Module 4 CIRCUIT BREAKERS

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Course objectives: To explain the principle of circuit interruption and different types of circuit breakers.

4.0 Introduction

The **electric arc** is a type of electric discharge between electrodes. The arc formation between the contacts of CB is entirely due to Ionization process such as ionization by collision, photo ionization, thermal ionization, etc in circuit-breakers, the arc persists during the brief period after separation of current carrying contacts. The circuit-break should be capable of extinguishing the arc without getting damaged. The interruption of D.C. arcs is relatively more difficult than a.c. arcs. In a.c. arcs, as the current becomes zero during the regular wave, the arc vanishes and it is prevented from restriking.

4.1 Fault clearing time is the time between the instant of fault and instant of final are interruption (in circuit breaker).
Fault clearing time is the sum of relay-time and circuit breaker-time.

Remember the time events

Fault Clearing Time = [Relay Time] + [Breaker Time]

Fault Instant to Closing of relay contacts	+	Closing of relay contacts to Final Arc-extinction in C.B.

The relay-time is the time between the instant of occurrence of fault and the instant of closure of relay contacts. Or, it is the time between the instant when the operating quantity reaches the pick-up value and the instant of closure of relay contacts.

The circuit breaker time is the total of time taken by operating mechanism to open to circuit breaker contacts and the arching time. It is also called total break time.

The fault clearing time is significant due to the following reasons:

1. Rapid fault clearing minimizes the damage. During short circuit tests on bus bars, with fault duration of 0.07 second, with 60 kA R.M.S. value of current, no damage was observed after the tests. With fault duration of 7 seconds, however, the bus bars were completely destroyed.

2. Rapid fault clearing improves power system stability. For the reason, the slow relays and slow circuit breakers should not be preferred for protection, where stability is important. This applies to protection of EHV transmission lines, protection of large machines like important generator, large transformer, large-motors, etc., and protection in important generating stations and receiving stations

Though fast fault clearing is desirable, time lag is purposely provided in majority of protection systems for the following purposes:

- To permit discrimination between main and back-up protection.
- To prevent the operation of relay during transients, starting currents, permissibly load fluctuations, etc.

The relay-time of fast relays is of the order of a few cycles and that of inverse time relays can be adjusted between about 6 seconds to 60 seconds. The circuit-breaker time of slow circuit- breakers is of the order of 5 cycles and that of fast circuit-breakers is of the order of 2 cycles to 3 cycles.

4.2 ARC VOLTAGE

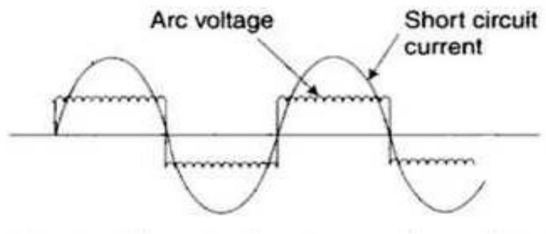


Fig 1, Short Circuit current and arc voltage

Above figure shows the wave shape of arc voltage. The voltage drop across the arc is called arc voltage. As the arc path is purely resistive, the arc voltage is in phase with the arc current. The magnitude of the arc voltage is very low, amounting to only a few per cent of the rated voltage. A typical value may be about 3 per cent of the rated voltage

4.3 Restriking Voltage and Recovery Voltage

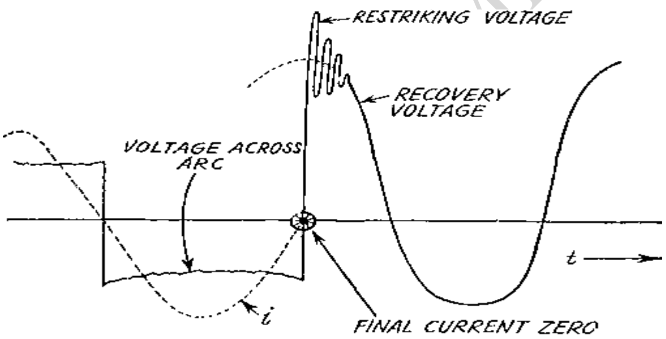


Fig 2, Restriking Voltage and Recovery Voltage Final Current Zero

The voltage across the contacts of circuit breaker is arc voltage when the arc exists. This voltage becomes system voltage (power frequency voltage (50Hz)) when the arc is completely interrupted. The arc is extinguished at the instant of Current Zero, the voltage across the breaker terminal does not normalise instantaneously but it oscillates and there is a transient condition. At the instant of arc getting interrupted a high frequency voltage appears across the contacts (Breaker pole) which is superimposed on power frequency (50 Hz) system voltage Is known as **restriking voltage.**

This high frequency transient voltage tries to restrike the arc**; hence it is called restriking voltage or transient recovery voltage (TRV).** Such voltage has a power frequency component plus an oscillatory component, the oscillatory transient component is due to inductance and capacitance in ckt, power frequency component is due to system voltage(refer above figure)

The frequency of transient component is given by Fn= $\frac{1}{2\pi\sqrt{LC}}$

Fn =frequency of transient voltage, Hz
L=EQUIVENT INDUCTANCE, Henry , C= EQUIVENT Capacitance, farad

This transient oscillatory component subsides (vanishes) after few micro sec(less than 0.1 mile sec) and the normal frequency system voltage is established after arc is completely extinguished, this voltage which appear across breaker contact after arc is finally extinguished is called **recovery voltage.**

4.4 Arc Interruption

These circuit- breakers employ various techniques to extinguish the arc resulting from separation of the current- carrying contacts. The mode of arc extinction is either 'high resistance interruption' or 'zero-point interruption'

The techniques adopted for the arc extinction can be classified into the following three categories:

1. High resistance interruption. The resistance of the arc (current path) is increased with time rapidly so as to reduce the current to value insufficient to maintain the arc.

The arc resistance can be increased by lengthening, splitting, cooling the arc, the main drawback with this type of interruption is that energy dissipated is high and so it is only used in low and medium power ac C.B and in dc circuit breaking.

In this method the length of the arc is increased so as to increase the voltage across the arc. The voltage of the arc is increased till it more than the system voltage across the contacts; At this point the arc gets extinguished.

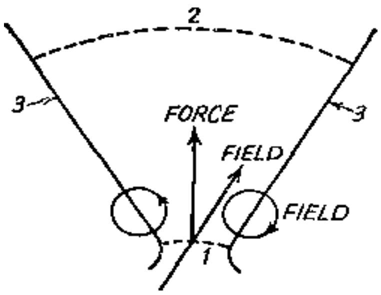
Rarc = V arc / i arc

Assuming arc current (i arc) to be constant the resistance of the arc can be increased by increasing voltage Of the Varc. The arc voltage hence the arc resistance can be increased by increasing length of the arc.

The method is used in low and medium voltage a.c. (air break cb) and D.C. circuit breakers.

The arc resistance is increased by the following methods

Lengthening the arc by means of arc runners



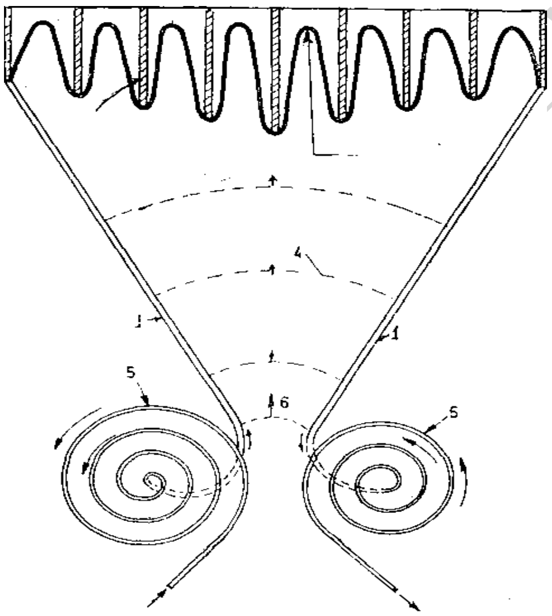
Function of the arc runners.

1. Initial position of arc
2. Final position of arc.
3. Arc runners(in vertical plane)
4. Field (in horizontal plane)
5. Force due to electrodynamic forces (in vertical plane)

Arc runners are horn-like blades of conducting material, which are connected to arcing contacts with their tips radiating upwards in *'V* shape. The arc originates at the bottom and blows upwards by electromagnetic force. The tips of the arc more upwards along arc runners or arc horns rapidly. The length of the arc increases and the arc is extinguished (Interrupted).

Splitting of Arc

The arc is elongated and split by arc splitters. These are specially made plates of resin bonded fiber glass. These are placed in the path perpendicular to the arc and the arc in pulled into them by electromagnetic force experienced by the arc by means of magnetic field applied in proper direction so as to pull the arc upwards. When the arc is pulled in space between the plates, it gets elongated constrained split and cooled. By virtue of these effects the arc gets extinguished.



1. Arc runner (metallic)
2. Arc splitters
3. Elongated arc
4. Arc in process of travelling
5. Blow-out coils (metallic)
6. Origin of Arc

Cooling of Arc. Cooling of the arc brings about recombination of ionized particles, cooling is brought by bringing the arc (ionized gas) is contact with cooler air.

If a gas containing positive ions and electrons there is a tendency for these to come together and combine to form a neutral atom. This phenomenon is termed as recombination. Recombination takes place directly in gas, and is important in the process of arc extinction

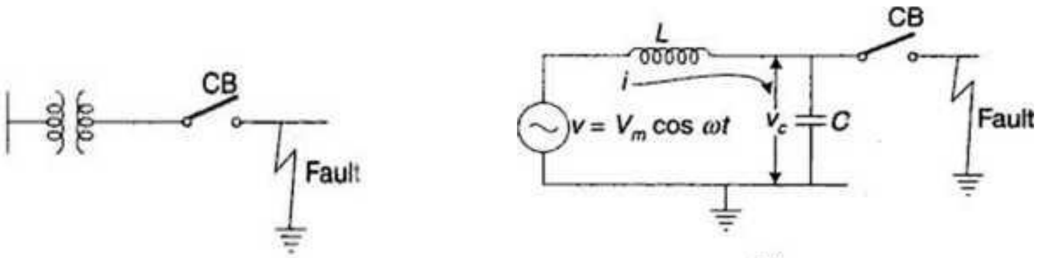
2. Current zero interruption. This method is employed in a.c arc interruption The arc is interrupted at natural current zero of the alternating current wave and the dielectric strength of the contact-gap is increased to such an extent that it can withstand the voltage stress across it. This method is employed in a.c. arc interruption. Actually the alternating current passes through zero 100 times per seconds in 50 cycle's current wave. At every current zero the arc vanishes for a brief moment.

