CIRCUIT BREAKER.

⇒ A circuit breaker can make or break a circuit either manually or automatically under all conditions (no load, full load, short-ckt conditions.

⇒ A circuit breaker is a piece of equipment which can
(i) Make or break a circuit either mannally or by remote control under normal conditions
(ii) Break a circuit automatically under fault conditions
(iii) Make a circuit either manually or by remote control under fault conditions.

Thus, a circuit breaker incorporates manual as well as automatic control for switching functions. The latter control employs relays and operates only under fault conditions.

→ fn of CB → is to isolate the faulty point of the power system in case of abnormal condn.

* Different types of CB are used to perform this fn. There are low voltage CB and high voltage CB. High voltage CBs are mainly used in substation and low voltage CB are used in home circuits.

→ Imp high voltage CB used in the electrical substation are.
- SF_6 Circuit Breaker
- Vaccum Circuit Breaker.

low Voltage CB includes
- Miniature Circuit Breaker (MCB)
- Molded Case Circuit Breaker (MCCB)
- Residual Current Circuit Breaker (RCCB) or
- Ground fault Circuit Interrupter (GFCI)

Soumya Souraja Panda

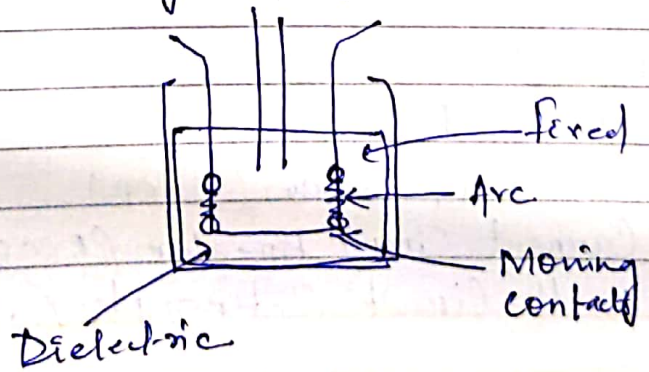
Operating Principle

A circuit breaker essentially consists of fixed and moving contacts, called Electrodes. Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty. Of course the contacts ~~with~~ can be opened manually or by remote control whenever desired. When a fault occurs on any part of the system, the trip coils of the CB gets energized and the moving contacts are pulled apart by some mechanism, thus opening the ckt.

→ When the contacts of a CB are separated under fault conditions, an arc is struck betⁿ them. The current is thus able to continue until discharge ceases.

→ The prodⁿ of arc not only delays the current-interruption process but it also generates enormous heat which may cause damage to the system or to the CB itself.

→ Therfore, the main problem in a CB is to extinguish the arc within the shortest possible time so that heat generated by it may not reach dangerous value.



Arc Phenomenon :-

When a short circuit occurs, a heavy current flows through the contacts of the circuit breaker before they are opened by the protective system. At the instant when the contacts begin to separate, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature. The heat produced in the medium betⁿ contacts (usually the medium is oil or air) is sufficient to ionize the air or vaporize ~~the~~ and ionize the oil. The ionized air or vapour acts as conductor and an arc is struck between the contacts.

→ The potential difference between the contacts is quite small and is just sufficient to maintain the arc.

→ The arc provides low resistance path and consequently the current in the circuit remains uninterrupted so long as the arc persists.

→ During the arcing period, the current flowing betⁿ the contacts depends upon the arc resistance. The greater the arc resistance, the smaller the current that flows betⁿ the contacts.

The arc resistance depends upon the following factors :-

① Degree of ionizatⁿ - Arc Resistance increases with the decrease in the number of ionized particles betⁿ the contacts.

② Length of the arc - Arc Resistance increases with the length of the arc i.e separation of contacts.

(3) Cross-Sectional Area of Arc :- The arc resistance increases with the decrease in area of cross-section of the arc.

Principle of Arc Extinction

The factors responsible for the maintainence of arc betⁿ the contacts arc
① Potential difference b/w the contacts.
② Ionized particles betⁿ Contacts.

① When the contacts have a small separation, the potential difference betⁿ them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such distance that the potential difference becomes insufficient to maintain the arc. But this method is impractical in high voltage systems where a separation of many metres may be required.

② The ionized particles betⁿ the contacts tend to maintain the arc. If the arc path is deionized, the arc extinction will be facilitated. This may be achieved by cooling the arc or removing the ionised particles from the space between the contacts.

Methods of arc extinction

There are two methods of extinguishing the arc in the CB.
① High Resistance Method.
② ~~Current~~ low Resistance method (Current zero method)

High Resistance Method

→ In this method, arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc. Consequently, the current is interrupted or the arc is extinguished.

→ The principle disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in DC CB and low capacity AC CB.

The resistance of the arc may be increased by :-

(1) Lengthening the arc :- The resistance of the arc is directly proportional to its length. The length of the arc can be increased by increasing the gap b/w contacts.

(2) Cooling the arc :- Cooling helps in the deionizat^{n} of the medium bet^{n} the contacts. This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

(3) Reducing X-section of the arc :- If the area of X-section of the arc is reduced, the voltage necessary to maintain the arc is increased, the resistance of the arc path is increased

(4) Splitting the arc.
The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series.

Low Resistance or Current zero Method :-

→ This method is employed for arc extinction in ac circuits only.
→ In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally.
→ All modern high power a.c circuit breakers employs this method for arc extinction.

→ In an a.c system, current drops to zero after every half cycle. At every current zero, the arc extinguishes for a brief moment.
→ Now the medium betⁿ the contacts contain ions and electrons so that it has small dielectric strength and can be easily broken down by the rising contact voltage known as restriking voltage.
→ If such a breakdown does occur, the arc will persist for another half cycle.
→ If immediately after current zero, the dielectric strength of the medium b/w contacts is build up more rapidly than the voltage across the contacts, the arc fails to restrike and the current will be interrupted.

