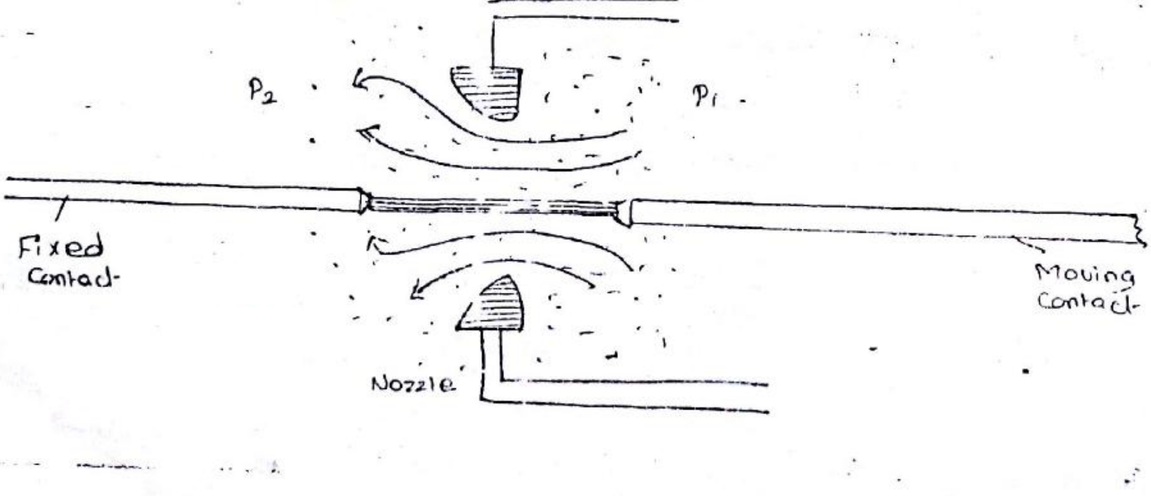
SF_6 Circuit Breakers:-

* Sulphur hexaflouride (SF_6) has good dielectric strength & excellent arc quenching property.
* It is an inert, non-toxic, non flammable & heavy gas.
* At atmospheric pressure, its dielectric strength is about 2.5 times that of air.
* At 3 atmospheric pressure, its dielectric strength is equal to that of transformer oil.
* It is an electronegative gas. (ie) it has high affinity for electrons. when a free electron comes in collision with a neutral gas molecule, the electron is absorbed by the neutral gas molecule & a negative ion is formed. As the negative ions so formed are heavy they do not attain sufficient energy to contribute to ionisation of the gas. This property gives a good dielectric property.
* Besides good dielectric strength, the gas has an excellent property of recombination after the removal of the source which energizes the arc. This gives an excellent arc quenching property.
* The gas has also an excellent heat transfer property. It's thermal time constant is about 1000 times shorter than that of air.

* under normal conditions, SF_6 is chemically inert & it does not attack metal or glass.
* However it decomposes to SF_4, SF_2, S_2, F_2 & S & F at temperatures of the order of 1000°c.
* After arc extinction, the products of decomposition recombine in a short time, within about 1 μsec.
* In the presence of moisture, the decomposition products can attack Contacts, metal parts & rubber sealings in SF_6 C.B's. Therefore the gas in the breaker must be moisture free. To absorb decomposition products, a mixture of sodalime (NaOH + CaO) & activated alumina can be placed in the arcing chamber.
* one major disadvantage of SF_6 is its condensation at low temperature. The temperature at which SF_6 changes to liquid depends on the pressure. At 15 atm. pressure the gas liquifies at a temperature of about 10°c. Hence SF_6 breakers are equipped with thermostatically Controlled heaters whenever such low ambient temperatures are encountered.
* SF_6 C.B's are manufactured in the voltage range 3.6KV to 765KV. However they are preferred for voltages 132KV & above.
* The dielectric strength of SF_6 gas increases rapidly after final current zero. SF_6 C.B's can withstand severe RRRV & are capable of breaking capacitive current without restriking.
* problems of current chopping is minimised.
* Electrical clearances are very much reduced due to high dielectric strength of SF_6.

Types of SF6 circuit Breakers:-

Double pressure SF6 circuit Breakers:-



* This is the early design of SF6 C.B's. It's operating principle is similar to that of air blast C.B's.

* In this type, gas from high pressure system is released into low pressure system through a nozzle during arc extinction process.

* In this C.B, gas is made to flow from zone P_1 to P_2 through a convergent divergent nozzle.

* The nozzle is located such that flow of gas covers the arc.