However, the arc restrike (appears) again with the rising current wave, to stop this process it is necessary to remove the ionized gas b/w the contacts or to recombine electrons in ionized gas at a rate greater than that at which they are being released, by either method the resistance of the arc-path rapidly increases until the path again become insulator. In a.c. circuit-breakers the arc is interrupted at a current zero as zero current position offer most favourable situation for this where residual ionization is small. At current zero, the space between contacts is deionized quickly by introducing fresh unionized medium such as oil or fresh air, or SF6 gas, between the contacts. The dielectric strength of the contact space increases to such an extent that the arc does not continue after current zero. A high voltage may appear across the contacts. The voltage may re-establish the arc if the dielectric strength of gap is less than the restriking voltage. In that case the arc continues for another half cycle and may get extinguished at next current zero.

In various types of circuit-breaker designs, the provision is made to remove the hot gases from the contact space immediately after the arc so as to fill the contact space by fresh dielectric medium of high dielectric strength.

Expression for Restriking Voltage and Rate of Rise of Restriking Voltage (RRRV)

The rate of rise of restriking voltage usually abbreviated by R.R.R.V. is a rate expressed in volts per micro-second,



(b)

Fig (a) Fault on a feeder near circuit breaker (b) Equivalent electrical circuit for analysis of restriking voltage

The above figure (a) shows a short circuit on a feeder beyond the location of the circuit breaker. Figure (b) shows an equivalent electrical ckt where L and C are the inductance and Capacitance per phase of the system upto the point of CB location.

When the circuit breaker is closed, the short circuit current flows through R, L and the contact of CB, the capacitance C being short-circuited by the fault. Hence, the circuit of Fig (b) becomes completely reactive and the fault current is limited entirely by inductance of the system.

When the circuit-breaker 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 Fig. 2

The frequency of transient component is given by Fn= $\frac{1}{2\pi\sqrt{LC}}$

Fn =frequency of transient voltage, Hz
L= Inductance/ Phase, Henry
C= Capacitance b/w Phase and earth / phase, farad

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

$$L\frac{di}{dt}+\frac{1}{C}\int idt = E$$

where E is the system voltage at the instant of arc interruption. As the transient oscillation is a fast phenomenon, E can be regarded as a constant for a short duration.

$$i = \frac{dq}{dt} = \frac{d(Cv_c)}{dt},$$ where v_c = voltage across the capacitor.

Therefore, $$\frac{di}{dt} = \frac{d^2(Cv_c)}{dt^2} = C\frac{d^2v_c}{dt^2}$$

$$\int \frac{idt}{C} = \frac{q}{C} = v_c$$

Substituting these values in the equation given above, we get

$$LC\frac{d^2v_c}{dt^2}+v_c = E$$

Taking Laplace Transform of both sides of the equation, we get

$$LC\,S^2v_c(S)+v_c(S) = \frac{E}{S}$$

where $v_c(S)$ is the Laplace Transform of v_c.
Other terms are zero as initially $q = 0$ at $t = 0$,

or $$v_c(S)\,[LCS^2+1] = \frac{E}{S}$$

or $$v_c(S) = \frac{E}{S[LCS^2+1]} = \frac{E}{LCS\left(S^2+\frac{1}{LC}\right)}$$

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

or $$v_c(S) = \frac{w_n^2E}{S(S^2+w_n^2)} = \frac{w_nE}{S}\left(\frac{w_n}{S^2+w_n^2}\right)$$

Taking the inverse Laplace, we get

$$v_c(t) = w_nE\int_0^t \sin w_n\,t$$

$$= w_nE\left[\frac{-\cos w_nt}{w_n}\right]_0^t$$

As $v_c(t) = 0$ at $t = 0$, constant = 0.

$$v_c(t) = E\,(1 - \cos w_n t) \quad \text{or} \quad v_c(t) = E\left(1 - \cos \frac{1}{\sqrt{LC}}\, t\right)$$

$$= \text{Restriking voltage}$$

The maximum value of restriking voltage= $2\,E_{\text{peak}}$

$$= 2 \times \text{peak value of the system voltage}$$

The Rate of Rise of Restriking voltage (RRRV)

$$= \frac{dE}{dt}(1 - \cos w_n t)$$

$$= w_n E \sin w_n t$$

The maximum value of RRRV $= w_n E$

$$= w_n E_{\text{peak}}$$

For a 132 kV system, the reactance and capacitance up to the location of the circuit breaker is 3 ohms and 0.015 μF, respectively. Calculate the following:

(a) The frequency of transient oscillation.

(b) The maximum value of restriking voltage across the contacts of the circuit breaker.

(c) The maximum value of RRRV.

Solution

(a) The frequency of transient oscillation

$$L = \frac{3}{2\pi 50}, \quad f = 50, \text{ the system frequency}$$

$$= \frac{3}{100\,\pi} = 0.00954 \text{ H}$$

$$f_n = \frac{1}{2\pi\sqrt{LC}}$$

$$= \frac{1}{2\pi\sqrt{0.00954 \times 0.015 \times 10^{-6}}}$$

$$= \frac{10^5}{2\pi \times 1.1962} = \frac{10^5}{7.5241} = 13.291\,\text{kHz}$$

(b) The restriking voltage

$$v_c = E\,[1 - \cos w_n t]$$

The maximum value of the restriking voltage = $2\,E_{peak}$

$$= 2 \times \frac{132}{\sqrt{3}}\sqrt{2} = 215.56\,\text{kV}$$

(c) The maximum value of RRRV = $w_n E_{peak}$

$$= 2\pi f_n \times \frac{132}{\sqrt{3}} \times \sqrt{2} \times 1000$$

$$= 2\pi \times 13.291 \times 1000 \times \frac{132}{\sqrt{3}} \times \sqrt{2} \times 1000\ \text{V/s}$$

$$= 9010.45 \times 10^6\ \text{V/s} = 9.01045\ \text{kV/}\mu\text{s}$$

Resistance Switching

To reduce the restriking voltage, RRRV and severity of the transient oscillations, a resistance is connected across the contacts of the circuit breaker. This is known as resistance switching. The resistance is in parallel with the arc. A part of the arc current flows through this resistance resulting in a decrease in the arc current and increase in the deionisation of the arc path and resistance of the arc. This process continues and the current through the shunt resistance increases and arc current decreases. Due to the decrease in the arc current, restriking voltage and RRRV are reduced. The resistance may be automatically switched in with the help of a sphere gap as shown in Fig. The resistance switching is of great help in switching out capacitive current or low inductive current.

The analysis of resistance switching can be made to find out the critical value of the shunt resistance to obtain complete damping of transient oscillations. Below Figure shows the equivalent electrical circuit for such an analysis. The value of resistance R at which the frequency of Restriking voltage becomes zero is called “Critical Damping Resistance’.

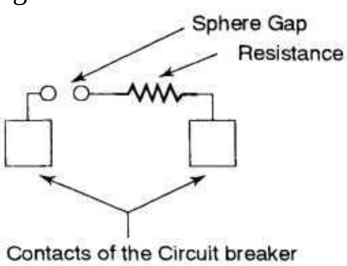


FIGURE Resistance switching

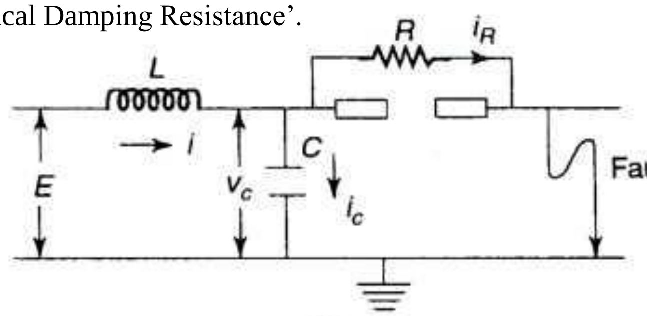


FIGURE Circuit for analysis of resistance switching

Let us see the effect of such a resistance on the frequency of restriking voltage transient

The voltage equation is given by

$$L\frac{di}{dt}+\frac{1}{C}\int i_C\,dt = E \quad \text{and} \quad i = i_c + i_R$$

Therefore, the above equation become

$$L\frac{d(i_c+i_R)}{dt}+v_c = E$$

or $$L\frac{di_c}{dt}+L\frac{di_R}{dt}+v_c = E$$

$$i_c = \frac{dq}{dt} = \frac{d(Cv_c)}{dt}$$

Therefore, $$\frac{di_c}{dt} = \frac{d^2(Cv_c)}{dt^2} = C\frac{d^2v_c}{dt^2}$$

$$\frac{di_R}{dt} = \frac{d(v_c/R)}{dt} = \frac{1}{R}\frac{dv_c}{dt}$$

Substituting these values in the main equation, we get

$$LC\frac{d^2v_c}{dt^2}+\frac{L}{R}\frac{dv_c}{dt}+v_c = E$$

Taking Laplace Transform, we get

$$LCS^2v_c(S)+\frac{L}{R}S\,v_c(S)+v_c(S) = \frac{E}{S}$$

Other terms are zero, as $v_c = 0$ at $t = 0$

or $$LCv_c(S)\left[S^2+\frac{1}{RC}S+\frac{1}{LC}\right] = \frac{E}{S}$$

or $$v_c(S) = \frac{E}{SLC\left[S^2+\frac{1}{RC}S+\frac{1}{LC}\right]}$$

For no transient oscillation, all the roots of the equation should be real. Or root is zero, i.e. $S = 0$ which is real. For the other two roots to be real, the roo of the quadratic equation in the denominator should be real. For this, tl following condition should be satisfied.

$$\left[\left(\frac{1}{2RC}\right)^2-\frac{1}{LC}\right] \ge 0 \quad \text{or} \quad \frac{1}{4R^2C^2} \ge \frac{1}{LC}$$

or $$\frac{4}{LC} \le \frac{1}{R^2C^2} \quad \text{or} \quad R^2 \le \frac{LC}{4C^2}$$

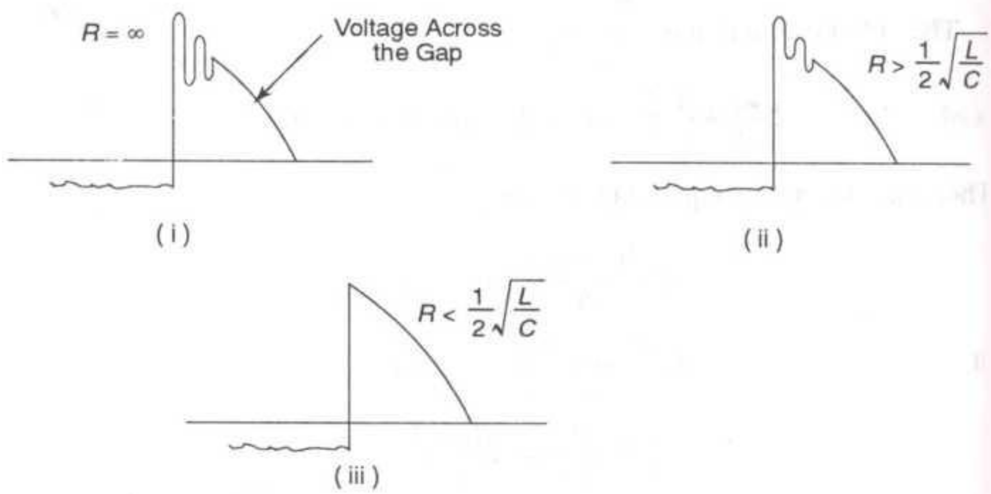


FIGURE Transient oscillations for different values of R

or $$R^2 \leq \frac{1}{4} \cdot \frac{L}{C} \quad \text{or} \quad R \leq \frac{1}{2}\sqrt{\frac{L}{C}}$$

Therefore, if the value of the resistance connected across the contacts of the circuit breaker is equal to or less than $\frac{1}{2}\sqrt{L/C}$ there will be no transient oscillation. If $R > \frac{1}{2}\sqrt{L/C}$, there will be oscillation. $R = \frac{1}{2}\sqrt{L/C}$ is known as critical resistance. Figure 9.9 shows the transient conditions for three different values of R. The frequency of damped oscillation is given by

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

In a 220 kV system, the reactance and capacitance up to the location of circuit breaker is 8 Ω and 0.025 μF, respectively. A resistance of 600 ohms is connected across the contacts of the circuit breaker. Determine the following:

(a) Natural frequency of oscillation.
(b) Damped frequency of oscillation.
(c) Critical value of resistance which will give no transient oscillation.
(d) The value of resistance which will give damped frequency of oscillation, one-fourth of the natural frequency of oscillation.

