A Review on Different Types of Circuit Breakers

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Abstract: Circuit breakers are indispensable safety devices used in electrical systems to protect against overcurrents, short circuits, and electrical faults. This abstract provides an overview of the various types of circuit breakers, each designed to address specific needs and challenges within diverse applications.

Circuit Breaker

A circuit breaker is a mechanical switch that automatically operates to protect a circuit from the damage caused by fault current. It automatically breaks the circuit upon sensing a huge draw of current flow due to overloading or short circuit. It can also manually break open the circuit for maintenance or fault clearance. It can safely close & open a circuit to protect it from damage.

Objective of Circuit Breaker

The main objective of a circuit breaker is to safely break open the circuit

- It should momentarily withstand the fault current
- It should safely break open the circuit
- It should quickly extinguish the arc.
- Its terminals should withstand the voltage after breaking.
- It should prevent the arc from re-striking.

Mediums used for Arc Extinction

The electrical arc tries to make the circuit, so the current still flows in it. It must be extinguished & different kinds of circuit breakers use various insulating or dielectric arc extinction mediums such as.

- Air
- Vacuum
- Insulating Oil
- Insulating gas such as SF6 (Sulphur hexafluoride)

Other than the medium being used arch quenching, various arc extinction techniques are used to quickly & safely eliminate an arc.

Methods used for Arc Extinction

- **Cooling of Arc**: The arc heats up the air molecule which ionizes & reduces the resistance of the air. Cooling the arc will recombine the ionized particle into its natural state & increase the dielectric strength of the air molecule. As the resistance of the medium increases, the voltage required to maintain the arc also increases & the current starts to drop resulting in arc quenching.
- **Air Blasting**: Such a method is used in the air blast circuit breaker, where the arc is quenched using a blast of compressed air. The ionized air particles are replaced with non-ionized air molecules that

have higher dielectric strength. It increases the resistance thus reducing the current which leads to the extinction of the arc.

- **Increasing the length of arc**: The arc length is directly proportional to its voltage. Increasing the length of the arc by separating the contact terminals further apart will increase the voltage required to maintain it. Thus it will extinguish.
- **Reducing cross-section of arc:** Another technique is to reduce the cross-section of arc by reducing the contact sizes. Therefore, the voltage required for arc increases & extinguish it.
- **Deflecting the arc:** In this technique, a magnetic field is created to deflect the arc. it blows out the arc into a section of the circuit breaker called arc chute where it is cooled off & extinguishes.
- **Dividing or splitting the arc:** In this technique, the arc is split into multiple arcs by proving multiple contacts in between. The arc is split into numerous small arc in series which increases its length & resistance. Therefore, reducing the arc current & eventually extinguishing it.
- **Zero current quenching:** this is the most common method used in the AC circuit breaker. There are inherently multiple zero currents in an AC waveform. The circuit is opened at the exact point of zero current. So that the current does not rise to generate arc.
- **Using charged capacitor in parallel**: This technique is used in DC circuit breaker. The DC does not have natural zero currents. Therefore, a charged capacitor with an inductor is used in parallel to introduce an artificial zero current in the line to extinguish the arc.

Basically, a circuit breaker is necessary to install on every line to protect it from any kind of hazard or disasters.

Circuit breakers are manufactured by keeping various features in mind such as;

- Intended Voltage Applications
- Alternating or Direct Current
- Location of the installation
- Design Characteristics
- Method and medium used for current interruption (Arc Extinction)

There are various types of circuit breakers that are differentiated based on various characteristics. Circuit breakers are mainly classified into two types;

- AC Circuit Breaker
- DC Circuit Breaker

AC Circuit Breaker

AC refers to alternating current whose voltage & current fluctuates along the zero value many times in a second. The energy at this zero point is null which can be utilized to break the circuit without generating the arc. Circuit breakers used for AC are quite different than in DC. The inherent zero crossings in AC provide multiple chances in a second for the arc to extinguish itself.

The strength of the arc is directly proportional to the level of the voltage. Therefore, low voltage arcs can be easily quenched but high voltages arc require a more sophisticated approach to extinguish it. therefore, the CB are classified based on their voltage level.