The rapid increase of dielectric strength of the near current zero can be achieved by.
> Causing the ionized particles in space betⁿ Contacts to recombine into neutral molecules
> Sweeping the ionized particles away and replacing them by an un-ionized particles

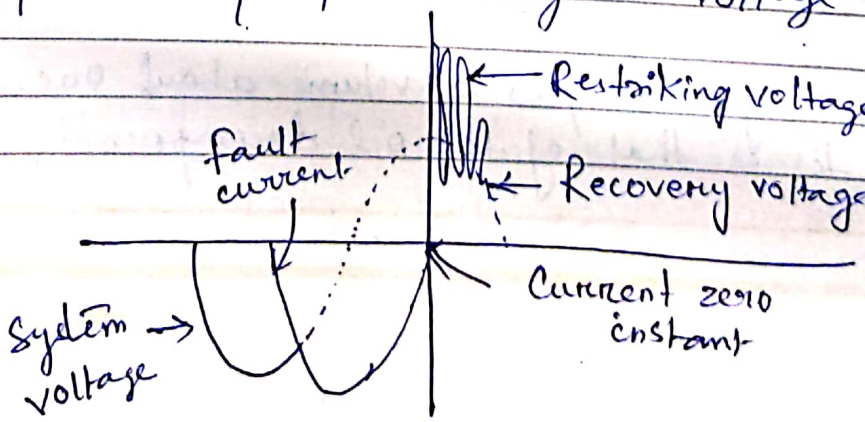
The deionizat^n of the medium can be achieved by
① Lengthening of the gap [D.S $\propto$ l]
② High pressure — high pressure → density ↑ → higher rate of de-ionizat^n.
③ Cooling — D.S $\propto$ Cooling
④ Blast effect.

Definations of Arc Voltage, Re-striking Voltage And Recovery Voltage

① **Arc Voltage** :- It is the voltage that appears across the contacts of the circuit breaker during the arcing period. When the contacts of the circuit breaker separates an arc is formed. The voltage that appears across the contacts during arcing period is called Arc Voltage. This arc voltage is low except for the period the fault-current is at or near zero current point. At current zero, the arc voltage rises rapidly to peak value and this peak voltage tends to maintain the current flow in the form of arc.

② **Restriking Voltage** :- It is the transient voltage that appears across the contacts at or near current zero during Arcing period. The ~~ee~~ interruption of current in the ckt depends on this voltage

③ **Recovery Voltage** :- It is the normal freq (50 Hz) RMS voltage that appears across the contacts of the circuit breaker after final arc extinction. It is approximately equal to system voltage



CLASSIFICATION OF CIRCUIT BREAKER

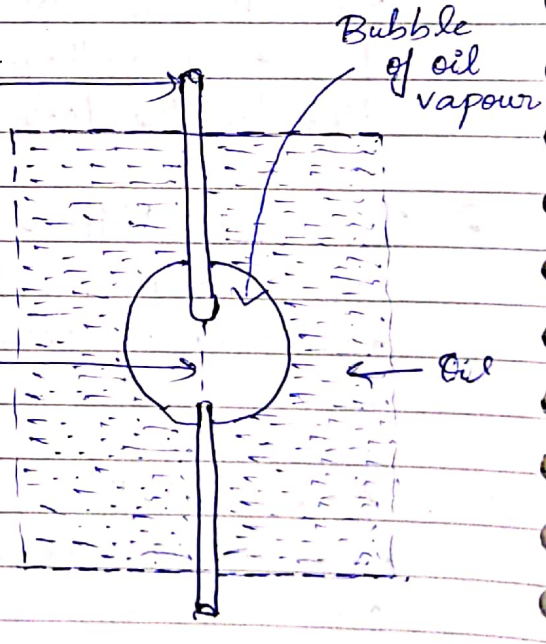
The most general way of classifying is based on the medium used for arc extinction. The medium used for arc extinction is usually air, oil, SF_6 or vaccum.

Types of CB

- Oil CB (employes some insulating oil / o/f oil for arc extinction)
- Air blast CB (high pressure air blast is used)
- SF_6 CB (SF_6 gas is used)
- vaccum CB (vaccum is used for arc extinction)

OCB

In this CB, transformer oil is used as an arc quenching medium.



- The Contacts are opened under oil and an arc is struck betn them.
- Then the heat of the arc evaporates the surrounding oil and dissociates it into a substantial volume of gaseous hydrogen gas at high pressure.
- The hydrogen gas occupies a volume about one thousand times that of the oil decomposed.

Hydrogen - (70 - 80%)
Other gases - methane, ethylene, acetylene.

Then the oil is pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region and adjacent portions of the contacts.

The arc extinction is faciliated mainly by two processes
(1) The hydrogen gas has high heat conductivity and cools the arc, thus helping the deionisation of the medium b/w the contacts.

(2) The gas sets up turbulence in the oil and forces it into the space betⁿ contacts, thus eliminating the arcing products from the arc path.

Advantages:-
(1) It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties
(2) It acts as an insulator and permits smaller clearance b/w live conductors and earthed components.

Disadvantages:-
(1) Risk of fire
(2) Quality of oil deteriorates
(3) It may form an explosive mixture with air.

Applications.
OCBs are generally used upto 66 kV
OCBs have following voltage ratings:-
3.6 kV, 7.2 kV, 12 kV, 36 kV, 72.5 kV, 145 kV, 245 kV.

Types of OCB

1. Bulk oil CB (dead tank CB)
   - → Plain breake OCB
   - → Arc Control OCB
2. low oil CB

Bulk Oil CB

→ dead tank CB

Because the tanke of this breaker is held at ground potential. The amount of oil used in the CB mainly depends on the system voltage.

110 KV, oil → 8 kg to 10,000 kg oil

220 KV, 50,000 kg oil

Minimum OCB

Oil tank is placed on a porcelain insulator for insulating it from the ground.

MOCB places interupting unit in insulating chamber at line potential.

