

LECTURE NOTES

On

Switch Gear And Protective Devices

On

6th Semester of Electrical Engineering Branch

Prepared by

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Chapter 1 // Introduction to Switch

// Gears //

{ SOPD }

* Switch Gears :- The apparatus use for switching, controlling & protecting the electrical ckt & equipment is known as switch gears.
+ It is essentially consist of switching and protecting device such as switch, bus, ckt breakers & relays etc.

+ During normal operating condⁿ switch gears permits to sw on or off the electrical equipment.

+ In case of fault condⁿ the sw gears detect the fault & disconnect the unhealthy section from the system.

⇒ Essential features of switch gears :-

The essential features of sw gears are :-

1. Complete reliability :-

The requirement of sw gears is more & more important beca of the interconnection & increasing capacity of generating station.
+ Sw gears is use to the power system for improve reliability. If the fault occurred on an any part of the power system they must operate to ^{isolate} the fault section from the normal section.

2. Absolutely certain discrimination :-

In fault occur on any section of power system the sw gears must be the

able to discrimination betn 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 SW gear must operate quickly so that no damage is done to generator, HT & others equipment.

→ If the fault is not clear by SW gear quickly it is spread into healthy parts & thus complete shut-down of the system occurs.

4. Provision for manual control:-

A SW gear must have provision for manual control. In case the electrical (electronics) control fails the necessary ops. can be carried out through manual

5. Provision for Instrumental control:-

There must be provision for instrument which may be required.

* Switch Gear Equipment:-

The SW gear covers all the apparatus & equipments employed for switching, protecting, controlling the electrical power system.

→ It includes SW, buses, ckt breaker, isolator, relay, potential t/b (PT), CT & lightning arrestor etc.

→ Switch:- S/w is a ^{most} 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 s/w are use for low voltage application
 → The s/w may be classified into the following category

(i) Air s/w

(ii) Oil s/w

Air break switch:-
 → It is an air s/w & it is design to open a ckt under load.
 → In this s/w the special arcing horns are provided to open the s/w.
 → Arcing horns are piece of metal betⁿ which arc is form during opening operation
 → As the s/w open the horns are spread farther and farther so the arc is interrupted. This s/w generally use out-door.

(b) Isolator and disconnecting switch:-
 This s/w is design to open a ckt under no load. Its main purpose is to isolate one portion of the ckt from the other.

→ This s/w are generally use on both side of ckt breaker in order to repair & replacement of ckt breakers.

(c) Oil switch:-
 The contacts of this s/w 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 melts 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 increases, this rises the temperature of the fuse element melts.

* 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) Normal condition.

→ It is design to operate manually under

→ normal condition & auto-matically under fault condition.

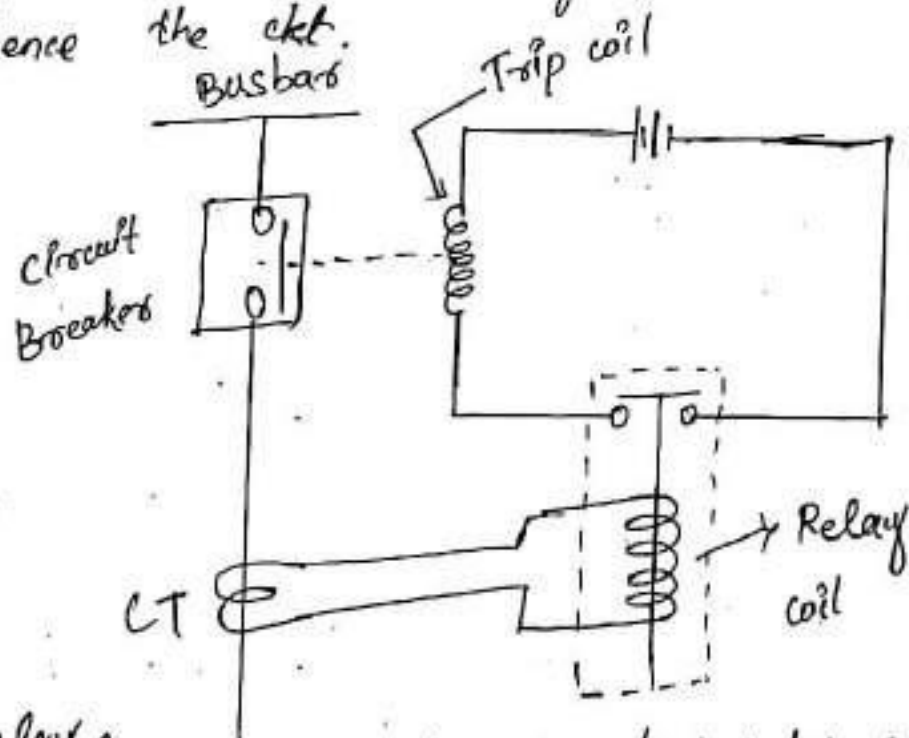
→ The circuit breaker consist of 2 types of contact;

(1) Moving contact

(2) Fixed contact

* Under normal operation condⁿ the ^{contact of} A.C.B. remain closed and it carries the normal full load current, in this case the EMF at the secondary end of the CT is insufficient to operate the trip coil of the breaker.

