

**LECTURE NOTES**  
On  
**Switch Gear And Protective Devices**  
On  
6th Semester of Electrical Engineering Branch

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Chapter 11 Introduction to Switch ||  
|| Gear ||  
{ SGPD }

- \* Switch Gear :- The apparatus use for switching, controlling & protecting the electrical ckt & equipment is known as switch gear.  
+ It is basically consist of switching and protecting device such as switch, bus, ckt breakers & relays etc.
- + During normal operating cond' switch gear permit to s/w on or off the electrical equipment.
- + In case of fault cond' the s/w gear detect the fault & disconnect the unhealthy section from the system.

⇒ Essential features of switch gear :-

The essential features of s/w gear are:-

1. Complete reliability :-

The requirement of s/w gear is more & more important bcz of the interconnection & increasing capacity of generating station.  
+ S/w gear is use to the power system to improve reliability. If the fault occurred on an any part of power system they must operate to <sup>isolate</sup> the power section from the normal section.

2. Absolutely certain discrimination :-

In fault occurs on any section of power system the s/w gear must be the

able to discrimination b/w the faulty

section & the healthy section.

→ It will ensure continuity of power supply.

### 3. Quick Operation :-

When fault occurs at any part of the power system the S/IW gear must operates quickly so that no damage is done to generator, H/B & other equipment.

→ If the fault is not clear by S/IW gear quickly if it is spread into healthy part & thus complete shut-down of the system occurs.

### 4. Provision for manual control :-

A S/IW gear must have provision for manual control. In case the electrical (Electronics) control fails the necessary op. can be carried out through manual

control.

5. Provision for Instrument :-  
There must be provision for instrument which may be required.

### \* Switch Gear Equipment :-

The S/IW gears covers all the apparatus & equipment employed for switching, protecting, controlling the electrical power system.

→ It includes S/IW, buses, circuit breaker, isolators, relay, potential H/B (PT), CT & lightning arrestor etc.

- ⇒ Switch :- SW is a <sup>most</sup> simplest device to on or off the electrical ckt & equipments.
- ⇒ It is design to operate manually and can't protect to electrical system for any fault.
- ⇒ The SW are use for low voltage application following
- ⇒ The SW may be classified into the following category

- (i) Air SW
- (ii) Oil SW

#### (a) Air break switch :-

- It is an air SW & it is design to open a ckt under load.
- In this SW the special arcing horns are provided to open the SW.
- Arcing horns are piece of metal bar which arc off form during opening operation.
- As the SW open the horns are spread farther and farther so the arc is interrupted. This SW generally use out-door.

#### (b) Isolator and disconnecting switch :-

- This SW is design to open a ckt under no load. Its main purpose is to isolate one portion of the ckt from the other.

- This SW are generally use on both side of ckt breakers in order to repair & replacement of ckt breakers.

#### (c) Oil switch :-

The contacts of this SW are open under oil i.e. t/o oil.

→ These switches are used for ckt of HV & large current carrying capacity.

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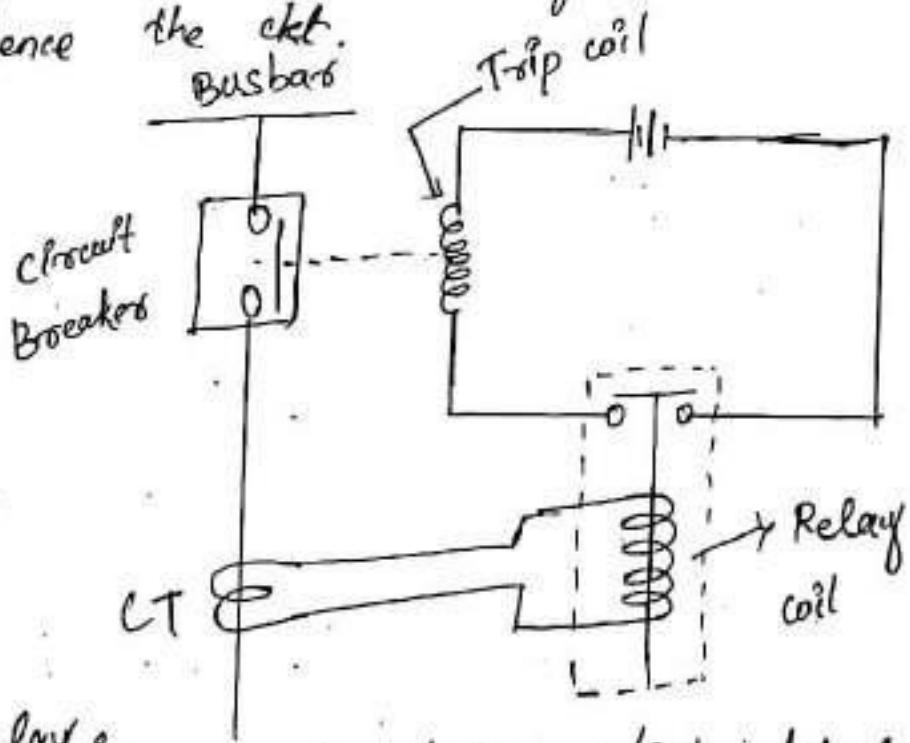
\* Fuse :- (fault condition)

- A fuse is a short piece of wire is meltz when excessive current flow through it.
- It is inserted in series with the ckt.
- Under normal operating condition the fuse element is at a temperature below its melting point, so it carries normal load current without over heating.
- When a short ckt overload occurs the current through the fuse element is increase, this rises the temperature of the fuse element meltz.

\* Circuit breaker :-

- A ckt breaker is an equipment which can open or close a ckt under all condition that is no load, full load & fault (auto) condition.
- It is design to operate manually under normal condition & automatically under fault condition.
- The circuit breaker consist of 2 types of contact;
  - 1) Moving contact
  - 2) Fixed contact

- + Under normal operation cond<sup>n</sup> the 1 CoB. remain closed and it carries the normal ball load current, in this case the EMF at the secondary end of the CT is insufficient to operate the trip coil at the breaker.
- + When a fault occurs over current in the CT primary and increase the emf at the secondary end these energies the trip coil at the breaker & the moving contact are pulled down thus the opening of contact & hence the ckt.



\* Relay :-  
 A relay is a device which detect the fault & supply information to the ckt breaker. for ckt interruption.

- It can be divided into 3 parts ;
- i) The primary cond of the CT which is connected in series with the ckt.
- ii) The second ckt is the secondary cond of the CT which is conn<sup>n</sup> to the relay operating coil

iii) The 3rd ckt is the tripping ckt which consist of a source to supply the trip coil.

\* Busbar Arrangement :-

When a no. of generators or feeders operating at a same voltage and directly conn'c electrically, busbars are used as the common electrical component.

\* The busbars are copper rods or thin tubes which are operated at constant voltage.

\* There are some imp. busbar arrangement used in power station, these are :-

### of Single busbar system :-

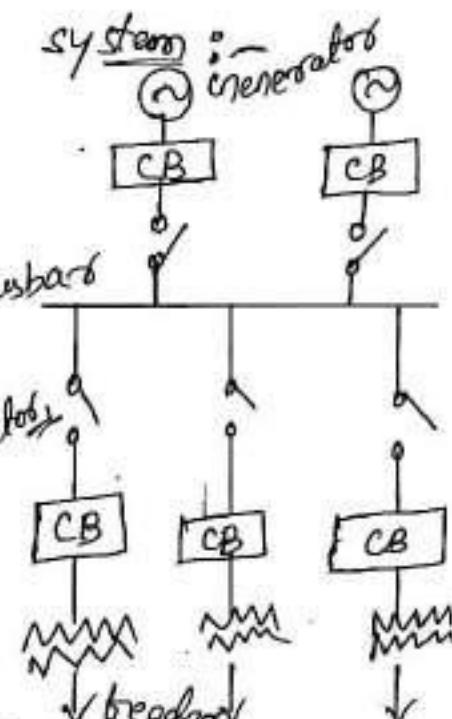
\* The single busbar system has the simplest design.

\* and is use for the power busbar station.

\* It is also used in small <sup>isolators</sup> <sup>outdoor station</sup> having few no. of out going & incoming feeders & generators.

\* Here the generators, out going lines and tbt are connected to the single busbar.

\* Each generator & feeder is controlled by a ckt breaker. The isolators permits to isolate the generator & feeder & ckt breakers from the busbar for maintenance.



7) Advantage :-

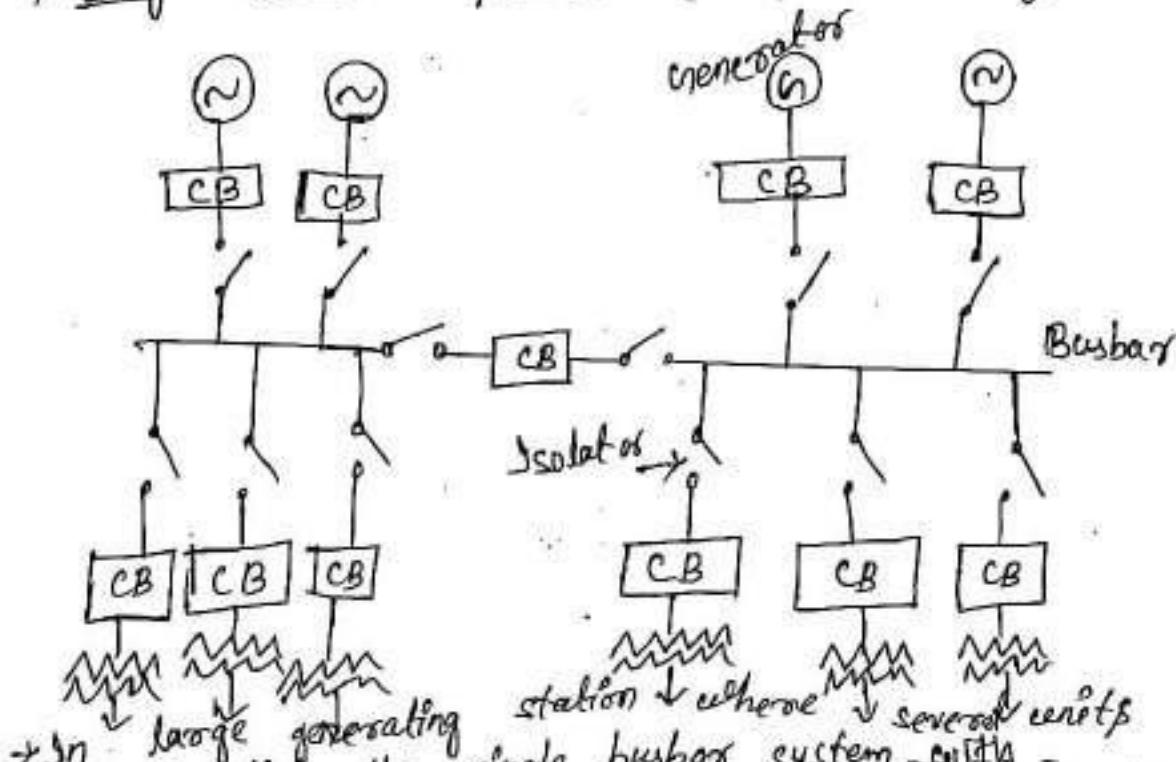
7) This type of arrangement has low initial cost, less maintenance & simple operation.

7) Disadvantage :-

7) The busbar can't be clean, repaired or tested without de-energising the whole system.

7) If a fault occurs in a busbar there is complete interruption of the supply.

8) Single busbar system with sectionalization :-



7) In large generating station where several units are installed, the single busbar system with sectionalization bus is used, so that the fault on any section of the busbar will not cause complete short down.

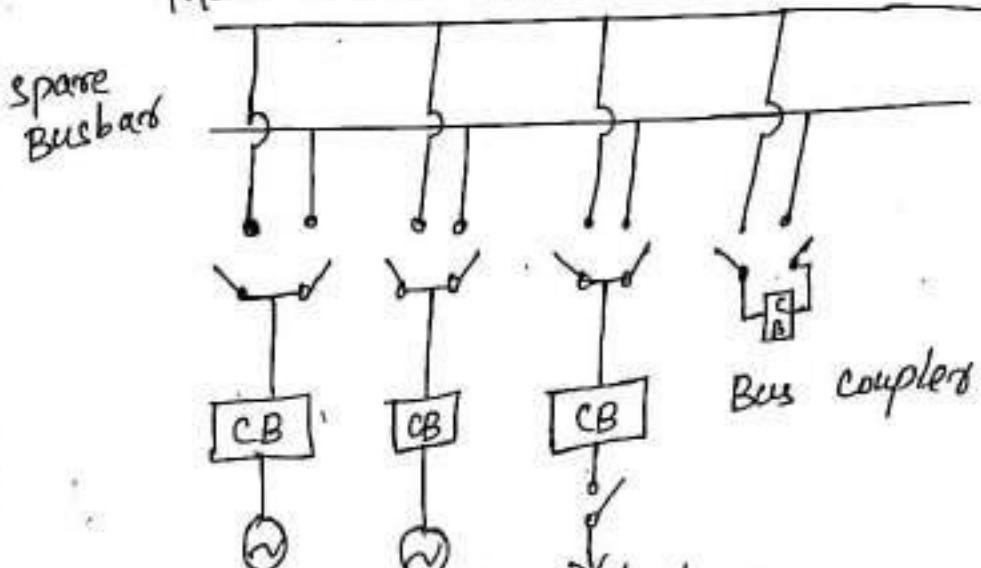
7) Here the busbar is divided into 2 sections & connected by a circuit breaker & isolator.

8) Advantage :- If a fault occurs on any section of the busbar that can be isolated without affecting the supply to the other section.

8) This permits the use of CBs of lower capacity in the feeder.

8) Repair & maintenance of any section of the busbar can be carried out by de-energized other section.

## Main busbar $\longleftrightarrow$ Duplicate Busbar System



- The system consist of 2 busbar ;
  - (i) Main Busbar
  - (ii) Spare (add) "
- Each generators & feeders conn to either busbar with the help of bus couplers, which is consist of CB. & isolators
- Advantage:-
  - If repair & maintenance to be carried on the main busbar. the supply need not be interrupt as the certain load can be transferred to the spare busbar.
  - The testing of feeders & CB can be done by putting them on the spare busbar.
  - If a fault occurs in <sup>one</sup> busbar the continuity of the supply to the cb can be maintained by transferring it to the other busbar.

→ Switch gear Accommodation.—  
 Depending upon the voltage to be handle the s/w gear may be classified into 2 type : (a) Out-door type  
 (b) In-door "

Out-door :-  
For the voltage beyond 66KV SW gear equipment are installed out-door.  
It is because for such voltage (HV) the clearance b/w conductors & the space required for SW, CB, fuses & other equipment becomes so large.

(b) In-door types -

The voltage below 66KV SW gear is generally installed in-door.

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\* Short Circuit :-

When ever a fault occurs on a n/w such that a large current flows in one or more phases a short ckt is to be occurs.  
When a short ckt occurs a heavy current called short ckt current flowing through the circuit.

\* Cause of short ckt :-

A short ckt in a power system is the result of some kind of abnormal condition in the system.  
It may be cause due to external or internal effect.

(a) Internal Effect :- The internal effects are caused by break-down of equipment or transmission like, deterioration of insulation of a generator, fuses etc.  
Such trouble may be due to ageing of insulation inadequate design or improper installation.

(b) External effect :- The external effect causing short ckt includes insulation failure due to lightning, search over-load.

of equipment and mech. damage by public.

\* Effect of short ckt :- When a short ckt occurs the current in the system increase to an abnormal high value & decreased to a low value.

+ The heavy current due to the short ckt causes excessive heating which may result in fire. Some times the short ckt causes damage to the system.

\* Fault in a power system :-

+ A Fault occurs when a 2 or more conductors that normally operate at a Potential difference come in contact with each other

+ The fault in a 3 $\phi$  system can be classified into 2 main categories,

(1) Symmetrical fault

(2) Unsymmetrical ,

(1) Symmetrical fault :-

The fault which gives rise to the symmetrical fault current (i.e. equal fault current with  $120^\circ$  displacement) is called symmetrical fault.

+ The most common example of this system is when all the 3 conductors of the 3 $\phi$  line are brought together simultaneously into a short ckt condition.

(2) Un-symmetrical fault :-

which give rise to unsymmetrical current (i.e. unequal line current with unequal displacement) are called Unsymmetrical fault.

1) This fault. are :  
2) single line to ground fault (22) double line to ground  
3) Line to line fault

\* Symmetrical fault :-

The fault which gives rise to the symmetrical fault current (i.e. equal fault current with  $120^\circ$  displacement) is called symmetrical fault.

Ex:- 3  $\phi$  fault.

\* Limitation of fault current :-

Excessive heating

Resulting fire or explo

Reduction in voltage causes mis-operation of rotating a machine.

Over voltage if generator protection system operates.

\* Percentage Reactance :-

The reactance of a generator, t/f, reactor is usually expressed in percentage reactance.

The percentage reactance of a ckt is defined as the total voltage drop in the ckt when the full load current is flowing.

$$\% x = \frac{I x}{V} \times 100$$

where,  $I \rightarrow$  full load current

$V \rightarrow$  Phase voltage

$x \rightarrow$  Reactance in ohm per phase

\* Percentage Resistance :-

The resistance of a generator, t/f, reactor is usually expressed in % resistance.

The % resistance of a ckt is defined as

the total voltage drop in the cle when  
the resistive full load current is flowing.

$$\% R = \frac{IR}{V} \times 100$$

\* Percentage Impedance :- effect of % of resistance  
It is the sum of % of resistance  
and % reactance.

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\* % x :-

$$\% x = \frac{Ix}{V} \times 100$$

$$\Rightarrow x = \frac{\% x V}{I \times 100}$$

$$\Rightarrow x = \frac{\% x \times V \times V}{I \times 100 \times V}$$

$$\Rightarrow x = \frac{\% x \times \frac{V}{1000} \times \frac{V}{1000} \times 1000 \times 1000}{I \times 100 \times V}$$

$$\Rightarrow x = \frac{\% x \times KV \times KV \times 1000}{I \times 100 \times KV}$$

$$\left[ \frac{V}{1000} \neq KV \right]$$

$$\Rightarrow x = \frac{(\% x KV)^2 \times 1000}{KV \times 100}$$

$$\Rightarrow x = \frac{\% x (KV)^2 \times 10}{KV}$$

$$\Rightarrow \boxed{\% x = \frac{x \times KV}{10 \times (KV)^2}}$$

\* Base kVA :-

The % x of diff m/c depends  
upon the kVA ratings.

Generally the various equipment use in th

power system have diff' KVA rating, therefore it is necessary to find the % $\chi$  of all the elements on a common KVA rating. These common KVA rating is known as Base KVA.

$$\text{The } \% \chi \text{ at base KVA} = \frac{\text{Base KVA}}{\text{Rated KVA}} \times \% \chi \text{ of rated KVA}$$

\* Short ckt. KVA :-

$$\text{S.C. KVA} = \text{Base KVA} \times \frac{100}{\% \chi}$$

$$\text{Short ckt current (I}_{sc}\text{)} = \frac{V}{\chi}$$

$$\Rightarrow I_{sc} = \frac{V \times I \times 100}{\% \chi \times \chi} \quad [\because \chi = \frac{\% \chi \times V}{100 I}]$$

$$\Rightarrow I_{sc} = \frac{I \times 100}{\% \chi}$$

$$\text{We know, short ckt KVA} = \frac{3V I_{sc}}{1000}$$

\* Put the value of  $I_{sc}$  & we get;

$$= \frac{3V I \times 100}{1000 \times \% \chi}$$

$$\text{S.C. KVA} = \text{Base KVA} \times \frac{100}{\% \chi}$$

\* Steps for symmetrical fault calculation :-

- \* Draw the single line diagram indicated all rated quantities.
- \* Choose a convenient base KVA & convert all  $\% \chi$  to this base value.
- \* Draw the reactance diagram using the new reactance obtained & find the total  $\% \chi$ .

- + Find the full load current corresponding to the full load base KVA.
- + Find the short ckt current ( $I_{sc}$ ) by using the formula;  $I_{sc} = \frac{I \times 100}{\% \chi}$
- + Find the S.C. KVA by using the formula i.e.  $S.C. KVA = \text{Base KVA} \times \frac{100}{\% \chi}$
- Q The figure shows of a 3φ system;  
Find  $I_{sc}$  that will flow into a complete 3φ ckt at fault (F).

\* Base KVA = 20,000

+ We know,

$\frac{600}{\% \chi} \text{ of base KVA} = \frac{\text{Base KVA}}{\text{Rated KVA}} \times \% \chi \text{ of rated KVA}$

$$= \frac{20,000}{15,000} \times 30\%$$

+ For 'A':-  $= 40\%$

For 'B':-  $= 50\%$

$$\% \chi \text{ of Base KVA} = \frac{20,000}{20,000} \times 50\%$$

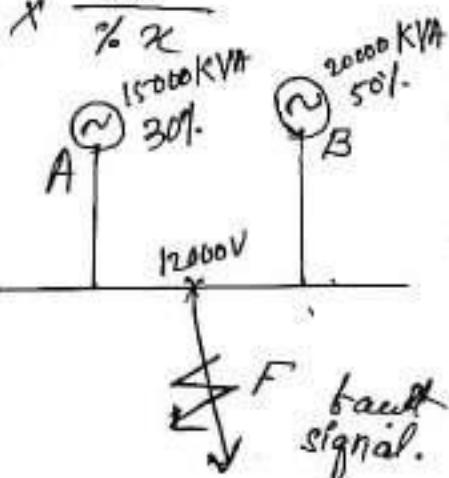
$$= 50\%$$

+ Total  $\% \chi = 50\% / 40\%$

$$= \frac{50 \times 40}{50 + 40} = 22.22$$

+  $I = \frac{\text{Base KVA}}{\sqrt{3} \times \sqrt{\chi}}$

$$\Rightarrow I = \frac{20,000 \times 10^3}{\sqrt{3} \times 12000} = 962.25 \text{ Amp.}$$



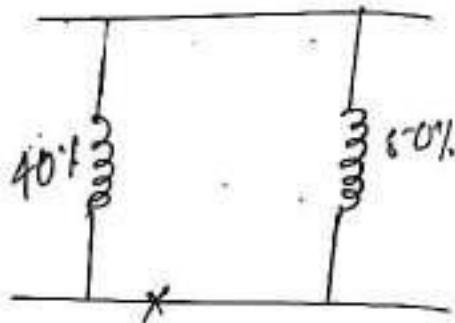
$$7) \text{ Short ckt current } (I_{sc}) = \frac{I \times 100}{x\%}$$

$$\Rightarrow I_{sc} = \frac{902.25 \times 10^0}{22.22} = 4330.5 \text{ Amps}$$

$$7) \text{ Short ckt KVA} = \text{Base KVA} \times \frac{100}{x\%}$$

$$= 20,000 \times \frac{100}{22.22}$$

$$= 90009.00$$



1) Assume;

Base KVA = 10,000

for 'A' Alternator,

$\therefore \% \text{ at base KVA} = \frac{\text{Base KVA}}{\text{Rated KVA}} \times 100 \text{ at rated KVA}$

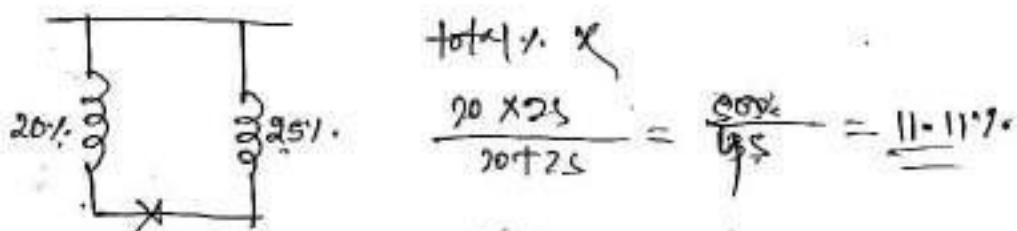
$$= \frac{10000}{15000} \times 100$$

$$= 66.67\%$$

for 'B' Alternator,

$\therefore \% \text{ at base KVA} = \frac{10000}{20000} \times 500$

$$= 25\%$$



$$\Rightarrow I = \frac{\text{Base KVA} \times 10^3}{V_3 \times V} = \frac{10000 \times 10^3}{V_3 \times 12 \times 10^3} = 481.125.$$

$$\text{S.C. } \mathfrak{I} = \frac{I \times 100}{V \times X} = \frac{481.125 \times 100}{11.11} = 4330.5 \text{ A}$$

$$\text{S.C. KVA} = \frac{\text{Base KVA} \times 100}{V \times X} = \frac{10,000 \times 100}{11.11} = 90009$$

A 3Ø transmission line operated at 10kV & having a R of 1Ω & X of 4Ω is connected to the generating station <sup>busbar</sup> through 5MVA step-up t/t, having a X of 5%. The busbars are supplied by a 10MVA alternator having 10% reactance. Calculate the s.c. kVA fed to the symmetrical b/w phases if (i) occurs (i) At the load & other transmission line voltage terminal of the t/t.

