UNIT – 3

CIRCUIT BREAKER

Unit-03 /Lecture-01

INTRODUCTION ABOUT CIRCUIT BREAKER –

CIRCUIT BREAKER: -
Electrical Circuit Breaker is a switching device which can be operated manually as well as automatically for controlling and protection of electrical power system respectively. As the modern power system deals with huge currents, the special attention should be given during designing of circuit breaker to safe interruption of arc produced during the operation of circuit breaker.

WHAT IS ARC
During opening of current carrying contacts in a circuit breaker the medium in between opening contacts become highly ionized through which the interrupting current gets low resistive path and continues to flow through this path even the contacts are physically separated. During the flowing of current from one contact to other the path becomes so heated that it glows. This is called arc.

ARC IN VACUUM:
As there is no such media the arc in vacuum circuit breaker differs from general arc in circuit breaker. In vacuum arc the electrons, ions and atoms are all derived from the electrodes itself. The absolute vacuum is not practically possible to create so there are some gases in practical vacuum chamber but the gas pressure here is so low that it does not have any significant role in conduction process during arc. In this sense the vacuum arc is therefore really a metal vapour discharge.

BULK OIL CIRCUIT BREAKER:
BOCB is such types of circuit breakers where oil is used as arc quenching media as well as insulating media between current carrying contacts and earthed parts of the breaker. The oil used here is same as transformer insulating oil.

MINIMUM OIL CIRCUIT BREAKER OR MOCB:
These types of circuit breakers utilize oil as the interrupting media. However, unlike bulk oil circuit breaker, a minimum oil circuit breaker places the interrupting unit in insulating chamber at live potential. The insulating oil is available only in interrupting chamber. The features of designing MOCB are to reduce requirement of oil, and
hence these breaker are called minimum oil circuit breaker.

SF6 CIRCUIT BREAKER:
A circuit breaker in which the current carrying contacts operate in Sulphur Hexafluoride or SF6 gas is known as an SF6 Circuit Breaker.

VACUUM CIRCUIT BREAKER:
A vacuum circuit breaker is such kind of circuit breaker where the arc quenching takes place in vacuum. The technology is suitable for mainly medium voltage application.

ELECTRICAL FUSE :
An electrical fuse is a weakest part of an electrical circuit which breaks when more than predetermined current flows through it. A fuse is a part of the circuit which consists of conductor which melts easily and breaks the connection when electric current exceeds the predetermined value.

FUSE WIRE:

The function of fuse wire is to carry the normal current without excessive heating but more than normal current when pass through fuse wire, it rapidly heats up and melts.

Switchgear and Protection

Switchgear protection plays a vital role in modern power system network, right from generation through transmission to distribution end. The current interruption device or switching device is called circuit breaker in switchgear protection system.

- The circuit breaker can be operated manually as when required and it is also operated during over current and short circuit or any other faults in the system by sensing the abnormality of system. The circuit breaker senses the faulty condition of system through protection relay and this relay is again actuated by faulty signal normally comes from current transformer or voltage transformer.
- Switchgear has to perform the function of carrying, making and breaking the normal load current like a switch and it has to perform the function of clearing the fault in addition to that it also has provision of metering and regulating the various parameters of electrical power system. Thus the switchgear includes circuit breaker, current transformer, voltage transformer, protection relay, measuring instrument, electrical switch, electrical fuse, miniature circuit breaker, lightening arrestor or surge arrestor, electrical isolator and other associated equipment.
- Electric switchgear is necessary at every switching point in the electrical power system. There are various voltage levels and hence various fault levels between the generating stations and load centers. Therefore various types of switchgear assembly are required depending upon different voltage levels of the system.
- Besides the power system network, electrical switchgear is also required in industrial works, industrial projects, domestic and commercial buildings.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Define- Arc, Circuit breaker and its types	RGPV/ June 2013	7
Q.2	Electrical Fuse- Definition anf Fuse material	RGPV/ June 2012	7

Unit-03 /Lecture-02

What is Circuit Breaker?

Definition of circuit breaker: –

Electrical circuit breaker is a switching device which can be operated manually as well as automatically for controlling and protection of electrical power system respectively. As the modern power system deals with huge currents, the special attention should be given during designing of circuit breaker to safe interruption of arc produced during the operation of circuit breaker.

Introduction to Circuit Breaker

The modern power system deals with huge power network and huge numbers of associated electrical equipment. During short circuit fault or any other types of electrical fault these equipment as well as the power network suffer a high stress of fault current in them which may damage the equipment and networks permanently. For saving these equipment and the power networks the fault current should be cleared from the system as quickly as possible. Again after the fault is cleared, the system must come to its normal working condition as soon as possible for supplying reliable quality power to the receiving ends.

In addition to that for proper controlling of power system, different switching operations are required to be performed. So for timely disconnecting and reconnecting different parts of power system network for protection and control, there must be some special type of switching devices which can be operated safely under huge current carrying condition. During interruption of huge current, there would be large arcing in between switching contacts, so care should be taken to quench these arcs in circuit breaker in safe manner.

The circuit breaker is the special device which does all the required switching operations during current carrying condition.

Working Principle of Circuit Breaker

The circuit breaker mainly consists of fixed contacts and moving contacts. In normal “on” condition of circuit breaker, these two contacts are physically connected to each other due to applied mechanical pressure on the moving contacts. There is an arrangement stored potential energy in the operating mechanism of circuit breaker which is realized if switching signal given to the breaker. The potential energy can be stored in the circuit breaker by different ways like by deforming metal spring, by compressed air, or by hydraulic pressure. But whatever the source of potential energy, it must be released during operation. Release of potential energy makes sliding of the moving contact at extremely fast manner. All circuit breaker have operating coils (tripping coils and close coil), whenever these coils are energized by switching pulse, the plunger inside them displaced. This operating coil plunger is typically attached to the operating mechanism of circuit breaker, as a result the mechanically stored potential energy in the breaker mechanism is released in forms of kinetic energy, which makes the moving contact to move as these moving contacts mechanically attached through a gear lever arrangement with the operating mechanism. After a cycle of operation of circuit breaker the total stored energy is released and hence the potential energy again stored in the operating mechanism of circuit breaker by means of spring charging motor or air compressor or by any other means.

Operating principle of circuit breaker.

The circuit breaker has to carry large rated or fault power. Due to this large power there is always dangerously high arcing between moving contacts and fixed contact during operation of circuit breaker. Again as we discussed earlier the arc in circuit breaker can be quenching safely if the dielectric strength between the current carrying contacts of circuit breaker increases rapidly during every current zero crossing of the alternating current. The dielectric strength of the media in between contacts can be increased in numbers of ways, like by compressing the ionized arcing media since compressing accelerates the deionization process of the media, by cooling the arcing media since cooling increase the resistance of arcing path or by replacing the ionized arcing media by fresh gasses. Hence a numbers of arc quenching processes should be involved in operation of circuit breaker.

Types of Circuit Breaker

- **According different criteria there are different** types of circuit breaker**. According to their arc quenching media the circuit breaker can be divided as-**

1. Oil circuit breaker.
2. Air circuit breaker.
3. SF_6 circuit breaker.
4. Vacuum circuit breaker.

- **According to their services the circuit breaker can be divided as-**

1. Outdoor circuit breaker
2. Indoor breaker.

- **According to the operating mechanism of circuit breaker they can be divided as-**

1. Spring operated circuit breaker.
2. Pneumatic circuit breaker.
3. Hydraulic circuit breaker.

- **According to the voltage level of installation** types of circuit breaker **are referred as-**

1. High voltage circuit breaker.
2. Medium voltage circuit breaker.
3. Low voltage circuit breaker.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Define circuit breaker and explain principle of operation	RGPV/ June 2013	7
Q.2	Classify various types of Circuit breaker	RGPV/ June 2011	7

Unit-03 /Lecture-03

What is Arc ?

During opening of current carrying contacts in a circuit breaker the medium in between opening contacts become highly ionized through which the interrupting current gets low resistive path and continues to flow through this path even the contacts are physically separated. During the flowing of current from one contact to other the path becomes so heated that it glows. This is called arc.

Arc in Circuit Breaker

Whenever, on load current contacts of circuit breaker open there is an arc in circuit breaker, established between the separating contacts. As long as this arc is sustained in between the contacts the current through the circuit breaker will not be interrupted finally as because arc is itself a conductive path of electricity. For total interruption of current the circuit breaker it is essential to quench the arc as quick as possible. The main designing criteria of a circuit breaker is to provide appropriate technology of arc quenching in circuit breaker to fulfill quick and safe current interruption. So before going through different arc quenching techniques employed in circuit breaker.