High Voltage AC Circuit Breaker

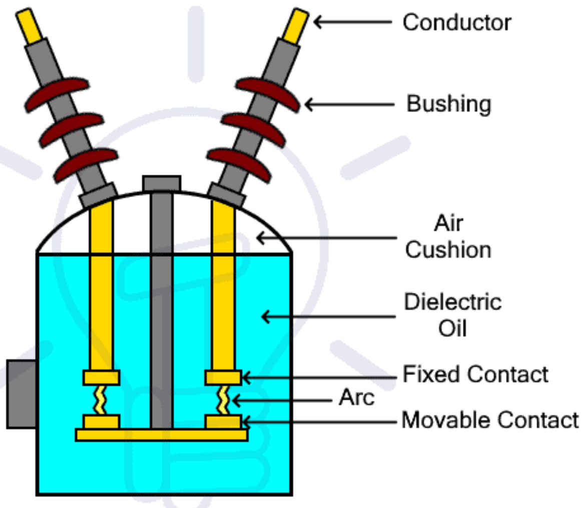
The definition of high voltage depends on context. IEC considers high voltages as the voltage that exceeds 1000v. Such voltage has a tendency to generate an arc that is not easily extinguishable. Circuit breakers used for making & breaking contacts at such voltages are called HV circuit breakers.

The arc extinction can be done using various methods in such high voltages. The HV circuit breaker may or may not use OIL for arc extinction; therefore, they are classified into two types:

- Oil Circuit Breaker
- Oil-Less Circuit Breaker

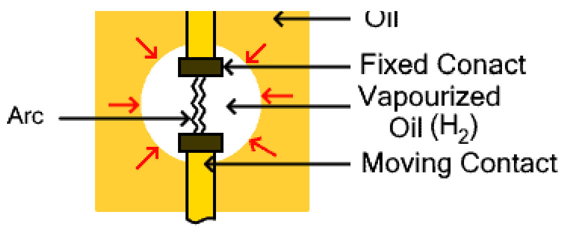
Oil Circuit Breaker

The type of circuit breaker that uses oil as a dielectric or insulating medium to quench the arc is called oil circuit breaker. It is one of the oldest types of high voltage circuit breaker & it mainly uses the **transformer oil**. The oil used in such circuit breakers has very good insulating properties far better than air. The CB contacts are submerged in oil which is used to quench the arc once the contacts separate. The heat generated by the arc is dissipated inside the oil.



Oil Circuit Breaker

When CB breaks its current-carrying contacts inside the oil, the distance between the contacts starts increasing. Initially, there is a very small distance between the contacts but there is also a very high voltage gradient. Due to this, the oil between the contacts starts ionizing & creates an arc between the contacts.



The arc generates a lot of heat & vaporizes the oil surrounding it which is mostly decomposed into hydrogen gas. The hydrogen gas bubbles are rapidly generated surrounding the contact almost ten times the volumes of the oil. This oil surrounding the gas bubbles put a lot of pressure on it increasing de-ionization of the medium. De-ionization of the medium increases its dielectric strength that will quench the arc at zero crossing of the current.

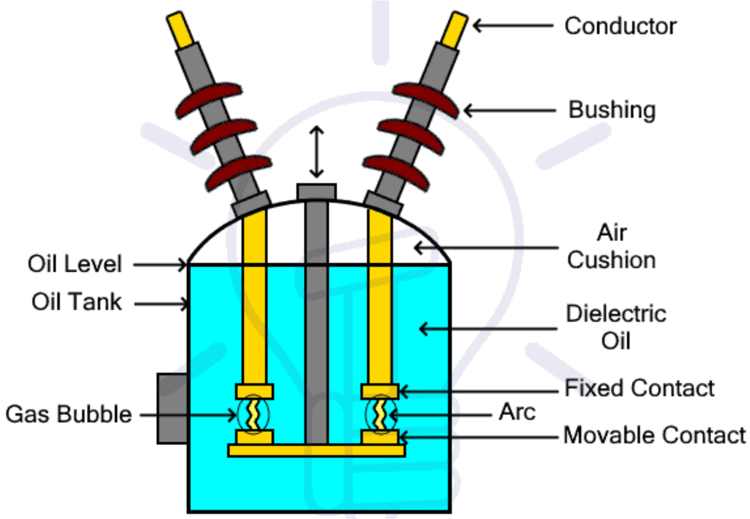
Besides that, the cooling effect of the oil & the gas bubbles also helps in arc quenching.

Based on the amount of oil being used in OCB (Oil Circuit Breaker), they are classified into two types

- Bulk Oil Circuit Breaker (BOCB)
- Minimum Oil Circuit Breaker (MOCB)

Bulk Oil Circuit Breaker (BOCB)

Such type of oil circuit breaker uses the insulating oil to quench the arc as well as insulate the live contacts from the earthed parts of the CB. Such CB uses oil in bulk.



