UNIT-1

Introduction:-

Every electric circuit needs a switching device and protective device. switching and protective have been developed in different forms. switch gear is a general term covering a wide range of equipment concerned with switching and protection.

In a power system switchgear serves two basic purposes.

→ switching during normal operating conditions for the purpose of operation and maintenance.

→ switching during abnormal conditions such as short-circuits and interrupting the fault currents.

Thus the apparatus including its associated auxiliaries employed for controlling, regulating or switching on or off the electrical circuits in the electrical power system is known as switchgear. It includes switches, fuses, circuit breakers, isolators, relays, current and potential transformers, indicating instruments, lightning arresters and control panels.

A CB is a device that interrupts the abnormal or fault currents and in addition performs the function of a switch. CB and fuses both possess a time element of operation, whereby they operate practically instantaneously on short circuits but with definite time lag on overloads

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Circuit Breakers:-

CB's are mechanical devices designed to close or open contact members, thus closing or opening of an electrical circuit under normal or abnormal conditions

Automatic circuit breakers, which are usually employed for the protection of electrical circuits, are equipped with a trip coil connected to a relay or other means, designed to open the breaker automatically under abnormal conditions such as over-current. The automatic circuit breakers perform the following duties.

→ It carries the full-load current continuously without overheating or damage.

→ It opens and closes the circuit on no-load.

→ It makes and breaks the normal operating current and.

→ It makes and breaks the short-circuit currents of magnitude upto which it designed for.

The CB performs first three duties satisfactorily but in performing forth duty ~~them~~ i.e, when it is to make or break short circuit currents, it is subjected to mechanical and thermal stresses. The circuit breakers are rated in terms of maximum voltage, number of poles, frequency, maximum continuous current carrying capacity, maximum interrupting capacity and max momentary and 4-s current carrying capacity.

The circuit breakers are also rated in MVA which is the product of interrupting current, rated voltage and 10^{-6}.

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Operating principle:- A circuit breaker is a switching and current interrupting device. It consists, essentially, of fixed and moving contacts, which are touching each other and carry the current under normal conditions i.e, when circuit breaker is closed. when the circuit breaker is closed, the current carrying contacts, called the electrodes, engage each other under the pressure of a spring.

During the normal operating condition the CB can be opened or closed by a station operator for the purpose of switching and maintenance. To open the circuit breaker only a small pressure is required to be applied on a trigger whenever a fault occurs on any part of the power system the trip coils of the breaker get energized and the moving contacts are pulled apart by some mechanism, thus opening the circuit. The seperation of current carrying contacts produces an arc. The current is thus able to continue until the discharge ceases. The production of arc not only delays the current interruption process but it also generates enormous heat which may cause damage to the system or to the breaker itself. Therefore, the main problem in a circuit breaker is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

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Arc phenomena:-

The arc consists of a column of ionized gas i.e, a gas which molecules have lost one or more of their electrons resulting in positive ions and electrons. The ionization is facilitated by a) an increase in field strength
b) increase in mean free path
c) high temperature

The electrons which have a negative charge are attracted towards the positive contact i.e, anode and the electrons being light moves towards anode quickly. The positive ions are attracted towards the negative contact i.e, cathode, but as the positive ions comprise almost the entire weight of the atom, they move towards the negative of the atom, they moves towards the negative contact collide slowly. Thus the fast moving electron collides with the slowing moving ion constituting an arc between the contacts.

when a fault occurs in a power system, an enormous power can be fed into the fault, which requires the opening of circuit. The circuit can be opened with the help of a circuit breaker. while opening the contacts of the circuit breaker an arc is established between the contacts. This arc should be extinguished as early as possible.

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Arc voltage:

The voltage drop across the arc is called arc voltage The arc voltage and current characteristics can be expressed as

$$E_a = A + \frac{B}{\sqrt{I_a}}$$

where I_a = Arc current

E_a = Arc voltage

A and B = Constants

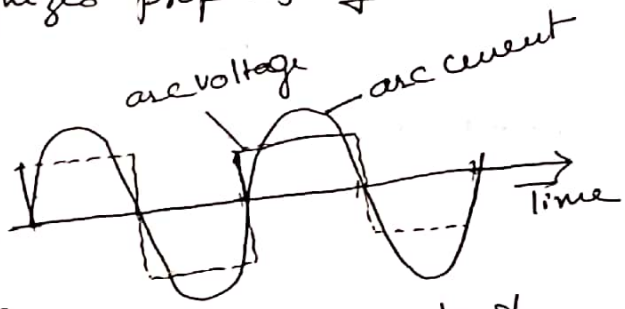
$A = \alpha + \gamma l$ where $l \rightarrow$ arc length

$B = \beta + \delta l$

The avg values of α, β, γ and δ for arcs in air between copper electrodes are 30V, 10VA, 10V/cm and 30VA/cm respectively.

From the above equation, it can be observed that the volt-ampere characteristic of the arc will be negative, so that when the arc voltage is high, the current is low and vice-versa. This is very well recognized property of arc.

From the graphical representation, the arc voltage is always in phase with arc current since the arc path is purely resistive The magnitude of the arc voltage increases in each successive current loop, since the contacts of the circuit breaker assumed to be seperated there by increasing the arc length and there by the voltages.



Short circuit current & arc voltage at an AC arc.

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Initiation of the Arc:-

When a fault occurs, a heavy current flows through the contacts of the circuit breaker before they are opened by the protective system. This makes the circuit breaker contacts to separate. The separation of the circuit breaker contacts which are carrying current gives rise to an arc without changing the current wave form.

Initially when the contacts just begin to separate, the magnitude of current is very large but the contacts resistance being very small, a small voltage appears across them. But the distance of separation being very very small, a large voltage gradient is set up which is good enough to cause ionization of the particles between the contacts. As copper contacts are used for the circuit breakers very little thermal ionization can occur at temperature below melting point

For effective field emission the voltage gradient required is 10^6 v/cm. Obviously the arc is initiated by the field emission rather than the thermal ionization. This high voltage gradient exists only for a fraction of micro seconds But in the short period a large number of electrons have been liberated from the cathode and these electrons while reaching the anode, on their way would have collided with the atoms and molecules of the gases. Each emitted electron tends to create others and these in turn derive energy from the field and multiply.

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In short, the work did by the initially emitted electron enables the discharge to be maintained. If the current is high, the discharge attains the form of an arc having a temperature high enough for thermal ionization, which results in lower voltage gradient.

Thus the arc is initiated due to the field effect and then maintained due to thermal ionization

~~Maintenance of Arc~~:-

Arc Interruption Methods:-

In circuit breaker's various methods are employed to extinguish the arc resulting from seperation of the current carrying contacts. The arc can be quenched either by "high resistance interruption" or "low resistance interruption"

High resistance interruption:-

In this method, the arc is so controlled that its effective resistance increases with time so that the current is reduced to a value insufficient to maintain the arc. with an A.C. quantity the total resistance of the circuit also tends to bring the current in phase with the circuit voltage so that at current zero, the voltage appearing across the contacts which is known as "restricting voltage" is relatively low. The energy dissipated in this method is high. Hence the application of this method is in DC circuit breakers and low and medium power industrial type air CB's.

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The resistance of the arc can be increase by any one of the following methods.

→ lengthening of arc :- The length of the arc can be increased by increasing the gap length between the contacts but it is not practicable to draw the arc out to such a length that the voltage available becomes inadequate to maintain the arc.

→ cooling of arc :- The voltage required to maintain ionization increases with a decrease of temperature so that cooling effectively increase the resistance

→ splitting of arc: The arc resistance can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experience the effect of lengthening and cooling. The arc may be split by introducing some conducting plates between the contacts.

→ Constraining the arc :-

If the arc can be constrained into very narrow channel the voltage necessary to maintain it is increased.

This method is mainly employed in Air-blast CB's.

→ Low resistance (or) current zero interruption :-

In this method, the arc gets extinguished at natural current zero of the A.c wave and is prevented from restricting again by rapid build-up of dielectric strength of the contact space.

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The rapid increase of dielectric strength or post-zero resistance is necessary for successful interruption and this is achieved by the following methods.

→ Lengthening of the gap: The dielectric strength is proportional to the length of gap so that lengthening by rapid operating of the contact is an obvious procedure. The permissible arc length is limited, however, by other considerations.

→ High pressure: If the pressure is increased, the density of particles constituting the discharge also increases. The increased density of particles causes higher rate of deionization and thus the dielectric strength of deionization and thus the dielectric strength of the medium between the contacts is increased.

→ Cooling: Unnatural combination of ions and electrons takes place more rapidly if they are allowed to cool. Cooling by conduction to adjacent parts.

→ Blast effect: If the ionized particles between the contacts are swept away and replaced by unimagined particles, the dielectric strength of the medium can be increased considerably. This can be achieved by forcing the cool un-ionized gas or liquid into the contact space.

These methods are used in oil and air-blast breakers

This process is employed in all A.C. circuit breakers

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There are two main theories which explains the current zero interruption. They are

→ Recovery rate theory (Slepian's theory)

→ Energy balance theory (Cassie's theory)

Recovery rate theory:-

In CB's the arc is formed due to the ionization of the gap between its contacts. So, in order to extinguish the arc, the electrons and ions present in the gap are to be removed immediately after the current reaches zero. Because, the ionization will be minimum at current zero instant, removal of electrons and ions is possible by either of the two different ways. They are as follows.

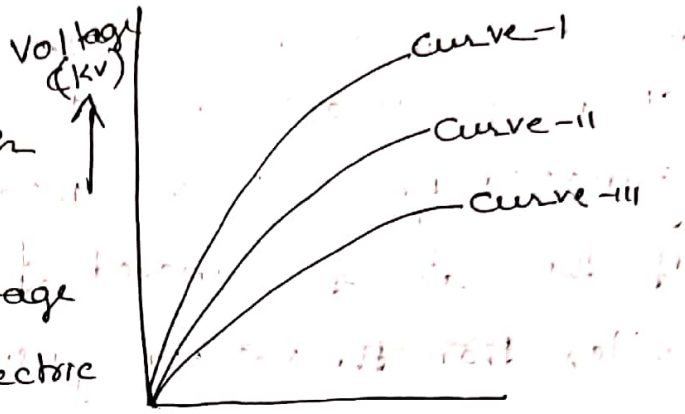
→ recombining them into neutral molecules

→ sweeping them away by inserting a suitable insulating medium into the gap.

The arc is interrupted if the rate of removal of ions from the gap is faster than the rate of ionization in the gap. In other words, if the dielectric strength of the gap builds-up rapidly so that it is always greater than the restriking voltage, the arc doesnot restrike after current zero interruption. As this theory describes the arc extinction process as the race between dielectric strength and restriking voltage, it is also called as "voltage race theory".

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In the below figure, if the dielectric strength builds as in curve-I when compared with that of restriking voltage as in curve-II, the arc will be extinguished. Since the dielectric strength builds more rapidly than the restriking voltage.