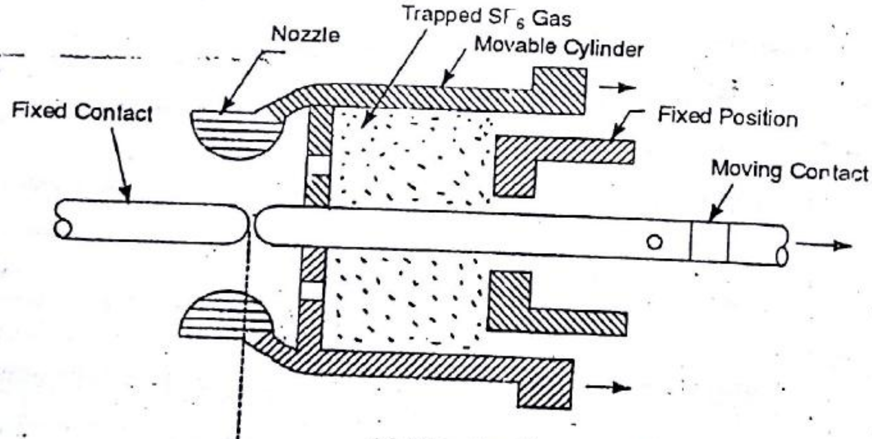
* Gas flow attains almost supersonic speed in divergent portion of nozzle, thereby gas takes away the heat from periphery of arc causing reduction in diameter of the arc.

* Finally arc diameter becomes almost zero at current zero & arc gets extinguished.

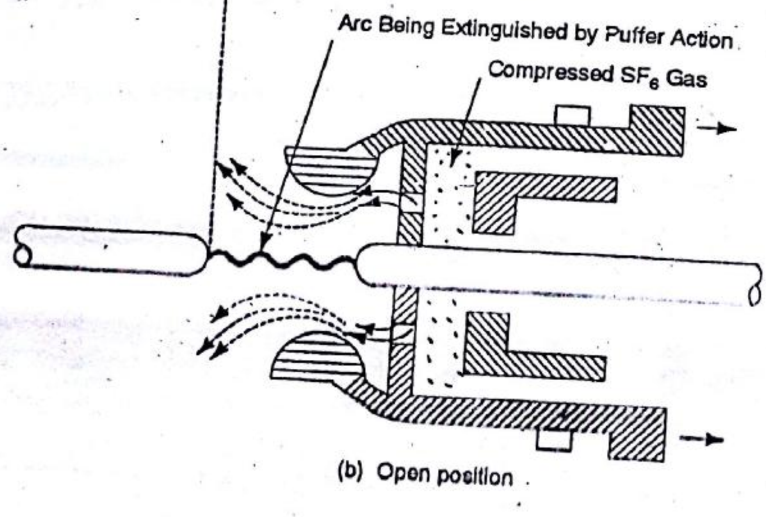
* Arc space is filled with fresh SF6 gas which increases dielectric strength of contact space.

* Because of its complicated design & construction, & its need for various auxiliaries such as Su, compressors, filters & control devices, this type of C.B's have become obsolete.

Puffer type SF6 circuit Breakers:-



(a) Closed position



(b) Open position

* This type of circuit breakers are also sometimes called single pressure or impulse type SF_6 C.B's.

* In this type of breakers, gas is compressed by a moving cylinder system & it is released through a nozzle to quence the arc. This type is available in the voltage range 3.6kV to 765kV.

* Fig (a) shows a puffer type breaker in closed position. The moving cylinder & the moving contact are coupled together.

* When the contacts separate & the moving cylinder moves, the trapped gas is compressed. The trapped gas is released through a nozzle & flows axially to quench the arc as shown in Fig (b).

* There are two types of tank designs.

  Live tank design & dead tank design.

* In live tank design, interrupters are supported on procelain insulators.

* In dead tank design, interrupters are placed in SF_6 filled tank which is at earth potential.

* Live tank design is preferred for outdoor substation.

* A number of interrupters [are connected in series] on insulating supports are employed for EHV systems upto 765kV.

* In the C.B, the steady pressure of the gas is kept at 5 kg/cm^2.

* The gas pressure in the interrupter compartment increases rapidly to a level much above its steady value to quench the arc.

Advantages of SF_6 circuit Breakers:-

1. Size of SF_6 C.B is smaller than conventional C.B of same rating.
2. SF_6 gas is non-inflammable & chemically stable, decomposition products are not explosive hence no danger of fire.
3. Same gas is recirculated in the circuit hence requirement of gas is small.
4. Ample overload margin: For the same size of conductors, current carrying ability of SF_6 C.B is about 1.5 times that of air blast C.B because of more heat transferability.
5. The breaker is silent in operation & does not make sound like air blast C.B due to its closed gas circuit.
6. Sealed construction avoids contamination by moisture, dust etc. There are no carbon deposits.

7. Minimum Maintenance is required. It requires light Foundation & minimum auxiliary equipment.

8. Ability to interrupt low & high fault currents, Magnetising currents (I_μ) capacitive currents without excessive overvoltages with small arcing time.