> uses less space

less oil, less space, less weight, tank size is small, less maintainence.

AIR BLAST CIRCUIT BREAKER

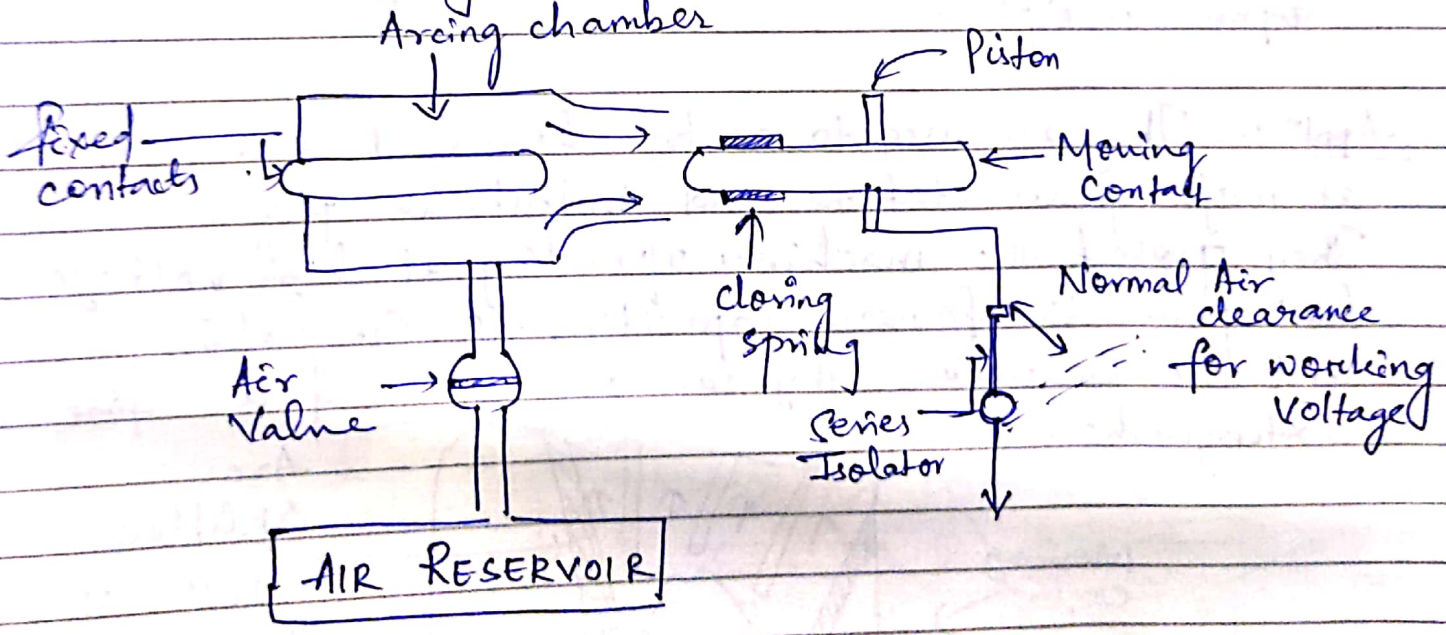
→ These CB employ high pressure air blast as arc quenching medium. The air blast cools the arc and sweeps away the arc products to atmosphere

→ As compressed air is used for arc extinction. Hence, these are also called compressed air circuit breakers.

→ Majority of circuit breakers for voltages beyond 110 KV are of this type. Hence, these are most suitable for high voltages.

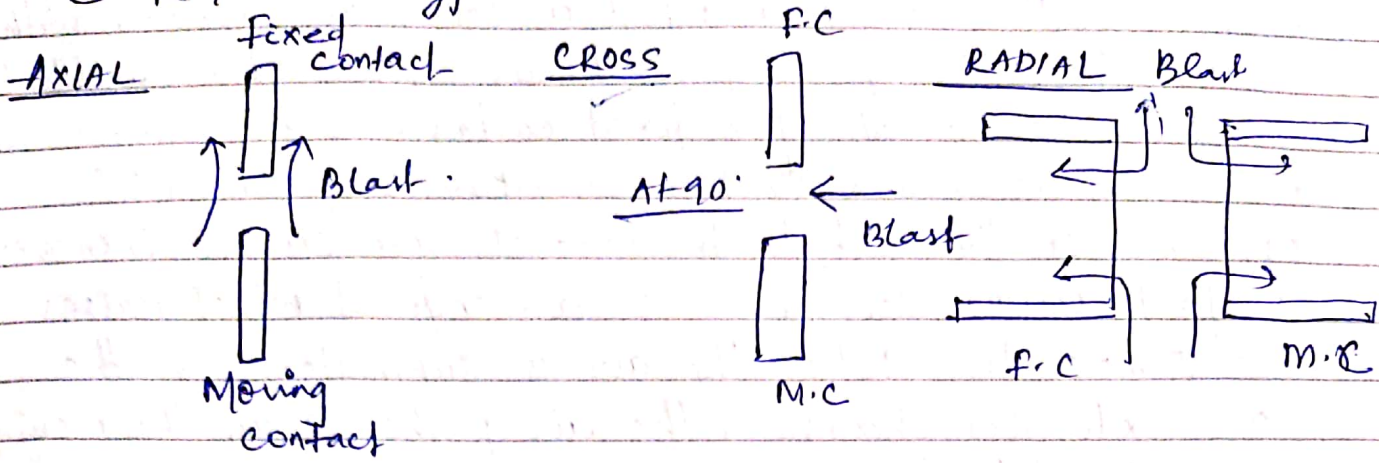
Construct" & Working

At bottom, there is a tank which is called air reservoir with a Valve. An auxiliary compressed air system of an air blast circuit breaker consists of a fixed contact and a moving contact, enclosed in an arc extinction chamber. Under normal operating conditions, both the contacts are closed. Whenever, a fault occurs, high currents are induced which raises the temperature. When the air is submitted into the arc extinction chamber, the air pushes away the moving contact establishing an arc. The air inside the arc extinction chamber will have high pressure than the atmospheric pressure. The air blast cools the arc and sweeps away all the ionized gases along with it. Because of this, the dielectric builds up rapidly b/w the contacts which prevents the reestablishment of arc. Thus, the flow of current is interrupted



