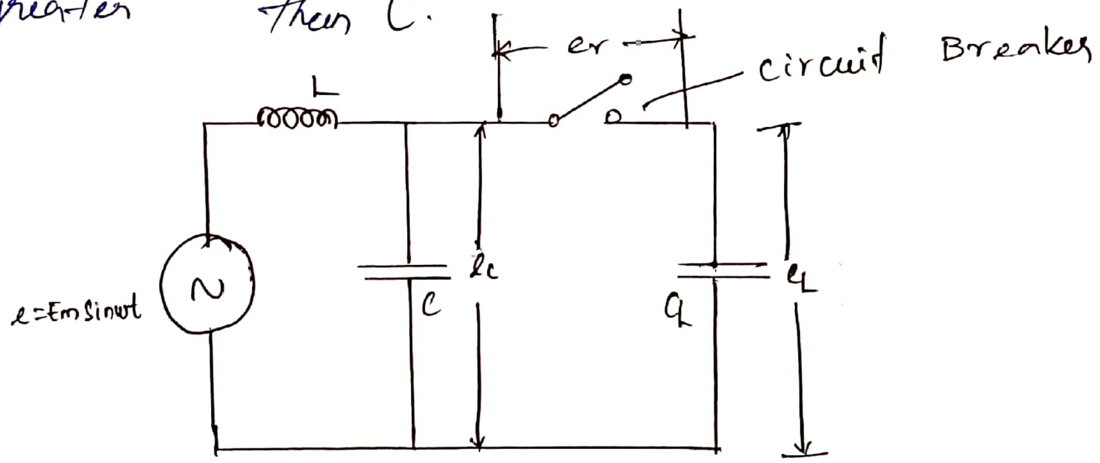
1. Write a brief note on interruption of capacitive current.

In power system capacitor banks are used in the network which supplies reactive power at leading power factor.

There are various conditions such as opening a long transmission line on no load or disconnecting a capacitor bank etc. in which it is required to interrupt the capacitive currents which is a difficult task for the circuit breaker.

The value of load capacitance C_L is greater than C.



The voltage across a capacitor cannot change instantaneously.

The current supplied to the capacitor are generally small and interruption of such currents take place at first current zero.

Also at the beginning, the rate of rise

of recovery voltage is low and increases slowly.

Whenever such circuit is opened a charge is trapped in the capacitance C_L.

The voltage e_L across the load capacitance will hold the same value when circuit was opened.

This voltage is nothing but peak of supply voltage as power factor angle is nearly 90° leading.

After opening the circuit the voltage V_c across the capacitance C oscillates and approaches a new steady value.

But due to small value of capacitance C, the value attained is close to the supply voltage.

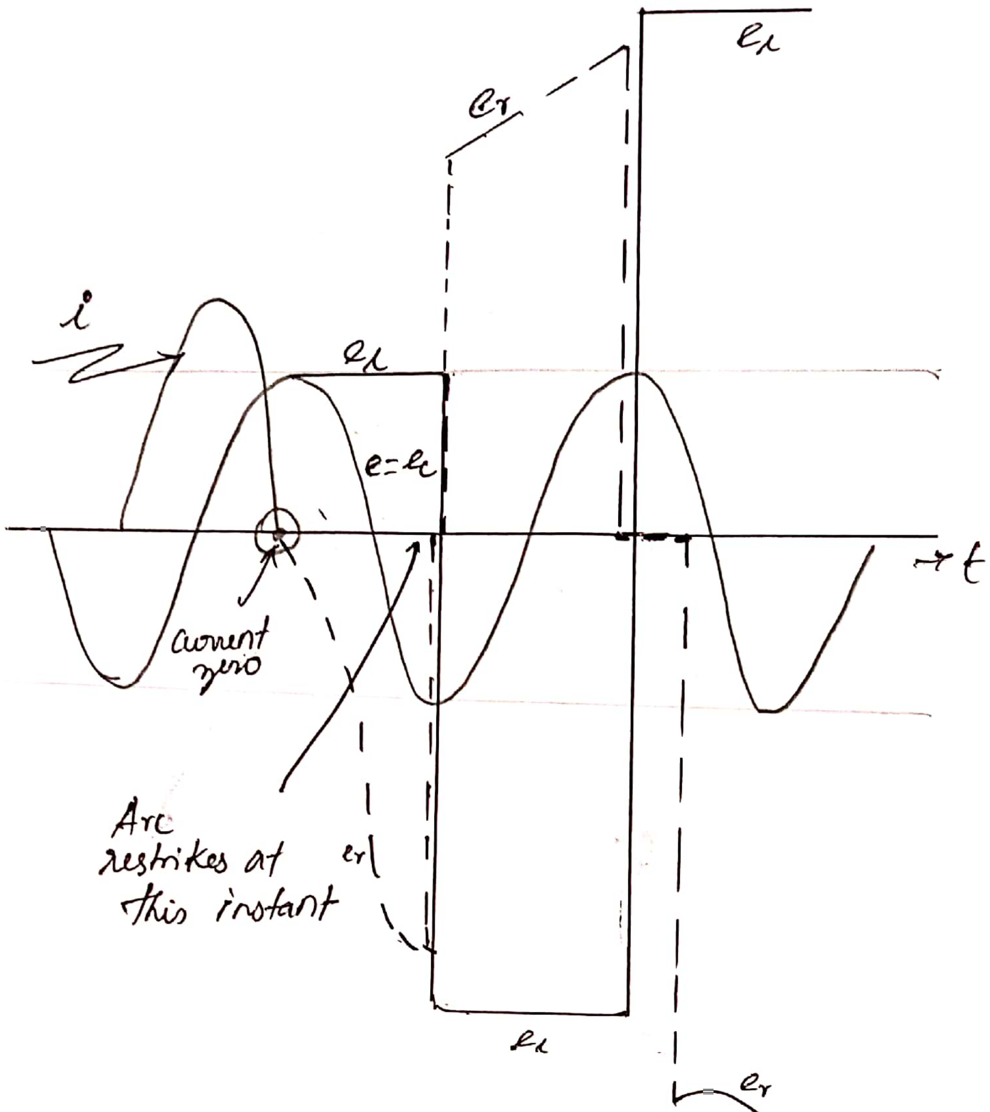
The recover voltage e_r is nothing but difference between e_c and e_L.