Solution

$$L = \frac{8}{2\pi 50} = \frac{8}{100\pi} = 0.02544 \text{ H}$$

(i) Natural frequency of oscillation $= \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$

$$= \frac{1}{2\pi}\sqrt{\frac{1}{0.02544 \times 0.025 \times 10^{-6}}}$$

(ii) Frequency of damped oscillation is given by

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

$$= \frac{1}{2\pi}\sqrt{\frac{1}{0.02544 \times 0.025 \times 10^{-6}} - \frac{1}{4(0.025 \times 10^{-6})^2 \times (600)^2}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{10^{10}}{6.36} - \frac{10^{10}}{9}} = 3.413 \text{ kHz}$$

(iii) The value of critical resistance

$$R = \frac{1}{2}\sqrt{\frac{L}{C}} = \frac{1}{2}\sqrt{\frac{0.02544}{0.025 \times 10^{-6}}} = 504.35\,\Omega$$

(iv) The damped frequency of oscillation is $\frac{1}{4} \times 6.304$ kHz $= 1576$ Hz

$$1576 = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{1}{4C^2R^2}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{1}{0.02544 \times 0.025 \times 10^{-6}} - \frac{1}{4(0.025 \times 10^{-6})^2 \times R^2}}$$

or

$$1576 = \frac{1}{2\pi}\sqrt{\frac{10^{10}}{6.36} - \frac{10^{16}}{25R^2}}$$

Therefore, $R = 520.8\ \Omega$.

4.5 Interruption of Low Magnetizing Current (Current Chopping)

The necessity of interrupting small inductive current arises while disconnecting transformers on no load. No-load currents of transformer, i.e. magnetizing currents are almost at zero power factor lag, the current is smaller than normal current rating of the breaker. The breaking of such a low current presents a sever duty on the circuit-breaker

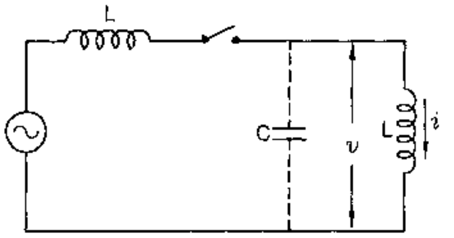
When interrupting low inductive currents such as magnetizing currents of transformer, shunt reactor, **the rapid deionization of contact space and blast effect may cause, the current to be interrupted before its natural zero. This phenomenon of the interruption of current before its natural zero is called current chopping**.

In such a situation, the energy stored in the Inductance (magnetic field) appears in the form of high voltage across the stray capacitance at the moment of current Interruption, which will cause restriking of the arc.

$$\frac{1}{2} Li^2 = \frac{1}{2} CV^2 \text{ Joules}$$

$$V = i\sqrt{L/C}$$

The frequency of transient Oscillation is given by $F_n = \frac{1}{2\pi\sqrt{LC}}$



Circuit diagram illustrating interruption of low inductive current.

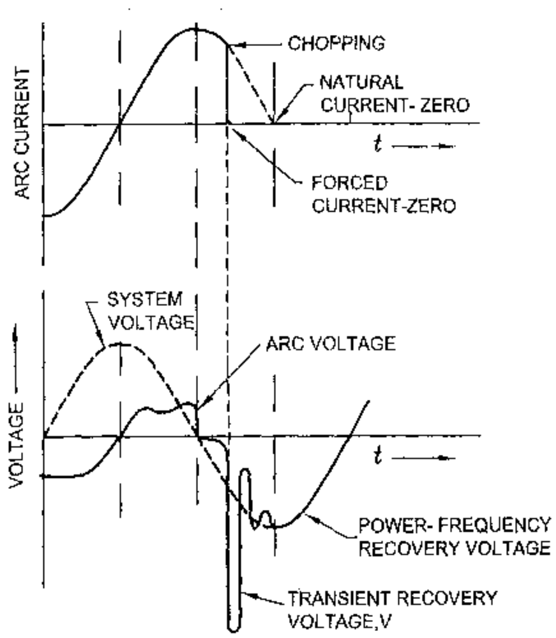


Fig. Interruption of low magnetizing currents.

Such a transient voltage having high RRRV appears across the contacts, unless the arc continues. If it restrikes a further, chop may, occur or several chops may occur before the current is finally interrupted, circuit-breaker in ay fails to clear the fault.

If the restrike does not occur; the severe voltage appears across the CB contacts and on the system.

Resistance switching is adopted to overcome the effect of over-voltages due to current Chopping

A circuit breaker interrupts the magnetising current of a 100 MVA transformer at 220 kV. The magnetising current of the transformer is 5% of the full load current. Determine the maximum voltage which may appear across the gap of the breaker when the magnetising current is interrupted at 53% of its peak value. The stray capacitance is 2500 μF. The inductance is 30 H.

Solution The full load current of the transformer

$$= \frac{100 \times 10^6}{\sqrt{3} \times 220 \times 10^3} = 262.44 \text{ A}$$

$$\text{Magnetising current} = \frac{5}{100} \times 262.44 = 34.44 \text{ A}$$

$$\text{Current chopping occurs at } 0.53 \times 34.44\sqrt{2} = 25.83 \text{ A}$$

$$\frac{1}{2} Li^2 = \frac{1}{2} Cv^2$$

$$\therefore \quad \frac{1}{2} \times 30 \times (25.83)^2 = \frac{1}{2} \times 2500 \times 10^{-6} v^2$$

$$\therefore \quad v = 2829 \text{ kV}$$

4.6 CLASSIFICATION of Circuit Breaker

The a.c circuit-breakers can be classified on the basis of rated voltages. Circuit-breakers below rated voltage of 1000 V are called low voltage circuit-breakers and above 1000 V are called high voltage a.c. circuit-breakers.

The type of the circuit-breaker is usually identified according to the medium of arc extinction the classification of the circuit breakers based on the medium of arc extinction is as follows:

1. Air break circuit-breaker/Miniature circuit-breaker.
2. Air blast circuit-breaker
3. Oil circuit-breaker (tank type of bulk oil)
4. Minimum oil circuit-breaker.
5. Sulphur hexafluoride circuit-breaker. (Single pressure or Double Pressure).
6. Vacuum circuit-breaker.

The construction of the circuit-breakers depends upon its type (arc-quenching medium), voltage rating and structural form.

Air-break Circuit-breakers. Utilize air at atmospheric pressure for arc-extinction

Air-blast Circuit-breakers. Utilize high pressure compressed air for arc, they need compressed air plant.

Bulk-oil and Minimum-oil Circuit-breakers. Utilize Dielectric oil (Transformer oil) for an. extinction. In Bulk-oil circuit breakers, the contacts are separated inside a steel tank filled with dielectric oil. In minimum oil circuit-breakers the contacts are separated in an insulating housing (interrupter) filled with dielectric oil,

SF6 Circuit-breakers. Sulphur-hexa-fluoride gas is used for arc extinction. There are two types:

Single Pressure puffer type SF6 Circuit-breakers, in which the entire circuit-breaker is filled with SF6 gas at single pressure (4 to 6 kgf/cm2). The pressure and gas flow required for arc extinction is obtained by piston action.

Double pressure type SF6 Circuit-breaker, in which the gas from high-pressure system is released into low pressure system over the arc during the arc quenching process

4.7 AIR BREAK CIRCUIT BREAKER

In this type of a circuit breaker, air at atmospheric pressure is used as an arc extinguishing medium. Below Figure shows an air-break circuit breaker. It employs two pairs of contacts—main contacts and arcing contacts. The main contacts carry current when the breaker is in closed position. They have low contact resistance. When contacts are opened, the main contacts separate first, the arcing contacts still remain closed. Therefore, the current is shifted from the main contacts to the arcing contacts. The arcing contacts separate later on and the arc is drawn between them.

In air-break circuit breakers, the principle of high resistance is employed for arc interruption. The arc resistance is increased by lengthening, splitting and cooling the arc. The arc length is rapidly increased employing arc runners and arc chutes. The arc moves upward by both electromagnetic and thermal effects. It moves along the arc runner and then it is forced into a chute. It is split by arc splitters. A blow-out coil is employed to provide magnetic field to speed up arc movement and to direct the arc into arc splitters. The blow-out coil is not connected in the circuit permanently. It comes in the circuit by the arc automatically during the breaking process. The arc interruption is assisted by current zero in case of ac air break circuit breakers. High resistance is obtained near current zero.

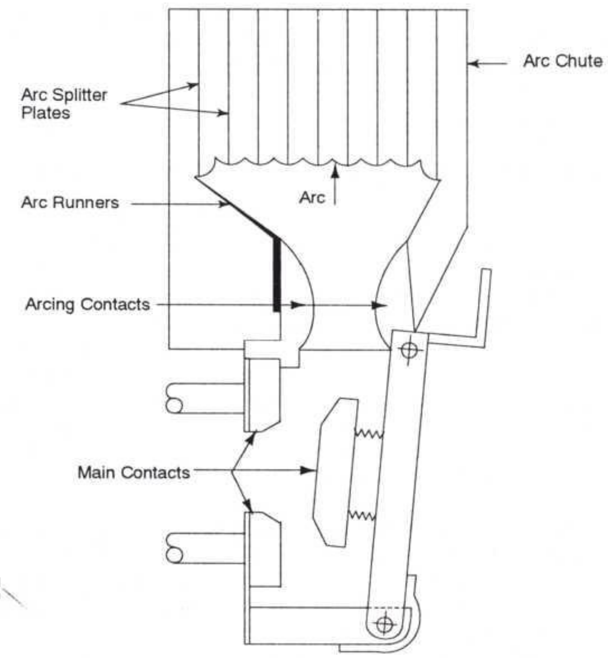


FIGURE Air-break circuit breaker

AC air-break circuit breakers are available in the voltage range 400 to 12 kV. They are widely used in low and medium voltage system. They are extensively used with electric furnaces, with large motors requiring frequent starting, in a place where chances of fire hazard exist, etc. Air-break circuit breakers are also used in dc circuit up to 12 kV.

