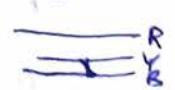
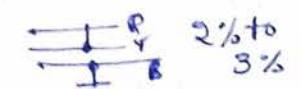


## Introduction to Switchgear

- Electrical equipment or electrical machine must satisfy two main requirements.
- (i) They must be able to operate continuously under normal service condition.
  - (ii) They must be withstand for short time in over current & over voltage condition.
- The two condition for normal or safe operation is:-
- (i) Normal/reated current  $\geq$  Actual load current
  - (ii) Rated voltage  $\geq$  Working voltage of the piece of equipment.
- Magnitude of current in a electrical equipment depend upon the value of voltage & the effective impedance. And lesser the effective impedance greater the short ckt current in faulty section.
- Short ckt current is harmful due to 2 reason.
- (i) During short ckt time, when the heavy current flow through the ckt, it will overheat the equipment.
  - (ii) It produces electro dynamic interaction which may destroy or damage the instrument.
- \* Most of the frequent short ckt faults on overhead lines are
- i) 1-φ to ground (L-G)  $\rightarrow$    $\rightarrow 70\%$
  - ii) phase to phase (L-L)  $\rightarrow$    $\rightarrow 15\%$
  - iii) Two phase to ground (L-L-G)  $\rightarrow$    $\rightarrow 10\%$
  - iv) phase to phase & 3rd phase to ground  $\rightarrow$    $2\% \text{ to } 3\%$
  - v) All the 3-phases to ground (L-L-L-G)  $\rightarrow$    $2\% \text{ to } 3\%$
  - vi) All the 3-φ shorted  $\rightarrow$    $2\% \text{ to } 3\%$

## Faults in power system

following reasons.

- i) Break down may occur at normal voltage due to following reasons.
    - Break down may occur at normal voltage due to
      - The deterioration or ageing of insulation.
      - Blowing of heavy rains, tree falling across the line,
      - Vehicles colliding with towers & poles etc.
  - ii) Break down may occur at abnormal voltage due to switching surges & lightning strokes.
- So it is necessary to protect the power system from harm during fault condition & to maintain continuity of supply. And this is achieved by a device called as Switch gear.

In other words the apparatus used for switching, controlling & protecting the electrical circuit & equipment is known as Switch gear.

### Essential Features of Switchgear :-

- i) Complete Reliability :-
- Reliability means that the protection system must be function correctly at all times and under all condition of fault & abnormal condition of power system.
- Simplicity is most close to reliability, because simple protection scheme is less will be the no. of relays.

### Absolutely certain discrimination :-

When fault occurs on any section of the power system, the switch gear must able to discriminate between the faulty section & the healthy section. It should isolate

the faulty section from the system without affecting the healthy section. This will ensure continuity of supply.

(iii) Quick operation :-

- When fault occurs on any part of the power system, the switchgear must operate quickly so that no damage is done to generators, transformers and other equipment by the short circuit currents.
- If fault is not cleared by switchgear quickly, it is likely to spread onto healthy parts, thus endangering complete shut down of the system.

(iv) provision for manual control :-

A switchgear must have provision for manual control. In case the electrical control fails, the necessary operation can be carried out through manual control.

(v) provision for instruments :-

There must be provision for instruments which may be required. These may be in the form of ammeters or voltmeter on the unit itself or the necessary current and voltage transformers for connecting to the main switch board or a separate instrument panel.

## Switchgear Equipment :-

Switchgear covers a wide range of equipment connected with switching & interrupting currents under both normal & abnormal conditions. It includes :-

- Switches
- Fuses
- Circuit breakers
- Relays & other equipment.

### ① Switches :-

A switch is a device which is used to open or close an electrical circuit in convenient way. It can be used under full-load or no-load conditions but it cannot interrupt the faulty currents.

When the contacts of a switch are opened, an arc is produced in the air bet<sup>n</sup> the contacts. This is particularly true for cuts of high voltage & large current capacity. The switches may be classified into air switches, oil switches.

② Fuses :- A fuse is a short piece of wire or thin strip which melts when excessive current flows through it for sufficient time. It is inserted in series with the circuit to be protected.

### ③ Circuit Breakers :-

A circuit breaker is an equipment which can open or close a cut under all conditions such as no-load, full-load and fault conditions.

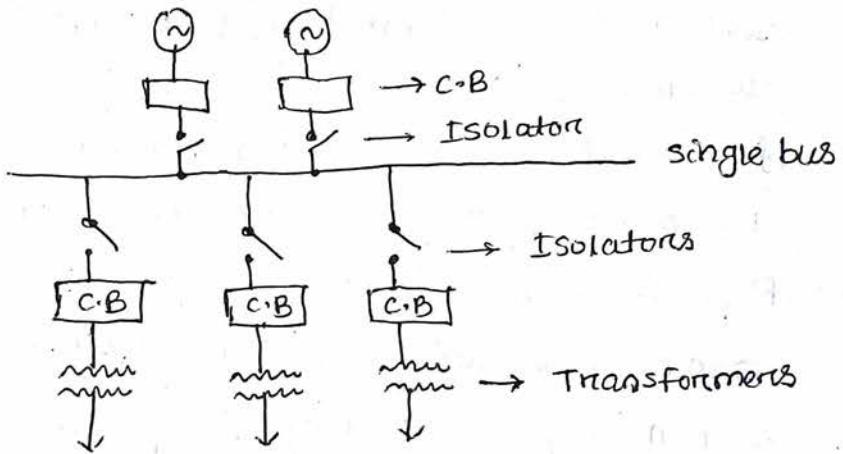
④ Relays :- A relay is a device which detects the fault & supplies information to the breaker for circuit interruption.

### Bus-Bar Arrangements :-

- When a number of generators or feeders operating at the same voltage have to be directly connected electrically bus-bars are used as the common electrical component.
- Bus-bars are copper rods on thin walled tubes & operate at constant voltage.

① Single Bus-bar System : -

- The single bus-bar system has the simplest design and is used for power stations. It is also used in small outdoor station having relatively few outgoing or incoming feeders and lines.
- The generators, outgoing lines & transformer are connected to the bus-bar.
- Each generator & feeder is controlled by a circuit-breaker.
- The isolators permit to isolate generators, feeders and circuit breakers from the bus-bar for maintenance.



Advantages : - → Low initial cost.

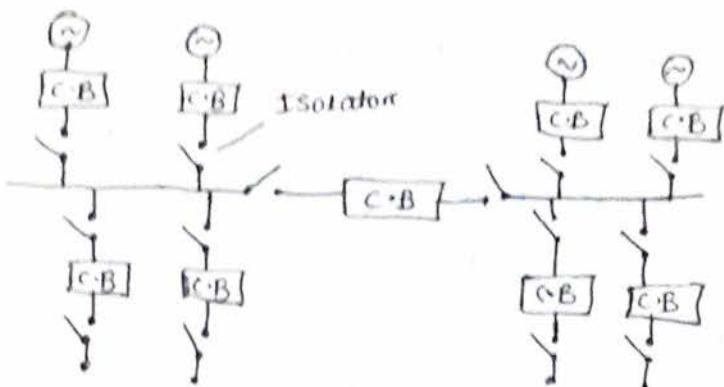
→ Less maintenance & simple operation.

Disadvantages : - → The bus bar cannot be cleaned, repaired or tested without de-energising the whole system. → If a fault occurs on the bus-bar itself there is a complete interruption of supply.

- ② Single bus-bar system with sectionalisation : -
- In large generating stations where several units are installed, it is a common practice to sectionalise the bus so that fault on any section of the

bus-bar will not cause complete shutdown.

- Fig. shows the bus-bar divided into 2 sections connected by a circuit breaker & isolators.



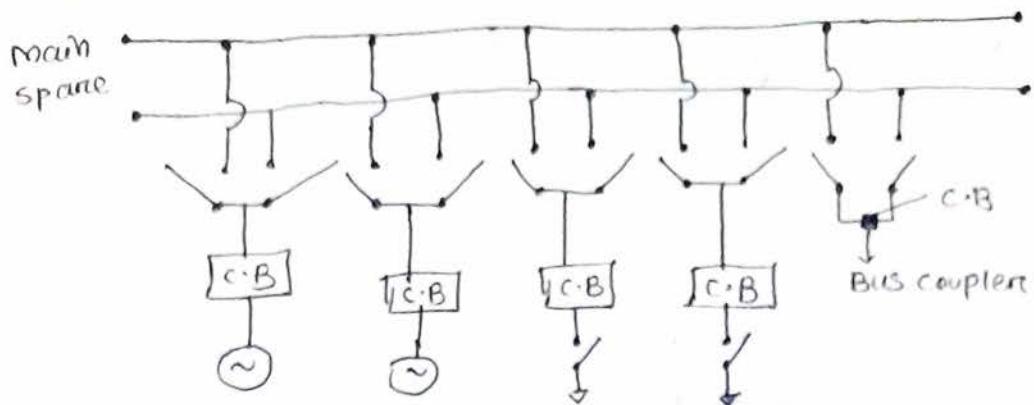
Advantages :-

- If a fault occurs on any section of the bus-bar, the section can be isolated without affecting the supply to other sections.
- If a fault occurs on any feeder, the fault current is much lower than with unsectionalised bus-bar.
- Repairs & maintenance of any section of the bus-bar can be carried out by de-energizing that section only, eliminating the possibility of complete shut down.

### ③ Duplicate bus-bar System :-

- In large stations, it is important that breakdowns & maintenance should interfere as little as possible with continuity of supply.
- In order to achieve this objective, duplicate bus-bar system is used in important stations.
- Such a system consists of two bus-bars, a main bus-bar and a spare bus-bar.

→ Each generator & feeder may be connected to either bus-bar with the help of bus coupler which consists of a ckt breaker and isolators.



Advantages :-

- If repair & maintenance is to be carried on the main bus, the supply need not be interrupted as the entire load can be transferred to the spare bus.
- If a fault occurs on the bus-bar, the continuity of supply to the ckt can be maintained by transferring it to the other bus-bar.

Switchgear Accommodation :-

Depending upon the voltage to be handled, switchgear may be classified into i) outdoor type & ii) indoor type

i) out-door type :-

For voltages beyond 66 KV, switchgear equipment is installed outdoor. It is because for such voltages the clearances between conductors and the space required for switches, ckt breakers, transformers and other equipment become so great that it is not economical to install all such equipment <sup>below</sup> indoor.

ii) Indoor type :- For voltages ~~below~~ 66 KV,

switchgear is generally installed indoor because of economic considerations.

Sym → in the case of a fault the protective device will open the circuit breakers at the nearest location to the place of origin.

### Short Circuit :-

When ever a fault occurs on a network such that a large current flows in one or more phases, a short circuit is said to have occurred.

### Short - Circuit Currents :-

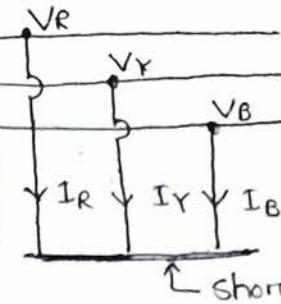
Most of the failures on the power system lead to short-cut fault & cause heavy current to flow in the system. The calculation of these short-cut currents are important for following reasons:-

- i) A short-cut on the power system is cleared by a circuit breaker or a fuse. It is necessary to know the maximum possible values of short-cut current so that switchgear of suitable rating may be installed to interrupt them.
- ii) The magnitude of short-cut current determines the setting & sometimes the types & location of protective system.
- iii) the magnitude of short-cut current determines the size of the protective reactors which must be connected in the system so that cut breakers is able to withstand the fault current.

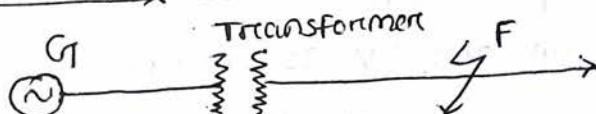
## Symmetrical Fault Calculations

### Symmetrical Faults on 3- $\phi$ System :-

- The fault on the power system which gives rise to symmetrical currents (i.e equal fault currents in the lines with  $120^\circ$  displacement) is called a symmetrical fault.
- The symmetrical fault occurs when all the 3 conductors of a 3- $\phi$  line are brought together simultaneously into a short cut condition as shown in fig.
- This type of fault gives rise to symmetrical currents i.e equal fault currents with  $120^\circ$  displacement.
- Thus referring to fig. fault currents  $I_R$ ,  $I_Y$  &  $I_B$  will be equal in magnitude with  $120^\circ$  displacement among them.
- Because of balanced nature of fault, only one phase need be considered in calculations since condition in the other two phases will also be similar.



### Limitation of Fault current :-



- When a short circuit occurs at any point in a system, the short-cut current is limited by the impedance of the system upto the point of fault.
- Thus referring to fig., if a fault occurs on the feeder at point F, then the short cut current from the generating station will have a value limited by the impedance of generator & transformer and the impedance of the line between the generator and the point of fault.
- This shows that the knowledge of the impedances

of various equipment and circuits in the line of the system is very important for the determination of short-circuit currents.

- In many situations, the impedances limiting the fault current are largely reactive, such as transformers, reactors & generators.
- Cables & lines are mostly resistive but where the total reactance in calculations exceeds 3 times the resistance, the latter is usually neglected.
- The error introduced by this assumption will not exceed 5%.

### Percentage Reactance :-

It is the percentage of the total phase-voltage dropped in the circuit when full-load current is flowing.

$$\text{i.e. } \% X = \frac{I \times}{V} \times 100 \quad (1)$$

where  $I$  = full-load current

$V$  = phase voltage

$X$  = reactance in ohms per phase

Alternatively percentage reactance ( $\% X$ ) can also be expressed in terms of KVA and KV as under

$$\% X = \frac{(KVA)X}{10(KV)^2} \quad (2)$$

where  $X$  is the reactance in ohms.

If  $X$  is the only reactance element in the cut, then short-circuit current is given by :-

$$I_{sc} = V/X = I \times \left( \frac{100}{\% X} \right)$$

### Base KVA :-

Generally the various equipments used in the power system have different KVA ratings. Therefore it is

necessary to find the percentage reactances of all the elements on a common kVA rating. This common kVA rating is known as base kVA.

$$\% \text{ reactance at base kVA} = \frac{\text{Base kVA}}{\text{Rated kVA}} \times \% \text{ reactance at rated kVA}$$

### Short-circuit kVA :-

The product of normal system voltage & short-circuit current at the point of fault expressed in kVA is known as short-circuit kVA.

Let  $V$  = normal phase voltage in volts

$I$  = full-load current in amperes at base kVA.

$\% X$  = percentage reactance of the system on base kVA upto the fault point.

$$\text{short-circuit current } I_{sc} = I (100/\% X)$$

$$\text{Short-circuit kVA for 3-Ø cut} = \frac{3VI_{sc}}{1000}$$

$$= \frac{3VI}{1000} \times \frac{100}{\% X}$$

$$= \text{Base kVA} \times 100/\% X$$

### Location of Reactors :-

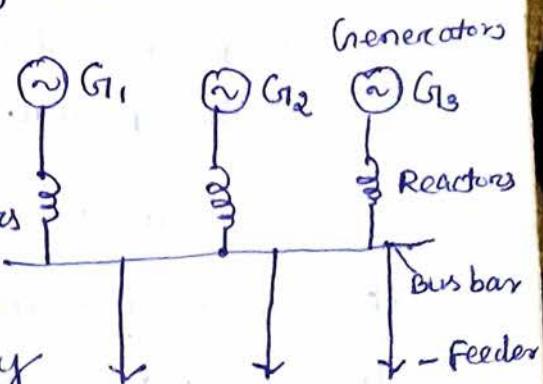
#### i) Generators reactors :-

When the reactors are connected in series with each generator, they are known as generators reactors.

#### Dis-advantages :-

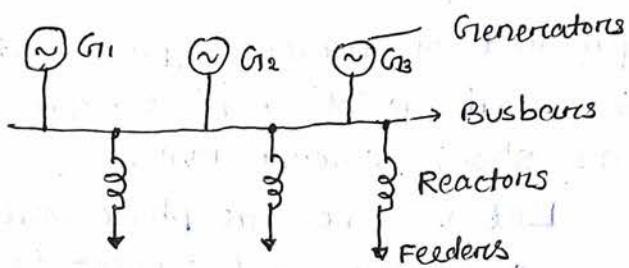
→ There is a constant voltage drop & power loss in the reactors even during normal operation.

→ If a fault occurs on any feeder, the continuity of supply to other is likely to be affected.



## 2) Feeder reactors :-

When the reactors are connected in series with each feeder, they are known as feeder reactors. Since most of short-circuits occur on feeders, a large number of reactors are used for such circuits.



### Advantages :-

- If a fault occurs on any feeder, the voltage drop in its reactor will not affect the bus-bars voltage so that there is a little tendency for the generator to lose synchronism.
- The fault on a feeder will not affect other feeders and consequently the effects of fault are localized.

### Dis-advantages :-

- There is a constant power loss & voltage drop in the reactors even during normal operation.
- If the number of generators is increased, the size of feeder reactors will have to be increased, to keep the short-cut currents within the ratings of the feeder circuit breakers.

## 3) Bus-bar reactors :-

The above two methods of locating reactors suffer from the dis-advantage that there is considerable voltage drop & power loss in the reactors even during normal operation. This advantage can be overcome by locating the reactors in the bus-bars.

There are 2 methods for this purpose namely

- i) Ring system &
- ii) Tie-bar system.

i) Ring system :-

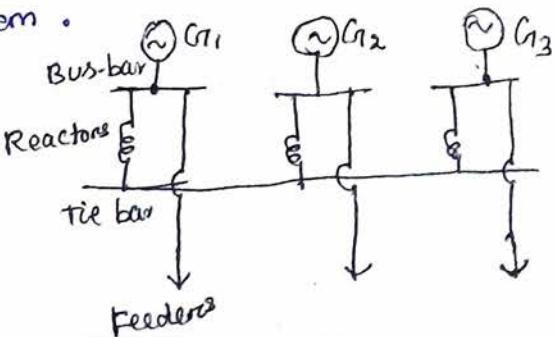
- In this system, bus-bar is divided into sections and these sections are connected through reactors as shown in fig.

→ one feeder is fed from one generator only. Under normal operating conditions, each generator will supply its own section of the load & very little power will be fed by other generators. This results in low power loss & voltage drop in the reactors.

→ However the principal advantage of the system is that if a fault occurs on any feeder, only one generator (to which the particular feeder is connected) mainly feeds the fault current while the current fed from other generators is small due to the presence of reactors. Therefore only that section of bus-bar is affected to which the feeder is connected, the other section being able to continue in normal operation.

ii) Tie-bar system :-

- Fig. shows the tie-bar system. Comparing the ring system with tie-bar system, it is clear that in the tie-bar system, there are effectively two reactors in series between sections so that reactors must have approximately half the reactance of those used in a comparable ring system.



### Dis-advantages :-

This system has the dis-advantage that it requires an additional bus-bar i.e. the tee-bar.

Reactors :- In order to limit the short-cut currents to a value which the circuit breakers can handle, additional reactances known as reactors are connected in series with the system at suitable points.

### Steps for Symmetrical fault Calculations :-

- Draw a single line diagram of the complete network indicating the rating, voltage & percentage reactance of each element of the network.
- Choose a numerically convenient value of base KVA and convert all percentage reactances to this base value.
- Corresponding to the single line diagram of the network, draw the reactance diagram showing one phase of the system & the neutral. Indicate the % reactances on the base KVA in the reactance diagram. The transformers in the system should be represented by a resistance in series.
- Find the total % reactance of the network upto the point of fault. Let it be  $X\%$ .
- Find the full-load current corresponding to the selected base KVA and the normal system voltage at the fault point. Let it be  $I'$ .
- Short-cut current  $I_{sc} = I' \times \frac{100}{X\%}$

$$\text{Short-cut KVA} = \text{Base KVA} \times \frac{100}{X\%}$$

## Problems

- Q) Fig. shows the single line diagram of a 3-Ø system. The percentage reactance of each alternator is based on its own capacity. Find the short-cut current that will flow into a complete 3-Ø short-cut at F.

Ans: Let the base kVA be 35000 kVA

% Reactance of alternator A at the base kVA

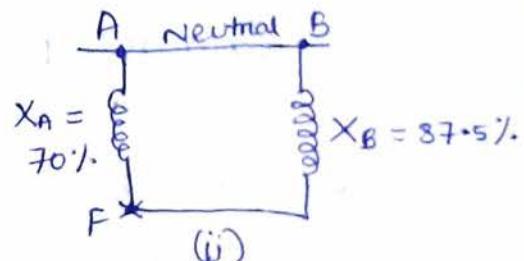
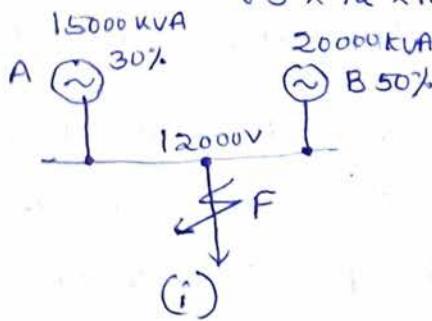
$$\% X_A = \frac{35000}{15000} \times 30 = 70\%$$

% Reactance of alternator B at the base kVA

$$\% X_B = \frac{35000}{20000} \times 50 = 87.5\%$$

Line current corresponding to 35000 kVA at 12 kV

$$I = \frac{35000 \times 10^3}{\sqrt{3} \times 12 \times 10^3} = 1684 \text{ A}$$



Total % Reactance from generators neutral up to fault point  $\% X = X_A + X_B$

$$= \frac{X_A X_B}{X_A + X_B}$$

$$= \frac{70 \times 87.5}{70 + 87.5} = 38.89\%$$

$$\begin{aligned} \text{Short cut current } I_{sc} &= I \times \frac{100}{\% X} \\ &= 1684 \times \frac{100}{38.89} \\ &= \underline{\underline{4330 \text{ A}}} \end{aligned}$$

② A 3-Ø, 20 mVA, 10 kV alternator has internal reactance of 5% & negligible resistance. Find the external reactance per phase to be connected in series with the alternator so that steady current on short circuit does not exceed 8 times the full load current.

Ans:- Full load current  $I = \frac{20 \times 10^6}{\sqrt{3} \times 10 \times 10^3}$   
 $= 1154.7 \text{ A}$

Voltage per phase  $V = \frac{10 \times 10^3}{\sqrt{3}} = \frac{10000}{\sqrt{3}} \text{ Volts}$

As the short-circuit current is to be 8 times the full-load current,

∴ Total percentage reactance required

$$= \frac{\text{Full-load current}}{\text{Short-circuit current}} \times 100$$

$$= (1/8) \times 100 = 12.5\%$$

∴ External percentage reactance required

$$= 12.5 - 5 = 7.5\%$$

Let  $X_{-2}$  be the per phase external reactance required

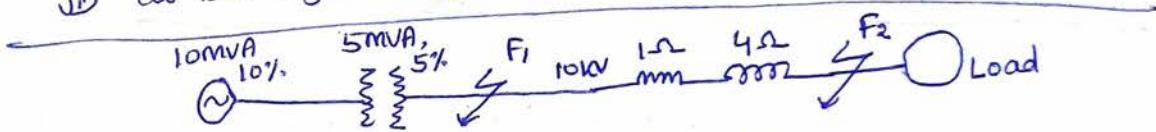
Now %age reactance  $= \frac{IX}{V} \times 100$

$$\Rightarrow 7.5 = \frac{1154.7 \times X}{\frac{10000}{\sqrt{3}}} \times 100$$

$$X = \frac{7.5 \times 10000}{\sqrt{3} \times 100 \times 1154.7}$$

$$= \underline{\underline{0.375 \Omega}}$$

- 3) A 3-phase transmission line operating at 10kV and having a resistance of  $1\Omega$  and reactance of  $4\Omega$  is connected to the generating station bus-bars through 5MVA step-up transformer having a reactance of 5%. The bus-bars are supplied by a 10MVA alternator having 10% reactance. Calculate the short-circuit KVA fed to symmetrical fault between phases if it occurs i) at the load end of transmission line ii) at the high voltage terminals of the transformer.