Its initial value is zero as the circuit breaker will be closed and increases slowly in the beginning.

When V_c reverse after half cycle, the recovery voltage is about the twice the normal peak value.

Therefore it is possible that at this instant arc may restrike as the electrical strength between the circuit breaker contacts is not sufficient.

The circuit will be reclosed and e_L oscillates at a high frequency.



At the instant of restriking the arc, the recovery voltage V_r is zero.

The voltage across the load capacitance reaches 3 times the peak value of normal supply voltage.

The recovery voltage then starts increasing. If again restriking of arc takes place a high frequency of oscillation of e_L takes place.

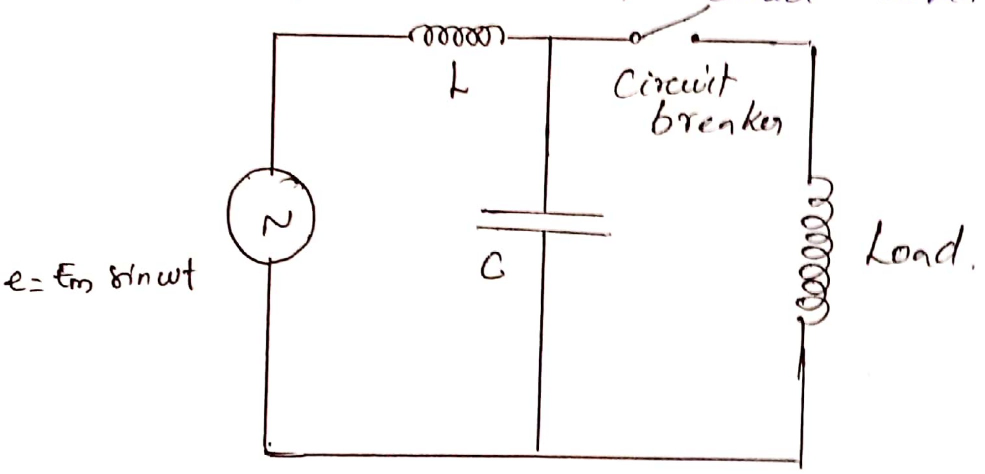
Such several repetitions of the restriking cycle will increase the voltage across load capacitance to a dangerously high value.

3) Discuss the phenomenon of current chopping.

There are certain circumstances like disconnecting transformers on no load in which it is necessary to interrupt small inductive currents.

This current is normally smaller than the normal current rating of the breaker. Interrupting such current causes severe duty on the circuit breaker.

This phenomenon is called current chopping.



While interrupting low inductive currents the rapid ~~dio~~ deionization of contact space and blast effect may cause the current to reduce abruptly to zero well before the natural current zero.

This current chopping causes very serious voltage oscillations.

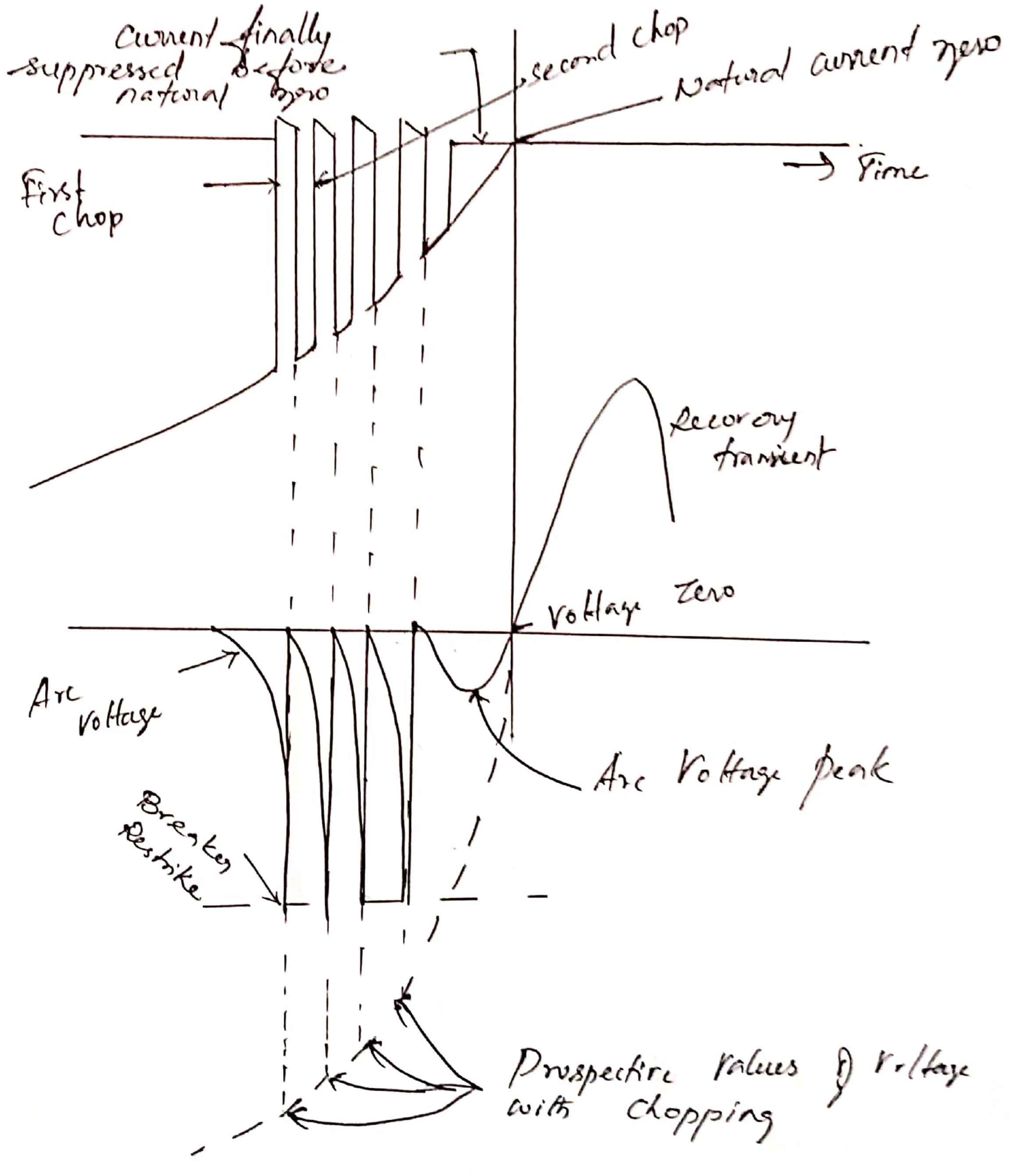
Let the arc current be i when it is chopped down to zero value. The stored energy in the inductor which $\frac{1}{2}Li^2$ will be discharged in to the Capacitance so that the Capacitor is Charged to prospective voltage V such that.