4.8 OIL CIRCUIT BREAKER

Mineral oil has better insulating properties than air. Due to this very reason it is employed in many electrical equipment including circuit breakers. Oil has also good cooling property. In a circuit breaker when arc is formed, it decomposes oil into gases. Hence, the arc energy is absorbed in decomposing the oil. The main disadvantage of oil is that it is inflammable and may pose a fire hazard. Other disadvantages include the possibility of forming explosive mixture with air and the production of carbon particles in the oil due to heating, which reduces its dielectric strength.

Bulk oil Circuit Breaker

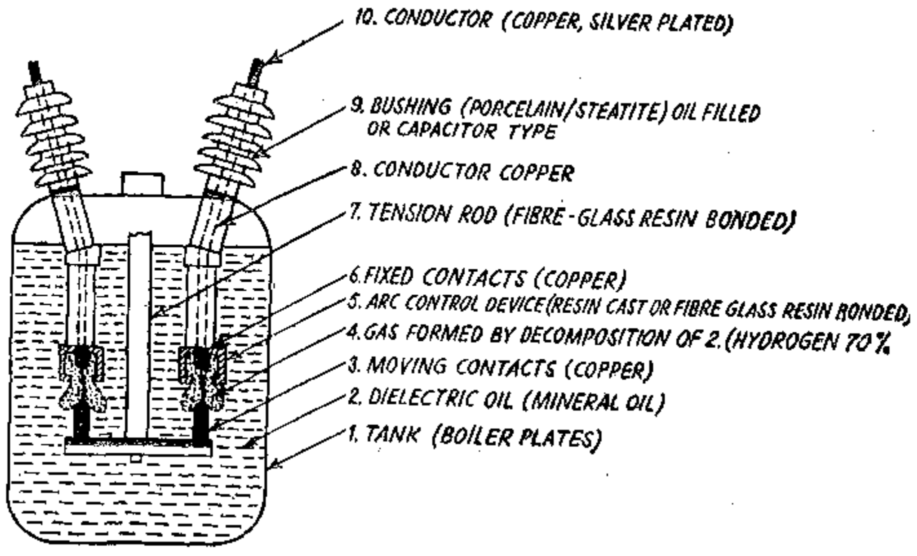
Plain oil circuit breaker (Double break)

The bulk oil circuit breakers generally employed in our power systems are of this type. In these the gases produced during arcing are confined to small volumes by the use of an insulating, rigid arc chamber (Arc Control Device or arc control pots) surrounding the contacts. Thus, higher pressures can be developed to force the oil and gas through or around the arc to extinguish it. These small, high pressure resistant chambers are known as arc control pots or sometimes as explosion pots.

With the improvement in the design of the arc control pots, great reductions have been effected both in arc duration and total break time

The main features that have an important bearing upon the performance of a plain-break oil circuit breaker are:

- Length of break.
- Speed of contact movement.
- Head of oil above contacts.
- Clearance to earthed metal adjacent to contacts.



Bulk oil circuit-breaker with arc control device.

In plain-break oil circuit breaker there is a fixed and a moving contact immersed in Bulk oil. The metal tank is strong, weather tight to keep moisture out and earthed.

Figure shows a double break plain oil circuit breaker. When contacts separate there is a severe arc which struck between the contact decomposes the oil into gases. The gas obtained is mainly hydrogen. The volume of gases produced is about one thousand times that of the oil decomposed. Hence, the oil is pushed away from arc and the gaseous medium surrounds the arc. The arc interrupting factors are as fallows

- Elongation of the arc.
- Formation of gaseous medium in between the fixed and moving contacts. This has a high heat conductivity and high dielectric strength.

A large gaseous pressure is developed because a large amount of energy is dissipated within the tank. Therefore, the tank of the circuit breaker is made strong to withstand such a large pressure. When gas is formed around the arc, the oil is displaced. To accommodate the displaced oil, an air cushion between the oil surface and the tank is essential. The air cushion also absorbs the mechanical shock produced due to upward oil movement of oil.

Sufficient level of oil above the contacts is required to provide substantial oil pressure at the tank so it prevent escape of liberated hydrogen gas from oil to air, thus prevent formation of explosive mixture,

Certain gap between the contacts must be created before the arc interruption occurs. To achieve this speed of the break should be as high as possible, Welding of contacts may result on short-circuit interruption if the speed of contact movement is slow

The Double breaks in series provide rapid arc elongation (increases the length of the arc such that arc resistance increases), but this arrangement has the disadvantage of unequal voltage distribution across the breaks.

To assist arc interrupting process arc control device are fitted to fixed contact, this arc control device are semi-enclosed chamber made up of insulating material, the performance of Ocb depends on effectiveness of arc control device

The operating mechanism i.e. opening and closing of breaker contacts are obtained by lowering and rising tension rod. the arc control device are normally connected to fixed contact such that contact separation take place inside the semi-enclosed chamber the gas produced in the chamber produces very high pressure in it, This arc is extinguished by the oil and by the gases formed by the decomposition of oil, there by the arc interruption is very quick. . As the moving contacts leave the arc control Plain break bulk oil circuit-breaker.
The trapped gas gets released from the arc control device, while doing so, the arc is extinguished by blast effect

Disadvantages

- Contacts may get welded during arc interruption process if the speed of contacts movement is slow.
- Large amount of oil for higher voltage is necessary in bulk oil circuit-breakers through only a small quantity is necessary for arc extinction. The large quantity is

necessary to provide insulation between the live parts and earthed steel tank. If the container is made of ceramic material, the size of container could be made small.

- Decomposition of oil produce carbon particle which result in contamination and decrees of dielectric strength of transformer oil.
- The entire oil in the tank is likely to get deteriorated duo to sludge formation in the proximity of arc. Then the entire oil needs replacement

Minimum oil circuit breaker.

This type is also known as poor oil or small oil circuit-breaker. In minimum oil circuit- breakers the current interruption takes place inside 'interrupter'. The enclosure of the interrupter is made of insulating material like porcelain. Hence the clearance between the live parts and the enclosure can be reduced and lesser quantity of oil require for internal insulation. There are two chambers separated from each other, but both filled with oil. The upper chamber is arc extinction chamber. The oil from this chamber does not mix with that in the lower chamber. Lower chamber acts like a dielectric support.

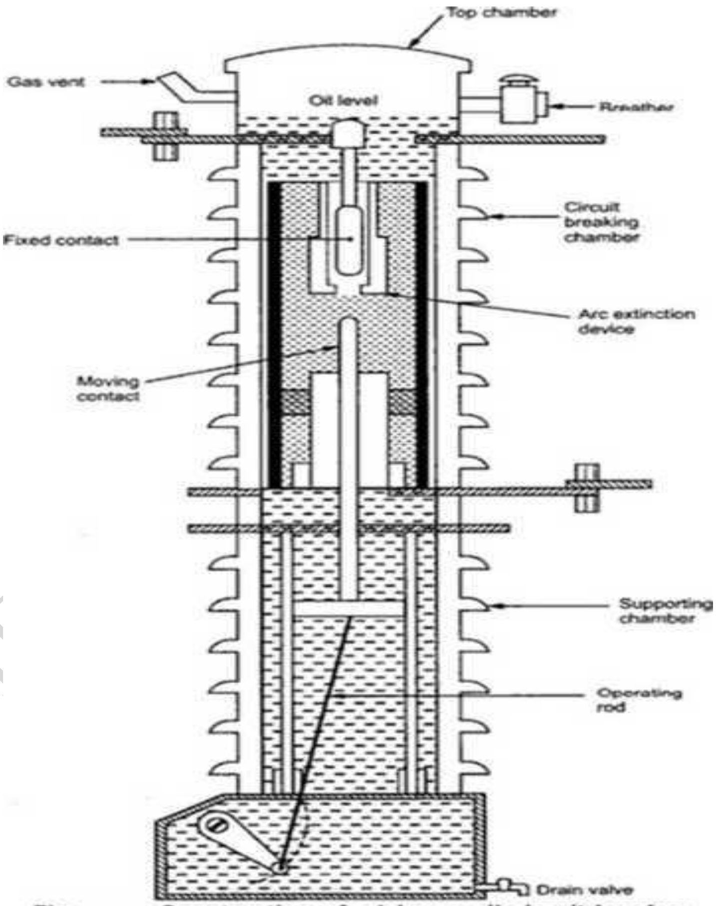


Fig. Construction of minimum oil circuit breaker

PRINCIPLE OF ARC-EXTINCTION ON OIL BREAKERS

As the current carrying contacts are separated under oil, the heat of the arc causes decomposition of the oil. The gases formed due to the decomposition expand, causing increase in pressure. The pressure built-up and the flow of gases is influenced by the design of arc-control device speed of contact travel, the energy liberated by the arc, etc. The gas flowing near the contact zone causing cooling and splitting of the arc. The contact space is filled with fresh dielectric oil after the final arc interruption at a current zero.

The advantages of minimum oil circuit breaker arc

- The quantity of oil required is small.
- The space requirement is reduced.
- The risk of fire is reduced.

Disadvantages

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

4.9 Air Blast Circuit Breaker

Air blast circuit breakers are suitable for operating voltages of 132 kV and above. They have also been used in 11 kV-33 kV range for certain applications. At present, SF6 circuit breakers are preferred for 132 kV and above. Vacuum circuit breakers are preferred for 11 kV-33 kV range. Therefore, the air blast circuit breakers are becoming obsolete.

In air blast circuit-breaker (also called compressed air circuit-breaker) high pressure air (at 20-30 kg/cm) is used as an arc quenching medium, this high pressure is forced over the arc through a nozzle at the instant of contact separation. The ionized gas between the contacts is blown away by the blast of the air. After the arc extinction the chamber is filled with high pressure air, which prevents restrike of arc.

PRINCIPLE OF ARC QUENCHING IN ABCBs

The air blast circuit-breaker needs an auxiliary compressed air system which supplies air to the air receiver of the breaker. For opening operation, the air is admitted in the arc extinction chamber. It pushes away the moving contacts. In doing so the contacts are separated and the air blast takes away the ionized gases along with it and assists arc extinction. Within one or two cycles the arc is extinguished by the air blast and the arc extinction chamber is filled with high pressure air has higher dielectric strength than that of atmospheric pressure. Hence small contact gap of few centimetres is enough the flow of air around contacts is guided by the nozzle shaped contacts. It may be axial cross or a suitable combination

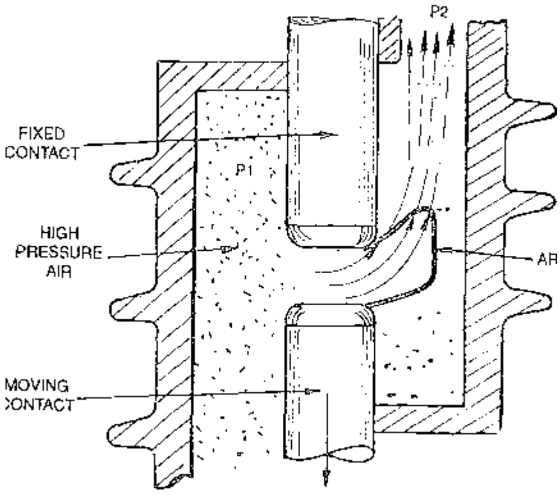


Fig. Flow of air in Air-blast C.B.