* When a fault occurs over current in the CT primary and increase the emf in the secondary and these energies the trip coil of the breaker & the moving contact are pulled down thus the opening of contact & hence the ckt.



* Relay :-

A relay is a device which detects the fault & supplies 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 end of the CT which is conn^d to the relay operating coil

ii) 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^d electrically, busbars are used as the common electrical component.

- The busbars are copper rods of thin tubes which are operated at constant voltage.
- There are some imp. busbar arrangement used in power station, these are :-

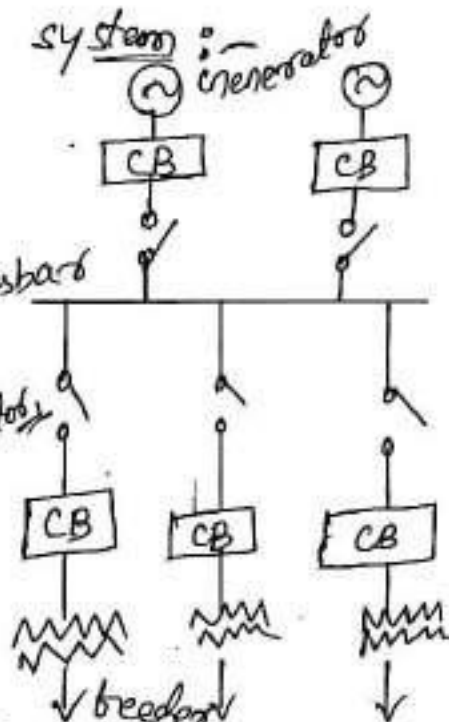
i) Single busbar system :-

- The single busbar system has the simplest design.
- and is use for the power station.

- It is also used in small outdoor station having less no. of out going & incoming feeders & generators.

- Here the generators, out-going lines and t/t are connected to the single busbar.

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



→ Advantage :-

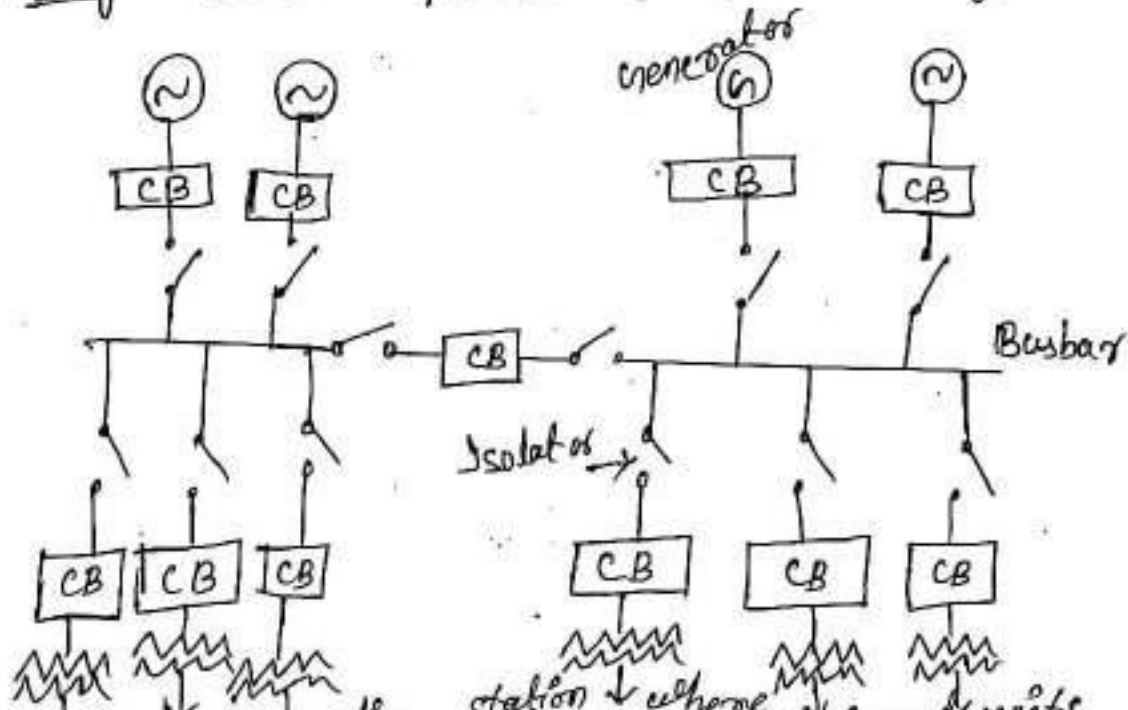
→ This type of arrangement are low initial cost, less maintenance & simple operation.

→ Disadvantage :-

→ The busbar can't be clean, repair or tested without de-energising the whole system.

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

ii) Single busbar system with sectionalization :-



→ 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.

→ Here the busbar divided into 2 section & connected by a ckt breaker & Isolator.