SOLN:- Let 10000 KVA be the base KVA

% reactance of alternator on base KVA

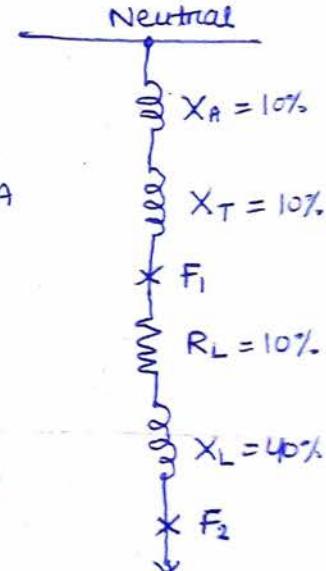
$$\% X_A = \frac{10000}{10 \times 10^3} \times 10 = 10\%$$

% reactance of transformer on base KVA

$$\% X_T = \frac{10000}{5 \times 10^3} \times 5 = 10\%$$

% reactance of transmission line is

$$\begin{aligned}\% X_L &= \frac{(KVA) \times \text{reactance in } \Omega}{10 (\text{kV})^2} \\ &= \frac{10000 \times 4}{10 \times (10)^2} = 40\%\end{aligned}$$



% age resistance of transmission line

$$\% R_L = \frac{10000 \times 1}{10 \times (10)^2} = 10\%$$

i) For a fault at the end of a transmission line (point F<sub>2</sub>)

$$\begin{aligned}\text{Total \% reactance} &= \% X_A + \% X_T + \% X_L \\ &= 10 + 10 + 40 = 60\%\end{aligned}$$

$$\% \text{ resistance} = 10\%$$

$\therefore$  % impedance from generator neutral upto

$$\text{fault point } F_2 = \sqrt{(60)^2 + (10)^2} = 60.83\%$$

$$\therefore \text{short-circuit KVA} = 10000 \times 100 / 60.83 = 16440 \text{ kVA}$$

transformer (point F<sub>1</sub>)

Total % reactance from generator neutral upto  
fault point F<sub>1</sub> = % X<sub>A</sub> + % X<sub>T</sub>

$$= 10 + 10 = 20\%$$

$$\therefore \text{Short-circuit KVA} = 10000 \times 100/20$$
$$= \underline{\underline{50000 \text{ KVA}}}$$

Q) The plant capacity of a 3-φ generating station consists of two 10,000 KVA generators of reactance 12% each and one 5000 KVA generator of reactance 18%. The generators are connected to the station bus-bars from which load is taken through 3 5000 KVA step-up transformers each having a reactance of 5%. Determine the maximum fault MVA which the circuit breakers can handle :-

- i) low voltage side and
- ii) high voltage side may have to deal with.

Let 10000 KVA be the base KVA.

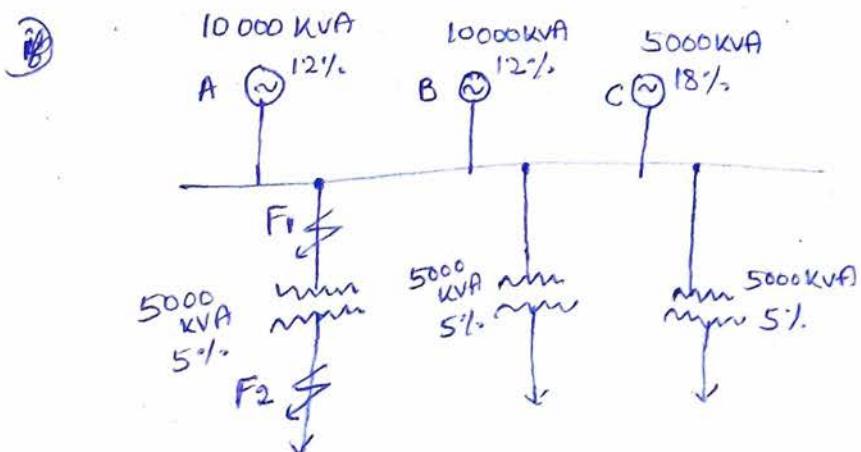
The percentage reactance of generators A, B & C and that of each transformer on the selected base KVA is

$$\% X_A = 12 \times 10000/10000 = 12\%$$

$$\% X_B = 12 \times 10000/10000 = 12\%$$

$$\% X_C = 18 \times 10000/5000 = 36\%$$

$$\% X_T = 5 \times 10000/5000 = 10\%$$



Q)

ii) When the fault occurs on the low voltage side of the transformer (point F<sub>1</sub>), the reactance diagram at the selected base kVA will be as shown in fig.

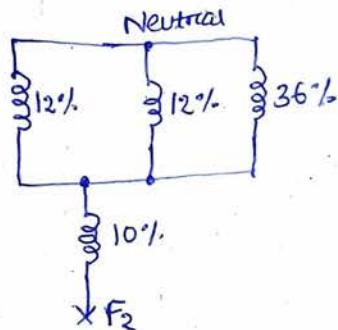
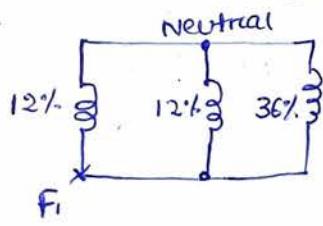
Obviously, total reactance upto the point of fault F<sub>1</sub> is the parallel combination of the reactances of the 3 alternators.

i.e. Total % reactance from generator neutral upto fault point F<sub>1</sub> = % X<sub>A</sub> || % X<sub>B</sub> || % X<sub>C</sub>

$$\begin{aligned} \text{point F}_1 &= \% X_A || \% X_B || \% X_C \\ &= 12\% || 12\% || 36\% \\ &= \frac{6 \times 36}{6 + 36} = 5.14\% \end{aligned}$$

$$\therefore \text{Fault MVA} = 10000 \times \frac{100}{5.14} \times \frac{1}{1000} = 194.5$$

iii) When the fault occurs on the high voltage side of the transformer (point F<sub>2</sub>), the reactance diagram will be as shown in fig.



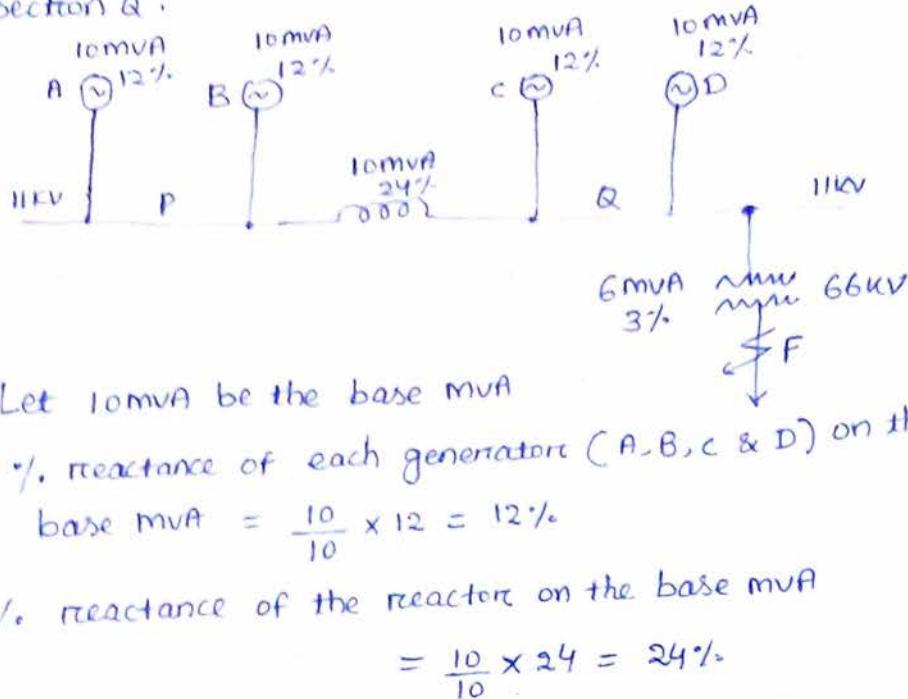
Total % reactance from generator neutral upto fault point F<sub>2</sub> = 5.14 + 10 = 15.14%.

$$\therefore \text{Fault MVA} = 10000 \times \frac{100}{15.14} \times \frac{1}{1000}$$

$$= 66$$

Q.) An 11KV generating station has four identical 3-Ø alternators A, B, C & D each of 10 MVA capacity and 12% reactance. There are two sections of bus-bars P & Q linked by a reactor rated at 10 MVA with 24% reactance. Alternators A & B are connected to bus-bar section P & alternators C & D to bus-bar section Q. From each section, load is taken through a number of 6 MVA, 11KV/66KV step-up transformers, each having a reactance of 3%. Calculate the current fed into fault if a short-circuit occurs on all phases near the high-voltage

terminals of one of the transformers at the bus-bar section 'Q'.



Q: A  
with  
Each  
connec  
to a  
section

Let 10mVA be the base mVA

% reactance of each generator (A, B, C & D) on the base mVA

$$\% \text{ reactance} = \frac{10}{10} \times 12 = 12\%$$

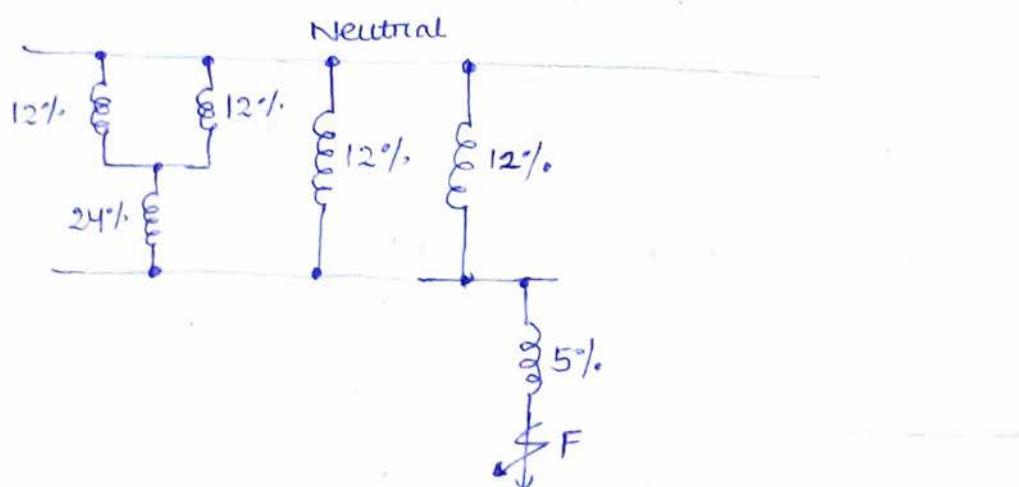
% reactance of the reactor on the base mVA

$$= \frac{10}{10} \times 24 = 24\%$$

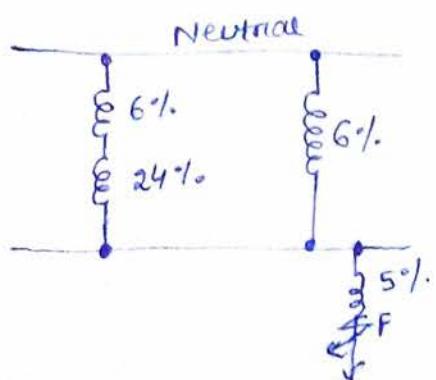
% Reactance of the transformer on the base mVA

$$= \frac{10}{6} \times 3 = 5\%$$

When fault occurs at point F, the reactance diagram on the selected base mVA will be as shown in fig (i)



This further reduces to the cut shown in fig (ii)



% reactance from generators neutral upto fault point F

$$= \frac{30 \times 6}{30 + 6} + 5$$

$$= 5 + 5 = 10\%$$

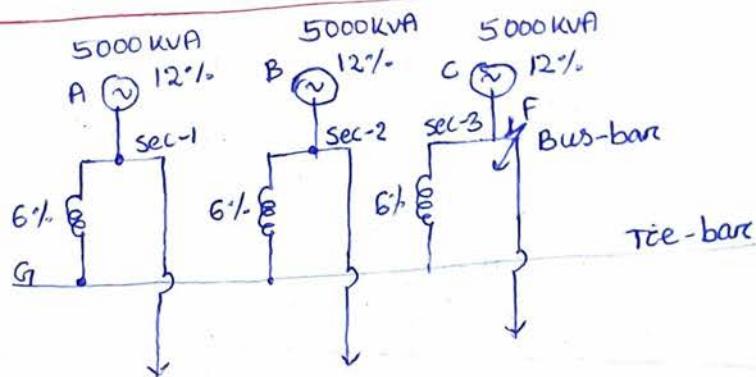
bus-bar

$$\text{Fault MVA} = 10 \times \frac{100}{10} \\ = 10 \text{ MVA}$$

Short-circuit current

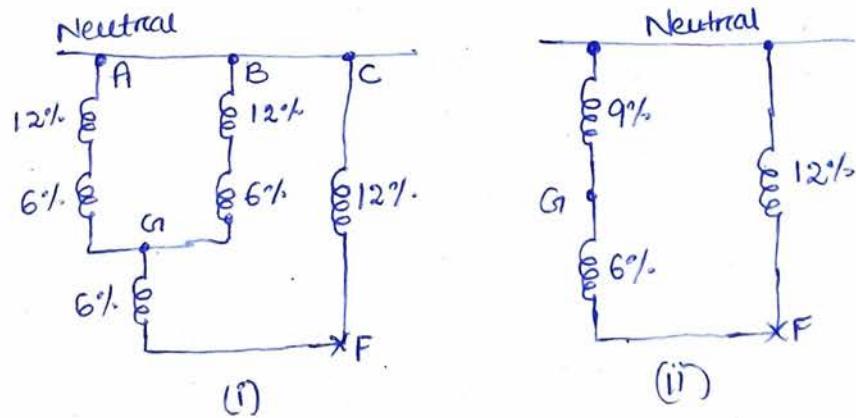
$$I_{SC} = \frac{100 \times 10^6}{\sqrt{3} \times 66000} = 875 \text{ A}$$

**Q:** A generating station has 3 section bus-bars connected with a tie-bar through 6% reactors rated at 5000 kVA. Each generator is of 5000 kVA with 12% reactance and is connected to one section of bus-bars. Find the total steady input to a dead short-circuit between the lines on one of the sections of bus-bars (i) with reactors and (ii) without reactors.



Let 5000 kVA be the base kVA.

(i) with reactors :-



Total % reactance from generator neutral upto fault point F =  $(9\% + 6\%) \parallel 12\%$ .

$$= \frac{15 \times 12}{15 + 12} = 6.67\%$$

$\therefore$  short-circuit input =  $5000 \times 100 / 6.67$   
 $= 74962 \text{ kVA}$   
 $= 74.962 \text{ MVA}$

(ii) without reactors :-

Suppose no reactors are used. Then for a fault on section 3, the total reactance upto the fault point will be a parallel combination of the reactances of the three generators i.e.

Total % reactance upto fault point F

$$= 12\% \parallel 12\% \parallel 12\%$$

$$= 12/3 = 4\%$$

$$\therefore \text{Short-circuit input} = 5000 \times 100/4$$

$$= 125000 \text{ KVA}$$

$$= \underline{\underline{125 \text{ MVA}}}$$

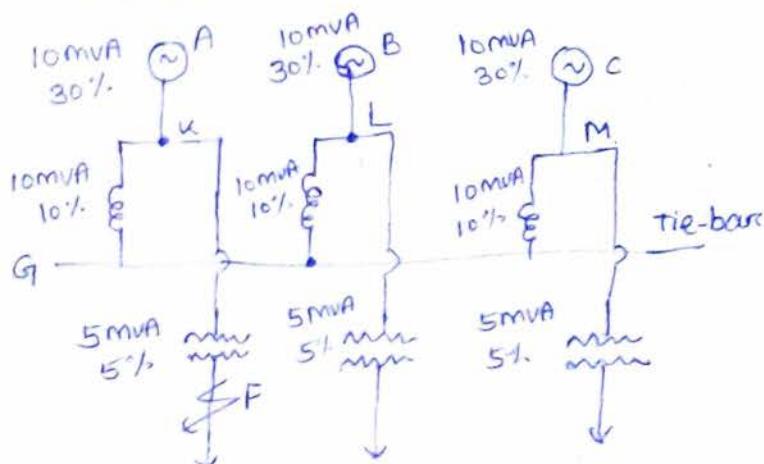
Total

upto f

**Q:** A generating station is laid out as shown in fig.

The ratings & percentage reactances of different elements are as indicated. If a 3-ph short-cut occurs on any feeder near transformer secondary (e.g. point F) Find the short-cut mva fed to the fault.

Soln:- Let us choose 5mva as the base value.



**Q:** The  
reactor  
A, then  
reactor

% age reactance of each generator on the base mva

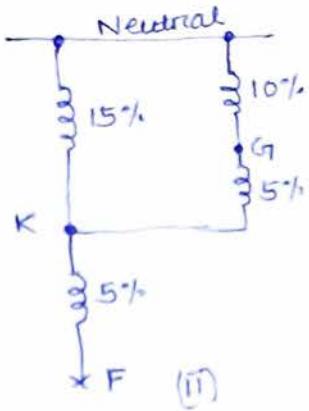
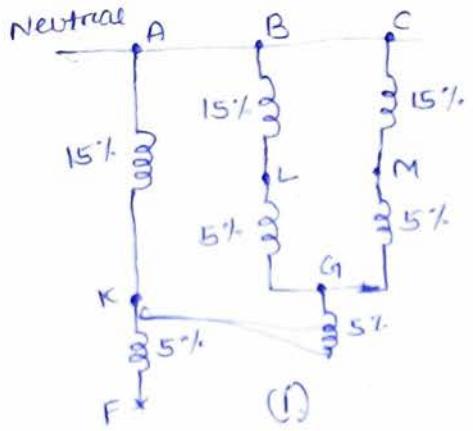
$$= 30 \times 5/10 = 15\%.$$

% age reactance of each reactor on the base mva

$$= 10 \times 5/10 = 5\%.$$

% age reactance of each transformer on the

$$\text{base mva} = 5 \times 5/5 = 5\%.$$



Total % age reactance from generator neutral upto fault point F =  $(10\% + 5\%) \parallel 15\% + 5\%$ .

$$\begin{aligned}
 &= \frac{15 \times 15}{15 + 15} + 5 \\
 &= 7.5 + 5 \\
 &= 12.5\%
 \end{aligned}$$

$$\begin{aligned}
 \text{Short circuit MVA} &= \text{Base MVA} \times \frac{100}{\% \text{ Fault reactance}} \\
 &= 5 \times 100 / 12.5 \\
 &= \underline{\underline{40}}
 \end{aligned}$$

Q: The section bus-bars A & B are linked by a bus-bar reactor rated at 5000 kVA with 10% reactance. On bus-bar A, there are two generators each of 10000 kVA with 10% reactance and on B two generators each of 8000 kVA with

## Fuses

A fuse is a short piece of metal, inserted in the circuit, which melts when excessive current flows through it & thus breaks the circuit.

Advantages :— → It is the cheapest form of protection available. → It requires no maintenance.

- It can break heavy short-circuit currents without noise or smoke.
- The smaller sizes of fuse element impose a current limiting effect under short-circuit conditions.
- The inverse time-current characteristic of a fuse makes it suitable for overcurrent protection.
- The minimum time of operation can be made much shorter than with the circuit breakers.

Dis-advantages :—

- Considerable time is lost in rewinding or replacing a fuse after operation.
- The current-time characteristic of a fuse cannot always be co-related with that of the protected apparatus.

Desirable characteristics of fuse element :—

- i) low melting point e.g:- tin, lead.
- ii) high conductivity e.g:- Silver, copper.
- iii) free from deterioration due to oxidation e.g:- Silver
- iv) low cost e.g:- lead, tin, copper.

Fuse Element Materials :—

- The most commonly used materials for fuse element are lead, tin, copper, zinc & silver.
- For small currents upto 10A, tin or an alloy of tin & lead (lead 37%, tin 63%) is used for making the fuse element.

- for larger currents, copper or silver is employed.
- It is a usual practice to tin the copper to protect it from oxidation.
- zinc is good if a fuse with considerable time-lag is required i.e. one which does not melt very quickly with a small overload.

Important terms :-

### i) Current rating of fuse element :-

- It is the current which the fuse element can normally carry without overheating or melting.
- It depends upon the temp. rise of the contacts of the fuse holder, fuse material & the surroundings of the fuse.

### ii) Fusing current :-

- It is the minimum current at which the fuse element melts and thus disconnects the cut protected by it.
- Its value will be more than the current rating of the fuse element.

For a round wire, the approximate relationship bet<sup>n</sup> fusing current  $I$  and diameter ' $d$ ' of the wire is 
$$I = Kd^{3/2}$$

Where  $K$  is a constant called the fuse constant. Its value depends upon the metal of which the fuse element is made.

The fusing current depends upon the various factors such as :-

- material of fuse element → previous history
- length → diameter → type of enclosure used.
- size & location of terminals

- iii) Fuse
- It is a curve
  - Fusion factor

cut curve

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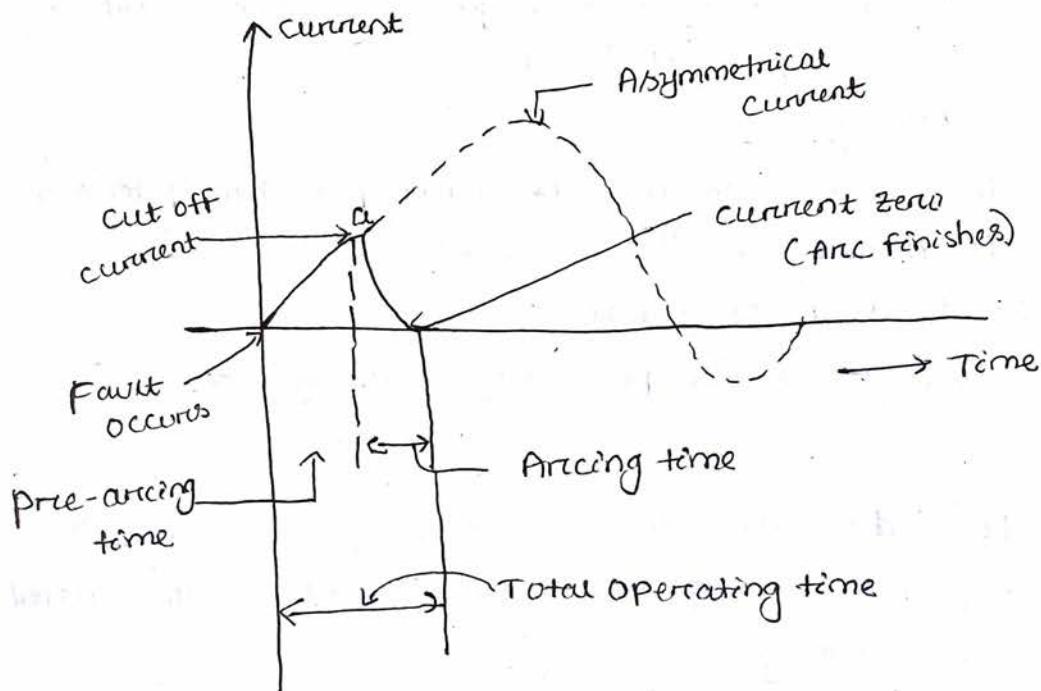
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### iii) Fusing factor :-

- It is the ratio of minimum fusing current to the current rating of the fuse element i.e  
$$\text{Fusing factor} = \frac{\text{minimum fusing current}}{\text{current rating of fuse}}$$
- Its value is always more than 1.
- For a semi-enclosed or rewirable fuse which employs copper wire as the fuse element, the fusing factor is usually 2.



### iv) Prospective Current :-

It is the r.m.s value of the first loop of the fault obtained if the fuse is replaced by an ordinary conductor of negligible resistance.

### v) Cut-off current :-

It is the maximum value of fault current actually reached before the fuse melts.