9. Problems connected with current chopping are minimum.

10. No contact replacement required. contact corrosion is very small hence contacts do not suffer oxidation.

Disadvantages:-

1. Sealing problem arises due to the type of construction.
2. Imperfect Joint lead to leakage of gas.
3. The presence of moisture in the system is very dangerous.
4. Double pressure SF_6 C.B are relatively costly due to the type of construction & complex gas system.
5. Internal parts should be cleaned throughly during periodic maintenance under clean & dry environment.
6. special facilities are needed for transporting the gas which is very costly.
7. SF_6 breakers are costly as there is high cost of SF_6 gas.
8. Since the gas is to be reconditioned after every operation, additional equipment is required for the same.
9. Arced SF_6 gas is poisonous & should not be inhaled.

Applications:-

A typical C.B consists of interrupter units. Each unit is capable of interrupting currents upto 60kA & voltages in the range of 50-80kV. A Number of units are connected in series according to the system voltage.

Vaccum circuit Breakers:-

* The dielectric strength and arc interrupting ability of high vaccum is superior to those of procelain, oil, air & SF_6 at atmospheric pressure.
* It has now become possible to achieve pressures as low as 10^{-8} torr.

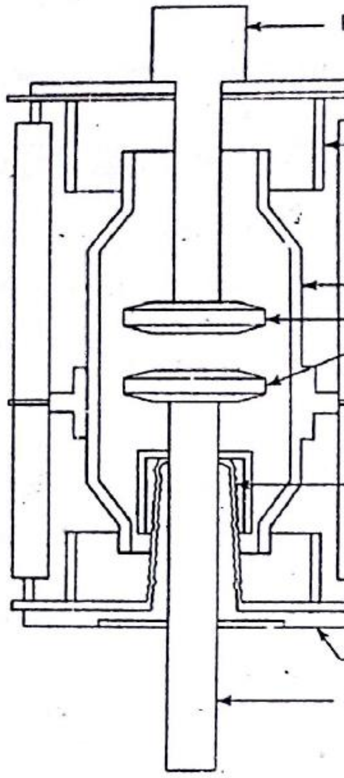
* In high vaccum of the order of 10^{-5} mm of mercury, the mean free path of the residual gas molecules becomes very large. It is of the order of few metres.
* Therefore, when contacts are separated by a few mm in high vaccum, an electron travels in the gap without collision.
* The formation of arc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

Principle of operation:-

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

Construction:-

* The breaker enclosure is made up of insulating material such as glass, procelain or glass fibre reinforced plastic.
* The vapour condensing shield is made of synthetic resin.
* This shield is provided to prevent the metal vapour reaching the insulating envelope.



* As the interrupter has a sealed construction, a stainless metallic bellows is used to allow the movement of the lower contact.
* one of its ends is welded to the moving contact.
* Its other end is welded to the lower end flange.
* Its contacts have large disc shaped faces.
* These faces contain spiral segments, so that the arc current produces axial magnetic field.
* This geometry helps the arc a move over the contact surface.
* The movement of arc over the contact surface minimises metal evaporation, & hence erosion of the contact due to arc.
* Two metal end flanges are provided.
* They support the fixed contact, outer insulating enclosure, vapour condensing shield & the metallic bellows.
* The sealing technique is similar to that used in electronic valves.

Working :-

* when the contacts are separated due to some abnormal conditions, an arc is struck between the contacts.
* The arc is produced due to ionisation of metal ions & depends very much on material of contacts.

* The arc interruption process in vaccum interrupters is different from other types of C.B's.

* The separation of contacts causes release of vapour which is filled in the contact space.

* It contains positive ions liberated from contact material. The vapour density depends on the current in the arc.

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

* When current to be interrupted is very small in vaccum the arc has several parallel paths. The total current is divided into many parallel arcs which repel each other & spreads over contact surface. This is called diffused arc which can be interrupted easily.

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

* Arc extinction in vaccum breakers is greatly influenced by material & shape of contacts & techniques of condensing metal vapour. The path of the arc is kept moving so that temperature at any one point will not be high.

* After final arc interruption, there is rapid building up of dielectric strength which is pecularity of vaccum breaker. They are suitable for capacitor switching as it will give restrike free performance. The small currents are interrupted before natural current zero which may cause chopping whose level depends on material of contact.

  * If the vapour pressure is increased, chopping level can be lowered.
  * If thermal conductivity is low, chopping level is also low.

Advantages:-

1. They are compact in size & have longer life.
2. There are no fire hazards
3. There is no generation of gas during & after operation
4. There is no restriction on interruption of fault current. (outstanding quality)
5. They require less maintenance & quite in operation.
6. They can successfully withstand lightning surges.
7. They have low arc energy
8. They have low inertia & hence smaller power is required for control mechanism.