Build-up of dielectric strength and restriking voltage.

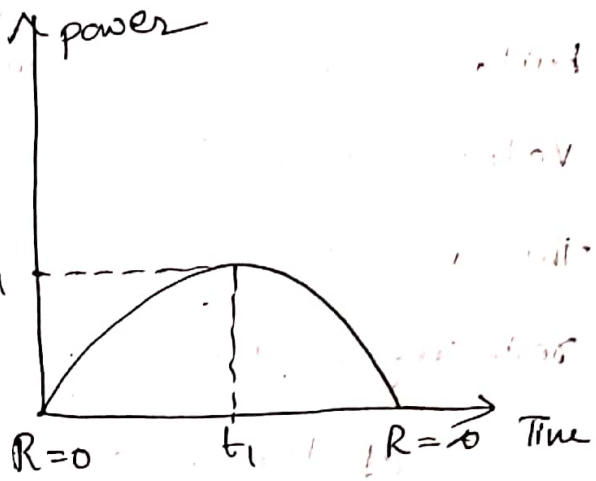
If the dielectric strength builds as in curve-III the arc restrikes. Since, the restriking voltage rises more rapidly than the dielectric strength due to which the ionization resists and the break down of the gap occurs.

Energy balance theory :-

At current zero instant, the restriking voltage and hence the power will be zero. At next instant, the gap between the contacts contains some ions. Therefore the gap will have finite post-zero resistance. As the restriking voltage exists, its associated current an the power will have some finite value. At the instant final arc extinction as no ions are present in the gap, its resistance will be infinite. So the power will be zero. Hence, in between the instant to current zero and final arc extinction. the power increases zero to a maximum value at some instant, t_1 and from there it falls back to

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zero as shown in below figure



Variation of power with time

As the power exists in the gap for a finite duration of time, energy appears in the gap in the form of heat. so, the CB has to remove the heat generated by suitable means. If the rate of removed of heat is less than the rate of generation of heat, the arc restrikes and continues for the next ~~tet~~ half cycle. If the rate of removal of heat is faster than the rate of generation of heat, the arc will extinguish

Restriking voltage and Recovery voltage :-

The voltage across the contacts of the circuit breaker is arc voltage when the arc persists. This voltage becomes the system voltage when the arc is extinguished. The arc is extinguished at the instant of current zero. After the arc has been extinguished. the voltage across the breaker terminals does not normalise instantaneously but it oscillates and there is a transient condition. The transient voltage which appears across the breaker contacts at the instant of arc being extinguished is known as restriking voltage. The power frequency rms voltage, which appears across the breaker contacts after the arc is finally extinguished and transient oscillations die out is called

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"Recovery voltage". The below figure shows the restriking and recovery voltage.

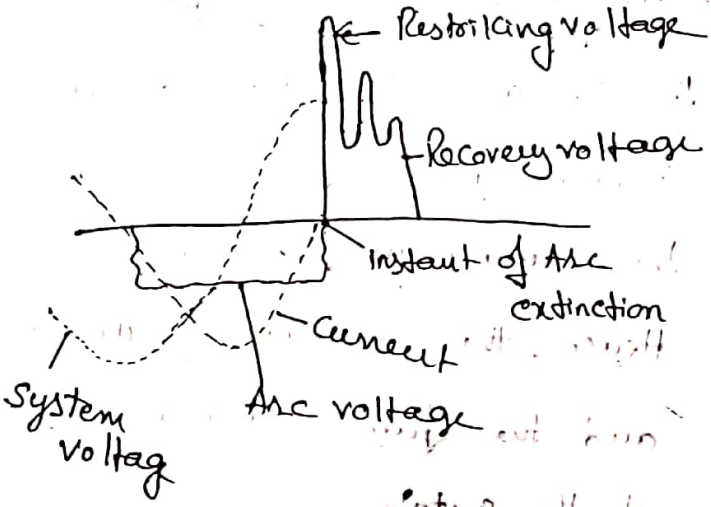


fig: Restriking and Recovery voltage.

Expression for Restriking voltage and RRRV:

The below figure shows a short circuit (fault) on a feeder beyond the location of the circuit breaker

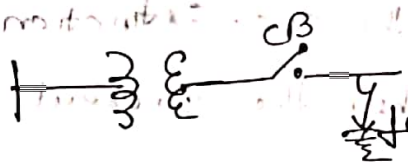
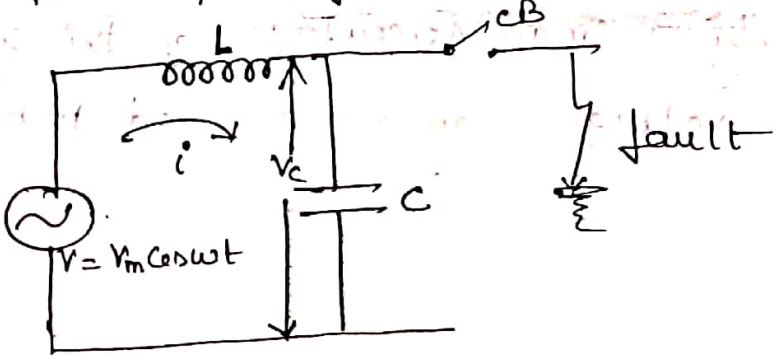


fig: fault on a feeder near circuit breaker

The below figure shows an equivalent electrical circuit where L and C are the inductance and capacitance per phase of the system up to the point of circuit breaker location, respectively.



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The resistance of the circuit has been neglected. During the time of fault a heavy fault current flows in the circuit. when the circuit breaker is closed, the fault current flows through L and the contacts of the circuit breaker the capacitance c being short circuited by the fault. Hence, the circuit of above fig: becomes completely reactive and the fault current is limited entirely by inductance of the system.

The fault is cleared by the opening of the CB contacts. The parting of the CB contacts does not in itself interrupt the current because an arc is established between the parting contacts and the current continues to flow through the arc. successful interruption depends upon controlling and finally extinguishing the arc. Extinction of the arc takes place at the instant when the current passes through zero.

Since the above circuit is completely reactive, the voltage at the instant of current zero will be at its peak. The voltage across the CB contacts, and therefore across the capacitor C, is the arc voltage. In high-voltage circuits it is usually only a small percentage of the system voltage Hence, the arc voltage may be assumed to be negligible

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For the analysis of this circuit, the time is measured form the instant of interruption, when the fault current comes to zero. since the voltage is a sinusoidally varying quantity and is at its peaks at the moment of current zero, it is expressed as 'Vm cosωt'.

when the CB contacts are opened and the arc is extinguished, the current i is diverted through the capacitance C, resulting in a transient condition. The inductance and the capacitance form a series oscillatory circuit. The voltage across the capacitance which is restriking voltage, rises and oscillates, as shown in the above figure.

The natural frequency of oscillation is given by

$$f_n = \frac{1}{2\pi}\frac{1}{\sqrt{LC}} \quad \text{—— (1)}$$

and the natural angular frequency is

$$\omega_n = \frac{1}{\sqrt{LC}} \quad \text{—— (2)}$$

The voltage across the capacitance which is the voltage across the contacts of the CB can be calculated in terms of L, C, f_n and system voltage.

The mathematical expression for the transient condition is as follows.

$$L\frac{di}{dt} + \frac{1}{C}\int i\,dt = V_m \cos\omega t \quad \text{—— (3)}$$

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Immediately after the instant of arc extinction, the voltage across the capacitance (v_c) which is the restriking voltage, oscillates at the natural frequency given by eqn (1). Since the natural frequency oscillation is a fast phenomenon, it persists for only a small period of time. During this short period which is of interest, the change in the power frequency term is very little and, hence negligible, because $\cos\omega t \approx 1$.

Hence the sinusoidally varying voltage $V_m \cos\omega t$ in eqn (3) can be assumed to remain constant at V_m during this short interval of time i.e, the transient period.

Substituting $V_m \cos\omega t \approx V_m$ the eqn (3) can be written as

$$L\frac{di}{dt} + \frac{1}{C}\int i\,dt = V_m \quad \text{---} (4)$$

$$i = \frac{dq}{dt} = \frac{d(CV_c)}{dt} \quad \text{---} (5)$$

where, V_c = voltage across the capacitor = Restriking voltage

$$\frac{di}{dt} = \frac{d^2(CV_c)}{dt^2} = C\frac{d^2V_c}{dt^2} \quad \text{---} (6)$$

$$\frac{1}{C}\int i\,dt = \frac{q}{C} = V_c \quad \text{---} (7)$$

Substituting these values in eqn (4), we get

$$LC\frac{d^2V_c}{dt^2} + V_c = V_m \quad \text{---} (8)$$

Taking laplace Transform of both sides of eqn (8), we get

$$LCs^2V_c(s) + V_c(s) = \frac{V_m}{s}$$

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where, $V_c(s)$ is the laplace Transform of V_c

other terms are zero as initially $q=0$ at $t=0$

$$V_c(s)\left[LCs^2+1\right] = \frac{V_m}{s}$$

(or) $$V_c(s) = \frac{V_m}{s(LCs^2+1)} = \frac{V_m}{LCs\left(s^2+\frac{1}{LC}\right)}$$

$$\omega_n = \frac{1}{\sqrt{LC}} \text{ therefore, } \frac{1}{LC} = \omega_n^2$$

(or) $$V_c(s) = \frac{\omega_n^2 V_m}{s(s^2+\omega_n^2)} = \frac{\omega_n V_m}{s}\left(\frac{\omega_n}{s^2+\omega_n^2}\right) \quad \text{---} (9)$$

Taking the inverse laplace of eq (9), we get

$$V_c(t) = \omega_n V_m \int_0^t \sin\omega_n t$$

$$= \omega_n V_m \left[\frac{-\cos\omega_n t}{\omega_n}\right]_0^t$$

(Or) $V_c(t) = 0$ at $t=0$, constant $=0$.

$$V_c(t) = V_m(1-\cos\omega_n t) \quad \text{---} (10)$$

This is the expression for the restriking voltage

The maximum value of the restriking voltage occurs at $t = \frac{\pi}{\omega_n} = \pi\sqrt{LC}$

Hence, the maximum value of restriking voltage $= 2V_m$

$= 2 \times$ peak value of the system voltage

The amplitude factor of the restriking voltage is defined as the ratio of the peak of the transient voltage to the peak value of the system frequency voltage. If losses are ignored, this factor becomes 2.

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The Rate of Rise of Restriking voltage (RRRV)

$$= \frac{d}{dt}[V_m(1-\cos\omega_n t)]$$

$$\therefore RRRV = V_m \omega_n \sin\omega_n t \quad \text{——} (11)$$

(or)

The maximum value of RRRV occurs when $\omega_n t = \pi/2$

i.e, when $t = \pi/2\omega_n$.