On the occurrence of a fault, the fault current has a very large first loop due to a fair degree of asymmetry.

is the cut-off current.

The cut-off value depends upon :-

- Current rating of fuse
- Value of prospective current
- Asymmetry of short-circuit current

viii) Pre-arcing time :-

- It is the time between the commencement of fault and the instant when cut off occurs.
- The pre-arcing time is generally small, a typical value being 0.001 second.

vii) Arcing time :-

This is the time bet<sup>n</sup> the end of pre-arcing time & the instant when the arc is extinguished.

viii) Total operating time :-

It is the sum of pre-arcing & arcng times.

ix) Breaking capacity :-

It is the r.m.s value of a.c component of max<sup>m</sup> prospective current that a fuse can deal with at rated service voltage.

## Types of fuses :-

i) Low voltages fuses :-

ii) Semi-enclosed rewirable fuse :-

Rewirable fuse (also known as ket-ket type) is used where low values of fault current are to be interrupted. It consists of i) a base and ii) a fuse carrier. The base is of porcelain & carries the fixed contacts to which the incoming & outgoing phase wires are connected.

The fuse carrier is also of porcelain & holds the fuse element (tinmed copper wire) bet' its terminals. The fuse carrier can be inserted in or taken out of the base when desired.

When a fault occurs, the fuse element is blown out and cut is interrupted. The fuse carrier is taken out & the blown out fuse element is replaced by the new one. The fuse carrier is then re-inserted in the base to restore the supply.

Advantages :- → The detachable fuse carrier permits the replacement of fuse element without any danger of coming in contact with live parts.  
→ Cost of replacement is negligible.

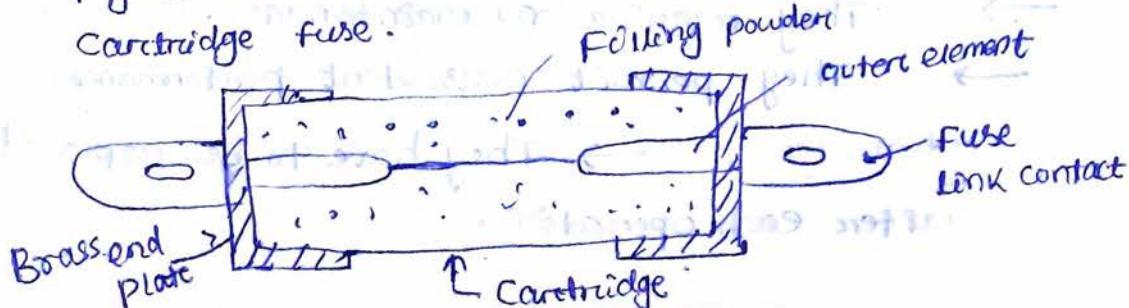
Dis-advantages :- → There is a possibility of renewal by the fuse wire of wrong size or by improper material.

→ This type of fuse has a low-breaking capacity & hence cannot be used in cuts of high fault level.

Use :- Semi-enclosed rewirable fuses are made upto 500A rated current but their breaking capacity is about 4000A. Therefore the use of this type of fuses is limited to domestic & lighting loads.

### ② High-Rupturing capacity (H.R.C) cartridge fuse

- The primary objection of low & uncertain breaking capacity of semi-enclosed rewirable fuses is overcome in H.R.C Cartridge fuse.  
→ Fig. shows the essential parts of a typical H.R.C cartridge fuse.



- It consists of a heat resisting ceramic body having metal end-caps to which is welded a thin current-carrying element.
- The space within the body surrounding the element is completely packed with a filling powder.
- The filling material may be chalk, plaster of paris, quartz or marble dust and acts as an arc quenching and cooling medium.
- Under normal load conditions, the fuse element is at a temp. below its melting point. Therefore it carries the normal current without overheating.
- When a fault occurs, the current increases and the flux element melts before the fault current reaches its first peak.
- The heat produced in the process vapourises the melted silver element.
- The chemical reaction b/w the silver vapour and the filling powder results in the formation of a high resistance substance which helps in quenching the arc.

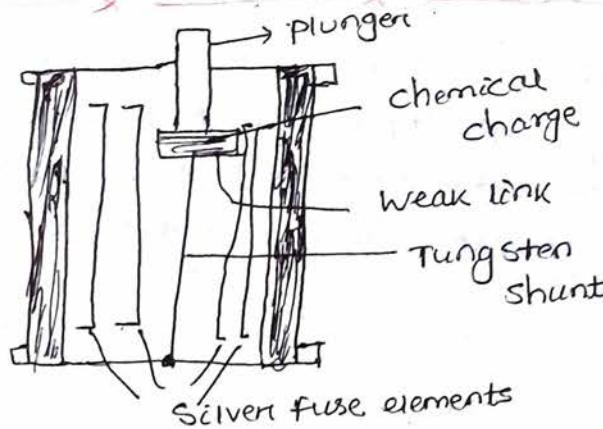
#### Advantages :-

- They are capable of clearing high as well as low fault currents.
- They do not deteriorate with age.
- They have high speed of operation.
- They provide reliable discrimination.
- They require no maintenance.
- They permit consistent performance.

#### Dis-advantages :- → They have to be replaced after each operation.

→ Heat produced by the arc may affect the associated switches.

### ③ H.R.C fuse with tripping device:-



Sometime H.R.C cartridge fuse is provided with a tripping device. When the fuse blows out under fault conditions, the tripping device causes the circuit breaker to operate. Fig. shows the essential parts of a H.R.C fuse with a tripping device. The body of the fuse is of ceramic material with a metallic cap rigidly fixed at each end. (These are connected by a number of silver fuse elements. At one end is a plunger which under fault conditions sets the tripping mechanism of the circuit breaker and causes it to operate. The plunger is electrically connected through a fusible link, chemical charge and a tungsten wire to the other end of the cap as shown.

When a fault occurs, the silver fuse elements are the first to be blown out and then current is transferred to the tungsten wire. The weak link in series with the tungsten wire gets fused & causes the chemical charge to be detonated. This forces the plunger outward to operate the cut breaker. The travel of the plunger is so set that it is not ejected from the fuse body under fault conditions.

In case of a 3- $\phi$  fault on a 3- $\phi$  system, the fuse  
operates the tripping mechanism at circuit breaker  
to open all the 3-phases so that prevents single phase  
to open all the 3-phases so that prevents single phase

Use :- Low voltage fuse fuses may be fitted with a  
breaking capacity of 1600A to 2000A at 400V.  
They are extensively used on low-voltage distribution  
system against over load and short-circuit conditions.

### High voltage fuses :-

#### i) Cartridge type :-

This is similar in general construction to the low  
voltage cartridge type except that special design  
features are incorporated. Some designs employ two  
elements wound on the form of a hexagonal frame  
Corona effects at higher voltages. In such design,  
there are 2 fuse elements in parallel, one of low  
resistance (silver wire) & the other of high resistance  
(tungsten wire).

- Under normal load conditions, the low resistance  
element carries the normal current.
- When a fault occurs, the low resistance element  
is blown out & the high resistance element reduces  
the short-circuit current & finally breaks the cut.

High voltage cartridge fuses are made  
upto 33kV with breaking capacity of about 2700A  
at that voltage. Rating of the order of 200A at 6.6kV  
and 11kV and 50A at 33kV are also available.

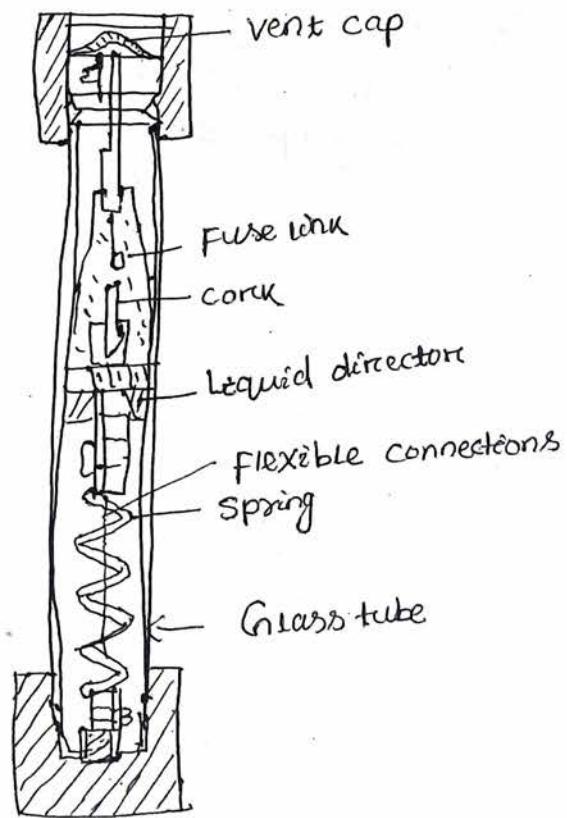
#### ii) Liquid type :-

These fuses are filled with carbon tetrachloride  
and have the widest range of application to low voltage

They may be used for currents upto about 1000A  
current on systems upto 132KV and may have breaking  
capacities of the orders of 6000A.

\* Fig. Shows the essential parts of the liquid fuse.

It consists of a glass tube filled with carbon tetrachloride solution & sealed at both ends with brass caps. The fuse wire is sealed at one end of the tube and the other end of the wire is held by a strong phosphor bronze spiral spring fixed at the other end of the glass tube. When the current exceeds the prescribed limit, the fuse wire is blown out. As the fuse melts, the spring retracts part of it through a baffle (or liquid director) and draws it well into the liquid. The small quantity of gas generated at the point of fusion forces some part of liquid into the passage through baffle and there it effectively extinguishes the arc.



(iii) Metal clad fuses:- Metal clad oil-immersed fuses have been developed with the object of providing a substitute for the oil circuit breakers. Such fuses can be used for very high voltage cuts & operate most satisfactorily under short-circuit conditions approaching

## Difference between a fuse & circuit breaker

SL No.	particular	Fuse	circuit breaker
1.	function	It performs both detection & isolation functions.	It performs detection function only. The detection of fault is made by relay system.
2.	Operation	Inherently completely auto-breaker.	Requires elaborate equipment (gearings) for auto-break action.
3.	Breaking capacity	Small	Very large
4.	operating time	very small ( $0.002$ Sec or so)	Comparatively Large ( $0.1$ to $0.2$ Sec)
5.	Replacement	Requires replacement after every operation.	No replacement after operation.

# CIRCUIT BREAKERS

- A circuit breaker is a piece of equipment which can
- (i) make or break a circuit either manually 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.

## Operating principle : -

A circuit breaker essentially consists of fixed & moving contacts called electrodes. Under normal operating conditions, these contacts remain closed and will not open automatically until & unless the system becomes faulty. Of course, the contacts 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 circuit breaker get energised and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them. The current is thus able to continue until the discharge ceases. The production of arc not only delays the current interruption process but it also generates enormous heat which may cause damage to the system or to the circuit breaker itself.

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

## Arc phenomenon : -

When a short-cut occurs, a heavy current flows through the contacts of the breaker before they are opened by the protective system. At the instant when the contacts begin to separate, the contact area decreases rapidly & large fault current causes increased current density & hence rise in temperature

the heat produced in the medium between contacts usually the medium as oil or air is sufficient to ionise the air or vapourise and ionise the oil. The ionised air or vapour acts as conductor & an arc is struck between the contacts. The p.d between the contacts is quite small and is just sufficient to maintain the arc. The arc provides a low resistance path & consequently the current in the circuit remains uninterrupted so long as the arc persists.

During the arcing period, the current flowing bet<sup>n</sup> the contacts depends upon the arc resistance. The greater the arc resistance, the smaller the current that flows between the contacts. The arc resistance depends upon the following factors:-

- i) Degree of ionisation : - the arc resistance increases with the decrease in the number of ionised particles between the contacts.
- ii) Length of the arc : - the arc resistance increases with the length of the arc, i.e. separation of contacts.
- iii) Cross-Section of arc : - the arc resistance increases with the decrease in area of x-section of the arc.

### Principles of Arc Extinguishment :-

- i) P.d between the contacts
  - ii) ionised particles between contacts
- When the contacts have a small separation, the p.d between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that p.d becomes inadequate to maintain the arc.

However this method is impracticable in high voltage system where a separation of many metres may be required.

- ii) The ionised particles between the contacts tend to maintain the arc. If the arc path is deionised, the arc extinction will be facilitated. This may be achieved by cooling the arc or by bodily removing the ionised particles from the space between the contacts.

### Methods of Arc Extinguishment : -

There are 2 methods of extinguishing the arc in circuit breakers such as : -

- i) High resistance method ii) Low resistance or current zero method.

#### i) 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 and the arc is extinguished. The principal disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in d.c. circuit breakers & low-capacity a.c. circuit breakers.

The resistance of the arc may be increased by :-

##### i) 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 between contacts.

- ii) Cooling the arc : - Cooling helps in the deionisation of the medium between the contacts. This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

### iii) 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. In other words, the resistance of the arc path is increased. The cross-section of the arc can be reduced by letting the arc pass through a narrow opening or by having smaller area of contact.

### iv) Splitting the arc :-

The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthening & cooling. The arc may be split by introducing some conducting plate between the contacts.

### 2) Low resistance arc current zero method :-

This method is employed for arc extinction in a.c. cuts only. In this method, arc resistance is kept low until current is zero, where the arc extinguishes naturally and is prevented from restriking, inspite of the rising voltage across the contacts. All modern high power a.c. cut breakers employ 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 bet<sup>n</sup> the contacts contains ions & 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 bet<sup>n</sup> contacts is built 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 medium near current zero can be achieved by :-

- a) causing the ionised particles in the space between contacts to recombine into neutral molecules.
- b) Sweeping the ionised particles away and replacing them by un-ionised particles.

therefore, the real problem in an arc interrupter is to rapidly de-ionise the medium between contacts as soon as the current becomes zero so that the rising contact voltage or restriking voltage cannot breakdown the space between contacts. The de-ionisation of the medium can be achieved by:-

i) lengthening of the gap :-

The dielectric strength of the medium is proportional to the length of the gap between contacts. Therefore by opening the contacts rapidly, higher dielectric strength of the medium can be achieved.

ii) high pressure :- If the pressure in the vicinity of the arc is increased, the density of the particles constituting the discharge also increases. The increased density of particles causes higher rate of de-ionisation & consequently the dielectric strength of the medium between contacts is increased.

iii) Cooling :- Natural combination of ionised particles takes place more rapidly if they are allowed to cool. Therefore dielectric strength of the medium between the contacts can be increased by cooling the arc.

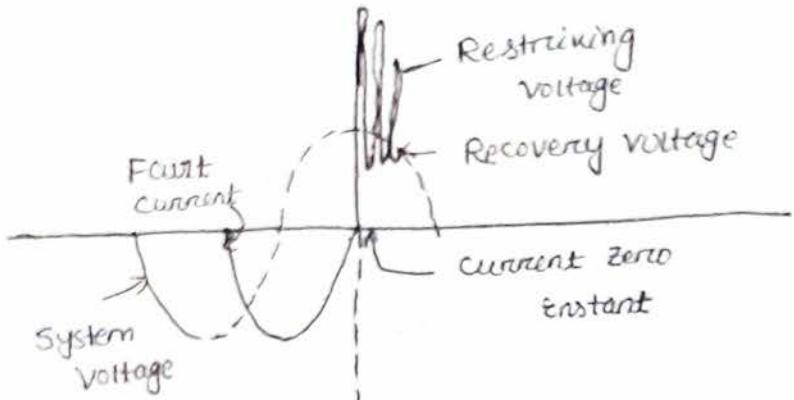
iv) blast effect :- If the ionised particles bet'n the contacts are swept away & replaced by un-ionised particles, the dielectric strength of the medium can be increased considerably. This may be achieved by a gas blast directed along the discharge or by forcing oil into the contact space.

### i) Arc voltage :-

It is the voltage that appears across the contacts of the circuit breaker during the arcing period.

### ii) Restriking voltage :-

It is the transient voltage that appears across the contacts at or near current zero during arcing period.



At current zero, a high-frequency transient voltage appears across the contacts and is caused by the rapid distribution of energy between the magnetic & electric fields associated with the plant and transmission lines of the system. This transient voltage is known as restriking voltage.

The current interruption in the circuit depends upon this voltage. If the restriking voltage rises more rapidly than the dielectric strength of the medium between the contacts, the arc will persist for another half-cycle. On the other hand if the dielectric strength of the medium builds up more rapidly than the restriking voltage, the arc fails to restrike and the current will be interrupted.

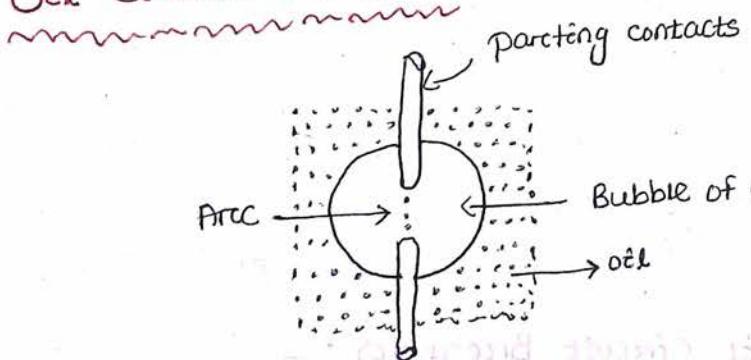
### iii) Recovery voltage :-

It is the normal frequency (50 Hz) RMS voltage that appears across the contacts of the circuit breaker after

final arc extinction. It is approximately equal to the system voltage.

When contacts of circuit breaker are opened, current drops to zero after every half cycle. At some Current Zero, the contacts are separated sufficiently apart & dielectric strength of the medium between the contacts attains a high value due to the removal of ionised particles. At such an instant, the medium between the contacts is strong enough to prevent the breakdown by the restriking voltage. Consequently, the final arc extinction takes place and circuit current is interrupted. Immediately after final current interruption, the voltage that appears across the contacts has a transient part. However, these transient oscillations subside rapidly due to the damping effect of system resistance & normal circuit voltage appears across the contacts. The voltage across the contacts is of normal frequency and is known as recovery voltage.

### Oil Circuit Breakers :-



In such circuit breakers, some insulating oil (e.g. transformer oil) is used as an arc quenching medium. The contacts are opened under oil and an arc is struck between them. The heat of the arc evaporates the surrounding oil and dissociates it into a substantial volume of gaseous hydrogen at high pressure. The hydrogen gas occupies a volume about one thousand times that of the oil decomposed.

The oil is therefore pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region and adjacent portions of the contacts. The arc extinguishes it facilitated mainly by 2 processes. Firstly the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionization of the medium between the contacts. Secondly, the gas sets up turbulence in the oil and forces it onto the space between contacts, thus eliminating the arcing products from the arc path. The result is that arc is extinguished and circuit current interrupted.

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- Advantages :-
- i) It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.
  - ii) It acts as an insulator & permits smaller clearance between live conductors and earthed components.
  - iii) The surrounding oil presents cooling surface in close proximity to the arc.

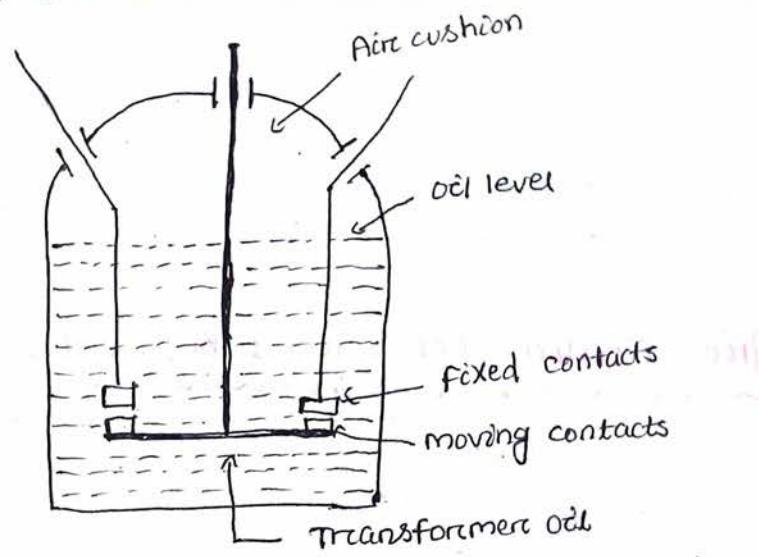
Dis-advantages :-

- i) It is inflammable and there is a risk of a fire.
- ii) It may form an explosive mixture with air.
- iii) The arcing products (e.g Carbon) remain in the oil and its quality deteriorates with successive operations. This necessitates periodic cleaning & replacement of oil.

Plain Break Oil Circuit Breakers :-

A plain-break oil circuit breaker involves the simple process of separating the contacts under the whole of the oil in the tank. There is no special system for arc control other than the increase in length caused by the separation of contacts. The arc extinction occurs when a certain critical gap between the contacts is reached.

The plain-break oil circuit breaker is the earliest type from which all others circuit breakers have developed. It has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather-tight earthed tank containing oil upto a certain level and an air cushion above the oil level. The air cushion provides sufficient room to allow for the reception of the arc gases without the generation of unsafe pressure on the dome of the circuit breaker. It also absorbs the mechanical shock of the upward oil movement. Fig. shows a double break plain oil circuit breaker. It is called a double break because it provides two breaks in series.



Under normal operating conditions, the fixed & moving contacts remain closed and the breaker carries the normal circuit current. When a fault occurs, the moving contacts are pulled down by the protective system and an arc is struck which vapourises the oil mainly into hydrogen gas. The arc extinction is facilitated by the following processes:-

- i) The hydrogen gas bubble generated around the arc cools the arc column and aids the de-ionisation of the medium between the contacts.
- ii) The gas sets up turbulence in the oil & helps in

- iii) As the arc lengthens due to the separating contacts, the dielectric strength of the medium is increased.

### Dis-advantages :-

- i) There is no special control over the arc other than the increase in length by separating the moving contacts. Therefore for successful interruption, long arc length is necessary.
- ii) These breakers have long and inconsistent arcing times.
- iii) These breakers do not permit high speed interruption.

Due to these dis-advantages, plain-break oil circuit breakers are used only for low-voltage applications where high breaking-capabilities are not important. It is a usual practice to use such breakers for low capacity installations for voltages not exceeding 11kV.

### Arc Control Oil Circuit Breakers :-

In case of plain-break oil circuit breakers, there is very little artificial control over the arc. Therefore comparatively long arc length is essential in order that turbulence in the oil caused by the gas may assist in quenching it. However it is necessary and desirable that final arc extinction should occur while the contact gap is still short. For this purpose, some arc control is incorporated and the breakers are then called arc control circuit breakers.

There are 2 types of such breakers namely:-

#### i) Self-blast oil circuit breakers :-

in which arc control is provided by internal means i.e. the arc itself is employed for its own extinction efficiently.

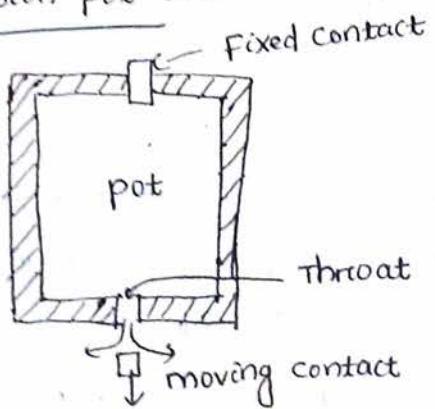
(i) Powered blast oil circuit breakers :-  
In which arc contact is provided by mechanical means external to the circuit breaker.

(ii) Self-blast oil circuit breakers :-

In this type of circuit breaker, the gases produced during arcing are confined to a small volume by the use of an insulating rigid pressure chamber or pot surrounding the contacts. Since the space available for the arc gases is restricted by the chamber, a very high pressure is developed depends upon the value of fault current to be interrupted. As the pressure is generated by the arc itself therefore such breakers are sometimes called self-generated pressure oil circuit breakers.

The pressure chamber is relatively cheap to make and gives reduced final arc extinction gap length and arcing time as against the plain-break oil circuit breaker.