Types of ABCB

1. Axial blast type
2. Cross-blast type
3. Radial blast type.

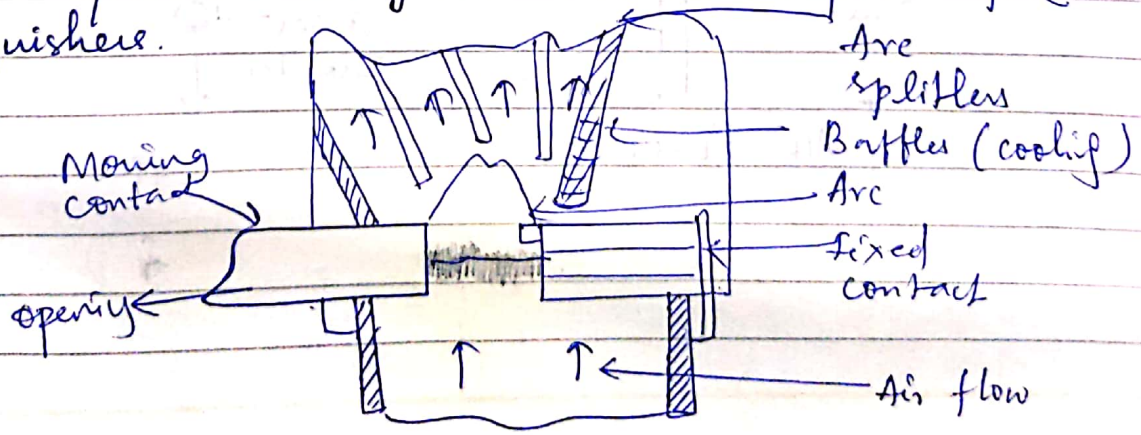


Cross.

Disadvantages:- ① An air Compressor plant has to be installed and Maintained.

② In ABCB, upon arc interruption, it produces a high level of noise when air is discharged to the open atmosphere.

Appln:- They are used to control transient overvoltages at major power stations and industrial plants. They protect the machines operating at high voltages like power transformers, Capacitors, AC Generators and DC Generators. They can also be used as fire Extinguishers.



Arc (length) ↑

R ∝ l.

R ↑ dielectric strength ↑ Arc finish.

Arcing products finished.

SF_6 Circuit Breaker

~~Current~~
Voltages → 115 kV to 230 kV
power → 10 MVA to 20 MVA

SF_6 gas → Arc Quenching Medium.
→ effective for high power & high voltages.
→ 3.6 to 760 kV
→ SF_6 gas is an electronegative gas and has a high tendency to absorb free electrons.

$$SF_6 + e^- \rightarrow SF_6^-$$ (immobile negative ions)

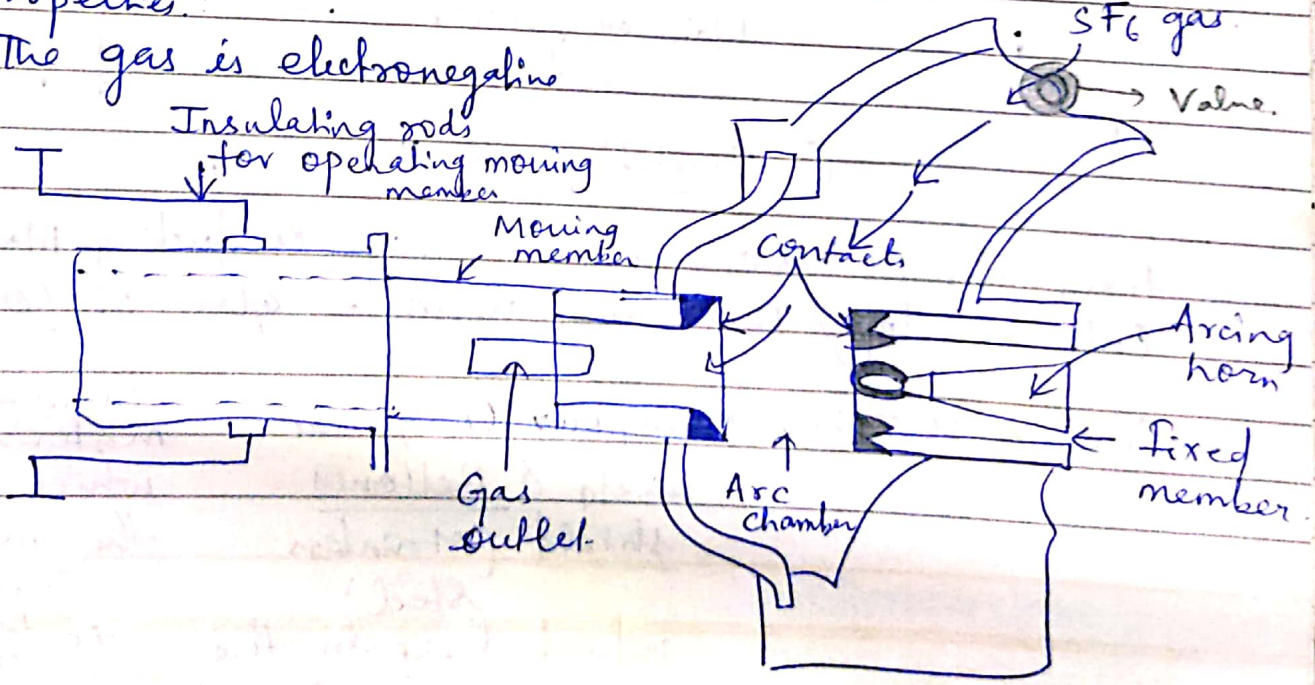
negative ion are heavier as compared to free e^- & they do not get sufficient energy to lead cummulative ionization in the gas under a given electric field.
→ This property give rise to a very high dielectric strength of SF_6.