<u>In the axial blast type</u> air flow shown in Fig. (a) The flow of air is longitudinal along the arc

In axial blast type air flow, the air flows from high pressure reservoir to the atmosphere through a convergent divergent nozzle. The difference in pressure and the design of nozzle is such that as the air expands into the low-pressure zone, it attains almost supersonic velocity. The flow of air through the nozzle is governed by the parameters like pressure ratio, area of throat, exit area of nozzle, and is influenced by the diameter of the arc itself

The air flowing at a high speed axially along the arc causes removal of heat from the periphery of the arc and the diameter of the arc reduces to a low value at current zero. At this instant the arc is interrupted and the contact-space is flushed with fresh air flowing through the nozzle. Resistance switching is employed in axial blast type to reduce RRRV.

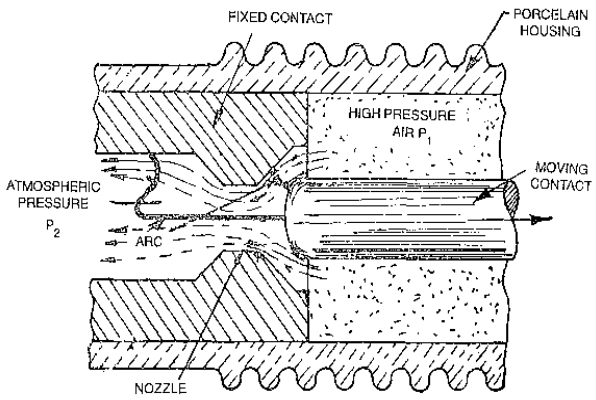
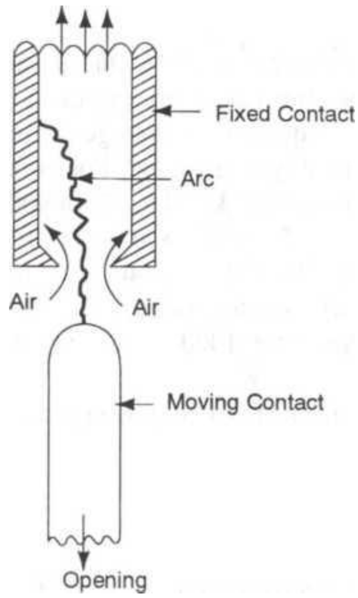
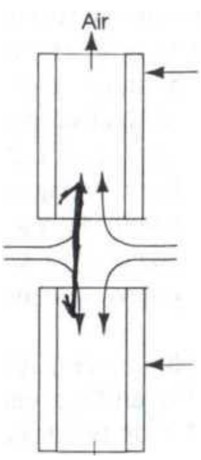


Fig. (a) Axial Flow.



(b)

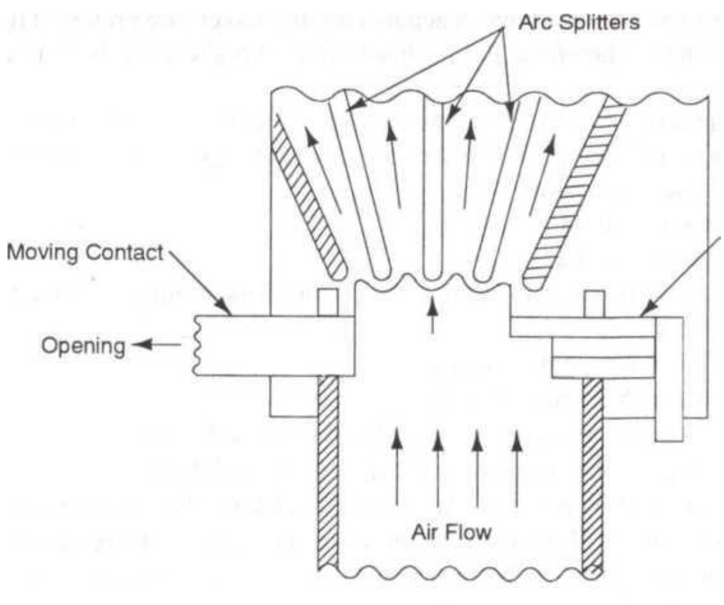


(C)

(b) Single blast type axial-blast circuit breaker (c) Double blast type (or radial-blast type) axial- blast circuit breaker

Cross-blast circuit breaker

In a cross-blast type circuit breaker, a high-pressure blast of air is directed perpendicularly to the arc for its interruption. Below Figure (a) shows a schematic diagram of a cross-blast type circuit breaker. The arc is forced into a suitable chute. Sufficient lengthening of the arc is obtained, resulting in the introduction of appreciable resistance in the arc itself. Therefore, resistance switching is not common in this type of circuit breakers. Cross-blast circuit breakers are suitable for interrupting high current (up to 100 kA) at comparatively lower voltages



(a)

The advantages of air blast circuit breakers over oil circuit breakers are:

- Cheapness and free availability of the interrupting medium, chemical stability and inertness of air.
- High speed operation.
- Elimination of fire hazard.
- Short and consistent arcing time and therefore, less burning of contacts.
- Less maintenance.
- Suitability for frequent operation.
- Facility for high speed reclosure.

<u>The disadvantages of an air blast circuit breaker are as follows.</u>

- An air compressor plant has to be installed and maintained, Required more auxiliary components.
- Upon arc interruption the air blast circuit breaker produces a high-level noise when air is discharged to the open atmosphere. In residential areas, silencers need to be provided to reduce the noise level to an acceptable level, not suitable in residential area
- Problem of current chopping.
- Problem of restriking voltage.

<u>4.10 SF6 Circuit Breakers</u>

Sulphur hexafluoride (SF6) is heavy gas its density is five times that of air, having good dielectric strength and excellent arc quenching (Interrupting) property.

<u>Properties of SF_6</u>

It is an chemically inert and it does not attack metals or glass, Colourless, odourless, Nontoxic, Pure SF6 gas is not harmful to health, nontoxic, and non-flammable. At atmospheric pressure, its dielectric strength is about 2.5 times that of air. At 3 atmospheric pressure its dielectric strength is equal to that of transformer oil.

Advantages are it is an **<u>electronegative gas</u>**, i.e. it has high affinity for electrons. When a free electron comes in collision with a neutral SF_6 gas molecule, the electron is absorbed by the neutral gas molecule and a negative ion is formed. As the negative ions so formed are heavy they do not (Ionize easily) attain sufficient energy to contribute to ionisation of the gas, thus prevent breakdown of SF_6 gaseous Insulator, This property gives a good dielectric property.

Electro negativity of the gas gives **<u>lower arc-time constant</u>**. The time required for the medium to regain its dielectric strength after final current zero is called arc-time constant. The arc-time constant of SF6 gas is of the order of a few Microseconds

The gas has an excellent property of recombination after the removal of the source which energizes the arc. This gives an excellent arc quenching property. The gas has also an excellent heat transfer property. Its thermal time constant is about 1000 times shorter than that of air.

Major disadvantage is that the SF6 gas liquefies at certain low temperatures, the temperature at which SF6 changes to liquid depends on the pressure. The liquefaction temperature increases with pressure. At 15 atm. pressure, the gas liquefies at a temperature of about 10°C. Hence, SF6 breakers are equipped with thermostatically controlled heaters wherever such low ambient temperatures are encountered.

However, it decomposes to SF_4, SF_2, S_2, F_2, S and F at temperatures of the order of 1000°C after arc extinction, the products of decomposition recombine in a short time, within about 1 microsecond. In the presence of moisture, the decomposition products can attack contacts, metal parts and rubber sealing's in SF6 circuit breakers. Therefore, the gas in the breaker must be moisture-free. To absorb decomposition products, a mixture of soda lime (NaoH + Cao) and activated alumina can be placed in the arcing chamber.

SF_6 is now being very widely used in electrical equipment like high voltage metal enclosed cables; high voltage metal clad switchgear, bushings, circuit- breakers, current transformers, etc.

SF6 circuit breakers are manufactured in the voltage range 3.6 kV to 765 kV. However, they are preferred for voltages 132 kV and above. The dielectric strength of SF_6 gas increases rapidly after final current zero. SF6 circuit breakers can withstand severe RRRV and are capable of breaking capacitive current without restriking. Problems of current chopping is minimised. Electrical clearances are very much reduced due to high dielectric strength of SF6

Preparation of SF_6 Gas

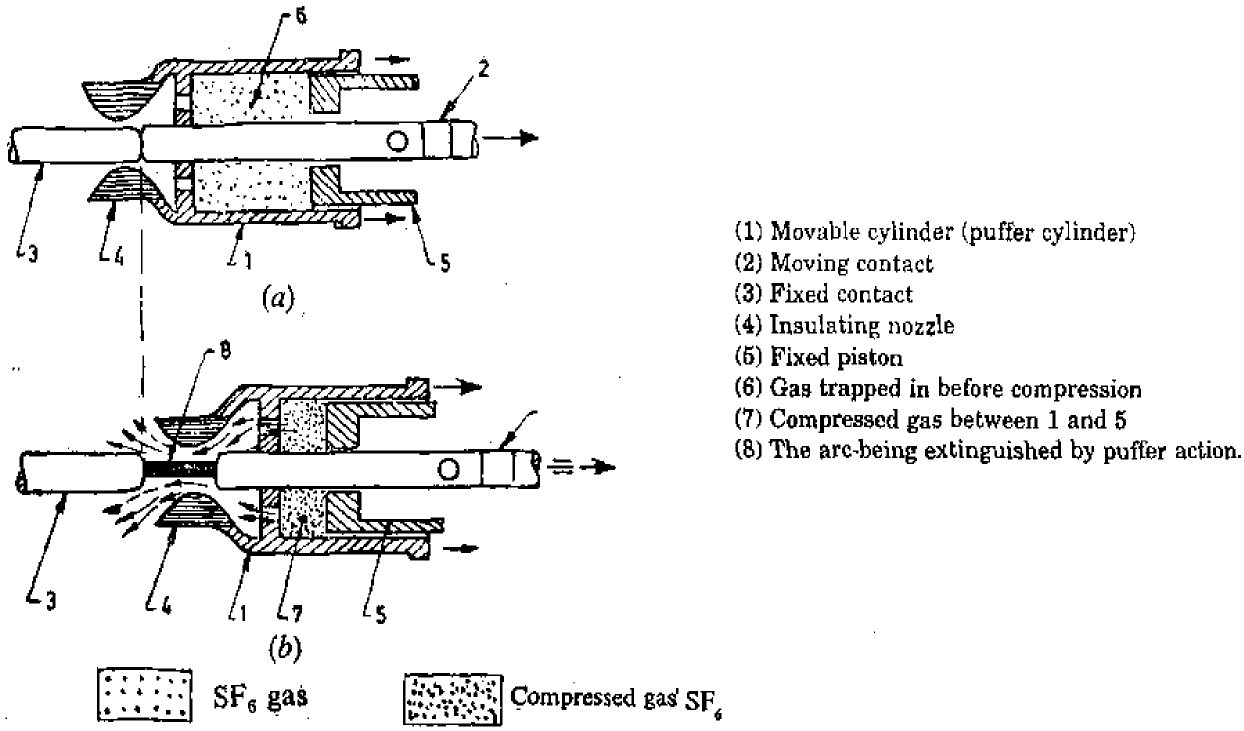
Sulphur hexafluoride gas is prepared by burning coarsely crushed roll sulphur in fluorine gas, in a steel box, provided with staggered horizontal shelves, each bearing about 4 kg of sulphur. The steel box is made gas-tight. The gas thus obtained contains other fluorides such as $S_2 F_{10}$, SF_4 and must be purified further SF_6 gas is generally supplied by chemical firms. The cost of gas is low if manufactured on a large scale.