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

$$V = i\sqrt{L/C} \text{ volts.}$$

The frequency of natural oscillations

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



This Voltage will appear across the circuit breaker contacts.

Such a transient voltage having high RRRV appears across the contact.

There will be restriking of arc at some point.

If the arc restrikes further, chop may occur.

Thus before final interruption of current there will be many chops and circuit breaker will fail to clear the fault.

Alternately if the restrike does not occur the severe voltage stress will appear across the circuit breaker.

After first chopping the deionizing force which is still in action acts and second chop of current takes place.

But the arc current is now smaller than the previous one and arc current collapses and restriking voltage is again build.

3. Derive the expression to find the critical values of resistance to be connected across the circuit breaker contacts.

The excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R across the circuit breaker contacts.

This process is known as Resistance switching.

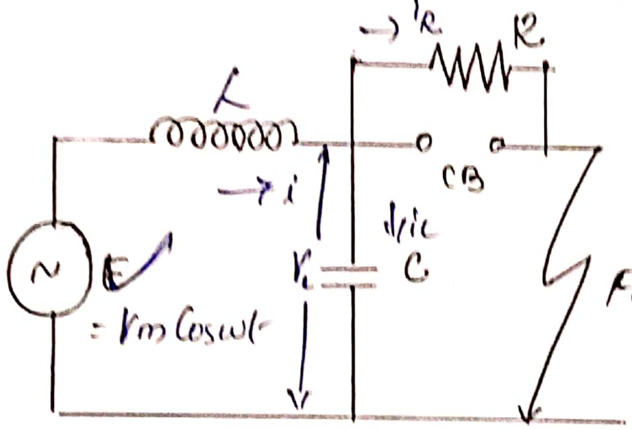
When resistance is connected across the arc a part of the arc current flows through the resistance.

This will lead to decrease in arc current and increase in rate of deionization of the arc path and resistance of arc.

This will increase current through shunt resistance.

This process continues untill the current through arc is diverted through the resistance.

The resistance may be automatically switched in and arc current can be transferred.



The following derivation will show how damping is achieved.

Voltage equation is given by

$$L\frac{di}{dt} + \frac{1}{C}\int i_c\,dt = V_m$$

$$i = i_c + i_R$$

$$L\frac{d(i_c + i_R)}{dt} + V_c = V_m$$

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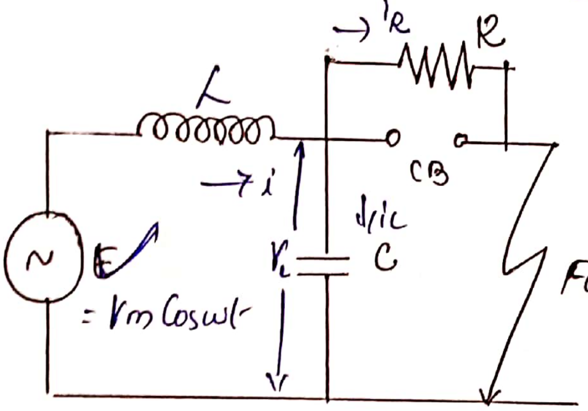


The following derivation will show how damping is achieved.

Voltage equation is given by

$$L\frac{di}{dt} + \frac{1}{C}\int i_C\,dt = V_m$$

$$i = i_C + i_R$$

$$L\frac{d(i_C + i_R)}{dt} + V_C = V_m$$

$$L\frac{di_L}{dt} + L\frac{di_R}{dt} + v_c = V_m \rightarrow ①$$

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

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

$$\frac{di_R}{dt} = \frac{d(v_c/R)}{dt} = 1/R\frac{dv_c}{dt} \rightarrow ③$$

Substituting values in ①

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

Taking Laplace transform of both sides.

$$LCs^2v_c(s) + L/R\, s v_c(s) + v_c(s) = V_m/s$$

other terms are zero.

$v_c = 0$ at $t = 0$

$$LCv_c(s)\left[s^2 + 1/RC\, s + 1/LC\right] = V_m/s.$$

$$V_c(S) = \frac{V_m}{SLC\left(s^2 + 1/RC(s) + 1/LC\right)} \rightarrow ④$$

For no transient oscillation all the roots of equation should be real

one root is zero $s = 0$.

other ~~two~~ roots to be real.

$$\left[\left(1/2RC\right)^2 - 1/LC\right] \geq 0$$

$$L\frac{di_L}{dt} + L\frac{di_R}{dt} + v_c = V_m \rightarrow (1)$$

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

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

$$\frac{di_R}{dt} = \frac{d(v_c/R)}{dt} = \frac{1}{R}\frac{dv_c}{dt} \rightarrow (3)$$

Substituting values in (1)

$$LC\frac{d^2V_c}{dt^2} + \frac{L}{R}\frac{dV_c}{dt} + V_c = V_m$$

Taking Laplace transform of both sides.

$$LCs^2V_c(s) + \frac{L}{R}sV_c(s) + V_c(s) = V_m/s$$

other terms are zero.