$$V = 10 \text{ kV} \quad 5 \text{ MVA} = 5 \times 10^6 \text{ VA} \\ = 5,000,000 \\ = 5000 \text{ KVA}$$

$$10 \text{ MVA} = 10,000 \text{ KVA}$$

we know,

$$\begin{aligned}\rightarrow \% X &= \frac{X \times \text{KVA}}{10 \times (\text{KV})^2} \\ &= \frac{4 \times 10,000}{10 \times (10)^2} \\ &= 40\%.\end{aligned}$$

$$\begin{aligned}\rightarrow \% R &= \frac{R \times \text{KVA}}{10 \times (\text{KV})^2} \\ &= \frac{1 \times 10,000}{10 \times (10)^2} = 10\%.\end{aligned}$$

For alternator :-

$$\text{Base KVA} = 10 \times 10^3 \text{ KVA}$$

$$\begin{aligned}\% X \text{ at base KVA} &= \frac{\text{Base KVA}}{\text{RATED KVA}} \times \% X \text{ at rated KVA} \\ &= \frac{10 \times 10^3}{10 \times 10^3} \times 10\%.\end{aligned}$$

For transformer :-

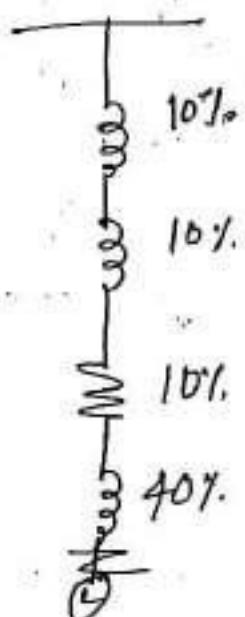
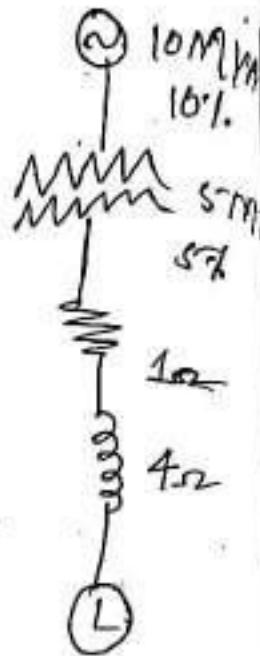
$$\% X \text{ at base KVA} = \frac{10 \times 10^3}{10 \times 10^3} \times 5\%.$$

Total resistance (%R) = 10%.

$$\begin{aligned}\% X &= 10\% + 10\% + 40\% \\ &= 60\%\end{aligned}$$

$$\begin{aligned}\% \text{ Impedance } (Z\%) &= \sqrt{(10)^2 + (60)^2} \\ &= 60.82\%\end{aligned}$$

$$\begin{aligned}\text{Current (I)} &= \frac{P}{V_B \times V} \\ &= \frac{10 \times 10^3}{10 \times 10} = 577.35 \text{ Amp}\end{aligned}$$



$$\gamma \text{ Short ckt current } (I_{sc}) = \frac{I \times 100}{Z\%} \\ = \frac{577.35 \times 100}{60.82}$$

$$= 949.246 \text{ Amp}$$

$$\gamma \text{ Short ckt KVA} = \text{Base KVA} \times \frac{100}{Z\%} \\ = 10,000 \times \frac{100}{60.82} \\ = 16441.9$$

$$\gamma \text{ } \% X \text{ total} = 10\% + 10\% = 20\%$$

$$\gamma I_{sc} = \frac{I \times 100}{Z\%} \\ = \frac{577.35 \times 100}{20} \\ = 2886.75 \text{ Amp}$$

$$\gamma \text{ S.C. KVA} = 10,000 \times \frac{100}{Z\%} \\ = 10,000 \times \frac{100}{20} \\ = 50,000$$

1) + plant capacity of a 3φ generating station consist of two 10,000 KVA generators of reactance 12% each & one 5,000 KVA generator of reactance 18%. The generators are connected to the station busbar from which load is taken through three 5,000 KVA step up CTs each having  $X = 5\%$ . Determine the max<sup>m</sup> fault MVA which the CB  $V = 11 \text{ kV}$

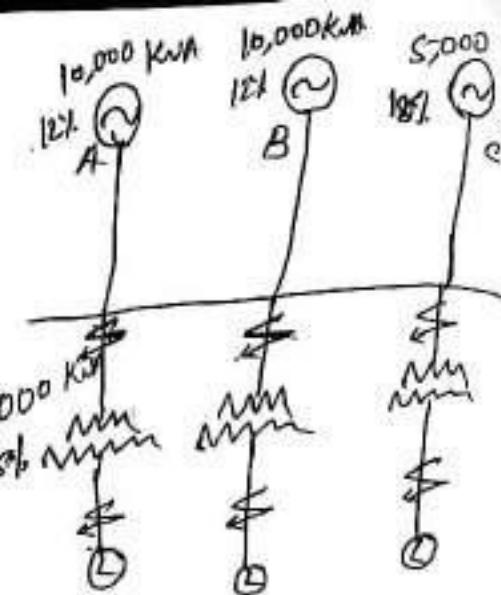
- low voltage side
- High voltage side of the CT

Base KVA = 10,000

For 'A' alternator;

$\gamma$  % x at Base KVA =

$$\frac{10,000}{10,000} \times 12\% = 12\%.$$



For 'B' alternator;

$$\gamma \% x \text{ at Base KVA} = \frac{10,000}{10,000} \times 12\% = 12\%.$$

For 'C' alternator;

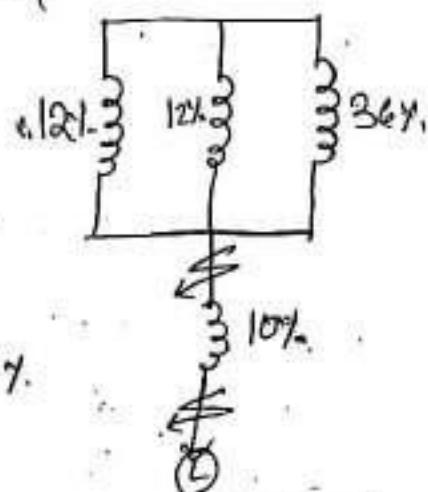
$$\gamma \% x \text{ at Base KVA} = \frac{10,000}{5,000} \times 18\% = 36\%.$$

For transformer;

$$\gamma \% x \text{ at Base KVA} = \frac{10,000}{5,000} \times 5\% = 10\%.$$

$$12\% / 12\% / 36\%.$$

$$\frac{12 \times 12}{12+12} = \frac{144}{24} = 6\%.$$

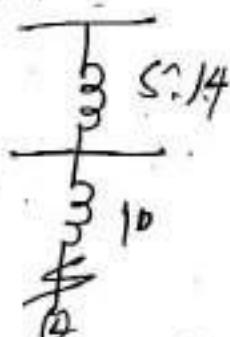


$$\frac{\text{Total Reactance}}{\text{Base KVA}} = \frac{6 \times 36}{10,000} = 0.216 = 0.147.$$

Total

$$\text{reactance} = 0.147 + 0.10 = 0.247.$$

For low voltage side



$$\gamma I = \frac{10,000 \times 10^3}{\sqrt{3} \times 11 \times 10^3} = 524.86$$

$$\gamma I_{SC} = \frac{524.86 \times 100}{15.14} = 3966.7 \text{ Amp}$$

$$\gamma S.C. \text{ kVA} = 10,000 \times \frac{100}{15.14} = 66050.19 \text{ kVA}$$

$$\gamma \text{ For low voltage side} = \frac{10,000 \times 100}{5.14} = 194552.52 = 194.55 \text{ MVA}$$

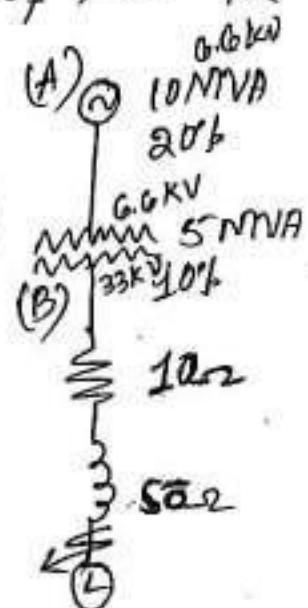
$$\gamma \text{ For high voltage side} = 6605 \text{ MVA}$$

Q1

A 10MVA, 6.6KV 3φ Y-conn alternator having  $X$  of 20% is conn through a 5MVA 6.6KV 33KV  $\frac{t_b}{X}$  of 10%  $X$  to a transmission line having a  $R \& X$  of per conductor per km of 0.22 & 1.2 respectively. A 50km along the line, a S.C. occurs betw the 3 conductors, find the S.C. current.

$$\text{For total } 50\text{km} \Rightarrow 0.2 \times 50 = 10.2 = R$$

$$X = 1 \times 50 = 50.2$$



→ For alternator,

$$10\text{MVA} = 10,000\text{KVA}$$

→ For  $t_b$ ,

$$5\text{-MVA} = 5,000\text{KVA}$$

→ Assume, Base kVA = 10,000kVA

$$(A)\% X \text{ at Base kVA} = \frac{10,000}{10,000} \times 20\% = 20\%.$$

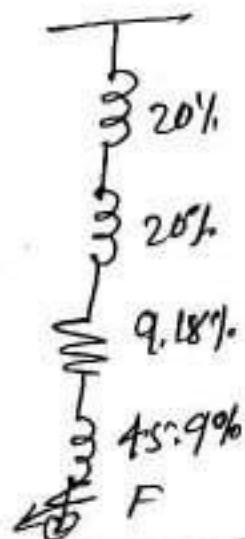
$$(B)\% X \text{ at Base kVA} = \frac{10,000}{5,000} \times 10\% = 20\%.$$

→ We know,

$$\% X = \frac{X \text{ at Base}}{10 X (KV)^2}$$

$$\% X = \frac{50 \times 10,000}{10 \times (33)^2} = 45.9\%$$

$$\% R = \frac{R \times KVA}{10 X (KV)^2} = \frac{10 \times 10,000}{10 \times 33^2} = 9.18\%$$



$$9. x_{\text{total}} = 20 + 20 + 48.9 = 88.9$$

$$\begin{aligned} \gamma \quad \% Z &= \sqrt{(R)^2 + (X)^2} \\ &= \sqrt{(0.18)^2 + (88.9)^2} \\ &= 86.369\% = 86.34\% \end{aligned}$$

$$\begin{aligned} \gamma \quad \text{current (I)} &= \frac{P}{\sqrt{3} \times V} \\ &= \frac{10,000}{\sqrt{3} \times 0.6} = 874.77 \text{ A} \end{aligned}$$

$$\begin{aligned} \gamma \quad \text{Short ckt current (I}_{sc}\text{)} &= \frac{I \times 100}{\gamma Z\%} \\ \Rightarrow I_{sc} &= \frac{874.77 \times 100}{86.34\%} = 10126.9 \text{ A} \end{aligned}$$

$$\begin{aligned} \gamma \quad \text{Short ckt KVA} &= \text{Base KVA} \times \frac{100}{\gamma Z\%} \\ &= 10,000 \times \frac{100}{86.34\%} \\ &= 11578.1 \text{ KVA} \\ &= 11.578 \text{ MVA} \end{aligned}$$

\*Reactor control of  $I_{sc}$ :

The  $I_{sc}$  can be limited by increasing the total system impedance, but practically a power system has large reactance as compare to its resistance so, generally addition of reactance are preferred over addition of resistance.

The reactors which are used for limiting the  $I_{sc}$  of a power system are known as current limiting reactors or series reactors.

### \* Advantage:-

- The reactors limits the blow off  $I_{sc}$  current ( $I_{sc}$ ) & thus protect the equipment from over heating as well as from failure.
- These are permits the installation of ckt breakers at lower rating.

### \* Disadvantage:-

- Additional  $\% X$  increase the total  $X$  or  $\% X$  of the system.
- This increase the reactive voltage drop which decrease the P.F. ( $\cos\phi$ ).
- The voltage regulation is also poor (less).
- For this reason the reactors are generally used in large interconnected system, but not preferable for small system.

### \* Location of Reactor:-

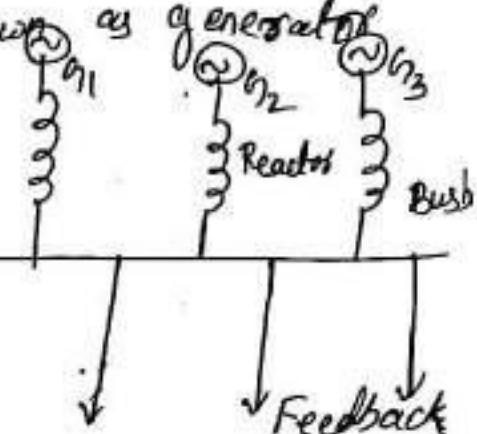
The  $I_{sc}$  limiting reactor may be conn in series with :-

1. Generators
2. Feeders
3. Busbars (Generators & feeders common point)

### \* Generator Reactor:-

When the reactors are conn in series with generators they are known as generator reactors.

- Here the  $X$  of reactor are considered to be a part of  $\% X$  of the generator.



+ It protects a generator against  $I_{sc}$  in case of fault.

+ Advantage :- It is simple.

+ Disadvantage :-

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

+ If a busbar or feeder fault occurs closed to the busbar, the voltage at the busbar will be reduced to a low value thereby causing the generator to fall out of step.

+ If a fault occurs on any feeder the continuity of power supply is to be effected. DT-19/4/19

\* Feeder Reactor :-

+ When the reactors are conn' in series with feeders are known as feeder reactors. In this case larger capacity reactors or more no. of reactors are used as most of the short ckt occurs on feeders.

+ Advantage :-

+ If a fault occurs on any feeders the voltage drop in the reactors will not effect the busbar voltage.

+ The fault on any feeders will not effect others feeders.

+ Disadvantage :-

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

+ If a s.c. occurs at busbars no protection is provided to the generator.

→ If the no. of generators is increased the size of breeders reactor will have to be increased to keep the s.c. current ( $I_{sc}$ ) with in the rating of the breeders.

4. Busbar Reactor:- (1) Ring system

→ It is 2 types:- (2) Tiebar system.

4. Ring System:-

→ In this system busbar is

divided into no. of sections

→ these sections are connected through reactor as shown in fig.

→ Generally one feeder is fed from one generator only.

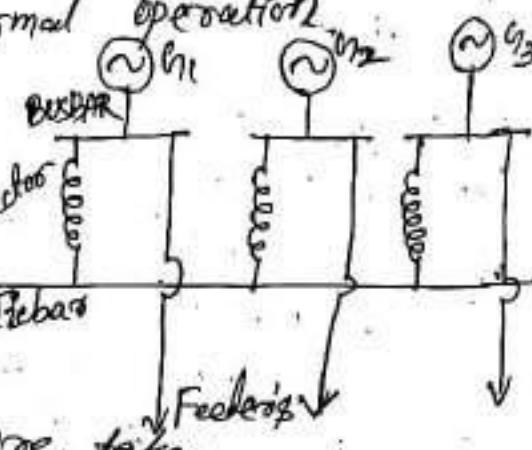
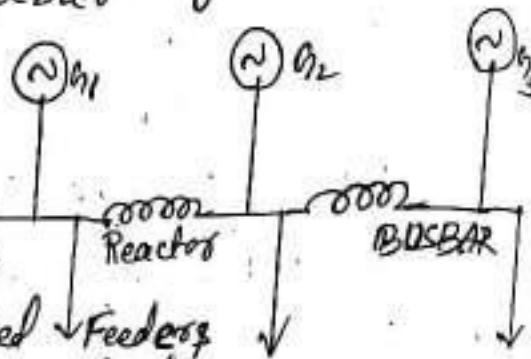
→ Under normal operating condn each generator will supply its own section of the load, this result in low power loss & voltage drop in the reactor.

→ Advantage:-  
 → If a fault occurs on any feeder, only one generator which feeds the fault current while the current from other generators is small due to the presence of reactor. Therefore only that section of the busbar is affected & the other section will able to continue in normal operation.

(2) Tiebar System:-

→ In this system two reactors are conn in series with in the individual bus section

→ The outgoing feeders are taken



from reactor side to generating units of the reactors are connected in both individual bus sections. & it common tiebar system.

\* Advantage:-

→ The system has advantage of using smaller capacitive reactors.

\* Disadvantage:-

→ This system requires additional busbars i.e. tiebar.

Q) The section busbars.

A & B are linked by a busbar reactor rated

at 5000 KVA with 10% reactance. On busbar A there are 2 generators each of 10,000 KVA with 10% off and on busbar B there are 2 generators each of 8,000 KVA with 12% off. Find the steady MVA (S.C.) fed into a dead S.C. between all phases on B with busbar reactors in the ckt.

Assume Base kVA = 15,000 KVA

$$\rightarrow \% \text{ off at Base kVA} = \frac{15,000}{15,000} \times 10\% = 10\%.$$

$$\rightarrow \% \text{ off at Base kVA} = \frac{15,000}{8,000} \times 12\% = 22.5\%.$$

$$\rightarrow \% \text{ off at base kVA} = \frac{15,000}{15,000} \times 10\% = 10\%.$$

(Reactors)

$$\frac{15 \times 10}{15 + 10} = 7.5\%$$

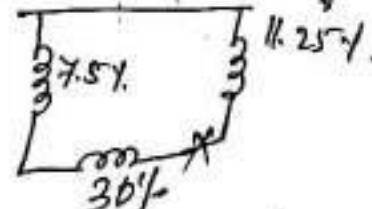
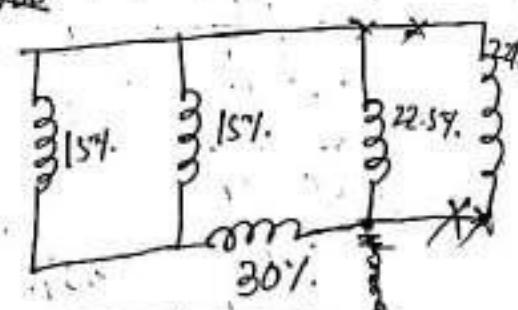
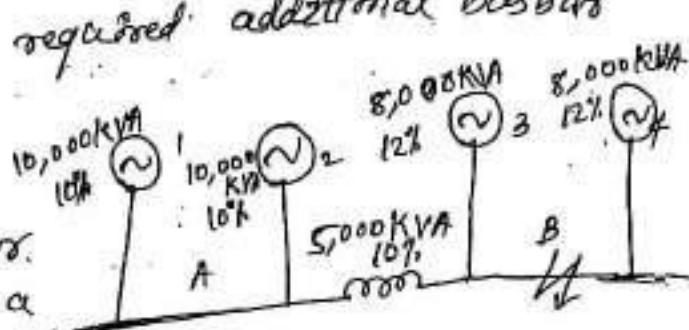
$$(22.5 \times 22.5) = 22.5 \times 22.5\%$$

$$\frac{22.5 \times 22.5}{22.5 + 22.5} = 11.25\%$$

$$30 + 7.5 = 37.5\%$$

$$37.5 // 11.25$$

$$\frac{37.5 \times 11.25}{37.5 + 11.25} = 8.63\%$$



$$\begin{aligned}
 \text{S.C. KVA} &= \text{Base KVA} \times \frac{100}{\% \chi} \\
 &= 15,000 \times \frac{100}{8.65} = 173410.4 \text{ KVA} \\
 &= 173.41 \text{ MVA}
 \end{aligned}$$

Q) A generating station has 3 section busbars connected with a tiebar through 6% reactors rated at 5,000 KVA. Each generator is 5,000 KVA with 12% reactance. Find the total S.C. MVA when S.C. occurs betw the lines on one of the sections of the busbar (1) with reactors

To Assume;

$$\text{Base KVA} = 5,000$$

$\% \chi$  for generators at

$$\begin{aligned}
 \text{Base KVA} &= \frac{55000}{5000} \times 12\% \\
 &= 12\%
 \end{aligned}$$

$$\% \chi \text{ at reactance base KVA} = \frac{5000}{5000} \times 6\% = 6\%$$

$$12+6$$

$$= 18\%$$

$$18/18$$

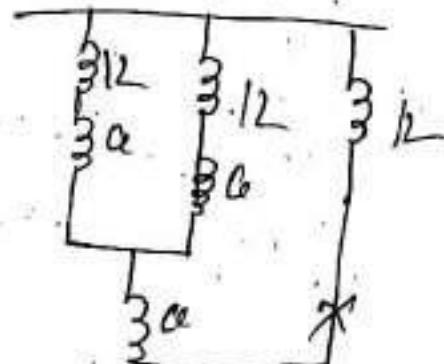
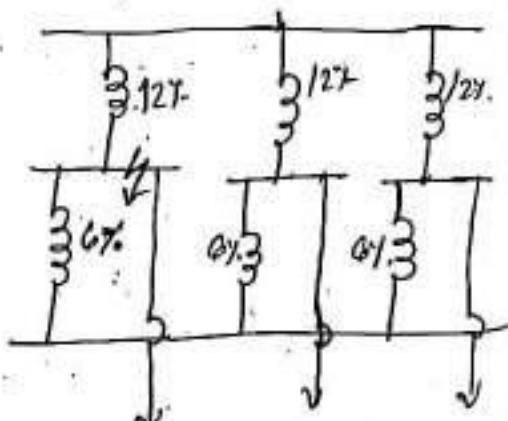
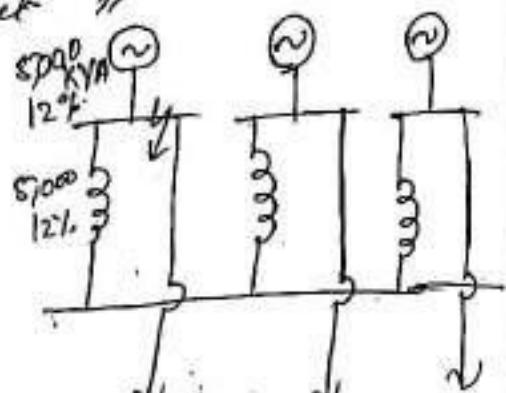
$$2 \frac{18 \times 18}{18+18} = 9\%$$

$$9+6 = 15\%$$

$$15\% / 12\%$$

$$\frac{15 \times 12}{15+12} = 6.00\%$$

(2) Without "



$$S.G \text{ at Base } KVA = \frac{57000 \times 100}{6.66} = 75075 \text{ KVA} \\ = 75 MVA$$