physical

→ non-inflammable.
→ Gas is colourless, odourless & non-toxic.
→ high density
→ Excellent heat transfer properties.
→ The gas is electronegative

chemical

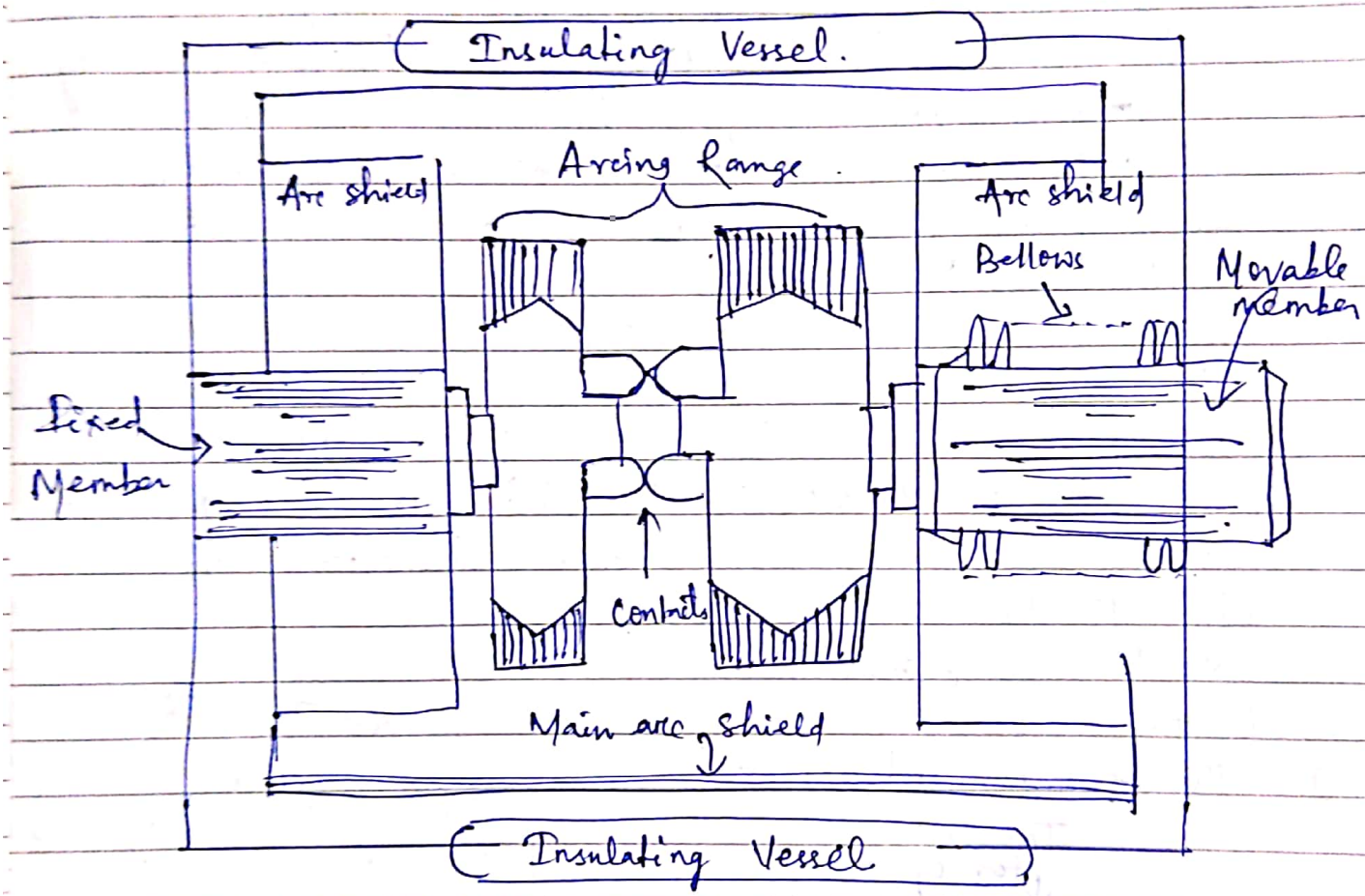
→ chemically inert gas
→ Metallic flourides provides good dielectric Strength



Vaccum Circuit Breaker {(VCB)}

Vaccum → Arc Quenching Medium. Vaccum order — 10^{-5} to 10^{-7} torr
↓
superior dielectric medium of extinguishing the arc compare to other medium.

→ This circuit breaker is used to break the voltage level bet^{n} 22 KV to 66 KV, (60 to 100 MVA)



Fixed Contact, Moving contact → high conducting Material
Outer envelop / Insulating vessel → glass or Ceramic
↓
insulated material which provide the mechanical support to Glass

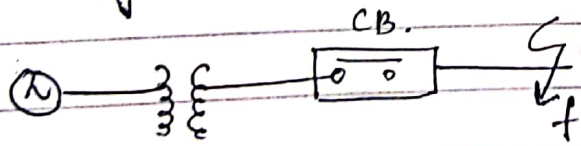
Vaccum chamber → Vapour Condensation shield & Bellows shield. (stainless Steel) which help in the movt of moving chamber.

When moving contact moves, an arc generates bet^n the contacts while the contacts are in vaccum, how an arc is formed The tips of contacts gets overheated due to high temp. of Conductor, so the metal contacts release the positive ions as a vapour. When vapour accumulate bet^n both contacts, vapour ionized due to high Temp, due to this the current flows which appear as an arc. The value of current in arc, depends upon rate of produces the vapour. When value of current will reduce vapour red^n rate will also reduce.