$V_c = 0$ at $t = 0$

$$LCv_c(s)\left[s^2 + \frac{1}{RC}s + \frac{1}{LC}\right] = V_m/s.$$

$$V_c(s) = \frac{V_m}{sLC\left(s^2 + \frac{1}{RC}(s) + \frac{1}{LC}\right)} \rightarrow (4)$$

For no transient oscillation all the roots of equation should be real

one root is zero $s = 0$.

other two roots to be real.

$$\left[\left(\frac{1}{2RC}\right)^2 - \frac{1}{LC}\right] \geq 0$$

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

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

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

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

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

When $R \leq \frac{1}{2}\sqrt{L/C}$ no transient Oscillation,

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

if $R = \frac{1}{2}\sqrt{L/C}$ Critical Resistance.

The frequency of damped oscillation is given by

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

4. In a 220kV system the reactance and capacitance upto the location of circuit breaker is 8Ω and 0.025μF respectively. A resistance of 600Ω 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 oscillations.

d) The value of resistance which will give damped frequency of oscillation one fourth of the natural frequency of oscillation.

$L = 8/2\pi 50 = \frac{8}{100 \times \pi} = 0.0254H.$

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

$= 6.304 KHz.$

ii) Frequency of damped oscillation is given by

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

$= 3.413 KHz.$

iii) The value of critical resistance

$$R = \frac{1}{2}\sqrt{\frac{L}{C}} = \frac{1}{2}\sqrt{\frac{0.0254}{0.025 \times 10^{-6}}}$$

$= 504.35 \Omega.$

iv) The damped frequency of oscillation.

$\frac{1}{4} \times 6.304 KHz = 1576 Hz.$

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

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

$R = 520.8 \Omega$

5. Explain the terms : Restriking voltage, recovery voltage and RRRV. Derive expression for restriking voltage and RRRV.

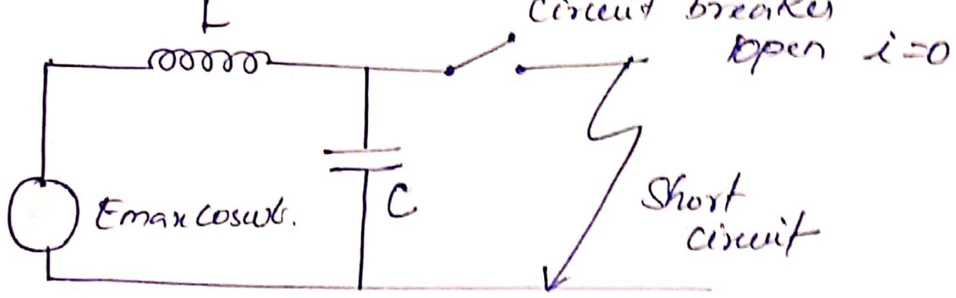
Transient voltage that appears across the circuit breaker contacts at the instant of arc extinction is called restriking voltage.

The rate of rise of restriking voltage RRRV is nothing but rate which is expressed in volts per microsecond.

e as restriking voltage.

$$RRRV = \frac{de}{dt} \quad V/\mu s$$

The maximum instantaneous value attained by the restriking voltage is called peak restriking voltage.



Initial circuit breaker is closed and at that time current flowing through it is 'i'

$$i = \frac{E_m}{\omega L} \cos(\omega t - 90^\circ)$$

$$i = \frac{E_m}{\omega L} \sin \omega t$$

If the applied source voltage is $E_m \cos\omega t$ since the effect of 'C' can be neglected as it is short circuited by breaker switch.

When circuit breaker is opened then if current is to be interrupted this can be simulated by assuming a cancelling current equal and opposite to original current, being injected at circuit breaker.

$$i = \frac{1}{L}\int e\,dt + C\frac{de}{dt}.$$

$$di/dt = e/L + C\frac{d^2e}{dt^2}$$

The solution of 'e' will thus depend on the current and if interruption takes place at current zero when $t=0$

$$i = \frac{E_m}{\omega L}\sin\omega t.$$

After opening of circuit breaker.

$$\frac{di}{dt} = \frac{E_m}{\omega L}\cdot\omega\cos\omega t$$

$$= \frac{E_m}{L}\cos\omega t. \text{ at } t=0$$

$$\frac{E_m}{L}\cos\omega t = e/L + C\frac{d^2e}{dt^2}$$

Standard equation and solution of this equation

$$e = E_m\left[1 - \cos\omega\left[\frac{t}{\sqrt{LC}}\right]\right]$$

This is an expression for restriking voltage.

6. Expression for Maximum Value of Restriking Voltage Em and Corresponding Time tm.

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

If 'e' is to be maximum

$$\cos\left(\frac{t_m}{\sqrt{LC}}\right) = -1 \quad \text{where } t = t_m$$

$$\frac{t_m}{\sqrt{LC}} = \pi$$

$$t_m = \pi\sqrt{LC}$$

Peak value of restriking voltage

$$e_m = E_m\left[1 - (-1)\right]$$

$$\boxed{e_m = 2E_m}$$

Expression of RRRV and maximum RRRV

$$RRRV = \frac{de}{dt} = \frac{d}{dt}\left[E_m\left(\cos\left(\frac{t}{\sqrt{LC}}\right)\right)\right]$$

$$RRRV = \frac{E_m}{\sqrt{LC}} \sin t/\sqrt{LC}$$

Maximum $RRRV = \frac{E_m}{\sqrt{LC}}$ when $\sin \frac{t}{\sqrt{LC}} = 1$

$$\frac{t}{\sqrt{LC}} = \pi/2$$

$t = \frac{\pi\sqrt{LC}}{2}$ for maximum RRRV

Frequency of oscillation of Restriking Voltage.

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

Maximum RRV = $\frac{E_m}{\sqrt{LC}} = 2\pi f_n E_m$

[Maximum RRV = $2\pi E_m f_n$]

Restriking Voltage under Various Conditions.

$e = V_{ar}\left(1 - \cos\left[\frac{t}{\sqrt{LC}}\right]\right)$

$V_{ar} = K_1 K_2 K_3 E_m$

K_1 = factor which takes into accounts effect of circuit p.f.

$K_1 = \sin\phi$. [$\phi = 90°$ $K_1 = 1$]

K_2 is armature reaction on recovery voltage

K_3 - phase factor or first pole to clear factor.

7. For a 132KV system the reactance and capacitance upto the location of circuit breaker is 3Ω and 0.015 μF. Calculate

a) Frequency of transient oscillations.