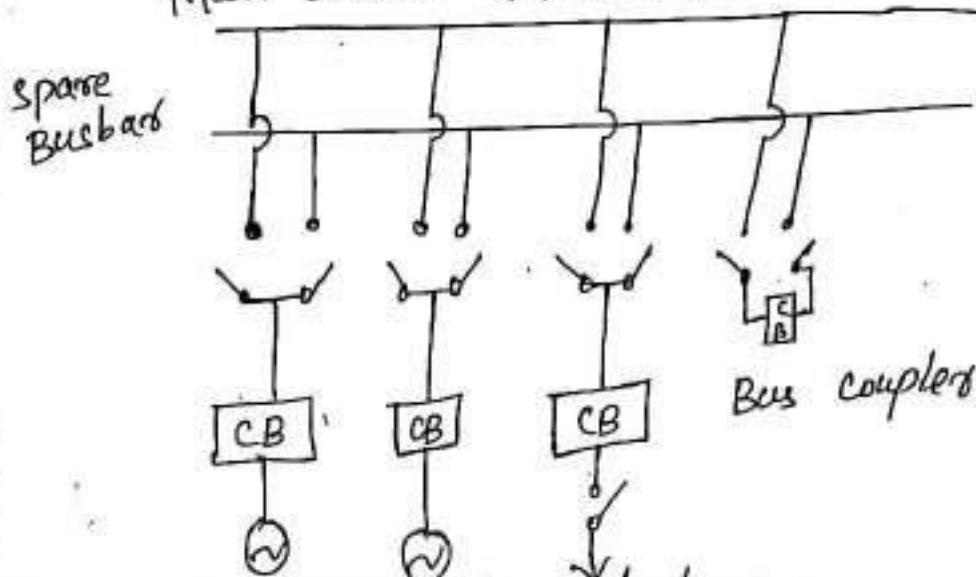
→ Advantage :-

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

ii) This permits the use of CB of lower capacity in the feeder.

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

Main busbar $\langle \text{iii} \rangle$ Duplicate Busbar System



→ The system consist of 2 busbar ;
 (i) Main Busbar

(ii) Spare (add) "

→ Each generator & feeder conn to either busbar with the help of bus coupler, which is consist of CB. & isolators

* Advantage:-

→ If repairs & maintenance to be carried on the main busbar, the supply need not be interrupt as the entire load can be transferred to the spare busbar.

→ The testing of feeder & CB can be done by putting them on the spare busbar.

→ If a fault occurs in busbar the continuity of the supply to the ckt can be maintain by transferring it to the other busbar.

* Switch Gear Accommodation. -

Depending upon the voltage to be handle the sw gear may be classified into 2 type ;
 (a) Out-door type
 (b) In-door "

cap out-door :-

- For the voltage beyond 66KV S/W gear equipments are installed out-door.
- It is because for such voltage (HV) the clearance betⁿ conductors & the space required for S/W, CB, HT & other equipment becomes so large.

(b) In-door type :-

The voltage below 66KV S/W 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 occur.
- When a short ckt occurs a heavy current called short ckt current flows 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 equipments or transmission line, deterioration of insulation in a generator, t/b 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-loading

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 ~~decrease~~ ^{will the system voltage} 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 ϕ system can be classified into 2 main categories,

- (1) Symmetrical fault
- (2) Unsymmetrical fault

(1) Symmetrical fault :-

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

→ The most common example of this system is when all the 3 conductors of the 3 ϕ 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.

→ This fault is :
ii single line to ground fault (ii) double line to ground
iii Line to line fault

* Symmetrical fault :-

→ The fault which gives rise to the symmetrical fault current (i.e. equal fault current with 120° displacement) is called symmetrical fault.

→ Ex:- 3 ϕ fault.

* Limitation of fault current :-

- Excessive heating
- Resulting fire or explo
- Reduction in voltage causes mis-operation of rotating a machine.
- Poor outage if generator protection system operates.

* Percentage Reactance :-

The reactance of a generator, t/b, 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.

$$\% X = \frac{IX}{V} \times 100$$

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/b, reactor is usually expressed in % resistance.

→ The % resistance of a ckt is defined as

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

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

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

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* %x :-

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

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

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

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

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

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

$$\Rightarrow x = \frac{\%x (KV)^2 \times 10}{KVA \times 100}$$

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

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

* Base KVA :-

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

Generally the various equipment use in the

power system have different KVA rating, therefore it is necessary to find the %x of all the elements on a common KVA rating. This common KVA rating is known as Base KVA.

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

* Short ckt. KVA :-

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

Short ckt current (I_{sc}) = $\frac{V}{x}$

$\Rightarrow I_{sc} = \frac{V \times I \times 100}{\%x \times V}$ $\left[\because x = \frac{\%x \times V}{100 I} \right]$

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

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

→ Put the value of I_{sc} & we get;

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

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

- * Steps for symmetrical fault calculation:-
- Draw the single line diagram indicated all rated quantities.
 - Choose a convenient base KVA & convert all %x to this base value.
 - Draw the reactance diagram using the new reactance obtained & find the total %x.