Hence, the max value of RRRV $= V_m \omega_n$.

$$\therefore \text{average RRRV} = \frac{\text{Peak value of RV}}{\text{Time to reach peak}}$$

$$= \frac{2V_m}{\pi\sqrt{LC}}$$

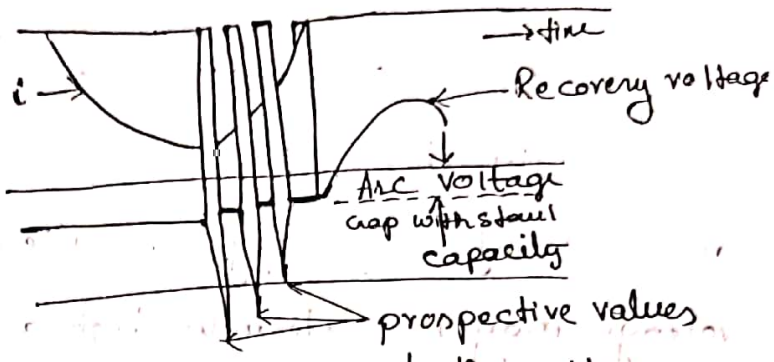
Current chopping:-

When a circuit breaker is made to interrupt small inductive currents such as currents due to no load magnetizing current of a transformer, it does so even before the current actually passes through zero value especially when the breaker exerts the same de-ionizing force for all current within its short circuit capacity. The low current ionized conducting path may become prematurely unstable, forcing the low arc current to zero along a very steep wave front. This phenomenon of breaking the current before it passes through the natural zero is known as "current chopping".

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This current chopping may take place even in circuit breakers which produce varying degree of de-ionizing force.

The effect of a practically instantaneous collapse of the arc current, even of only a few amperes, is potentially very serious from point of view of over voltages which may result in the system.



As shown in the above figure arc current gradually reduce with low arc voltage but at a certain time it suddenly become zero due to large de-ionized force. The current in the arc was following from the source through the inductance and the CB contacts. The energy contained in the electromagnetic field cann become zero instantaneously, and as such, it changes into some other form of energy. The only possibility is the conversio from electromagnetic energy to electro static energy i.e, curr is diverted from the arc to the capacitor as shown in figure.

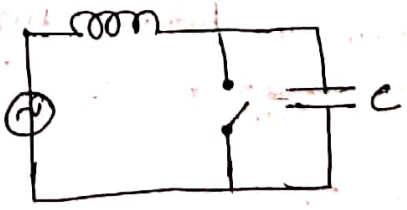


fig: current chopping

If I_a is the arc current, L and c are the inductance of the circuit and capacitance between breaker contacts respectively, then energy stored in L

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$$\frac{1}{2} L I_a^2 = \frac{1}{2} C V_c^2$$

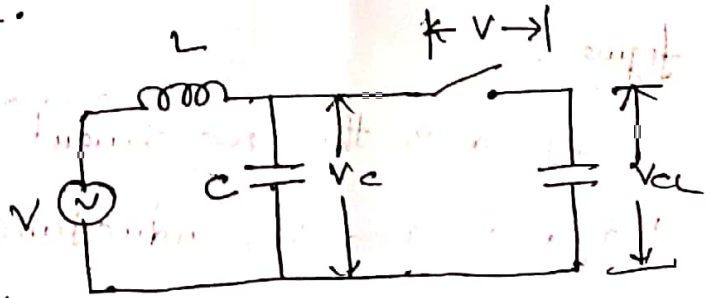
Energy transformed to c where V_c is the voltage developed across the breaker contacts,

$$V_c = I_a \sqrt{\frac{L}{C}} \text{ volts}$$

The developed voltage across the breaker contacts due to transfer of energy is called "prospective voltage". This voltage may be extremely high as compared to the normal system voltage. The de-ionizing force is still in action and current will again be chopped. Successive chops may occur as shown in above figure until a final chop brings the current to a zero prematurely with no further restrike since the gap is now in an advance of deionization.

Resistance switching

To reduce the restriking voltage, RRRV, severity of oscillations, high voltage transient appearing across the circuit breaker contacts during current chopping, a resistance across the breaker contacts is connected as shown in below figure. This is known as "resistance switching".



It is well known that the resistance in parallel with the circuit breaker damps

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the voltage oscillations. The shunt resistor makes a part of the current flows through it resulting in a decrease in the arc current and increase in the deionization of the arc path and resistance of the arc. This process continues as the current though the shunt resistance increases and arc current decreases. Due to the decrease in the arc current, RV and RRRV are reduced. The resistance can be automatically switched in with the help of sphere gap.

The shunt resistor may perform one or more of the following functions

→ To reduce the RRRV and amplitude of RV transient and thus ease or reduce the duties of CB.

→ To reduce transient voltage produced when switching inductive or capacitance loads.

→ To improve the uniformity of voltage sharing in case of multi break circuit breakers.

→ To suppress and to control the switching surge severity in an EHV system.

Reduction of transient recovery voltage requires considerably lower values or resistance where as, the voltage equalization requires a resistor of relatively high ohmic value. so, the resistance should be low compared to the reactance of the capacitance, shunting the breaks at the frequency of the recovery transient.

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The analysis of resistance switching can be made to find out the critical value of the shunt resistance to obtain complete damping of transient oscillation.

From Fig 1.8 the voltage equation is

$$L\frac{di}{dt} + \frac{1}{C}\int i_c\,dt = V \quad \text{——} (6)$$

And $i = i_c + i_R$

$$\therefore L\frac{d}{dt}(i_c + i_R) + \frac{1}{C}\int i_c\,dt = V \quad \text{——} (7)$$

$$L\frac{di_c}{dt} + L\frac{di_R}{dt} + V_c = V \quad \text{——} (8)$$

$$i_c = \frac{dq}{dt} = \frac{d(CV_c)}{dt} = C\frac{dV_c}{dt} \quad \text{——} (8)$$

$$i_R = \frac{V_c}{R} \quad (CB' \text{ is open}) \quad \text{——} (9)$$

Substituting eq's (8) and (9) in eq (7), we get

$$LC\frac{d^2V_c}{dt^2} + \frac{L}{R}\frac{dV_c}{dt} + V_c = V \quad \text{——} (10)$$

Taking laplace transform,

$$LC\left[s^2 + \frac{1}{RC}s + \frac{1}{LC}\right]V_c(s) = \frac{V}{s}$$

$$V_c(s) = \frac{V}{sLC\left[s^2 + \frac{1}{RC}s + \frac{1}{LC}\right]}$$

For no transient oscillation, all the roots of the equation should be real. one root is zero i.e, $s=0$ which is real. For the other two roots to be real, the roots of the quadratic equation in the denominator should be real.

i.e, discriminate $b^2 - 4ac \geq 0$

$$\left(\frac{1}{RC}\right)^2 - 4\times1\times\frac{1}{LC} \geq 0$$

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(or) $\frac{1}{R^2C^2} \geq \frac{4}{LC}$

$$\frac{LC}{R^2C^2} \geq 4$$

$$R^2 \leq \frac{LC}{4C^2} \Rightarrow R^2 \leq \frac{1}{2^2}\frac{L}{C}$$

$$R \leq \frac{1}{2}\sqrt{\frac{L}{C}}$$

Therefore, it is the value of the resistance connected across the contacts of the circuit breaker is equal to or less than $\frac{1}{2}\sqrt{\frac{L}{C}}$ there will no transient oscillations.

If $R > \frac{1}{2}\sqrt{\frac{L}{C}}$ there will be oscillation.

$R = \frac{1}{2}\sqrt{\frac{L}{C}}$ is known as critical resistance.

The frequency of damped oscillations is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{1}{4R^2C^2}} \text{ Hz}.$$

Ratings of circuit Breaker :-

The ratings of the CB's refer to the characteristic values that define the working conditions for which the circuit breaker is designed and built. circuit breakers must be capable of carrying the full load current continuously, without excessive temperature rise, and should be capable of withstanding the electrodynamics forces.

Various ratings of a CB are

→ The number of poles
→ Rated voltage and rated current

→ Rated symmetrical and asymmetrical breaking capacities
→ Rated making capacities
→ Rated short-time current or rated maximum duration of the short circuit.
→ Rated frequency
→ Rated operating duty.

Number of poles :-

The number of poles per phase of a CB is function of the operating voltage.

Rated voltage :-

During normal operating conditions the voltage at any point of the power system is not constant. The voltage levels at various points in a system vary depending upon the system condition and as result the CB has to operate under such variable voltage conditions.

The rated maximum voltage of a CB is the highest rms voltage, above nominal system voltage, for which the CB is designed and is the upper limit for operations.

Rated current

The rated normal current of a CB is the designed limit of current in rms amperes which it shall be capable of carrying continuously without exceeding the limit of observable temperature rise.

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Rated frequency.

The rated frequency of the CB is the frequency at which it is designed to operate.

The short time current wave is as shown in below fig

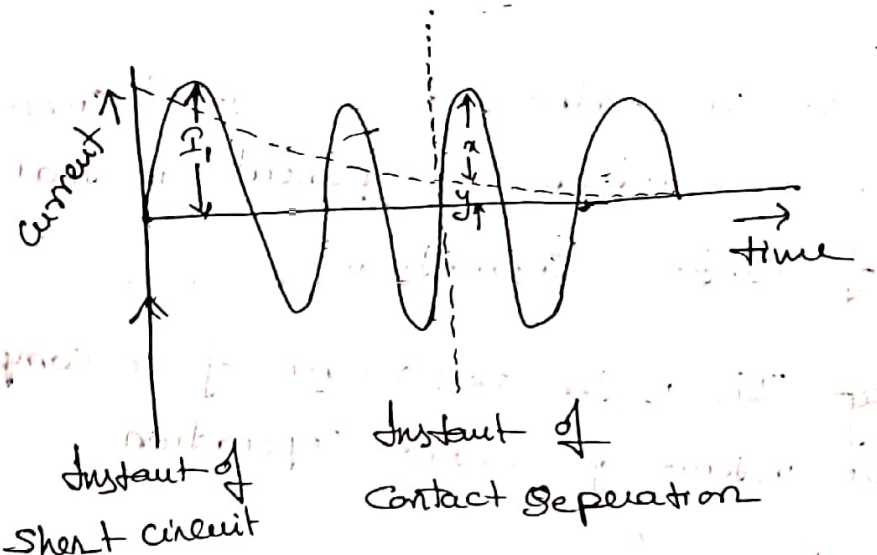


Fig: Determination of breaking current at the instant of contact seperation.

Breaking Current :-

After the instant of fault, the short circuit current starts decaying from a high initial value to a sustained value. In addition a owing to relaying time the CB starts open its arcing contacts only some time later, after the initiation of short circuit. Therefore the actual current interrupted by the circuit breaker is less than the initial value of the short circuit current.