Q) Assume,

→ Base KVA = 5,000 KVA

$$\gamma\% \text{ at Base kVA} = \frac{1000}{75000} \times 100\% = 1.33\%.$$

$$\% \chi \text{ at Base } KVA = \frac{50000}{20000} \times 50\% = 12.5\%$$

104. #1 12.5%

$$107.5 \quad 128.5$$

$$\frac{10 \times 12.5}{10 + 12.5} = 5.55\%$$

$$I = \frac{\text{Base KVA}}{\sqrt{3} \times V} = \frac{5,000 \times 10^3}{\sqrt{3} \times 12,000} = 240.56 \text{ Amp}$$

$$\gamma \quad T_{sc} = \frac{I \times 100}{\chi \gamma} = \frac{246.56 \times 10^6}{5.57} = 4334 \text{ Amp}$$

$$\rightarrow \text{Short dt. kVA} = \frac{\text{Base kVA} \times 100}{25}$$

$$= 52000 \times \frac{100}{55} = 96090.$$

Q2) Assume, Base kVA = 15,000 kVA

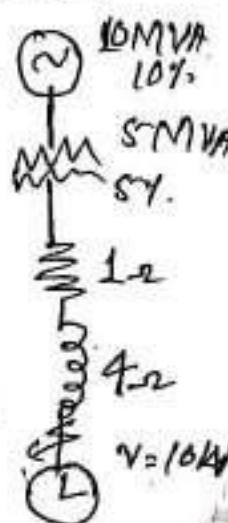
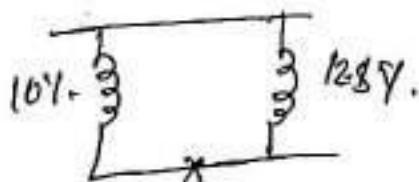
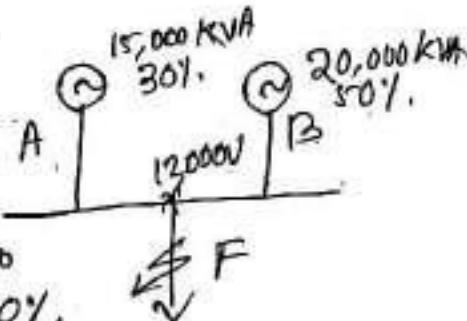
$$CONTRA = 40,000 \text{ kyr}$$

$$S_{MVA} = S_{\text{base}} \cdot 1000 \text{ MVA}$$

$$\rightarrow \text{P.V. at generator} = \frac{15000}{16,000} \times 327.5 = 157.5$$

$$\rightarrow \% \text{ x at } t/6 = \frac{2}{5} \times 100 \times 5\% = 15\%$$

$$\rightarrow \% \chi = \frac{KVA \times \chi}{10 \times (KV)^2} = \frac{15,000 \times 4}{10 \times (10)^2} = 60\%$$



$$\gamma \% R = \frac{R \times KVA}{10 \times (KV)^2} = \frac{1 \times 15000}{10 \times (10)^2} = 15\%$$

$$\gamma \text{ Total } \% x = 60 + 15 + 15 = 90\%$$

$$\gamma \% Z = \sqrt{(R)^2 + (x)^2}$$

$$\gamma = \sqrt{(90)^2 + (15)^2} = 91.24\%$$

$$I = \frac{\text{Base kVA}}{\sqrt{3} \times V} = \frac{15,000 \times 10^3}{\sqrt{3} \times 10 \times 10^3}$$

$$\gamma = 866 \text{ Amp}$$

$$\gamma I_{sc} = \frac{I \times 100}{Z\gamma} = \frac{866 \times 100}{91.24} = 949.14 \text{ Amp}$$

$$\gamma \text{ S.C. kVA} = \text{Base kVA} \times \frac{100}{Z\gamma}$$

$$= 15,000 \times \frac{100}{91.24} = 16440 \text{ kVA}$$

$$\gamma = 16,44 \text{ MVA}$$

$$\gamma V = 11 \text{ KV}$$

Assume,

$$\text{Base kVA} = 5,000 \text{ kVA}$$

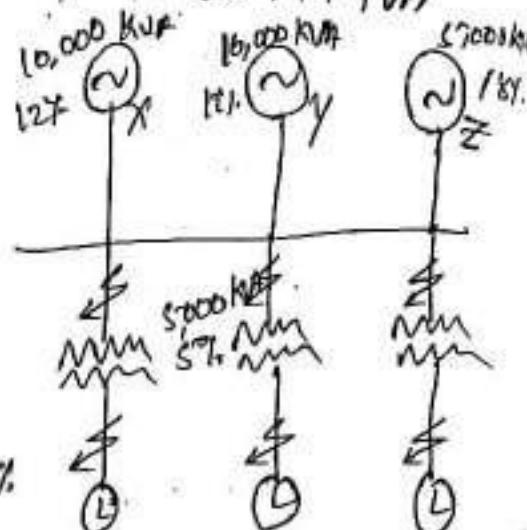
$$\gamma \% x \text{ at Base kVA} \text{ for } X$$

$$\gamma \text{ Generators} = \frac{5,000}{10,000} \times 12\% = 6\%$$

$$\gamma \% x \text{ for } Y \text{ generators} = \frac{5,000}{10,000} \times 12\% = 6\%$$

$$\gamma \% x \text{ for } Z \text{ generators} = \frac{5,000}{10,000} \times 18\% = 18\%$$

$$\gamma \% x \text{ at Base kVA} = \frac{5,000}{5,000} \times 5\% = 5\%$$



QH1 QH1/18%

$$= \frac{6 \times 6}{6+6} = 3\%$$

$$\frac{3718}{3+18} = 2.571. \text{ (for low voltage side)}$$

$$\gamma \text{ for high voltage side} = 2.571 = 7.57\%$$

$$\gamma I = \frac{5,000 \times 700}{13 \times 11 \times 700} = 262.43 \text{ Amp}$$

$$\gamma I_{sc} = \frac{I \times 100}{\% \gamma} = \frac{262.43 \times 100}{7.57} = 3466.4$$

$$\gamma \text{ Short ckt kVA} = 5,000 \times \frac{100}{7.57} = 66050.19 \text{ kVA}$$

(for high voltage side) = 66,050 MVA

$$\gamma I_{sc} = \frac{262.43 \times 100}{2.57} = 10211.28 \text{ AMP}$$

$$\gamma \text{ Short ckt kVA} = 5,000 \times \frac{100}{2.57} = 194552.5 \text{ kVA}$$

(for lower voltage side) = 194.552 MVA.

QH

$$0.2 \times 50 = 10 \text{ } \Omega = R, 10 \text{ MVA} = 10,000 \text{ kVA}$$

$$1 \times 50 = 50 \text{ } \Omega = X, 5 \text{ MVA} = 5,000 \text{ kVA}$$

$$\gamma \text{ Assume, Base kVA} = 20,000 \text{ kVA}$$

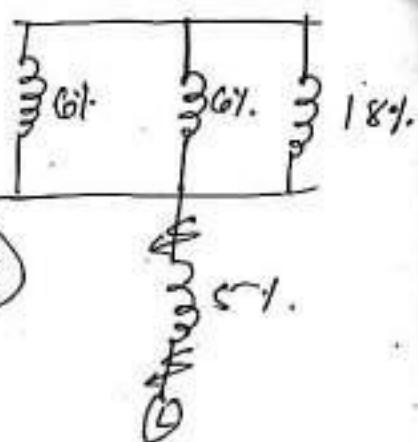
$$\gamma \% \gamma \text{ at Base kVA} = \frac{20,000}{10,000} \times 20\% = 40\%$$

(for A)

$$\gamma \% \gamma \text{ for B} = \frac{20,000}{5,000} = 10\% = 40\%$$

$$\gamma \% \gamma = \frac{X \times \text{KVA}}{10 \times (\text{KV})^2} = \frac{50 \times 20,000}{10 \times (33)^2} = 91.827\%$$

$$\gamma \% R = \frac{10 \times 20,000}{10 \times (33)^2} = 18.36\%$$



$$\rightarrow \text{Total } \% \chi = 40 + 40 + 91.82 = 171.82\%$$

$$\rightarrow \% \gamma = \sqrt{(171.82)^2 + (18.36)^2} = 172.79\%$$

$$\rightarrow I = \frac{20,000 \times 10^3}{13 \times 6.6 \times 10^3} = 1749.54 \text{ Amp.}$$

$$\rightarrow I_{sc} = \frac{I \times 100}{\% \gamma} = \frac{1749.54 \times 100}{172.79} = 1012.5 \text{ Amp.}$$

$$\rightarrow \text{S.C. kVA} = 20,000 \times \frac{100}{172.79} = 11548.4 \text{ kVA} \\ = 11.54 \text{ MVA}$$

Q) A 3φ 20MVA, 10kV alternator has internal reactance of 5% & negligible resistance, find the external  $X$  per ph. to be conn' in series with the alternator, so the s.c current ( $I_{sc}$ ) does not exceed 8 times the full load current.

$$\rightarrow I_{sc} = 8 \times \text{full load current} \quad 20MVA = 20,000 \text{ kVA}$$

$$\rightarrow I = \frac{20,000 \times 10^3}{10 \times 10^3} = 1154.4 \text{ Amp}$$

$$\rightarrow I_{sc} = 1154.4 \times 8 = 9237.6 \text{ Amp}$$

$$\rightarrow \text{We know, } I_{sc} = \frac{I \times 100}{\% X}$$

$$\Rightarrow \% X = \frac{I \times 100}{I_{sc}} = \frac{1154.4 \times 100}{9237.6} = 12.5\%$$

$$\boxed{\begin{aligned} I_{sc} &= I \times 8 \\ \Rightarrow \frac{I}{I_{sc}} &= \frac{1}{8} \\ \Rightarrow \frac{I_{sc}}{I} &= 8 \end{aligned}}$$

$$\rightarrow \text{External Reactance} = 12.5\% - 5\% = 7.5\%$$

$$\rightarrow \% X = \frac{X \times \text{KVA}}{10 \times (\text{KV})^2} \Rightarrow X = \frac{\% X \times (\text{KV})^2 \times 10}{\text{KVA}} = 0.375$$

$$\rightarrow \text{We know, } \% X = \frac{I X}{V_{ph}} \times 100 \quad V_{ph} = \frac{10 \times 10^3}{\sqrt{3}} = 5773.5$$

$$\Rightarrow X = \frac{\% X \times V}{I \times 100} = \frac{7.5 \times 5773.5}{1154.4 \times 100} = 0.375$$

Q) A 3φ 30MVA, 33kV alternator has internal  $X$  of 5% and negligible reactance. Find the external, per phase to be conn' in series alternator so the steady state current on short ckt does not exceed 10 times of the full load current.

$$\sqrt{3} = 33 \text{ kV}$$

$$I_{sc} = 10 \times \text{full load current}$$

$$\text{Let, } \text{Base KVA} = 15,000 \text{ KVA}$$

$$30 \text{ MVA} = 30,000 \text{ KVA}$$

$$I = \frac{30,000 \times 10^3}{33 \times 13 \times 10} = 5248.63 \text{ Amp}$$

$$I_{sc} = 10 \times 5248.63 = 52486.3 \text{ Amp}$$

We know,

$$I_{sc} = \frac{I \times 100}{\gamma \cdot x}$$

$$\Rightarrow \gamma \cdot x = \frac{I \times 100}{I_{sc}} = \frac{5248.63}{52486.3} \times 100 = \frac{1}{10} \times 100$$

$$\gamma \text{ External Reactance} = 10 - 5 = 5\% = 10\%$$

$$\gamma \cdot x = \frac{I \times 100}{\gamma} \times 100$$

$$\Rightarrow x = \frac{\gamma \times 100}{I \times 100}$$

$$\Rightarrow x = \frac{5 \times \frac{33000}{13}}{5248.63 \times 100} = 0.1812$$

→ A fuse is a short piece of metal in-series in the ckt which melts when excessive current flows through it and those break the ckt.

→ Principle of fuse :-

The fuse material generally made up on the material which having low melting point high conductivity & least <sup>so</sup> deterioration due to oxidation.

→ Ex:- Silver, copper etc.

→ It is inserted in series with the ckt to be protected.

→ Under normal operating cond' the fuse element is at temp. below its melting point.

→ Therefore it carries the normal current without over heating.

→ When a short ckt or over-loaded occurs the current through the fuse increase beyond its rated value.

→ Then rises the temp. of fuse element & the fuse element melts & disconnect the ckt, which is protected by it.

→ In this the fuse protect the device, m/c equipment from damage due to the excessive currents.

→ Advantage :-

→ It is the cheapest form of protection.

→ It req't no maintenance.

→ It can break having short ckt current without noise or smoke.

→ Minimum time of operation can be made much

shorted them the ckt breakers.

→ It is operation is completely auto-matic unlike a ckt breaker which required an elaborate equipment for automatic action.

→ Disadvantage:-

→ Considerable time is lost in re-wiring or replacing a fuse after operation.

→ On heavy short ckt discrimination b/w fuse if series can't be obtain unless there is sufficient diff' in the sizes of the fuse.

→ The current time characteristic of a fuse can't be always coordinated with protected equipment.

\* Desirable characteristic of fuse elements :-

→ The fuse of a fuse is to carry the normal current without over heating but when the current exceeds its normal value it rapidly heats up to melting point & disconnects the ckt protected by it.

→ In order to perform this function the fuse element should have following desirable characteristics.

1. Low melting point. Ex:- tin & lead.

2. High conducting copper & silver. oxidation

3. Free from deterioration due to oxidation.

Ex:- Silver

4. Low cost. Ex:- lead, tin, copper.

\* Fuse Element Material :-

→ The most commonly used material for fuse element are lead, tin, copper, zinc & silver.

→ For small current up to 10 amp, tin or

an alloy of lead & tin.

[lead = 34% & tin = 63%] is used for making the fuse element.

For larger current copper or silver is used.

\* Important terms :-

DT-09/01/2020

The following terms are much used in the analysis of fuse:

a) current rating of fuse element :-

It is the current which the fuse element can normally carry without over heating or melting.

It depends upon the temp. rise of the contacts of fuse holder, fuse material & surrounding of the fuse.

b) Fusing current :- It is minimum current at which the fuse element melts & thus disconnect the ckt protected by it.  
Its value will be more than the current rating of the fuse elements.

? The <sup>approximate</sup> relation betw<sup>n</sup> fusing current 'I' & diameter 'd' of a wire is

$$I = Kd^{3/2}$$

The fusing current depends upon the various factors such as :-  
a) Material of fuse element.  
b) Length

c) Diameter of terminal

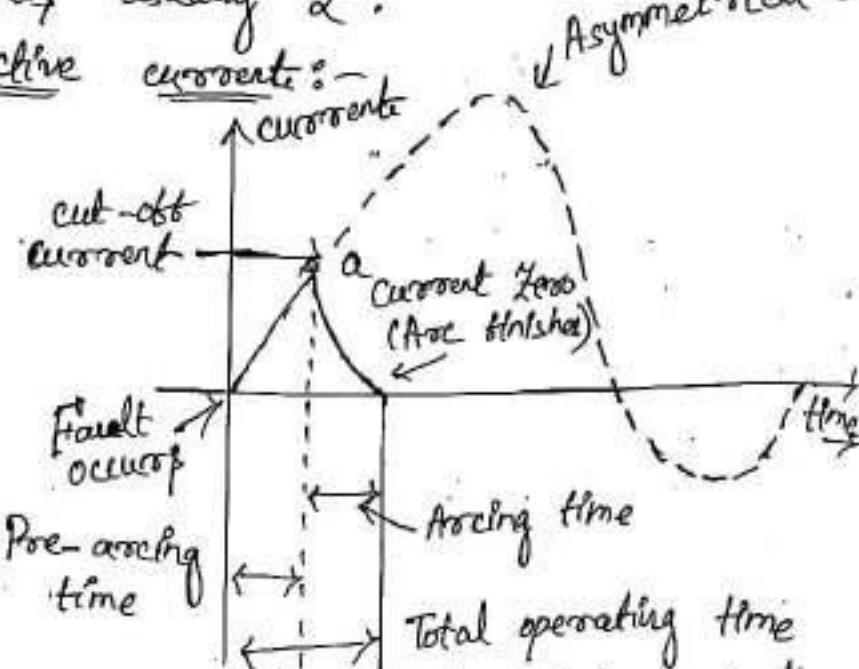
d) Size & location of terminal

e) Types of enclosures.

iii) Fusing factor :- It is the ratio of min<sup>n</sup> fusing current to the current rating of fuse.

Fusing factor =  $\frac{\text{min}^n \text{ fusing current}}{\text{current rating of fuse}}$

- Its value is always more than one.
- For all wire as the fuse element, the fuse factor is usually 2.
- Prospective current :-



- It is the RMS value of the 1st loop of the fault current obtained if the fuse is replaced by an ordinary conductor of negligible R.

→ Cut-off current :- It is a max<sup>n</sup> value of the fault current actually reach before the fuse melts. It depends upon current rating of fuse & the value of prospective current.

→ Pre-arcing time :-

It is the time b/w the commencement of fault & the instant where the cut-off occurs. A typical value of pre-arcing time is 0.001 sec.

→ Arcing time :- This is the time b/w the end of pre-arcing time & the instant when the arc is extinguished.

→ Total operating time :- It is the sum of pre-arcing time & arc time. It may be noted that the op. time of fuse is generally quite low, i.e. approximately 0.002 sec.

\* Types of Fuse :- Fuse is the simple current interrupting device for protection against excessive current. In general it may be classified into 2 types.

(i) Low voltage fuse

(ii) High " "

if Low voltage fuse :-

(a) Semi-closed rewirable fuse.

(b) High interrupting capacity cartridge fuse (HRC)

if Semi-closed rewirable fuse :-

→ The rewirable fuse also known as type.

→ These are used where low value of fuse current are to be interrupted.

→ They consist of a base & a fuse carrier.

→ The base is of porcelain & carries the fixed contact to which the incoming & outgoing of phase wires are connected.



→ The fuse carrier is also of porcelain & holds the fuse element betw its terminal.

→ When fault occurs the fuse element is blown out & the ckt is interrupted.

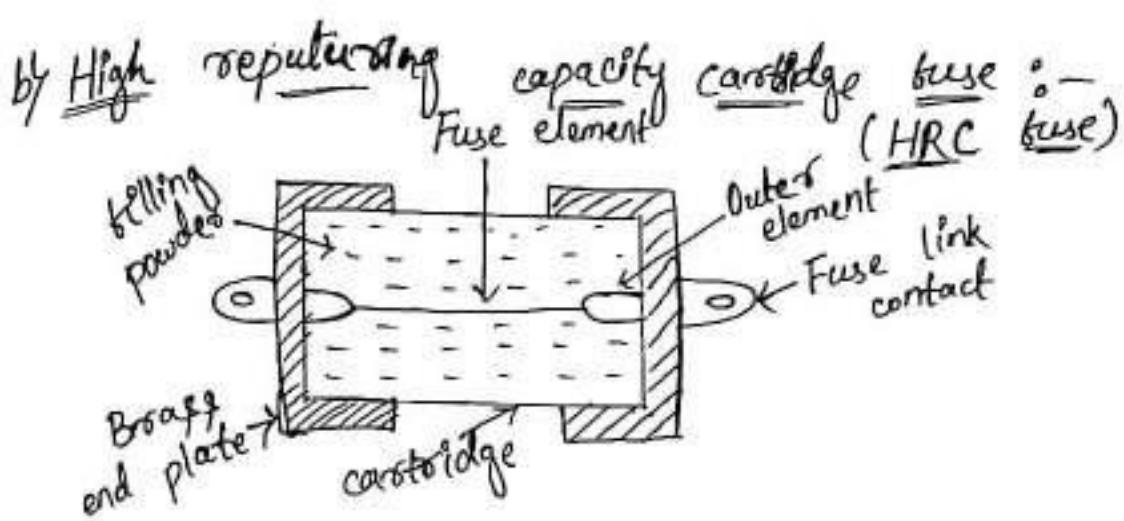
→ The fuse carrier is taken out & the fuse element

is replaced by the new one & then the fuse carrier is inserted in the base to restore the supply.

- This type of fuse has 2 advantages;
  - i) The fuse carrier permits the replacement of fuse element without any danger.
  - ii) The cost of replacement is negligible.

Disadvantage:-

- i) There is a possibility of removal by the fuse wire of wrong size or by improper material.
- ii) This type of fuse has a low breaking capacity & hence it can't be use the circuit at high fault level.
- iii) The fuse element subjected to the deterioration due to oxidation through the continuous heating of the element. Therefore after some time the current rating of the fuse is decreased i.e. the fuse operates at a lower current than originally rated.
- iv) The protective capacity of such fuse is uncertain. The accurate calibration of fuse wire is not possible becz the fusing current vary much depends upon the length of the fusing current.
- The semi-enclosed removable fuses are made upto 500amp rated current but the breaking capacity is low i.e. on 400 volt service.
- This type of fuse is limited to domestic & the use of lighting load.



- To overcome the disadvantage of semi enclosed rewirable fuse, HRC cartridge fuse is use.
- It consist of a heat resisting ceramic body having metal cap to which is welded silver current carrying element.
- The space within the body surrounding the element which is completely packed with a filling powder.
- The filling powder may be chalk, plaster of paris, quartz or marble dust etc. which act as arc quenching medium.
- Under normal load condition the fuse element is temp. below its melting pt. therefore it carries the normal current without over heating.
- When a fault occurs the current increase & the fuse element melt.
- The heat produced in the process vapourise the melted silver element.
- The chemical reaction b/w the silver vapour & the filling powder results in the formation of high resistance, which helps quenching the arc.

### \* Advantage :-

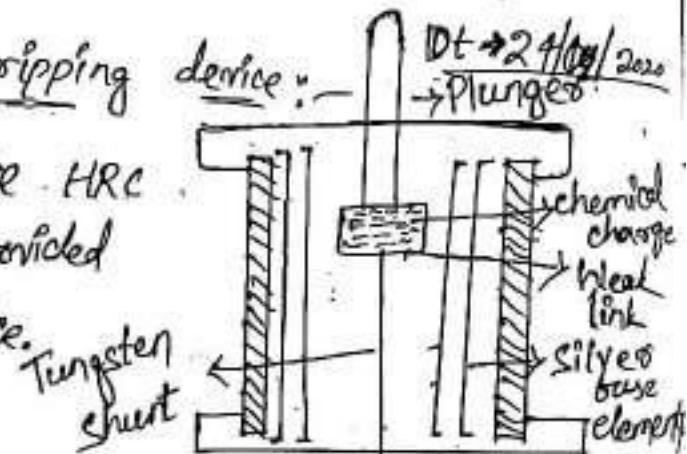
- i) These are capable of clearing high as well as low fault current.
- ii) These are not deteriorate with age.
- iii) They have high speed of operation.
- iv) They provide reliable distinction.
- v) They reqt no maintenance.
- vi) They permit consistent performance.

### \* Disadvantage :-

- i) They have to be replace after each operation.
- ii) Heat produce by the arc may effect the associated S/w.

### \* HRC fuse with tripping device :-

→ Here in this device HRC Cartridge fuse is provided with a tripping device.



- When the fuse blows out under the fault cond the tripping device causes the ckt breaker to operate. The body of the fuse is of ceramic material with a metallic cap fixed at each end. At one end a plunger is connected which under fault conditions hits the tripping metal of the ckt breaker & cause it to operate.
- The plunger is electrically through a fusible link, chemical charge & a tungsten wire to

the other end of the cap.

→ When a fault occurs the silver element at the first to be blown out & then the current is transferred to the tungsten wire.

→ The weak link in series with the tungsten wire gets fused & cause the chemical charge to be detonated. This forces the plunger outward to operate the ckt breaker.

→ Adv.:- In case of 1<sup>ph</sup> fault on a 3<sup>ph</sup> system the plunger operates the tripping mechanism of the C.B. to open all the 3<sup>ph</sup> & thus prevents single phasing.

→ The effect of ~~full~~ short ckt current need not be considered in the choice of C.B.

→ App :-

→ LV fuses:-

→ The LV HRC fuse may be built with a breaking capacity of 16,000 Amp to 30,000 Amp at 440 volt.

→ They are extensively used in LV distribution system against over load & short ckt cond?

→ High voltage fuses:-

The LV fuses have normal current rating & breaking capacity there for they can't be successively use on HV fuse, so.. we use HV fuse for the HV ckt

(a) Cartridge type This is similar to the LV cartridge type except the special design features.

→ Some design employ fuse element wound in the form of helix, so as to avoid corona effect at higher voltage.

\* Some design theorems are 2 fuse element in parallel one is low resistance (silver) & the other of high R (tungsten wire)

\* Under normal load only the low R element carry the normal current but when the fault occurs the low R element is blown out & high R element reduce the short ckt current & finally break the ckt.

\* HV cartridge fuse are used upto 33kV with breaking capacity of 8700 Amp.

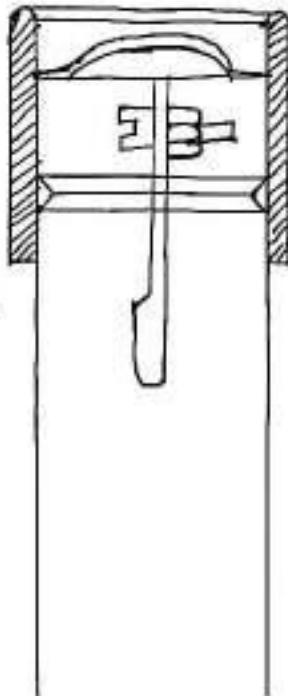
(b) Liquid type :-

\* These fuse are filled with carbon tetrachloride they may be used for the ckt upto 100 amp rated current on the system upto 132 KV & the breaking capacity of 6100 amp. It consist of a glass tube filled with carbon tetrachloride ( $CCl_4$ ) soln & sealed at both end with brass cap.

\* The fuse wire is sealed at one end of the tube & the other end of the wire is held by a strong phosphorous brass spring fixed at the other end of the glass tube.

\* When current exceeds the fuse wire is blown out

A fuse wire of circular cross-section has a radius of 0.8 mm the wire blows off at a  $I$  of 8 Amp. Calculate the  $R$  of the wire that will blow off at a  $I$  of 1 amp.



Given

$$r' = 0.8 \text{ mm}$$

$$I' = 8 \text{ Amp}$$

$$I'' = 1 \text{ amp}$$

$$\therefore I'' = ? \quad K + 1$$

$$\boxed{I = Kd^{3/2}}$$

$$\therefore I^2 = d^3$$

$\Rightarrow$  Heat produced per sec  $\Rightarrow$  Heat loss per sec

$\Rightarrow I^2 R = \text{Constant} \times \text{Eff. surface area}$

$\Rightarrow I^2 R = \text{constant} \times d \times l$

$$\Rightarrow I^2 \cdot \rho \frac{L}{A} = \text{constant} \times d \times l$$

$$\Rightarrow I^2 = K \times d^3$$

$$\Rightarrow I^2 \propto d^3$$

$$\Rightarrow \left( \frac{I_2}{I_1} \right)^2 = \left( \frac{r_2}{r_1} \right)^3$$

$$\Rightarrow \left( \frac{1}{8} \right)^2 = \left( \frac{r_2}{0.8} \right)^3$$

$$\Rightarrow \frac{1}{64} = \frac{r^3}{0.8^3}$$

~~$$\frac{1}{64} = \frac{r^3}{0.8^3} = 8 \times 10^{-3}$$~~

$$\therefore r = \sqrt[3]{0.008} = 0.08 \text{ mm.}$$

→ A circuit breaker is a part of equipment which can make or break a ckt either manually or by remote control under normal conditions. Break a ckt automatically under fault condition.