Thermal Ionization of Gas

There are numbers of free electrons and ions present in a gas at room temperature due to ultraviolet rays, cosmic rays and radioactivity of the earth. These free electrons and ions are so few in number that they are insufficient to sustain conduction of electricity. The gas molecules move randomly at room temperature. It is found an air molecule at a temperature of 300°K (Room temperature) moves randomly with an approximate average velocity of 500 meters/second and collides other molecules at a rate of 10^{10} times/second. These randomly moving molecules collide each other in very frequent manner but the kinetic energy of the molecules is not sufficient to extract an electron from atoms of the molecules. If the temperature is increased the air will be heated up and consequently the velocity on the molecules increased. Higher velocity means higher impact during inter molecular collision. During this situation some of the molecules are disassociated in to atoms. If temperature of the air is further increased many atoms are deprived of valence electrons and make the gas ionized. Then this ionized gas can conduct electricity because of sufficient free electrons. This condition of any gas or air is called plasma. This phenomenon is called thermal ionization of gas.

Ionization due to Electron Collision

As we discussed that there are always some free electrons and ions presents in the air or gas but they are insufficient to conduct electricity. Whenever these free electrons come across a strong electric field, these are directed towards higher potential points in the field and acquire sufficiently high velocity. In other words, the electrons are accelerated along the direction of the electric field due to high potential gradient. During their travel these electrons collide with other atoms and molecules of the air or gas and extract valance electrons from their orbits. After extracted from parent atoms, the electrons will also run along the direction of the same electric field due to potential gradient. These electrons will similarly collide with other atoms and create more free electrons which will also be directed along the electric field. Due to this conjugative action the numbers of free electrons in the gas will become so high that the gas stars conducting electricity. This phenomenon is known as ionization of gas due to electron collision.

Deionization of Gas

If all the cause of ionization of gas are removed from an ionized gas it rapidly come back to its neutral state by recombination of the positive and negative charges. The process of recombination of positive and negative charges is known as deionization process. In deionization by diffusion, the negative ions or electrons and positive ions move to the walls under the influence of concentration gradients and thus completing the process of recombination.

Role of Arc in Circuit Breaker

When two current contacts just open, an arc bridges the contact gap through which the current gets a low resistive path to flow so there will not be any sudden interruption of current. As there is no sudden and abrupt change in current during opening of the contacts, there will not be any abnormal switching over voltage in the system.

If i is the current flows through the contacts just before they open, L is the system inductance, switching over voltage during opening of contacts, may be expressed as

V = L.(di/dt) where di/dt rate of change of current with respect to time during opening of the contacts. In the case of alternating current arc is monetarily extinguished at every current zero. After crossing every current zero the media between separated contacts gets ionized again during next cycle of current and the arc in circuit breaker is reestablished. To make the interruption complete and successful, this re-ionization in between separated contacts to be prevented after a current zero.

If arc in circuit breaker is absence during opening of current carrying contacts, there would be sudden and abrupt interruption of current which will cause a huge switching over voltage sufficient to severely stress the insulation of the system. On the other hand, the arc provides a gradual but quick, transition from the current carrying to the current breaking states of the contacts.

Arc Interruption or Arc Quenching or Arc Extinction Theory

Arc Column Characteristics

At high temperature the charged particles in a gas are rapidly and randomly move, but in absence of electric field, no net motion is occurred. Whenever an electric field is applied in the gas, the charged particles gain drift velocity superimposed on their random thermal motion. The drift velocity is proportional to the voltage gradient of the field and particle mobility. The particle mobility depends upon the mass of the particle, heavier particles, lower the mobility. The mobility also depends upon mean free paths available in the gas for random movement of the particles. Since every time a particle collides, it losses its directed velocity and has to be re-accelerated in the direction of electric field again. Hence net mobility of the particles is reduced. If the gas is in highly pressure, it becomes denser and hence, the gas molecules come closer to each other, therefore collision occurs more frequently which lowers the mobility particles. The total current by charged particles is directly proportional to their mobility. Therefore the mobility of charged particles depends upon the temperature, pressure of the gas and as well as nature of the gas. Again the mobility of gas particles determines the degree ionization of gas.

So from above explanation we can say that ionization process of gas depends upon nature of gas (heavier or lighter gas particles), pressure of gas and temperature of gas. As we said earlier the intensity of arc column depend up on the presence of ionized media between separated electrical contacts, hence, special attention should be given in reducing ionization or increasing deionization of media between contacts. That is why the main designing feature of circuit breaker is to provide different pressure control methods, cooling methods for different arc media in between circuit

breaker contacts.

Heat loss from Arc

Heat loss from arc in circuit breaker is taken place through conduction, convection as well as radiation. In circuit breaker with plain break arc in oil, arc in chutes or narrow slots nearly all the heat loss due to conduction. In air blast circuit breaker or in breaker where a gas flow is present between the electrical contacts, the heat loss of arc plasma occurs due to convection process. At normal pressure the radiation is not a significant factor but at higher pressure the radiation may become a very important factor of heat dissipation from arc plasma. During opening of electrical contacts, the arc in circuit breaker is produced and it is extinguished at every zero crossing of the current and then it is again reestablished during next cycle. The final arc extinction or arc quenching in circuit breaker is achieved by rapid increase of the dielectric strength in the medium between the contacts so that reestablishment of arc after zero crossing cannot be possible. This rapid increase of dielectric strength in between circuit breaker contacts is achieved either by deionization of gas in the arc media or by replacing ionized gas by cool and fresh gas.

There are various deionization processes applied for arc extinction in circuit breaker, let us discussed in brief.

Deionization of Gas due to Increasing Pressure

If pressure of the arc path increases, the density of the ionized gas is increased which means, the particles in the gas come closer to each other and as a result the mean free path of the particles is reduced. This increases the collision rate and as we discussed earlier at every collision the charged particles loss their directed velocity along electric field and again they are re-accelerated towards field. It can be said that over all mobility of the charged particles is reduced so the voltage required to maintain the arc is increased. Another effect of the increased density of particles is a higher rate of deionization of gas due to the recombination of oppositely charged particles.

Deionization of Gas due to Decreasing Temperature

The rate of ionization of gas depends upon the intensity of impact during collision of gas particles. The intensity of impact during collision of particles again depends upon velocity of random motions of the particles. This random motion of a particle and its velocity increases with increase of temperature of the gas. Hence it can be concluded like that if temperature of a gas is increased; its ionization process is increased and opposite statement is also true that is if the temperature is decreased the rate of ionization of gas is decreased means deionization of gas is increased. Therefore more voltage required to maintain arc plasma with a decreased temperature. Finally it can be said that the cooling effectively increases the resistance of the arc.

Different types of circuit breakers employ different cooling techniques which we will discuss later in the course of circuit breakers.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain various methods of arc extinction in a circuit breaker. Discuss problems associated with interruption of (i) Normal short circuit current (ii) capacitor switching	RGPV/ June 2013	7
Q.2	Explain Arc Quenching Phenomena of Circuit breaker	RGPV/ June 2011	7

Unit-03 /Lecture-04

Arc Interruption Theory

The insulating material (may be fluid or air) used in circuit breaker should serve two important functions. They are written as follows:

1. It should provide sufficient insulation between the contacts when circuit breaker opens.
2. It should extinguish the arc occurring between the contacts when circuit breaker opens.

The second point needs more explanation. To understand this point let us consider a situation if there is some fault or short circuit in the system, the relay provides desired signals to the circuit breaker so as to prevent system from ongoing fault. Now when circuit breaker opens its contacts, due to this an arc is drawn. The arc is interrupted by suitable insulator and technique.

Methods of Arc Interruption

There are two methods by which interruption is done.

1. High resistance method,
2. Low resistance method or zero interruption method.

- In high interruption method we can increase the electrical resistance many times to such a high value that it forces the current to reach to zero and thus restricting the possibility of arc being restruck. Proper steps must be taken in order to ensure that the rate at which the resistance is increased or decreased is not abnormal because it may lead to generation of harmful induced voltages in the system. The arc resistance can be increased by various methods like lengthening or cooling of the arc etc.

Limitations of high resistance method:

Arc discharge has a resistive nature due to this most of the energy is received by circuit breaker itself hence proper care should be taken during the manufacturing of circuit breaker like mechanical strength etc. Therefore this method is applied in dc power circuit breaker, low and medium ac power circuit breaker.