(iii) Plain explosion pot :-



It is a rigid cylinder of insulating material & encloses the fixed & moving contacts. The moving contact is a cylindrical rod passing through a restricted opening (called throat) at the bottom. When a fault occurs, the contacts get separated and an arc is struck between them. The heat of the arc decomposes oil into a gas at very high pressure in the pot. This high pressure forces the oil and gas through and round the arc to extinguish it.

If the fault arc extinction does not take place while the moving contact is still within the pot, it occurs immediately after the moving contact leaves the pot. It is because emergence of the moving contact from the pot is followed by a violent rush of gas and oil through the throat producing rapid extinction.

The principal limitation of this type of pot is that it cannot be used for very low or for very high fault currents. With low fault currents, the pressure developed is small, thereby increasing the arcing time. On the other hand, with high fault currents, the gas is produced so rapidly that explosion pot is liable to burst due to high pressure. For this reason, plain explosion pot operates well on moderate short-circuit currents only where the rate of gas evolution is moderate.

### b) Cross jet explosion pot :-

This type of pot is just a modification of plain explosion pot and is illustrated in fig. It is made of insulating material and has channels on one side which act as arc splitters. The arc splitters help in increasing the arc length, thus facilitating arc extinction. When a fault occurs, the moving contact of the circuit breaker begins to separate. As the moving contact is withdrawn, the arc is initially struck on the top of the pot. The gas generated by the arc exerts pressure on the oil in the ~~back~~ back passage. When the moving contact uncovers the arc splitter ducts, fresh oil is forced across the path. The arc is therefore driven sideways into the "arc splitters" which increase the arc length, causing arc extinction.

The cross-jet explosion pot is quite efficient for interrupting heavy fault currents.

House  
Earth and  
Operation

Back  
passage -

path of  
cool oil

c) Self  
This is  
explosion  
interrupt  
resistor

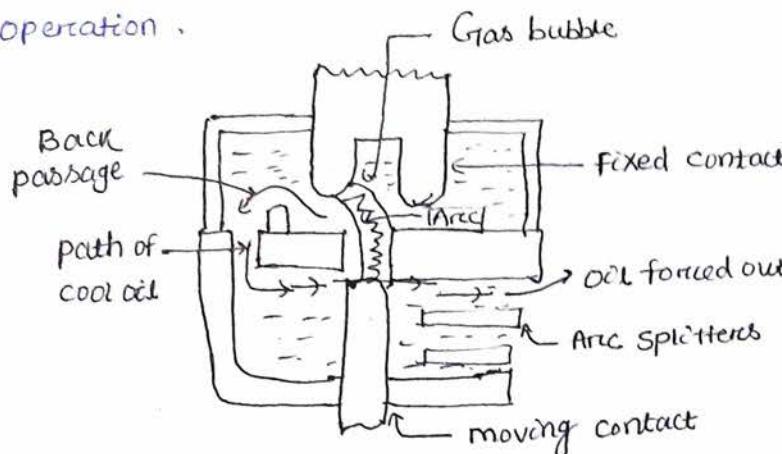
FE  
explosion  
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ducts in  
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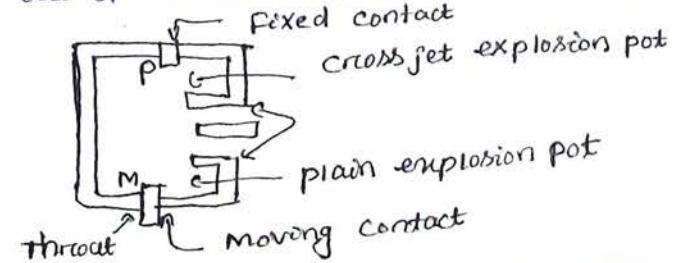
However, for low fault currents, the gas pressure is small and consequently the pot does not give a satisfactory operation.



### c) Self-compensated explosion pot:-

This type of pot is essentially a combination of plain explosion pot and cross-jet explosion pot. Therefore it can interrupt low as well as heavy short circuit currents with reasonable accuracy.

Fig. shows the schematic diagram of self-compensated explosion pot. It consists of two chambers, the upper chamber is the cross-jet explosion pot with two arc splitter ducts while the lower one is the plain explosion pot. When the short-circuit current is heavy, the rate of generation of gas is very high and the device behaves as a cross-jet explosion pot. The arc extinction takes place when the moving contact uncovers the first or second arc splitter duct. However, on low short-circuit currents, the rate of gas generation is small and the tip of the moving contact has the time to reach the lower chamber. During this time, the gas builds up sufficient pressure as there is very little leakage through arc splitter ducts due to the obstruction offered by the arc path & right angle bends. When the moving contact comes out of the throat, the arc is extinguished by plain pot action.



### iii) Forced - blast oil Circuit breakers : -

In the self-blast oil circuit breakers the arc itself generates the necessary pressure to force the oil across the arc path. The major limitation of such breakers is that arcing times tend to be long & inconsistent when operating against currents considerably less than the rated current. It is because the gas generated is much reduced at low value of fault currents. This difficulty is overcome in forced-blast oil circuit breakers in which the necessary pressure is generated by external mechanical means independent of fault currents to be broken.

In a forced-blast oil circuit breaker, oil pressure is created by the piston - cylinder arrangement. The motion of the piston is mechanically coupled to the moving contact. When a fault occurs, the contacts get separated by the protective system and an arc is struck between the contacts. The piston forces a jet of oil towards the contact gap to extinguish the arc. It may be noted that necessary oil pressure produced does not in any way depend upon the fault current to be broken.

### Advantages : -

- Since oil pressure developed is independent of the fault current to be interrupted, the performance at low currents is more consistent than with self-blast oil circuit breakers.
- The quantity of oil required is reduced considerably.

## Low oil Circuit Breakers:-

Construction :- There are 2 compartments separated from each other but both filled with oil. The upper chamber is the circuit breaking chamber while the lower one is the supporting chamber. The two chambers are separated by a partition and oil from one chamber is prevented from mixing with the other chamber. This arrangement permits two advantages. Firstly the circuit breaking chamber requires a small volume of oil which is just enough for arc extinction. Secondly, the amount of oil to be replaced is reduced as the oil in the supporting chamber does not get contaminated by the arc.

### i) Supporting chamber :-

It is a porcelain chamber mounted on a metal chamber. It is filled with oil which is physically separated from the oil in the circuit breaking compartment. The oil inside the supporting chamber and the annular space formed between the porcelain insulation and bakelized paper is employed for insulation purposes only.

### ii) Circuit-breaking chamber :-

It is a porcelain enclosure mounted on the top of the supporting compartment. It is filled with oil and has the following parts :-

- a) Upper & Lower fixed contacts
- b) moving contact
- c) turbulator

The moving contact is hollow and encloses a cylinder which moves down over a fixed piston. The turbulator is an arc control device and has both axial & radial vents. The axial venting ensures the interruption

of low currents whereas residual venting helps in the interruption of heavy currents.

### iii) Top chamber :-

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

Operation :- Under normal operating conditions, the moving contact remains engaged with the upper fixed contact. When a fault occurs, the moving contact is pulled down by the tripping springs and an arc is struck. The arc vaporises the oil and produces gases under high pressure. This action constrains the oil to pass through a central hole in the moving contact and results in forcing series of oil through the respective passages of the turbulators. The process of turbulation is orderly one in which the sections of the arc are successively quenched by the effect of separate streams of oil moving across each section in turn and bearing away its gases.

Advantages :- A low oil circuit breaker has the following advantages over a bulk oil circuit breaker.

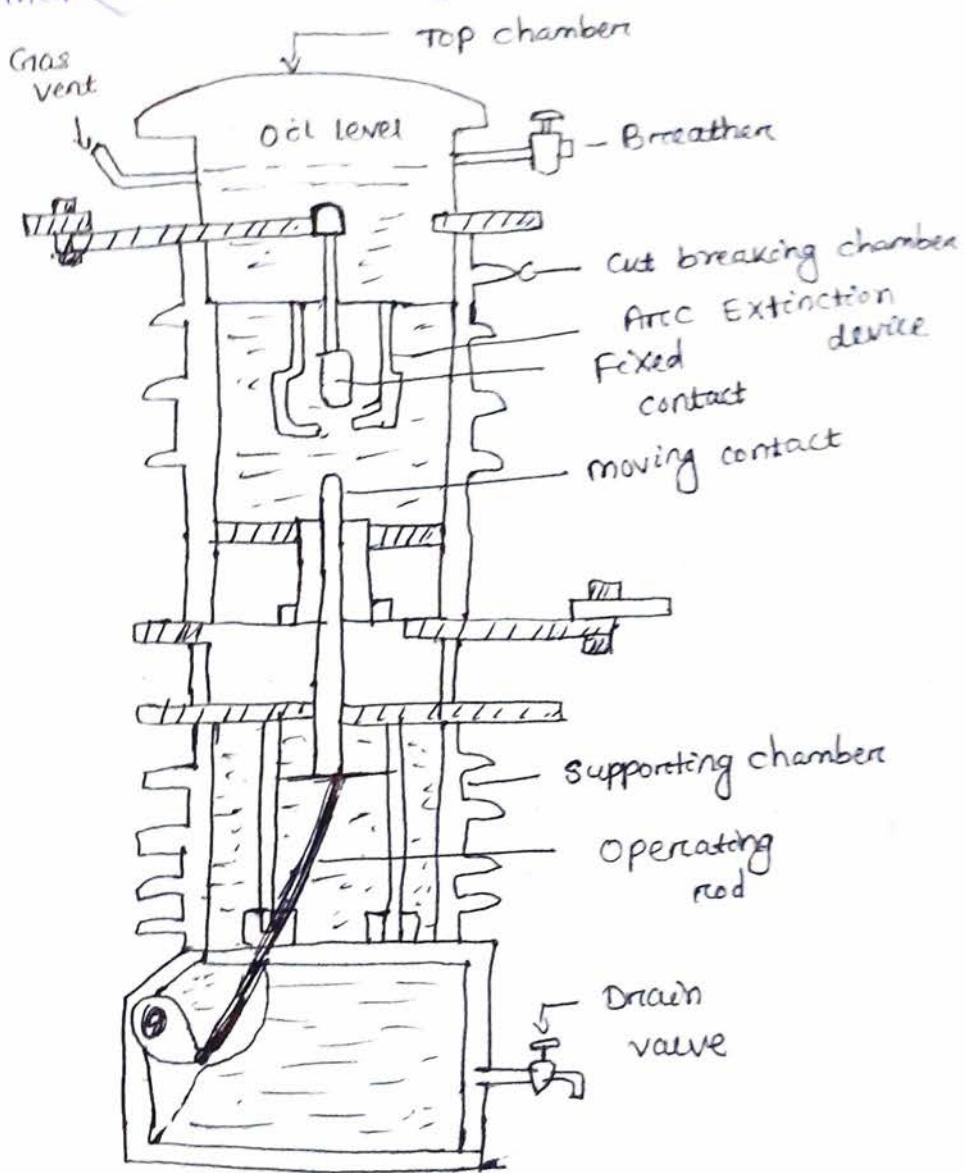
- i) It requires lesser quantity of oil.
- ii) It requires smaller space.
- iii) There is reduced risk of fire.
- iv) Maintenance problems are reduced.

Dis-advantages :- i) Due to smaller quantity of oil, the degree of carbonisation is increased.

- (ii) There is a difficulty of removing the gases from the contact space in time.
- (iii) The dielectric strength of the oil deteriorates rapidly due to high degree of carbonisation.

Maintenance of Oil Circuit Breakers :-

The maintenance of oil circuit breaker is generally concerned with the checking of contacts and



## Maintenance of oil circuit breakers :-

The maintenance of oil circuit breakers is generally concerned with the checking of contacts and dielectric strength of oil. After a circuit breaker has interrupted fault currents a few times or load currents several times its contacts may get burnt by arcing and the oil may lose some of its dielectric strength due to carbonization. This results in the reduced rupturing capacity of the breaker. Therefore it is a good practice to inspect the circuit breaker at regular intervals of 3 or 6 months. During inspection of the breaker, the following points should be kept in view:

- i) check the current carrying parts & arcing contacts. If the burning is severe, the contacts should be replaced.
- ii) check the dielectric strength of the oil. If the oil is badly discoloured, it should be changed or reconditioned. The oil in good condition should withstand 30KV for one minute in a standard oil testing cup with 4mm gap between electrodes.
- iii) check the insulation for possible damage. clean the surface and remove carbon deposits with a strong and dry fabric.
- iv) check the oil level.
- v) check closing and tripping mechanism.

## Air-Blast Circuit Breakers :-

These breakers employ a high pressure air-blast as an arc quenching medium. The contacts are opened in a flow of air-blast established by the opening of blast valve. The air-blast cools the arc & sweeps away the arcing products.

Advantages  
i) The arc is extinguished quickly.  
ii) The contacts are protected from the heat.

iii) The contacts are cleaned automatically.

iv) The arc length is automatically controlled.

v) Due to the high pressure air-blast, the contacts are protected.

## Dis-adv.

i) Arc length is fixed.

ii) It is difficult to trip the breaker.

iii) It is expensive.

iv) It is not suitable for high voltage type.

products to the atmosphere. This rapidly increases the dielectric strength of the medium between contacts & prevents from re-establishing the arc. Consequently, the arc is extinguished and flow of current is interrupted.

- Advantages :-
- i) The risk of fire is eliminated.
  - ii) The arcing products are completely removed by the blast whereas the oil deteriorates with successive operations; the expense of regular oil replacement is avoided.
  - iii) The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small. This reduces the size of the device.
  - iv) The arcing time is very small due to the rapid build up of dielectric strength between contacts. Therefore, the arc energy is only a fraction of that in oil circuit breaker thus resulting in less burning of contacts.
  - v) Due to lesser arc energy, air-blast circuit breakers are very suitable for conditions where frequent operation is required.
  - vi) The energy supplied for arc extinction is obtained from high pressure air and is independent of the current to be interrupted.

Dis-advantages :-

- i) The air has relatively inferior arc extinguishing properties.

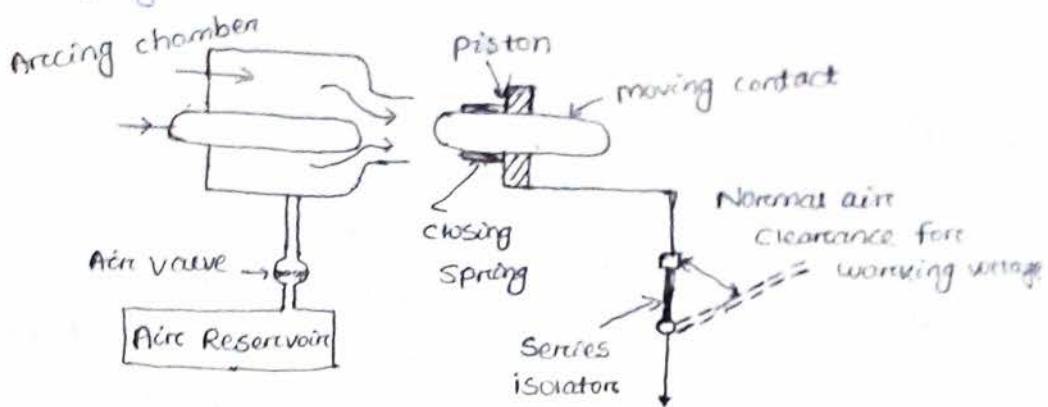
- ii) The air-blast circuit breakers are very sensitive to the variations in the rate of rise of restriking voltage.
- iii) Considerable maintenance is required for the compression plant which supplies the air-blast.

Application :- The air blast circuit breakers are finding wide applications in high voltage installations. Majority of the circuit breakers for voltages beyond 110KV are of this type.

## Types:-

### D) Axial-blast air circuit breakers:-

Fig. shows the essential components of a typical axial-blast air circuit breaker. The fixed and moving contacts are held in the closed position by spring pressure under normal conditions. The air reservoir is connected to the arcing chamber through an air valve. This valve remains closed under normal conditions but opens automatically by the tripping impulse when a fault occurs on the system.

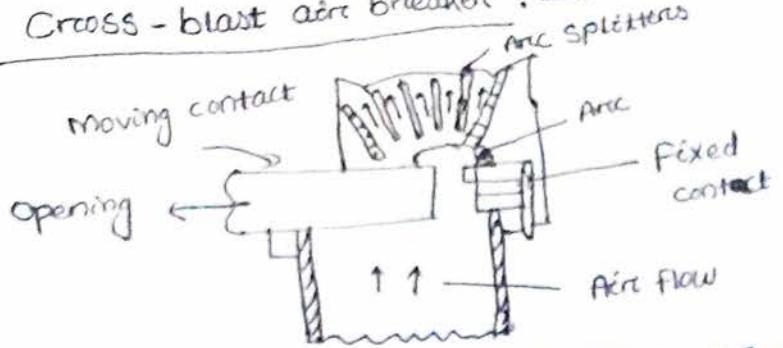


When a fault occurs, the tripping impulse causes opening of the air valve which connects the circuit breaker reservoir to the arcing chamber. The high pressure air entering the arcing chamber pushes away the moving contact against spring pressure. The moving contact is separated and an arc is struck. At the same time, high pressure air-blast flows along the arc and takes away the ionized gases along with it. Consequently, the arc is extinguished and current flow is interrupted.

It may be noted that in such circuit breakers the contact separation required for interruption is generally small ( $1.75\text{ cm}$  or so). Such a small gap may constitute inadequate clearance for the normal service voltage. Therefore an isolating switch is incorporated as a part of this type of circuit breaker.

This switch opens immediately after fault interruption to provide the necessary clearance for insulation.

ii) Cross-blast arc breaker :-



In this type of circuit breaker, an air-blast is directed at right angles to the arc. The cross-blast lengthens and forces the arc into a suitable chute for arc extinction. Fig. shows the essential parts of a typical cross-blast arc circuit breaker. When the moving contact is withdrawn, an arc is struck between the fixed & moving contacts. The high pressure cross-blast forces the arc into a chute consisting of arc splitters & baffles. The splitters serve to increase the length of the arc & baffles give improved cooling. The result is that arc is extinguished and flow of current is interrupted. Since blast pressure is same for all currents, the inefficiency at low currents is eliminated. The final gap for interruption is great enough to give normal insulation clearance so that a series isolating switch is not necessary.

Sulphur Hexafluoride ( $SF_6$ ) Circuit Breakers :-

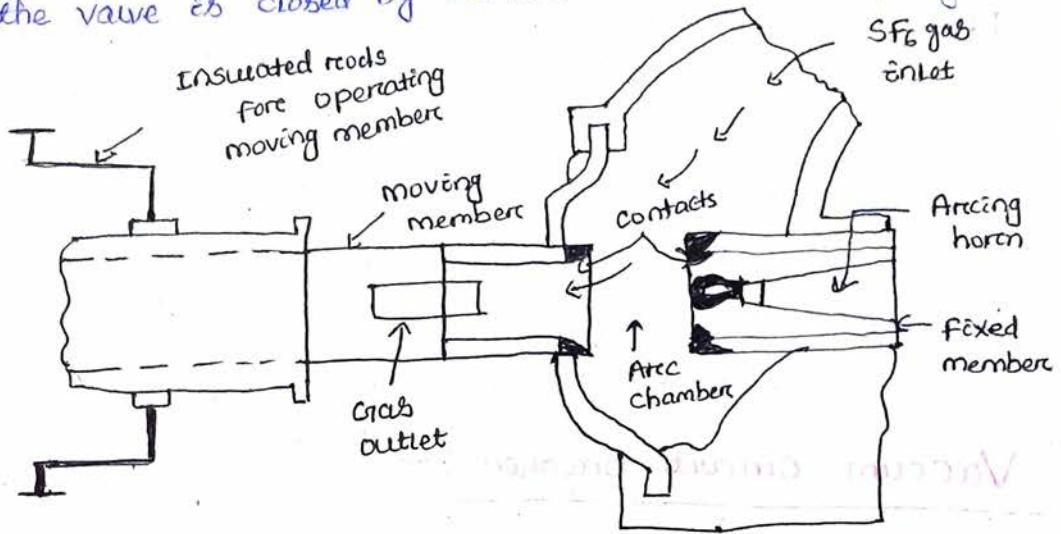
In such circuit breakers, Sulphur hexafluoride ( $SF_6$ ) gas is used as the arc quenching medium. The  $SF_6$  is an electro-negative gas and has a strong tendency to absorb free electrons. The contacts of the breaker are opened in a high pressure flow of  $SF_6$  gas and an arc is struck between them. The conducting free electrons in the arc are rapidly captured by the gas to form relatively

immobile negative ions. This loss of conducting electrons in the arc quickly builds up enough ionization strength to extinguish the arc. The SF<sub>6</sub> circuit breaker found to be very effective for high power and high voltage switchgear.

Construction : — Fig. shows the parts of a typical SF<sub>6</sub> circuit breaker. It consists of fixed & moving contacts enclosed in a chamber C called arc interruption chamber containing SF<sub>6</sub> gas. This chamber is connected to SF<sub>6</sub> gas reservoir. When the contacts of breaker are opened, the valve mechanism permits a high pressure SF<sub>6</sub> gas from the reservoir to flow towards the arc interruption chamber. The fixed contact is a hollow cylindrical current carrying contact fitted with an arcing horn. The moving contact is also a hollow cylinder with rectangular holes in the sides to permit the SF<sub>6</sub> gas to let out through these holes after flowing along & across the arc. The tips of fixed contact, moving contact and arcing horn are coated with copper-tungsten arc resistant material. Since SF<sub>6</sub> gas is costly, it is reconditioned & reclaimed by suitable auxiliary system after each operation of the breaker.

Working : — In the closed position of the breaker, the contacts remain surrounded by SF<sub>6</sub> gas at a pressure of about 2.8 kg/cm<sup>2</sup>. When the breaker operates, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronised with the opening of a valve which permits SF<sub>6</sub> gas at 14 kg/cm<sup>2</sup> pressure from the reservoir to the arc interruption chamber.

The high pressure flow of SF<sub>6</sub> rapidly absorbs the free electrons in the arc path to form immobile negative ions which are ineffective as charge carriers. The result is that the medium between the contacts quickly builds up high dielectric strength and causes the extinction of the arc. After the breaker's operation (i.e. after arc extinction), the valve is closed by the action of a set of springs.