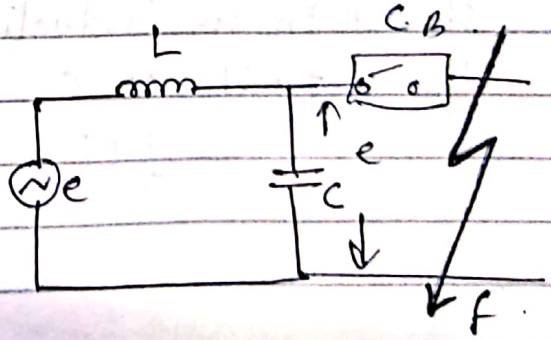
→ The production of arc is due to the ionisation of metal ions and it depends upon the material of contacts. The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in a short time.

→ Vaccum has very fast rate of recovery of dielectric strength. The arc extinction in a vaccum CB occurs with a short contact separat^n (0.525 cm).

Problems of Circuit Interrupt^n:



→ Short ckt occuring in transmission line



Equivalent ckt where L & C are the per phase inductance & capacitance of the system.

① Rate of rise of Re-striking Voltage (RRRV)

It is defined as the rate of increase of re-striking voltage.
Unit - KV/μsec.

LC, produces a transient freq, $f_n = \frac{1}{2\pi\sqrt{LC}}$

The RRRV decides whether the arc will restrike or not.

Case-1 RRRV > Rate of rise of dielectric strength b/w contacts → Arc (Re-strike)

Case-2 RRRV < Rate of rise of dielectric strength b/w contacts → Arc will not restrike.

Value of RRRV depends on
① Recovery voltage
② Natural freq of Oscillat°.

② Current chopping

It is the phenomenon of current interruption before the natural current zero is reached.

→ As the chop occurs at current, i. Therefore, the energy stored in an inductor ($\frac{1}{2}Li^2$) will be transferred to the capacitance C.

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

$$\Rightarrow e^2 = \frac{Li^2}{C}$$

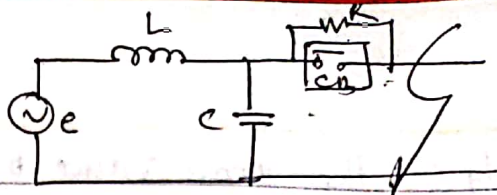
$$\Rightarrow e = i\sqrt{\frac{L}{C}} \text{ volts.}$$

↑ prospective voltage

Q L = 4 mH, C = 0.001 MF, current chop = 50 A.

$$e = i\sqrt{\frac{L}{C}}$$

Resistance Switching



$v = iR$

The current chopping, capacitive current breaking etc give rise to severe voltage oscillations. These excessive voltage surges during circuit interrupt^n can be prevented by the use of shunt resistance R connected across the CB contacts. This is known as Resistance Switching.

→ When a fault occurs, the contacts of the CB are opened and an arc is struck bet^n the contacts. Since the contacts are shunted by resistance R, a part of arc current flows through this resistance. This results in the decrease of arc current and increase in the rate of de-ionisation of the arc path. Consequently, the arc resistance is ↑sed. The ↑sed arc resistance leads to further ↓se in current through the shunt Resistance. This process continues until the arc current becomes so small that it fails to maintain the arc. Now, the arc is extinguished & circuit current is interrupted.

CB rating

1. Breaking capacity
2. Making capacity
3. Short-time capacity

Breaking Capacity :- It is the rms value of current that a CB is capable of breaking at given recovery voltage & RRR

For a 3-ϕ ckt,

Breaking Capacity $= \sqrt{3} \times V \times I \times 10^{-6}$ MVA

V = Rated line Voltage (volts)

I = Breaking current (Amperes)

Making Capacity :- The peak value of current during the 1st cycle of current wave after the closure of CB is known as making capacity.

Making capacity = 2.55 × Symmetrical breaking capacity

Short-time Rating

It is the period for which the CB is able to carry fault current while remaining closed.

→ The short time rating of a CB depends upon its ability to withstand.

(a) Electromagnetic force effects.

(b) Temp Rise.

x = Max^m value of AC Component.

y = DC Component.

Sym. breaking current = rms value of ac component

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

Asym. breaking current = rms value of total current

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

Several equipments in the power sys that such as generator, Xmer, Xmission lines may be subjected to overvoltage

- Lighting
- opening of CB
- Grounding of conductor

Overvoltage

Magnitude of the voltage will be much more than the normal voltage

If this overvoltage will remain in the system, then it may damage the equipments.

Protection Against Overvoltage & Lightning.

Voltage Surge & Causes of Over-voltage.

Voltage Surge :- A sudden rise in voltage for a very short duration on the power system is known as voltage surge or transient voltage.

Causes of over Voltage.

- Internal causes
  - Switching Surges
  - Insulation failure
  - Arcing Ground.
  - Resonance
- External causes
  - lightning

Internal cause :- This is the cause of overvoltages on the power system are primarily due to oscillations set up by the sudden changes in the circuit conditions.

① Switching Surges :- The overvoltages produced on the power system due to switching operations are known as Switching Surges.

② Insulation failures :- The most common case of insulation failure in a power system is the grounding of conductor. (i.e Insulation failure both line and earth)

(L-G)

⑤ Arcing Ground

The phenomenon of intermittent arc taking place in line to ground fault of a 3-ϕ system with consequent production of transients is known as Arcing Ground.

→ The arcing ground produces severe oscillations of 3 to 4 times the normal voltage.

→ The transient produced due to arcing ground are cumulative and may cause serious damage to the equipment in the power system by causing breakdown of insulation.

④ Resonance

→ Resonance occurs when inductive reactance of the circuit becomes equal to capacitive reactance.

$$X_L = X_C$$

→ Under Resonance, the impedance of the circuit is equal to resistance of the ckt and the pf is unity.

→ Resonance cause high voltages in the electrical system.

External Causes

→ Surges due to lightning are very severe and may increase the system voltage to several times the normal value.