- Low resistance method is applicable only for ac circuit and it is possible there because of presence of natural zero of current. The arc gets extinguished at the natural zero of the ac wave and is prevented from restricting again by rapid building of dielectric strength of the contact space.

There are two theories which explains the phenomenon of arc extinction:

1. Energy balance theory,
2. Voltage race theory.

Before going in details about these theories, we should know the following terms.

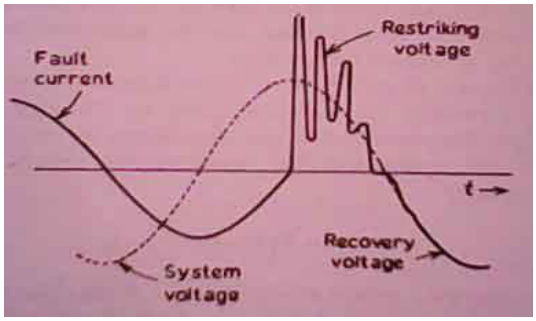
Restriking voltage:

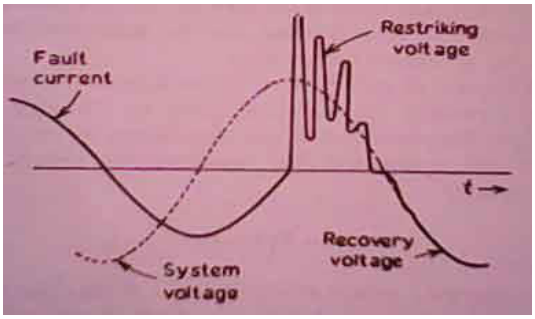
It may be defined as the voltage that appears across the breaking contact at the instant of arc extinction.

Recovery voltage :

It may be defined as the voltage that appears across the breaker contact after the complete removal of transient oscillations and final extinction of arc has resulted in all the poles.

Active recovery voltage : It may be defined as the instantaneous recovery voltage at the instant of arc extinction.





Arc voltage :

It may be defined as the voltage that appears across the contact during the arcing period, when the current flow is maintained in the form of an arc. It assumes low value except for the point at which the voltage rise rapidly to a peak value and current reaches to zero.

1. **Energy Balance Theory**: When the contact of circuit breaker are about to open, restriking voltage is zero, hence generated heat would be zero and when the contacts are fully open there is infinite resistance this again make no production of heat. We can conclude from this that the maximum generated heat is lying between these two cases and can be approximated, now this theory is based on the fact that the rate of generation of heat between the the contacts of circuit breaker is lower than the rate at which heat between the contact is dissipated. Thus if it is possible to remove the generated heat by cooling, lengthening and splitting the arc at a high rate the generation, arc can be extinguished.
2. **Voltage Race Theory** : The arc is due to the ionisation of the gap between the contact of the circuit breaker. Thus the resistance at the initial stage is very small i.e. when the contacts are closed and as the contact separates the resistance starts increasing. If we remove ions at the initial stage either by recombining them into neutral molecules or inserting insulation at a rate faster than the rate of ionisation, the arc can be interrupted. The ionisation at zero current depends on the voltage known as restriking voltage.

S.NO	RGPV QUESTIONS	Year	Marks

Q.1	Distinguish between the recovery voltage and restriking voltage.	RGPV/ June 2013,2014	7
Q.2	Explain the significance of RRRV in operation of Circuit breaker.	RGPV/ June 2013,2014	7
Q.3	Explain (i) Recovery voltage (ii) Active recovery voltage (iii) Restriking voltage (iv) RRRV (v) RRRV (vi) Current chopping (vii) resistance switching	RGPV/ June 2012,2013	7
Q.4	Discus recovery rate theory and energy balance theory of arc interruption of CB.	RGPV/ Dec 2012,	7
Q.5	Explain various methods of Arc Quenching	RGPV/ Dec 2011,	7

Expression for restriking voltage

Let us define an expression for restriking voltage. For loss-less or ideal system we have,

$$v = V\left[1 - cos\left(\frac{t}{\sqrt{LC}}\right)\right]$$

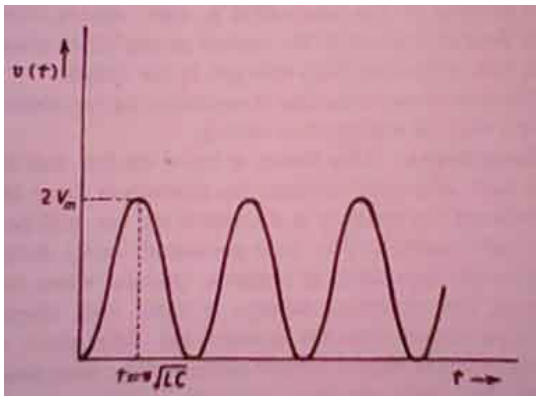
Here v = restriking voltage.

V = value of voltage at the instant of interruption.

L and C are series inductor and shunt capacitance up to fault point.

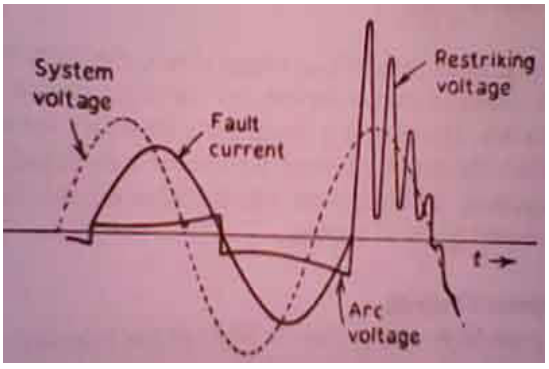
Thus from above equation we can see that lower the value of product of L and C, higher the value of restriking voltage.

The variation of v versus time is plotted below:



voltage across breaker contacts ” width=”382” height=”280” class=”size-full wp-image-7523” /> Restriking voltage across breaker contacts

Now let us consider a practical system, or assume there finite loss in the system. As fig. shown below in this case the restriking voltage is damped out due to the presence of some finite resistance. Here it is assumed that the current lags behind the voltage by an angle(measured in degrees) of 90.However in practical situation angle may varies depending upon time in cycle at which the fault is occurred.



Air Circuit Breaker

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 SF_6 circuit breakers.

Oil Circuit Breaker Bulk and Minimum Oil Circuit Breaker

Mineral oil has better insulating property than air. In oil circuit breaker the fixed contact and moving contact are immerged inside the insulating oil. Whenever there is a separation of current carrying contacts in the oil, the arc in circuit breaker is initialized at the moment of separation of contacts, and due to this arc the oil is vaporized and decomposed in mostly hydrogen gas and ultimately creates a hydrogen bubble around the arc. This highly compressed gas bubble around the arc prevents re-striking of the arc after current reaches zero crossing of the cycle. The oil circuit breaker is the one of the oldest type of circuit breakers.

Operation of Oil Circuit Breaker

The operation of oil circuit breaker is quite simple let's have a discussion. When the current carrying contacts in the oil are separated an arc is established in between the separated contacts. Actually, when separation of contacts has just started, distance between the current contacts is small as a result the voltage gradient between contacts becomes high. This high voltage gradient between the contacts ionized the oil and consequently initiates arcing between the contacts. This arc will produce a large amount of heat in surrounding oil and vaporizes the oil and decomposes the oil in mostly hydrogen and a small amount of methane, ethylene and acetylene. The hydrogen gas cannot remain in molecular form and it is broken into its atomic form releasing lot of heat. The arc temperature may reach up to 5000° K. Due to this high temperature the gas is liberated surround the arc very rapidly and forms an excessively fast growing gas bubble around the arc. It is found that the mixture of gases occupies a volume about one thousand times that of the oil decomposed.

From this figure we can assume how fast the gas bubble around the arc will grow in size. If this growing gas bubble around the arc is compressed by any means then rate of de – ionization process of ionized gaseous media in between the contacts will accelerate which rapidly increase the dielectric strength between the contacts and consequently the arc will be quenched at zero crossing of the current cycle. This is the basic operation of oil circuit breaker. In addition to that cooling effect of hydrogen gas surround the arc path also helps, the quick arc quenching in oil circuit breaker.

Types of Oil Circuit Breakers

There are mainly two types of oil circuit breakers available-

Bulk Oil Circuit Breaker or BOCB

Bulk oil circuit breaker or BOCB is such types of circuit breakers where oil is used as arc quenching media as well as insulating media between current carrying contacts and earthed parts of the breaker. The oil used here is same as transformer insulating oil.