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

c) The maximum value of RRRV.

a) Frequency of oscillation $L = \frac{3}{2\pi 50}$

$= \frac{3}{100\pi} = 0.00954\ H.$

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

$= 13.291\ kHz.$

b) The restriking Voltage

$V_c = V_m[1 - \cos\omega_n t]$

$= \frac{2 \times (132)\sqrt{2}}{\sqrt{3}}$

$= 215.56\ kV.$

C) Maximum Value of RRRV $= 2\pi f_n V_m$

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

$= 9.01045\ kV/\mu s.$

8. Explain the working and operation of air circuit breaker.

Atmospheric pressure air is used as an arc extinguishing medium.

The principle of high resistance interruption is employed for such type of breakers.

The length of arc is increased using arc runners which will increase its resistance in a way that the voltage drop across the arc becomes more than the supply voltage.

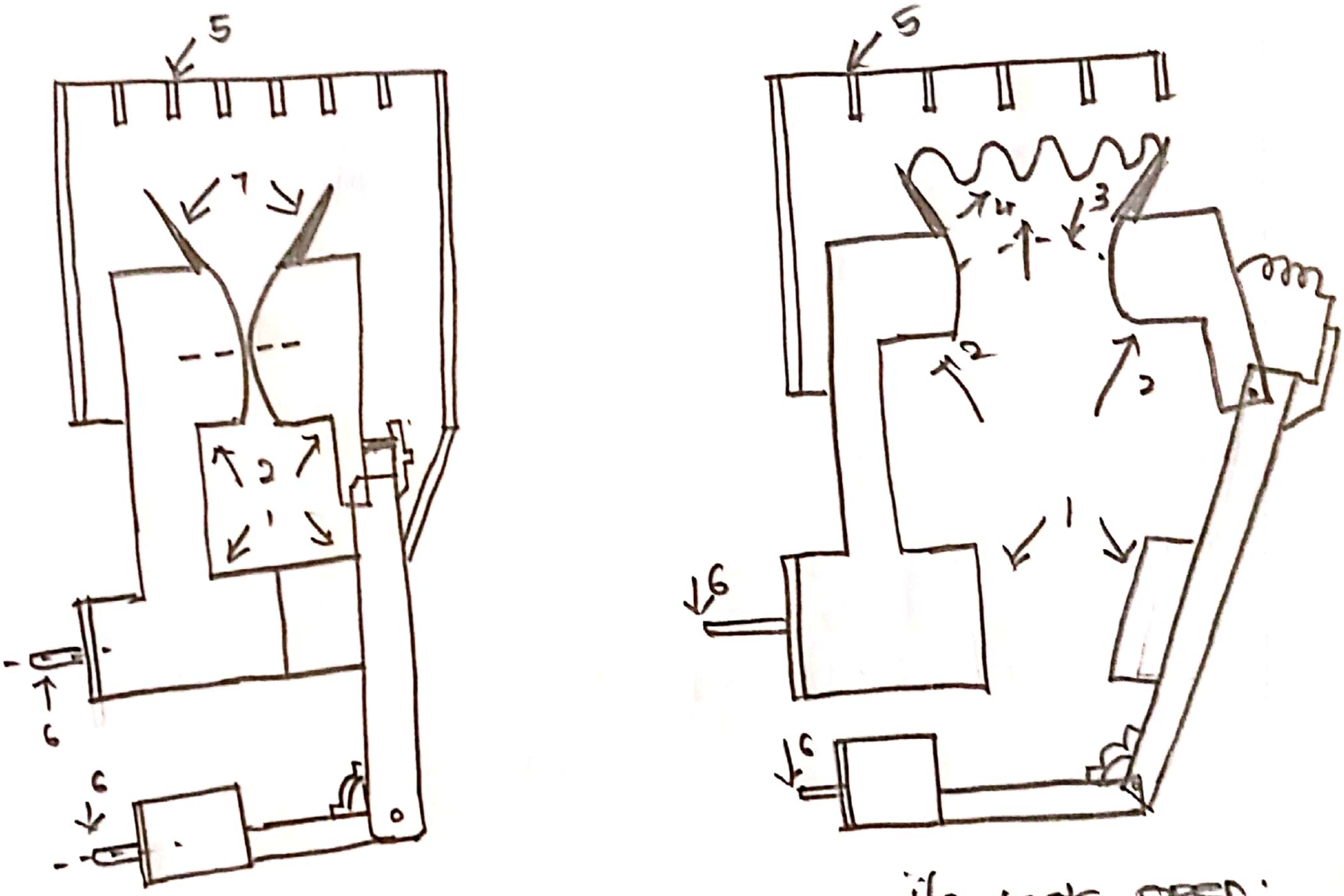
It consists of two sets of contacts

1) Main Contacts 2) Arcing contacts.

During normal condition, the contacts remain closed.

Whenever fault occurs the tripping signal makes the circuit breaker contacts to open.

The arc is drawn in between the contacts.



i) contact closed ii) contacts open.

1. Main contacts 2. Arcing contacts. 3. Arc rising in the direction of the arrow 4. Arc getting split 5. Arc splitter plates 6. Current carrying terminals 7. Arc runners.

Air Break Circuit Breaker

The surrounding air gets ionized. The arc is then cooled to reduce the diameter of arc core.

While seperating the main contacts are seperated first.

The current is then shifted to arcing contains.

Later on the arcing contacts are seperated first.

Due to lengthning and cooling, arc resistance increases which will reduce the faults current and will not allow to reach at high value.

The current zero points in the arc wave will help the arc extinction.

With increase in arc resistance the drop across it will go on increasing.

Whenever arc leaves the contacts it is passed through arc runners with the help of blow out coils which provide a magnetic field, due to which it will experience a force as given by electromagnetic theory ($F = BIl$).

The force will assist in moving the arc upwards.