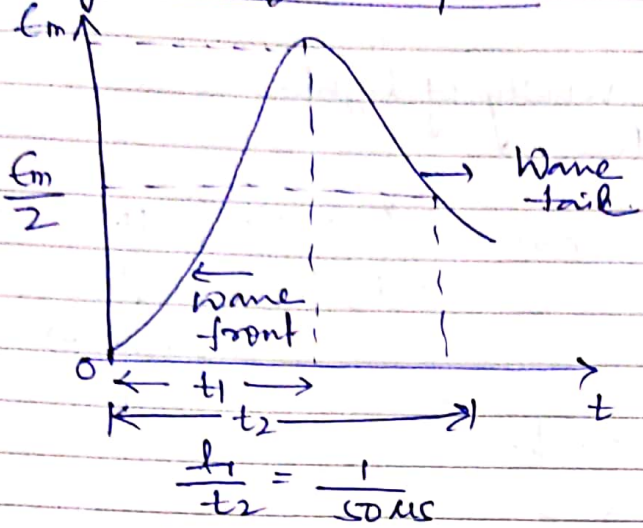
→ If the equipment in the power system is not protected against lightning surges, these surges may cause considerable damage.

→ Usually, it strike the transmission lines if that case it leads to insulat^{n} breakdown.

Protective Devices → lightning Arrestors

Lighting Discharge Waveform

! Represents the characteristics of lighting discharge



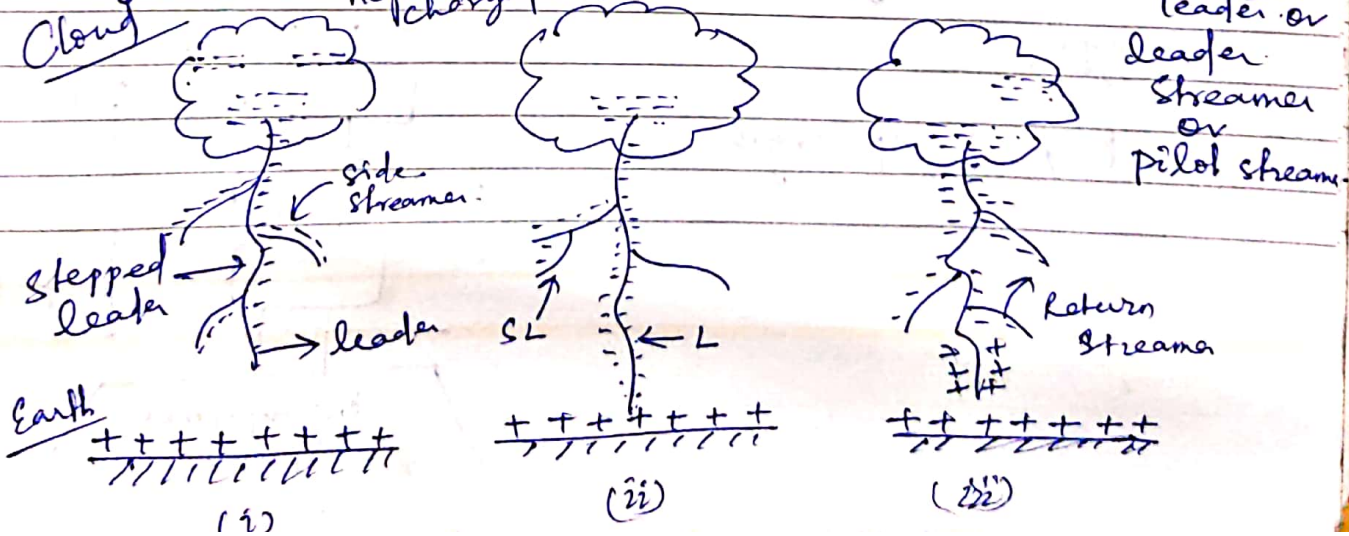
$\frac{t_1}{t_2} = \frac{1}{50\,\mu s}$

Rise time / fall time → (1 to 5 μs)

Mechanism of lighting discharge

Lighting (huge spark) :- electrical discharge that occurs betⁿ the cloud & earth, betⁿ clouds or betⁿ the charge centres of the same cloud.

→ If the potential gradient is such as manner it reach 5 kv/cm to 10 kv/cm & when comparing with the atmospheric air, the potential exceeds. lightning going to occur.



Spark leader or leader streamer or pilot streams.

Leader Streamer / Pilot Streamer

$I < 100\ A$

Velocity → 0.05% of velocity of light

luminous velocity → low

Single flash → 0.00005s – 0.5s → 87% NC, 13% PC } 100 L stroke per sec

Lightning current → 10 kA to 90 kA.

Types of lightning stroke

- Direct stroke
- Indirect stroke

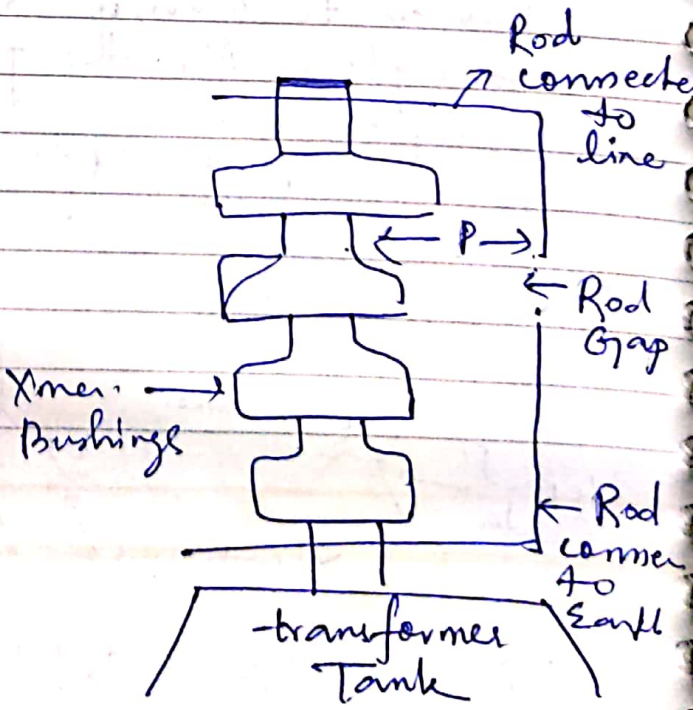
Types of Lightning Arrestors

Lightning Arrester is a device used for protection of power system against the high voltage surge which is connected between the line and earth to divert the incoming high voltage wave to the earth. It is also called as Surge diverter.