Bulk Oil Circuit Breaker

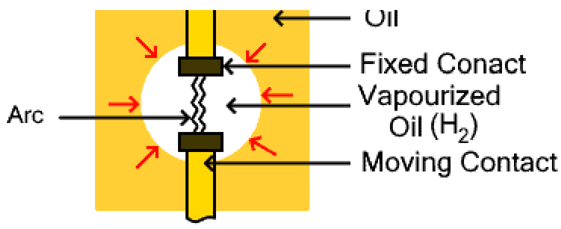
BOCB has an iron tank that holds the insulating oil inside. The contacts (fixed & moving) are submerged inside the oil. Upon breaking the contacts, the arc generates heat & produces gas. The pressurized gas displaces the oil inside the tank where air at the top of the tank is used as a cushion. Therefore, the tank should not be completely filled with oil. Also, the tank must be strong enough to absorb the pressure released by the gas. There is also a gas vent for releasing the gas safely outside.

The arc is quenched by utilizing the compressed gas generated by the heat of the arc. Since the contacts are moving, the distance is also increased between the contacts. it also increases the resistance for the arc. Also, the cooling effect of the gas also plays its role in quenching the arc once the current goes through zero crossing.

The BOCB is divided into further two types based on the division of arcs to quickly extinguish it.

Single Break Bulk Oil Circuit Breaker

In single break BOCB, there is only one fixed contact & one moving contact. Upon fault current, the moving contact pushes backward generating an arc that is extinguished by the compressed gas inside the oil. As the name suggests, there is only one break between the contacts.



Double Break Bulk Oil Circuit Breaker

In double break BOCB, there are two fixed contacts & one moving contact. The fixed contacts are fixated to the tank at both ends connected to the live conductors while the moving contact can move upward & downward using an insulating rod.

In normal conditions, the moving contact is pushed upward to make the contact at both ends with the fixed contacts. upon fault conditions, the moving contacts is pulled downward to break the contacts & generating arcs at both ends. This way, the arc is split into two parts having lower strength which can be easily cooled off & quenched inside the oil.

Advantages

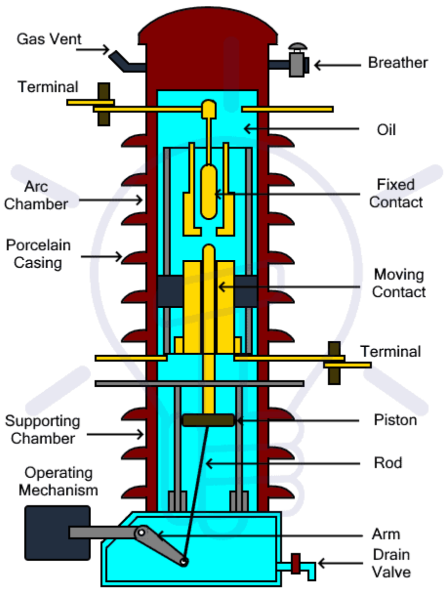
- The oil used for arc quenching has very high dielectric strength
- The oil insulates the live contacts from the earthed parts
- The oil produces hydrogen gas with the heat from the arc which is beneficial for arc quenching.
- The pressure of oil compresses the gas to deionize the medium.
- The gas also helps in cooling the medium.

Disadvantages

- The oil is inflammable & causes a fire hazard.
- The contacts can get damaged with the arc.
- The carbonization of the oil from the contacts reduces its dielectric strength.
- The contacts & the oil must be checked & maintained regularly.
- The use of huge amount of oil increases its cost
- Their large oil-filled tanks are heavy & take large space.

Minimum Oil Circuit Breaker (MOCB)

As we know the bulk oil circuit breaker uses a huge amount of oil to quench the arc which may pose a threat for fire hazard. To reduce such risk, the MOCB uses far less oil than in BOCB. The oil is only used for arc quenching & not to isolate the live parts from earthed parts.



Minimum Oil Circuit Breaker

MOCB has two chambers: the arc chamber & the supporting chamber. The arc chamber is made from porcelain encased with bakelised paper. It is filled with insulating oil. This chamber is used for quenching the arc. It contains fixed & moving contacts.