Minimum Oil Circuit Breaker or MOCB

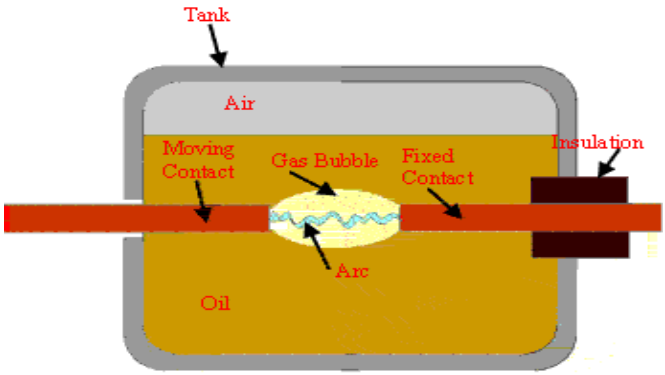
These types of circuit breakers utilize oil as the interrupting media. However, unlike bulk oil circuit breaker, a minimum oil circuit breaker places the interrupting unit in insulating chamber at live potential. The insulating oil is available only in interrupting chamber. The features of designing MOCB is to reduce requirement of oil, and hence these breaker are called minimum oil circuit breaker.

Bulk Oil Circuit Breaker

Construction of Bulk Oil Circuit Breaker

The basic construction of bulk oil circuit breaker is quite simple. Here all moving contacts and fixed contacts are immerged in oil inside closed iron vessel or iron tank. Whenever the current carrying contacts are being open within the oil the arc is produced in between the separated contacts. The large energy will be dissipated from the arc in oil which vaporizes the oil as well as decomposes it. Because of that a large gaseous pressure is developed inside the oil which tries to displace the liquid oil from surrounding of the contacts. The inner wall of the oil tank has to withstand this large pressure of the displaced oil. Thus the oil tank of bulk oil circuit breaker has to be sufficiently strong in construction. An air cushion is necessary between the oil surface and tank roof to accommodate the displaced oil when gas forms around the arc. That is why the oil tank is not totally filled up with oil it is filled up to certain level above which the air is tight in the tank. The breaker tank top cover should be securely bolted on the tank body and total breaker must be properly locked with foundation otherwise it may jump out during interruption of high fault current. In these type of equipment where expansible oil is enclosed in an air tight vessel (oil tank) there must be a gas vent fitted on the tank cover. Naturally some form of gas vent always is provided on the cover of bulk oil circuit breaker tank. This is very basic features for construction of bulk oil circuit breaker.

Arc Quenching in Bulk Oil Circuit Breaker



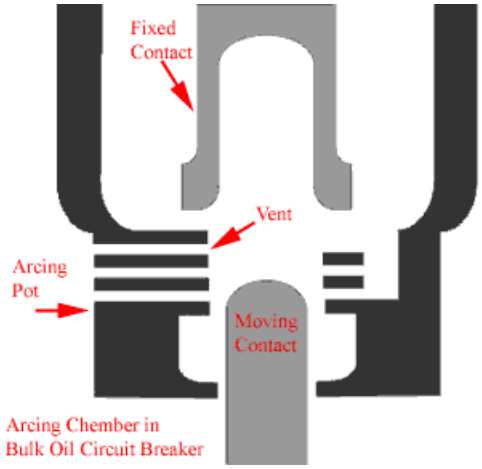
Conceptual view of Bulk Oil Circuit Breaker

When the current carrying contacts in the oil are separated an arc is established in between the separated contacts. This arc will produce rapidly growing gas bubble around the arc. As the moving contact move away from fixed contact the length of arc is increased as a result the resistance of the arc increases. The increased resistance causes lowering the temperature and hence reducing the formation of gasses surround the arc. The arc quenching in bulk oil circuit breaker takes place when current passes through zero crossing. If we go through the arc quenching phenomenon more thoroughly we will find many other factors effects the arc quenching in bulk oil circuit breaker. As the gas bubble is enclosed by the oil inside the totally air tight vessel, the oil surround it will apply high pressure on the bubble, which results highly compressed gas around the arc. As the pressure is increased the de – ionization of gas increases which helps the arc quenching. The cooling effect of hydrogen gas also helps in arc quenching in

oil circuit breaker.

Single Break Bulk Oil Circuit Breaker

In single break bulk oil circuit breaker there is one pair of current carrying contacts for each phase of power circuit. The each pair of current carrying contacts in this bulk oil circuit breaker consists of one fixed contact and one moving contact. Fixed contact is stationary contact and moving contact moves away from fixed contact during opening of the circuit breaker. As the moving contact is being moved away from fixed contact the arc is produced in between the contacts and it is extinguished during zero crossing of the fault current, due to the reasons as explain in previous chapter. As the days go on further research works have been done to improve better arc control in single break bulk oil circuit breaker. The main aim of development of bulk oil circuit breaker is to increase the pressure developed by the vaporization and dissociation of oil. Since in large gas pressure, the mean free paths of electrons and ions are reduced which results in effective deionization. So if the pressure can be increased, the rate of deionization is increased which helps to quick arc extinction. It has been found that if the opening of fixed and moving contacts is done inside a semi closed insulated chamber then the gas bubble created around the arc will get less space of expansion, hence it becomes highly compressed. These semi closed insulated arcing chamber in bulk oil circuit breaker is known as side vented explosion pot or cross jet pot. The principle of operation of cross jet pot is quite simple let's have a discussion. The pressure developed by the vaporization and dissociation of the oil is retained in the side vented explosive pot by withdrawing the moving contact through a stack of insulating plates having a minimum radial clearance around the contact. Thus there is practically no release of pressure until the moving contact uncovers one of the side vents. The compressed hydrogen gas can then escape across the arc path, thus exerting a powerful cooling action on the ionized column.



When the current zero is reached, the post arc resistance increased rapidly due this cooling action. At higher breaking currents larger will be the pressure generated and a bulk oil circuit breaker gives its best performance at the highest current within its rating. These single break bulk oil circuit breaker may have problem during clearing low currents such as load current of the breaker.

Various improvement in the design of pressure chamber or side vented explosive chamber have been suggested to overcome the problem of low current interruption. One solution of this is providing a supplementary oil chamber below the side vents. This supplementary oil chamber is known as compensating chamber which provides fresh source of oil to be vaporized in order to feed more clean gas back across the arc path during clearing low current.

Double Break Bulk Oil Circuit Breaker

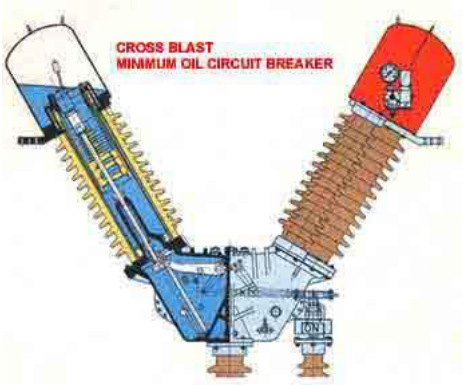
Various improvements in the design of bulk oil circuit breaker have been suggested to satisfactory and safe arc interruption especially at currents below the rated maximum. One solution to this problem is to use an intermediate contact between tow current carrying contacts. The arc is here split into two parts in series. The aim here is to extinguish the second arc quickly by using the gas pressure and oil momentum due to the first arc. In double break bulk oil circuit breaker, there are two fixed contact and are bridged by one moving contact. The moving contact is fitted with driving mechanism of the oil circuit breaker by means of an insulated rod. As the moving contact bridge moves downwards the contact gaps are created with fixed contacts at both end of the intermediate moving contact bridge. Hence arcs are produced at both contacts gap.

Minimum Oil Circuit Breaker

As the volume of the oil in bulk oil circuit breaker is huge, the chances of fire hazard in bulk oil system are more. For avoiding unwanted fire hazard in the system, one important development in the design of oil circuit breaker has been introduced where use of oil in the circuit breaker is much less than that of bulk oil circuit breaker. It has been decided that the oil in the circuit breaker should be used only as arc quenching media not as an insulating media. Then the concept of minimum oil circuit breaker comes. In this type of circuit breaker the arc interrupting device is enclosed in a tank of insulating material which as a whole is at live potential of system. This chamber is called arcing chamber or interrupting pot. The gas pressure developed in the arcing chamber depends upon the current to be interrupted. Higher the current to be interrupted causes larger the gas pressure developed in side the chamber, hence better the arc quenching. But this put a limit on the design of the arc chamber for mechanical stresses. With use of better insulating materials for the arcing chambers such as glass fiber, reinforced synthetic resin etc, the minimum oil circuit breaker are able to meet easily the increased fault levels of the system.