The breaking current of the CB is the current in that pole at the instant contact - seperation. It is expressed by two values.

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→ Symmetrical breaking current

It is the value of symmetrical breaking current which the CB is capable of breaking at a stated recovery voltage and a stated reference RV under prescribed conditions.

~~This is the rms value of the total current comprising the ac and dc components in that pole at the instant of contact separation.~~

I_{sy} This is the rms value of ac component in the pole at the instant of contact separation

$$I_{sym} = \frac{x}{\sqrt{2}}$$

→ Asymmetrical breaking current

It is the value of the asymmetrical breaking current which the circuit breaker is capable of breaking at a stated recovery voltage and a stated reference RV under prescribed conditions.

This is the rms value of the total current comprising the ac and dc components in that pole at the instant of contact separation

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

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Making Current :-

The making current of a CB, when closed on a short circuit, is the rms value of the total current which is measured from the envelope of the current wave at the time of its first major peak.

The making capacity of a CB is the current that the CB is capable of making as stated voltage under prescribed conditions of use and behaviour. The rated making capabilities of CB are those which correspond to rated voltage.

Rated making capacity $= 1.8 \times \sqrt{2} \times$ symmetrical breaking capacity

$$\boxed{\text{Rated making capacity} = 2.55 \times \text{symmetrical breaking capacity}}$$

Factor 1.8 is employed to account for the asymmetry present in the short circuit current.

Rated short time Current :-

The short time current of the CB is the rms value of the current that a CB can carry in a fully closed position without damage for the specified short time interval under prescribed conditions. It is normally expressed in KA for a period of 1sec or 4sec, known as one-second rating and four-second rating respectively. These ratings are based on thermal limitations.

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So, the short time rated current is the current that can be safely applied with the circuit breaker in the normal conditions, for 3sec, if the ratio of symmetrical breaking current to making current is less than 40 or for 1-second otherwise.

Rated operating duty :-

The operating duty of a CB consists of a prescribed number of unit operation at stated intervals.

These are two alternatives for rated operating duty for CB which are not intended for auto-reclosure.

Specifications of circuit Breakers :-

Specifications for CB's are given by Indian standards:

IS 2516 (parts I and IC) 1985: Requirements and Tests
IS 2516 (part III) 1980: Design and construction
IS 2516 (part IV) 1980: Type test and Routine Tests

CB specifications under International electro technical commission Standards are given by:

IEC pub 56-2 (1971) HV ac CB : Ratings
IEC pub 56-3 (1971)
IEC pub 56-1 (1971)
IEC pub 157-1 (1973): High voltage ac CB : part I - General and definitions.

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Auto Reclosing:

It has been observed from statistical data of fault that most of the line faults in a transmission system are transient type. It exists for a short time and these can be removed faster if the particular phase is disconnected from the system momentarily so that the arc extinguishes. After quenching of the arc, the line can be recharged. Thus, the CB can be made automatic to isolate first the faulty phase and then to reclose the line. Normal service can be then be restored provided the fault is cleared. However, if the fault is not cleared after the first reclosure, a double or triple attempt of isolation and reclosure can be made. If the fault still persists, the breaker may permanently open till it is reset manually. Auto reclosing may be single or three phase type. Mostly single-phase auto reclosing breakers are preferred as most of the transmission faults are single phase to ground faults. Mostly, single shot or double shot auto reclosing breakers are available. The breakers may be rapid auto reclosing type or delayed auto reclosing type. Synchronous check is essential for delayed auto reclosing breakers.

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Advantages

→ Auto-reclosing circuit breakers enhances stability margins

→ They improve the system reliability

→ For CB's located in remote areas, the auto reclosing feature minimizes the need for an operation to close the CB manually, whenever it trips.

→ Unnecessary large duration outages due to temporary faults can be avoided.

→ In case of radial feeders fed from only one end, it maintains the continuity of supply during Temporary faults.

→ It allows flow of synchronizing power through the interconnection during single phase to ground faults using single phase auto reclosing scheme.

Types of auto-reclosing are:

→ Single shot
→ Multi-shot
→ Single phase
→ Three phase
→ Delayed

Single shot auto-reclosing:-

Single phase auto-reclosing refers to the auto reclosing of a CB, only one the rele reclose is made as soon as possible.

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This type of auto reclosing scheme is employed in case of EHV lines where there is possibility of either temporary or permanent faults but not semi permanent faults. A temporary fault on EHV lines will be disappear with in one recloser operation. However, there is no need of further reclosure operations for permanent faults. The reason for absence of semi permanent fault is the height at which EHV transmission system is installed.

In case of protection of EHV lines at both ends both the CBs must be tripped and reclosed simultaneously in order to ensure that the line remains de-energized from a specified duration.

Multi-shot auto-reclosing:

It refers to auto-reclosing of a CB more than once with in a predetermined reclosing sequence. The reclosing can be provided upto 3 times. The first reclosure is provided as soon as possible. If the supply is not fully restored the 2nd and 3rd reclosures are provided after few seconds and 1 or 2 minutes respectively. Even then, if the fault persists then it is a permanent fault and further reclosure will be provided manually only after repairs.

This type of auto reclosing scheme is employed with the lines where semi permanent faults can occur i.e, for lines with voltage ≤ 33 kV. Because semi permanent faults can be

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cleared only after 2 or 3 reclosures. In this auto reclosing scheme, as several tripping and reclosing operations may takes place. so the maintainence of CB increases. So, the vaccum CB which are almost maintenance free will be most suitable for this scheme.

Single phase auto reclosing :-

Single phase or single pole auto reclosing refers to the auto reclosing of one pole of a CB following a designed single pole trip for LG faults. The design in CB is such that each pole will have its own tripping and closing mechanism. For implementation of this auto reclosing scheme, a complex relaying scheme has to be provided which can detect the faulty phase. During multi phase faults. the relaying scheme trips all the three phases and auto reclosing will be done for all the three phases.

Due to complexity in design of CB and relaying scheme, it is most expensive auto reclosing scheme. Also this scheme suffers with a problem of dc ionization time. It is due to the fact that when only faulty phase is isolated, the capacitive coupling between the healthy phases and the faulty phase tends to maintain the arc. Hence, the deionization takes a long time.

This type of auto reclosing scheme is provided for the interconnections where two different power system are being interconnected with a single trip line.

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Three-phase auto reclosing:-

It refers to the simultaneous auto reclosing of all the three phases. For implementation of this auto-reclosing scheme, simple relaying scheme is required. Since, the relaying scheme need not have to detect the fault phase and instead it should simply detect the occurence of fault and trip all the three phases. So, the design of CB is also quite simple as it is not required to have an individual tripping and closing mechanism for each pole. Moreover, it has a additional advantage of having less deionization time, since, all the three phase are tripped simultaneously.

Delayed auto-reclosing:-

It refers to the auto-reclosing of CB after an intentional time. As the delay time will be longer than the used in high speed auto-reclosing the problems associate with deionization and power swings are absolutely absent. In this scheme, all 3-phases are tripped and reclosed simultaneously. This scheme is employed for an inter-connected power system with a number of lines.

Basic principle of operation of CB & constructional details.

The basic construction of a CB requires the seperation of contacts in an insulating fluid which serves two functions. They are

→ Extinguishing the arc between the contacts on the opening of CB.

→ providing insulation between the contacts and from each contact to earth.

The different type of arc quenching medium employed in the CB's are air, oil, vaccum and SF_6 gas. so, the different types of CB's where the arc queueing medium is the criterions of arc.

→ Air blast CB

→ Oil circuit breaker

→ vaccum circuit breakers

→ SF_6 circuit breaker

* Air blast CB are recommended for voltages in the rauge of 66 kV to 1100 kV.
* They are also employed for specific applications in the voltage rauge of 11kV to 33 kV
* Minimum oil circuit breaker are recommended for the voltages in the rauge of 3.3kV to 220kV.
* vaccum CB are recommended for voltages in the rauge of 3.3kV to 33kV
* SF_6 CB are recommended for voltages in the rauge of 3.3kV to 765 kV.

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The fluids that can be used in a CB ① 18
should have the following properties.

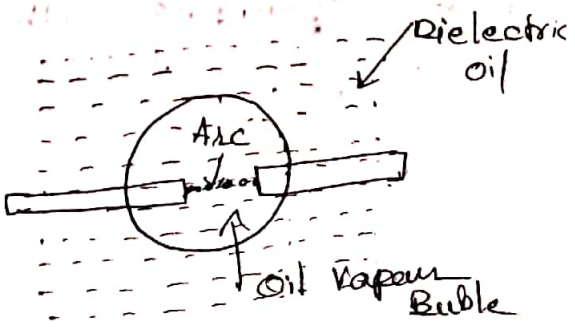
→ High dielectric strength
→ Non inflammability
→ High thermal stability
→ chemical stability
→ Arc extinguishing ability
→ Commercial availability at moderate cost.

Oil Circuit Breakers:

Mineral oil has better insulating properties than air. Due to this reason it is employed in many electrical equipment including CB's. Oil has also good cooling property. Thus insulating oil is employed as arc quenching medium.

The contacts are opened under oil and an arc is struck between them. The heat of the arc evaporates surrounding oil and dissociates it into a substantial volume of gaseous hydrogen at high pressure.

The hydrogen gas occupies a volume about 1000 times that of the oil decomposed. The oil is therefore pushed away from the arc and expanding H_2 gas surrounds the arc region and adjacent portions of the contacts as shown in below figure



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The arc extinction is facilitated by two processes. They are

→ The H_2 gas has high heat conductivity and cools the arc, thus aiding the deionization of medium between contacts

→ The gas sets up turbulence in the oil and forces it into the space between the contacts.

Thus eliminating the arcing products from the arc path. Hence the arc energy is absorbed in decomposing the oil into gases.

Advantages of oil being used as an arc-quenching medium

→ The oil acts as an insulator between live part and earth

→ The oil has high dielectric strength

→ The oil absorbs arc energy while decomposing

→ The gases formed by the decomposition of oil have good cooling properties.

Disadvantages:

→ Oil is inflammable

→ It forms the explosive mixture with air

→ It requires maintenance and periodic replacement.

There are two basic types of oil CB's. They are

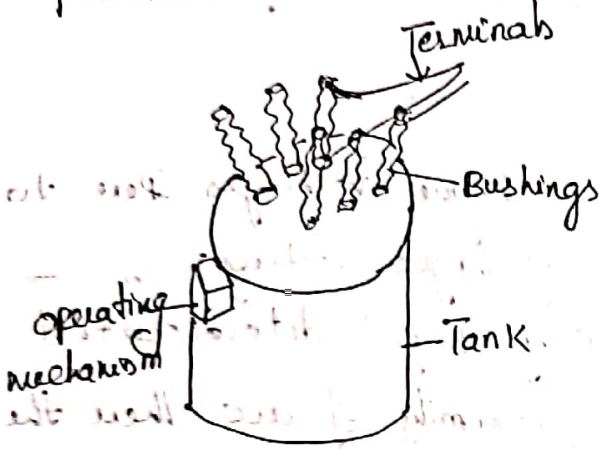
→ CB's operating with large quantity of oil - Bulk oil CB

→ CB's operating with minimum quantity of oil - Minimum oil CB's.