→ Thus a ckt. breaker is incorporated manual as well as automatic control for switching function.

#### \* Operating Principle :-

A ckt. breaker essentially consists of a fixed contact & a moving contact under normal operating condn. This contact remain close and it will not open automatically and unless the system becomes faulty.

→ The contact can be opened manually whenever desired when a fault occurs on any part of the system. the trip coil of the ckt. breaker get energised and the moving contact are pulled a part by some mechanism, thus the ckt. will open.

\* Arc Phenomenon :- When a short ckt occurs a heavy current flows through the contact of ckt. breaker before these open by the protecting system, at the instant. When the contact began to separate to contact area decrease rapidly & the large fault current cause increase large current density and hence raising temperature.

→ The heat produced and medium b/w contact (usually the medium is oil or air) is sufficient to ionise the air or oil.

- The ionised air or vapour act as a conductor and an arc is struck betn the contact.
- The potential diff<sup>r</sup> betn the contact is quite small & just sufficient to maintain the arc.
- The arc provides a low R. path & consequently the current in the ckt remain uninterrupted so long as the arc is present.
- During the arcing period the current flowing betn the contact depends upon the arc R. greater the arc resistance, the smaller is the current that flows betn the contact.
- The arc R depends upon the following factors

\* (i) Degree of ionization:-

- The arc R increase with the decrease of the no. of ionise particle betn the contact.

(ii) Length of the Arc:-

The arc R increase with the length of the arc i.e. separation of contact.

(iii) Cross-section area of arc:-

The arc R increase with decrease the cross-sectional area of the arc.

\* Methods of Arc Extension:-

There are 2 methods of extinguishing of arc in CB, these are
 

- (i) high R method
- (ii) low R , or current - 0 method

### High R Method :-

→ In this method the Arc R is increased with time, so that current is reduced to a value insufficient to maintain the arc.

∴ the I is interrupted & the arc is extinguished.  
→ The diss. of this method is dissipation of high energy in the arc.

∴ It is employed only in dc ckt breakers & low capacity AC ckt breakers.

→ The R of the arc may be increased by

(a) Lengthening ( $\rightarrow$ ) the arc :- The R of the arc is directly proportional to its length. The length of the arc can be increase by increasing the gap between that contact.

(b) Cooling the arc :-

→ The cooling helps in the de-ionisation of the medium b/w the contact, this increase the arc R.

(c) Reducing the crosssection area of the arc :-

→ If the area of crosssection of arc is reduced, the R of the arc increase. The crosssection area of the arc can be reduce by letting the arc pass through a narrow opening or by having smaller area of contact.

(d) Splitting the Arc :-

The R of the arc can be increase by splitting the arc into a no. of smaller arcs. The arc may be split by introducing inserties. Some conducting plate b/w the 2 contacts.

\* Low R method :-

This method is employed for arc extension in AC ckt only. In this method arc R

If kept low until current is zero, where the arc extinguishes naturally

→ In an AC system the I drop to zero, after even half cycles. At every I zero the arc extinguishes for a brief moment.

→ Now the medium b/w the contact contain ion & electrons so that it has small dielectric strength & can easily break-down by the rising contact voltage known as restriking voltage.

→ The de-ionise of the medium can be achieved by

\* lengthening of the gap:—The dielectric strength of the medium is proportional to the length of the gap b/w the contact.

→ ∴ By opening the contact rapidly higher dielectric strength can be achieved

\* High Pressure:—If the pressure of the arc is increased the density of charge particle constituting the discharge also increase. The increase density of particle cause higher rate of deionisation & consequently dielectric strength of medium at contact is increased.

\* Cooling:—The natural combination of ionise particles takes place more rapidly if they are allowed to cool.

∴ dielectric strength of the medium can be increased by cooling the arc.

\* Blast effect:—If the ionise particle been the contact are swept away & replace by un-ionised

particle the dielectric strength of the medium can be increase & may be achieve by a gas blast or by breaking the oil betw the contacts.

#### \* Classification of ckt breaker :-

- There are several way of classifying the CB. however the most general way of classification is on the basic of medium used for arc extinction.
- Accordingly the ckt breaker may be classified into following types:-

1) Oil ckt breaker:- which employed some insulating oil for arc extinction.

2) Air blast CB In which a high pressure air blast is used for extinguish. arc.

3) Sulphur hexa fluoride CB:- (SF<sub>6</sub>) :- In which SF<sub>6</sub> gas is used for arc extinction.

4) Vacuum CB:- In which vacuum is use for arc extinction.

#### 1) Oil ckt breaker:-

In such CB some insulating oil is use as an arc quenching medium.

→ The contact are open under oil & the arc is struck betw them.

→ The heat of the arc evaporate the surrounding oil & produce the gaseous hydrogen at high pressure.

→ The H gas occupies a volume of 1000 times that of the oil decompose. The oil is pushed away from the arc & an expanding H gas bubbles surround the arc region & adjacent portion of the contact.

→ The arc extinction

→ ∵ The arc is extinguished the ckt current interrupted.

⇒ Adv. :-

⇒ Oil as an arc quenching medium :-

⇒ It observe the arc energy to decompose the oil into gases.

⇒ It act as an insulator & permit smaller clearance betw the conductors.

⇒ Dis. adv. :-

⇒ It is inflammable & there is a risk of fire

⇒ It may form an explosive mixture with air.

⇒ Type of oil CB :-

The oil CB can be classified into following types.

(a) Bulk oil ckt breaker :-

Which use a large quantity of oil

→ The oil has to serve to purpose,

(a) It extinguish the arc during opening of the contact.

(b) It insulate the current conducting part from one another

→ Such ckt breakers can be classified into 2 types

(A) Plain break oil CB

(B) Arc control " "

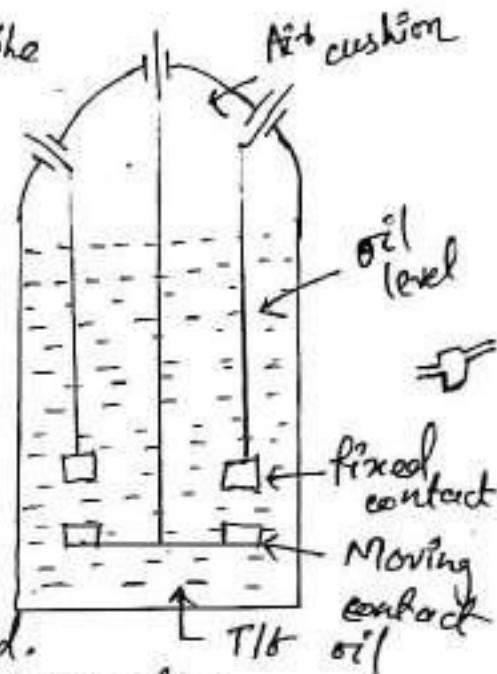
Q) Low oil CB :-  
→ which uses min<sup>n</sup> amount of oil. In such  
CB oil is used only for arc

extinction

Dt-11/02/2020

\* Plain break oil CB :-

- This ckt breaker involves the simple process of separating the contact under the oil.
- There is no special system for arc control other than increase in length, caused by the separation of contact.
- The arc extinction occurs when a certain critical gap between the contact is reached.
- It has a very simple construction.
- It consists of fixed & moving contact which is enclosed in a tank containing oil upto a certain level. and an air cushion above the oil level.
- The air cushion provides sufficient space for allowing the reception of the arc gases without the generation of unsafe pressure.
- Under normal operating cond<sup>n</sup> the time & moving contact remain closed & the ckt breaker carries the normal ckt current.
- When a fault occurs the moving contact arc pulled down by the protective system & an arc is struck which vapourise the oil into hydrogen gas.
- The arc extinction is by the following process;



7.  $H_2$  gas bubble generated around the arc, cools the arc.

8. As the arc lengthens due to the separating contact, the dielectric strength of the medium is increased. As the result the arc is extinguished & the ckt current interrupted.

\* Dis. Adv. :- There is no special control over the arc other than increase in length by separating the moving contact, i.e. too successful interruption long arc length if necessary.

→ These breakers have long & inconsistency arcing time.

→ These breakers do not permit high speed interruption.

→ Due to this dis. adv. the plain break oil CB are used only for LV app.

\* arc control oil CB :-

→ It is necessary & desirable that the final arc extinction should occur while the contact gap is short. For this purpose some arc control is incorporated (use) & the breaker which are used the breakers is called as arc control CB.

→ There are 2 types of this CB;

1) Self blast oil CB

2) Forced blast oil CB

3) Self blast oil CB :- It is the CB in which arc control is provided by internal means i.e. the arc itself is employed for its own extinction efficiently.

- In this type of CB the gases produced during arcing are confined (2/100) to a small volume by the use of insulating chambers or pot surrounding the contact.
- Since the space available for arc gases is restricted by the chamber, a very high pressure is developed to force the oil & gas through the arc to extinguish it.
- The magnitude of pressure developed depends on the value of fault current to be interrupted.
- When the pressure is generated by the arc itself it is called self generated pressure of CB.
- There are several designs of pressure chamber has been developed. These are;

(i) Plain explosion pot

(ii) Cross jet explosion pot

(iii) Self compensated pot

\* Self blast oil CB : (PEP)

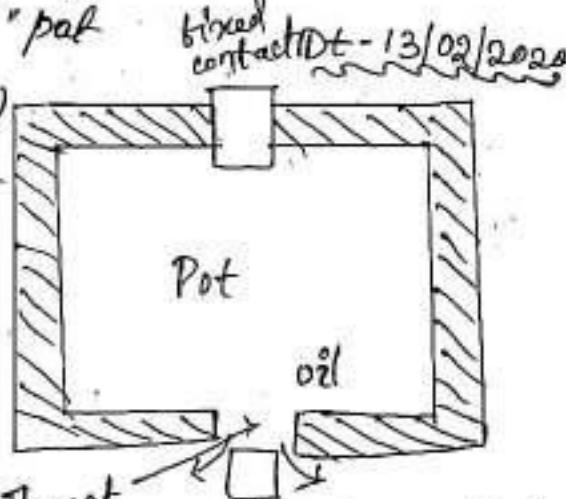
if Plain explosion pot :-

It is a rigid cylinder of insulating material & encloses the fixed & moving contact as shown in fig.

The moving contact is a cylindrical rod passing through a restricted opening (called throat) at the bottom. When a fault occurs the contact get separated

if an arc is struck between them.

The heat of the arc decomposes oil into a gas at a very high pressure in the pot,



- This high pressure forces the oil & gas around the arc & thus the arc is extinguished.
- The principle limitation of this pot is it can't be used for very low or very high fault currents.
- The plain explosion pot operation on moderate T<sub>sc</sub> only.

ii) Coors jet explosion pot :- (CJEP)

→ This type of pot is a modification of Plain explosion pot as shown in fig.

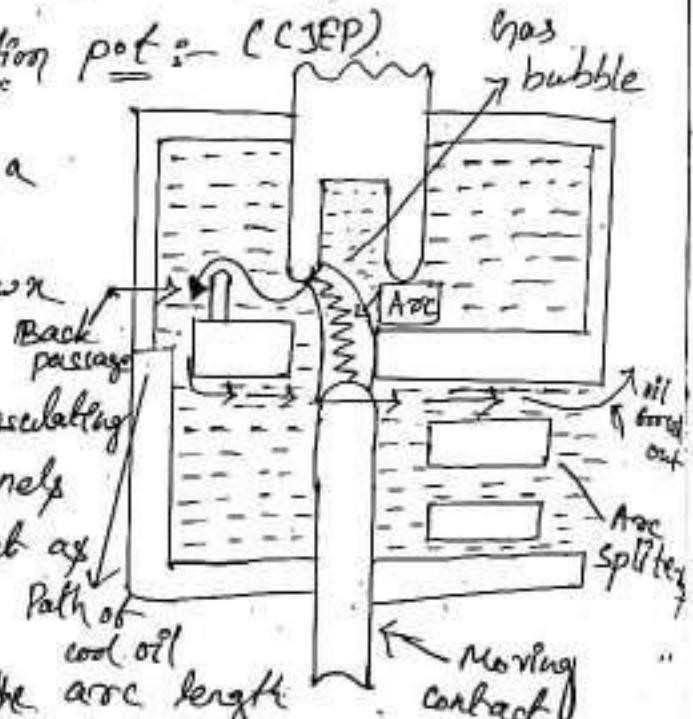
→ It is made up of insulating material & has a channel on one side which act as arc splitters. Path of cool oil

→ It helps in increase the arc length thus the arc is extinguished.

→ When a fault occurs the moving contact of the CB begins to separate or start to separate as the moving contact is withdrawn, the arc is initially struck in the top of the pot.

→ The gas generated by the arc exerts pressure on the oil, when the moving contact uncovers the arc splitters duct, touch oil is forced across the arc path.

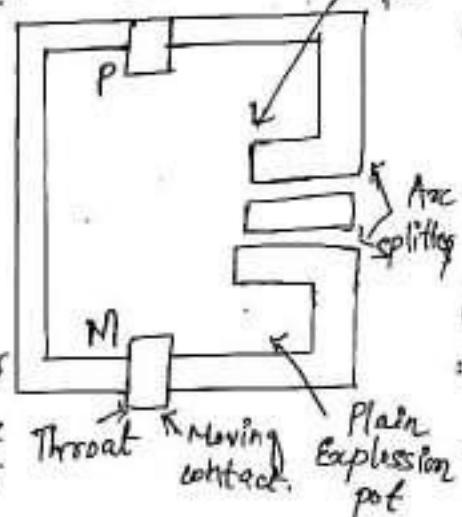
∴ The arc is driven into the arc splitter which increase the arc length. Thus the



arc is extinguished.

\* This pot is quite efficient for interrupting heavy fault current.

Self compensated explosion pot :- Cross jet  
Fixed contact, explosion pot  
This type of pot is a combination of plain explosion type pot & cross jet pot. It can interrupt low as well as heavy s.c. current ( $I_{sc}$ ). It consists of 2 chambers. The upper chamber is CIEP with two cross jet splitters duct, while the lower one is PEP.



When  $I_{sc}$  is heavy the rate of generation of gas is very high & the device behaves as a CIEP. At when the low  $I_{sc}$  the rate of gas generation is low or small.

When the moving contact comes out from the throat the arc is extinguished by plain explosion pot action.

Force blast oil CB :- In this arc control method arc is provided by mechanical means for

the ckt breaker externally. The major limitation of self blast oil CB is that the arcing time is long. To overcome this limitation we use force blast oil CB in which the necessary pressure is produced by the external mechanical means which is independent of blast current.

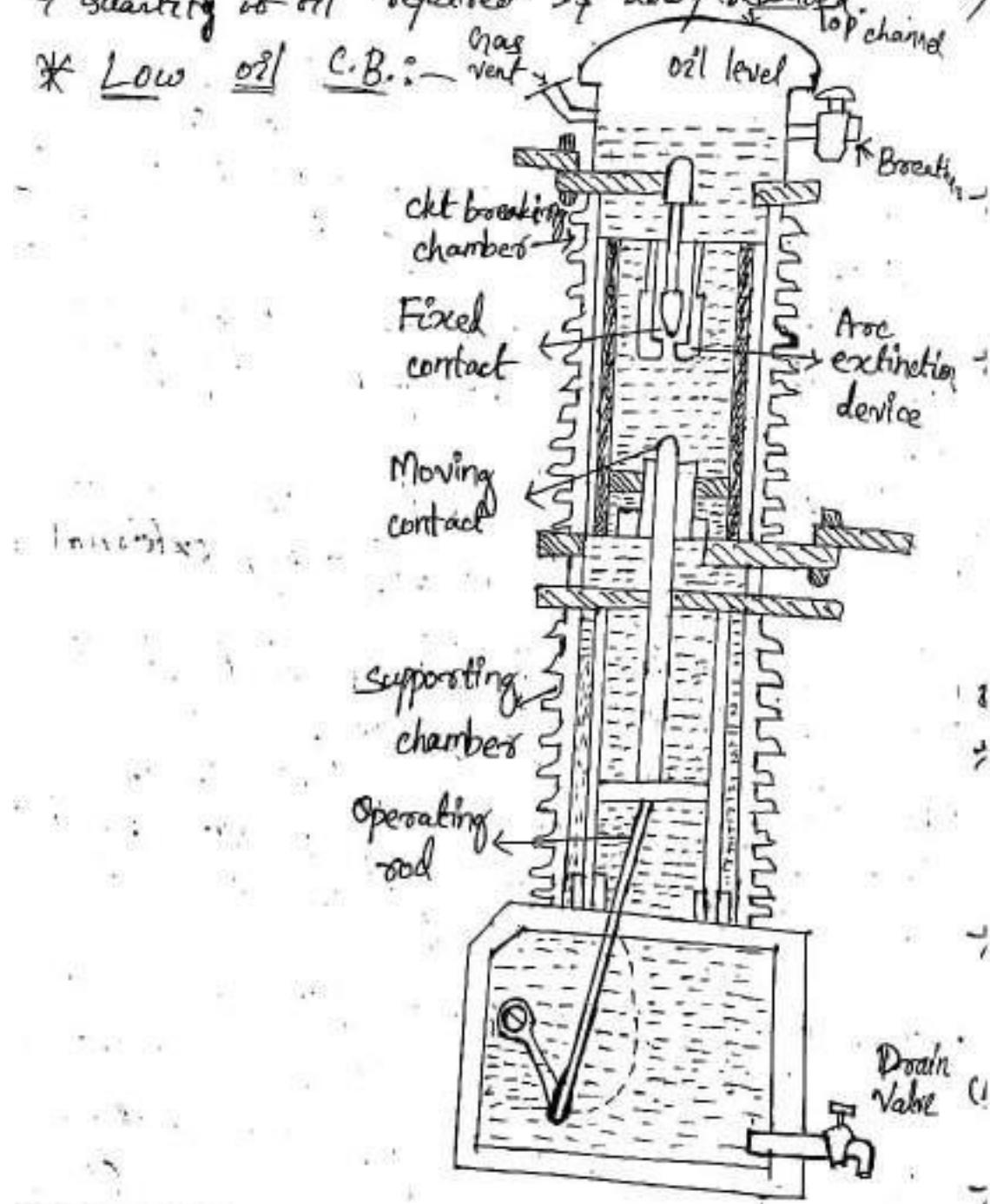
In a force blast oil CB oil pressure is created by the piston cylinders arrangement. The movement of piston is mechanically coupled to the moving contact.

When a fault occurs the contact separated by the protective system & an arc is struck between the fixed contact & moving contact. The piston forces a jet of oil toward the arc gap to extinguish the arc.

\* Adv. - Since oil pressure developed is independent of fault current the performance at low current is more constant than self blast oil C.B.

\* Quantity of oil required is low/reduced.

\* Low oil C.B. - Gas vent oil level top chamber Breather



→ In the bulk oil CB the oil has to perform 2 functions  
(i) It act as an arc quenching medium  
(ii) It insulates from the earth.

\* For this reason the quantity of oil in a bulk oil CB is very high.

→ But in case of low oil CB a small amount of oil is used as an arc quenching medium.

#### \* Construction :-

→ There are 2 compartments separated from each other but both filled with oil. The upper chamber is the ckt breaking chamber while the lower chamber is supporting chamber.

→ The 2 chambers by separated partition & oil from one chamber is prevented from mixing with other chambers.

→ This arrangement permits 2 advantages :-  
(i) The ckt breaking chamber reqs a small volume of oil which is enough for arc extinction.

(ii) The amount of oil is to be replaced by reduced as the oil in the supporting chamber does not get contaminated by arc.

#### (a) Supporting chamber :-

→ It is a porcelain chamber mounted on a metal chamber. It is filled with oil which is separated from the oil in the ckt breaking chamber.

→ The oil inside the supporting chamber, porcelain & the bakelite paper is employed for insulation

purpose.

(b) Ckt breaking chamber :- It is a porcelain enclosed mounted on the top of the supporting chamber.

→ It is filled with oil & it has the following parts

(2) Upper & lower fixed contact

(3) Moving contact

iii) Turbulator

- The moving contact is a hollow cylinder which moves down over a fixed piston & include a & include a
- The turbulator is an arc control device & has both axial & radial vent. The axial venting ensures the interruption of low current whereas as the radial venting help in the interruption of heavy current.
- (C) Top chamber: It is a metal chamber mounted on the ckt breaking chamber it provides expansion space for the oil in the ckt breaking chamber.
- Operation:- Under normal operating cond' the moving contact remains closed with the fixed contact.
- When a fault occurs the moving contact is pulled down & an arc is struck b/w the fixed contact & moving contact.
- The arc energy vapourise the oil & produces gassing under high pressure. This action constricts the oil to pass through the central hole of the moving contact & results in forcing oil through the passage of the turbulator.
- The process of turbulation which is used to successively quenching the arc.

- \* Adv. :-
  - 1) A low oil ckt breaker has following adv. over a bulk oil CB;
  - 2) It uses lesser quantity of oil & it uses less space

iii) There is reduce risk of fire.

iv) Maintenance problem is reduce

\* Disadv.: -

i) Due to smaller quantity of oil, the degree of carbonisation is increase.

ii) There is a difficulty of removing the gases from the contact space in time.

iii) The dielectric strength of oil deteriorates rapidly due to the high degree of carbonisation.

\* Maintenance of oil CB:-

The maintenance of oil CB generally concerned with the checking of contact & the dielectric strength of oil.

† During the inspection of breakers following point to be taken.

1) Check the current carrying part & arcing contact, If the burning in previous the contact should be replaced.

2) Check the dielectric strength of oil, If the oil is badly discoloured it should be changed.

3) Check the oil level.

4) Check the insulation.

5) Check closing & tripping mechanism.

\* Air Blast ckt breaker:-

In this ckt breaker high pressure air blast used as arc quenching medium. The contact are opened in a flow of air blast establish by the opening of blast valve.

† Air blast cool the arc & sweep away the arcing product to the atmosphere.

‡ This rapidly increases the dielectric strength of medium both the contact & prevent from

re-establishment of arc and the arc is established & the blow of I is interrupted.

\* Adv.:-

⇒ The air blast CB has the following adv. over an oil CB & these are:

1. The risk of fire is eliminated.
2. The arcing products are completely removed by the air blast whereas as the oil deteriorates with successive op.
3. The arcing time is very small.
4. The energy supply for arc extinction is obtain from high pressure air & is independent of the I to be interruption.

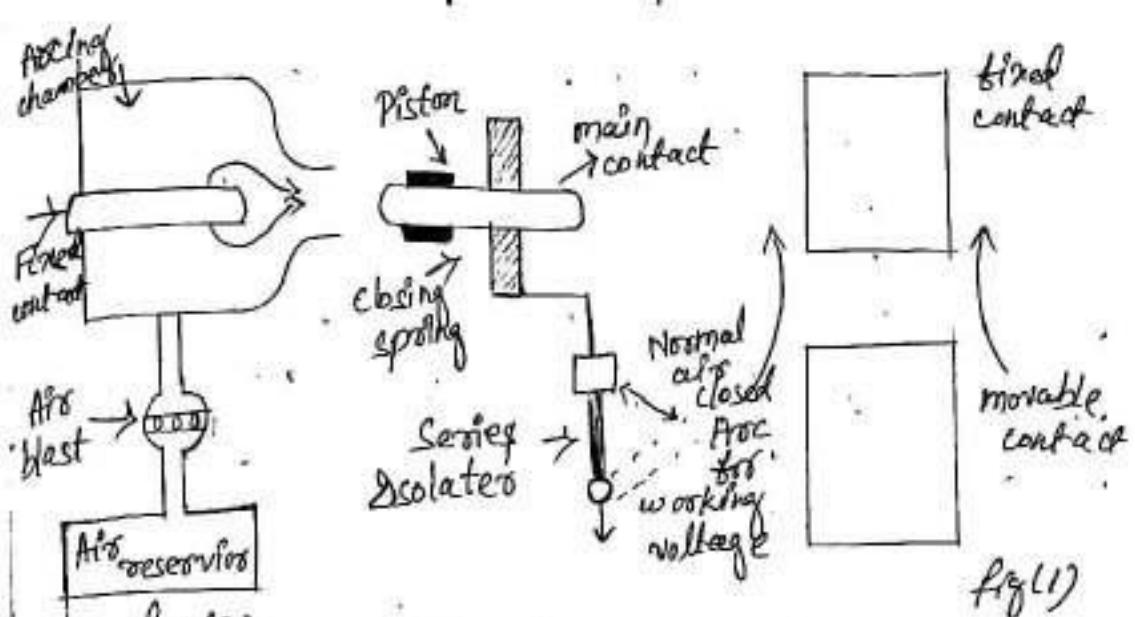
\* Disadv.:- The use of air as a quenching medium has the following disadvantage:-

- ⇒ The air blast CB are very sensitive to the variation in the rate of rise of Re-striking voltage.
- ⇒ Considerable maintenance is reqd for the compressor plant which supply the air blast.