The supporting chamber is made from porcelain mounted on top of a metal chamber. This chamber is used for isolating the arc chamber as well as support the arc chamber by mounting it on top of it. this chamber is also filled with oil used only for insulation.

The moving contact moves upwards & downwards with the help of a fixed armed in the supporting chamber. The moving contact has a fixed piston which is used for forcing the oil upwards helping to quench the arc.

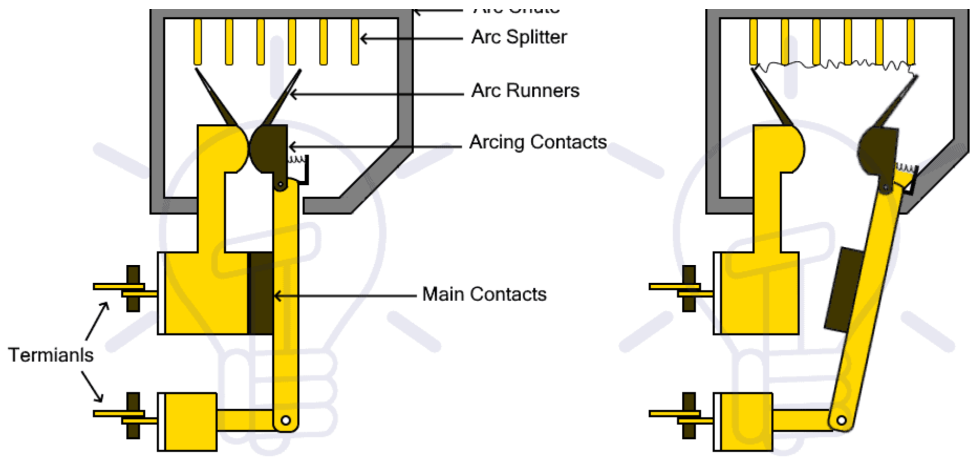
Under normal conditions, the lower moving contact makes a connection with the upper fixed contact. Upon fault condition, the arm pulls the moving contact downward & an arc is generated. This arc is extinguished by the pressurized gas in the oil surrounding it & by pushing the oil from the support chamber with the help of the piston. As the contact moves downward, a vent becomes available for the hydrogen gas to exhaust out.

In terms of venting, MOCB is divided into two types.

Air Circuit Breaker (ACB)

It is a type of HV oil-less circuit breaker that uses air as its arc extinguishing medium. It is used for short circuit & overcurrent protection up to 15KV & 800 to 10K Amps. It is preferable than oil circuit breaker due to the absence of inflammable oil & the risk of fire hazards.

As we know, the objective of a circuit breaker is to safely extinguish the arc & prevention of arc re-striking. In order to extinguish the arc, we have to increase the arc voltage (minimum voltage required to maintain the arc). ACB uses the air as a medium to extinguish the arc. Unlike the other mediums, the air can be used in various ways to extinguish the arc by using various methods such as cooling the arc, increasing the arc length, splitting the arc & air blasting, etc.



Air Circuit Breaker

In ACB, there are two pairs of contacts i.e. main contacts (made of copper) & arcing contacts (made of carbon). Under normal conditions, the main contacts are used for the normal supply of current. Under fault current, the main contacts open while the arcing contacts remain closed.

As soon as the main contacts open up, the current will flow through the arcing contacts. at this point, there is no arc & the main contacts are safe. The arc generates once the arcing contact opens up. The arc sweeps upwards resulting in cooling & increasing the length of the arc. Thus the arc is extinguished at zero current.

ACB is further divided into the following types.

- Plain Air Circuit Breaker
- Arc-Chute Circuit Breaker
- Magnetic Blow Out Circuit Breaker

- Air Blast Circuit Breaker

Air Blast Circuit Breaker

Air Blast Circuit Breaker or ABCB uses a blast of compressed air for the arc interruption. The air is stored & compressed in a tank. This air is released through a nozzle at a very high speed to extinguish the arc. They have high voltage capacity of up to 450KV. They are used for 220KV lines in switchyards.

The air blast circuit breaker is further divided into four types

- Axial Blast Air Circuit Breaker
- Axial Blast with sliding moving contact ACB
- Radial Blast Air Circuit Breaker
- Cross Blast Air Circuit Breaker

Sulphur Hexafluoride (SF6) Circuit Breaker

Sulphur Hexafluoride or shortly known as SF6 is a non-flammable & insulating gas that has very high electronegativity. It has a high tendency to absorb electrons.