Working Principle or Arc Quenching in Minimum Oil Circuit Breaker

Working Principle of minimum oil circuit breaker or arc quenching in minimum oil circuit breaker is described below. In a minimum oil circuit breaker, the arc drawn across the current carrying contacts is contained inside the arcing chamber.



Hence the hydrogen bubble formed by the vaporized oil is trapped inside the chamber. As the contacts continue to move, after its certain travel an exit vent becomes available for exhausting the trapped hydrogen gas. There are two different types of arcing chamber is available in terms of venting are provided in the arcing chambers. One is axial venting and other is radial venting. In axial venting, gases (mostly Hydrogen), produced due to vaporization of oil and decomposition of oil during arc, will sweep the arc in axial or longitudinal direction.

Working principle Minimum Oil Circuit Breaker

Axial venting arc chamber.

The moving contact has just been separated and arc is initiated in MOCB.

The ionized gas around the arc sweep away through upper vent and cold oil enters into the arcing chamber through the lower vent in axial direction as soon as the moving contact tip crosses the lower vent opening and final arc quenching in minimum oil circuit breaker occurs

The cold oil occupies the gap between fixed contact and moving contact and the minimum oil circuit breaker finally comes into open position.

Radial venting or cross blast, the gases (mostly Hydrogen) sweep the arc in radial or transverse direction.

- The axial venting generates high gas pressure and hence has high dielectric strength, so it is mainly used for interrupting low current at high voltage.
- On the other hand radial venting produces relatively low gas pressure and hence low dielectric strength so it can be used for low voltage and high current interruption.

Many times the combination of both is used in minimum oil circuit breaker so that the chamber is equally efficient to interrupt low current as well as high current. These types of circuit breaker are available up to 8000 MVA at 245 KV.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Derive the expression for Re-Striking voltage in terms of system capacitance and	RGPV/ June 2013	7
Q.2	Write short notes on Air blast circuit breaker.	RGPV/ June 2013,14	7
Q.3	Describe with the neat sketch principle of operation, construction and working of minimum oil CB. What is the advantage over bulk oil CB.	RGPV/ June 2013	

Unit-03 /Lecture-05

Air Circuit Breaker

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 SF_6 circuit breakers.

Working Principle of Air Circuit Breaker

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.

Types of ACB

There are mainly two types of ACB are available.

1. Plain air circuit breaker.
2. Air blast Circuit Breaker.

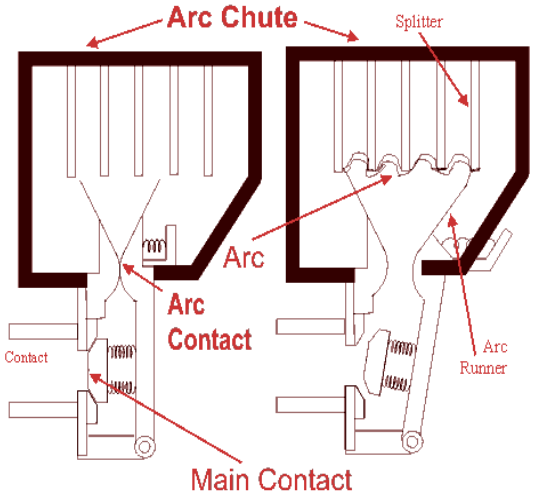
Operation of ACB

- 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 be made 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. High temperature plastics reinforced with glass fiber and ceramics are preferable materials for making arc chute.
- The second objective that is lengthening the arc path, is achieved concurrently with fist 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 technique 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 mini arc chute. So each of the split arcs has its won cooling and lengthening effect due to its mini arc chute and hence individual split arc voltage becomes high. These collectively, make the overall arc voltage, much higher than the system voltage.

AIR BREAK CIRCUIT BREAKER (ACB)

The air circuit breaker, operated within the voltage level 1 KV, does not require any arc control device. Mainly for heavy fault current on low voltages (low voltage level above 1 KV) ABCs with appropriate arc control device, are good choice. These breakers normally have two pairs of contacts. The main pair of contacts carries the current at normal load and these contacts are made of copper. The additional pair is the arcing contact and is made of carbon. When circuit breaker is being opened, the main contacts open first and during opening of main contacts the arcing contacts are still in touch with each other. As the current gets, a parallel low resistive path through the arcing contact during opening of main contacts, there will not be any arcing in the main contact. The arcing is only initiated when finally the arcing contacts are separated. The each of the arc contacts is fitted with an arc runner which helps, the arc discharge to move upward due to both thermal and electromagnetic effects as shown in the figure. As the arc is driven upward it enters in the arc chute, consisting of splitters. The arc in chute will become colder, lengthen and split hence arc voltage becomes much larger than system voltage at the time of operation of air circuit breaker, and therefore the arc is quenched finally during the current zero.



Although this type of circuit breakers have become obsolete for medium voltage application, but they are still preferable choice for high current rating in low voltage application.

Air Blast Circuit Breaker

These types of air circuit breaker were used for the system voltage of 245 KV, 420 KV and even more, especially where faster breaker operation was required. Air blast circuit breaker has some specific advantages over oil circuit breaker which are listed as follows,

1. There is no chance of fire hazard caused by oil.
2. The breaking speed of circuit breaker is much higher during operation of air blast circuit breaker.
3. Arc quenching is much faster during operation of air blast circuit breaker.
4. The duration of arc is same for all values of small as well as high currents interruptions.
5. As the duration of arc is smaller, so lesser amount of heat realized from arc to current carrying contacts hence the service life of the contacts becomes longer.

6. The stability of the system can be well maintained as it depends on the speed of operation of circuit breaker.
7. Requires much less maintenance compared to oil circuit breaker.

There are also some **disadvantages of air blast circuit breakers-**

1. In order to have frequent operations, it is necessary to have sufficiently high capacity air compressor.
2. Frequent maintenance of compressor, associated air pipes and automatic control equipments is also required.
3. Due to high speed current interruption there is always a chance of high rate of rise of re-striking voltage and current chopping.
4. There also a chance of air pressure leakage from air pipes junctions.

As we said earlier that there are mainly two types of ACB, plain air circuit breaker and air blast circuit breaker. But the later can be sub divided further into **three different categories.**

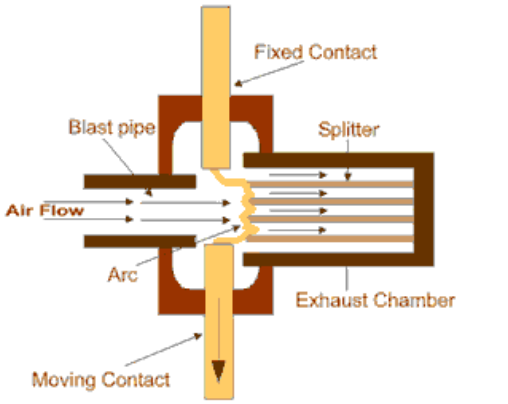
1. **Axial Blast ACB.**
2. **Axial Blast ACB with side moving contact.**
3. **Cross Blast ACB.**

Axial Blast Air Circuit Breaker

In axial blast ACB the moving contact is in contact with fixed contact with the help of a spring pressure as shown in the figure. There is a nozzle orifice in the fixed contact which is blocked by tip of the moving contact at normal closed condition of the breaker. When fault occurs, the high pressure air is introduced into the arcing chamber. The air pressure will counter the spring pressure and deforms the spring hence the moving contact is withdrawn from the fixed contact and nozzle hole becomes open. At the same time the high pressure air starts flowing along the arc through the fixed contact nozzle orifice. This axial flow of air along the arc through the nozzle orifice will make the arc lengthen and colder hence arc voltage become much higher than system voltage that means system voltage is insufficient to sustain the arc consequently the arc is quenched.

Cross Blast Air Circuit Breaker

The working principle of cross blast air circuit breaker is quite simple. In this system of air blast circuit breaker the blast pipe is fixed in perpendicular to the movement of moving contact in the arcing chamber and on the opposite side of the arcing chamber one exhaust chamber is also fitted at the same alignment of blast pipe, so that the air comes from blast pipe can straightly enter into exhaust chamber through the contact gap of the breaker. The exhaust chamber is spit with arc splitters. When moving contact is withdrawn from fixed contact, an arc is established in between the contact, and at the same time high pressure air coming from blast pipe will pass through the contact gap and will forcefully take the arc into exhaust chamber where the arc is split with the help of arc splitters and ultimately arc is quenched.