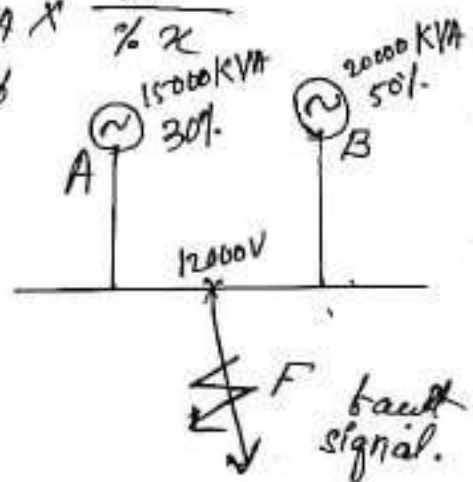
→ Find the full load current corresponding to the full load base KVA.

→ Find the Short ckt current (I_{sc}) by using the formula; $I_{sc} = \frac{I \times 100}{\%X}$

→ Find the S.C. KVA by using the formula
i.e. $S.C. KVA = \text{Base KVA} \times \frac{100}{\%X}$

Q The figure shows of a 3 ϕ system;

Find I_{sc} that will flow into a complete 3 ϕ ckt at fault (F).



* Base KVA = 20,000

→ We know,

$$\frac{\text{for 'A'}}{\%X \text{ of}} \text{ base KVA} = \frac{\text{Base KVA}}{\text{Rated KVA}} \times \%X \text{ at rated KVA}$$

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

$$= 40\%$$

→ For 'B' :-

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

$$= 50\%$$

→ Total $\%X = 50\% + 40\%$

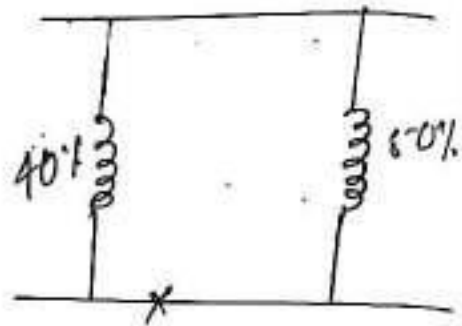
$$= \frac{50 \times 40}{50 + 40} = 22.22$$

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

$$\Rightarrow I = \frac{20,000 \times 10^3}{\sqrt{3} \times 12,000} = 962.25 \text{ Amp.}$$

$$\begin{aligned} \text{Short ckt current } (I_{sc}) &= \frac{I \times 100}{\%} \\ \Rightarrow I_{sc} &= \frac{902.25 \times 100}{22.22} = 4030.5 \text{ Amp} \end{aligned}$$

$$\begin{aligned} \text{Short ckt KVA} &= \text{Base KVA} \times \frac{100}{\%} \\ &= 20,000 \times \frac{100}{22.22} \\ &= 90009.00 \end{aligned}$$



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Assume ;

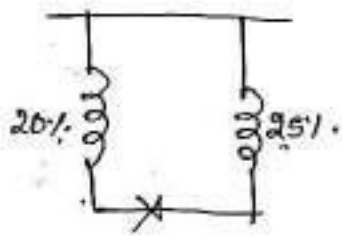
$$\text{Base KVA} = \underline{10,000}$$

For 'A' Alternator

$$\begin{aligned} \% \text{ at base KVA} &= \frac{\text{Base KVA} \times \% \text{ at rated KVA}}{\text{Rated KVA}} \\ &= \frac{20,000 \times 10}{10,000} \times 30\% \\ &= 20\% \end{aligned}$$

For 'B' Motor

$$\begin{aligned} \% \text{ at base KVA} &= \frac{10,000 \times 25}{20,000} \times 50\% \\ &= 25\% \end{aligned}$$



$$\text{total } \% X = \frac{20 \times 25}{20 + 25} = \frac{500}{45} = \underline{\underline{11.11\%}}$$

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

$$\text{S.C } I = I \times \frac{100}{\% X} = 481.125 \times \frac{100}{11.11}$$

$$\text{S.C KVA} = \text{Base KVA} \times \frac{100}{\% X} = 90009$$

$$= 10,000 \times \frac{100}{11.11}$$

$$= 90009$$

A 3 ϕ transmission line operates at 10KV & having a R of 1 Ω & X of 4 Ω is connected to the generating station through 5MVA step-up t/b, 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 betn phases if it occurs (i) At the load end of the transmission line. (ii) At the high voltage terminal of the t/b.