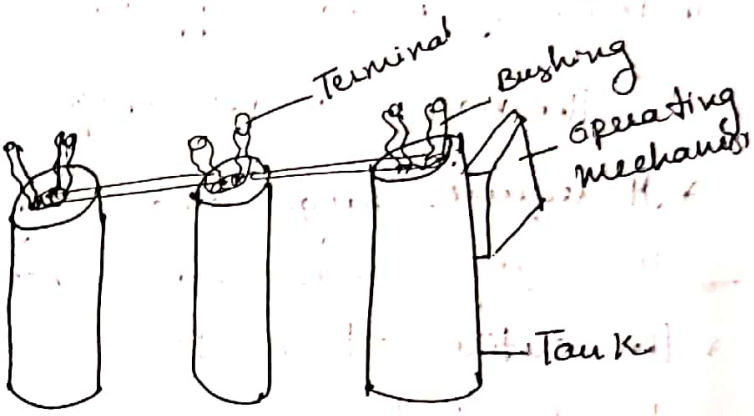
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Bulk oil CB's:

The bulk oil CB has three seperate tanks for 72.5k and above, for 36KV and below single tank construction i popular. In single tank constoction a phase barrier are provided between phases and is shown in below figure!



appearance of a single tank three-phase bulk oil breaker



Appearance of a three phase bulk oil CB with three tanks.

This type of CB is used for indoor metal clad draw out typ switchgear up to 12KV above 12KV, it is useally of outdoon type.

In this type of CB's, oil perforins two functions. It acts as an arc extinguishing medium and it also serves as insulation between the live terminals and earth. The oi used here is also called as transformer oil

The contact separation takes place in steel tanks filled with oil. The gases formed due to the heat of the arc expand and set the turbulent flow in the oil.

To assist the arc extinction process, arc control devices are fitted to the contact assembly. These are Semi-enclosed chamber of dielectric materials. The performanc of oil CB depends on the effectiveness of the arc control devices

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The construction and venting of arc control devices is such that the gases flow axially or radially with respect to the arc.

The main advantage of bulk oil CB is that the protective transformers can be accommodated on the bushing instead of being supplied as a separate piece of apparatus.

The major disadvantage of bulk oil CB are.

→ It requires huge amount of oil at higher voltages. Due to this very reason it is not used at higher voltages.

→ The entire oil in the tank is likely to get deteriorated due to sludge formation in the proximity of arc. Then the entire oil needs replacement.

→ The tanks are too big.

These causes lead to the development of the Minimum oil CB.

Minimum Oil CB's (MOCB)

The MOCB uses solid materials for insulating purposes and uses just enough oil for arc quenching. The interrupting device is enclosed in a tank of insulating material, the whole of which is at line voltage during operation. So, these are also known as live tank breakers.

Description and Construction :-

The construction of a single phase MOCB is as shown below. There are two compartments separated from each other but both filled with oil.

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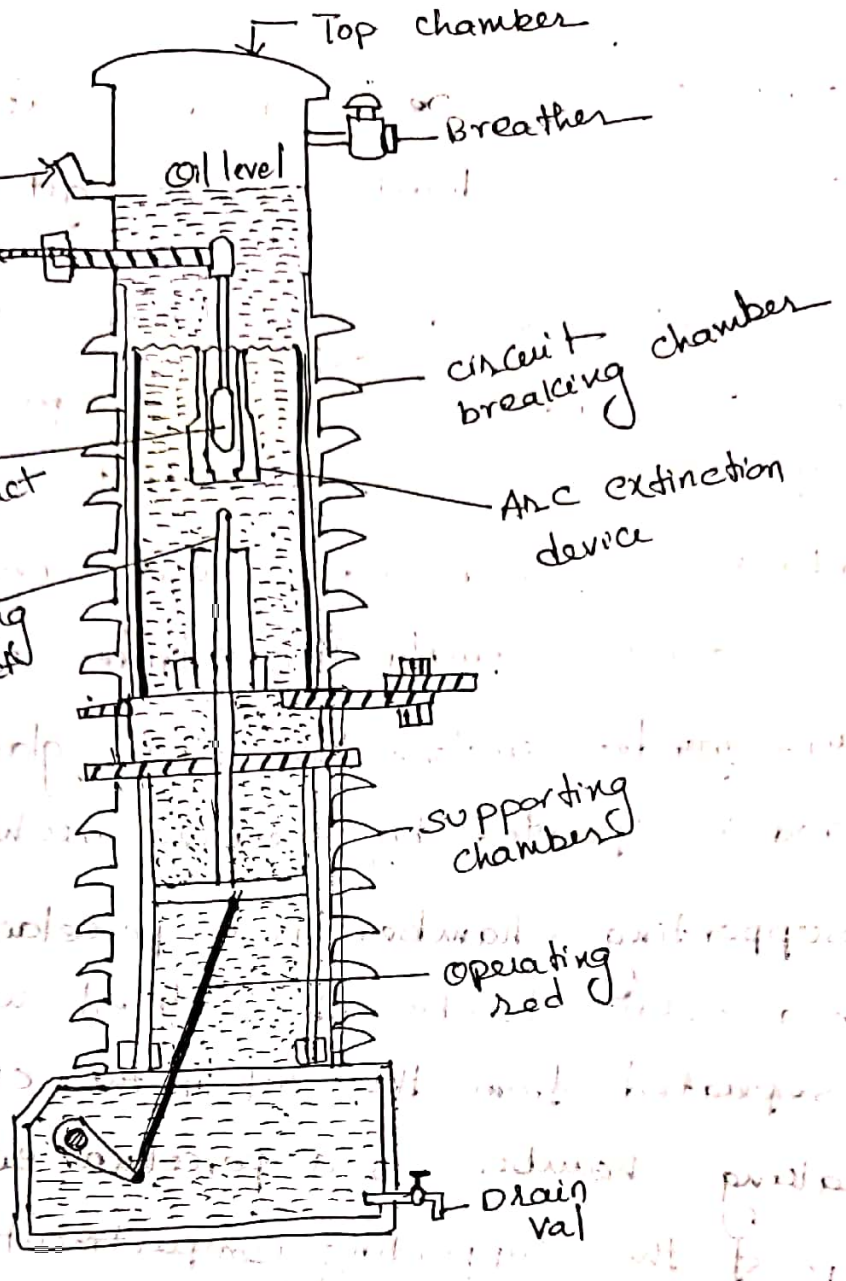


fig: Minimum oil CB

The upper chamber is the CB chamber (or) arc extinction chamber. The lower chamber is the support chamber acts like a dielectric support. The two chambers are seperated by a partition and oil from one chamber is prevented from mixing with the other chamber. This arrangement is advantageous in two ways.

→ The CB chamber requires a small volume oil which is just enough for arc extinction.

→ The amount of oil to be replaced is reduced as the oil in the supporting chamber doesnot get contaminated by the arc.

Arc extinction device is fitted to the upper fixed contact. The lower fixed contact is ring shaped. The moving contact makes a sliding contact with the lower fixed contact. A resin bounded glass fiber cylinder encloses the contact assembly. This cylinder is also filled with oil. porcelain cylinder encloses the fiber-glass cylinder. The operating rod is operated by operating mechanism.

Supporting chamber is a porcelain chamber mounted on a metal chamber. It is filled with oil which is physically seperated from the oil in the CB compartment. Circuit breaking chamber is a porcelain enclosure mounted on the top of the supporting compartment and is filled with oil. It consists of upper and lower fixed contacts, moving contact and tabulator.

The moving contacts is hollow and includes a cylinder which moves down over a fixed piston. the tabulator is an arc control device and has both axial and vertical vents. In axial venting, the gases sweep the arc in longitudinal direction, it generates high pressures along with high dielectric strength and ensures interruption of low currents at high voltages. In radial venting the arc is

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is blown in transverse direction is generates low pressures, has low dielectric strength and ensures interruption of high currents at low voltages.

The top chamber is a metal chamber and is mounted on the circuit breaking chamber. It provides expansion space for the oil in the circuit breaking compartment. It is also provided with a separator which prevents any loss of oil by centrifugal action caused by CB operation during fault condition.

The MOCBs can be self blast type or cross blast type or combination of two. In self blast type the arc is quenched adapts itself to the current forces with the arc is quenched to be broken. The larger the short circuit current, the more is the oil decompressed and more is the amount of gas developed for cooling. So, self blast type MOCBs quench the arc more effectively as the current increases and this principle is employed in most designs.

Operation :- under normal operating conditions the moving contact (MC) remains engaged with the upper fixed contact. When a fault occurs, the MC is pulled down by the tripping springs and an arc is struck. As the current carrying contacts are separated under the oil, the heat of the arc causes the decomposition of oil.

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The arc energy vaporizes the oil, ~~the heat of the arc causes the decomposition~~ the gases thus formed expand causing increase in pressure. This action constraints the oil to pass through the central hole in the rod and results in forcing of series of oil through the respective passages of the tabulator. The process of tabulation in orderly one in which the sections of arc are successively quenched by the effect of seperate streams of oil moving across each section. The gas following near the contact zone causes cooling and splitting of arc, At current zero of the wave, the arc diameter is very small and the gas flow is able to interrupt the arc. The interruption of the arc stops the generation of gas and flow of oil. The contact space is filled with fresh dielectric oil after the final arc interruption at a current zero.

Advantages.

→ Smaller quantity of oil
→ less weight and size.
→ lower cost
→ suitable for both automatic and manual operation
→ Easier access to the contacts
→ Reduced risk of fire and reduced maintenance problems
→ suitable for both indoor and outdoor applications.

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Disadvantages:-

→ Due to smaller quantity of oil, the degree of carbonization is increased
→ Totally unsuitable for repeated cycles of operation
→ Difficulty of removing the gases from the contact space in time
→ Dielectric strength of oil deteriorates rapidly due to high degree of carbonization
→ Requires more frequent inspection & replacement of oil
→ Difficulty in locating current transformers.
→ Greater contact damage
→ Lower rupturing capacity

This type of CB is available upto 8000MVA at 245KV with a total break time of 3 to 5 cycles.

Applications:-

→ For indoor applications, minimum oil CB can be used up to 36KV
→ For outdoor applications, minimum oil CB can be used upto the line voltage of 220KV.

Air Blast Circuit Breakers:- (ABCB)

The drawback of the oil CB's are the fire risk due to the inflammable oil, the deterioration of the oil, necessitating the periodic replacement and the difficulty of reaching the contacts for maintenance purposes. This leads to the development of CB's using compressed air or gas as the

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the interrupting medium. Though gases such as nitrogen, carbon dioxide (or) hydrogen can be used as the arc interrupting medium but compressed air is the accepted circuit breaking medium for gas blast CB's.