Disadvantages:-

* A Major problem that occurs with this type of C.B's is that there is erosion of materials from electrodes & evolution of gases from the electrodes during arcing.

Applications:-

Vaccum circuit breakers have now become popular for voltage ratings upto 36kV. up to 36kV they employ a single interrupter.

Ratings of circuit Breakers:-

A circuit breaker has to perform the following major duties under short - circuit conditions.

1. To open the contacts to clear the fault.
2. To close the contacts on a fault.
3. To carry fault current for a short time while another circuit breaker is clearing the fault.

Therefore, in additional to rated current, voltage & frequency, circuit breakers have the following important ratings.

1. Breaking capacity
2. Making capacity
3. short - time capacity

1. Breaking capacity:-

It is of two types

i) symmetrical breaking capacity
ii) Asymmetrical breaking capacity.

i) symmetrical breaking capacity:-

It is the rms value of the ac component of the fault current that the circuit breaker is capable of breaking under specified conditions of recovery voltage.

ii) Asymmetrical breaking capacity:-

It is the rms value of the total current comprising of both ac & dc components of the fault current that the circuit breaker can break under specified conditions of recovery voltage.

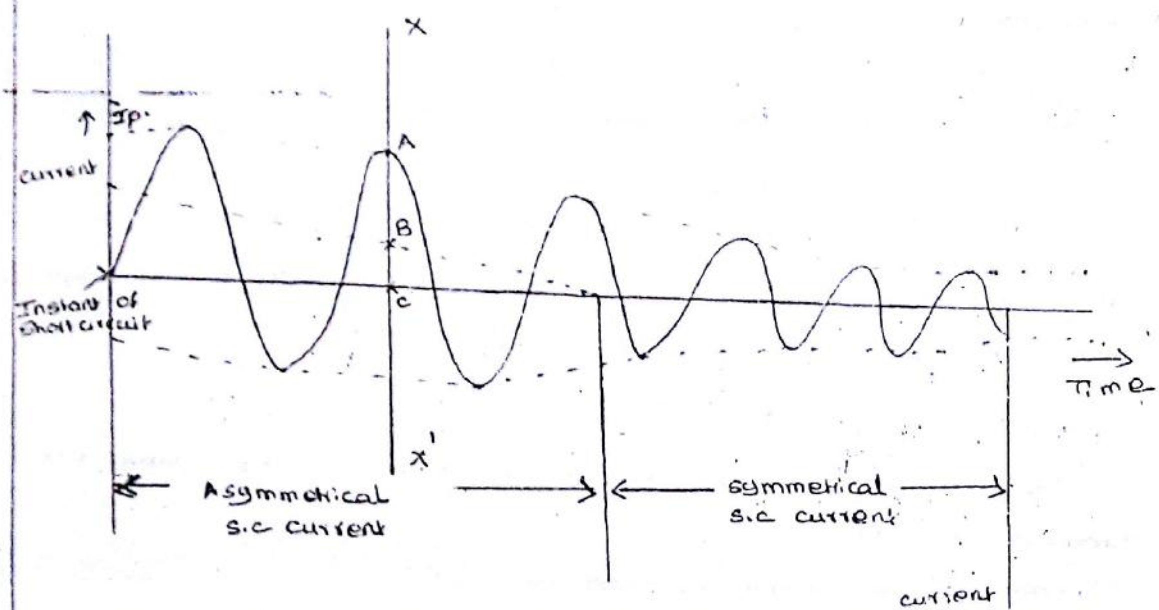


Fig shows a short circuit current wave. The short circuit current contains a dc component which dies out gradually. In the begining, the short circuit current is asymmetrical due to the dc component. When dc dies out completely, the short circuit current becomes symmetrical.

The line X-X' indicates the instant of contact separation. AB is the peak value of the ac component of the current at this instant. Therefore, the symmetrical breaking current which is the rms value of the ac component of the current at the instant of contact separation is equal to current $AB/\sqrt{2}$. The section BC is the dc component of the short-circuit current at this instant. Therefore, asymmetrical breaking current is given by

$$I_{asym} = \left(\frac{AB}{\sqrt{2}}\right)^2 + (BC)^2$$

For a 3 phase C.B,

Breaking capacity = $\sqrt{3}$ x rated voltage in kV x rated current in kA.

If the rated current is symmetrical, then breaking capacity will be symmetrical. If the rated current is asymmetrical, then breaking capacity will be asymmetrical.

The rated asymmetrical breaking current = 1.6 times the rated symmetrical current.

Making capacity:

The rated making current is defined as the peak value of the total current in the first cycle at which a circuit breaker can be closed onto a short circuit. Ip is the making current.

Making current = $\sqrt{2}$ × 1.8 × symmetrical breaking current

$\sqrt{2}$ — to obtain peak value.