Principle of Cross Blast Air Circuit Breaker

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain construction, principle of operation and application of air blast CB.	RGPV/ June 2013	7
Q.2	Explain construction, principle of operation and application of air break CB.	RGPV/ June 2011	7

Unit-03 /Lecture-06

Sulfur Hexafluoride

SF6 Gas Properties

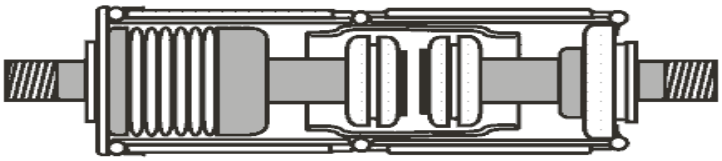
High voltage switchgear became popular. As the demand of this gas was increasing many manufacturers in Europe and America started producing SF_6 gas in large scale, during that time.

At the beginning sulphur hexafluoride gas only used for insulating purpose in the electrical system. But soon it was realized that this gas has tremendous arc quenching property. Hence, this gas also began to be used in circuit breaker as arc quenching medium.

During process of producing of this gas, other by products like SF_4, SF_2, S_2F_2, S_2F_{10} are also produced in small percentages. Not only are these byproducts, impurities like air, moisture, CO2 also present in the gas, during production. All these by-products and impurities are filtered at different stages of purification to get pure and refine final product.
Chemical Properties of Sulphur Hexafluoride Gas
For examine chemical properties of sulphur hexafluoride gas, we first introduce structure of this molecule. In this gas, molecule, one sulphur atom is surrounded by six fluorine atoms.

Vacuum Circuit Breaker or VCB and Vacuum Interrupter

A vacuum circuit breaker is such kind of circuit breaker where the arc quenching takes place in vacuum. The technology is suitable for mainly medium voltage application. For higher voltage vacuum technology has been developed but not commercially viable. The operation of opening and closing of current carrying contacts and associated arc interruption take place in a vacuum chamber in the breaker which is called vacuum interrupter. The vacuum interrupter consists of a steel arc chamber in the centre symmetrically arranged ceramic insulators. The vacuum pressure inside a vacuum interrupter is normally maintained at 10^{-6} bar.



Cross section of Vacuum Interrupter

The material used for current carrying contacts plays an important role in the performance of the vacuum circuit breaker. CuCr is the most ideal material to make VCB contacts. Vacuum interrupter technology was first introduced in the year of 1960. But still it is a developing technology. As time goes on, the size of the vacuum interrupter is being reducing from its early 1960's size due to different technical developments in this field of engineering. The contact geometry is also improving with time, from butt contact of early days it gradually changes to spiral shape, cup shape and axial magnetic field contact. The vacuum circuit breaker is today recognized as most reliable current interruption technology for medium voltage switchgear. It requires minimum maintenance compared to other circuit breaker technologies.

Advantages of Vacuum Circuit Breaker or VCB

Service life of vacuum circuit breaker is much longer than other types of circuit breakers. There is no chance of fire hazard as oil circuit breaker. It is much environment friendly than SF_6 Circuit breaker. Beside of that contraction of VCB is much user friendly. Replacement of vacuum interrupter (VI) is much convenient.

Operation of Vacuum Circuit Breaker

The main aim of any circuit breaker is to quench arc during current zero crossing, by establishing high dielectric strength in between the contacts so that reestablishment of arc after current zero becomes impossible. The dielectric strength of vacuum is eight times greater than that of air and four times greater than that of SF_6 gas. This high dielectric strength makes it possible to quench a vacuum arc within very small contact gap. For short contact gap, low contact mass and no compression of medium the drive energy required in vacuum circuit breaker is minimum. When two face to face contact areas are just being separated to each other, they do not be separated instantly, contact area on the contact face is being reduced and ultimately comes to a point and then they are finally de-touched. Although this happens in a fraction of micro second but it is the fact. At this instant of de-touching of contacts in a vacuum, the current through the contacts concentrated on that last contact point on the contact surface and makes a hot spot. As it is vacuum, the metal on the contact surface is easily vaporized due to that hot spot and create a conducting media for arc path. Then the arc will be initiated and continued until the next current zero.

At current zero this vacuum arc is extinguished and the conducting metal vapor is re-condensed on the contact surface. At this point, the contacts are already separated hence there is no question of re-vaporization of contact surface, for next cycle of current. That means, the arc cannot be reestablished again. In this way vacuum circuit breaker prevents the reestablishment of arc by producing high dielectric strength in the contact gap after current zero.

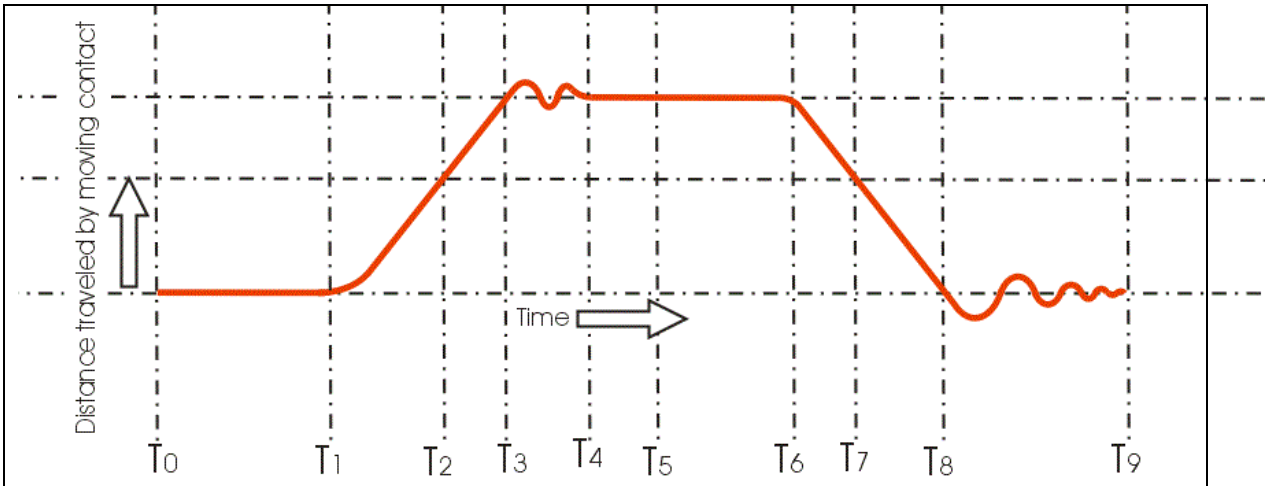
There are two types of arc shapes. For interrupting current up to 10 kA, the arc remains diffused and the form of vapor discharge and cover the entire contact surface. Above 10 kA the diffused arc is constricted considerably by its own magnetic field and it contracts. The phenomenon gives rise over heating of contact at its center. In order to prevent this, the design of the contacts should be such that the arc does not remain stationary but keeps travelling by its own magnetic field. Specially designed contact shape of vacuum circuit breaker make the constricted stationary arc travel along the surface of the contacts, thereby causing minimum and uniform contact erosion.

Circuit Breaker Operation

he primary function of an electrical circuit breaker is to provide opening and closing the current carrying contacts. Although it is seems to be very simple. But we should remember, that, one circuit breaker remains at its closed position for maximum period of its life span. Very occasionally it is required to operate a circuit breaker for opening and closing its contacts. Hence, circuit breaker operation must be very reliable without any delay or sluggishness. For achieving this reliability the circuit breaker operating mechanism becomes more complex than it was first thought.

Opening and closing distance, as well as stroke between contacts and velocity of moving contacts during operation, are the most important parameters to be considered during designing circuit breaker. Contact gap, traveling distance of moving contacts and their velocity are determined by types of arc quenching medium, current and voltage rating of a circuit breaker.

A typical circuit breaker operating characteristic curve is shown in the graph below.



Here in the graph, X axis represents time in milli seconds and y axis represents distance in milli meter.

Let's at time, T_0 current starts flowing through the closing coil. After time T_1 the moving contact starts traveling towards fixed contact. At time T_2 moving contact touches fixed contact. At time T_3 the moving contact reaches at its close position. $T_3 - T_2$ is overloading period of these two contacts (moving and fixed contact). After time T_3 the moving contact bounce back little bit and then again comes to its fixed closed position, after time T_4.Now we come to the tripping operation. Let's at time T_5 current starts flowing through trip coil of the circuit breaker. At time T_6 moving contact starts traveling backward for opening the contacts. After time T_7, the moving contact finally detaches the fixed contact. Time ($T_7 - T_6$) is over lapping period. Now at time T_8 the moving contact comes back to its final open position but here it will not be at rest position since there will be some mechanical oscillation of moving contact before coming to its final rest position. At time T_9 the moving contact finally comes to its rest position.