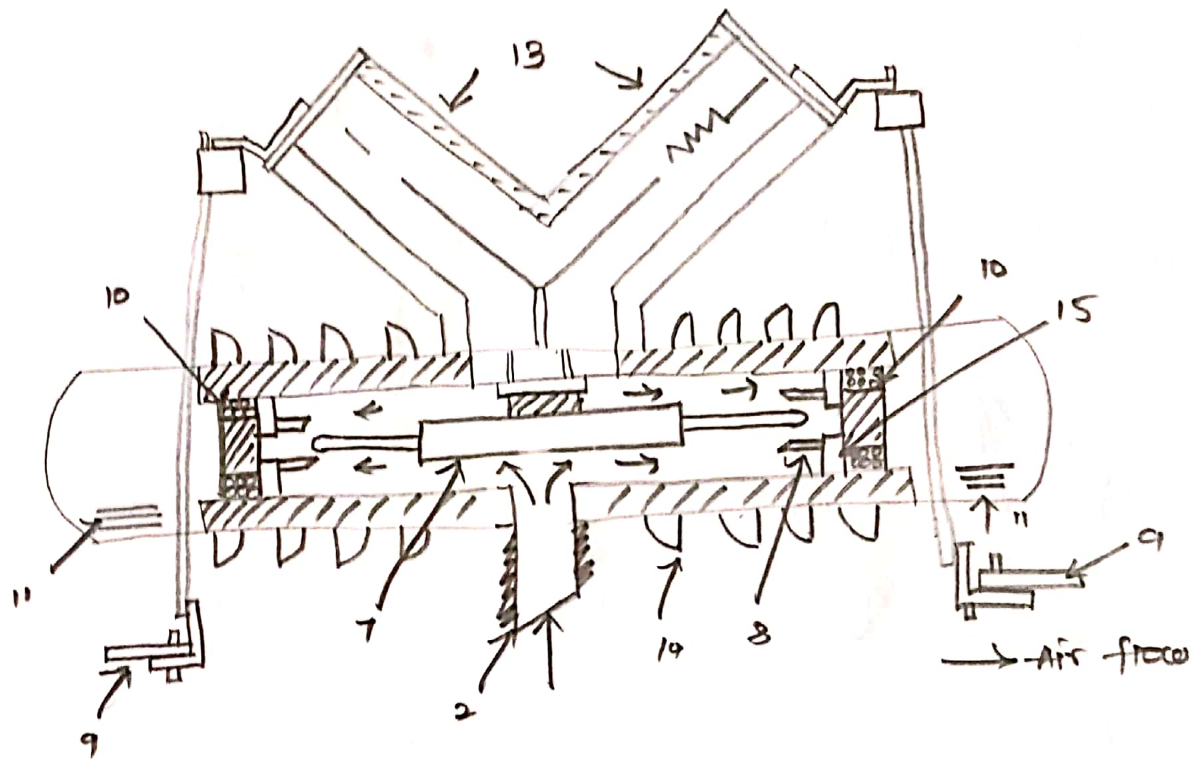
The magnetic field produced is inssufficient to extinguish the arc.

For systems having low inductances arc get extinguished before reaching extremity of runners because lengthening of arc will increase the voltage drop which is insufficient to maintain the arc.

7. Explain the working of air blast circuit breaker with reference to i) Axial blast ii) Cross blast.

These type of circuit breakers were employed in earlier days of voltages ranging from 11 to 1100 kV.

At high voltages this type of circuit breakers are most suitable.



Air Blast circuit Breaker

1. Tank air reservoir
2. Hollow insulator assembly
3. Double arc extinction Chamber
4. Pneumatic operating mechanism.
5. Operating rod.
6. Pneumatic valve
7. Fixed contact
8. Moving contact
9. Connection for current
10. Compression springs
11. Openings of air outlet
12. Arcing horns.
13. Resistance switching unit
14. Enclosure
15. Port.

An auxiliary compressed air system is required by this type of circuit breaker. This will supply air to the air reservoir of the breaker.

During the opening operation, the air is allowed to enter in the extinction Chamber which pushes away moving Contacts.

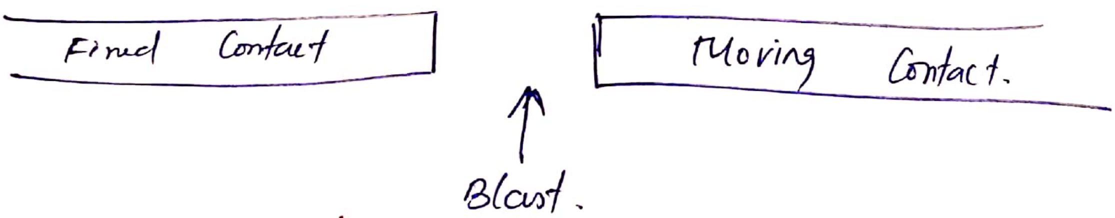
The contacts are seperated and the blast air will take ionized gas with it and helps in extinguishing arc.

Cross blast Type.

The flow of air is across the arc. The moving contact is near to the arc splitter assembly.

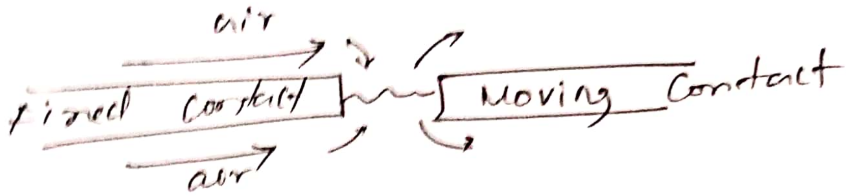
The air blast forces the arc on the arc splitter plates.

This plate will lengthen the arc. Depending upon the breaking Capacity number of plates are decided.



Axial blast type.

In air blast circuit breaker, the pressure generated in the extinction Chamber



In this type the flow of blast of air is along the line of arc.

There are two subtypes which are shown. The double blast arrangement is also called radial blast type due to the fact that the blast flows radially into the space between the contacts.

The high speed air flowing axially along the arc will cause removal of heat from the periphery of the arc.

The diameter of arc reduces to a low value at current zero.

10. With a help of neat block diagram, explain the construction, operating principle, applications and advantages of SF6 circuit breaker.

Pure sulphur hexafluoride gas is inert and thermally stable.

It is having good dielectric and arc extinguishing properties.

It is also an electronegative gas and has strong tendency to absorb free electrons.