These CB's are used for high pressure air-blast as an arc quenching medium. They find wide application in system operating voltage at 132 kV and above (upto 400kV) with breaking capacity upto 7500MVA and above.

The advantages of air-blast CB over oil CB are

→ No risk of fire hazard and explosion
→ high speed operation
→ short and consistent arc duration
→ Frequent operations of the CB are possible
→ Reduced maintenance
→ facility of high speed reclosure
→ Comparatively less weight.

Disadvantages :

→ Their construction is much more complicated
→ Air leakages at the pipe line fittings create the problem
→ High cost of the plant components
→ Requires highly trained personnel for their maintenance
→ sensitivity to RRRV
→ problem of restriking voltage
→ problem of current chopping.

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Principle of arc extinction :-

An ABCB requires an auxiliary compressed air system which supplies air to the breaker air receiver. When opening is required, compressed air is admitted to the arc extinction chamber. It pushes away the moving contact In doing so the contacts are seperated and the AB takes away the ionized gases along with it and assist arc extinction. Air blast extinguish the arc with in one or two cycles and once the arc chamber is filled with high pressure air, which prevent restrike. In some low capacity CB's the isolator is an integral part of the CB. The CB opens and immediately after the isolator opens to provide additional gap. In EHV Switchyard, isolators are generally independently mounted

The ABCB's fall under the category of external extinguishing energy type. The energy supplied for arc extinction obtained from high pressure air and is independent of current to be interrupted.

Types of air blast CB's :-

Air blast CB's, according to type of flow of blast of compressed air, are classified as follows.

→ Axial blast type :-

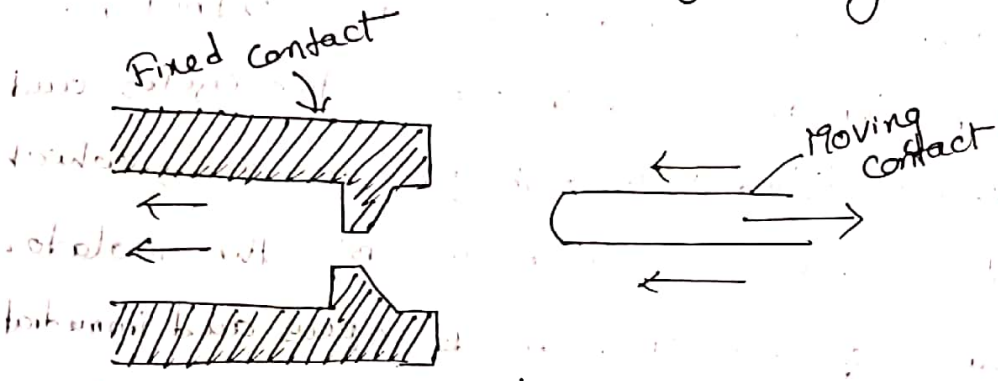
→ cross blast type

→ Radial blast type

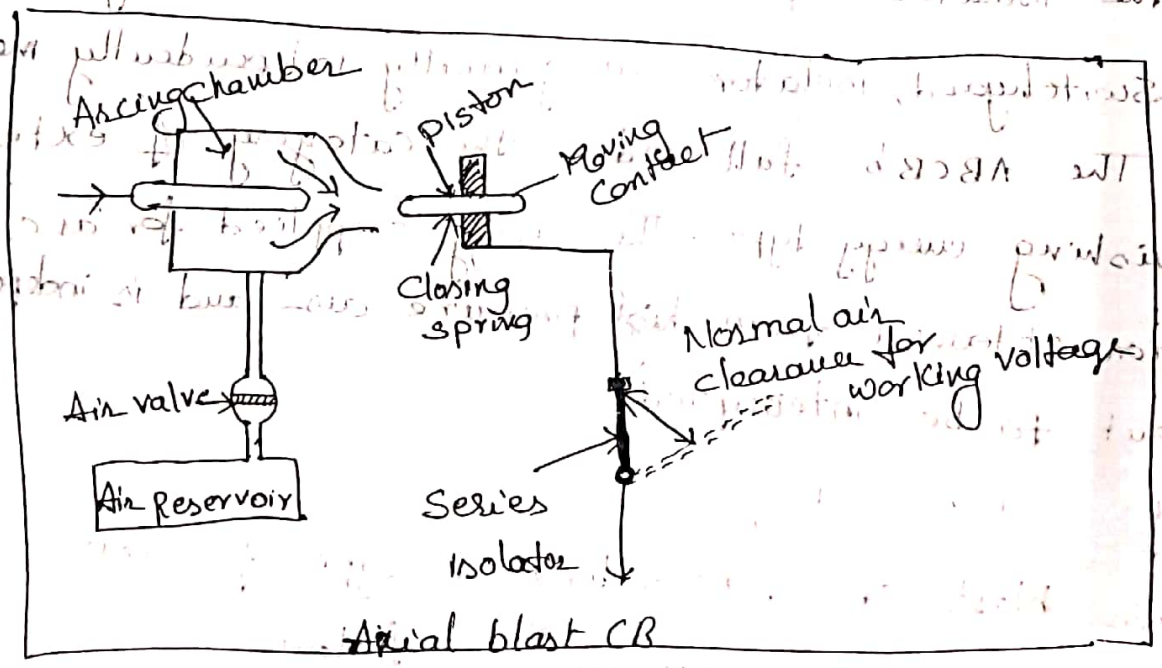
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→ Axial Blast CB's:-

The most common type of air blast CB employing axial flow of blast air for extinction of arc is shown in below figure. The moving contact is connected to a piston and the shaft of the contact is guided by guide springs. The circuit breaker is closed by opening lower air valve.



a) Axial blast



When the fault occurs, the relay operates and opens the upper air valve. The compressed air enters the arcing chamber and piston chamber and accelerates the moving contact. On the separation of contacts an arc is struck, the cold air rushes round the contacts axially and blows out the arc

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It is generally applied for high voltage transmission System and interconnected network.

Cross Blast Air CB's :-

In this type of CB, an air blast is directed at right angles to the arc as shown in below figure

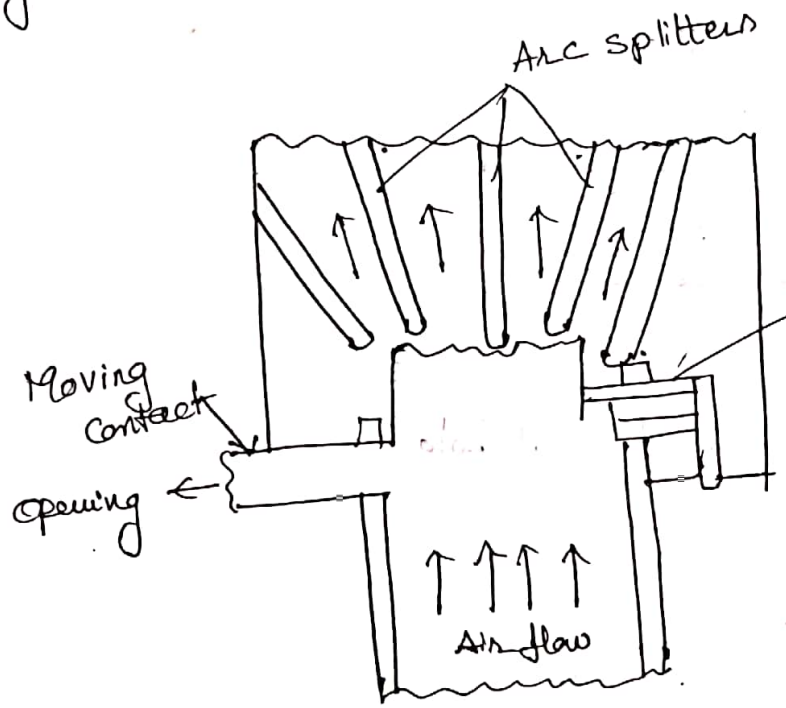


Fig: cross blast CB.

The cross blast lengthens and forces the arc into a suitable chute for arc extinction. When the MC is withdrawn, an arc is struck between the FC and MC. The high pressure cross-blast forces the arc into a chute consisting of arc splitters and baffles. The splitters serve to increase the length of the arc and the baffles give improved cooling. Thus, the arc is extinguished and the flow of current is interrupted. Since blast pressure is same for all currents, the inefficiency at low current is eliminated. The final gap for insulation clearance is great enough to normal insulation clearance

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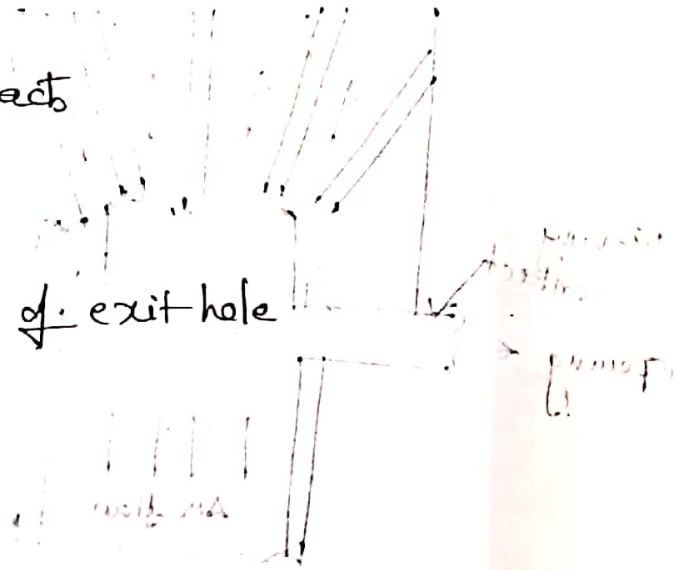
so that a series isolating switch is not necessary.

These CB's finds applications for high current interruption at relatively lower voltages.

Factors of ABCB

The factors which influence the performance of an air-blast CB are

→ Air pressure
→ Distance between contacts
→ Contact materials
→ Mass flow
→ Area of cross section of exit hole
→ circuit Severity
→ shunt resistance.



Sulphur Heraflueride (SF_6) CB :-

In the CB discussed in previous section's, the extinguishing force builds up relatively slowly after the moment of contact separation. But the prevention arc re-ignition needs a high dielectric strength of the arc path and its fast recovery after current zero. The SF_6 CB serves for the purpose of quick recovery voltage build up and quick arc extinction. In this type of CB, SF_6 gas is used as an arc quenching medium.

SF_6 gas has excellent insulating strength because of its affinity for electrons (electro negativity) i.e, whenever a free electron collides with the neutral gas molecule to form negative ion, the electron is absorbed by the neutral gas

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molecule. The attachment of the electron with the neutral gas molecule may occur in two ways.