$$V = 10KV \quad 5MVA = 5 \times 10^6 VA$$

$$= 5,000,000$$

$$= 5000 KVA$$

$$10MVA = 10,000 KVA$$

we know,

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

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

For alternator :-

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

For transformer :-

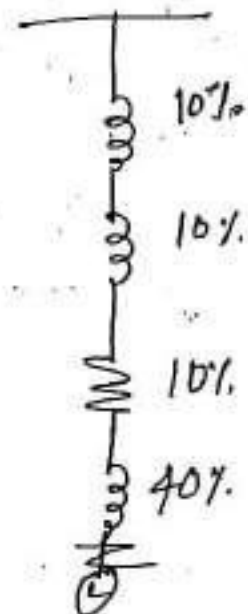
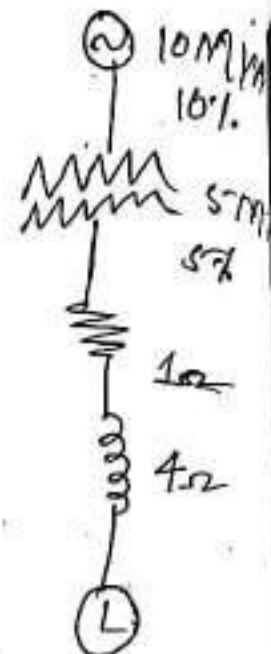
$$\begin{aligned} \%X \text{ at base KVA} &= \frac{10 \times 10^3}{5 \times 10^3} \times 5\% \\ &= 10\% \end{aligned}$$

Total resistance (%R) = 10%

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

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

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



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

$$= 949.246 \text{ Amp}$$

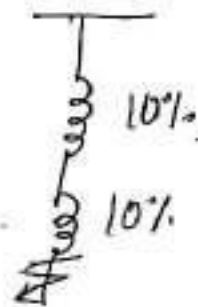
$$\begin{aligned} \gamma \text{ Short ckt kVA} &= \text{Base kVA} \times \frac{100}{\%} \\ &= 10,000 \times \frac{100}{60.82} \\ &= 16441.9 \end{aligned}$$

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

$$\begin{aligned} \gamma I_{sc} &= \frac{I \times 100}{\%} \\ &= \frac{577.35 \times 100}{20} \end{aligned}$$

$$= 2886.75 \text{ Amp}$$

$$\begin{aligned} \gamma \text{ S.C. kVA} &= 10,000 \times \frac{100}{\%} \\ &= 10,000 \times \frac{100}{20} \\ &= 50,000 \end{aligned}$$



1) A plant capacity of a 3 ϕ generating station consist of two 10,000 kVA generators of reactance 12% each & one 5,000 kVA generator of reactance 18%. The generators are conn^d to the station busbar from which load is taken through three 5,000 kVA step up tr^{ns} each having $\% X$ of 5%. Determine the max^m fault MVA which the CB $V = 11 \text{ kV}$

(i) low voltage side
(ii) High voltage " of the tr^{ns}

Base KVA = 10,000

→ For 'A' alternator;

→ %x at Base KVA =

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

→ For 'B' alternator;

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

→ For 'C' alternator;

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

→ For transformer;

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

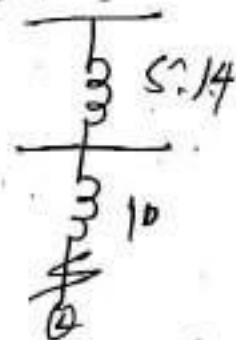
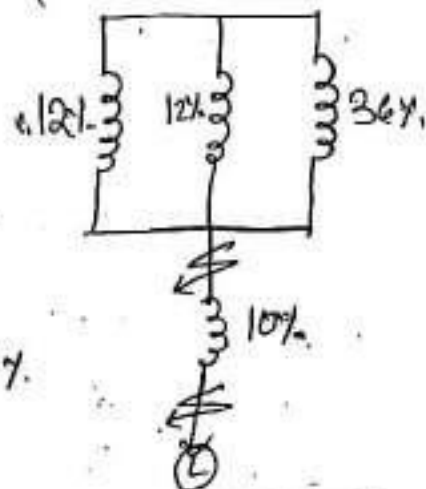
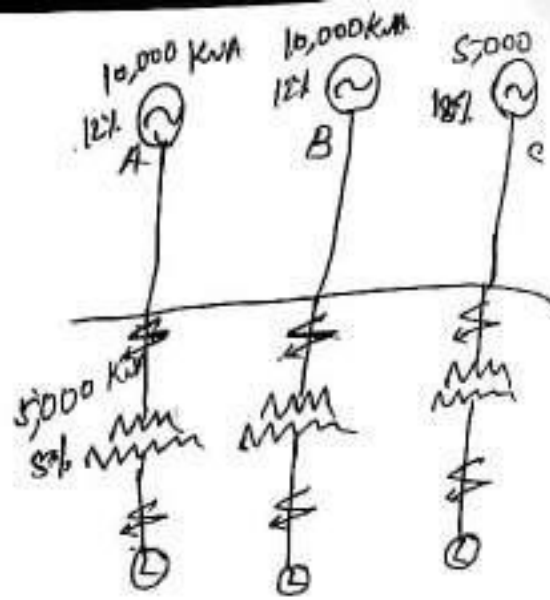
$$12\% \parallel 12\% \parallel 36\%$$