The gas is transported in liquid form in cylinders. Before filling the gas, the circuit-breaker is evacuated to the pressure of about 4 mm of mercury so as to remove the moisture and air. The gas is then filled in the circuit-breaker. The gas can be reclaimed by the gas-handling unit

Types of SF6 Circuit Breakers

Puffer-type SF_6 circuit breakers

This type of circuit breakers are also sometimes called single-pressure or impulse type SF_6 circuit breakers. In this type of breakers, gas is compressed by a moving cylinder system and is released through a nozzle to quench the arc.



(a) Breaker fully closed (b) Contacts separated, puffing action in progress.
Fig. . Puffer action principle.

These circuit-breakers employ a principle of puffer action illustrated in above Fig

Fig (a) illustrates the fully closed position of the interrupter. The moving cylinder (1) is coupled with the movable conductor (2) against the fixed piston (5) and there is a relative movement between (1) and (5) and the gas is compressed in the cavity (6). This trapped gas is released through the nozzle (4), during arc extinction process. During the travel of the moving contact (2) and movable cylinder (1) the gas puffs over the arc and reduces the arc diameter by axial convection and radial dissipation. At current zero, the arc diameter becomes too small and the arc gets extinguished. The puffing action continues for some time even after the arc extinction and the contact space is filled with cool, fresh gas.

MERITS OF SF_6 CIRCUIT-BREAKERS

- Outdoor SF_6 CB is simple less costly, maintenance free
- Due to outstanding arc quenching property of SF6 the arcing time is very small. This reduces contact erosion
- During arcing of SF6 breaker, no carbon dioxide is formed and hence no reduction of dielectric strength
- SF6 breaker is compact in size and electrical clearances are drastically reduced
- The gas is non-inflammable and chemically stable. The decomposition products are not explosive. Hence there is no danger of fire or explosion.
- Same gas is recirculated in the circuit. Hence requirement of SF_6 gas is small
- Ample overload margin. For the same size of conductors, the current carrying ability of SF6 circuit-breakers is about 1.5 times that of air blast circuit-breakers because of superior heat transferability of SF6 gas.
- The breaker is silent and does not make sound like air-blast-circuit breaker during operation.
- The sealed construction avoids the contamination by moisture, dust, sand etc. No costly compressed air system like Air Blast CB.
- The maintenance required is minimum, the breaker may need maintenance once in four to ten years!
- Ability to interrupt low and high fault currents, magnetising currents, capacitive current, without excessive over-voltages. The SF6 gas circuit-breaker can perform the various duties like clearing short-line faults, opening unloaded transmission lines capacitor switching transformer, reactor switching etc. much smoothly.
- Excellent insulating arc extinguishing physical and chemical properties of SF6 gas is the greater advantage of SF_6 breakers. No frequent contact replacement.

SOME DEMERITS OF SF6 CIRCUIT-BREAKER

- Sealing problems arise. Imperfect joints load to leakage of gas.
- In this case of leakage in the breaker tank, this gas, being heavier than air settles in the surroundings and may lead to suffication of the operating personnel. However, it is non- poisonous
- Arced SF_6 gas is poisonous and should not be in inhaled or let-out.
- Influx of moisture in the breaker is very harmful to SF_6 gas circuit-breakers. Several failures reported due to this cause.
- Mechanism of higher energy level is necessary for puffer type SF_6 breakers. Lower speeds due to friction, misalignment can cause failure of breaker.
- The internal parts should be cleaned thoroughly during periodic maintenance under clean, dry environment. Dust of Teflon and sulfides should be removed.

- Special facilities are needed for transporting the gas, transferring the gas and maintaining the quality of gas. The deterioration of quality of the gas affects the reliability of the SF_6 circuit breaker.

<u>Non Puffer Type SF_6 Circuit Breaker</u>

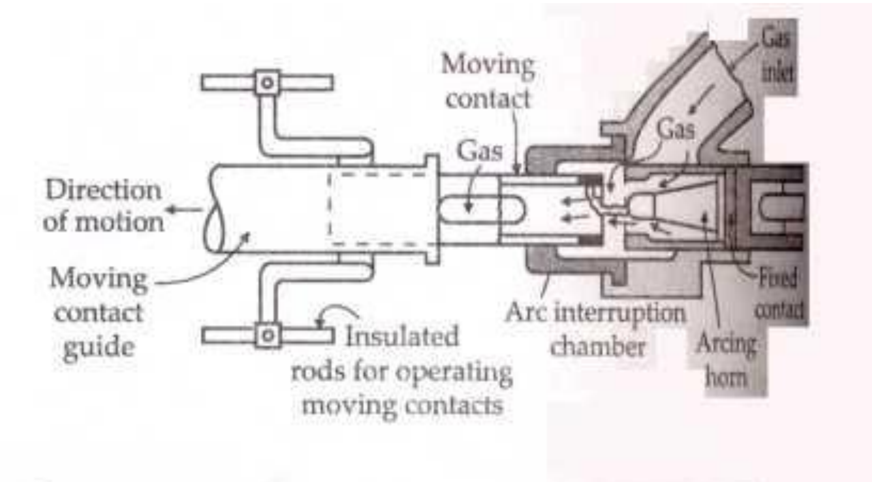


Fig. Constructional layout of SF_6 breaker.

It consists of a fixed current carrying hollow cylindrical contact fitted with an arcing horn. The moving portion consists of another hollow cylinder with rectangular holes in the sides so that gas after blowing along and across the arc is let out through these apertures. The moving contact of each interrupter is so mounted on two insulated roads that all the moving contacts operate simultaneously. Generally three interrupted units are mounted in series. (Above shown is one interrupter) When the breaker closed the current passes from the fixed contact into the side wall of the moving contact. From the moving contact the current is conducted to the adjacent fixed contact though the moving contact guide. In this way the current is conducted in each interrupter in the closed position. An arcing horn is placed inside the fixed contact. Its head projects into the moving contact when the breaker operates, an arc is struck between the fixed contact and the moving contact but it quickly transfers from the fixed contact to the arcing horn and greatly reduces the burning and pitting at the fixed contacts. The tips of the fixed contact, arcing horn and the moving contact are coated with copper tungsten arc resistance material.

The interruption of the arc is achieved by the action of sulphur hexafluoride gas forcing gas at high pressure flows through tubes leading to interrupter units at a high speed and producing both axial and cross blast effects.

A closed system is used for the gas. Since the gas is costly, it is reconditioned and reclaimed after each operation of the breaker. Necessary auxiliary system is therefore provided for this purpose.

4.11 Vacuum Circuit Breaker

The dielectric strength and arc interrupting ability of high vacuum is superior to those of porcelain, oil, air and SF_6 at atmospheric pressure. SF_6 at 7 atm. pressures and air at 25 atm. pressure have dielectric strengths higher than that of high vacuum. The pressure of 10^{-5} mm of mercury and below is considered to be high vacuum. Low pressures are generally measured in terms of torr; 1 torr being equal to 1 mm of mercury. It has now become possible to achieve pressures as low as 10^{-8} torr.

In high vacuum, of the order of 10^{-5} mm of mercury, the mean free path (Collision Path B/W Molecules) of the residual gas molecules becomes very large. It is of the order of a few metres. Therefore, when contacts are separated by a few mm in high vacuum, an electron travels in the gap without making collision.

In vacuum CB the formation of arc is due to metal vaporisation, not from the gaseous medium b/w electrode contacts as in case of other CB, in vacuum arc electrons and ions do not come from the medium in which the arc is drawn but they come from the electrodes due to the evaporation of their surface material. The breakdown strength is independent of gas density (Gas evolved from electrodes surface). It depends only on the gap length and surface condition and the material of the electrode. The breakdown strength of highly polished and thoroughly degassed electrodes is higher. Copper-bismuth, silver-bismuth, silver-lead and copper-lead are good materials for making contacts of the breaker

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

Operation (Arc extinction in vacuum interrupters)

The arc interruption process in vacuum interrupters is quite different from that in other types of circuit-breakers. The vacuum as such is a dielectric medium and arc cannot persist in ideal vacuum. However, the separation of current carrying contacts causes the vapour to be released from the contacts surface giving rise to plasma. Thus, 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 and after the current zero, the medium regains the dielectric strength provided vapour density around Contacts has substantially reduced.

Construction

Figure shows the schematic diagram of a vacuum circuit breaker. Its enclosure is made of insulating material such as glass, porcelain or glass fibre reinforced plastic. The vapour condensing shield is made of synthetic resin. This shield is provided to prevent the metal vapour reaching the insulating Envelope. As the interrupter has a sealed construction a stainless metallic bellows is used to allow the movement of the lower contact. One of its ends is welded to the moving contact. Its other end is welded to the lower end flange (Caps), Its contacts have large disc-shaped faces. These faces contain spiral segments so that the arc current produces axial magnetic field. This geometry helps the arc to move over the contact surface. The movement of arc over the contact surface minimises metal evaporation, and hence erosion of the contact due to arc. Two metal end flanges are provided. They support the fixed contact, outer insulating enclosure, vapour condensing shield and the metallic bellows. The sealing technique is similar to that used in electronic valves.