⇒ Types of air blast CB:  
Depending upon the direction of the air blast to the arc, the air blast CB can be classified into 3 types; (a) Axial blast type  
(b) Cross blast. (c) Radial blast

(a) Axial Blast type:-

- ⇒ In which the air blast is directed along the arc path as shown in fig.
- ⇒ The fig. shows the essential part of air blast. The fixed & moving contact are held in the close position by the spring under normal condn.



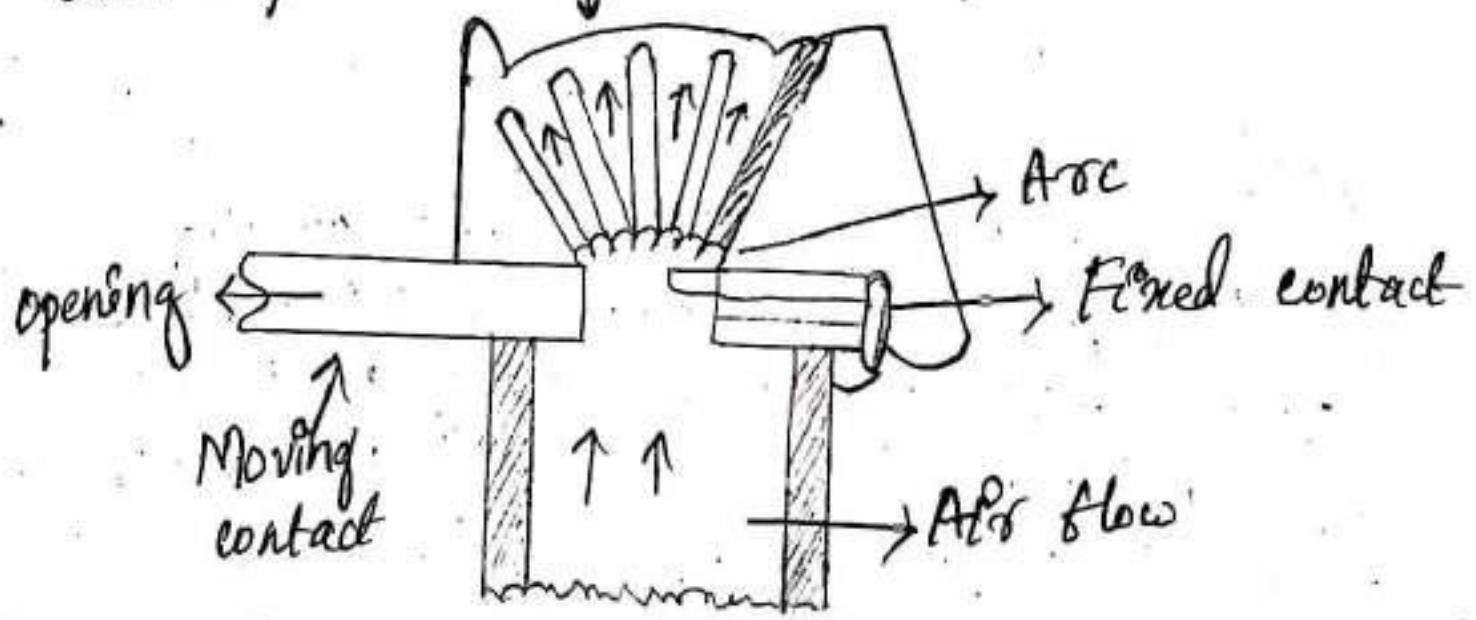
fig(1)

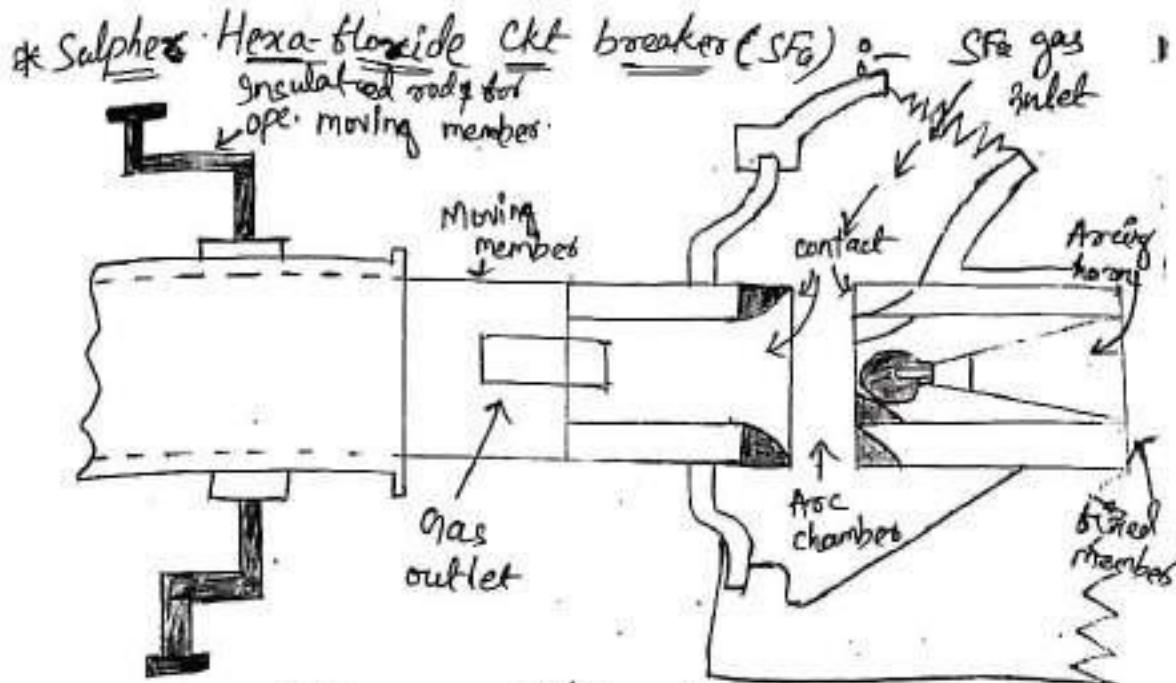
- The air reservoir is connected to the arcing chamber through an air valve. The air valve remains closed under normal operating cond" but it opens automatically by tripping mechanism when a fault occurs on the system.
- When a fault occurs the tripping impulse causes opening of air valve which connect the CB reservoir to the arcing chamber.
- The high pressure air entering the arcing chamber push away the moving contact against spring pressure.
- The moving contact is separated & an arc is produced and at the same time high pressure air blast flow along the arc and therefore, the arc is extinguished and the current flow interrupted.

### (b) Cross blast air blast CB:-

- In this type of CB air blast is directed at right angle to the arc.
- The cross blast lengthen and force the arc for arc extinction.

- When the moving contact is separated, an arc is produced b/w ~~fixed~~ & moving contact.
- The high pressure cross blast forces the arc into an arc splitter. The splitters serve to increase the length of the arc. This results in the arc extension & the flow of current is interrupted. Arc splitters





† A CB which uses Sulphur hexa-fluoride or SF<sub>6</sub> gas as arc extinguish medium is known as SF<sub>6</sub> CB.

† The SF<sub>6</sub> gas is a very good dielectric material which can resist high potential.

† SF<sub>6</sub> is an electro negative gas & has a strong tendency to absorb free electrons whenever the CB opens if contact an arc will formed b/w the 2 contact at the same time a high pressure SF<sub>6</sub> gas pumped on the arc.

† The conducting free electron in the arc are rapidly captured by the gas to form relatively immobile -ve ion.

† This losses the conducting electron in the arc & quickly build up the insulation strength to extinguish the arc.

† The SF<sub>6</sub> CB are very effective for high power or high voltage ope..

† Construction:- The SF<sub>6</sub> CB consist of a fixed contact and a moving contact & closed in an arc interrupter chamber which contain SF<sub>6</sub> gas.

- This chamber is connected to the SF<sub>6</sub> gas reservoir.
- When the contact of CB are open the valve mechanism permit a high pressure SF<sub>6</sub> gas from the reservoir to blow forward across interruption chamber. The fix contact & moving contact are hollow cylindrical arrangement. The moving contact contain rectangular holes in the side to permit the SF<sub>6</sub> gas out through these holes after blowing along the arc.
- The tips of fixed contact & moving contact & arcing horn are coated with copper-Tungsten arc R material.
- Since SF<sub>6</sub> is costly, it is recycled & reused by the suitable auxiliary system after each op. of the ckt-breaker.

\* Working :-

In the closed position : at the breaker the contact remain surrounded by SF<sub>6</sub> gas at a pressure of 2.8 to 3.2 kg/cm<sup>2</sup>

- When the breaker op. the moving contact is separated from the fix contact & the arc is struck between the contacts.
- The movement of moving contacts is synchronised with the opening of valve which permit SF<sub>6</sub> gas at pressure of 14 kg/cm<sup>2</sup> from the reservoir to arc interruption chamber.
- The high pressure blow of SF<sub>6</sub> gas rapidly absorb the free e- in the arc path & quickly build up high dielectric strength & causes the extinction of arc.

→ After the CB ope. the valve is closed by the action of spring.

\* Adv.:-

→ Due to superior arc quenching property of SF<sub>6</sub> gas the SF<sub>6</sub> CB have many adv. over oil or air ckt breakers these are;

1. Due to the superior arc quenching property of SF<sub>6</sub> gas such CB have very short arcing time.

2. Since the dielectric strength of SF<sub>6</sub> gas is 2 to 3 times of air such breaker can interrupt large current.

3. The SF<sub>6</sub> gas CB gives noise less operation.

4. The closed gas encloses keep the interior dry so that there is no moisture problem.

5. There is no risk of fire in such breakers becz SF<sub>6</sub> gas is non-inflammable (unburnable).

6. The SF<sub>6</sub> CB have less maintenance cost and require min<sup>n</sup> auxiliary equipment. Since SF<sub>6</sub> CB are totally enclosed & sealed from atmosphere, they are particularly suitable where explosion hazard could exist.

\* Dis-advantage :-

1. The SF<sub>6</sub> CB are costly due to the high cost of SF<sub>6</sub> gas.

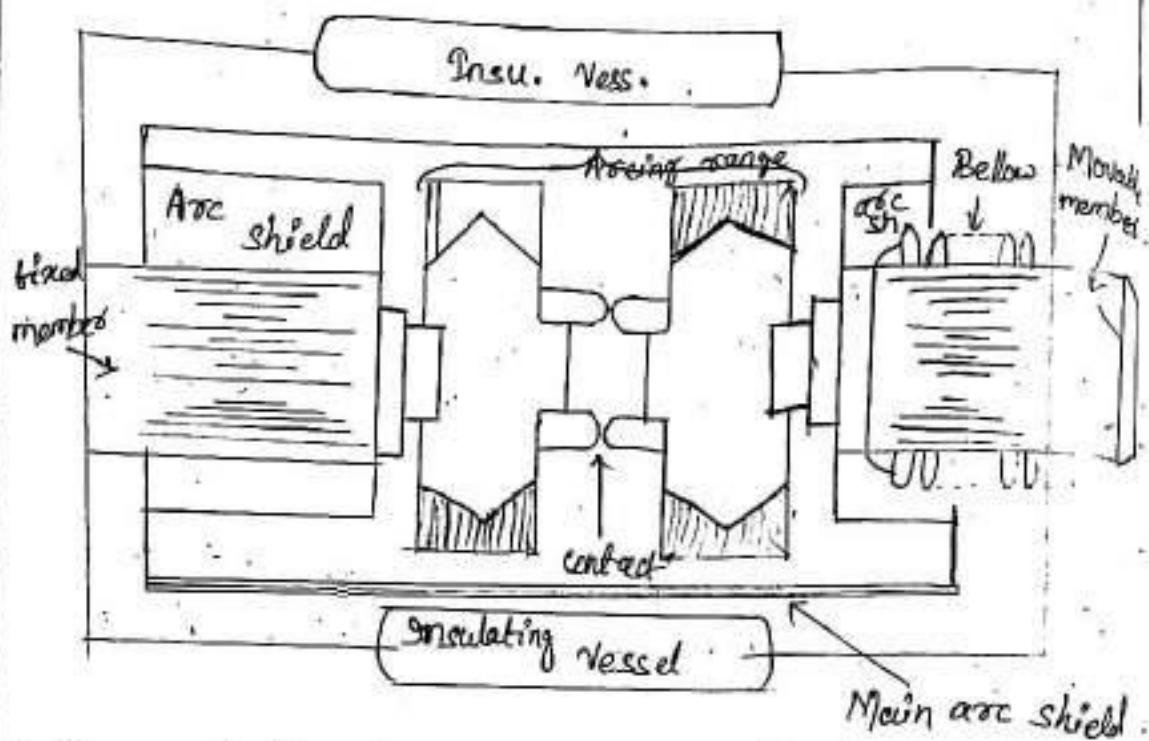
2. Since SF<sub>6</sub> gas has to be reuse or recond<sup>n</sup> after every operation, additional equipment is reqd for this purpose.

\* Application :-

→ The SF<sub>6</sub> CB have been developed for the voltage of 115 kV to 230 kV, power rating of 10 MVA

to 20MVA.

## \* Vacuum ckt breakers (VCB)



- In such breakers vacuum is used as arc quenching medium, since vacuum offers the highest insulation strength it has superior arc quenching property than any other medium.
- For ex. when contact of CB are opened in vacuum, the interruption occurs at 1st  $I_{Z_0}$  with dielectric strength betw the contact building up at a rate of 10. of times higher than the other CB.

\* Operation:- When the contact of the breakers are opened in vacuum an arc is produced betw the contact by the ionisation of metal at the contact. However the arc is quickly extinguished bcz the metallic vapours, electrons & ion produced during <sup>arc</sup> rapidly condense on the scorch of the CB contact.

- Resulting in quick recovery of dielectric strength. In the CB as shown as the arc is produced in vacuum it is quickly extinguished due to the 1st recovery of dielectric strength.
- Construction: It consists of fixed contact, moving contact & arc shield mounted inside a vacuum chamber.
- The movable member is connected to the control mechanism by stainless steel bellows.
- This enables the permanent sealing of the vacuum chamber ~~so~~ as to eliminate the probability of leakage.
- A glass vessel, ceramic vessel is used as the outer insulating body. The arc shield prevent the deterioration of the internal dielectric strength.

\* Adv.:- The vacuum CB have the following adv.

- (1) They are compact, reliable & have longer life.
- There are no fire hazard.
- They require little maintenance.
- They can successfully withstand the lightning surge.
- They have low arc energy.
- It can interrupt the heavy fault I.
- \* The VCB are employed for outdoor application ranging from 22KV to 66KV. with a limited rating of 60 to 200 MVA. These CB are suitable for the rural area.

# Protective Relays

ch-5

\* Relay should operate as fast possible in a fault condition but it should not operate so fast there should be occurs in damage to the system.

\* Fundamental requirement of protective relay :-

\* Sensitivity :-

→ The ability of relay to operate or detect with a low value of actuating quantity.

→ Generally it is a function of volt amper rating of relay coil i.e. if the rating is low the sensitivity is high.

\* Reliability :- On the occurrence of fault the operating mechanism of a relay must operate so that the ckt breakers can isolate the faulty part by obtaining information from the relay.

\* Simplicity :- A relay construction should be simple, so that the cost is less & difficulty in maintenance can be avoided.

\* Economic :- A relay should not be costly enough work by used in protective system.

→ In common practice total relaying cost should not more than 5% of the total coil, but cost can be compromised in case of important load & equipment.

\* Types of Relay :-

→ According to the operation of a relay, the relay can classified into 2 types.

1. Electromagnetic Attraction type

2. Induction type

1. Electromagnetic Attraction type :- This type relay operated by the nature of an ammeter being

attracted to the poles of an electromagnet which is drawn into a solenoid.

→ Such relay can be operated by both A.C. or D.C. quantity.

→ The important type of electromagnetic attraction type relay are :-

(i) Attraction armature type relay

(ii) Solenoid type relay

(iii) Balanced beam type relay

→ Attraction armature type relay :-

→ The fig. shows the schematic arrangement of an attracted armature type relay.

→ It has a laminated electro-magnet (M) carrying a coil (C) & a laminated armature.

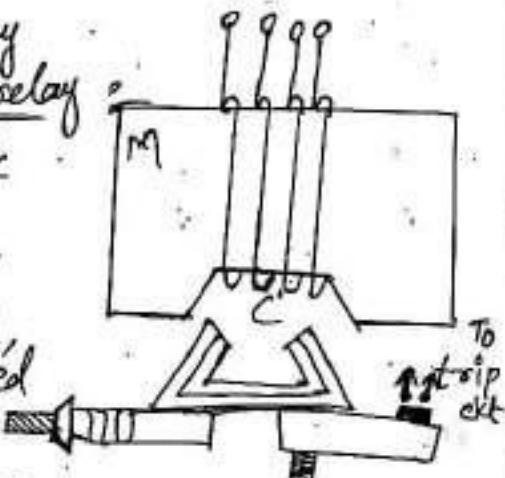
→ The armature is balanced by a counter weight & carries a pair of spring contact at its free end.

→ Under normal operating condition the current flows through relay coil & such that the counter weight holds the armature in the free as shown in fig.

→ However when a short ckt occurs the thrown relay coil is increased & the relay armature is attracted upward.

→ The contact on the relay armature attached to the relay frame thus complete the trip ckt which result in the opening of the CB & therefore the faulty section can be disconnected from the healthy section.

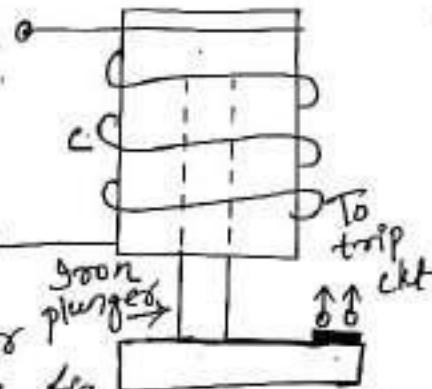
→ The minimum current at which the relay armature is attracted to close the trip ckt is called as peak-up current.



### 1) Solenoid type relay :-

The fig. shows the schematic arrangement of solenoid type relay.

It consists of solenoid & movable iron plunger, as shown in fig. Under normal operating condition the current through the relay coil is such that it holds the plunger <sup>iron</sup> ~~plunger~~ by the spring as shown in fig.



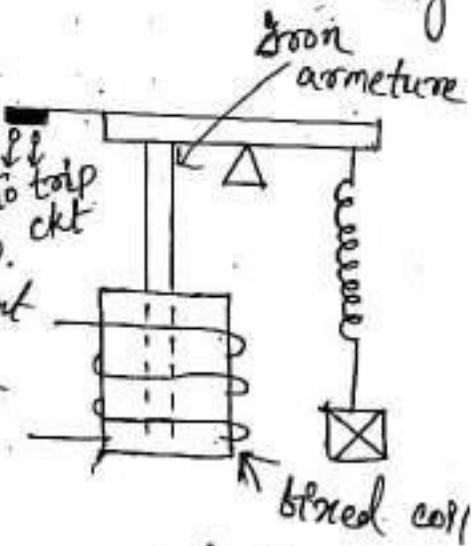
When the fault occurs the current through the relay coil becomes more than the peak up. value causing the plunger to be attracted to the solenoid.

The upward movement of the plunger close the trip ckt & thus the CB open & the faulty section can be disconnected from the healthy section.

### 2) Balanced beam type relay:-

The fig. shows of a balanced beam type relay. It consists of an iron armature & a balanced beam ckt.

Under normal condition the current through the relay coil is such that the beam is at the horizontal position.



But when a fault occurs the current through the relay coil becomes greater than the peak up value & the beam is attracted to closed the trip ckt this causes the opening of ckt breaker to isolate the faulty section.

## 2. Electromagnetic Induction type relay :-

- This type of relay operate on the principle of the electro-magnetic induction.
- This type of relay mainly used for the purpose of AC quantity.
- This relay basically operate when an aluminium disc b/w 2 alternating magnetic field which has same frequency but separate phase displacement b/w each other to rotate the disc.
- More is the phase displacement there will be more torque produced as the disc.
- The following 3 type of structure commonly used for obtaining the phase difference in the fluxes & hence the operating torque in the induction relay this are :-

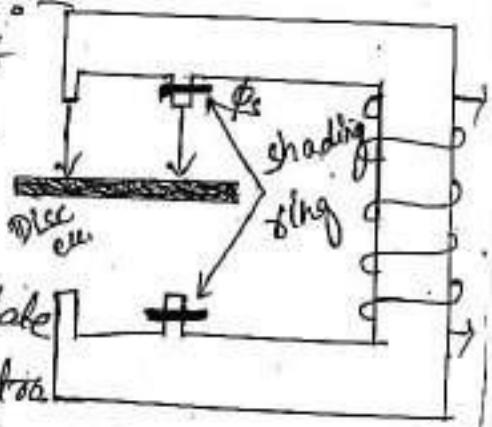
i. Shaded pole structure

ii. Watt-hour meter/double watt structure.

iii. Induction cup structure.

### ii) Shaded pole structure :-

- The general arrangement of shaded pole structure is shown b/w.



- It consists of an aluminium disc which is feed to rotate in the air gap of an electro magnet.

→  $\frac{1}{2}$  of each pole is surrounded by a copper band which is known as shading ring. To cutting the flux.

→ The alternating flux  $\phi_s$  in the shading portion will produced the current in the ring lag behind the flux ' $\phi_u$ ' in the unshaded portion by an angle.

'd', so the torque produced is given by

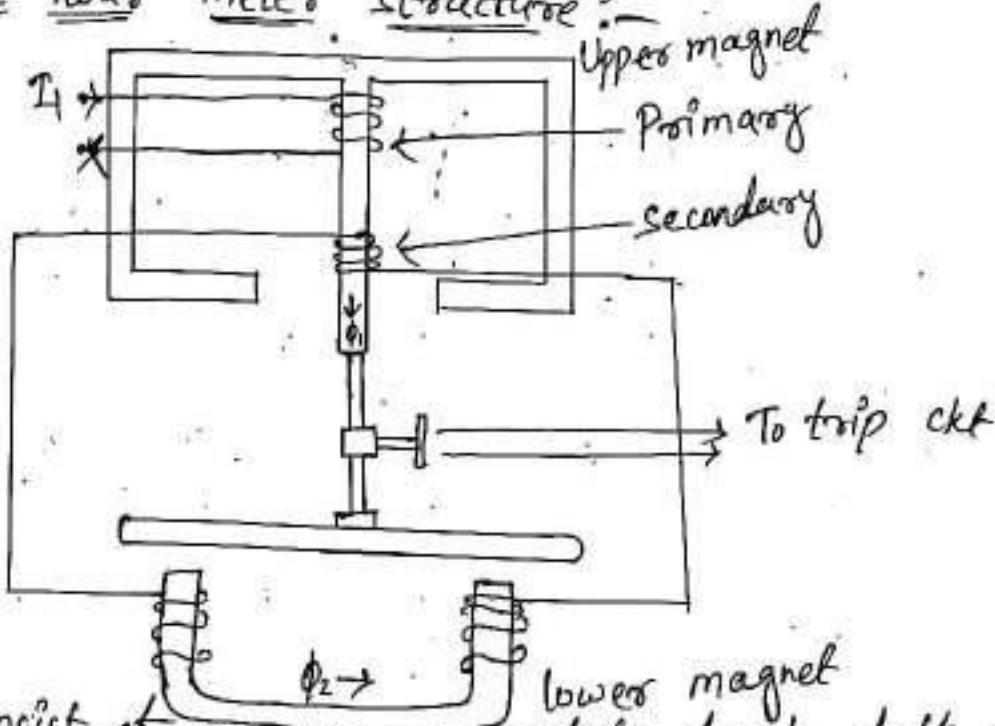
$$Td \phi_s \phi_u \sin d$$

→ The fluxes ' $\phi_s$ ' & ' $\phi_u$ ' is directly proportional to the current 'I' in the relay coil.

$$Td I^2 \sin d$$

$$T d \phi_c, T d \phi_u$$

iii) Watt-hour meter structure:



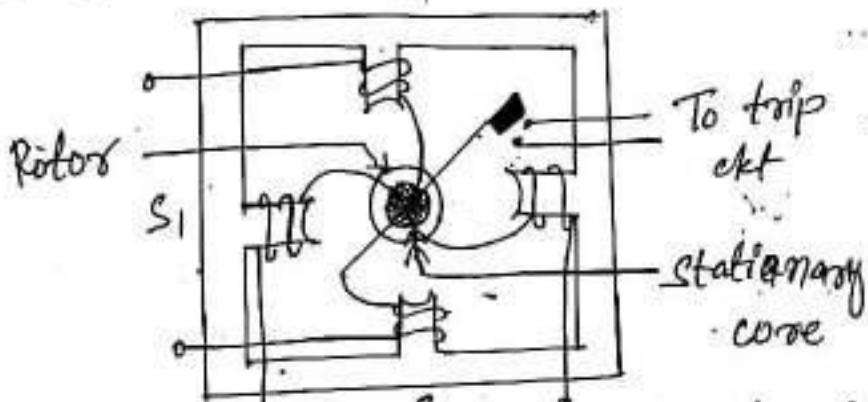
→ It consists of an arrangement to rotate freely between the pole of 2 electro-magnet. The upper magnet carries 2 winding i.e. the primary & secondary.