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

$$\rightarrow \text{Total reactance} = \frac{6 \times 36}{6 + 36} = \frac{216}{42} = 5.14\%$$

$$\rightarrow \text{Total reactance} = 5.14 + 10 = 15.14\%$$

→ For low voltage side



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

$$\therefore I_{sc} = \frac{524.86 \times 100}{15.14} = 3466.7 \text{ Amp}$$

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

$$\begin{aligned} \therefore \text{For low voltage side} &= \frac{10,000 \times 100}{15.14} \\ &= 194552.52 \\ &= 194.5 \text{ MVA} \end{aligned}$$

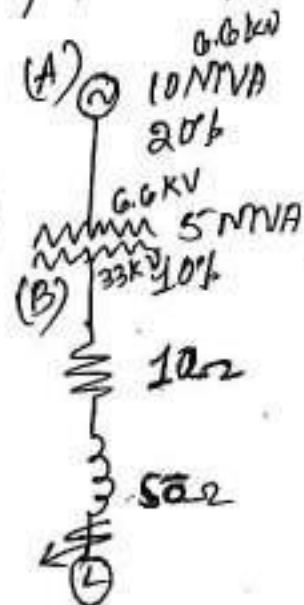
$$\therefore \text{For high voltage side} = 66.05 \text{ MVA}$$

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Q1. A 10MVA, 6.6KV 3 ϕ Y-conn alternator having X of 20% is conn through a 5MVA 6.6KV, 33KV t/b of 10% X to a transmission line having a R & X of per conductor per km of 0.2 Ω & 1 Ω respectively. A 50KM along the line, a S.C. occurs betn the 3 conductors, find the S.C. current.

For total 50KM $\Rightarrow 0.2 \times 50 = 10\Omega = R$
 $X = 1 \times 50 = 50\Omega$



\rightarrow For alternator,

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

\rightarrow For t/b,

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

\rightarrow Assume, Base kVA = 10,000 KVA

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

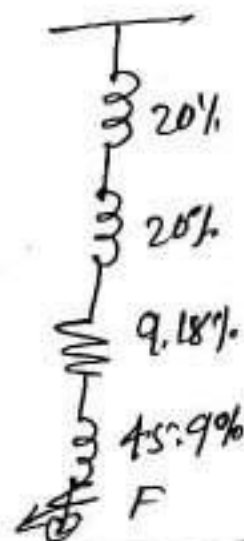
$$(B)\% X \text{ at Base kVA} = \frac{10,000}{5,000} \times 10\% = 20\%$$

\rightarrow We know,

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

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

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



$$I_{x \text{ total}} = 20 + 20 + 45.9 = 85.9$$

$$\begin{aligned} \rightarrow \% Z &= \sqrt{(R)^2 + (X)^2} \\ &= \sqrt{(0.18)^2 + (85.9)^2} \\ &= 86.369\% = 86.37\% \end{aligned}$$

$$\begin{aligned} \rightarrow \text{current (I)} &= \frac{P}{\sqrt{3} \times V} \\ &= \frac{10,000}{\sqrt{3} \times 6.6} = 874.77 \text{ A} \end{aligned}$$

$$\begin{aligned} \rightarrow \text{Short ckt current (I}_{sc}) &= \frac{I \times 100}{\% Z} \\ \Rightarrow I_{sc} &= \frac{874.77 \times 100}{86.37\%} = 101269 \text{ A} \end{aligned}$$

$$\begin{aligned} \rightarrow \text{Short ckt KVA} &= \text{Base KVA} \times \frac{100}{\% Z} \\ &= 10,000 \times \frac{100}{86.37\%} \\ &= 11578.1 \text{ KVA} \\ &= 11.578 \text{ MVA} \end{aligned}$$

* Reactors 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 reactor or series reactor.

* Advantage:-

- The reactor limits the flow of s.c current (I_{sc}) & thus protect the equipment from over heating as well as from failure.
- These are permits the installation of circuit breakers at lower rating.

* Disadvantage:-

- Additional % X increase the total X or Z 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:-

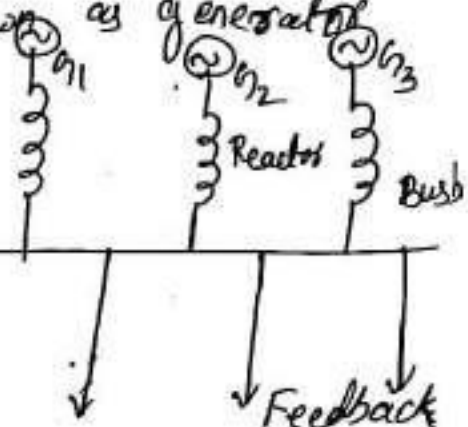
The I_{sc} limiting reactor may be connected in series with:-

1. Generators
2. Feeder
3. Buses (Generators & feeder common point)

* Generator Reactor:-

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

- Here the X of reactors are considered to be a part of % X of the generator.



→ It protect a generator against I_{sc} in case of fault.

→ Advantage :- → It is simple.