→ As direct attachment,

$$SF_6 + e \rightarrow SF_6$$

→ As dissociate attachment,

$$SF_6 + e \rightarrow SF_5 + F$$

The negative ions formed are relatively heavier and immobile as compared to free electrons and are therefore, ineffective as current carries. so that ionized SF_6 has as high electric streugth as unionized gases at equal density. Thus, these processes represent an effective way of removing electrons from the space. This property, therefore, gives rise to very high dielectric streugth for SF_6. The arc is then better interrupted by slowing down the electrons by cooling in case of SF_6. The thermal time constant of SF_6 is low and as a result the pressures at which it should be stored and used are relatively smaller as compared to air. Also for the same limiting voltage the natural frequency of mains may be greater (almost 100 times) in case of SF_6 as compared to air.

Properties of SF_6:

⇒ This gas is extremely stable and inert, and its density is five times that of air.

→ It is non-toxic and non-inflammable

→ It is an ideal medium for circuit interruption. Its properties make it an ideal medium insulating and arc-quenching mediu

→ It has a thermal conductivity higher than that of air and helps in better cooling of current carrying parts.

→ Heat content property at temperatures below 6000°K is much higher than that of air and it helps in continues cooling of the arc zone after current zero.

→ Due to electronegativity of SF_6 gas the arc time constant of SF_6 is very low and rate of rise of dielectric strength is high

→ It is chemically stable up to 500°C and doesnot react with structural material up to 500°C

→ SF_6 gas not only possesses a good dielectric strength but also it has the unique property of fast recombination after the source energizing the spark is removed. This property makes it effective in arc quenching.

→ Moisture is very harmful to the properties of the SF_6 gas.

→ The low arc time constant and its capacity to absorb free electrons due to its electro magnetic character make SF_6 an excellent medium for arc quenching.

→ It has exceptionally low reactivity and doesnot attack metals plastics, etc.

→ Its dielectric strength at atmospheric pressure is 2.35 times that of air and 30% less than oil. At three times the atmospheric pressure, it is more than that of oil.

The gas at atmospheric pressure can interrupt currents of the order of 100 times the value of those that can be interrupted in air with a plain breaker interrupter.

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Construction of SF_6 CB :-

The essential parts of SF_6 breaker are

→ Interrupter unit
→ Operating unit
→ Bushings
→ Gas system.

Interrupter Unit :-

This unit is that in which arc is interrupted. The unit is in turn connected to SF_6 gas reservior. This consists of fixed contacts and moving contacts. The fixed contacts comprise of a set of current carrying fingers and an arc probe. The moving contact is a hollow cylinder with holes their sides to allow SF_6 gas.

When the breaker is in the closed position, the fingers make contact round and the contacts are surrounded by interrupting nozzles and a blast shield which controls arc displacement. Side vents in the moving contact allow the high pressure gas into the main tank.

→ Operating Mechanism :- In operation the tripping spring device the moving contacts and simultaneously opens the valve of the pressure reservoirs. The gas under pressure flows into the breaking chambers the arc. At the end of the operation the mechanism releases the valve of the pressure reservoir which is closed by the action of set of springs.

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→ Bushings :- They contain a hollow conductor a fixing flange, upper and lower insulators and the springs which hold the assembly together. They contain SF_6 gas at a pressure of 2kg/cm. The SF_6 gas in bushings communicate with that in the tank through small holes in the upper part of the hollow conductor.

Gas System :

The operating pressure of SF_6 gas in the circuit breaker is 14kg/cm^2 to extinguish the arc. A compressor sends back after each break to the high pressure reservoir. Being a closed circuit no gas escapes to the atmosphere. An auxiliary reservoir of SF_6 gas at 14kg/cm^2 is located below each tank, containing enough gas for 4 consecutive breaks without the need for starting up the compressor.

Principle components of the system are

→ A filter for removing traces of impurities by the contact of the gas with the arc
→ Compressor for circulation of gas
→ Filter for removal of traces of oil in the gas
→ Relief valve for holding the value of the high pressure with in correct limits
→ safety & control devices for maintaining the operating pressure.

Operation :- In a closed position of the CB, the contacts remain surrounded by SF_6 gas at a pressure of 2.8 kg/cm^2. When the CB operates, the moving contact is pulled apart and arc is struck between the contacts. During the arcing period,

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SF_6 gas is blown axially along the arc. The gas removes the heat from the arc by axial convection and radial dissipati As a result, the arc diameter reduces during the decreasin mode, of the current wave. The diameter becomes small durin current zero.

The movement of the Mc synchronizes with the opening a value which permits SF_6 gas 14 Kg/cm^2 pressure from the reservoir to the arc interruption chamber

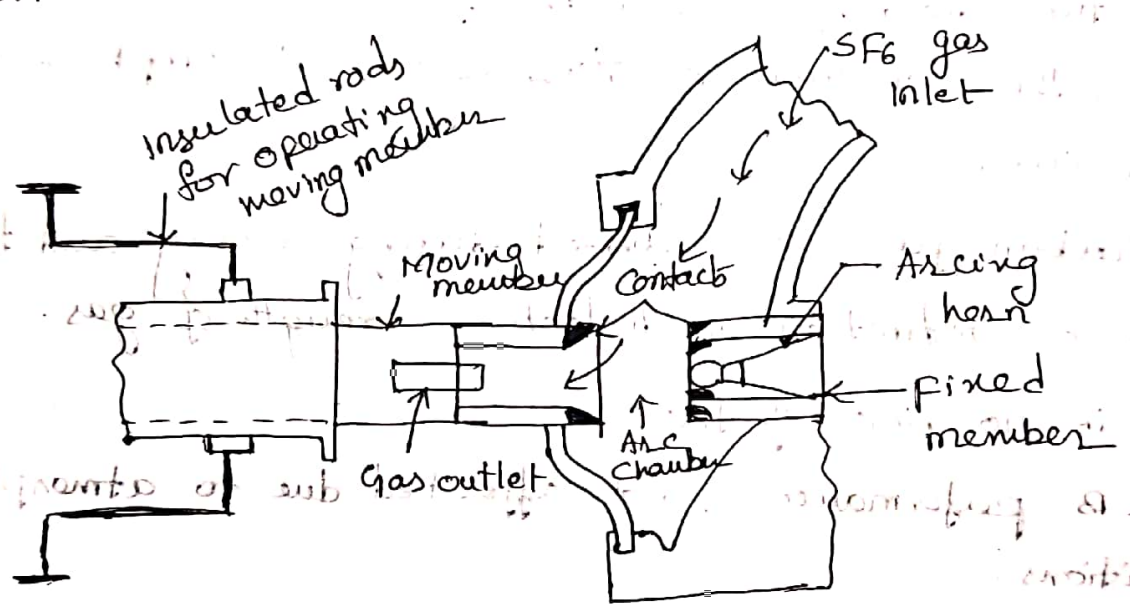


fig: SF_6 CB

The high pressure flow of SF_6 rapidly absorbs the free electrons in the arc path to form immobile negative ions which are ineffective as charge carriers. Thus the SF_6 medium between the contacts quickly builds up high dielectric streigth and causes the extinction of the arc.

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Advantages:

→ The current chopping tendency is minimum by using the gas SF_6 at low pressure and low velocity

→ The closed circuit gas cycle and low velocity operation eliminates the moisture problem and gives noiseless operation

→ Because of the outstanding arc quenching properties of SF_6 the arcing time is small and therefore contact erosion is less.

→ since the dielectric strength of SF_6 is 2 to 3 times that of air, these circuit breakers can interrupt much larger currents

→ No carbon particle is formed during arcing and therefore there is no reduction in dielectric strength of gas.

→ There is no risk of fire.

→ The CB performance is not affected due to atmospheric conditions.

→ Electric clearances are drastically reduced due to high dielectric strength of SF_6

→ low maintenance cost and auxiliary equipment.

Disadvantages:

→ SF_6 breakers are costly due to high cost of SF_6

→ since SF_6 gas has to be reconditioned after every operation of the breaker, additional equipment is required for this purpose.

Applications: SF_6 CB have been developed for voltages 115KV to 230KV, power ratings 10MVA to 20MVA and interrupting time less than 3 cycles.

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Types of SF_6 CB

There are two types of SF_6 CB. They are

→ Double pressure

→ puffer-type.

Double pressure :- This is the early design of SF_6 CB. Its operating principle is similar to that of ABCB's. In this type of a CB, the gas from a high-pressure compartment is released to the low pressure compartment to extinguish arc. Because of its complicated design and construction and its need for various auxiliaries such as gas compressors, filters and control devices, this type of CB's have become absolete.

Puffer-type :- This type of CB's are also some times called single pressure or impulse type SF_6 CB's. In this type of breaker gas is compressed by a moving cylinder system and is released through a nozzle to quench the arc. This type is available in the voltage range 3.6 kV to 765 kV.

The below figure shows a puffer type breaker in closed position. The moving cylinder and the moving contact are coupled together. when the contacts seperates and moving cylinder moves, the trapped gas is compressed. The trapped gas is released through a nozzle and flow axially to quench the arc as shown in below figure. There are two types of tank designs. one is live tank design and other is dead tank design.

In live tank design, interrupters are placed in SF_6 filled tank which is at earth potential live tank design is proffered for outdoor substations.

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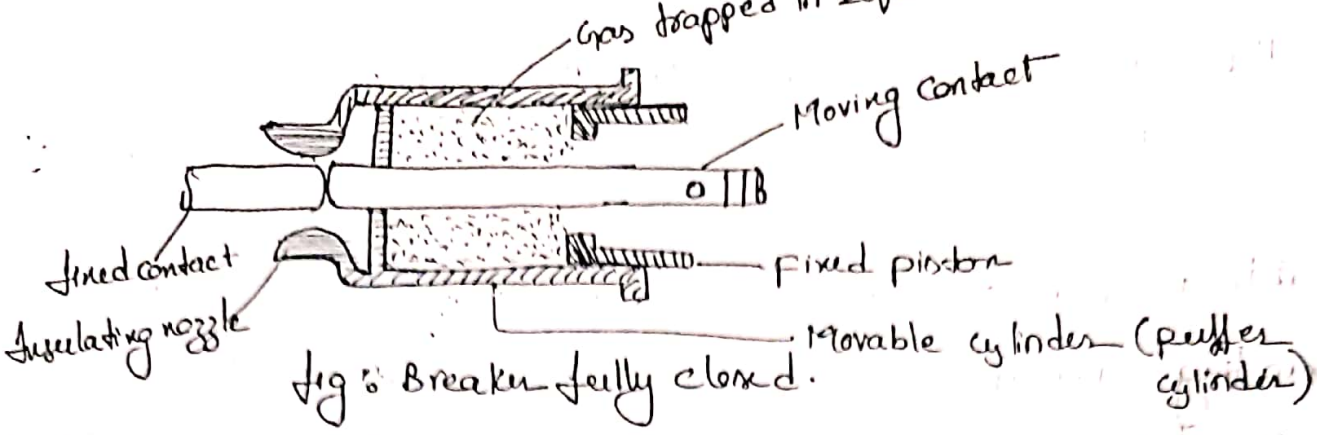


fig: Breaker fully closed.