The contacts of the breaker are opened in a high pressure flow of SF_6 gas and an arc is struck between them.

The conduction electrons from the arc are captured by the gas to form relatively immobile negative ions.

Thus SF_6 circuit breakers are found to be very effective for high power and high voltage service and widely used in electrical equipments.

Construction of Non-puffer type SF_6 breaker.

It consists of arc interruption chamber wherein fixed contacts are enclosed.

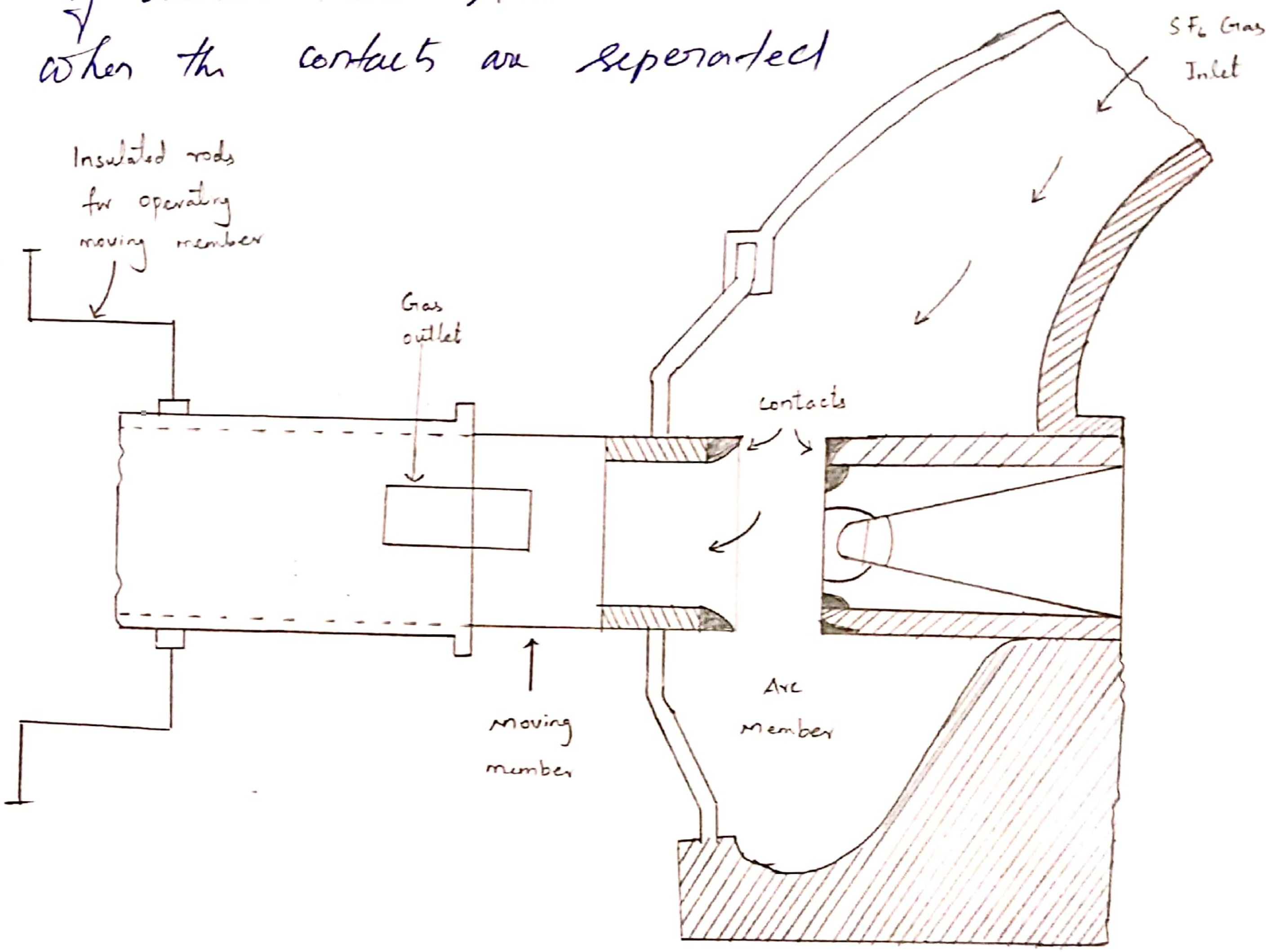
When the contacts of circuit breaker are opened the valve mechanism allows high pressure SF_6 gas from the reservoir to flow toward the arc interruption chamber.

The fixed contact is a hollow, cylindrical current carrying contact fitted with arc horn. The moving contact is also hollow cylinder containing holes in the sides to permit SF_6 gas to pass through these holes after flowing across the arc.

The tips of fixed and moving contacts are coated with copper tungsten arc resistant material.

During the normal working conditions the contacts are in closed position which are surrounded by SF_6 gas at a pressure of about 2.8 kg/cm².