### Advantages:-

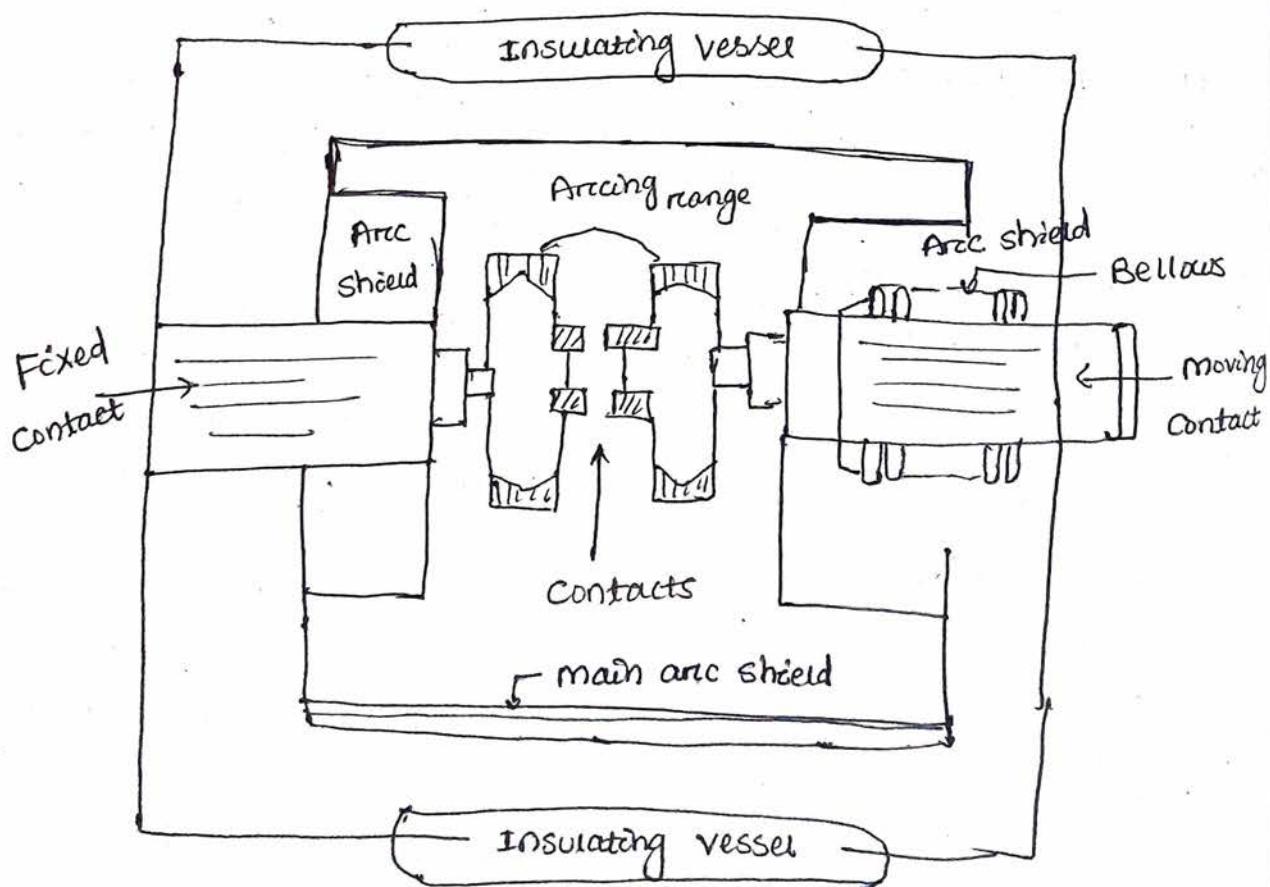
- i) Due to the superior arc quenching property of SF<sub>6</sub>, such circuit breakers have very short arcing time.
- ii) Since the dielectric strength of SF<sub>6</sub> gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.
- iii) The SF<sub>6</sub> circuit breaker gives noiseless operation due to its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker.
- iv) The closed gas enclosure keeps the interior dry so that there is no moisture problem.
- v) There is no risk of fire in such breakers because SF<sub>6</sub> gas is non-inflammable.
- vi) There are no carbon deposits so that tracking & insulation problems are eliminated.
- vii) The SF<sub>6</sub> breakers have low maintenance cost, light foundation requirements and minimum auxiliary equipment.
- viii) Since SF<sub>6</sub> breakers are totally enclosed & sealed from atmosphere, they are particularly suitable where there is dust or coal mines.

## Dis-advantages :-

- i) SF<sub>6</sub> breakers are costly due to the high cost of SF<sub>6</sub>.
- ii) Since SF<sub>6</sub> gas has to be reconditioned after every opening of the breaker, additional equipment is required for this purpose.

Applications : — A typical SF<sub>6</sub> circuit breaker consists of interrupter units each capable of dealing with currents upto 60kA and voltages in the range of 50 - 80kV. A number of units are connected in series according to the system voltage. SF<sub>6</sub> circuit breakers have been developed for voltages 115kV to 230kV, power ratings 10MVA to 20MVA & interrupting time less than 3 cycles.

## Vaccum Circuit Breaker :-



→ Here the Vacuum is used as the quenching medium.  
Since Vacuum offers the highest insulating strength  
and has far superior arc quenching properties than  
others.

### Construction :-

- Vacuum cut breaker is very simple in construction.
- The outer envelope is normally made of glass due to the easy to joint the end caps and also it help to examine the breaker from outside.
- When it becomes milky white from its silvery mirror it indicates that the baffle is losing its vacuum.
- The main arc shield is made up of stainless steel is placed betn the contacts & the envelope is used to prevent the metal vapour reaching the envelope as it reduces the breakdown strength between the contacts.
- Inside the main arc shield, the breaker has 2 contacts, one is fixed & others is moving contact.
- The metallic bellows is made up of stainless steel is used to move the moving contact.
- The peripheral of the endcap is sealed to the envelop consisting of insulating vessel.

### Working principle :-

- The moving contact is fixed to the spring operated mechanism. So that metallic bellows inside the chamber moved during opening & closing of the moving contacts.
- When the contact separates from the fixed contact, an arc is struck betn the contacts.
- An arc is produced betn the contacts due to ionisation of the metal vapours of the contacts.
- The arc is quickly extinguished because the metallic vapour, electron, ion produces during arc rapidly

Condense on the circuit breaker wall. And also shielded by the fixed & moving contact shields.

→ Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker with a short contact separation.

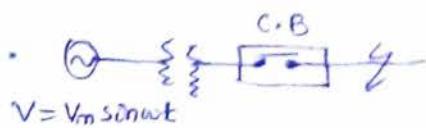
Advantages :-

- It is compact, reliable & have long life.
- It has no fire hazards.
- There is no generation of gas during & after operation.
- It require little maintenance.
- It has low arc energy.

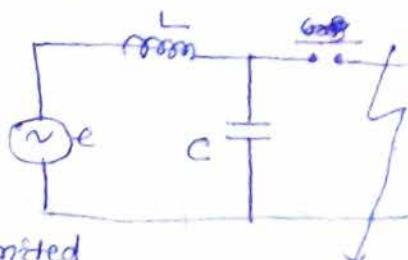
Problems of Circuit Interruption :-

(i) Rate of Rise of Restriking Voltage :-

→ It is the rate of increase of restriking voltage. If voltage in  $\text{kV}$  & time in  $\mu\text{sec}$ . So that rate of restriking voltage is  $\text{kV}/\mu\text{sec}$ .

$$V = V_m \sin \omega t$$


→ Before current interruption, the capacitance 'C' is short circuited by the fault & the short cut current through the breaker is limited by inductance 'L'.



→ Hence short cut current will lag the voltage by  $90^\circ$ . where  $i$  represents the short cut current.  
 $i_a \leftarrow$  the arc voltage.

→ The generator voltage appears across the 'L' when the contacts are opened & the arc finally extinguished.

→ This Lc combination forms an oscillatory and produces a transient of frequency.

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

→ Now the voltage which appears across C is the restriking voltage. It is twice the peak neutral-phase voltage =  $2E_m$ .

→ The rate of rise of restriking voltage depends upon

- (i) Recovery voltage
- (ii) Natural frequency of oscillation

→ If  $R \cdot R \cdot R \cdot V$  is greater than the rate of rise of dielectric strength bet' the contacts, the arc will re-strike. However the arc will fail to re-strike if  $R \cdot R \cdot R \cdot V$  is less than the rate of increase of dielectric strength between the contacts of the breaker.

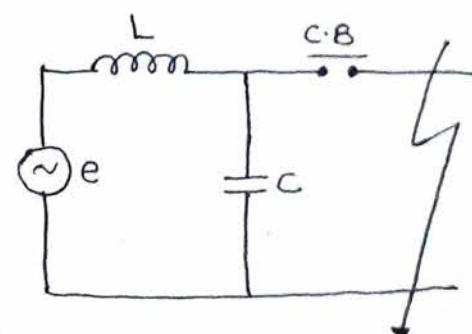
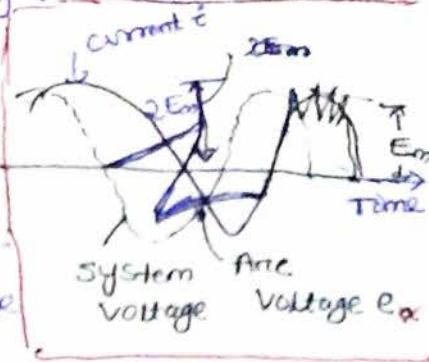
(iii) Current chopping :-

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

→ Suppose the arc current is  $i$  when it is chopped down to zero value. As the chop current is  $\dot{i}$ , therefore the energy stored in inductance is  $L\dot{i}^2/2$ . This energy will transfer to the capacitance  $C$ , changing the latter to a prospective voltage  $e'$  is given by

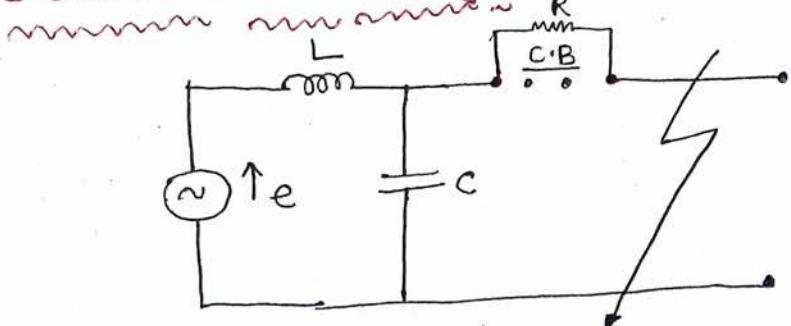
$$\frac{1}{2} L\dot{i}^2 = \frac{C e'^2}{2}$$

$$\Rightarrow e' = \dot{i} \sqrt{L/C} \text{ V}$$



- The prospective voltage  $e'$  is very high as compared to the dielectric strength gained by the gap. So that the breaker restrikes.
- As the deionising force is still in action, therefore chop occurs again, but this time the arc current is smaller than the previous case.

### Resistance Switching :-



- Due to current chopping, capacitive current breaking severe voltage surge is occurs during cut interruption.
- The voltage surge during cut interruption can be prevented by the use of shunt resistor  $R$  across the C.B. This is known as Resistance switching.
- When the fault occurs, the contact of the C.B. are opened & an arc is struck bet<sup>n</sup> the contacts and the arc current flows through the shunt resistor.
- This helps to decrease of arc current and an increase in the rate of de-ionisation of the arc-path. Consequently the arc resistance is increased. This process will continue till the arc current become small so that the arc will extinguished.
- The shunt resistor also helps in limiting the oscillatory growth of restriking voltage.

→ Hence the R is so chosen that the cut is critical damped. For this, the R value is chosen as  $R = 0.5 \sqrt{LC}$

→ The resistance switch performs the following functions.

- i) It reduces the rate of rise of restraining voltage.
- ii) It reduces the voltage surge due to current chopping and capacitor breaking.

### Circuit Breaker Rating :-

Under fault condition the C.B required to perform the following operations.

- It must be capable of opening the faulty cut and break the fault current.
- It must be capable of being closed on to a fault.
- It must be capable of carrying fault current for a short time.

Corresponding to the above mentioned duties the C.B have 3 ratings.

Breaking capacity :- It is a current that a C.B is capable of breaking at a given recovery voltage and under specified condition.

The breaking capacity is always stated at the r.m.s value of fault current at the instant of contact separation.

If I is the rated breaking current in A & V is the rated service line voltage in V.

$$\text{Breaking capacity} = \sqrt{3} VI \times 10^{-6} \text{ MVA}$$

## Making capacity :-

The peak value of current during the first cycle of current wave after the closure of C.B is known as making capacity.

Making current is equal to the max<sup>m</sup> value of asymmetrical current.

$$\text{Making capacity} = 2.55 \times \text{Symmetrical breaking capacity}$$

## Short time Rating :-

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

The short time rating of C.B depends upon its ability to withstand :-

- a) The electromagnetic force effects.
- b) Temperature rise

## Normal current Rating :-

It is the r.m.s value of current which the C.B is capable of carrying continuously at its rated frequency under specified condition.

problem :- A circuit breaker is rated as 1500A, 1000MVA, 33KV, 3-second, 3-phase oil circuit breaker.

- Find:-
- i) rated normal current
  - ii) breaking capacity
  - iii) rated symmetrical breaking current
  - iv) rated making current
  - v) short-time rating
  - vi) rated service voltage

SOL<sup>n</sup>: - i) Rated normal current = 1500 A

ii) Breaking capacity = 1000 mVA

iii) Rated symmetrical breaking current  
=  $\frac{1000 \times 10^6}{\sqrt{3} \times 33 \times 10^3}$  = 17496 A (n.m.s)

iv) Rated making current =  $2.55 \times 17496$   
= 44614 A (peak)

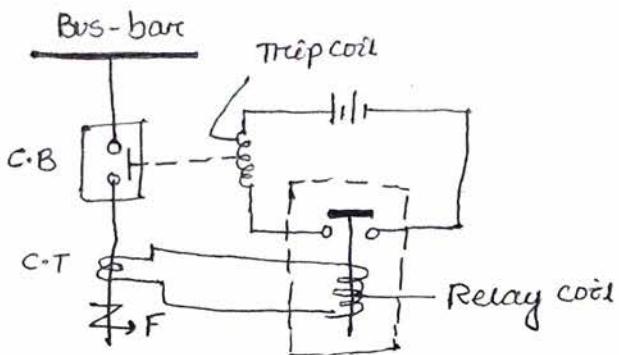
v) Short-time rating = 17496 A for 3 seconds

vi) Rated Service voltage = 33 KV (n.m.s)

## Protective Relays

A protective relay is a device that detects the fault and initiates the operation of the circuit breaker to isolate the defective element from the rest of the system.

A typical relay circuit is shown in fig.



This diagram shows one phase of 3-phase system for simplicity. The relay circuit connections can be divided into 3 parts.

- i) First part is the primary winding of a current transformer (C.T) which is connected in series with the line to be protected.
- ii) Second part consists of secondary winding of C.T & the relay operating coil.
- iii) Third part is the tripping circuit which may be either a.c or d.c. It consists of a source of supply, the trip coil of the circuit breaker and the relay stationary contacts.

When a short circuit occurs at point F on the transmission line, the current flowing in the line increases to an enormous value. This results in a heavy current flowing through the relay coil, causing the relay to operate by closing its contacts. This in turn closes the trip coil of the breaker, making the circuit breaker open and isolating the faulty section from the rest of the system.

In this way, the relay ensures the safety of the circuit equipment from damage and normal working of the healthy portion of the system.

### Fundamental Requirements of Protective Relaying :-

- i) Selectivity : - It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system.
- ii) Speed : - Electrical apparatus may be damaged if they are made to carry the fault currents for a long time.
- iii) Sensitivity : - It is the ability of the relay system to operate with low value of actuating quantity.
- iv) Reliability : - It is the ability of the relay system to operate under the pre-determined conditions. Without reliability, the protection would be rendered largely ineffective and could even become a liability.
- v) Economy : - The most important factor in the choice of a particular protection scheme is the economic aspect. Sometimes it is economically unjustified to use an ideal scheme of protection and a compromise method has to be adopted. As a rule, the protective gear should not cost more than 5% of total cost.

### Basic Relays :-

Most of the relays on electric power system are electro-mechanical type. Their working based on the principle of

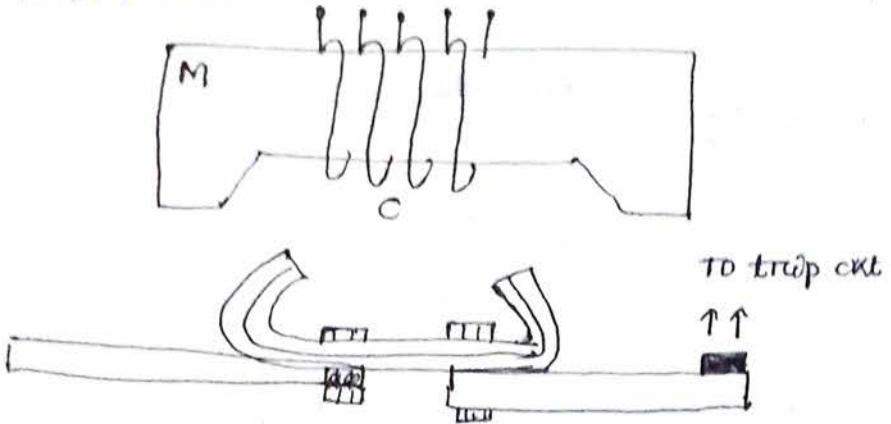
- i) Electromagnetic Attraction
- ii) Electromagnetic induction

This type of relay working on the principle that an armature being attracted to the poles of an electromagnet. Such relays may be operated by direct d.c. quantities.

It is of following types:-

i) Attracted armature type :-

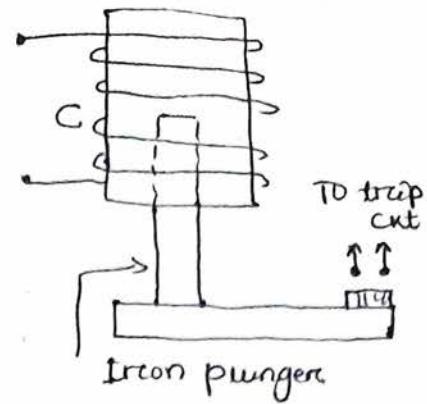
- It consists of electromagnet 'M' carrying a coil 'C' & pivoted laminated armature.



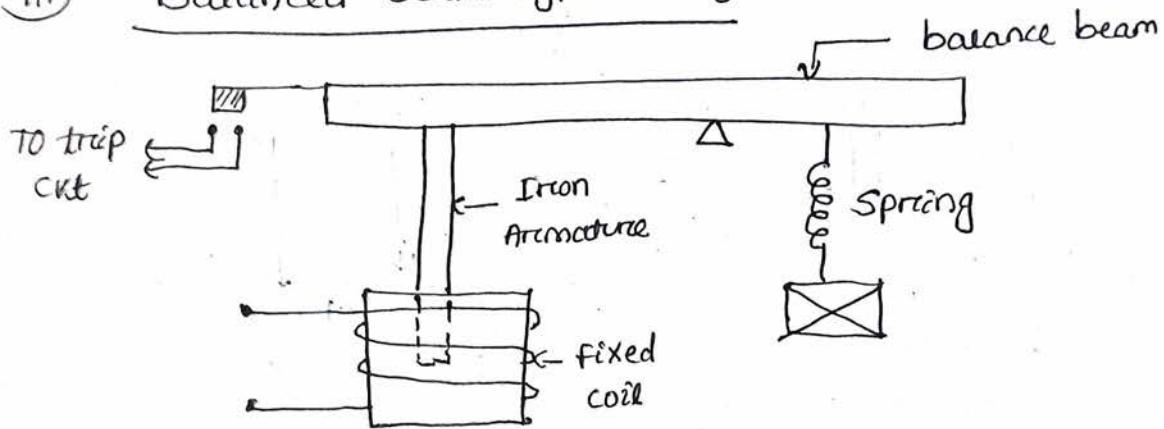
- The armature is balanced by a counter weight and carries a pair of sprung contact at its free end.
- Under normal condition, the current through the relay coil is such that the counter weight hold the armature in the position.
- When short circuit occurs the current through the relay coil increases and the relay armature attracted upward.
- The above action complete the trip cut. Hence the CB contacts are opened & disconnection of faulty section will occur.
- The minimum current at which the relay armature is attracted to close the trip cut is called pick-up current.

## ii) Solenoid type Relay :-

- It consists of a solenoid and movable iron plunger.
- Under normal condition, the current through the relay coil holds the plunger by gravity or spring in position.
- During fault, the relay coil has the current more than that of the pick-up current, which attract the plunger towards solenoid by means of which the trip cut is close down & the contacts of CB is opened.



## iii) Balanced beam type Relay :-

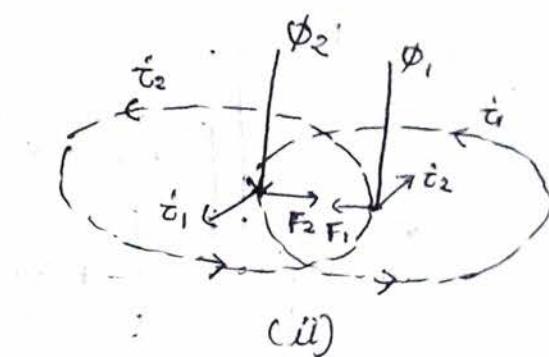
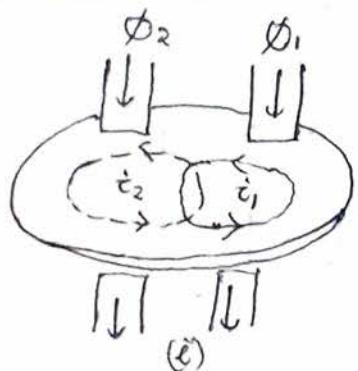


- It consists of a iron armature connected to a balance beam.
- In normal operating condition, the current through the relay coil is such that the beam is held in the horizontal position by the spring.
- When fault occurs, the current through the relay coil is increased and the beam is attracted towards the coil and the contacts of the CB is opened.

## Induction Relay :-

- Electromagnetic induction relay operates on the principle of induction motor and only used for AC.
- It consists of a pivoted aluminium disc placed in two magnetic field of same frequency but displaced in time and space.
- The torque produced in the disc by the interaction of the one of the magnetic field with the current induced in the disc by the other.

Let consider two ac flux  $\phi_2$  &  $\phi_1$ , differing in phase by an angle  $\delta'$  induced emf in the disc and cause the circulation of eddy current  $i_2$  &  $i_1$ .



From the above fig.

$$\phi_1 = \phi_{1\max} \sin \omega t$$

$$\phi_2 = \phi_{2\max} \sin(\omega t + \delta')$$

Hence  $\phi_2$  leads the  $\phi_1$  at an angle  $\delta'$ .

Let the path in which motor current flow have negligible self inductance. So the current will be in phase with their voltages.

$$\begin{aligned} i_1 &\propto \frac{d\phi_1}{dt} \propto \frac{d}{dt} \phi_{1\max} \sin \omega t \\ \Rightarrow i_1 &\propto \phi_{1\max} \cos \omega t \end{aligned}$$

$$\Rightarrow \boxed{\dot{\tau}_2 \propto \phi_{2\max} \cos(\omega t + \alpha)}$$

Now force  $F_1 \propto \phi_1 I_2 \propto F_2 \propto \phi_2 I_1$ ,  
 the fig. shows the two forces are in opposition.

$$F \propto F_2 - F_1$$

$$\propto \phi_2 \dot{\tau}_1 - \phi_1 \dot{\tau}_2$$

$$\propto \phi_{2\max} \sin(\omega t + \alpha) \phi_{1\max} \cos \omega t$$

$$- \phi_{1\max} \sin \omega t \phi_{2\max} \cos(\omega t + \alpha)$$

$$\propto \phi_{1\max} \phi_{2\max} [\sin(\omega t + \alpha) \cos \omega t - \sin \omega t \cos(\omega t + \alpha)]$$

$$\propto \phi_{1\max} \phi_{2\max} \sin \alpha$$

$$\boxed{F \propto \phi_1 \phi_2 \sin \alpha} \quad (i)$$

where  $\phi_1$  &  $\phi_2$  are the rms value of the flux.

From the eqn (i) it can be noted that

- The greater is the phase angle  $\alpha$  b/w the fluxes the greater will be the net force applied on the disc.
- The net force is same at every instant.
- The direction of net force & hence the direction of the motion of the disc depends upon which flux is leading.

There are 3 types of electro magnetic induction type relay are available.

- i) Shaded pole structure
- ii) Watt hour meters or double winding meters
- iii) Induction cup structure.

## Important Terms

i) Pick-up current :- It is the minimum current in the relay coil at which the relay starts to operate. When the relay coil current is equal or greater than the pick-up current, the relay operates to complete the trip coil circuit.

ii) Current Setting :-

It is necessary to adjust the pick-up current to any required value. This is known as current setting and is usually achieved by the use of tapping on the relay operating coil.

The values assigned to each tap are expressed in terms of %age full load rating of C.T with which the relay is associated.

$$\text{Pick-up current} = \frac{\text{Rated secondary current of CT}}{\times \text{current setting}}$$

Example :- In over current relay current setting = 125% connected to a C.T of 400/5.