Circuit Breaker Opening Operation Requirement

The circuit breaker is desired to be at open position as fast as possible. It is because of limiting contacts erosion and to interrupt faulty current as rapidly as possible. But total travel distance of the moving contact is not determined only by necessity of interruption of faulty current, but rather the contacts gap needed to withstand the normal dielectric stresses and lightning impulse voltage appears across the contacts when the CB is at open position.

The need for carrying the continuous current and for withstanding a period of arc in circuit breaker, make it necessary to use two sets of contacts in parallel one the primary contact which is always made of high conductive materials such as copper and the other is arcing contact, made of arc resistance materials such as tungsten or molybdenum, which has much lower conductivity than primary contacts. During opening circuit breaker operation, the primary contacts open before the arcing contacts.

However, due to the difference in the electrical resistance and the inductor of the electrical paths of the primary and arcing contacts, a finite time is required to attain total current commutation, i.e. from primary or main contacts to arcing contact branch.

So when the moving contact starts traveling from closed position to open position the contact gap gradually increases and after some time a critical contact position reaches which indicates the minimum conduct gap required for preventing re-arcing after very next current zero.

The remaining part of the travel is required only for maintaining sufficient dielectric strength between contacts gap and for deceleration purpose.

Circuit Breaker Closing Operation Requirement

During closing operation of circuit breaker the followings are required,

1. The moving contact must travel towards fixed contact at sufficient speed to prevent pre-arcing phenomenon. As the contact gap reduces, arcing may start before contacts are closed finally.
2. During closing of contacts, the medium between contacts is replaced, hence sufficient mechanical power to be supplied during this circuit breaker operation to compress dielectric medium in the arcing chamber.
3. After hitting fixed contact, the moving contact may bounce back, due to repulsive force which is not at all desirable. Hence sufficient mechanical energy to be supplied to overcome repulsive force due to closing operation on fault.
4. In spring – spring mechanism, generally tripping or opening spring is charged during closing operation. Hence sufficient mechanical energy also to be supplied to charge the opening spring.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Describe the construction, principle of operation of SF6 Circuit breaker	RGPV/ June 2012,2013,2014	7
Q.2	Explain the working of vacuum circuit breaker.	RGPV/ June 2014	7

Short Circuit Current of Circuit Breaker

When there is a short circuit fault in the electrical system, huge short circuit current flows through the system including the circuit breaker contacts unless the fault is cleared by tripping the CB. When the short circuit current flows through the CB, the different current carrying parts of the circuit breaker subjected to huge mechanical and thermal tresses. If the conducting parts of the CB do not have sufficient cross-sectional area, there may be a chance of dangerously high temperature rise. This high temperature may affect insulation quality of the CB.

The CB contacts also experience high temperature. The thermal tresses of CB contacts are proportional to I^2Rt, where R is the contact resistance, depends upon contact pressure and contact surface condition. I is the rms value of short circuit current and t is duration far which the short circuit current has flown through the contacts.

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.

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.

Theoretically at the instant of fault occurrence in a system, the fault current can rise to twice of its symmetrical fault level. At the instant of switching on a circuit breaker in faulty condition, of system, the short circuit portion of the system connected to the source. The first cycle of the current during a circuit is closed by circuit breaker, has maximum amplitude. This is about twice of the amplitude of symmetrical fault current waveform.

The breaker's contacts have to withstand this highest value of current during the first cycle of waveform when breaker is closed under fault.

On the basis of this above mentioned phenomenon, a selected breaker should be rated with short circuit making capacity.

As the rated **short circuit making current of circuit breaker** is expressed in maximum peak value,

it is always more than rated short circuit breaking current of circuit breaker. Normally value of short circuit making current is 2.5 times more than short circuit breaking current.

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 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 in it. 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 delays are 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. Even a circuit breaker fails to trip, the fault will be cleared by next higher positioned circuit breaker. In this case the fault clearing time is longer. 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 faulty 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 different current 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.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain ratings of Circuit breaker	RGPV/ June 2013	7
Q.2	Explain in brief the voltage rating of circuit breaker	RGPV/ June 2011	7

Unit-03 /Lecture-08

Electrical Fuse HRC Fuse High Rupturing Capacity

Electrical Fuse

In normal working condition of electrical network, the current flows through the network is within the rated limit. If fault occurs in the network mainly phase to phase short circuit fault or phase to ground fault, the network current crosses the rated limits. This high current may have very high thermal effect which will cause a permanent damage to the valuable equipments connected in the electrical network. So this high fault current should be interrupted as fast as possible. This is what an **electrical fuse** does. A fuse is a part of the circuit which consists of conductor which melts easily and breaks the connection when current exceeds the predetermined value.

An **electrical fuse** is a weakest part of an electrical circuit which breaks when more than predetermined current flows through it.

Fuse Wire

The function of **fuse wire** is to carry the normal current without excessive heating but more than normal current when pass through **fuse wire**, it rapidly heats up and melts.

Materials used for Fuse Wires

The **materials used for fuse wires** are mainly tin, lead, zinc, silver, antimony, copper, aluminum etc.

Fuse Wire Rating

The melting point and specific resistance of different metals used for fuse wire

Metal	Melting point	Specific Resistance
Aluminium	$240^{o}F$	2.86 μ Ω – cm
Copper	$2000^{o}F$	1.72 μ Ω – cm
Lead	$624^{o}F$	21.0 μ Ω – cm
Silver	$1830^{o}F$	1.64 μ Ω – cm
Tin	$463^{o}F$	11.3 μ Ω – cm
Zinc	$787^{o}F$	6.1 μ Ω – cm

Some Important Terms need for Fuse

1. **Minimum Fusing Current :** It is minimum value of current due to which fuse melts.
2. **Current Rating of Fuse :** It is maximum value of current due to which fuse does not get melt.
3. **Fusing Factor :** This is the ratio of minimum fusing current and current rating of fuse. Therefore, fusing factor = Minimum fusing current / current rating of fuse. The value of fusing factor is always more than 1.
4. **Prospective Current in Fuse:** Before melting, the fuse element has to carry the short circuit current through it.The prospective current is defined as the value of current which would flow through the fuse immediately after a short circuit occurs in the network.
5. **Melting Time of Fuse or Pre-arcing Time of Fuse:** This is the time taken by an fuse wire to be broken by melting. It is counted from the instant, the over current starts to flow through fuse, to the instant when fuse wire is just broken by melting.

6. **Arcing Time of Fuse:** After breaking of fuse wire there will be an arcing between both melted tips of the wire which will be extinguished at the current zero. The time accounted from the instant of arc initiated to the instant of arc being extinguished is known as arcing time of fuse.
7. **Operating Time of Fuse :** When ever over rated current starts to flow through a fuse wire, it takes a time to be melted and disconnected, and just after that the arcing stars between the melted tips of the fuse wire, which is finally extinguished. The operating time of fuse is the time gap between the instant when the over rated current just starts to flow through the fuse and the instant when the arc in fuse finally extinguished. That means operating time of fuse = melting time + arcing time of fuse.

Current Carrying Capacity of Fuse Wire

Current carrying capacity of a fuse wire depends upon numbers of factors like, what material used for it, what are the dimension of it, i.e. diameter and length, size and shape of terminals used to connect it, and the surrounding.