→ Disadvantage :-

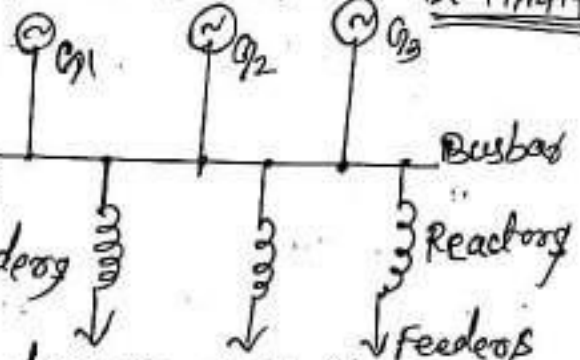
→ There is a constant voltage drop & power loss in the reactor during normal operation.

→ If a busbar or feeder fault occurs closed to the busbar, the voltage at the busbar will be reduce to a low value there by 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-19/12/19

* Feeder Reactor :-

→ When the reactors are conn^d 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 feeder the voltage drop in its reactor will not effect the busbar voltage.

→ The fault on any feeder will not effect other feeders.

→ Disadvantage :-

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

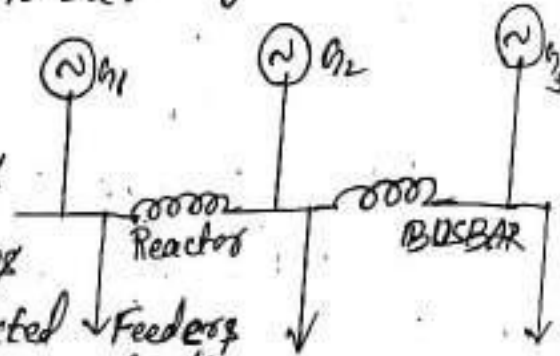
→ If a s.c. occurs at busbar no protection is provided to the generator.

→ If the no. of generators is increase the size of feeders reactor will have to be increase to keep the s.c. current (I_{sc}) within the rating of the feeders.

* Busbar Reactor:- (1) Ring system
→ It is 2 types:- (2) Tiebar system

→ Ring System:-

→ In this system busbar is divided into no. of sections & these sections are connected through reactor as shown in fig.



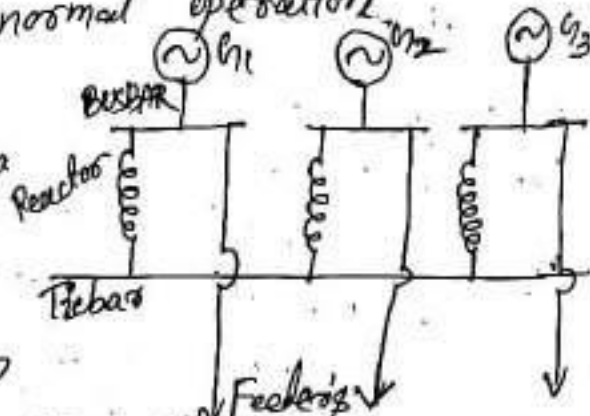
→ Generally one feeder is fed from one generator only.
→ Under normal operating condition each generator will supply its own section of the load, this results in low power loss & voltage drop in the reactor.

→ Advantage:-

→ If a fault occurs on any feeder, only one generator will feed 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 be able to continue in normal operation.

(2) Tiebar System:-

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



→ The outgoing feeders are taken

from reactor side to generating units of the reactors are conn in both individual bus section & it common tiebars system.

* Advantage:-

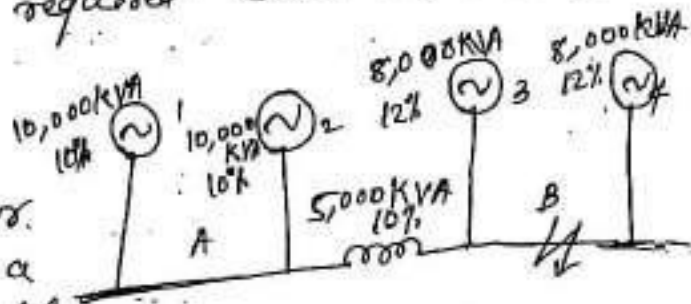
→ The system has advantage of using smaller capacitive reactor.

* Disadvantage:-

→ This system if required additional busbars i.e tiebars.

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% \times and on B 2 generators each of 8,000 KVA with 12% \times . Find the steady MVA (S.C.) fed into a dead s.c. b/n all phase on B with busbar reactor in the ckt.



Assume: Base kVA = 15,000 KVA

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

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

$$\% \times \text{ at base kVA} = \frac{15,000}{5,000} \times 10\% = 30\%$$

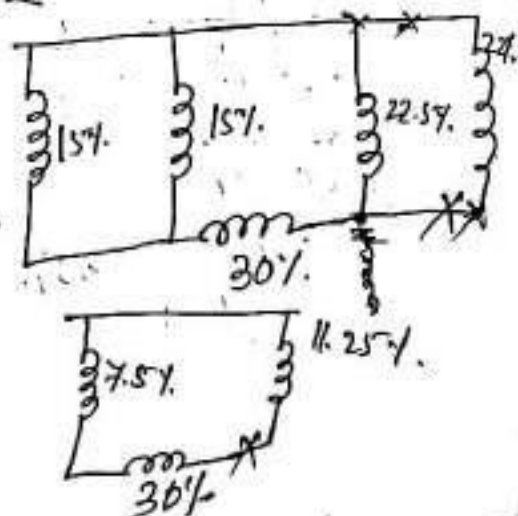
(Reactor) (15/15)