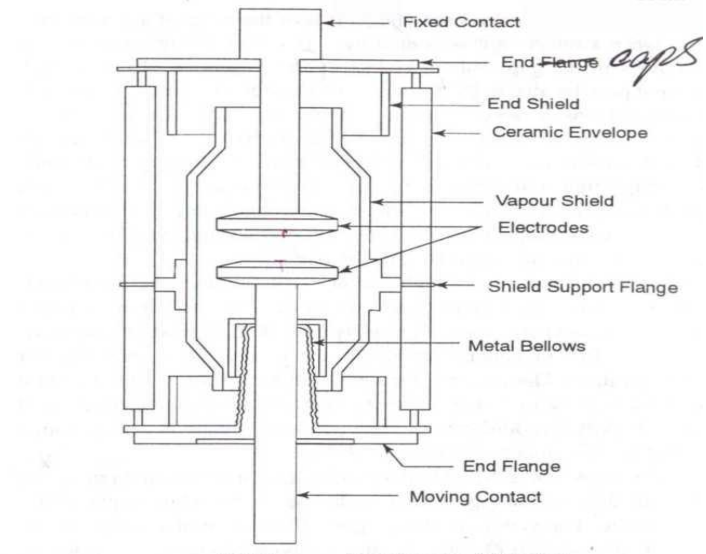


FIGURE Vacuum circuit breaker

Advantages

The vacuum circuit breaker is very simple in construction compared to other types of circuit breaker. The contact separation is about 1 cm which is adequate for current interruption in vacuum. As the breaker is very compact, power required to close open its contacts is much less compared to other types of breaker. It is capable of interrupting capacitive and small inductive currents, without producing excessive transient over voltages. Vacuum circuit breakers have other advantages like suitability for repeated operations, least maintenance, silent operation, long life, silent operation, high speed of dielectric recovery, less weight of moving parts, highest insulation strength etc.

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

Disadvantage

- Erosion of contact surface, material is lost from the surface
- Contact welding ender either momentary condition of closing or short circuit.

- In the event of loss of vacuum due to transit damage or failure, the entire interrupter is rendered useless. It cannot be repaired at site.
- For interruption of low magnetising currents in certain range, additional surge suppressors are required in parallel with each phase of a VCB

4.12 High Voltage DC Circuit Breakers

HVDC transmission lines are used for point to point transmission of large power over long distances. Such lines have many advantages over ac transmission lines such as lower cost, less stability problems, less corona loss and less radio interference, etc. The current in HVDC lines is controlled by controlling the firing circuits of the thyristors employed in rectifiers and inverters. Switching operations are performed from ac side with the help of ac circuit breakers

In ac circuits, current passes through natural current zeros, and hence it is possible to design ac circuit breakers to interrupt large currents. This feature is not available in dc. If a high current is suppressed abruptly in dc, a very high transient voltage appears across the contacts of the circuit breakers. Therefore, in dc circuit breakers, some external circuits have to be provided to bring down the current from full value to zero, smoothly without suppressing it suddenly

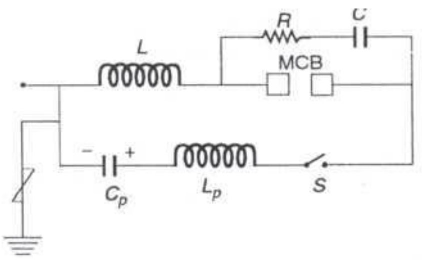


FIGURE : HVDC circuit breaker

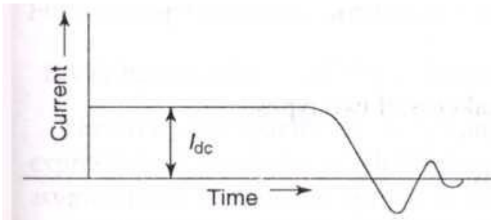


FIGURE : Artificial current zeros in dc

The additional circuit creates artificial current zeros which are utilized for arc interruption as shown in above Fig

Figure shows the schematic diagram of a HVDC circuit breaker. It consists of a main circuit breaker MCB and a circuit to produce artificial current zero and to suppress transient voltage

The main circuit breaker MCB may either be an SF6 or vacuum circuit breaker. R and C are connected in parallel with the main circuit breaker to reduce dv/dt after the final current zero. L is a saturable reactor in series with the main circuit breaker. It is used to reduce di/dt before current zero. Cp and L are connected in parallel to produce artificial current zero after the separation of the contacts in the main circuit breaker MCB. A non-linear resistor is used to suppress the transient overvoltage which may be produced across the contacts of the main circuit breaker.

Switch S, which is a triggered vacuum gap, is switched immediately after the opening of the contacts of the main circuit breaker. The capacitor ‘C’ is precharged in the direction as shown in the figure. When 5 is closed, the precharged capacitor Cp discharges through the main circuit breaker and sends a current in opposition to the main circuit current. This will force the main circuit current to become zero with a few oscillations. The arc is interrupted at a current zero.

4.13 Rating of Circuit Breaker

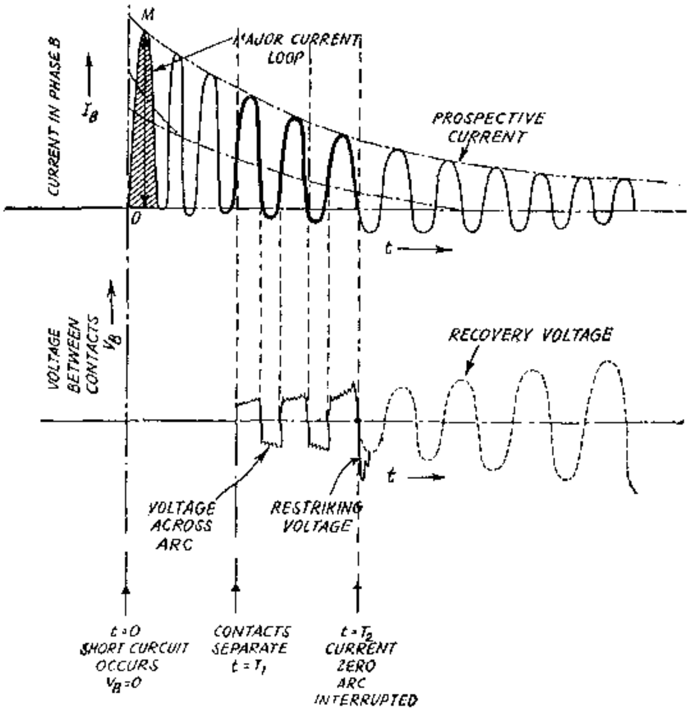


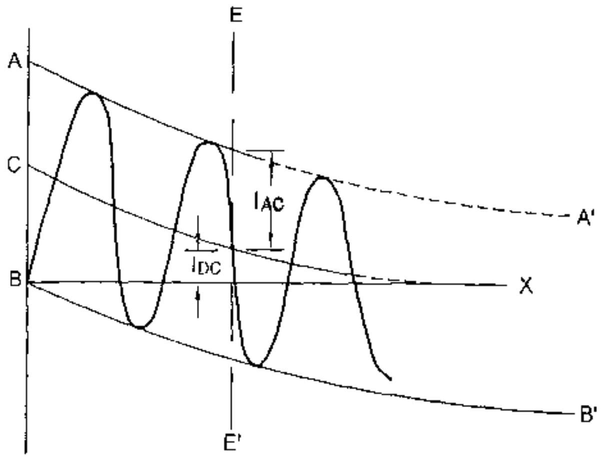
Fig. Oscillogram of current and voltage during fault-clearing.

Rated Short Circuit-Breaking Current

As the Short circuit occurs, the short circuit current attains high value, the CB contact start separating after the operation of relay. The contact of CB separate during transient state, the RMS value of current at the instant of contact separation is called **breaking current of** CB & Expressed in KA

The rated short-circuit breaking-current of a circuit-breaker is highest RMS value of short-circuit current which the circuit-breaker is capable of breaking under specified conditions of transient recovery voltage and power frequency voltage. It is expressed in kA R.M.S. at contact separation.

Referring to above Fig. the short-circuit current has a certain value at the instant of contact separation, (t = T1), the breaking current refers to value current at the instant of the contact separation



AA', BB' — Envelope of current wave

BX = Normal zero axis of wave

CX = Displaced zero axis of wave

EE = Instant of contact separation

I_{AC} = Peak value of A.C. component at EE

I_{DC} = D.C. component of current at EE

$\frac{I_{DC} \times 100}{I_{AC}}$ = Percentage of D.C. component at the instant EE

$\frac{I_{AC}}{\sqrt{2}}$ = r.m.s. value a.c. component.

Fig. Determination of breaking current.

The breaking current is expressed by two values :

(1) the r.m.s. value of a.c. component at the instant of contact separation EE, given by

$$\frac{I_{AC}}{\sqrt{2}}$$

(2) the percentage d.c. component at the instant of contact separation given by

$$\frac{I_{DC} \times 100}{I_{AC}}$$

The r.m.s. values of a.c. components are expressed in kA, the standard values being 8, 10, 12.5, 16, 20, 25, 31.5, 40, 45, 63, 80 and 100 kA.

The earlier practice was to express the rated breaking capacity of a circuit breaker in terms of MVA given as follows:

$$MVA = \sqrt{3}\ \text{kV} \times \text{kA}$$

where MVA = Breaking capacity of a circuit-breaker

kV = Rated voltage

kA = Rated breaking current.

Rated Short-circuit Making Current

If a CB closes on clearing the fault the current would increases to high value during 1st half cycle (first current loop). The highest peak value is reached during 1st current loop, this peak value is called **making current**

It may so happen that circuit-breaker may close on an existing fault. In such cases the current increase to the maximum value at the peak of first current loop. The circuit-breaker should be able to close without hesitation as contacts touch. The circuit-breaker should be able to withstand the high mechanical forces during such a closure. These capabilities are proved by carrying out making

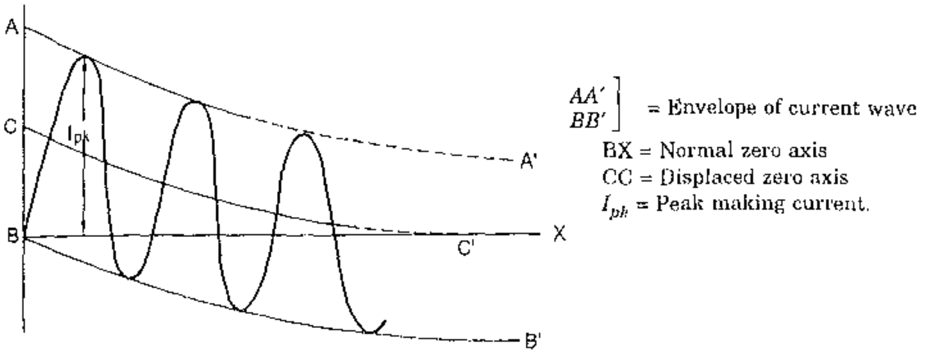


Fig. . Determination of peak making current.

current test. The rated short-circuit making current of a circuit-breaker in the peak value of first current loop of short-circuit current (I_{pk}) which the circuit-breaker is capable of making at its rated voltage

The rated short-circuit making current should be least 2.5 times the r.m.s. value of a.c. component of rated breaking current.

Rated making current $= 1.8 \times \sqrt{2} \times$ Rated short-circuit breaking

$= 2.5 \times$ Rated short-circuit breaking current.

the factor $\sqrt{2}$ converts the r.m.s. value to peak value. Factor 1.8 takes into account the doubling effect of short-circuit-current with consideration to slight drop in current during the first quarter cycle.