1.8 — to take the dc component into account.

Making capacity = $\sqrt{2}$ × 1.8 × symmetrical breaking capacity

= 2.55 × symmetrical breaking capacity.

Short-time current Rating:-

* It is based on thermal & mechanical limitations.
* The C.B must be capable of carrying I_{sc} for a short period while another C.B (in series) is clearing the fault.
* The rated short-time current is the rms value of the total current that the circuit breaker can carry safely for a specified short period.

Rated voltage, current & frequency:-

Voltage levels will not be same at all points & it varies due to system operating conditions. So manufacturers have specified a rated maximum voltage at which the operation of the C.B is guaranteed. This specified voltage is somewhat higher than the rated nominal voltage.

The rated current is the rms value of the current that a C.B can carry continuously without any temperature rise in excess of its specified limit.

- The rated frequency in the frequency at which the circuit breaker has been designed to operate.

Rated operating Duty:-

The operating duty of a circuit breaker prescribes its operation which can be performed at stated time intervals.

For the C.B's, which are not meant for auto reclosing, there are two alternative operating duties

1) O − t − CO − t' − CO
2) O − t'' − CO

where O − opening operation

CO − closing operation followed by opening without any intentional time lag.

t, t', t'' − time intervals between successive operations.

According to IEC (International Electromechanical Commission), the values of t & t' is 3 minutes & t'' is 15 seconds.

For circuit breakers with auto reclosing, the operating duty is as follows

O - Dt - CO

Dt - dead time of the C.B expressed in cycle.

According to BSS (British standard codes), there is only one operating duty For the C.B's not intended for auto-reclosing.

B - 3 - MB - 3 - MB

B - breaking

MB - making followed by breaking without any intentional time delay.

3 - time interval in Minutes.

For the C.B's with auto reclosing, the operating duty is written as

B - Dt - MB

Dt - dead time expressed in cycles.

Testing of Circuit Breakers:-

There are two types of tests of C.B's namely

1. routine tests

2. Type tests.

1. Routine Tests:-

These are performed on every piece of circuit breaker in the premises of the manufacturer. The purpose of the routine test is to confirm the proper functioning of a circuit breaker.

2. Type tests:-

These are performed in a high voltage laboratory on sampled pieces of CB's of each type to confirm their characteristics & rated capacities according to their design.

All routine & type tests are performed according to Indian Standard (IS) codes or International Electromechanical Commission (IEC) codes or British standard (BS) codes.

Tests such as breaking capacity, making capacity, short time current rating tests comes under short circuit testing of C.B's.

For C.B's of smaller capacity, these tests are carried out by direct testing techniques. CB's of large capacities are tested by the Synthetic testing method.

In addition to short circuit tests, mechanical tests, thermal tests, dielectric tests, capacitive charging - current - breaking test, small Inductive breaking current test etc. are also performed.

Short - circuit Testing stations :-

There are two types of short - circuit testing stations

1. Field type testing station
2. Laboratory type testing station.

1. Field type testing station:-

In this, the power required for testing is derived from a large power system. The C.B to be tested is connected to the power system. Large amount of power is easily available for testing. Hence this method of testing is economical for testing of C.B's particularly high voltage C.B's. But it lacks flexibility.

Its drawbacks are:

1. For research & development work, tests cannot be repeated again & again without disturbing the power system.
2. The power available for testing varies, depending upon the loading conditions of the system.
3. It is very difficult to control the transient recovery voltage, RRRV etc.

2. Laboratory type testing station:-

In this, the power required for testing is taken from specially designed generators, which are installed in the laboratory for such testing.

Its advantages are:

1. For research & development work, tests can be carried out again & again to confirm the designed characteristics & capacity.
2. Current, Voltage, restriking voltage, RRRV, etc. can be controlled conveniently
3. Tests for circuit breakers of large capacity can be carried out using Synthetic Testing.

Its drawbacks are:

1. High cost of Installation
2. Availability of limited power for testing of circuit breakers.

Short - circuit generator:-

* In a laboratory, short - circuit generators are used to provide power for testing.
* The design of such generators is different from a conventional generator.

* These are specially designed to have very low reactance to give the maximum short-circuit output.
* To withstand high electromagnetic forces their windings are specially braced & made rugged.
* They are provided with a flywheel to supply K.E during short circuits.
* This also helps in speed regulation, of the set.
* The generator is driven by a three-phase I.M.
* Impulse excitation or super excitation is employed to counteract the demagnetisation effect of armature reaction.

Short-circuit transformer:-

* such a transformer has a low reactance & it is designed to withstand repeated short-circuits.
* To get different voltages for tests, its windings are arranged in sections. By series & parallel combinations of these sections, the desired test voltage is obtained.
* To get lower voltages than the generated voltage, a 3 ϕ transformer is generally used.
* For higher voltages than the generated voltages, normally banks of single phase transformers are employed.
* As transformer remains in the circuit for a short time, they do not pose any cooling problem.