When the arc is struck between the contacts, the medium is ionized due to free electrons. The SF6 absorbs the free electrons & form negative ions that are far heavier than free electrons. Due to their heavyweight, they are immobile & reduces the mobility of charges. This enhances the dielectric strength of the medium where the arc is quenched. The SF6 has far more superior insulating & arc quenching capabilities than air almost 100 times better.

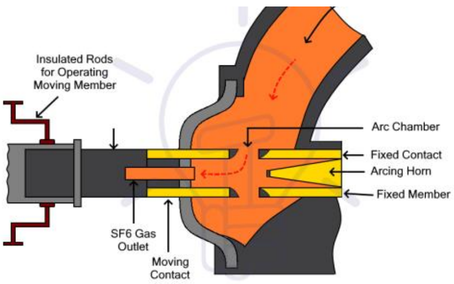
The SF6 is very expensive & a greenhouse gas. SF6 itself is not toxic but its product gases are toxic & Its emission is dangerous for the environment. Therefore, a close circuit gas system is designed for such breaker where the SF6 gas is reutilized after each operation. The system also monitors its pressure which is directly proportional to its dielectric strength.

There are three types of SF6 Circuit Breakers

- Non-Puffer Type SF6 Circuit Breaker
- Single Pressure Puffer Type SF6 Circuit Breaker
- Double Pressure Type SF6 Circuit Breaker

Non-Puffer Type

In non-Puffer SF6 CB, pressurized SF6 gas is stored in the gas chamber. While the arc quenching is done inside an interrupter unit. This unit has moving & fixed contacts that are basically hollow cylinders. The fixed contact has arc horns while the moving contact has vents for pressurized gas to flow.



Sulphur Hexafluoride SF6 Circuit Breaker

Under a fault condition, the moving contact is moved apart from the fixed contact. Its movement is synchronized with the valve of the gas chamber. as soon as the contacts open, the valve is opened & pressurized SF6 is introduced into the arc chamber. The SF6 quench the arc & flows through the hollow moving contact. This gas is then recombined & pumped back into the gas chamber for re-utilization.

Non-Puffer SF6 circuit breakers were used when they were first invented. Nowadays easier & simple SF6 breakers are used that utilize the puffer cylinder.

Advantages of SF6 Circuit Breaker

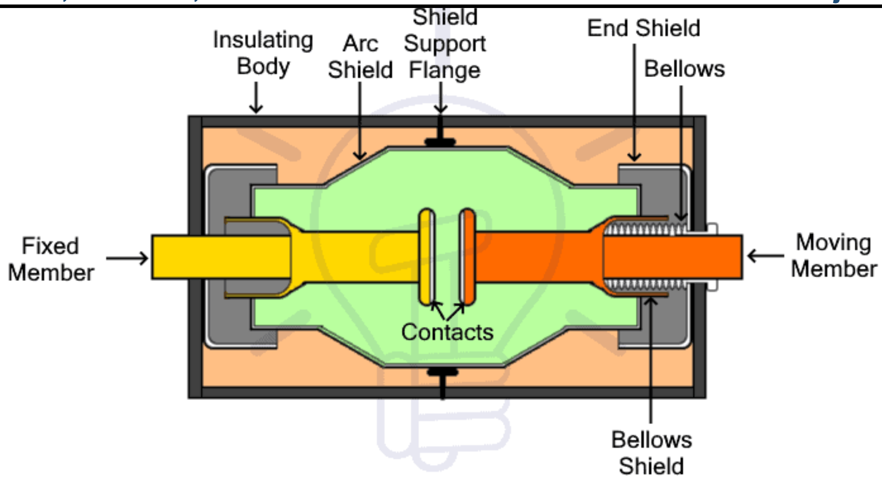
- Sulphur Hexafluoride SF6 has superior arc quenching property almost 100 times more effective than air.
- The arcing time of the SF6 circuit breaker is very short.
- The dielectric strength of SF6 gas is 2 to 3 times higher than air. It also increases with increasing pressure.
- Due to high dielectric strength, the required contact separation is small to prevent arc restriking.
- High dielectric strength leads to large current interruption capabilities.
- The SF6 CB has a compact design. Thus require small space & cost for installation.
- SF6 gas can handle all kinds of switching phenomena.
- SF6 CB has a closed circuit gas system with no leakage. Therefore, best for any installation in any kind of (extreme) environment.
- No carbon particles are formed with arcing, thus the dielectric strength does not reduce.
- It does not require an expensive & bulky air compressing system except for double pressure type which is obsolete.
- The operation of SF6 CB is noiseless.
- SF6 gas is non-toxic in its pure state.
- SF6 gas is non-flammable, thus no chance of fire hazards.
- Since its operation is flawless, it requires less maintenance.