Fuse Law

Fuse law determines the current carrying capacity of a fuse wire. The law can be established in the following way. At steady state condition that is when fuse carry normal current without increasing its temperature to the melting limit. That means at this steady state condition,

heat generated due to current through fuse wire is equal to heat dissipated from it.
Heat generated = $I^2.R$

Where R is the resistance of the fuse wire

$$I^2.\rho.\frac{l}{a}$$

Where ρ is the resistivity, l is the length and a is the cross sectional area of fuse wire

$$I^2.\rho.\frac{l}{\pi d^2/4}$$

Where d is the diameter of fuse wire

$$I^2.K_1.\frac{l}{d^2} \quad \text{.....(i)}$$

Where K_1 is a constant
Heat lost ∝ surface area of fuse wire ∝ πd.l

$$\text{Therefore, heat lost} = K_2.d.l \quad \text{.....(ii)}$$

Where K_2 is a constant
Now, equating (i) & (ii), we get,

$$I^2.K_1.\frac{l}{d^2} = K_2.d.l$$

$$\text{Where } K = \frac{K_2}{K_1} \text{ is another costant}$$

this is known as **fuse law**

Metal	**value of K when d is measured in mm**
Aluminium	59
Copper	80
Iron	24.6
Lead	10.8

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Discuss fuse characteristics. What is the difference between fusing current and current carrying capacity of fuse, discuss the factors on which the current carrying capacity of fuse depends,	RGPV/ June 2013	7
Q.2	Differentiate between type test and routine tests on CB.	RGPV/ June 2011	7

Unit-03 /Lecture-09

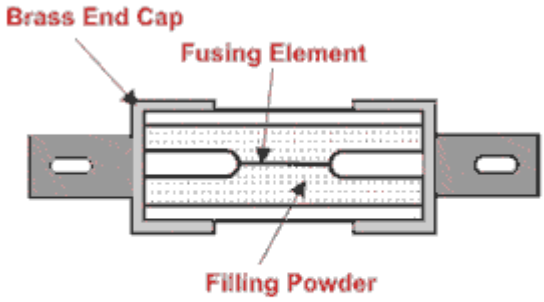
Rewirable or Kit Kat Fuse Unit

Rewirable or Kit Kat Fuse Unit

This is most commonly used fuse in our day to day life. This fuse has mainly two parts. The unit in which the incoming and outgoing line or phase wire connected permanently is known as fuse base. The removable parts which hold a the fuse wire and fits into the base, is known as fuse carrier. The fuse carrier is also known as **cutout**.

Cartridge Fuse

In **cartridge fuse** the fuse wire is enclosed in a transparent glass tube or bulb, the whole unit is sealed off. In case the fuse blows, it is to be replaced by new one as the **cartridge fuse** can not be rewired due to its sealing.



Construction of HRC Fuse

Lead – tin Alloy Fuse Wire or Eutectic Alloy Fuse Wire

For small value of current interruption lead – tin alloy fuse wire has been used in past. The most preferred lead – tin alloy for fuse wire containing 37% lead and 63% tin. This alloy fuse wire is also known as known as Eutectic Alloy Fuse Wire. This type of alloy has some specific characteristics due to which this is preferred as fuse wire.

1. It has the high brinnel hardness and has less tendency to spread over.

2. The alloy metal is quite homogeneous.

3. If the fusing characteristics of eutectic alloy and other composition of alloys is studied there is only one arrest point in eutectic alloy as compared to two other types of alloys.

Approximate fusing currents of lead – tin alloy fuse wire in air

HRC Fuse or High Rupturing Capacity Fuse

HRC fuse or **high rupturing capacity fuse**- In that type of fuse, the fuse wire or element can carry short circuit heavy current for a known time period. During this time if the fault is removed, then it does not blow off otherwise it blows off or melts.

The enclosure of **HRC fuse** is either of glass or some other chemical compound. This enclosure is fully air tight to avoid the effect of atmosphere on the fuse materials. The ceramic enclosure having metal end cap at both heads, to which fusible silver wire is welded. The space within the enclosure, surrounding the fuse wire or fuse element is completely packed with a filling powder. This type of fuse is reliable and has inverse time characteristic, that means if the fault current is high then rupture time is less and if fault current is not so high then rupture time is long.

Operation of HRC Fuse

When the over rated current flows through the fuse element of **high rupturing capacity fuse** the element is melted and vapourized. The filling powder is of such a quantity that the chemical reaction between the silver vapour and the filling powder forms a high electrical resistance substance which very much help in quenching the arc.

What is MCB?
Nowadays we use more commonly **miniature circuit breaker** or **MCB** in low voltage electrical network instead of fuse.
The **MCB** has some advantages compared to fuse.

1. It automatically switches off the electrical circuit during abnormal condition of the network means in over load condition as well as faulty condition. The fuse does not sense but **miniature circuit breaker** does it in more reliable way. MCB is much more sensitive to over current than fuse.

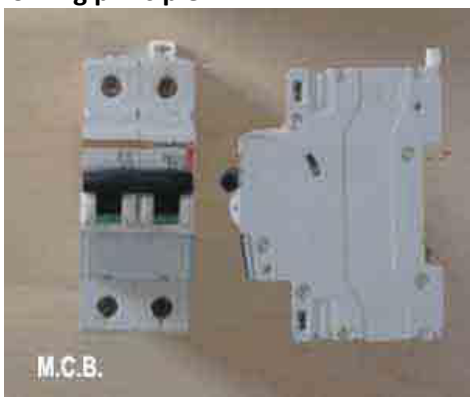
2. Another advantage is, as the switch operating knob comes at its off position during tripping, the faulty zone of the electrical circuit can easily be identified. But in case of fuse, fuse wire should be checked by opening fuse grip or cutout from fuse base, for confirming the blow of fuse wire.

3. Quick restoration of supply can not be possible in case of fuse as because fuses have to be rewirable or replaced for restoring the supply. But in the case of MCB, quick restoration is possible by just switching on operation.

4. Handling MCB is more electrically safe than fuse.
Because of to many advantages of MCB over fuse units, in modern low voltage electrical network, miniature circuit breaker is mostly used instead of backdated fuse unit.
Only one disadvantage of MCB over fuse is that this system is more costlier than fuse unit system.

Miniature Circuit Breaker

Working Principle Miniature Circuit Breaker
There are two arrangement of **operation of miniature circuit breaker**. One due to thermal effect of over current and other due to electromagnetic effect of over current. The thermal **operation of miniature circuit breaker** is achieved with a bimetallic strip whenever continuous over current flows through MCB, the bimetallic strip is heated and deflects by bending. This deflection of bimetallic strip releases mechanical latch. As this mechanical latch is attached with operating mechanism, it causes to open the miniature circuit breaker contacts. But during short circuit condition, sudden rising of current, causes electromechanical displacement of plunger associated with tripping coil or solenoid of MCB. The plunger strikes the trip lever causing immediate release of latch mechanism consequently open the circuit breaker contacts. This was a simple explanation of **miniature circuit breaker working principle**.



Miniature Circuit Breaker

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Differentiate rewire able fuse and Cartridge fuse	RGPV/ June 2013	7
Q.2	Write short note on MCB.	RGPV/ June 2011	7

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Numerical on CB to calculate RRRV	RGPV/ June 2012	7
Q.2	Numerical on circuit breaker ratings	RGPV/ June 2011	7

Important Model Questions for Unit Test and MID SEM Examinations

Switchgear and protection (EX-603)

(Strictly Based on RGPV EXAMINATION)

Unit-3

1. Distinguish between the recovery voltage and restriking voltage. **RGPV/ June 2014,2013**
2. Explain the significance of RRRV in operation of Circuit breaker. **RGPV/ June 2014,2013**
3. Write short notes on Air blast circuit breaker. **RGPV/ June 2014,2013**
4. Describe the construction, principle of operation of SF6 Circuit breaker.

   RGPV/ June 2014, 2013, 2012
5. Explain the working of vacuum circuit breaker. **RGPV/ June 2014**
6. Explain (i) Recovery voltage (ii) Active recovery voltage (iii) Restriking voltage (iv) RRRV (v) RRRV (vi) Current chopping (vii) resistance switching **RGPV/ June 2013, 2012**
7. Explain various methods of arc extinction in a circuit breaker. Discuss problems associated with interruption of (i) Normal short circuit current (ii) capacitor switching (iii) High voltage DC circuit breaking. **RGPV/ June 2013**
8. Describe with the neat sketch principle of operation, construction and working of minimum oil CB. What is the advantage over bulk oil CB. **RGPV/ June 2013**
9. Derive the expression for Re-Striking voltage in terms of system capacitance and inductance . **RGPV/ June 2012, DEC 2012**
10. Explain in brief (i) Testing of CB (ii) Arc quenching concept **RGPV/ June 2012**
11. Numerical on CB to calculate RRRV, **RGPV/ Dec 2012**
12. Discus recovery rate theory and energy balance theory of arc interruption of CB.

    RGPV/ Dec 2012
13. Explain construction, principle of operation and application of air blast CB.

    RGPV/ Dec 2011
14. Discuss fuse characteristics. What is the difference between fusing current and current carrying capacity of fuse, discuss the factors on which the current carrying capacity of fuse depends. **RGPV/ Dec 2011**
15. Differentiate between type test and routine tests on CB. **RGPV/ Dec 2011**