Master circuit breaker:-

* It is used as a backup C.B.
* If the C.B under test fails to operate, the master C.B opens.
* The master C.B is set to operate at a predetermined time after the initiation of the short circuit.
* After every test, it isolates the C.B under test from the supply source.
* Its capacity is more than the capacity of the C.B under test.

Making switch:-

* This switch is used to apply short-circuit current at the desired moment during the test.
* The making switch is closed after closing the master C.B & the test C.B.
* It must be bounce free to avoid its burning or contact welding.
* To achieve this, a high pressure is used in the chamber.
* Its speed is also kept high.

Capacitors:-

* capacitors are used to control RRRV.
* They are used in synthetic testing
* Capacitors are also used for voltage measurement purpose.

Reactors & resistors:-

* These are used to control short-circuit test current.
* They also control power factor.
* The resistor controls the rate of decay of the d.c. component of the current.
* They control the transient recovery voltage.

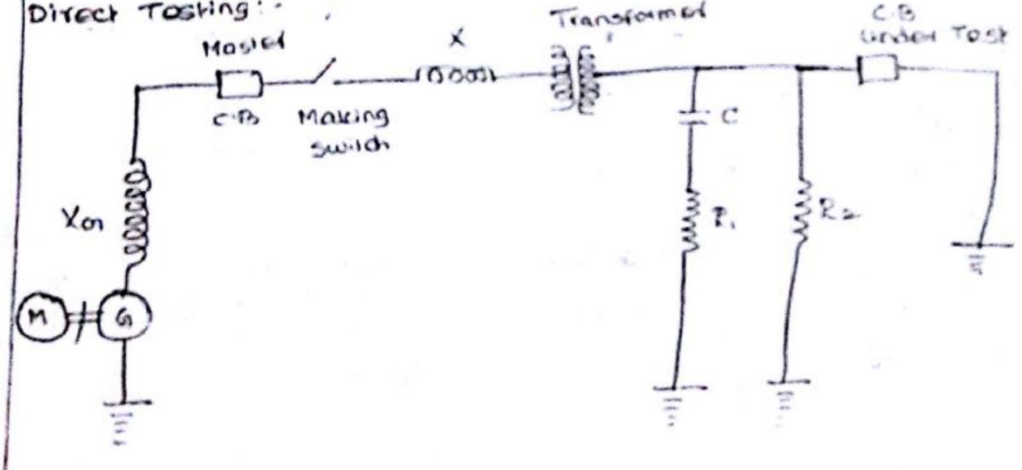
Testing procedure:-

During the short-circuit test, several switching operations are performed in a sequence in a very short time. for eg, the sequence of switching operations for breaking capacity test is as follows.

1. After running the driving motor of the short-circuit generator to a certain speed it is switched off.
2. Impulse excitation is switched on.
3. Master circuit breaker is closed.
4. Oscillograph is switched on.
5. Making switch is closed.
6. Circuit breaker under test is opened.
7. Master C.B is opened.
8. Exciter circuit of the short circuit generator is switched off.

It is not possible to perform this sequence of operations manually. There is an automatic control for the purpose. The time of operation for the above sequence is of the order of 0.2 second.

Direct Testing:-



* In direct testing, the C.B is tested under the conditions which actually exist on power systems.
* It is subjected to restriking voltage which is expected in practical situations.
* Fig shows an arrangement for direct testing.
* The reactor X is to control short-circuit current.
* C, R_1 & R_2 are to adjust transient restriking voltage.
* Short circuit tests to be performed are as follows:

Test for breaking capacity:-

* First of all, the master C.B - the C.B under test are closed.
* Then the short circuit current is passed by closing the making switch.
* The short circuit current is interrupted by opening the breaker under test at the desired moment.
* The following measurements are taken.

1. Symmetrical breaking current
2. Asymmetrical breaking current
3. Recovery voltage
4. Frequency of oscillation & RRRV.

The C.B must be capable of breaking all currents up to its rated capacity. As it is not possible to test at all values of current, tests are performed at 10%, 30%, 60% & 100% of its rated breaking current.

Test for making capacity:-

* The master C.B & the making switch are closed first, then the short circuit is initiated by closing the C.B under test.

* The rated making current (ie) the peak value of the first major loop of the short circuit current wave is measured.

Duty cycle test:-

The following duty cycle tests are performed.

1. B - 3 - B - 3 - B tests are performed at 10%, 30% & 60% of the rated symmetrical breaking capacity.
2. B - 3 - MB - 3 - MB tests are performed
   a) at not less than 100% of the rated symmetrical breaking capacity. &
   b) at not less than 100% of the rated making capacity.