Disadvantages of SF6 Circuit Breaker

- The byproducts formed from SF6 gas during arcing are toxic for the environment but they are mostly recombined into SF6
- The decomposed SF6 is toxic.
- SF6 is an expensive gas so these circuit breakers are costly.
- Leakage of SF6 from the joints must be continuously monitored.
- It requires special transportation & maintaining of the quality of gas.
- The SF6 is heavier than oxygen & can cause difficulty in breathing.
- Recombination & reconditioning of the SF6 gas requires additional equipment.

Vacuum Circuit Breaker (VCB)

A Vacuum Circuit Breaker or VCB is a type of circuit breaker that uses the vacuum as the arc quenching medium. The vacuum has very high dielectric strength & arc quenching properties far more superior than any other medium. It can quickly recover its dielectric strength. Due to its high dielectric strength, VCB requires a very small gap between its contacts to prevent restriking. The pressure of the vacuum used in VCB is in the range of $10^{\wedge -7}$ to $10^{\wedge -5}$ torr (1 torr = 1mm of Hg). It is suitable for switching medium-voltage ranging from 22kV to 66 kV.



Vacuum Circuit Breaker

The **switching operation** of current-carrying contacts & the arc interruption occurs inside a closed chamber called **Vacuum interrupter**. Its outer insulating body is made up of glass or ceramic material. It consists of fixed & movable contacts surrounded by arc shield. The arc shield is used for the prevention of the deterioration of the dielectric strength of the vacuum by preventing the ionized metallic vapours on the inner side of the outer insulating body. The movable member is connected to a controlled mechanism (for movement) using bellow. The bellow completely seals the vacuum chamber & prevents any leak.

The **operation** of VCB is very simple, the arc interruption occurs inside the vacuum upon first zero current. When a fault condition occurs, the contacts are separated. During separation, the contacts do not separate at once but its contact area is reduced which eventually reduces to a single point. The amount of current passing through this single point heats up the contact & vaporizes (reducing the dielectric strength of the vacuum) to create a medium for the arc. Thus the arc is generated. At next zero current, the conducting metallic vapors re-condenses on the contact surface & the dielectric strength of the vacuum is recovered. Since the contacts are separated & there are no vapors between them, the arc cannot re-strike. In simple words, a VCB quenches the arc by producing the high dielectric strength to prevent arc re-striking after the current zero.

Since the arc is generated due to the ionization of the contacts, its material plays a vital role in keeping the CB reliable & maintenance-free. Therefore, the VCB contact material must have the following properties

- It must have high electrical conductivity to avoid overheating upon normal load currents.
- It must have high thermal conductivity to dissipate large heat produced during arcing.
- It should have high arc withstanding capabilities & low current chopping level.
- It must have low resistance with high density.

The contacts are made from copper alloy such as Copper-bismuth, copper-lead, and copper-chromium material.

Advantages of VCB

- Vacuum is the absence of matter thus VCB has no fire hazards
- The Vacuum has very high dielectric strength & superior arc quenching properties than air & SF6.
- Due to high dielectric strength, VCB requires a small contact gap to extinguish the arc.
- VCB is compact & requires small installation space.
- It is free of maintenance thus it’s reliable having a long life.
- It does not produce any noise doing the operation.
- There are no toxic exhaust gases.
- Its operation is very fast.
- It is suitable for repeated use.
- It can break all types of fault currents.
- Since there is a vacuum, the control mechanism requires less power to move the contacts.

Disadvantages of VCB

- A single vacuum interrupter can only interrupt up to 38kV.
- For interrupting voltages more than 38kV, multiple vacuum interrupters must be connected in series.
- It's uneconomical for voltages exceeding 38Kv since it requires more than one VCB & the total cost increases.
- In case of loss of vacuum, the VCB becomes useless.

Conclusion

In conclusion, circuit breakers are integral components of electrical systems, serving as a first line of defence against electrical faults. The choice of the appropriate type of circuit breaker depends on the specific requirements and conditions of the electrical system. With ongoing technological advancements, circuit breakers continue to evolve to meet the changing needs of modern electrical infrastructure while prioritizing safety and reliability**.**

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