The rated secondary current of C.T is 5 A.

$$\begin{aligned}\text{Then pick up current} &= 5 \times 125/100 \\ &= \underline{\underline{6.25 \text{ A}}}\end{aligned}$$

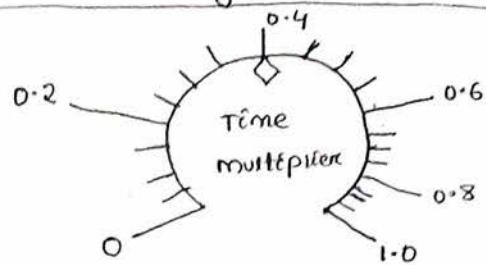
iii) Plug - Setting multiplier :- (P.S.M)

It is the ratio of fault current in relay coil to the pick-up current.

$$\text{P.S.M} = \frac{\text{Fault current in relay coil}}{\text{Pick-up current}}$$

$$= \frac{\text{Fault current in relay coil}}{\frac{\text{Rated Secondary current of CT}}{\times \text{current setting}}}$$

iv) Time - Setting Multiplier:



A relay is generally provided with control to adjust the time of operation. This adjustment is known as time-setting multiplier. The time-setting dial is calibrated from 0 to 1 on steps of 0.05 sec. The time-setting dial is calibrated from 0 to 1 on 5 steps.

If the time setting is 0.1 & time obtained from time vs psm curve is 3 sec. Then the actual relay operating time. =  $3 \times 0.1 = 0.3$  sec.

The operation of the relay can be controlled by adjusting the position of a movable back stop which controls the travel of the disc. So that the time in which relay will close varies.

Classification of functional Relay:

The relay is said to be functional according to the function they are performed.

In over current relay the current is greater than the current, which can tolerate.

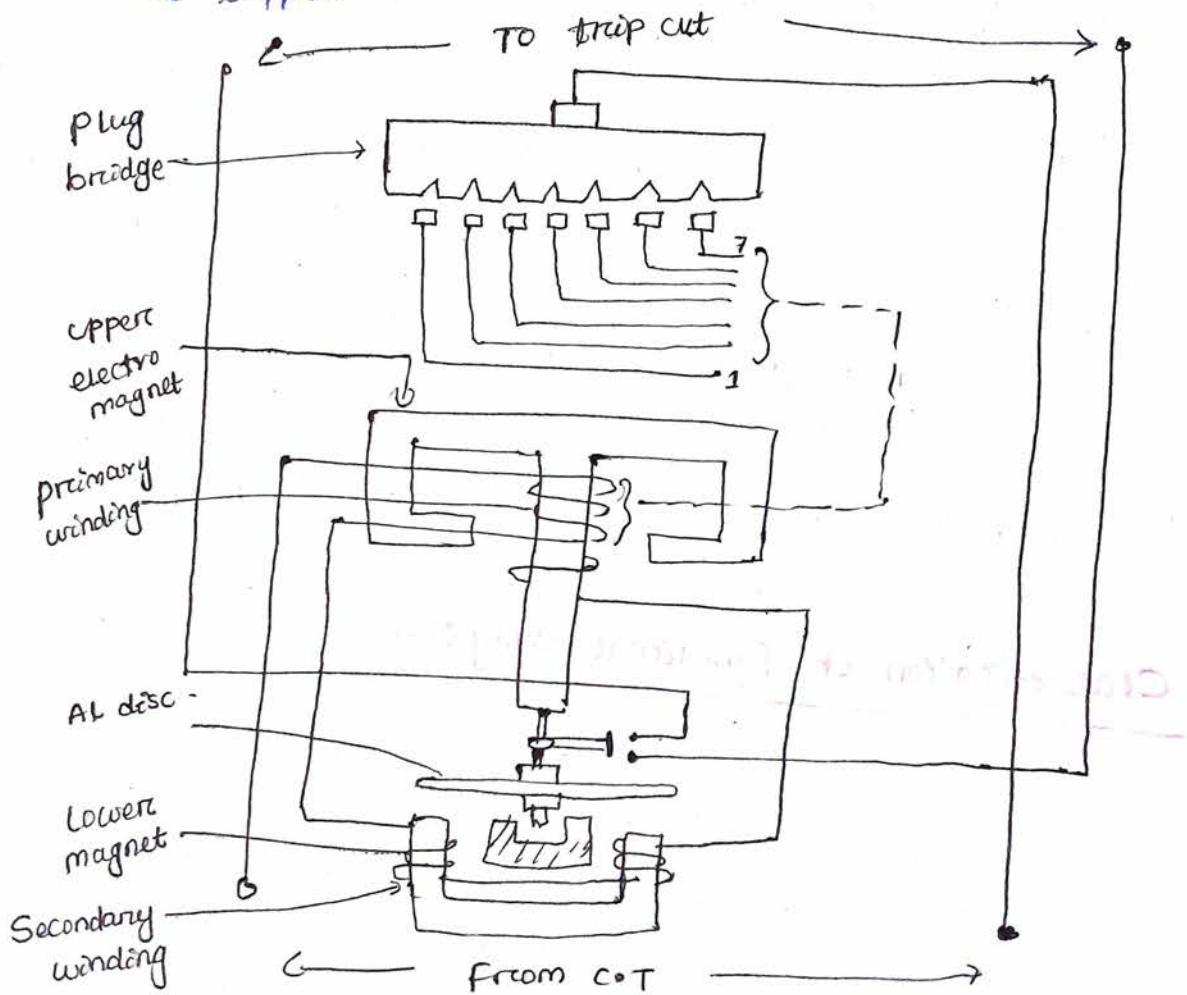
Over voltage relay is one which recognises over voltage on a circuit & initiate appropriate operation.

The functional relay is classified into following types.

- i) Induction type over current relay
- ii) Induction type reverse power relay
- iii) Distance relay
- iv) Differential relay
- v) Transistor scheme

## Induction type over current Relay (Non-directional)

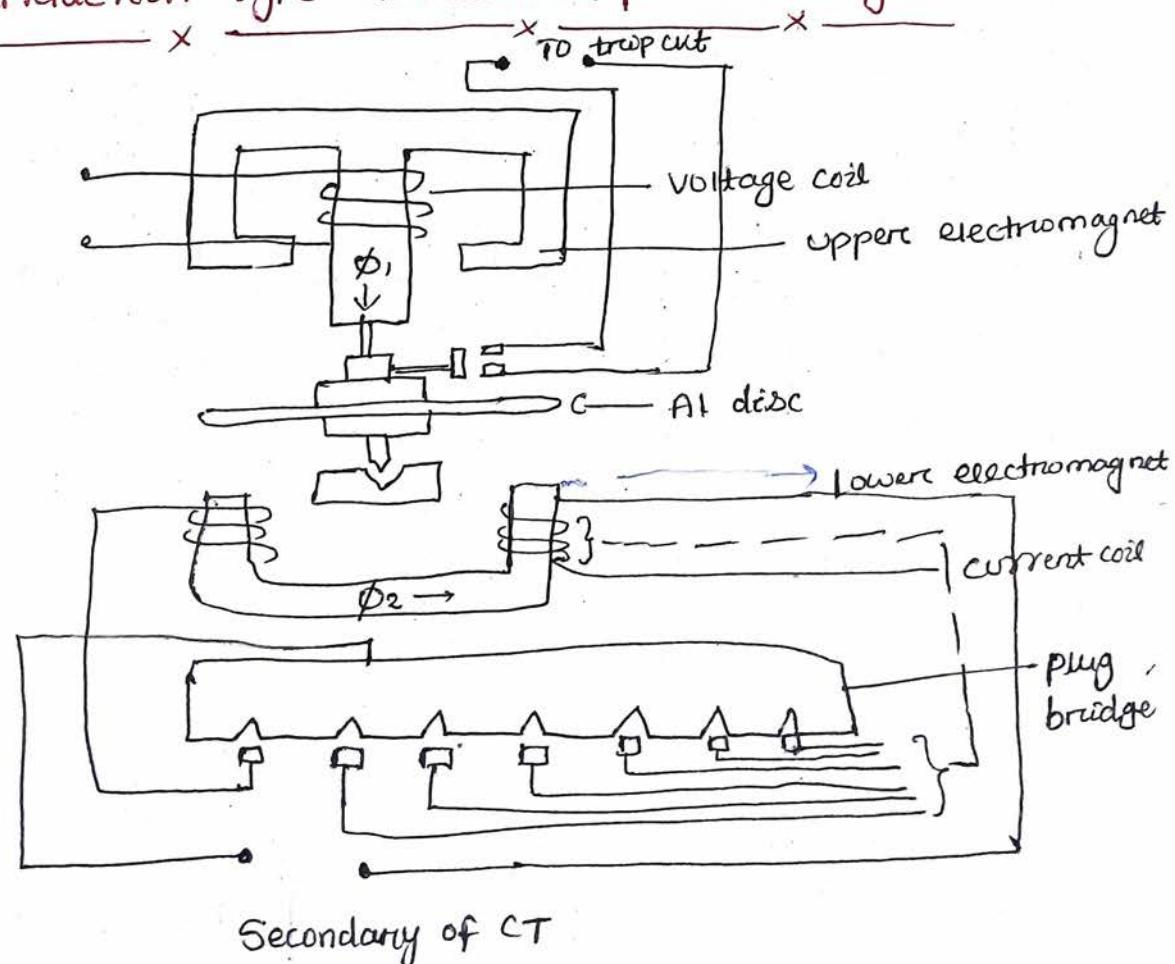
- An induction type over current relay giving inverse time operation with a definite minimum time characteristic.
- The relay has two electro magnet. The upper magnet has two windings, one of these is primary connected to the secondary of the CT in the line to be protected and is tapped at the intervals.



- The tappings are connected to a plug setting bridge by which the no. of turns in use can be adjusted. So that desired current setting can be achieved.
- The plug bridge is usually arranged to give seven sections of tapping to give current range from 50% to 200% in steps of 25%.

- If the relay is required to respond to response the earth fault the steps are arranged to give ranges from 10% to 70%.
- The value assigned to each tap are expressed in terms of % age of full load rating of CT with which the relay associates.
- The second winding is energized by induction from the primary and is connected in series with the winding on the lower magnet.
- By this arrangement a leakage fluxes of upper and lower magnet are sufficiently displaced in phase to set a rotational torque on suspended aluminium disc.
- The disc carries two moving contacts which is trip cut contacts. For necessary time setting the angle can be set to any value from 0° to 360°. This adjustment is known as time setting multipliers.

### Induction type directional power Relay :-



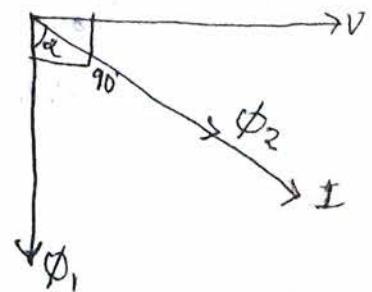
- The directional power relay operates when the power through the relay will be reversed if generator supplies to the network fails and the power from the other source flows to the network in the reverse direction.
- In case of motor such relay is used.

### Construction :-

- It consists of Al disc which is free to rotate between the poles of two electromagnet.
- The upper electromagnet has a winding called voltage or potential coil connected to the cut voltage source through PT.
- The lower electromagnet has separate winding called current coil connected to the secondary of CT.
- The current coil is provided with no. of tapping connected to the plug bridge so to give desired current setting.

### Operation :- → The torque developed in the disc suspended betn the two electromagnet is proportional to $VI$ .

- When the power flows in the normal direction the disc assisted by a spring tends to turn away the moving contact from fixed trip cut contacts, the relay remain idle.
- A reversal current in the cut reverses the torque when it is larger than that from the control spring torque the disc rotates in the reverse direction and the moving contact close the trip cut.
- The relay can be made sensitive by having very light Control Spring.
- Hence the flux  $\phi_1$  lags the supply voltage at an angle  $90^\circ$ .
- The flux  $\phi_2$  due to current coil is in phase with the operating current  $I$ .



→ Now the torque impressed on the disc is given as

$$T \propto \phi_1 \phi_2 \sin\theta$$

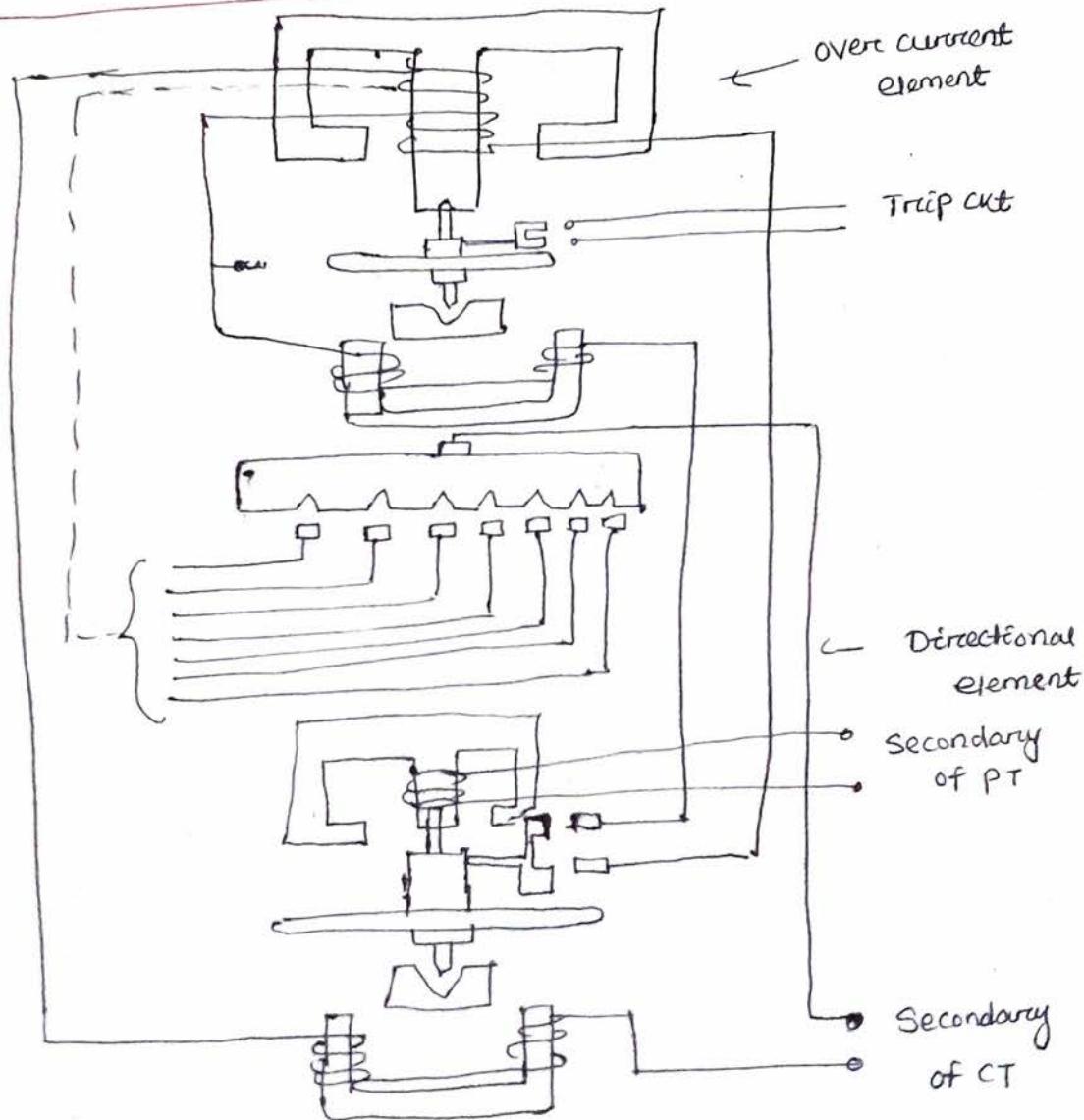
AS  $\phi_1 \propto V$ ,  $\phi_2 \propto I$  and  $\theta = 90 - \delta$

$$T \propto VI \sin(90 - \delta)$$

$$\Rightarrow T \propto VI \cos\delta$$

⇒ T ∝ power on the cut

### Induction type Directional Over Current Relay:-



→ Directional relay can't be operated at short circuit condition. To overcome this difficulty directional over current relay is designed which is independent of supply voltage and power factor.

- It consists of two relay elements i.e. directional element & non-directional element.
- Directional element is quite similar to the directional power relay.
- The voltage coil of this is connected to the cut voltage through PT while current coil is energized through a CT by cut current.
- The trip contact of the directional element connects in series with the secondary cut of the over current element.
- The over current element cannot operate until its secondary cut is completed. So that the directional element must be operate first.
- Non directional or over current element is quite similar to the non-directional over current relay.
- The spindle of the disc of this element has a moving contact, which closes the trip cut after the operation of the directional element.
- The tapping are provided over the upper magnet of the over current element, connected to the bridge to provide appropriate current setting.
- Under normal operating condition the relay is idle.
- If there is reversal of the current or power on the disc of the directional element it starts to operate to complete the cut for over current element.
- Due to over current a torque is produced on the disc & the trip coil cut contacts are closed.

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- The direction of the current is reversed.
- Current in the reverse direction exceeds the preset value.
- Excessive current.

Features :- i) High speed of operation

- High Sensitivity
- Short time thermal rating.
- Ability to operate at low value voltage
- Burden must not be excessive.

Differential Relay :-

It is defined as the relay that operates when the phasor difference of two or more similar electrical quantities exceed a predetermined value.

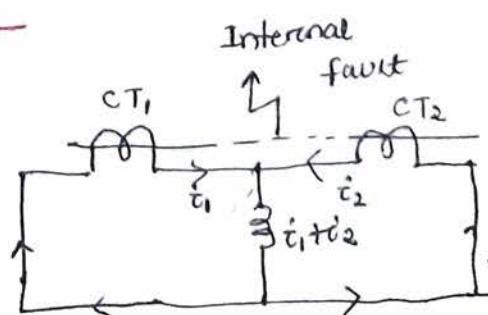
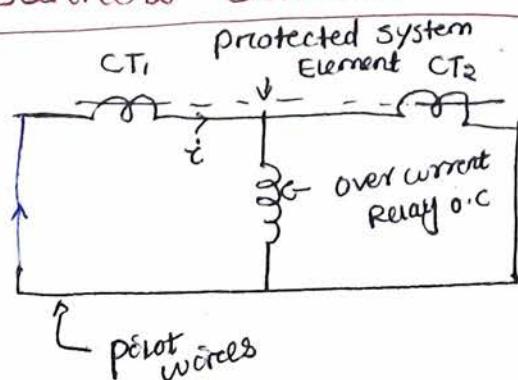
For differential relay it should have

- Two or more similar electrical quantities.
- These quantities has phase displacement for the operation of the relay.

Most of the relays are current differential relay in which phasor difference bet' the current entering and leaving the winding.

It is a unit protection.

Current Differential Relay :-

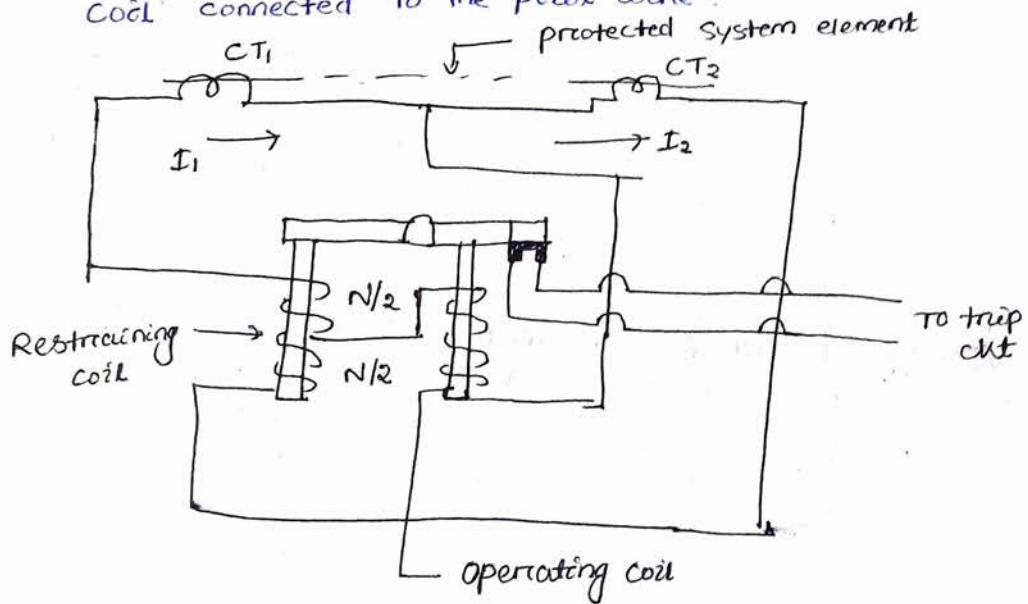


- In the above fig. the dotted line represents the element that is to be protected by differential relay.
- This system element might be a length of the circuit, a portion of the bus or a winding of generator and transformer.
- A pair of CTs are connected on either end of the section to be protected.

- The secondary of CTs are connected in series with the help of pilot wire in such a way that they carry induced current in same direction.
- The operating coil of an over current relay is connected across the secondary of CTs.
- At normal operation the current in the two CT secondaries are equal and the relay operating coil therefore doesn't carry any current.
- If short circuit develops anywhere bet' the two CTs, the sum of CTs secondary current flows to the fault from both the side.
- The differential relay current is proportional to the phasor difference bet' the current entering & leaving the protective element & if the differential current exceeds the relay pick-up value.

## Biased or %age differential relay:-

→ This system consists of an additional restraining coil connected to the pilot wire.



- Current induced in both the CTs flows through the restraining coil.
- The operating coil is connected to the mid point of the restraining coil.
- The torque due to restraining coil prevents the closing of trip cut contacts while the torque due to operating coil tend to close the trip cut contacts.
- Under normal operating condition, the torque developed by the restraining coil is greater than that of the operating coil and hence the relay remains idle.
- When any fault occurs, the operating torque exceeds the restraining torque, the trip cut contacts are closed to open the CB contacts.
- The restraining torque can be varied by varying the no. of turns in the restraining coil.
- The differential current in the operating coil is proportional to the (I<sub>1</sub>-I<sub>2</sub>) & the equivalent current

- In the above fig. the dotted line may be the element that is to be protected by metering.
- This system element might be a portion of the bus or a winding and transformer.
- A pair of CTs are connected in series to be protected.

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- The secondary of CTs may be connected in series to be protected.

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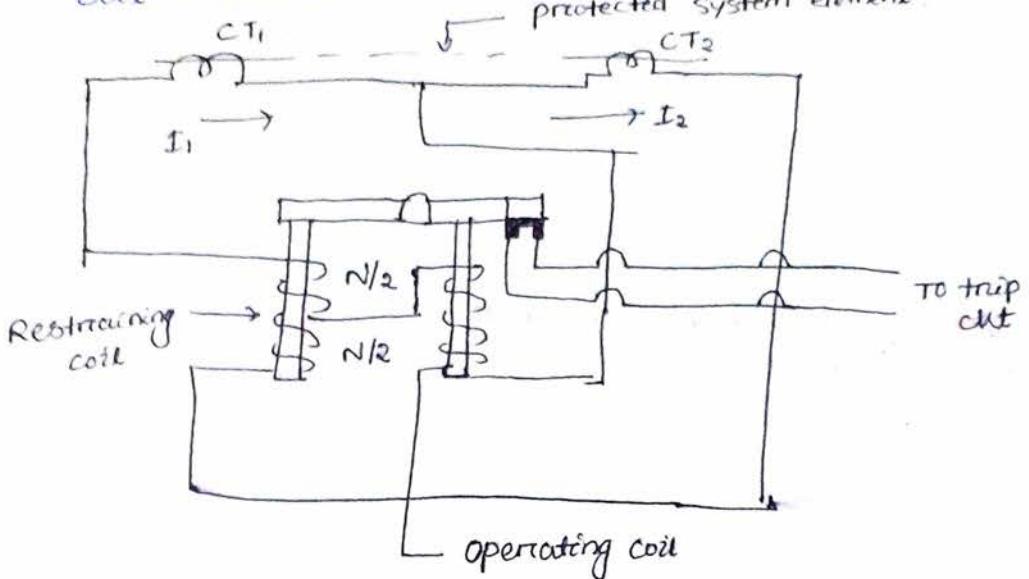
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## Biased or %age differential Relay:-

→ This system consists of an additional restraining coil connected to the pilot wire.