This test can also be performed as two separate tests

a) M - 3 - M make test
b) B - 3 - B - 3 - B break test

3. B-3-B-3-B tests are performed at not less than 100% of the rated asymmetrical breaking capacity.

Here B – breaking operation

M – Making operation

MB – Making operation followed by the breaking operation without any intentional time delay.

Short-time current test:-

* The rated short-time current is passed through the C.B under test for a specified short duration (1 second or 3 second) & current is measured by taking an oscillograph of the current wave.
* The short-time current should not cause any mechanical or insulation damage or any contact welding.
* The equivalent rms short-time current is evaluated as follows:

The time interval is divided into 10 equal parts. These are marked as $t_0, t_1, t_2 \ldots t_9, t_{10}$. The asymmetrical rms values of the current at these intervals are marked as $I_0, I_1, I_2 \cdots I_9, I_{10}$. The equivalent rms value of the short-time current using simpson formula is given by

$$I = \left[\frac{1}{3}\left[I_0^2 + 4(I_1^2 + I_3^2 + I_5^2 + I_7^2 + I_9^2) + 2(I_2^2 + I_4^2 + I_6^2 + I_8^2 + I_{10}^2)\right]\right]^{1/2}$$

Indirect Testing:-

* The testing of HV C.B's of large capacity also requires very large capacity of the testing station, which is uneconomical.
* It is also not practical to increase the short-circuit capacity of the testing station.
* Therefore, indirect methods of testing are used for the testing of large C.B's.

The important indirect methods of testing are:

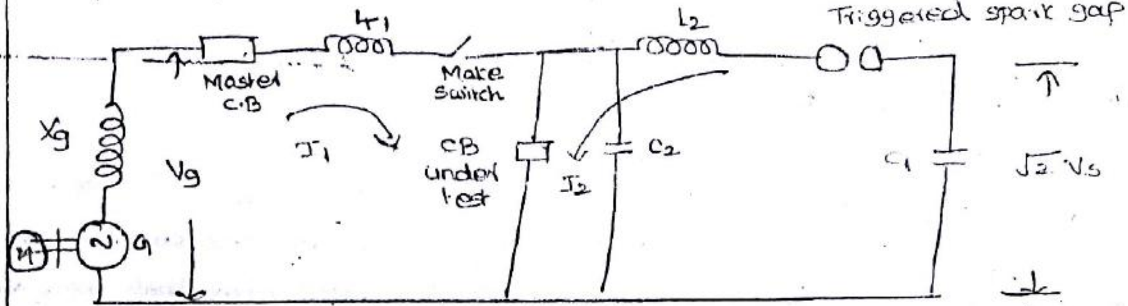
1. Unit testing
2. Synthetic testing

1. Unit testing:-

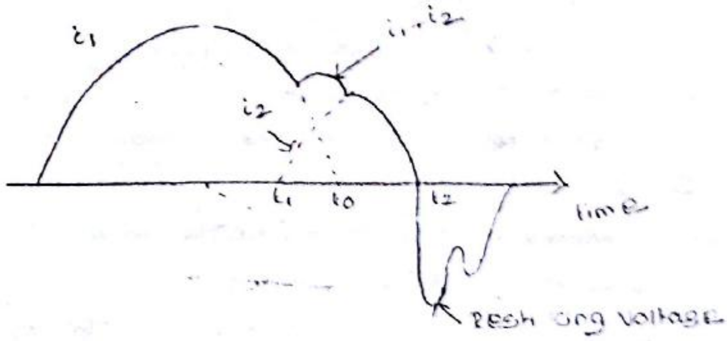
* Generally, high voltage C.B's are designed with several arc interrupter units in series.
* Each unit can be tested separately.
* From the test results of one unit, the capacity of the complete breaker can be determined.
* This type of testing is known as unit testing.

Synthetic testing:-

* In this method of testing, there are two sources of power supply for the testing, a current source & a voltage source.
* The current source is a high current, low voltage source.
* It supplies short circuit current during the test.
* The voltage source is a high voltage, low current source.
* It provides restriking & recovery voltage.
* There are two methods of synthetic testing – parallel current injection method & series current injection method.
* parallel current injection method is widely used as it is capable of providing RRRV & recovery voltage as required by various standards.