Short-time Current Rating

The circuit breaker must be capable of carrying short-circuit current for a short period while another circuit breaker (in series) is clearing the fault. The rated short-time current is the rms value (total current, both A.C. and D.C. components) of the current that the circuit breaker can carry safely for a specified short period

Rated Voltage, Current and Frequency

In a power system, the voltage level at all points is not the same. It varies, depending upon the system operating conditions. Due to this reason manufacturers have specified a rated maximum voltage at which the operation of the circuit breaker is guaranteed. The specified voltage is somewhat higher than the rated nominal voltage.

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

The rated frequency is also mentioned by the manufacturer. It is the frequency at which the circuit breaker has been designed to operate. The standard frequency is 50 Hz. If a circuit breaker is to be used at a frequency other than its rated frequency, its effects should be taken into consideration.

Selection of Circuit Breakers

Table shows the summary of various types of circuit breakers, their voltage ranges and arc quenching medium they employ. Table shows the choice of circuit breakers for various voltage ranges

TABLE Types of Circuit Breaker

Type	*Arc Quenching Medium*	*Voltage Range and Breaking Capacity*
Miniature circuit breakers	Air at atmospheric pressure	400-600V; for small current rating
Air-break circuit breakers	Air at atmospheric pressure	400 V-11 kV; 5-750 MVA
Minimum oil circuit breakers	Transformer oil	3.3 kV-220 kV; 150-25000 MVA
Vacuum circuit breakers	Vacuum	3.3 kV-33 kV; 250-2000 MVA
SF_6 circuit breakers	SF_6 at 5 kg/cm^2 pressure	3.3-765 kV; 1000-50,000 MVA
Air blast circuit breakers	Compressed air at high pressure (20-30 kg/cm^2)	66 kV-1100 kV; 2500-60,000 MVA

Earlier oil circuit breakers were preferred in the voltage range of 3.3 kV- 66 kV. Between 132 kV and 220 kV, either oil circuit breakers or air blast circuit breakers were recommended. For voltages 400 kV and above, air blast circuit breakers were preferred. The present trend is to recommend vacuum Circuit Breaker.

TABLE Selection of Circuit Breakers

Rated Voltage	*Choice of Circuit Breakers*	*Remark*
Below 1 kV	Air-break C.B.	
3.3 kV-33 kV	Vacuum C.B., SF_6 C.B., minimum oil C.B.	Vacuum preferred
132 kV-220 kV	SF_6 C.B, air blast C.B, minimum oil C.B.	SF_6 preferred
400 kV-760 kV	SF_6 C.B., air blast C.B.	SF_6 is preferred

4.14 Testing of Circuit Breakers

INDIRECT TESTING

The short-circuit power available in testing stations (of the order of 4000 MVA in laboratory type testing station) is not sufficient to test a complete breaker (which is of rated breaking capacity of the order of 10,000 MVA at 245 kV). Even single pole of an EHV circuit-breaker cannot be tested by direct testing method. As all EHV circuit-breaker are with several arc interrupter units tested per pole each unit can be separately tested. This is called Unit Testing. From tests on one unit, the capacity of the complete pole and breaker is determined. This method of Unit Testing is adopted internationally. Synthetic testing is another popular method which permits testing of breaker of capacity 5, times that of the plant.

The important indirect Testing Methods include the following :

Unit Testing. Which means testing one or more units separately.

Synthetic Testing. In which the current source providing short circuit current and voltage source supplying restriking and recovery voltage are different.

Substitution Tests. These are conducted for oil circuit breaker; the characteristics of current versus time are obtained for different voltages. The performance beyond the tested values is determined by approximation.

Compensation Tests. Which are conducted on oil circuit-breakers in critical range of low current by a suitable compensation such as increased frequency, increase restriking voltages etc.

Capacitance Tests. The capacitor which is charged by a voltage source is discharged through the breaker. An oscillatory circuit provides restriking voltage

UNIT TESTING OR ELEMENT TESTING

Almost all modern EHV circuit-breakers, minimum oil, Air Blast, SF6 etc. consist of two or more identical units (or interrupters) per pole. These interrupters operate (open or close) simultaneously and share the voltage across the pole almost equally. The breaking capacity in M.V.A. is also shared equally. Hence by testing one unit, the results can be applied to the capacity of the pole. This is known as Unit Testing or Element Testing.

While applying unit test the voltage must be reduced by factor a and all the impedances should be reduced by factor a to get test voltage across the unit same at that following expressions

$a = \frac{1}{n}$ when one unit is rested together.

$a = \frac{m}{n}$ when m units are tested together.

where n is number of units per pole.

For example consider 3 pole, 230 kV circuit-breaker with three units per pole. Test is to be conducted at normal voltage *i.e.* 230 kV between poles. Voltage across one pole is $230/\sqrt{3} = 133$ kV.

$$a = \frac{1}{n}, n = 3$$

∴ Voltages required for testing one unit

$$= a \times 133 = \frac{1}{3} \times 133 = 44.33 \text{ kV}$$

Further : L and C of test circuit should be reduced to get same natural frequency as that direct testing, *i.e.*

$$f_n = \frac{1}{2\pi\sqrt{LC}} \text{ in Direct Testing}$$

$$f_n = \frac{1}{2\pi\sqrt{aL \times \frac{C}{a}}} = \frac{1}{2\pi\sqrt{LC}}$$

The natural frequency of transient restriking voltage remains unchanged. Time scale also remains unchanged.

With breakers in which the voltage distribution across the pole is not evenly distributed amongest the units, some units will be stressed more and the others less. The test should be performed so as to test the highest stress coming over the unit. Hence correction must be made in unit testing results. Statistically, unit testing has been established as a reliable method of testing.

SYNTHETIC TESTING

In this method of testing, there are two sources of power supply for the testing, a current source and a voltage source. The current source is a high current, low voltage source. It supplies short-circuit current during the test. The voltage source is a high voltage, low current source. It provides restriking and recovery voltage

There are two methods of synthetic testing- parallel current injection method and series current injection method. Parallel current injection method is widely used as it is capable of providing RRRV and recovery voltage as required by various standards

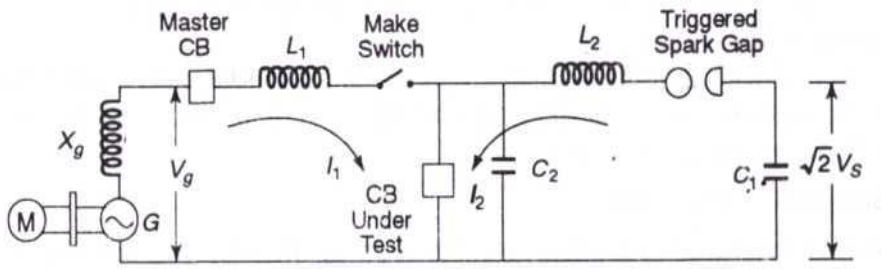


FIGURE Synthetic testing of circuit breaker

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

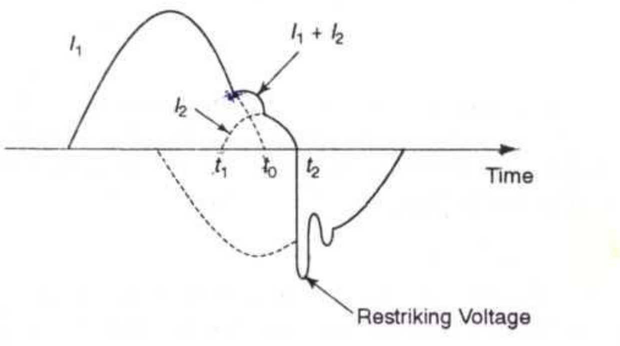


FIGURE Waveform during synthetic testing

Capacitance test

In this test a capacitor is charged by a D.C. voltage source. Capacitor is connected in series with an inductor and making switch. The breaker is connected across the capacitor. C and L from oscillatory circuit. The circuit-breaker under test is opened and voltage across the capacitor is discharged through the arc. The arc gets extinguished at a current zero. This test is used for investigating the behaviour of the breaker towards restriking voltage.

Compensation test

Oil circuit-breakers have internal source of extinguishing energy. For low currents extremely difficult extinguishing conditions may be experienced because of insufficient pressure build up. The characteristics of the breaker in critical range are ascertained by compensation test. These tests are conducted in critical range. In the test, the pressure in the arc extinction device, lengths and durations of arc etc. are recorded, test being conducted at reduced voltage. The reduction in voltage is-compensated by some other factor such as:

- Increased frequency.
- Applying impulse voltage at current zero.
- The pressure in the tank of an oil circuit breaker is given by $P=K\ V^{0.5}\ I^{0.2}$

The effect of reduced voltage can therefore be compensated by increasing current

SUBSTITUTION TEST

In substitution test a number of tests at closely graduated capacities are conducted on the breaker with internal source of extinguishing energy. Characteristics of arc duration and current to interrupted are plotted These are development tests.

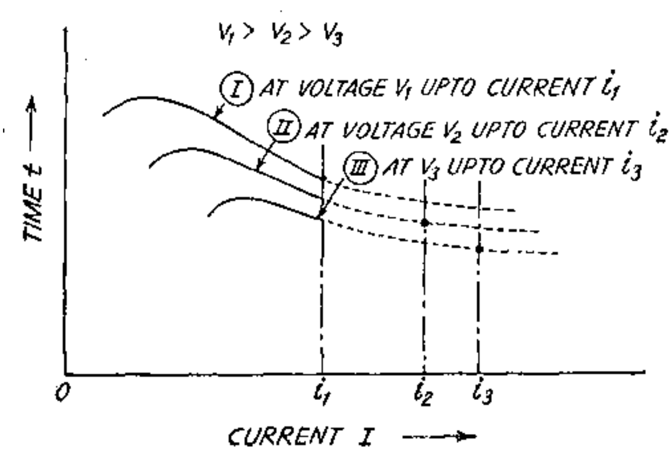


Fig. Substitution test characteristics.

The substitution test is conducted as follows:

1. Test the breaker at full voltage and upto current permitted by the capacity of the plant, i.e. current i_1 of characteristic I.
2. Test the breaker at reduced voltage upto current i_2 permitted by the test plant at reduced voltage V2 obtain the time required for various current upto i_2 and plot characteristic II
3. Likewise, plot characteristics III at voltage V3 upto current i3, characteristic IV at voltage V4 upto current i_1 etc where V1 is the highest test voltage V1> V3 > V4 etc. i_1 is the current at voltage V1 permitted by test plant.

On plotting the characteristic I, II, III, etc, these are extended by approximation as shown by the dotted lines. Form the extended line the breaker performance can be predicated for values of current beyond range of testing station.

Course outcome: Interpret the principle of circuit interruption in different types of circuit breakers

Future readings
1. http://nptel.ac.in/downloads/108101039/
2. https://www.electrical4u.com/protection-system-in-power-system/
3. http://electrical-engineering-portal.com