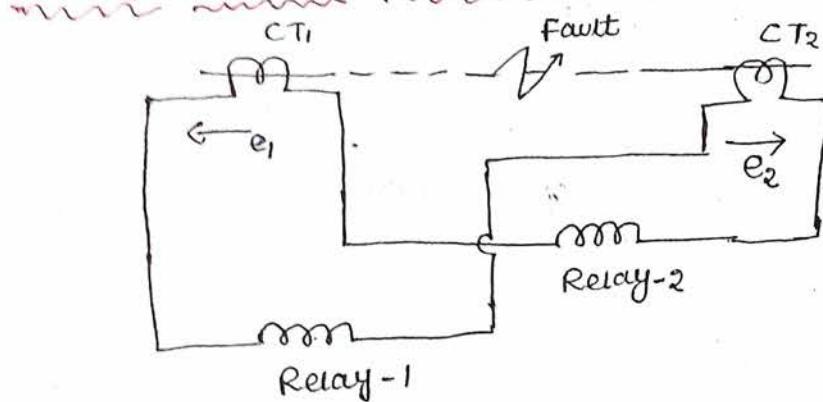


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- When any fault occurs, the operating torque exceeds the restraining torque, the trip cut contacts are closed to open the CB contacts.
- The restraining torque can be varied by varying the no. of turns in the restraining coil.
- The differential current in the operating coil is proportional to the (I<sub>1</sub> - I<sub>2</sub>) & the equivalent current

on the restraining coil is proportional to  $\frac{I_1 + I_2}{2}$ .

- The ratio of differential operating coil current to the restraining coil current is fixed a percentage. Hence it is known as % age differential relay.
- This relay is also called as biased differential relay because the restraining coil produces a biased coil as it provides additional flux.

### Voltage balance Differential Relay :-



- Voltage balance differential which are preferred for the feeder protection.
- In this arrangement two similar current transformer are connected at either end of the system element under protection by means of pilot wire.
- The relays are connected in series with the pilot wires one at each end.
- The relative polarity of CTs is such that there is no current through the relay under normal operating condition.
- The CTs used in such protection should be such that they should induce voltages in the secondary linearly w.r.t current.

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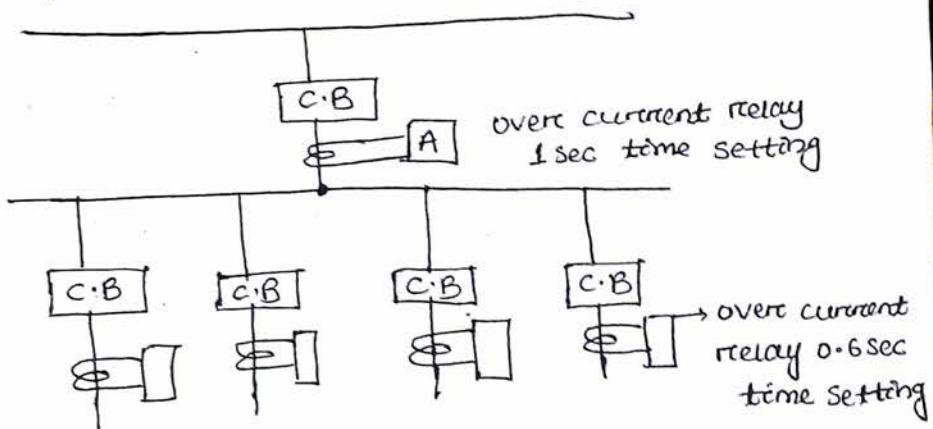
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- $\rightarrow$  when fault occurs, the current across the two primaries will differ from one another & so voltage in the secondaries of the CTs will differ & circulating current will flow through the operating coil of the relay. Thus the trip coil will close & the CB contacts are obtained.
- $\rightarrow$  This method may be employed for protection of feeders, alternators & transformers.

### Types of Protection :-

The protection scheme is divided into 2 parts.

- i) primary protection ii) Back-up protection.



### Primary protection :-

- $\rightarrow$  It is the protection scheme which is designed to protect the component parts of the system.
- $\rightarrow$  Each line has C.B & over current relay & they protect the line.
- $\rightarrow$  Some time fault are not cleared by the primary protection under such condition back-up protection will operate.

## Back-up protection : -

- It is designed to operate with sufficient time delay so that primary relay will get enough time to function.
- It provides back-up protection for each line.
- If a line fault is not cleared by the line relay within the given time, the back up protection starts to operate.
- During back-up relaying functions, a larger part is disconnected than when primary relaying functions correctly.

## • STATIC RELAY :-

Static Relay is one in which there is no armature and other moving element & response is developed by electronic, magnetic or other component without mechanical motion.

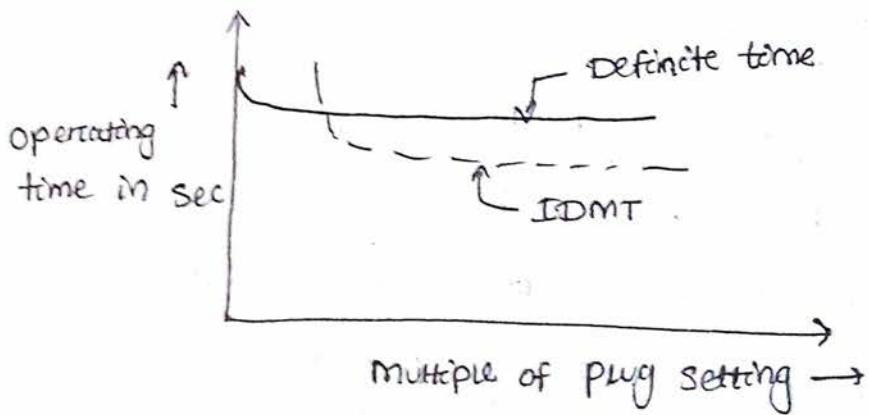
### Advantages of Static Relay :-

- The power consumption in case of static relay is very small.
- Quick response, long life, shock proof, few problems in maintenance, high reliability & high degree of accuracy.
- Absent of moving contacts, associates problems of arcing contact bounce, replacement of contacts etc.
- Quick reset action, a high reset value & absence of overshoot can easily achieved.
- There is no effect of gravity on operation. Hence it can be used in air-crafts.
- Greater Sensitivity.
- The basic building blocks of semiconductor circuitry permit a greater degree of sophistication in the shaping of operating characteristics.
- By combining various functional units, several conventional relay can be substituted by a single static relay.
- Static relay are very compact. A single static relay can perform several functions.

- The characteristics of static relay are accurate and superior.
- Static relay assisted by power line carrier can be employed for remote back-up & network monitoring.
- Static relay can be used for repeated operation.
- The risk of unwanted tripping is less.
- Static relay is provided with integrated features of self-monitoring, easy testing & servicing.
- Static protection control & monitoring system can perform several functions.

### Inverse Definite Minimum Time Relay (IDMT):-

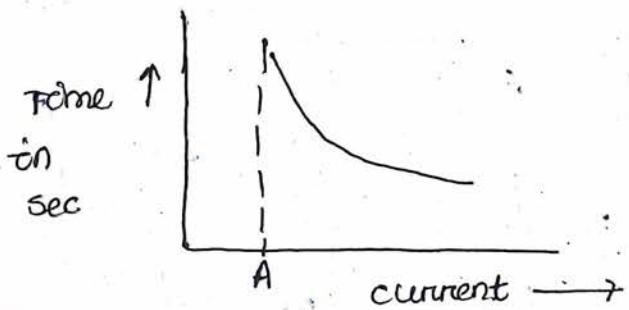
- Such a relay is one in which operating time is approximately inversely proportional to fault current near pick-up value and becomes substantially constant slightly above the pick-up value.



- The above thing can be achieved by using a core of the electromagnet which get saturated for current slightly greater than the pick-up current.

## Inverse-time over-current Relay :-

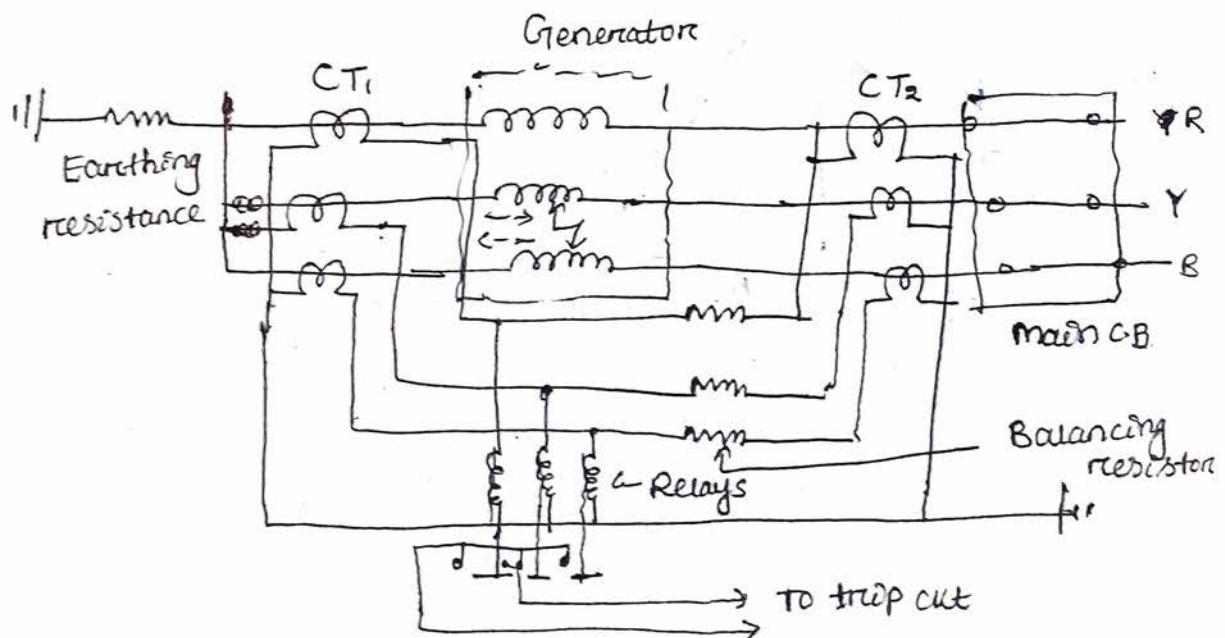
- An inverse time relay is one in which the operating time is approximately inversely proportional to the magnitude of the actuating quantity.
- At the value of current less than the pick-up value the relay never operates. At higher values the operating time of the relay decreases steadily with the increase in current.
- They are normally more inverse near the pick-up value of the actuating quantity & become less inverse as it increases.
- The operating time of all over current relays tends to become asymptotic to a definite minimum value with increase in the value of actuating quantity.



## Protection of Alternator :-

- Some important fault which may occur on an alternator :-
- i) Failure of prime mover
  - ii) Failure of field
  - iii) over current
  - iv) overspeed
  - v) over voltage
  - vi) unbalanced loading
  - vii) stator winding faults. → most serious fault.

## Differential protection of Alternator :-



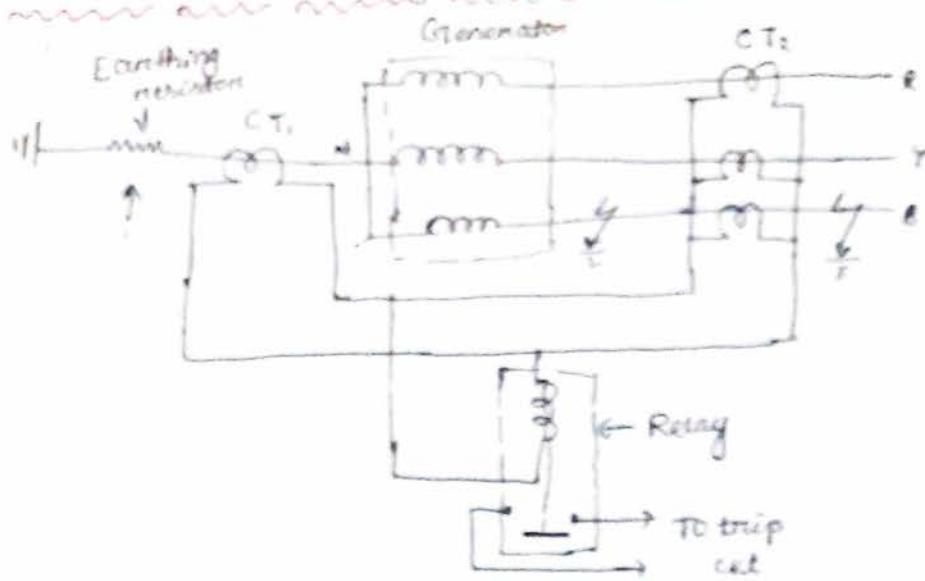
- It is the most common system employed for the protection of stator winding against earth fault & phase to phase fault.
- Hence current at the two ends of the protection system are compared. Under normal operating condition these currents are equal & during fault, the difference in

*an alternator*

Current is made to flow through the relay operating coil.

- This protection scheme is also known as Mertz - Price Circulating Current System.
- There are two sets of identical CTs & each set is mounted on either side of the stator phase winding.
- The secondaries of these CT sets are connected in star & their ends are connected through pilot wires.
- The relay coils are connected to stars as the CTs has common neutral point & their outer ends are connected to the each 3 pilot wires.
- The relays are connected across equipotential points of the 3 pilot wire. So that the burden on each CT is the same.
- To locate the relay coils adjacent to the CTs near the main C.B., balancing resistance is inserted in series with the pilot wire. And these resistances are adjustable to obtain the exact balance.
- Now assume if there is an earth fault on phase-R, the current in the secondaries of two CTs in phase R will become unequal & the difference in current will flow through the corresponding relay coil & CB will get tripped.
- If there is short cut betn two phases Y & B, it will cause fault current to flow through the two phases. Hence the current in affected CTs secondary will differ & the differential current will flow through the operating coil of the relay & CB will get tripped.

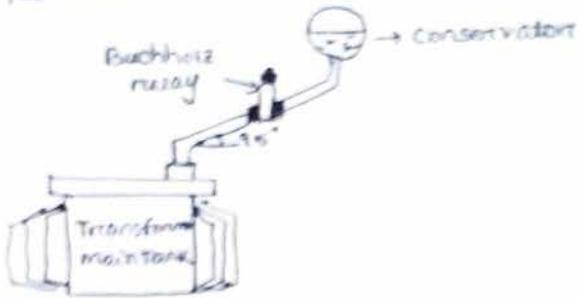
## Balanced Earth Fault Protection:-



- In small size generators, the neutral ends of the 3-phase winding are sometimes connected internally to a single terminal. Under such condition earth-fault protection is used.
- Such scheme doesn't provide any protection against phase to phase fault.
- In this scheme 3 line CTs, one mounted in each phase have their secondaries connected in parallel with that of a single CT which is mounted on the neutral point of star connected conductors.
- A relay is connected across the secondaries of CTs.
- The protection against earth fault is limited to the region but the neutral & line CTs.
- As this scheme provides protection of only the stator winding against the earth fault in stator. Hence this scheme is often called as restricted earth fault protection.
- Under normal operating condition, the current flowing

## Buchholz Relay :-

- Buchholz relay is a gas-activated relay installed in oil-immersed transformer for protection against all kinds of faults.
- It is usually installed in the pipe connecting the conservator to the main tank as shown in fig



Construction :- → It takes the form of a domed vessel placed in the connecting pipe between the main tank and the conservator.

- The device has two elements. The upper element consists of a mercury type switch attached to a float.
- The lower element contains a mercury switch mounted on a hinged type flap located on the direct path of the flow of oil from the transformer to the conservator.
- The upper element closes an alarm circuit during incipient faults whereas the lower element is arranged to trip the circuit breakers in case of severe internal faults.

Operation :- → In case of incipient faults within the transformer, the heat due to fault causes the decomposition of some transformer oil in the main tank. The products of decomposition contain more than 70% of hydrogen gas. The hydrogen gas being light tries to go into the conservator and in the process gets entrapped in the upper part of relay chamber. When a predetermined amount of gas gets accumulated, it exerts sufficient pressure on the float to cause it to tilt and close the contacts of mercury switch attached to it. This completes the alarm circuit to sound an alarm.

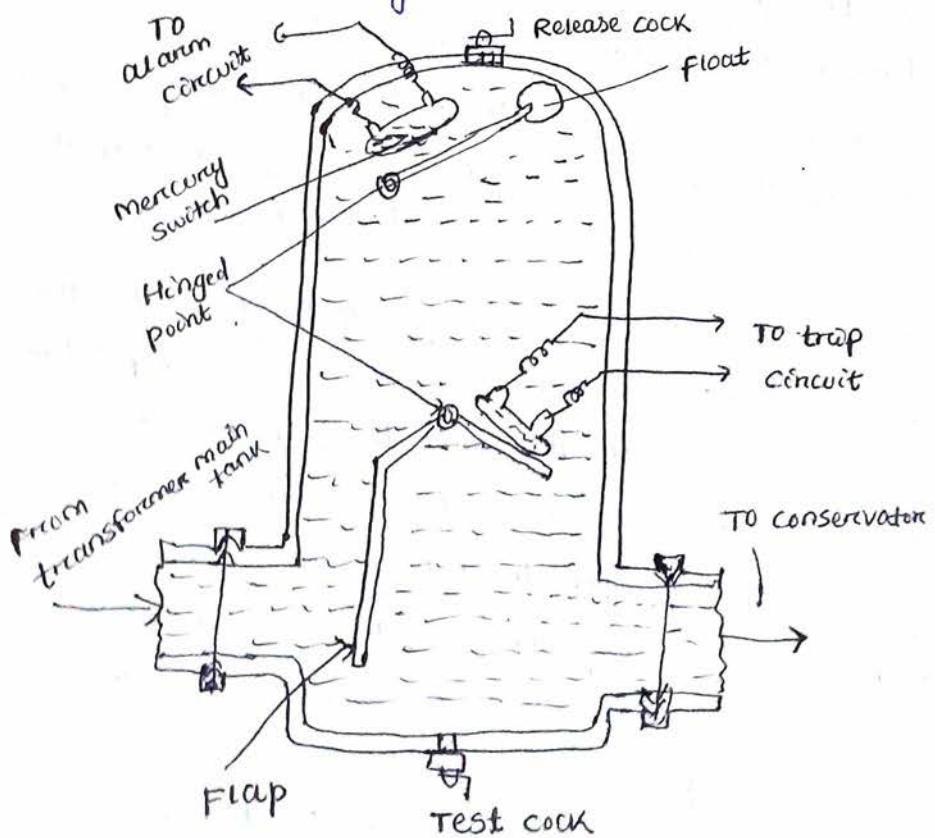
- ii) If a serious fault occurs in the transformer, an enormous amount of gas is generated in the main tank. The oil in the main tank rushes towards the conservator, such as the Buchholz relay and in doing so tilts the flap to close the contacts of mercury switch. This completes the trip circuit to open the circuit breaker controlling the transformer.

#### Advantages : —

- It is the simplest form of transformer protection.
- It detects the incipient faults at a stage much earlier than is possible with other forms of protection.

#### Dis-advantages : —

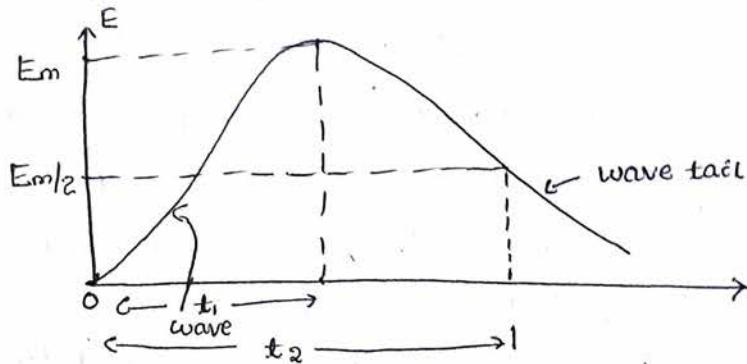
- It can only be used with oil immersed transformers equipped with conservator tanks.
- The device can detect only faults below oil level in the transformer. Therefore separate protection is needed for connecting cables.



## :- Protection Against over-voltage & Lightning :-

### Voltage Surge : -

A sudden rise in voltage for a very short duration on the power system is known as voltage surge or transient voltage. Transients or surges are of temporary nature & exist for a very short duration but they cause over voltage on the power system.



The voltage build-up is taken along y-axis and the time along x-axis.

It may be seen that lightning introduces a steep-fronted wave.

The steeper the wave front, the more rapid is the build-up of voltage at any point on the network.

### Causes of over-voltage : -

The over-voltages on a power system may be divided into 2 main categories.

#### Example :- ① Internal causes : -

- Switching surge → Arcing ground
- Insulation failure → Resonance

#### ② External causes : -

- Lightning

## Internal Causes of over-Voltage : -

### Switching Surge : - (unloaded line) :-

- When an open-ended line is connected to a source of voltage, travelling waves are set up which rapidly change the line.
- On reaching the open end of line, these waves are totally reflected without change of sign, thereby producing voltage-doubling at the ends.

### (For-loaded line)

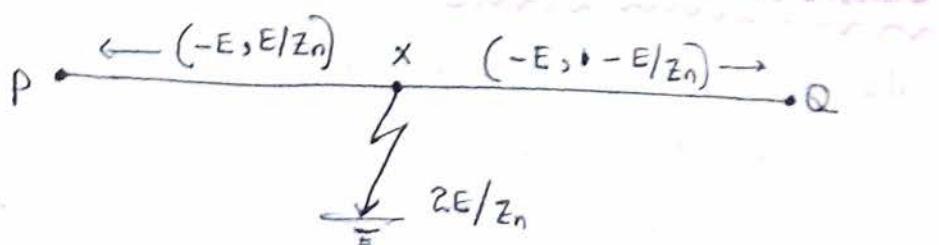
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F  
M → If a line carrying load is suddenly opened, a transient voltage of value given by  $E = i Z_0$  is set up.

where  $i \rightarrow$  is the instantaneous value of the current at the instant of opening of line.

$Z_0 \rightarrow$  is the natural or surge impedance of the line.

- It is obvious that transient voltage rise by the sudden interruption of load is not a function of the line voltage & therefore low voltage transmission line are liable to overvoltage of the same magnitude as high voltage system.

### Insulation Failure : -



- J  
F  
M → The most common case of insulation failure in a power system is the grounding of conductors, which may cause over voltage in the system.
- Hence a line at potential  $E'$  is earthed at point X.

- The earthing of the line causes two equal voltages of  $-E$  to travel along  $xQ$  &  $xP$  containing currents  $-E/Z_n$  &  $+E/Z_n$  respectively.
- Both these currents pass through  $x$  to earth. So that current to earth is  $2E/Z_n$ .

### Arcing Ground : -

- In early, the neutral of three phase lines was not earthed because of two advantages.
- In case of line-to-ground fault, the line is not put out of the action.
- Zero sequence currents are eliminated.

### Resonance : -

- Resonance in an electrical system occurs, when inductive reactance of circuit become equal to capacitive reactance.
- Under resonance, the impedance of the circuit is equal to the resistance of the circuit and the P.F is unity.
- Resonance causes high voltage in the electrical system.
- If generators e.m.f wave is distorted, the trouble of resonance may occur due to 5th or higher harmonics and in case of underground cables too.

### External causes of over voltage : - (Lightning)

- Lightning is a huge spark which is due to the electrical discharge taking place bet' the clouds within the same cloud and bet' the cloud and earth. Large no. of discharge occurs between or within clouds than to earth & enough of them terminate on to the earth and result in serious hazards.
- During uprush of warm moist air from earth, the friction bet' the air and the tiny particles of

Water causes the building up of charges.