* It is a circuit for parallel current injection method of synthetic testing.
* The high current source is a motor driven generator.
* It injects a high short circuit current I_1 into the circuit breaker under test at a relatively reduced voltage V_g.
* The inductance L_1 is to control the short circuit current.
* The master C.B & the C.B under test are tripped before current I_1 reaches its natural zero.
* These C.B's are fully opened by the time t_0.
* The capacitor C_1 is a high voltage source to provide recovery voltage.
* It is charged prior to the test, to a voltage $\sqrt{2}\, V_s$
* This voltage is equal to the peak power frequency voltage which will appear across the contacts at the moment the C.B under test interrupts the current.
* L_2 & C_2 control transient recovery voltage & RRRV.
* The triggered spark gap is fired at t_1, slightly before the short-circuit current I_1 reaches its natural zero.
* It is done to properly simulate the pre current zero zone during the test.
* There is a control circuit to fire the triggered spark gap at the appropriate moment.



waveform during synthetic testing

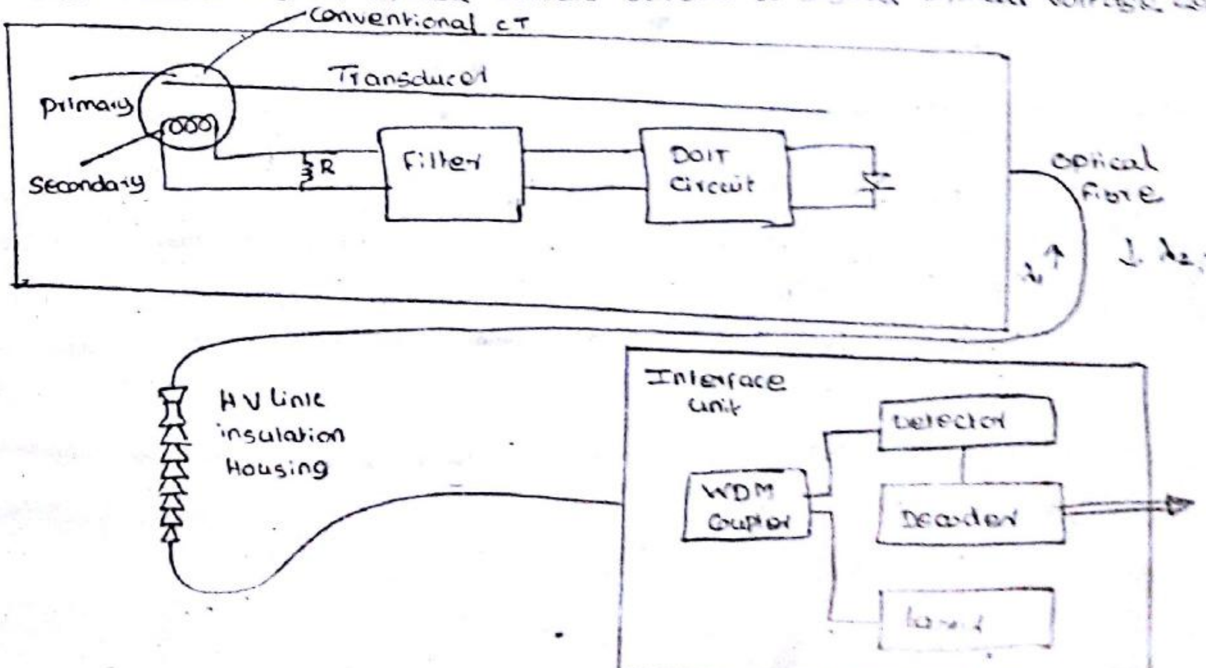
Intelligent circuit Breakers for Low voltage, Medium voltage & High Voltage Applications:-

* The conventional C.B's perform only on & off switching functions.
* Now the C.B's would have intelligence due to the algorithm provided in the Microprocessor located in the operating mechanism cabinet & connected to DOIT instrument transformer fitted in the main HV circuit. The intelligence functions will include

- communication with bank of breakers.
- communication with control room.
- Interlocking functions.
- Data transmission via fibre optic data bus etc.
- Remote switching via radio signals.

Digital optical Instrument Transformers (DOIT) :-

These include Digital optical current sensors & Digital optical voltage sensors.



* A digital optical current sensor system consists of a main conventional current transformer with copper primary / insulated copper wire secondary & fibre optic interface & fibre optic secondary leads between high potential zone & earth potential zone.
* The secondary insulation is simplified as the fibre optic is a dielectric medium.
* The burden on main current transformer is reduced.
* Hence size of main CT core is reduced & accuracy is increased.

Digital optical voltage sensor is fitted with the conventional capacitor voltage transformer (CVT or CCVT).

* The voltage values are sampled & digitized in a unit fitted to the lower capacitor unit of the capacitor voltage divider.
* The digitized optical signals are transmitted over the fibre optic link to the measurement, protection / monitoring, control circuit via OETP.
* The information is exchanged in the form of digitised light signals transmitted through optical fibres.
* The output of port CT's is given to interface unit on ground level via fibre-optic cable.
* Opto electric techniques are also used for controlling HVDC thyristor valves.
* The transmitter at sending end converts the electrical pulses into light pulses. These light pulses are transmitted through the fo cable. At the receiving end the light signals are converted into electrical signals.