→ The primary winding carries the relay current while the secondary winding is connected to the winding of the lower magnet.

→ The primary current induces emf in the secondary coil & so current ( $I_2$ ) circulates in it the flux ( $\phi_2$ ) induced in the lower magnet by the current ( $I_2$ ) in the secondary winding of the upper magnet.

→ Flux ' $\phi_2$ ' lags behind the ' $\phi_1$ ' by an angle 'd', the 2 fluxes ' $\phi_1$ ' & ' $\phi_2$ ' differing in phase by 'd' which produce the reqd torque on the disc.

- The torque produced is proportional to  $\Phi_1 \Phi_2 \sin\alpha$ .
- An important feature of this type of relay is that its operation can be controlled by opening or closing the secondary wind ckt, by Induction cup structure:-



- The construction of this type of relay is similar to the construction of Induction motors.
- The stator wind is supplied from the actuating quantity.
- The rotor core is kept stationary only the rotor conductor position being more freely.
- The moving element is a hollow cylinder rotor which turns on its exceed.
- The rotating field is produced by 2 pair of coil on the 4-pole.
- The rotating field induces the current & provided the necessary torque.
- If  $\Phi_1$  &  $\Phi_2$  represent the flux produced by the respective pair of coil.
- Then the torque produced is proportional to  $\Phi_1 \Phi_2 \sin\alpha$  where,  $\alpha$  = phase difference b/w the 2 flux.
- The induction cup structure is more efficient torque producer, than the shaded pole or the watt-hour cup structure.

### \* Important term :-

→ Peak-up current :- It is the minimum current of the relay coil at which the relay starts to operate. It is expressed in Amperes.

→ Current setting :- A relay can be made to operate at different peak-up current by providing tappings in the operating coil, this is known as current setting value of each tap. For over current relay tapping of 50% to 200% are provided with the tap at 25%.

\* Peak up current = rated secondary current of CT  
X current setting.

Ex:- An over current relay having a current setting of 125%. is connected to a supply through a CT of 400/5, then peak up current =  $5 \times 1.25 = 6.25$ .

→ Plug setting multiplier (PSM) :-

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

$$PSM = \frac{I_{\text{fault}}}{I_{\text{pick up}}} = \frac{I_{\text{fault}}}{\text{rated secondary current of CT} \times CS}$$

→ Time setting multiplier (TSM) :-

→ A relay can be adjusted the different operating time this adjustment is known as TSM.

→ The TSM is multiplied with the relay operating time Vs PSM time; get the actual operating time.

→ TSM generally expressed in second.

## \* Differential Relay:-

- This is the relay which operates the phasor difference of the 2 or more similar electrical quantity exceed a predetermined value.
- This type of relay is used where more sensitivity of the operation is required.
- Depending upon the actuating quantity the differential relay can be divided into 2 types.
  - 1 → Current balance protection system.
  - 2 → Voltage balance protection system.

### 1) Current balance protection system:-

- A pair of identical CT are used on either side of the protected system, the secondary of CT are connected in series in such a way that they carry the same current in the same direction.

- The operating coil of the over current relay is connected in the CT secondary ckt. To load  $200:1$   $200:1$

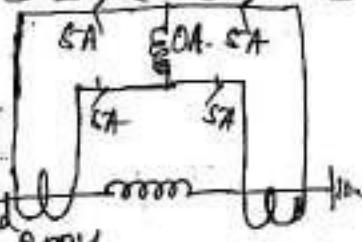
- Under normal operating condition a normal current flows through the both the CT. i.e. the current flows through the 2 CT. are equal.

- As the current at the 2 CT. are same there is no current flows through the relay coil so the relay can't be operate.

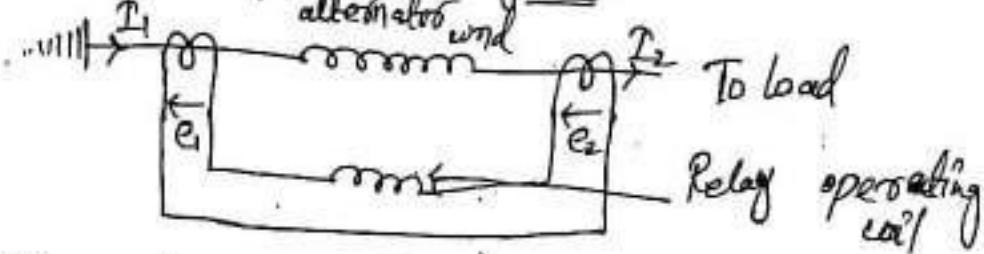
- If a fault occurs the secondary current of CT are not equal & the current flows through the relay coil & then the relay can be operated

- \* Disadvantage:-

- i) Exactly identical CT reqd.
- ii) The accurate matching of can't be achieve due to the pilot ckt impedance.



## If Voltage balance protection system :-



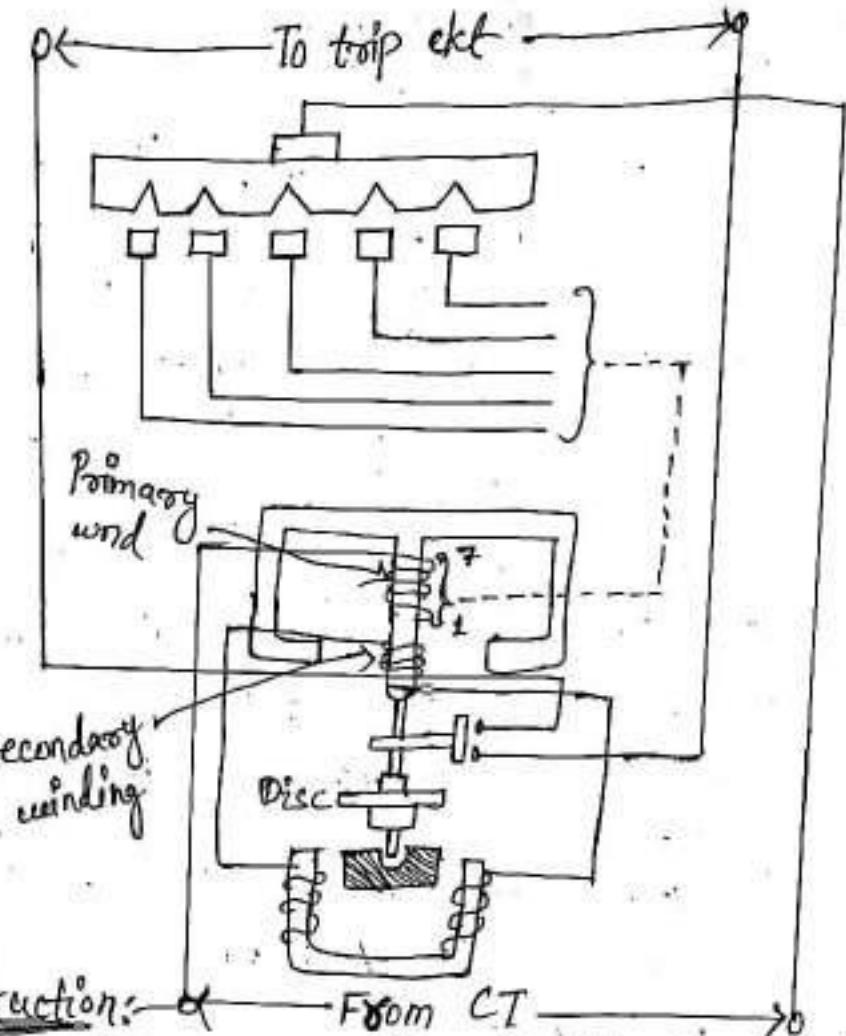
- In this scheme of protection system for similar CT are connected on either end of the protected system by means of pilot wire.
- Under normal condition equal current flows through the primary wind of the CT<sub>2</sub>. Therefore the secondary voltage of the 2 CTs are balanced to each other so no current flows through the relay operating current.
- When the fault occurs the protected one the 2 primary of the CT will differ from each other & the current flows through the relay operating coil which close the trip ckt.

## If Difference type of functional relay :-

- Relay can classified into the following type according to there function.
- i. Inductor type over current relay
- ii. Induction type ~~reverse~~ power relay
- iii. Distance relay
- iv. Differential relay
- v. Transistor relay

## If Induction type over current relay (Non-directional):-

- This types of relay operate on the induction principle. This relays are used in AC ckt only & can be operate for the fault current flows in either direction.



\*Construction:

- It consists of a metallic disc (Aluminium) which is free to rotate. In bet<sup>n</sup> the poles of 2 electromagnet i.e. upper & lower magnet.
- The upper electromagnet has the 2 wind i.e. primary & secondary wind.
- The primary wind is connected to a secondary of a CT in the line & is tap at intervals.
- The tappings are conn<sup>c</sup> to a plug setting by which the no. of active turns of the relay operating. coil varying too giving the desire current setting.
- The secondary wind is energized by induction from primary wind. & the secondary wind is connected in series with the wind of the lower magnet. The controlling torque is provided by a spring control.

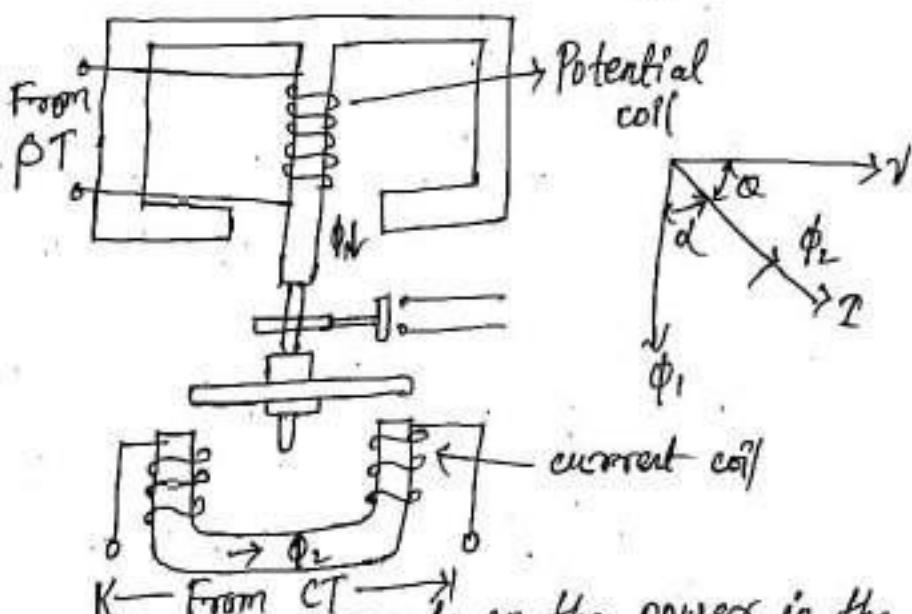
Operation:-  
The deflecting torque on the aluminium disc is set up due to the induction principle, this deflecting torque is opposed by the controlling torque which is provided by the spring.

Under normal operating condition the controlling torque is greater than the deflecting torque produced by the relay coil so the aluminium disc is remain stationary.

When the fault occurs the current on the protected ckt exceeds, so the deflecting torque becomes greater than controlling torque, so the disc rotates.

When the disc has rotated the trip ckt closes & operate the C.B. which isolate the faulty section.

Induction type direction power relay:-



This type of relay operate on the power in the ckt close in specific direction.

Construction:-

It consist of aluminium disc which is free to rotate in belt of pole of 2 electro-magnet. i.e. upper & lower electro-magnet.

The upper electro-magnet carries a winding

(called potential coil) on the control limb which is connected through a PT to the voltage source

- The lower magnet has a separate winding (called current coil) which is connected to the secondary of CT in the limb which is to be protected.
- The current coil is provided with a no. of tapping to provide different current setting.
- The controlling torque is provided by the spring control.

2. Operation:— From the phasor diagram the flux  $\phi_1$  due to the current in the potential coil will be nearly  $90^\circ$  lagging behind the applied voltage  $V$ .

→ The flux  $\phi_2$  due to the current coil will be nearly in phase with an operating current  $I$ .

$$T \propto \phi_1 \phi_2 \sin \alpha$$

$$\propto VI \sin(90 - \alpha)$$

$$\propto VI \cos \alpha$$

$T \propto$  Power in the circuit.

→ It is clear that the direction of the deflecting torque on the disc depend upon the direction of the power flow in the ckt.

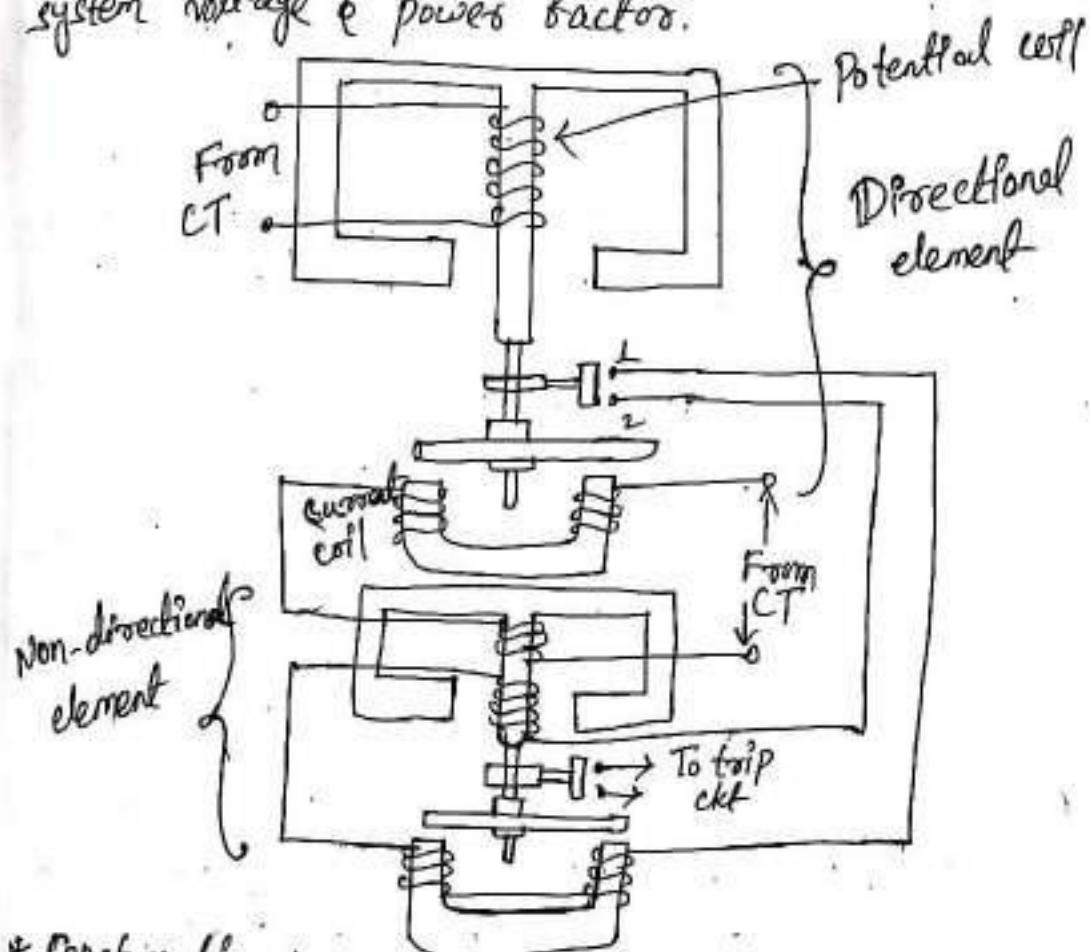
→ When the power in the ckt flows in the normal direction the relay inoperative.

→ When the fault occurs the direction of current reverse, this reverse the direction of deflecting torque on the disc.

→ When the reverse deflecting torque becomes enough the disc rotates in the reverse direction & the moving contact close the trip ckt, this cause the operation of CB which disconnected the faulty section.

## \* Induction type directional overcurrent relay:-

- The directional power relay is suitable for use as a protective relay under the short ckt condition.
- When short ckt occurs in the system voltage falls to a lower value so there may be insufficient torque difficultly is overcome in the directional over current relay which is independent of system voltage & power factor.



## \* Construction:-

- It consists of 2 relay element i.e. directional element & non-directional element.
- Directional element:-
  - It is essentially a directional power relay which operates when a power flow in specific direction.
  - The potential element of this element is connected through a PT.
  - Current coil of the element is energized through a CT this winding is carried over the upper

magnet at the non-directional element.

→ The trip contact (1 & 2) of the directional element are connected in series with the secondary ckt of the over current element. Therefore the directional element must operate fast i.e. (contact 1 & 2 should close) in order to operate the over current element.

→ Non-directional element:-

→ It is an over-current element similar to a non-directional over current relay.

→ The spindle of the disc of this element carries a moving contact which closes the trip ckt contact after the operation of directional elements.

★ Operations-

→ Under normal operating condition the power flow is in the normal direction. In the ckt,

→ So the directional power relay does not operate therefore the over-current element does not operate.

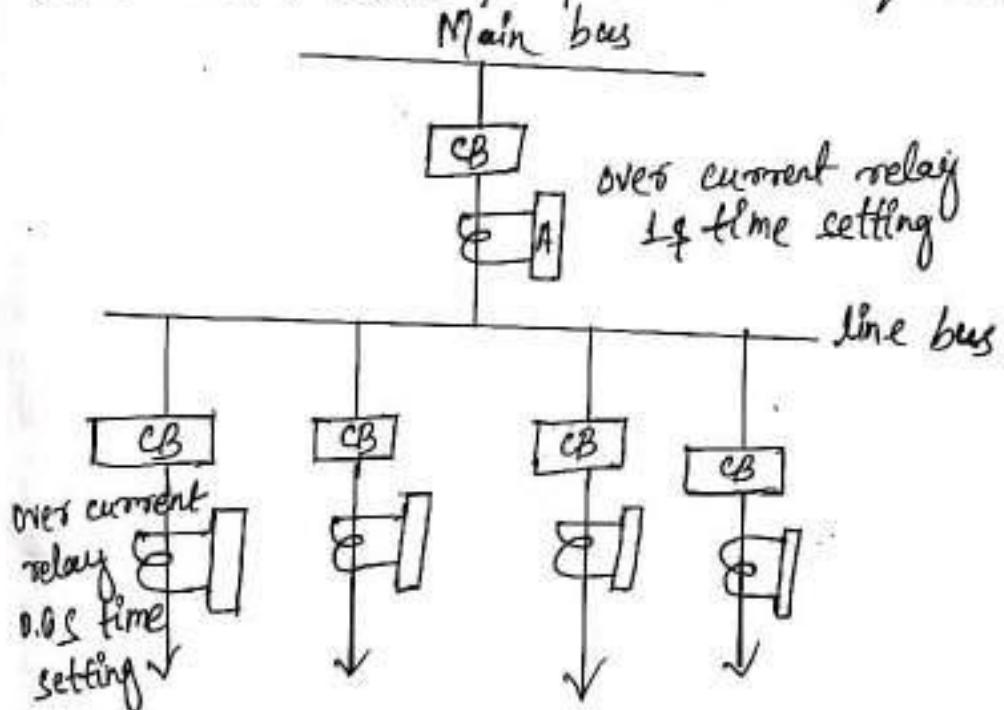
→ When a short ckt occurs, there is a provision for the current or power to flow in the reverse direction, therefore the disc of the upper element rotates which closes the contact 1 & 2. This complete the ckt for over-current relay.

→ So that the disc of the overcurrent relay rotates & closes the trip ckt, this operates the ckt breaker which isolate the faulty/ unhealthy section.

## \* Types of Protection :-

- When a fault occurs on any part of electric power system it must be cleared quickly for order to avoid damage or interference with the rest of the system.
- The protection scheme is divided into 2 classes these are (i) Primary Protection  
(ii) Backup " "
- Primary Protection :-

- It is the protection scheme which is designed to protect the component parts of the power system.
- The fig. shows each line has an over current relay that protects the line.
- If a fault occurs on any line it will be cleared by its relay & ckt breaker. This forms the primary or main protection.
- However sometimes faults are not cleared by primary relay system because of trouble with in relay wiring system or breakers under such condn. back up protection required.



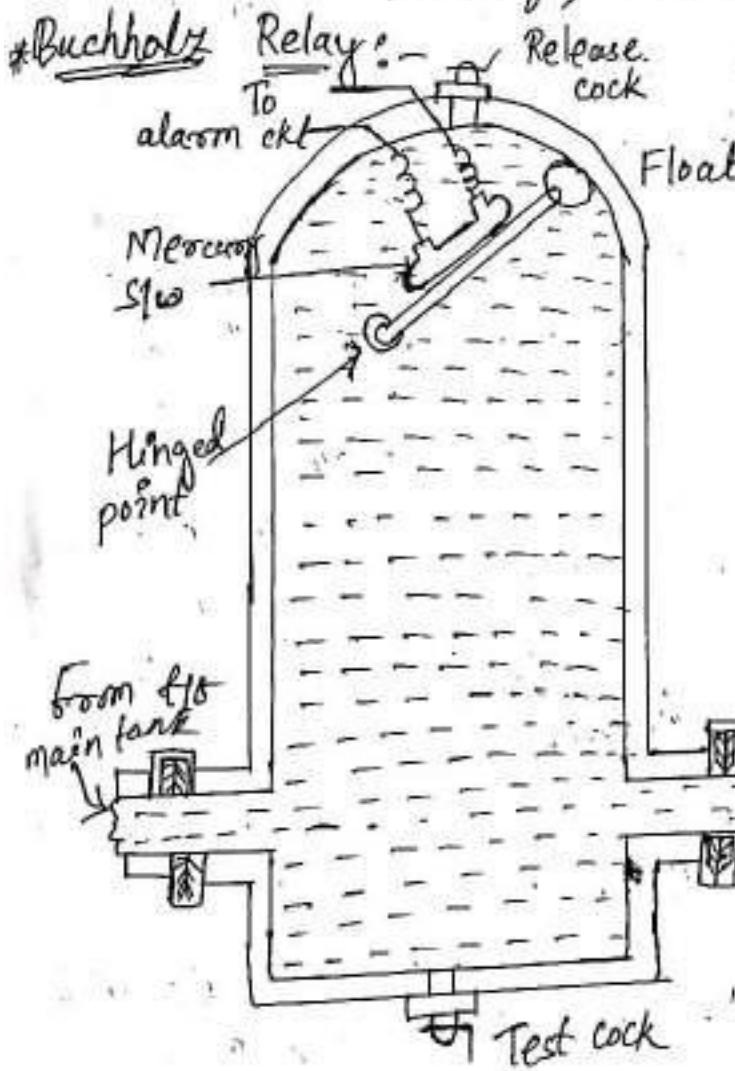
### Q) Backup Protection :-

- It is the second line of defense in case of failure of the primary protection.
- It is designed to operate with sufficient time delay so that primary relay will be given enough time to function.
- Fig. shows that, Relay 'A' provides back up protection for each of the four line.
- If a line fault is not cleared by its relay and breaker, the relay 'A' will operate after a definite time delay and clear the fault.

TD-06/03/20 {Protection of Electrical power // Ch-6  
// equipment and lines //}

- The electric power system consist of several equipments & these are alternator, t/f, busbar, transmission line & other equipments.
- It is desirable & necessary to protect each element from a variety of fault conditions.
- \* Protection of t/f :- The t/f's are the static device and totally enclosed and generally oil immersed. so there is a chance of fault occurring on them. so, there is necessity to provide the adequate to automatic protection for t/f against any possible fault.
- Common t/f fault :- The power t/f may suffer from:-
  - open ckt, over heating and short ckt etc
  - + An open ckt in 1φ of a 3φ t/f may cause undesirable heating. On the occurrence such fault the t/f can be disconnected manually from the system.
- The short ckt on the t/f arise (comes) from deterioration (loss) of insulation due to over heating. When an internal fault occurs the t/f must be disconnect quickly from the system. so the relay protection is necessary for internal fault.
- \* Protection system for t/f :- The principle relays and systems used for t/f protection are;
  - ↳ Earth fault relay (Providing the protection against arc fault only)

- ↳ Over I relay - (Providing the protection against phase to phase fault & over load)
- ↳ Differential system or circulating current system - (Providing protection against both earth & phase fault)
- ↳ Buchholz relay - (Providing protection against slow developing fault such as insulation failure at the wind, core heating, fall of oil level.)