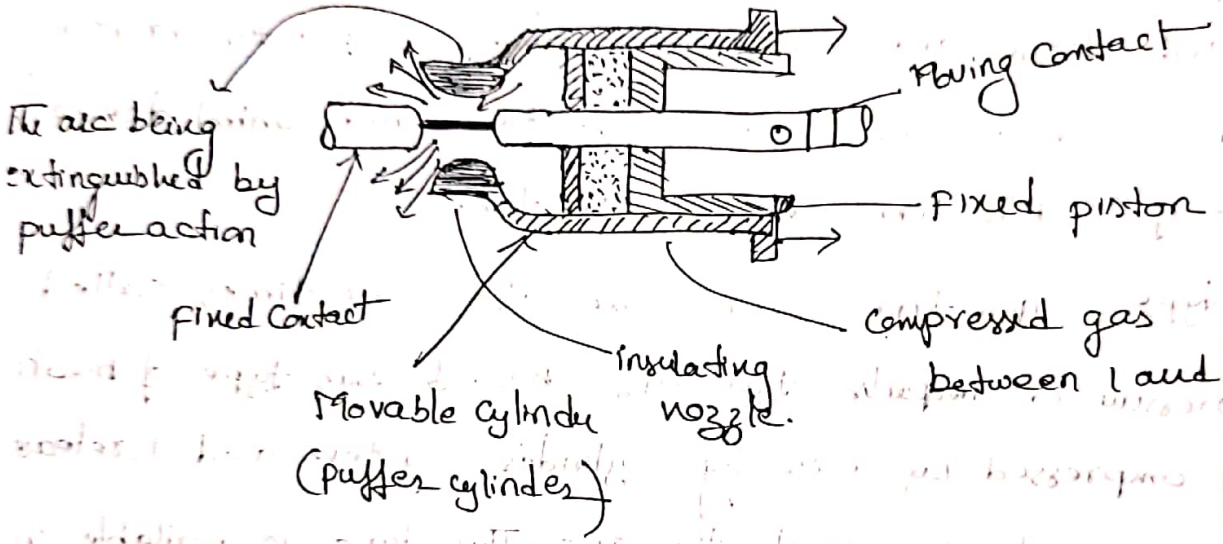


fig: Contacts seperated, puffing action in progress

SF6 gas. Compressed gas SF_6.

A number of interrupters (connected in series) on insulating support are used for EHV system upto 765KV. Two interrupters are used in a 420KV system.

Breaking time of 2 to 3 cycles can be achieved. In the CB the steady pressure of the gas is kept at $5 kg/cm^2$. The gas pressure in the interrupter compartment increases rapidly to a level much above its steady value to quench the arc

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Vacuum Circuit Breaker (VCB)

A vacuum system is one in which the pressure maintained is at a value below the atmospheric pressure and is measured in terms of mm of mercury. In VCB's vacuum is used as the arc quenching medium.

Principle:- when the current carrying contacts are seperated in a vacuum, an arc is produced between the contacts by the ionization of metal vapours of contacts. This is because the contacts of the CB are not smooth, but have microscopic sharp projections on the surface of the contacts which act as points of high intensity field, resulting in emission of electrons. since the cross sectional area of each projection is very small, the current density becomes very large and the heat produced causes melting of projections. so, an intensely hot spot is created at the instant of contact seperation from which vapour is shoot off, constituting plasma. with alternating current arc, the current decreases during a portion of the wave and tends to zero. Thereby the amount of vapour emission tends to zero and the amount of plasma tends to zero. Soon after the natural current zero, the remaining metal vapour, ions, electrons etc. formed during arc condense on the CB contacts and the dielectric strength builds up rapidly and restriking of arc is prevented.

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Construction :-

The vacuum breaker consists of the following parts.

→ Enclosure :- The enclosure is nothing but the outer envelope. It is made of glass normally, because

→ It is impermeable insulating material

→ Ease of joining it to the metallic end caps.

→ Ease of examining the state of the contacts after a current interruption, to know the degree of vacuum.

The enclosure must not be porous and should retain high vacuum of the order of 10^{-10} torr.

→ End Flanges : The two flanges are made of non-magnetic material, which support the enclosure fixed contact (FC), shields, bellows protective covers etc.

→ Contacts : The contacts are made of large stem with a large disc shaped faces. The disc is provided with symmetrical grooves in such a way that the segment of the contacts is not in the same line. The magnetic field set up by the components with such geometry causes the plasma of the arc to move rapidly over the contacts instead of remaining stable at one point The concentration of arc is thus prevented and the arc remains in diffused state.

→ Vapour condensing shields (sputter shields) : A metallic shield is provided in between the contacts and the enclosure. This is provided so that the metal vapour released from the contact surface during arcing is condensed on these shields and is provided from condensing on the metal envelope.

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→ Metallic Bellows :-

These are used to move the lower/moving contacts. These are made of stainless steel in general. One end of the bellows is welded to the metal flange and the other end is welded to the moving contact (MC). The bellows permit the sealed construction and their design is very important as the life of the VCB depends on the ability of this part to perform repeated operations satisfactorily. The bellows are covered by a protective shield.

The periphery of end cap is sealed in the envelop and the FC stem is an integral part of one end-cap. One end cap of the fixed as well as moving contact is brought out of the chamber for external connections. The lower end of the breaker is fixed to a spring operated or solenoid operated mechanism so that metallic bellows inside the chamber are moved upwards and downwards during closing and opening operation respectively.

Working :- The separation of current carrying contacts causes vapour to be released from the contacts giving rise to plasma. As the contacts separate, the contact space is filled with vapour of positive ions liberated from the contact material. The vapour density depends on the current in the arc. During the decreasing mode of the current wave the rate of release of the vapour reduces.

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The arc extension process is related to the material and shape of the contacts and the technique adopted in condensing the metal vapour. The contact geometry is so designed that the root of the arc keeps on moving so that the temperature at one point on the contact doesnot reach a very high value.

The arc is quickly extinguished at a final current zero b'cos the metallic vapours electrons and ions produced during arc are diffused in a short time and seized by the surfaces of moving and fixed members and shields. Since vacuum has very fast rate of recovery of dielectric strengths. the arc extinction in a vacuum breakers occurs with a short contact seperation say 0.625cm.

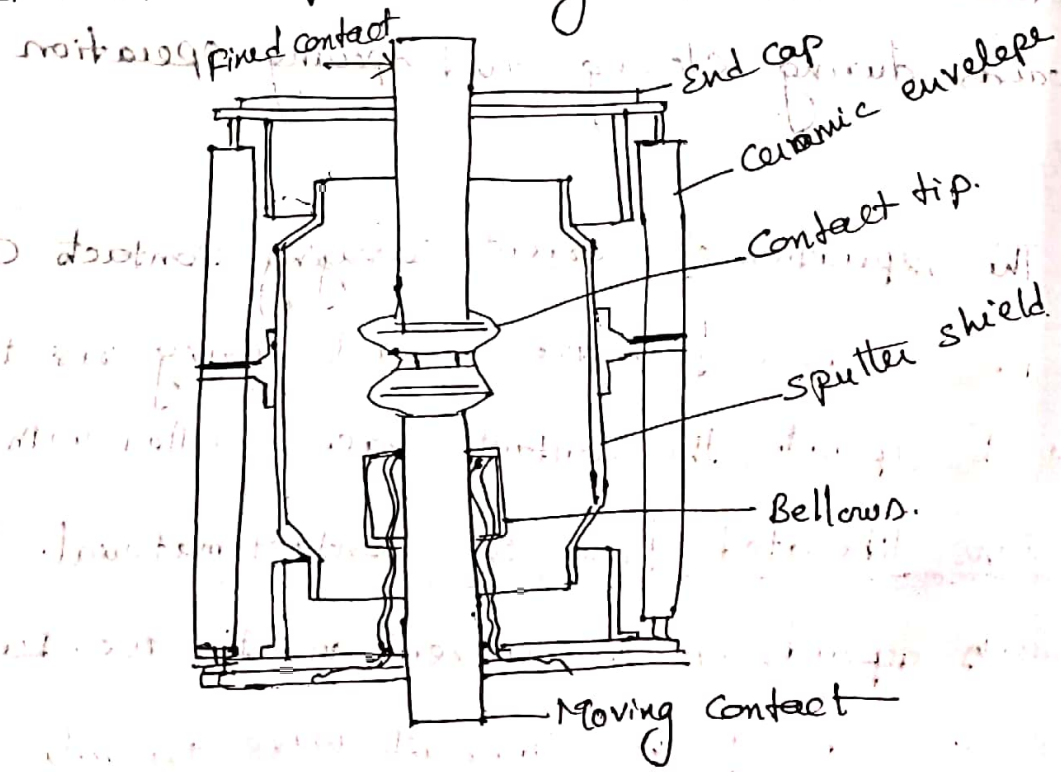


fig: Vacuum CB

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Advantages

→ They are compact, reliable and having longer life
→ There are no fire hazards
→ There is no generation of gas during and after operation
→ They can interrupt may fault current. It can break any heavy fault current perfectly just before the contact reach the definite open position.
→ They require little maintenance and are quiet in operation
→ They can succesfully withstand lightning surges.
→ They have low arc engy
→ They have low inertia and hence require smaller power for control mechanism

Disadvantages:

→ Requirement of high technology for production of vacuum interrupters.
→ It is uneconomical to manufacture vacuum interrupters in small quantity
→ Loss of vacuum, due to transit damage or failure, makes the entire interrupter useless and it cannot be repaired at site.
→ It needs additional surge suppressures in parallel with each phase in a certain range.

Applications:

As current chopping is not a serious problem in a vacuum in a vacuum CB and as they have excellent recovery characteristics, they find applications like transformer switching, line dropping, reactor switching, capacitor bank switching, arc furnace installations .. etc.

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They are being extensively used in substations, A feeding traction system and many other industrial applications As they are almost maintenance free, they are being widely used in 11KV and 33KV substations. In gas insulated substa also vacuum CB's are being employed for arc interruptio

Requirements of Contact Materials :-

The chief requirements of contacts materials for vacuum CB's.

→ High electrical conductivity in order to allow normal load currents without heating excessively.

→ High thermal conductivity for fast dissipation of heat.

→ The heat of vaporization should be such that the arc energy generates sufficient vapour to sustain arcing up to first neutral current zero instant and after that there is insufficient vapour.

→ High melting point

→ High arc withstand ability

→ Good mechanical strength in order to retain structural integrity during severe potential gradients at the surface.

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