When the contacts are seperated



* Construction of SF_6 Breaker

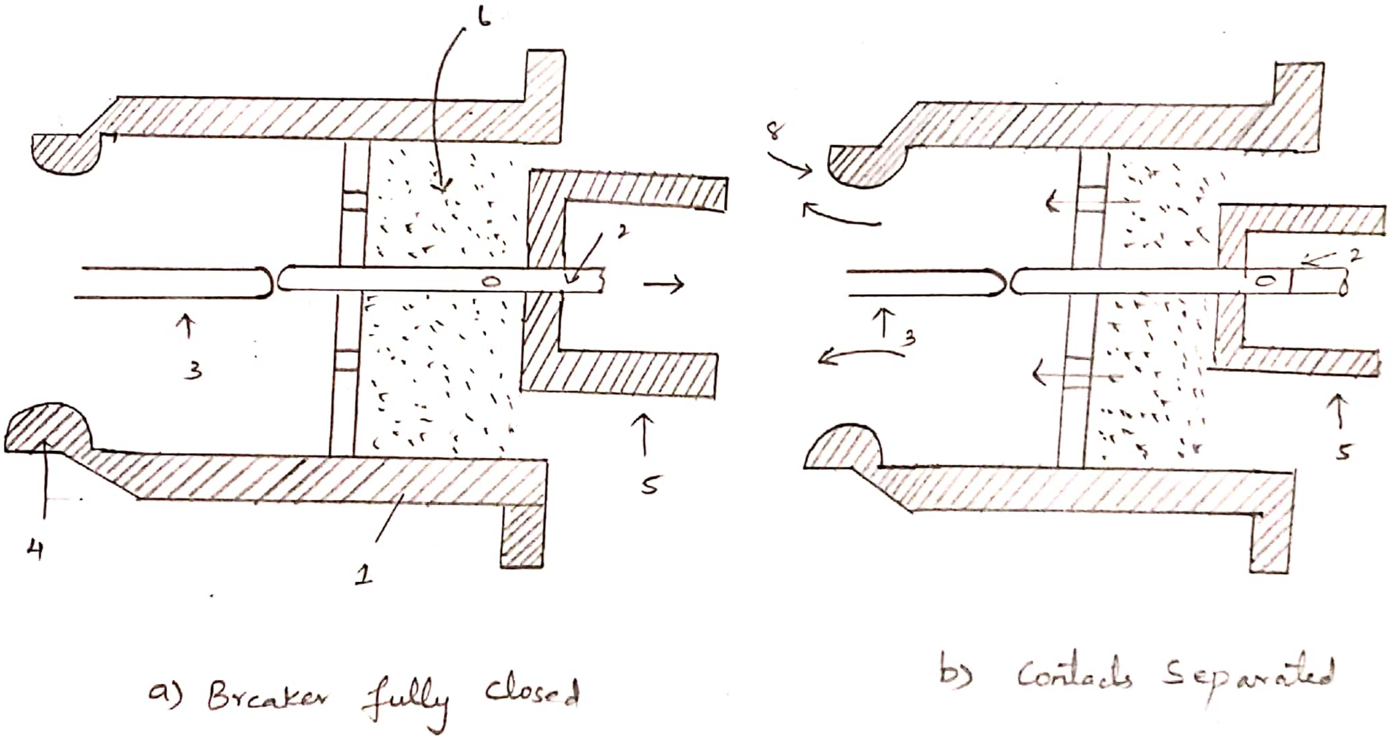
then arc is struck between. The movement of moving contacts and opening the valve are synchronize together which permits high pressure SF_6 gas from the reservoir to the arc interruption chamber.

Due to this arc diameter reduces and it becomes small during current zero with the turbulent flow around current zero, the arc is extinguished.

Scanned with CamScanner

Single pressure puffer type SF_6 CB.

It employs puffer principle. The operating mechanism (1) is installed at base of the insulator and is linked with movable contact in the interrupter by means of insulating operating rod (4) and a link mechanism (5). The circuit breaker is filled with SF_6 gas at a pressure of about 5 kgf/cm².



*Single pressure puffer type SF_6 breaker

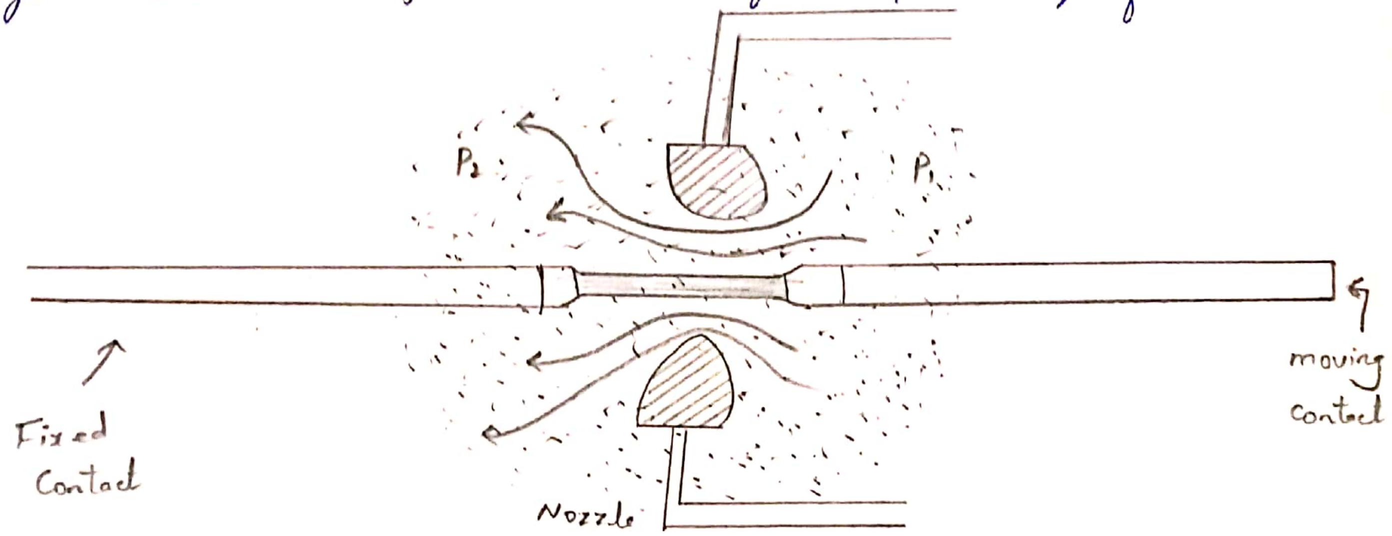
1- Moveable cylinder
2- Moving Contact
3- Fixed Contact
4- Insulating nozzle
5- Fixed piston
6- Gas trapped in before compression
7- Compressed gas between 1 and 5
8- The Arc being extinguished by puffer action

The breaking time obtained with puffer type breaker is nearly 3 cycles.

Double pressure type SF_6 circuit Breaker.

Gas from high pressure system is released into low pressure system through a nozzle during arc extinction process.

In this circuit breaker gas is made to flow of gas cover the arc. Gas flow attains almost supersonic speed in divergent portion of nozzle, thereby gas takes away the heat from periphery of arc causing



* Double pressure type SF_6 Circuit Breaker

reduction in diameter of the arc.

Finally arc diameter becomes almost zero at current zero and arc gets extinguished.

Arc space is filled with fresh SF_6 gas which increases dielectric strength of contact space.