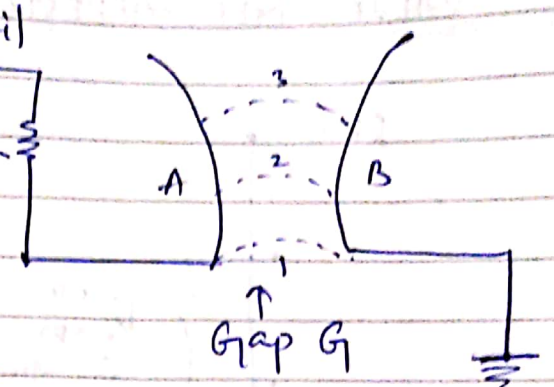
Types → Rod Gap type
→ Horn Gap type
→ Valve type

Rod-Type

$P \not< \frac{1}{3}$ gap length



Horn Gap Arrester



R → limit the follow on current to a smaller value

follow on current.

After the surge is over, even the current is flowing through which need to be interrupted. So that this current doesn't reach the apparatus and cause transients in it.

(L) → At normal freq, it allows small reactance
→ At transient freq, it allows high reactance (The coil will not allows any transients to pass to the apparatus.

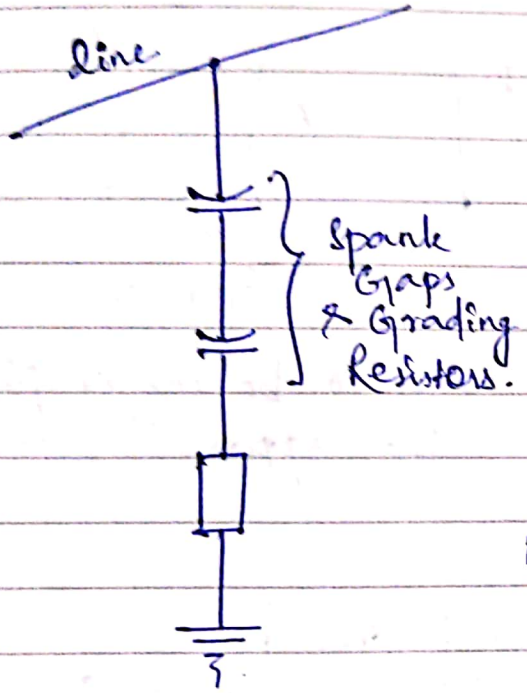
Normal Cond":- Gap → non-conducting
Over Voltage Cond" → Spark arises bet the gap

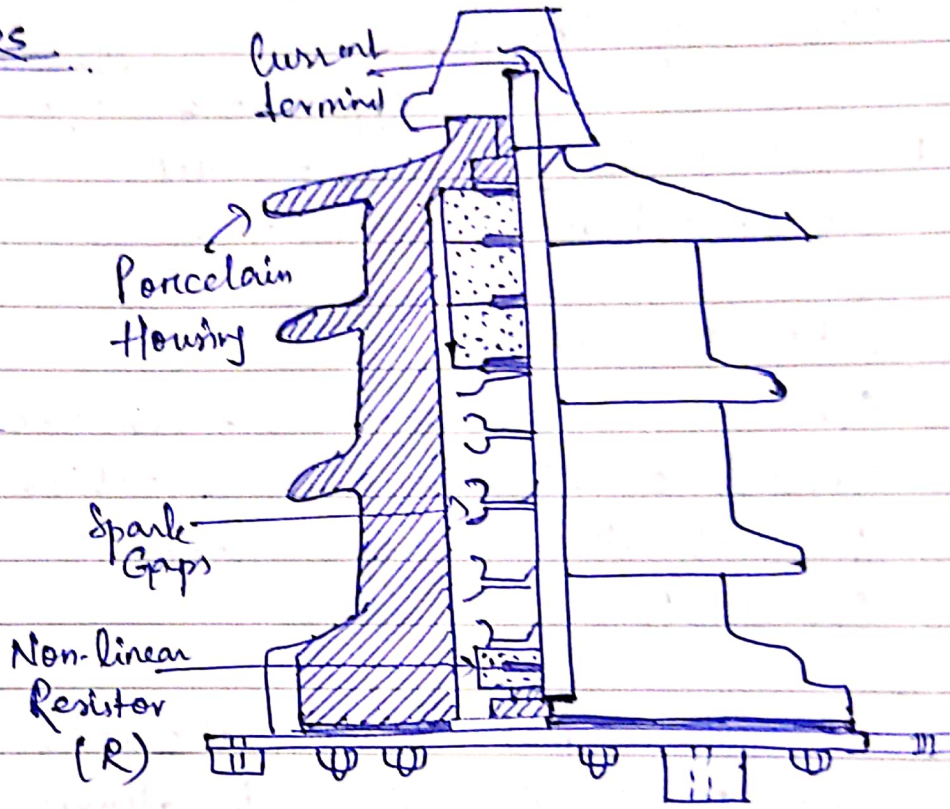
Adv :- ① Self clearing
② 'R' → to limit follow on current.

Disadv ① Bridging of Gap
② Setting change (due to corrosion)
③ It operates with time lag of 3 sec.

→ Auxiliary protect".

VALVE TYPE ARRESTERS





High Voltages

→ protectⁿ to Xmers & Cables