DT- 11/03/2020

→ This relay is a gas actuated relay installed in ~~the~~ oil immersed f/t for the protection of all kind of slow developing fault.  
 → It is used to give an alarm in case of slow developing fault in the f/t and it can be disconnect from the f/t in the event of severe internal fault.

- It is usually installed in the pipe connecting to the conservator to main tank.
- The buckholz relay is used in the oil immersed t/f having the rating as ~~except~~ 450 kVA.
- \* Construction:-

It takes the form of a domed vessel placed in the connecting pipe b/w the main tank & conservator.

- It has 2 elements. The upper element consist of a mercury type switch attached to a float.
- The lower element contains a mercury switch mounted on a hinge type float located in the direct path of the float at 5% from the t/f to the conservator tank.
- The upper element closes an alarm ckt during the slow developing slot whereas the lower element is arranged to trip the ckt breaker in case of severe fault.

\* Operation:- In case of slow developing fault with in the t/f the heat due to the fault causes decomposition of some t/f oil in the main tank. The product of decomposition contains more than 40% of the Hydrogen-gas.

→ The H-gas is in light weight so it always tries to go into the conservator & in the process gets entrapped in the upper part of the relay chamber.

→ When a preheated amount of gas gets

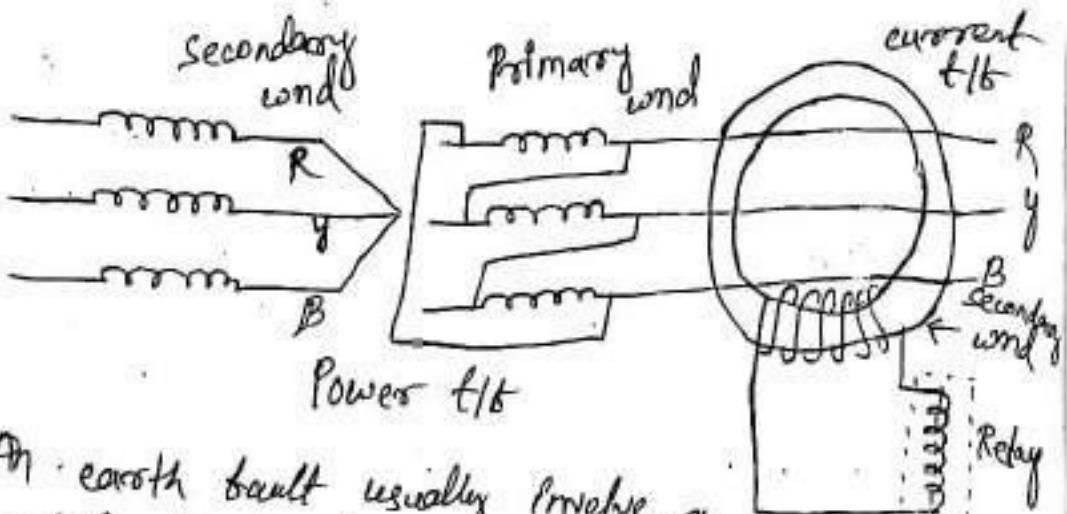
accumulated it exerts sufficient pressure on the float to cause it to tilt. move and close the mercury switch attached to it. This complete the alarm ckt to sound an alarm.

If a severe fault occurs in the t/b or if a <sup>high</sup> amount of gas is generated in an enormous amount the oil in the main tank rushes (up) towards the conservator via the bushholes relay and in doing so tilt the flap to close the contact of mercury switch. They complete the trip ckt to open the ckt breaker which controlling the t/b.

Advantage :- It is the simplest form of t/b fault protection. incipient (slow developing) at a 2. It detect much earlier than other form of protection.

Disadvantage :- 1. It can only used with oil immersed t/b equipped with conservator tank. can detect only fault below oil level in the t/b. Dt-12/03/20

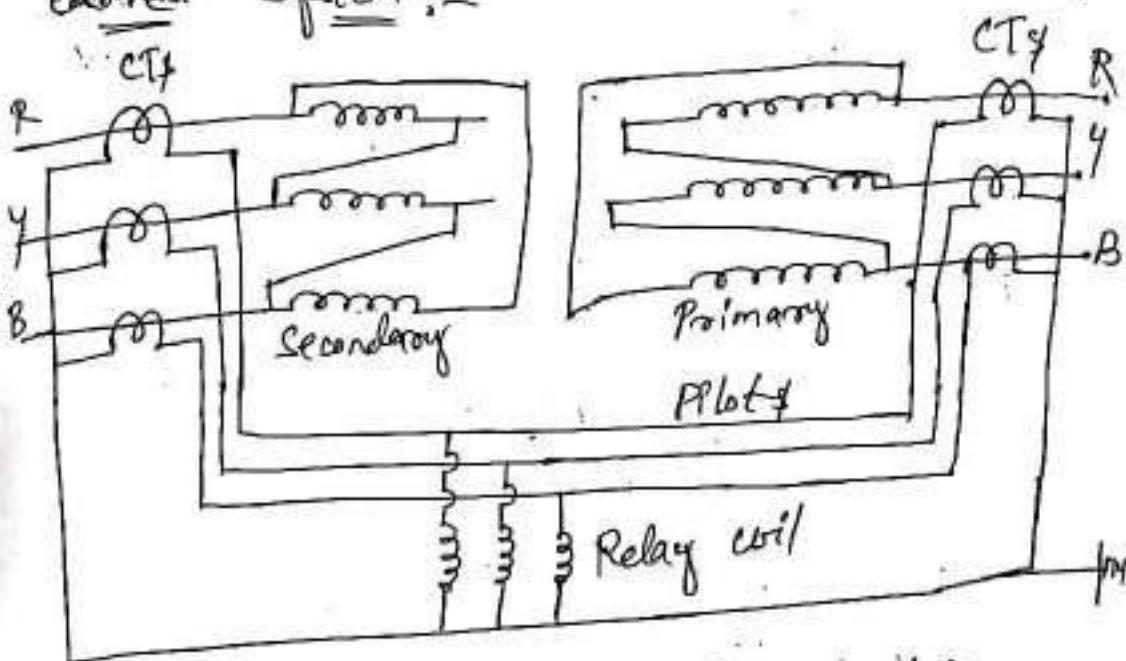
2. The device leakage protection :-  
\* Earth faults or leakage protection :-



- An earth fault usually involve a partial break down at wind insulation to earth & the earth fault may continue for a long time & cause considerable damage before it develops the short ckt & remove from the system.
- Under this case it is profitable to employ earth fault relay in order to ensure the disconn at earth fault in the early stage.
- An earth fault relay is essentially an over current relay & it is the method which provide the protection against earth fault in a f/t.
- In this method, the 3 lead of primary wind of the power f/t are taken through the core of a current f/t.
- The operating coil at the relay is conn to the secondary wind of the current f/t.
- Under normal cond the vector sum of the 3φ current is zero. & there is no resulting flux in the core at the current f/t. ∴ no current flows through the relay & it remains inoperative.

On the occurrence of an earth fault the vector sum of 3φ current is no longer zero & the resultant current set up flux in the core of the CT which induced EMF in the secondary and this energies the relay coil to trip the ckt breaker and disconnect the faulty t/t from the system.

Q Differential protection system or circulating current system ?



- The fig. shows the merk-principle circulating current scheme. For the protection of a 3φ delta-delta scheme. For the protection of a 3φ delta-delta scheme. For the protection of a 3φ delta-delta scheme.
- The CTs on the 2 sides of the t/t are connected to compensate for the φ offset between the power t/t primary & secondary.
- The CTs on the 2 sides are connected by pilot wires & one relay is used for each pair of CTs. During the normal operating condition the secondary of CTs carry identical current.
- ∴ The current entering & leaving the pilot wire at both end are same & no. i.e.

current flows through the relay.  
→ If a ground &  $\phi$  to  $\phi$  fault occurs the current in the secondary side of CT will not same and differential current flowing through the relay etc.

#### \* Protection of alternator:-

→ It is desirable & necessary to provide the protection against the wide range of fault which may occur in the modern generating plant. Some of the imp. fault which may occur on the alternator are:-

by Failure of Prime-movers  
by Failure of field winding

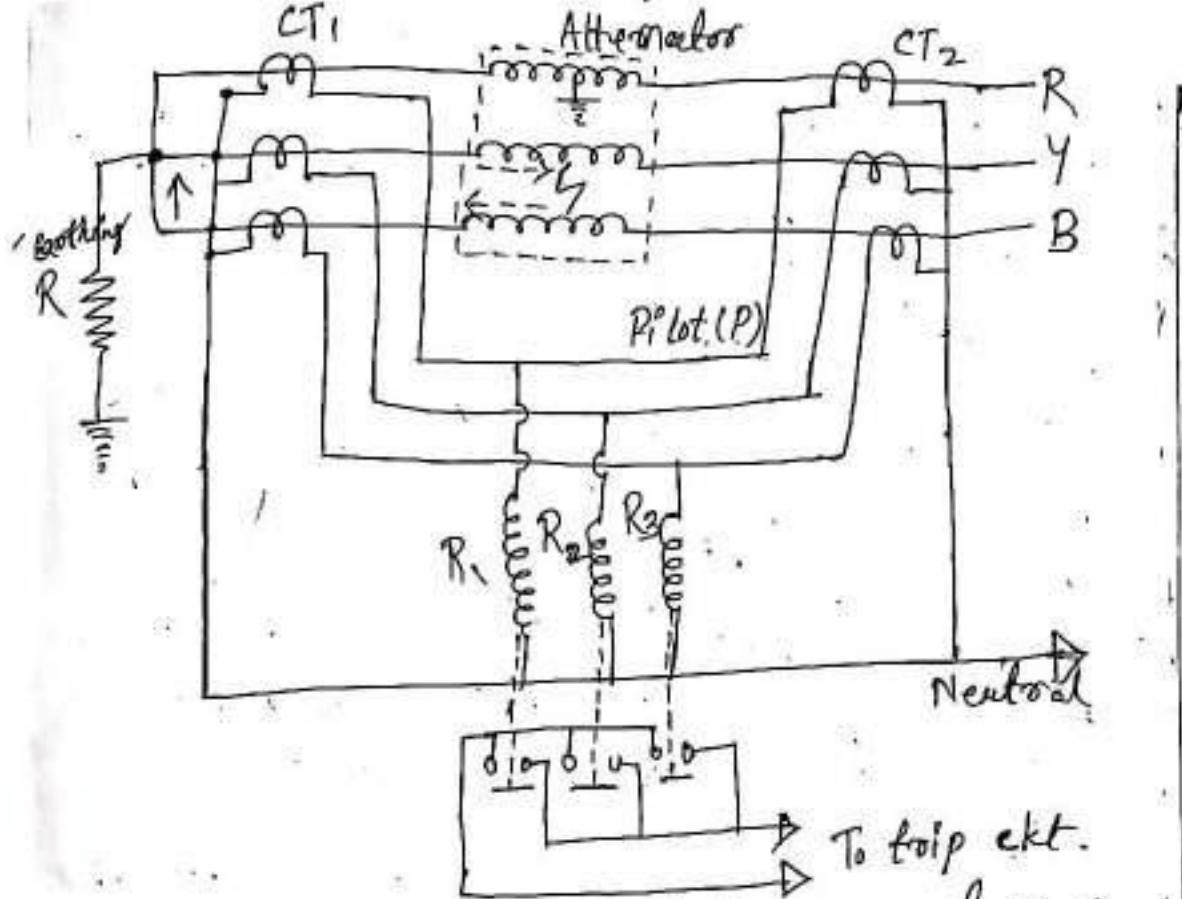
- iii) Over current
- iv) Over speed
- v) over voltage
- vi) Unbalanced loading
- vii) Stator wind fault.

→ The stator wind faults are the most dangerous which may cause damage to the expensive m/c. automatic protection necessary to clear such fault in order to minimize the damage.

→ For the protection of alternators against such fault, differential protection also known as mag. pulse system is most commonly employed.

→ Differential protection of Alternator:- DT-13/03/

→ The most common system used for the protection of stator wind fault employed circulating current principle.



↑ In this scheme current at the two end of the protected section are compared.  
 ↑ Under normal op. condn these currents are equal but in case of fault there may be difference in currents & this resulting difference current pass through the operating coil of the relay. Then the relay close its contact to isolate protected system section from the

↑ This form of protection is also known as merz-prince circulating current scheme.

↑ Schematic arrangement:  
 The fig. shows the schematic arrangement of differential I protection for a 3φ alternator.  
 ↑ Here the identical current t/f pilot CT<sub>1</sub> & CT<sub>2</sub> are placed on either side of each phase of the stator winding.

→ The secondary end of each set of CT are conn in star and the two neutral points & the corresponding terminal at the 2 star group being connected together by means of 4 core pilot wire.

→ Thus there is an independent path for the I. circulating in each pair of the CT & the corresponding pilot wire.

→ The relay coils are conn in star the neutral point being conn to the CT common neutral & the other ends are connected each at the 3 pilot wire.

→ The relays are conn across the equipotential point of the 3 pilot wire & these points are naturally located at the middle of the pilot cable.

\* Operation:- Under the normal operating condn the current at both end of each end will be equal & hence the I at secondary of 2-CTs connected in any phase will also be equal.

∴ there is a balanced circulating current in the pilot wire & no current flow through the relay coil.

→ When an earth fault or phase to phase fault occurs the diff. currents flowing through the relay ckt & then the relay operates to trip the ckt breakers.

→ Suppose an earth fault occur on phase

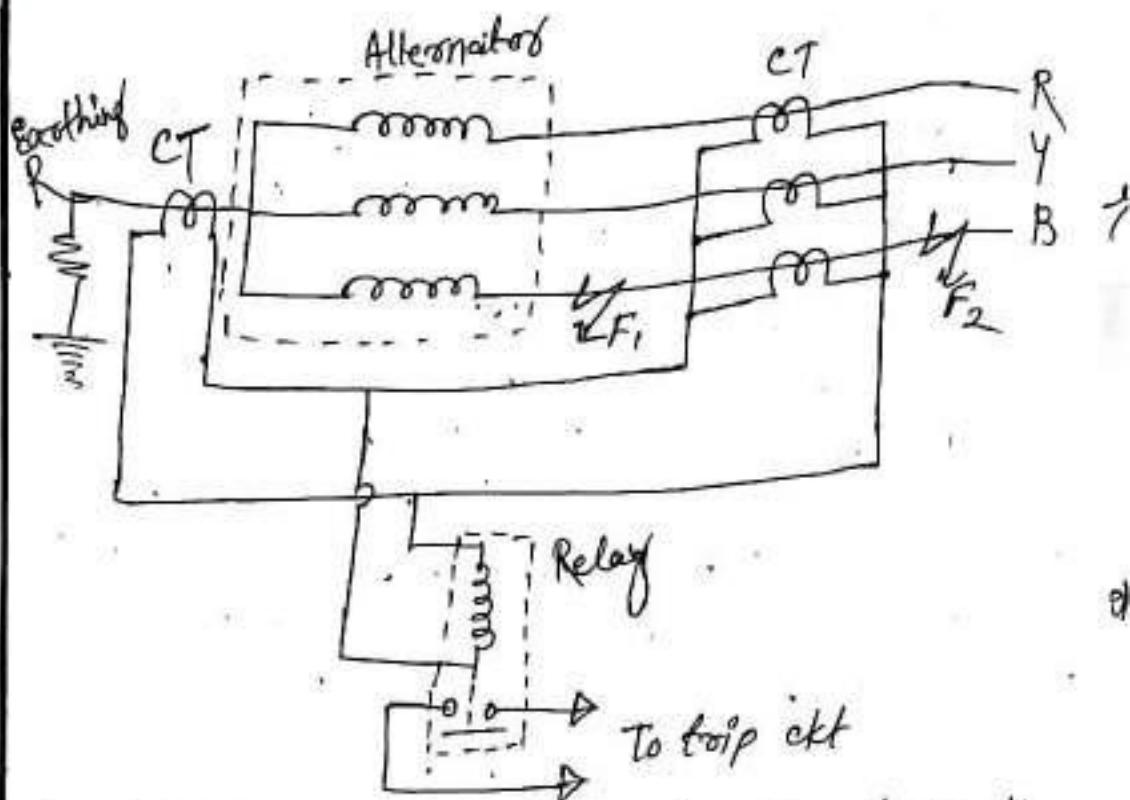
'R' due to break down of insulation to earth as shown in fig. The  $I$  in the effected phase (R) will flow through the core & frame of the m/c to earth.

Then the ckt. being completed through the neutral, earthing R. The  $I$  in the secondary at the two  $\phi$  in phase R will becomes un-equal and the difference of the 2 current will flow through the corresponding relay coil ( $R_1$ ) & then the relay operated to trip the ckt breakers.

\* Suppose now a short ckt fault occurs of both the phase Y & B as shown in fig. The  $I_{sc}$  circulate through the neutral end of the 2 wind and through the fault as shown by the dotted arrows. The  $I$  in the secondary of the CTs in each effected phase (Y & B) will becomes unequal & the diff'  $I$  will flow through the operating coils of the relays ( $R_2$  &  $R_3$ ) conn in these phase. Then <sup>relay</sup> close the contact of trip coil to close the ckt breaker.

\* Balanced earth fault protection system:-

In small size alternator the neutral & the 3 $\phi$  wind are conn internally for a single terminal,  $\therefore$  it is not possible to use the circulating  $I$  system, bcz there are no facilities to accommodate the necessary CTs in each phase wind.



- Schematic arrangement :- The fig. shows the schematic arrangement of balanced earth fault protection for a 3 $\phi$  alternator.
- It consists of 3 line CT, one mounted on each phase having their secondary conn in  $\Delta$  with the single CT in the conductor forming the star point of the alternator to earth.
- A relay is conn across the CT secondary.
- Operation :- Under normal operating condn the I flowing in the alternator leads & hence the I flowing in the secondary of the line. The I flowing in the secondary of the line is also zero and no I flowing through CT and the relay coil.
- Under this condn the I in the neutral wire is also zero.
- If the earth fault develops at  $F_2$  which is external to the protected zone the sum of the I at the terminal of the alternator is

exactly equal to the  $I$  in the neutral wire & hence no current flows through the relay.

When a earth fault occurs in  $I_1$  or within in the protected zone, these current will no longer equal & the differential  $I$  flows through the operating coil of the relay & the relay then close its contact to disconnect the alternator from the system.

#### Protection of busbars :-

The busbars & transmission line are the imp. element of the ele. power system & reqt the immediate protection against the possible fault occurring on them.

The busbars in the generating station & substation are imp. link b/w the incoming and outgoing ckt.

If the fault occurs in a busbar it can damage the incoming & outgoing section.

The busbar zone for the purpose of protection

include not only the busbars themselves but also the isolating sw, ckt breakers are used. In the event of fault on any section of the busbar all the ckt equipment connected to that section must be trip to give the complete isolation.

There are 2 most commonly used methods

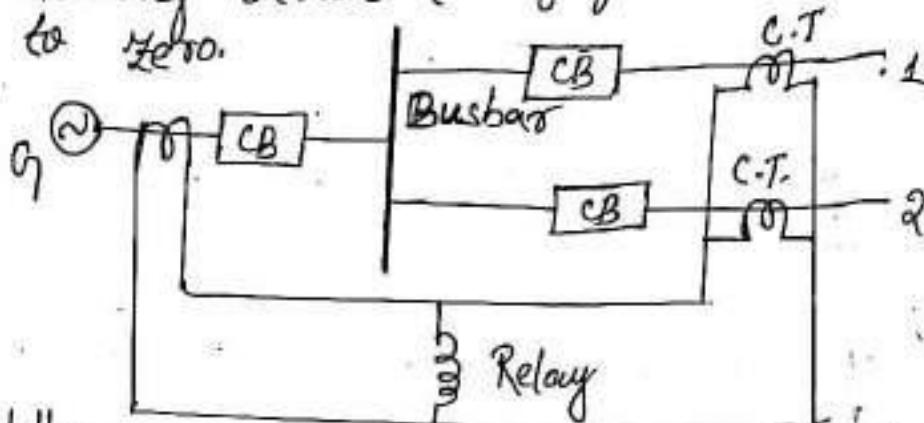
for the busbar protection are :-

(a) Differential protection

(b) Fault bus

Differential protection :- The basic method for busbar protection is the differential scheme of protection.

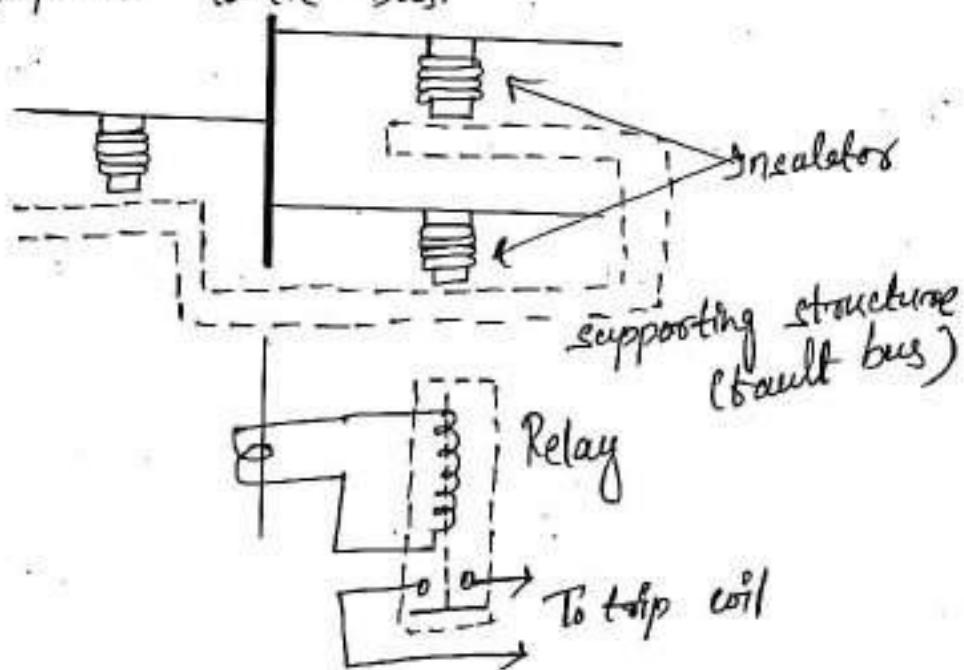
- In this scheme the current entering & leaving the bus are totalised.
- During normal operating condition the sum of incoming current & outgoing current is equal to zero.



- When a fault occurs, the fault current produces a differential current to operate a relay.
- The fig. shows the single line diagram of differential protection scheme.
- The busbar is fed by the generators and supplies load to two lines.
- The secondaries of CT in generator load, line 1 & line 2 are connected parallel.
- The protective relay is connected across this parallel connection.
- Under normal cond<sup>n</sup>, the sum of the current entering the bus is equal to the sum of the current leaving from bus and no current flows through the relay.
- If a fault occurs within the protected zone the current entering the bus will not equal to the current leaving the bus.
- The difference of these currents will flow through the relay & cause opening of Generator, Ckt breaker & each of the line ckt breakers.

## \* Fault bus protection :-

- This is design to provide the protection against the earth fault.
- This can be achieved by providing earthed metal barriers surrounding each conductor, throughout its entire length in the bus structure.
- In this arrangement, By detecting the flow of earth fault current, it is possible to detect the fault & determine their location this type of protection is known as fault bus protection.
- The metal supporting structure or fault bus is earthed through a CT. A relay is connected across the secondary of CT.
- Under normal operating condn. there is no current flow from fault bus to ground so the relay remain inoperative.
- When a fault occurs a connection b/w a conductor & earthed supporting structure will result in current flow to ground through the fault bus which causes the relay to operate.
- The ope. of relay will trip all breakers connecting equipment to the bus.



## \* Differential pilot wire protection:-

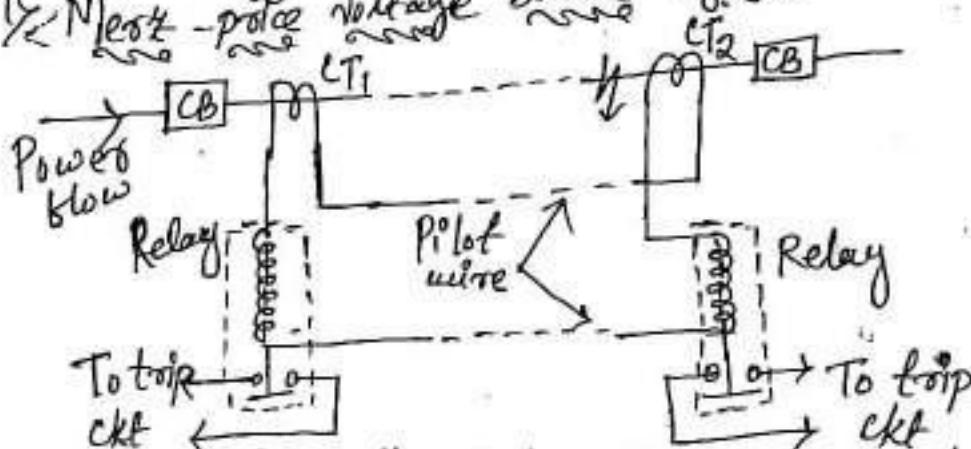
- \* The differential pilot wire protection is based on the principle that under normal condition the current entering one end of a line is equal to that leaving the other.
- \* But when fault occurs both the 2 ends, the diff. b/w incoming & outgoing current flow through the relay which operate the ckt breaker to isolate the faulty line.