- When drops of water are formed, the larger drop becomes positively charged and the smaller drop becomes negatively charged.
- When the drops of water accumulate, they form clouds, and hence cloud may possess either positive or negative depending upon the charges of drop of water they contain.
- The charge on a cloud may become so great that it may discharge to another cloud or to earth & we call this discharge as lightning.

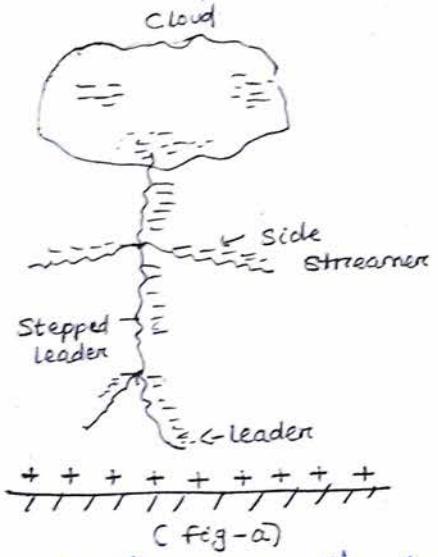
### Mechanism of Lightning Discharge :-

When a charged cloud passes over the earth, it induces equal & opposite charge on the earth. As the charge acquired by the cloud increases, the potential between cloud & earth increases and therefore gradient in the air increases. When the potential gradient is sufficient to break down the surrounding air, the lightning stroke starts.

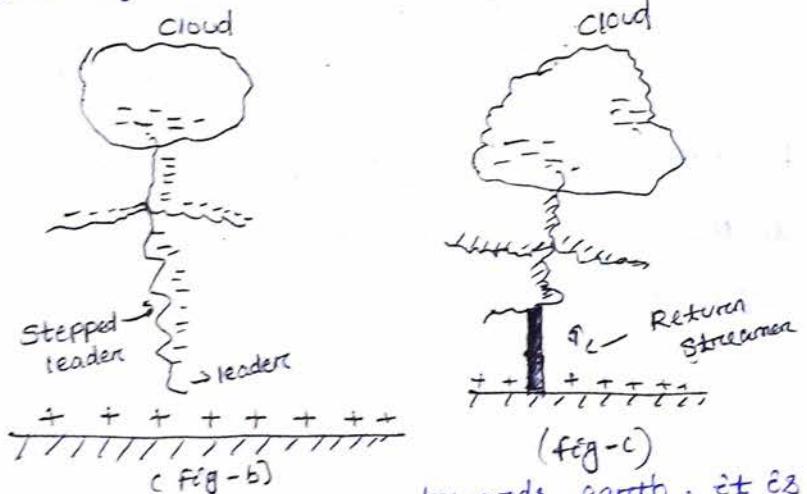
- As soon as the air near the cloud breaks down, a streamer called leader streamer or pilot streamer starts (from the cloud) towards the earth & carries charge with it. The leader streamer will continue its journey towards earth as long as the cloud, from which it is generated feels enough charge to it to maintain gradient at the tip of leader streamer above the strength of air.

If this gradient is not maintained, the leader streamer stops & the charge is dissipated without the

formation of a complete stroke.



→ As shown in the fig-B, the leader streamer continue its journey towards earth until it makes contact with earth or some object on the earth.



As the leader streamer moves towards earth, it is accompanied by points of luminescence which travel in jumps giving rise to stepped leader. The velocity of stepped leader exceeds one sixth of that of light and distance travelled in one step is about 50m.

→ The path of Leader streamer is a path of ionisation and therefore of complete breakdown of insulation. As the Leader streamer reaches near the earth, a return streamer shoots up from the earth to the cloud, following the same path as the main channel of the downward leader.

## Types of lightning Stroke :-

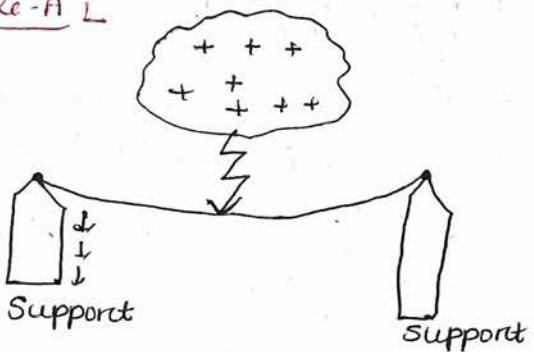
There are generally 2 types of lightning strokes.

- (i) Direct strokes      (ii) Indirect strokes

Direct strokes : — In the direct stroke, the lightning discharge is directly from the cloud to the subject equipment. EX: — An overhead line.

The direct strokes can be of 2 types.

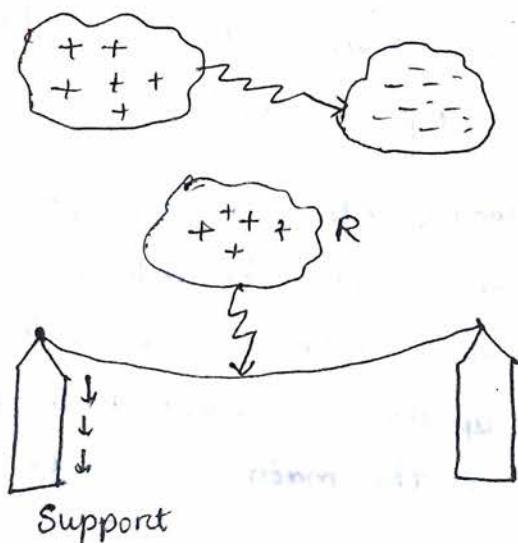
### Direct stroke - A



In stroke - A, the lightning discharge is from the cloud to the overhead line. The cloud will induce a charge of opposite sign on the tall object.

When the potential bet' the cloud and the line exceeds the break down value of air, the lightning discharge occurs between the cloud and line.

### Direct Stroke - B : —



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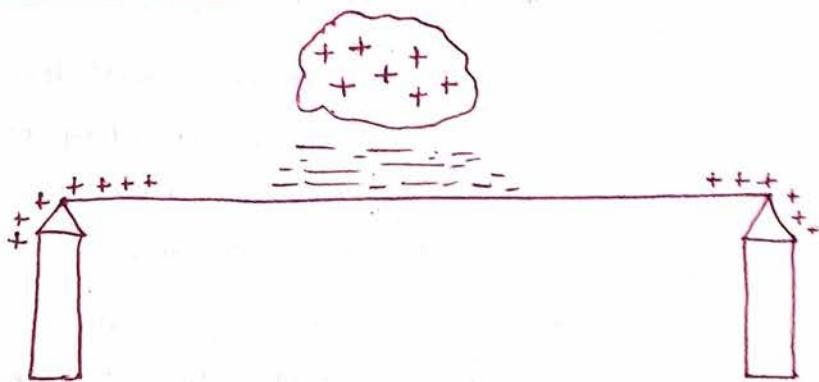
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In stroke-B the lightning discharge occurs on the overhead line as a result of stroke A betn the clouds.

There are 3 clouds P, Q & R having +ve, -ve & +ve charges respectively. The charge on the cloud Q is bound by cloud R. If the cloud P shifts too near the cloud Q, the lightning discharge will occur between them and charges on both these clouds disappear quickly.

The result is that charge on cloud R suddenly becomes free and it then discharges rapidly to earth, ignoring tall objects.

### Indirect Stroke:-



- Indirect strokes results from the electrostatically induced charges on the conductors due to the presence of charge clouds.
- A positively charged cloud is above the line & induces a -ve charge on the line by electrostatic induction.
- This -ve charge however will be only on that portion of the line right under the cloud and the portion of the line away from it will be +ve charged.
- This +ve charge leaks slowly to earth via the insulators to the earth.
- When the cloud discharge to earth or to the another cloud, the -ve charge on the wire is isolated as it can't flow quickly to earth over the insulators.

→ Thus the -ve charge rushes along the line in both direction in the form of travelling waves.

### Harful effects of lightning :-

- The travelling waves produced due to lightning stroke will shatter the insulators & may even wreck poles.
- If the travelling waves produced due to lightning hit the windings of a transformer or generator, it may cause considerable damage.
- The inductance of winding opposes any sudden passage of electric charge through it. Therefore the electric charges "piles up" against the transformer.
- It induces such an excessive pressure bet<sup>n</sup> the winding that the insulation may breakdown, resulting in the production of arc, while the normal voltage bet<sup>n</sup> the turns is never enough to start an arc.
- Once the insulation has broken down & an arc has been started by a momentary overvoltage, the line voltage is usually sufficient to maintain the arc long enough to severely damage the machine.
- If the arc is initiated in any part of the power-system by the lightning stroke, this arc will set up very disturbing oscillation in the line. This may damage the other equipment connected to the line.

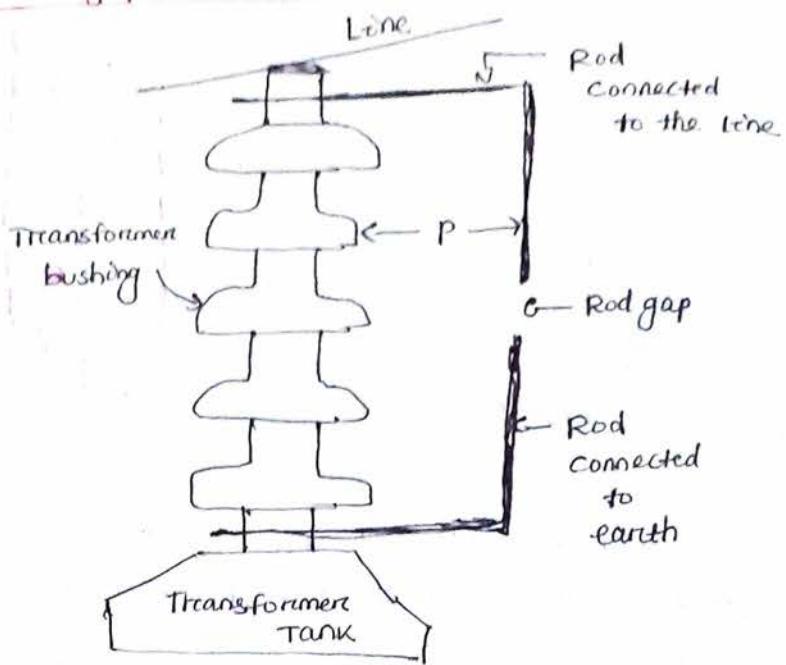
### Lightning Arresters :-

- A lightning arrester or a surge diverter is a protective device which conducts the high voltage surges on the power system to ground.

- The fig. shows the basic form of Surge diveters.
  - It consists of a spark gap in series with the non linear resistor.
  - one end of the diveter is connected to the terminal of the equipment to be protected & the other end is effectively grounded.
  - The length of the gap is so set that normal line voltage is not enough to cause an arc across the gap but a dangerously high voltage is breakdown the air insulation and form an arc.
  - The property of the non linear resistance is that its resistance decreases as the voltage increase & vice-versa.
- Operation: → Under normal operation, the lightning arrester is off the line i.e it conducts no current to earth or the gap is non conducting.
- On the occurrence of over voltage, the air insulation across the gap breaks down & an arc is formed, providing a low resistance path for the surge to the ground. In this way the excess charge on the line due to the surge is harmlessly conducted through the arrester to the ground instead of being sent back over the line.
  - As the gap sparks over due to over voltage, the arc would be a short ckt on the power system & may cause power follow current in the arrester.
  - Since the characteristics of resistor to offer high resistance to high voltage, it prevents the effect of a short cut. After the surge is over, the resistor offer high resistance to make the gap non conducting.

## Types of Lightning Arresters :-

### ① Rod gap Arrester :-



- It is a very simple type of diverters & consists of two 1.5 cm rods which are bent at a right angle with a gap in between.
- One rod is connected to the line & the other rod is connected to earth.
- The distance bet<sup>n</sup> the gap & insulator must not be less than one third of the gap length. So that the arc may not reach the insulator and damage it.
- The string of insulators for an overhead line on the bushing of transformer has frequently a rod gap across it.
- Under normal operating condition, the gap remains non conducting.
- On the occurrence of high voltage surge on the line, the gap sparks over & the surge current is conducted to earth.

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### ② Horn

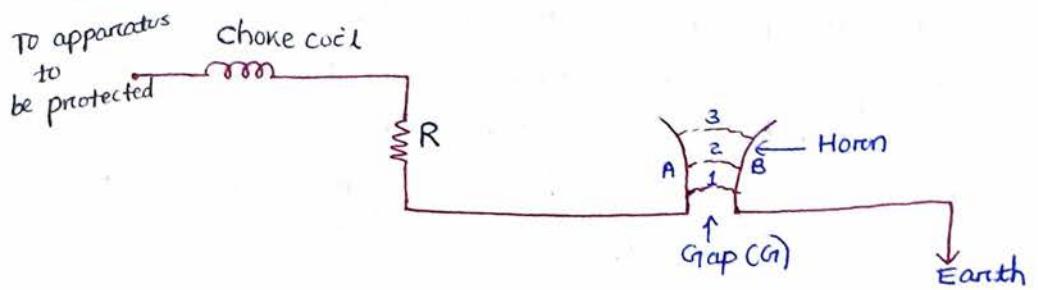
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### Dis-advantages : -

- After the surge is over, the arc in the gap is maintained by the normal supply voltage leading to a short cut in the system.
- The rod may get melt or get damaged due to the excessive heat produced by the arc.
- The climatic condition affect the performance of the rod-gap arresters .
- The polarity of the surge also affects the performance of these arresters .

### ② Horn-gap Arrestor : -



- It consists of two horn shaped metal rods A & B separated by a small air gap.
- The horns are so constructed that distance between them gradually increases towards the top.
- The horns are mounted on porcelain insulators.
- one end of the horn is connected to the line through a resistance R and choke coil 'L', while the other end is effectively grounded .
- The resistance R helps in limiting the follow current to a small value .
- The choke coil is so designed that it offers small reactance at normal power frequency but at a very high reactance at transient frequency .
- Thus the choke does not allow the transients to enter the apparatus to be protected .

- If the gap has the turns so adjusted that the supply voltage is not enough to cause an arc across the gap.
- Under normal conditions, the gap is maintained i.e. Nominal supply voltage is insufficient to break the arc between the gap.
- On occurrence of an over voltage spark-over takes place across the small gap G<sub>1</sub>.
- The heated air around the arc & magnetic effects of the arc cause the arc to travel up the gap.
- The arc moves progressively into position 1, 2, 3, ...
- At some position of the arc, the distance may be too great for the voltage to maintain the arc. Consequently the arc is extinguished.
- The excess charge on the line is thus conducted through the arrester to the ground.

Advantages :- → The arc is self clearing therefore this type of arrester doesn't cause short circuiting of the system after the surge is over or in the case of rod gap.

→ Series resistance helps in limiting the follow current to a small value.

Limitations :- → The bridging of gap by some external energy can render the device useless.

→ The setting of horngap likely to change due to corrosion or pitting. This adversely affects the performance of the arrester.

→ The time of operation is comparatively long.

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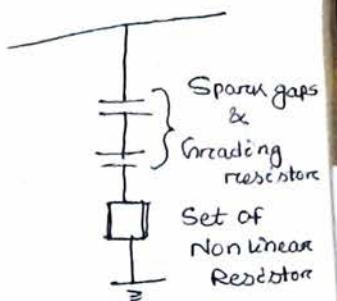
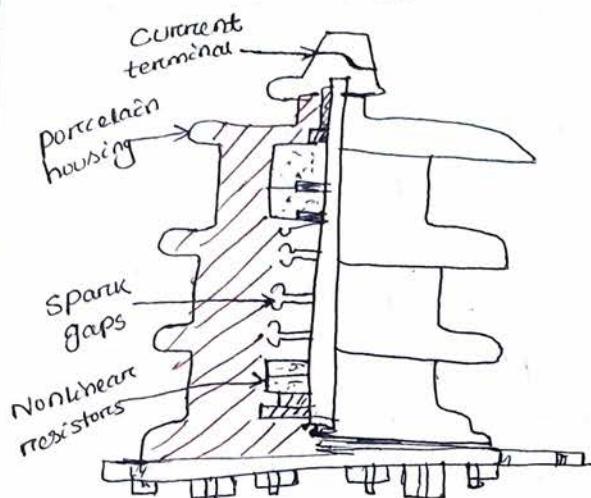
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### ③ Valve-type Arresters :-



- Valve type arresters incorporate non-linear and are extensively used on systems operating at high voltage.
- It consists of 2 assemblies : - i) Series spark gaps
- ii) Non-linear resistors discs in series.
- The non linear elements are connected in series with the spark gaps.
- The spark gap is a multiple assembly consisting of a number of identical spark gaps in series.
- Each gap consists of two electrode with a fixed gap spacing.
- The voltage distribution across the gap is linearised by means of additional resistance elements across the gaps.
- The spacing of series gaps is such that it will withstand the surge current to ground such as the non-linear resistor.
- The non-linear resistor discs are made of an inorganic compound such as Thyrite or manganite.
- These discs are connected in series.
- The non linear resistors have the property of offering a high resistance to current flow when normal system voltage is applied, but a low resistance to the flow of high surge current.

→ In other words, the resistance of these non-linear element decreases with the increase in current through them and vice-versa.

Operation : → under normal condition, the normal system voltage is insufficient to cause the breakdown of air gap assembly.

→ On the occurrence of over voltage, the breakdown of series spark gap takes place & the surge current is conducted to earth such as the non-linear resistors.

→ Since the magnitude of surge current is very large the non-linear element will offer a very low resistance to the passage of surge.

→ The result is that the surge will rapidly go to earth instead of being sent back over the line.

→ When the surge is over, the non-linear resistors assume high resistance to stop the flow of current.

Advantages : → They provide very effective protection against surges.

→ They operate very rapidly taking less than a second.

→ The impulse ratio is practically unit.

Limitations : -

→ They may fail to check the surges of very steep wave front from reaching the terminal apparatus.

→ Their performance is adversely affected by the entry of moisture into the enclosure.

Application : - According to the application valve type insulators is of 2 types.

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protection of important equipment in power stations  
operated voltage upto 220 KV.

- (ii) The line type arresters are also used for station handling voltages upto 66 KV.

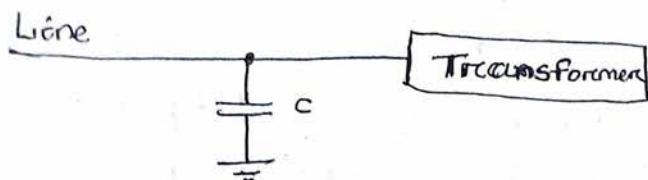
### Surge Absorber: -

A surge absorber is a protective device which reduces the steepness of wave front of a surge by absorbing surge energy.

- The surge diverter diverts the surge to the earth. But the surge absorber absorb the surge energy.

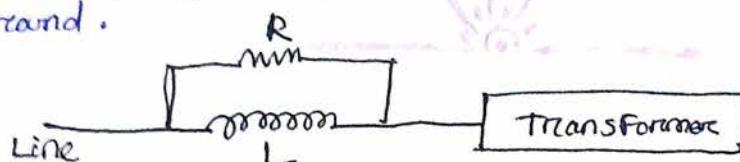
The few cases of surge absorptions are discussed below.

(i)



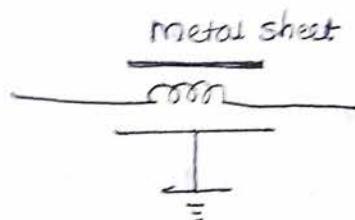
- Here a condenser is connected bet' the Line and earth act as a Surge absorber.
- Since the reactance of a conductor is inversely proportional to frequency, it will be low at high frequency and high at low frequency.
- Since the surges are of high frequency, the capacitor acts as short cut and passes them directly to earth.
- For power frequency, the reactance of the capacitor is very high & practically no current flows to the ground.

(ii)



- This type of absorber consists of a parallel combination of choke & resistance connected in series with the line.
- The choke offers high reactance to surge frequency.
- The surges are therefore forced to flow through the resistance 'R' where they are dissipated.

(III)

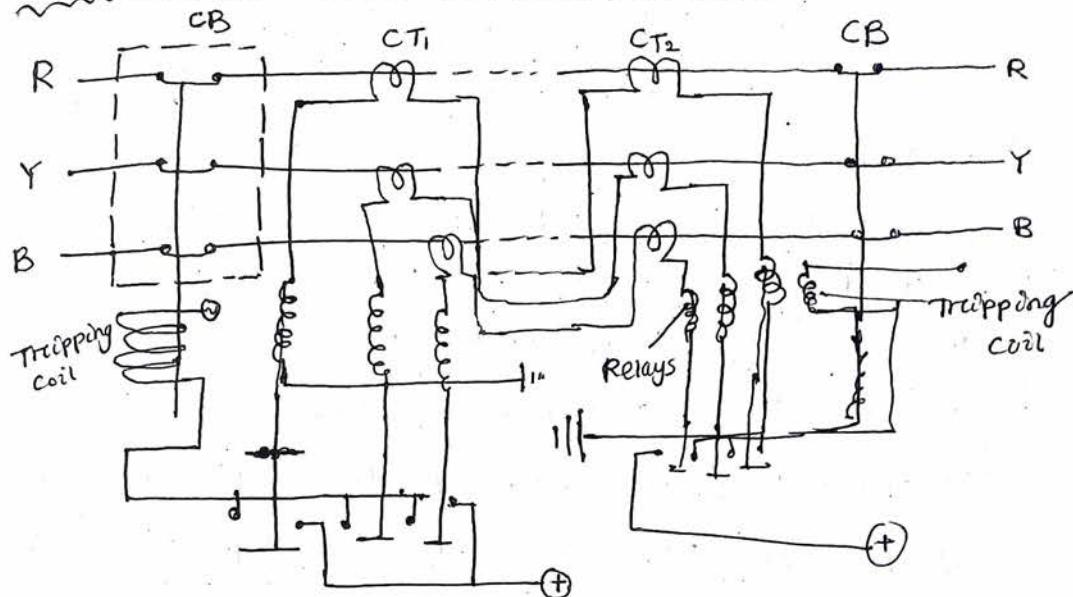


- This type of surge absorber is called as Ferranti surge absorber.
- It consists of an air-cored conductor connected in series with the line.
- The inductor is surrounded by but insulated from an earthed metallic sheet called dissipator.
- This arrangement is equivalent to transformer with secondary short circuited.
- The inductor forms the primary and the dissipator forms the short circuited secondary.
- The energy of the surge is used up in the form of heat generated in the dissipator due to transformation action.
- This type of surge is mainly used for the protection of transformer.



\* Impulse Ratio =  $\frac{\text{Breakdown voltage under surge condition}}{\text{Breakdown voltage under low frequency conditions}}$

Mercz - price Voltage balance system :-



- Mercz - price system is a differential system which is applied to feeder protection and utilizes the principle of voltage balance.
- In 3-phase system each conductor has its own pair of CTs & relays.
- The secondaries of CTs are connected in series by means of pilot wire.
- During normal condition, there is equal current will flow at two different ends of the feeder. So induced voltage in the secondaries of CTs are equal.
- As the secondaries are connected in the opposition, their secondary emfs are equalised resulting into no circulating current in the relays.
- During the fault condition, current differs at two ends. So induced emf in the secondaries will differ and Circulating current will flow through the pilot wires & relays & the faulty feeder will be isolated.

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- The CTS of this system is to be balanced ~~exactly~~ not only initially but permanently.
  - The induced voltage shall be proportional to the current and it is accomplished by employing distributed air gap CTS.
  - The pilot wires are usually form of a 3-core cable of size  $7/0.73\text{ mm}^2$ .

#### Advantages : —

- This system is independent of operating voltage and fault power factor.
- This system can be employed for protection of both ring main as well as parallel feeders.
- It provides instantaneous protection for ground faults.
- It provides instantaneous relaying by reducing the amount of damage to overhead conductors resulting from arcing faults.

#### Dis-advantages : —

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- It does not provide back-up protection or over-load protection.
  - It is very difficult to balance the secondaries of CTS.
  - The system will not operate in case a break in the pilot wires.
  - It is very expensive.
  - There is no time delay.