\* There are 2 types of differential protection scheme

1) Meier-prize voltage balance system.

2) Transly scheme.

1) Meier-prize voltage balance system:-



\* The fig. shows the single line diagram of meier-prize voltage balance system for the protection of a 3 $\phi$  line.

\* Identical current t/bx are placed in each phase at both ends of the line.

\* The pair of CTs in each line is connected in series with a relay in such a way that under normal cond'n their secondary voltage are equal and in opposite direction.

\* Under normal condition current entering the line at one end is equal to that leaving it at the other end. Therefore equal & opposite

voltage are induced in the secondaries of the CTs at the 2 end of line so that no current flows through the relay.

- If the fault occurs at point F on the line this will cause a greater current to flow through  $CT_1$  than  $CT_2$ .
- ∵ secondary voltage become unequal & circulating current flows through the pilot wire & relay.
- The ckt breakers at both ends of the line will trip out and the faulty line will be isolated.

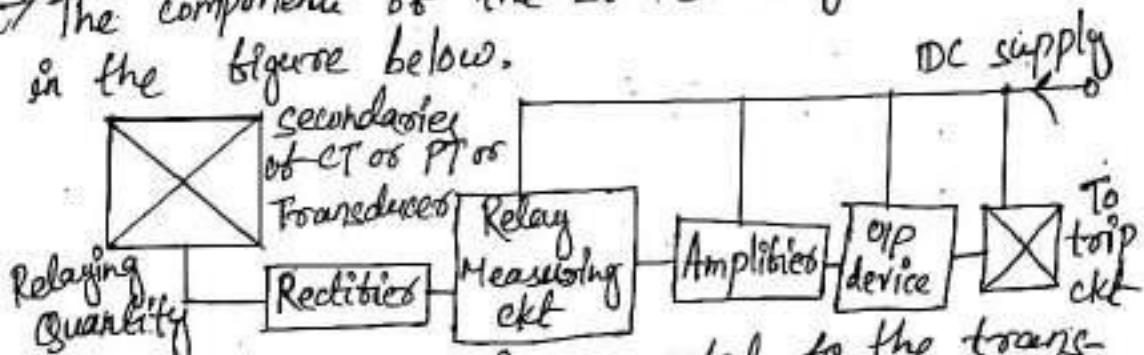
#### \* Advantage:-

- if This system can be used for ring main as well as parallel feeders.
- if This system provide instantaneous protection for ground fault.

#### \* Disadvantage:-

- if Accurate matching of current fib is very essential.
- if If there is a break in the pilot wire ckt the system will not operate.
- if This system is very expensive
- if This system can't be used for line voltage beyond 33KV because of constructional difficulties in matching the current transformer.

- \* Defn:- The relay which does not contain any moving parts is known as static relay.
- In such type of relays, the o/p is obtained by the static component like magnetic & electronic ckt.
- The relay which consist static & electro-magnetic static unit obtain the response & the electro-magnetic relay is only used for switching o/p.
- The components of the static relay is shown in the figure below.



- The i/p of the CT is connected to the transmission line, and their o/p is given to the rectifiers.
- The rectifiers was rectifying the i/p signal & pass it to the relaying measuring unit.
- The rectifying measuring unit has the comparators level detector & logic circuit.
- The o/p signal from relaying unit obtains only when the signal reaches the threshold value.
- The o/p of the relaying measuring unit acts as i/p to the amplifiers.
- The amplifiers amplifies the signal & gives the o/p to the o/p device.
- The o/p device activate the trip coil only when the relay operates.

- The output device is activated & gives the tripping command to the trip coil.
- The static relay only gives the response to the electrical signals.
- The other physical quantity like heat, temp. etc. is first converted into the analogue and digital electrical signal & then act as an input to the relay.

\* Advantage of static relay :-

- The static relay consumes very less power.
- The static relay gives quick response, long life, high reliability & accuracy.
- The reset time of the relay is very less.
- The relay amplifies the trip signal which increase their sensitivity.
- The chance of unwanted tripping is less in this relay.

\* Limitations of static relay :-

- Special maintenance is provided to the components.
- The relay is easily affected by the high voltage surge.
- The working of the relay depends on the electric component.
- The relay has less over-loading capacity.
- The static relay is more costly.
- The construction of the relay is easily affected by the surrounding interference.

## \* Instantaneous Over-current relay:-

- This relay is one in which no intentional time delay is provided for operation.
- In such relay, the relay contact close immediately after the current in the relay coil exceeds.
- In this relay a magnetic core is wound by a current coil.
- A piece of iron is so fitted by hinge support of restraining spring in the relay.
- When there is not sufficient current in the coil, the no contact remain open.
- When the current in the coil crosses a preset value, the attractive force becomes enough to pull the iron piece toward the magnetic core & therefore no contact get closed.
- This relay is referred as instantaneous over-current relay when the current in the coil gets higher than the preset current.

PROTECTIONS AGAINST OVER  
VOLTAGE AND LIGHTNINGover voltage &  
surge &

- The sudden rise in voltage for very short time on the power system is known as voltage surge or transient voltage.
- The transient or surge are of temporary nature. It exist for a very short period of time but they cause over voltage in the power system.
- The most important transient are caused by lightning striking to a transmission line.

## Cause of over voltage &amp;

The cause of over voltage of a power system may be divided into main categories.

- i) Internal cause
- ii) External cause.

## i) Internal cause &amp;

- The internal cause do not produce surge of large magnitude.

- The surge due to internal cause increase the system voltage to more normal voltage.

- The internal cause of over voltage on the power system can be produced by the suddenly change in weather condition.

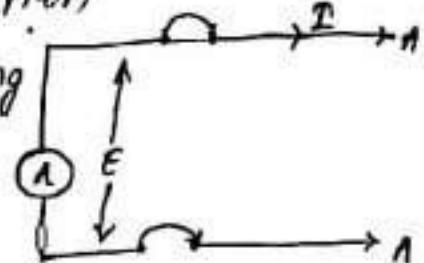
## Switching surge &amp;

The over voltage produced on the power system due to switching operating are known as switching surge.

2) In case of unload the line

dia

→ During the switch operation of unloaded line traveling wave are set up which produce over voltage on the line.



→ Consider a unloaded line connect the voltage source when the unloaded line connected to the voltage wave it set up which travel along the line.  
→ on reaching the terminals point 'A' it is reflected back to the supply with out change of the sign this cause voltage doubled i.e on the line becomes twice the normal value.

b) In case of loaded line

→ The over voltage will be also produce during the switching operation of loaded line.

→ Suppose a loaded line is interrupted this will be set up the high voltage.

Current chopping

→ when the breaking low current with an arc Bkt breaker, the powerful deionization effect of arc bkt cause the current to fall to 'zero' before the natural current 'zero'. This phenomenon is called current chopping & produce transient voltage across the breaker contact.

→ The over voltage due to current chopping are prevented by the resistance switching.

## Insulation failure :-

- The most common case of insulation failure is the grounding of conductor, which may cause over voltage in the system.

## Resonance :-

- Resonance of electrical system occurs when inductive reactance of the C.R.T equals to capacitive reactance.
- Under resonance cond' the impedance of the C.R.T is equal to resistance of the C.R.T & power factor becomes 1 so the resonance cause high voltage in electrical system.

## ii) External cause :-

### Lightning :-

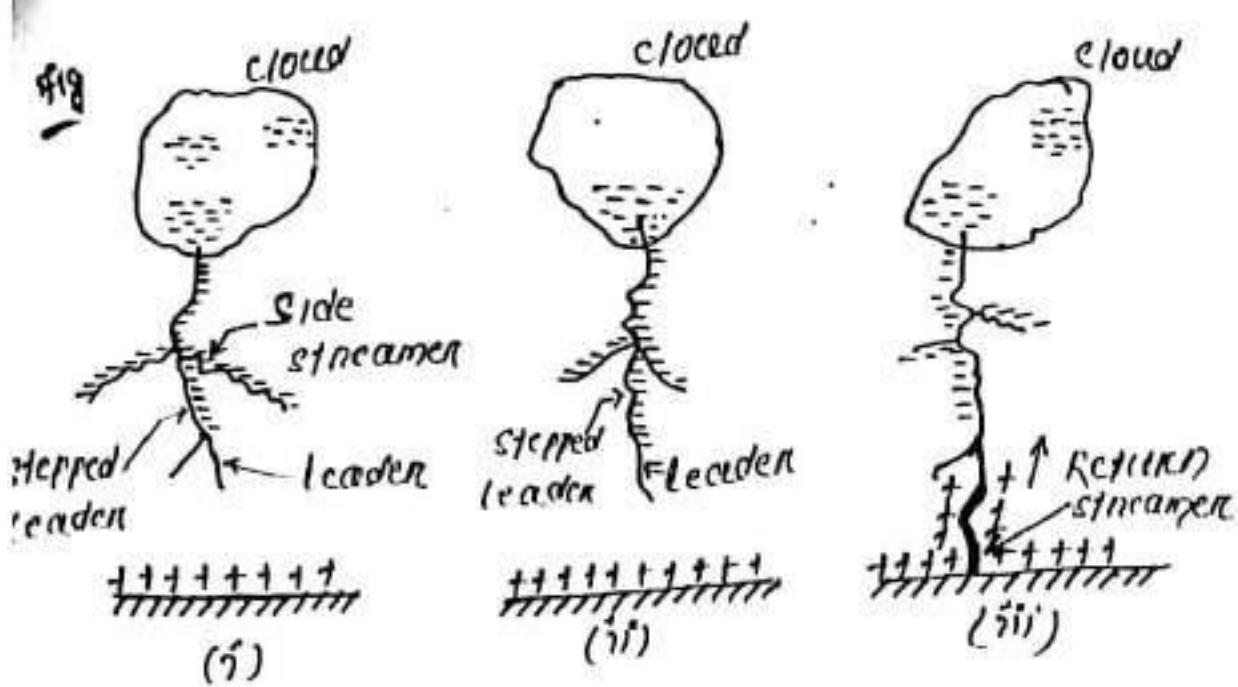
 An electric discharge betn cloud and earth betn clouds or betn the charge centre of the same cloud is known as lightning.

- Lightning is a huge spark and takes place when clouds are charged to such a high potential, with respect to earth or a neighbouring cloud thus the dielectric strength of neighbouring medium (air) is destroyed.
- There are several theories exist to explain how the clouds acquire charge the most accepted one is that during the uprush of warm moist air from earth, the friction betn the air and the tiny particles of water causes building up of charges.

- when drop of water formed, the larger drop becomes positively charged & the smaller drop becomes negatively charged.
- when the drops of water accumulate, they form clouds, & hence cloud may possess either a positive or a negative charge, depending upon the charge of drop of water they contain.
- The charge on a cloud may become so large 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.
- The figure shows a negatively charged cloud induces a positive charge on earth.
- As the charge acquired by the cloud increases, the potential difference b/w cloud & earth increases and therefore potential gradient in the air increases.
- when the potential gradient is sufficient ( $5 \text{ kV/cm}$  to  $10 \text{ kV/cm}$ ) to break down the surrounding air the lightning stroke



## Types of lightning stroke :-

There are two main ways for which a lightning strike the power system. these are

- (i) Direct stroke
- (ii) Indirect stroke

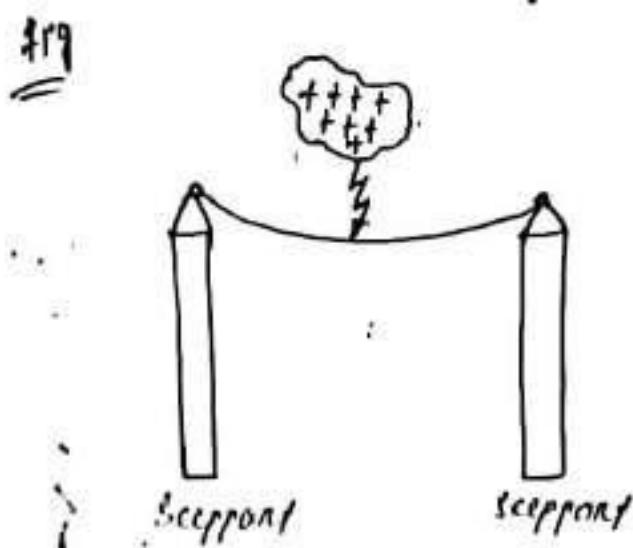
### Direct stroke

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In the direct lightning strokes, the cloud carries a large amount of charge and induces an opposite charge on taller objects such as temples, churches etc.

→ when the intensity of electrostatic field becomes sufficiently great to ionise the neighbouring air, the air break down and discharge takes place between the cloud and the object.

→ such type of discharge take a long time to produce and it strikes the highest and the most sharply pointed building.



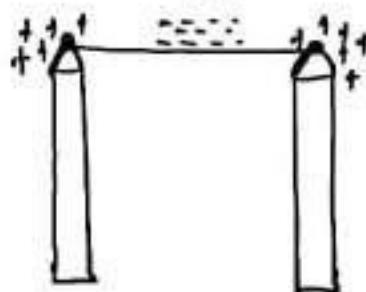
### Induced stroke II-

Induced stroke results from the electrification of induced charges on the conductors & due to the presence of charged clouds.

- A positively charged cloud is above the wire and induces a negative charge on the wire by electrostatic induction.
- This negative charge will be present only on the portion of the wire right under the cloud and portion of wire away from it will be positively charged as shown in fig.
- The induced negative charge leaps slowly to earth via the insulator.
- When the cloud discharge to earth or to another cloud, the -ve charge on the wire is released as it cannot flow quickly to earth over the insulator.



fig



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## Harmful effect of lightning :-

1) Direct or Indirect lightning stroke on a transmission line produces a steep-fronted (rise is fall sharply) voltage wave on the line

- The voltage of the wave may rise from zero to peak value (about 20000V) & then decay to half the peak value in 5  $\mu$ s.
- This steep fronted voltage wave will initiate travelling waves along the line in both directions.
  - (i) The travelling wave produced due to lightning surge will damage the insulators, and may also damage the poles
  - (ii) If the travelling wave produced due to lightning hit the windings of a transformer or generator, it may damage the equipment.
  - (iii) If the arc is initiated in any part of the power system by the lightning stroke, the arc will set up very disturbing oscillations in the line, this may damage other equipment connected to the line.

## Lightning Arrestor :-

→ A lightning arrester or a switch device is a protective device which conduct the high voltage surge on power switch to ground

- It consists of spark gap in series with a non-linear resistor, one end of the divider is connected to the terminal of equipment which is to be protected & the other end is connected to the ground.
- The length of the gap is set so that the normal line voltage can't enough to cause an arc.
- The property of the non-linear resistance is that the resistance decreases as voltage increases vice versa.
- Under normal condition operating the lightning arrester is off & it conducts no current to earth providing the low resistance path to the ground in this way the excess charge on the line due to the surge is harmlessly conducted to the arrester to the ground.

### Types of lightning Arrester -

There are several types of lightning arrester these are

- Rod-gap arrester
- Flame-gap arrester
- Multi-gap arrester
- Explosion type arrester
- Varistor type arrester

#### i) Rod-gap Arrester

→ It is very simple type of divider if it

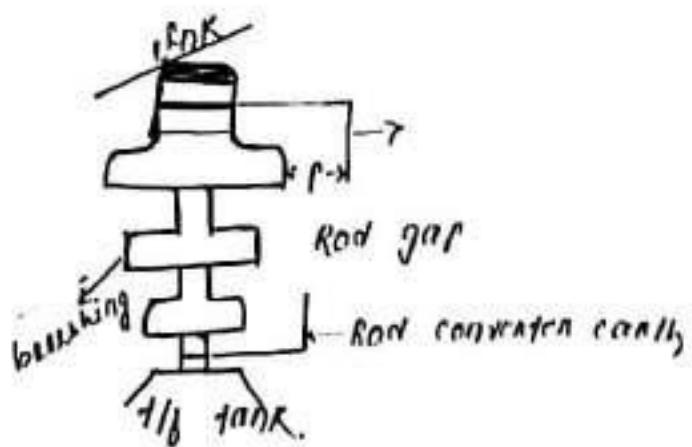
consists of two 1.5 cm rod which are send at

right angle with a gap b/w them.

→ one rod to be connected to the line ckt & the other rod to be connected to earth.

→ Under normal operating condition the gap remains non-conducting, on the occurrence of a high voltage on arc to produce 1 node to the surge current be conducting to the earth so as way the excess charge on the line is rapidly conducted to the earth.

fig



disadvantages :-

→ After the surge is over the arc to the gap of main trapped by normal supply voltage which is large to short ckt on system.

→ The rod may melt or get damaged due to excessive heat produced by the arc.

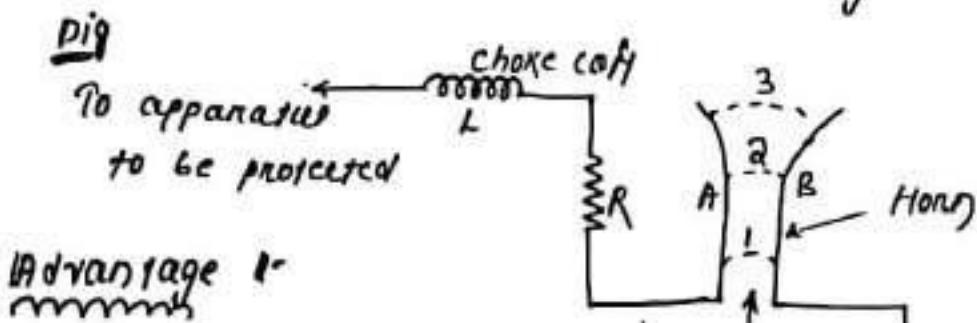
→ The climatic cond'n effect the performance of rod gap lightning arrester.

→ Due to the above disadvantages the rod gap arrester to only used as a backup protection  
i) in case of main arrester.

Horn gap arrester :-

CS It consist of two horn shape metal rod A & B separated by a small air gap.

- The horns are so constructed that the distance b/w the two horns gradually decreases toward the top as shown in fig.
- The horns are mounted on the porcelain insulator.
- One end of the horn is connected to the line through a resistance 'R' & a choke coil 'L' the other end is grounded.
- Under normal operating conditions the gap is non-conducting i.e. the current is insufficient to produce the gap b/w horns.
- On the occurrence of over voltage an arc is produced b/w the horns.
- The arc moves progressively into the position I.A. 3.
- At the position 3 the distance b/w the horns too large for the voltage to maintain the arc so the arc is extinguished.



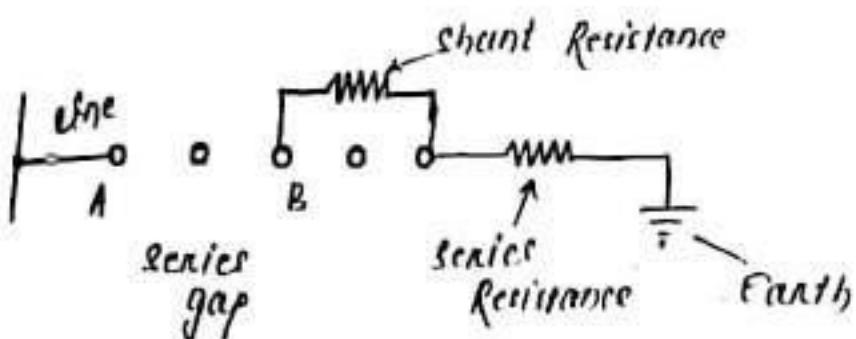
Advantage :-

- The arc is self clearing therefore this type of arrester does not cause short circuit after the surge it.
- The series resistance helps in limiting the current to a small value.
- The bridging of gap by some external agency or cause can render the device useless.
- The time of operation is comparatively long.

## 1) Multigap Arrestor -

- It consists of a series of metallic cylinders insulatored from one another & separated by small intervals of air gap.
- The 1st cylinder i.e (A) is connected to the line & the other connected to the ground through a series resistance.
- Under normal cond' the normal supply voltage fails to breakdown the gaps.
- On the occurrence of over voltage the breakdown of the gaps let's 'I.R.' occurs.
- The heavy current after breakdown will flow to the earth through the gap let's 'I.R.'
- When the surge is over the arc let's the 'B.T.C.' goes out & any current flowing through the circuit can be limited by the two resistances.
- This arrester can be employed where the system voltage does not exceed 32 KV.

### Diagram



## 2) Valve type Arrestor -

- Valve type arrester use the non-linear resistor
- It consists of two parts one is series spark gap
- Second one is non-linear resistance disc or

→ The non-linear elements are connected in series with the spark gap

→ The spark gap consisting consisting of a no. of identical spark gap in series each gap consist of two electrodes with a fixed gap.

→ The non-linear resistor dice are connected in series.

→ The non-linear resistors have the property of offering a high resistance to the current flow when normal system voltage is applied but provide a low resistance to flow of high surge current.

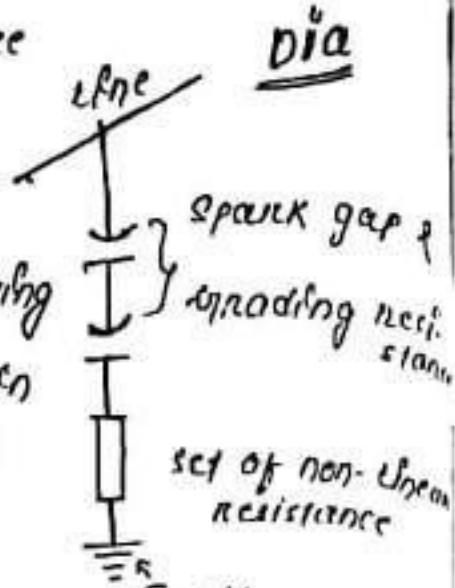
→ Under normal cond' the system voltage is not sufficient to cause the breakdown of airgap → on occurrence of over voltage an arc is produced the surge current conducted to earth through the non-linear resistance.

→ When the surge is over the non-linear resistor provide high resistance to stop the flow of current.

Advantages

→ It provide very effective protection against the surge

→ It operate very rapidly taking less than 1 sec.



Dis-Advantages of  
an annular

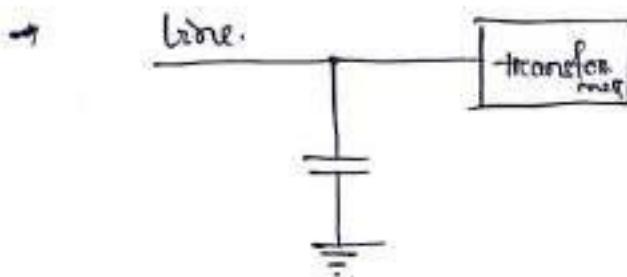
→ Their performance is adversely effected by the entry of moisture into the enclosure.

Application of  
an annular

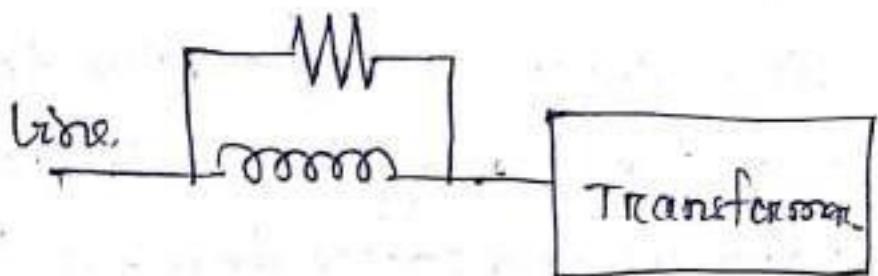
→ This type of annular are generally used for the protection of important equipment in power station operating on the voltage upto 220 KV or higher.

## Surge Absorber.

- The travelling waves set up on the transmission lines by the surge may reach the terminals of the apparatus and cause damage to it.
- To reduce it we use surge absorber.
- A surge absorber is a protective device which reduce the steepness of wave front of a surge by absorbing surge energy.
- A conductor connected between the line and earth can act as a surge absorber.
- The figure shows a capacitor as a surge absorber. to protect the transformer winding.



- Since the resistance of a condenser is inversely proportional to frequency, it will be low at high frequency and to high at low frequency.
- Since the surge are of high frequency, the capacitor act as a short circuit and passes them directly to earth.
- Another type of surge absorber consist of a parallel combination of choke and resistance connected in series with the line. as shown in fig.



The choke offers high reactance to surge frequency ( $X_L = 2\pi fL$ ) the surges are therefore, forced to flow through the Resistance R where they are dissipated.

Thank You.... End of the Chapter