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

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

$$30 + 7.5 = 37.5\%$$

$$\frac{37.5 \times 11.25}{37.5 + 11.25} = 8.65\%$$



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

$$= 15,000 \times \frac{100}{8.65} = 173410.4 \text{ KVA}$$

$$= 173.41 \text{ MVA}$$

Q. A generating station has 3 section busbars connected with a tiebar through 6% reactance rated at 5,000 KVA. Each generator is 5,000 KVA with 12% reactance. Find the total S.C. MVA when S.C. occurs betn the lines on one of the section of the busbar (1) With reactor (2) Without "

Assump;

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

% X for generator at

$$\text{Base KVA} = \frac{5,000}{5,000} \times 12\%$$

$$= 12\%$$

$$\% X \text{ at reactance base KVA} = \frac{5,000}{5,000} \times 6\% = 6\%$$

$$12 + 6$$

$$= 18\%$$

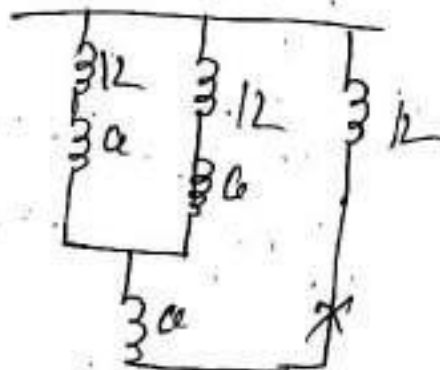
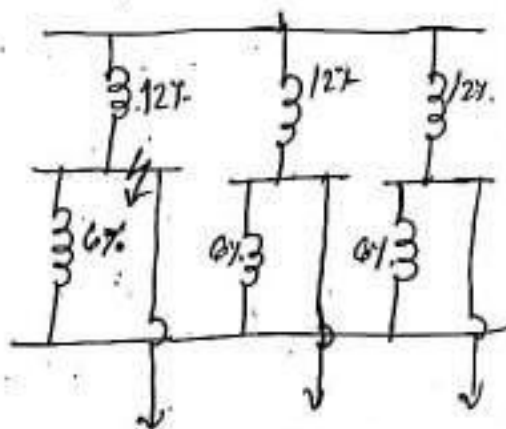
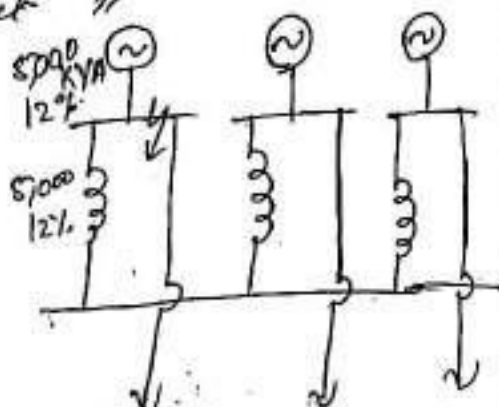
$$18 \parallel 18$$

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

$$9 + 6 = 15\%$$

$$15\% \parallel 12\%$$

$$\frac{15 \times 12}{15 + 12} = 6.66\%$$



$$S.C \text{ at Base KVA} = \frac{57,000 \times 100}{6.66} = 75075 \text{ KVA} \\ = 75 \text{ MVA}$$

Q. Assume,

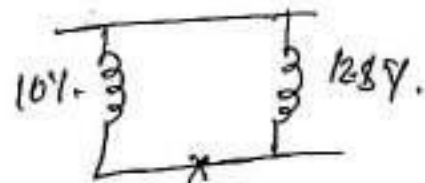
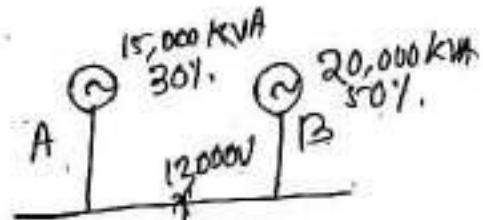
$$\rightarrow \text{Base KVA} = 5,000 \text{ KVA}$$

$$\rightarrow \%x \text{ at Base KVA} = \frac{5,000}{15,000} \times 30\% = 10\% \quad (\text{for A})$$

$$\rightarrow \%x \text{ at Base KVA} = \frac{5,000}{20,000} \times 50\% = 12.5\% \quad (\text{for B})$$

$$10\% \text{ / } 12.5\%$$

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



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

$$\rightarrow I_{sc} = \frac{I \times 100}{\%x} = \frac{240.56 \times 100}{5.55} = 4334 \text{ Amp}$$

$$\rightarrow \text{Short ckt KVA} = \frac{\text{Base KVA} \times 100}{\%x} \\ = \frac{5,000 \times 100}{5.55} = 90090$$

Q. Assume, Base KVA = 15,000 KVA

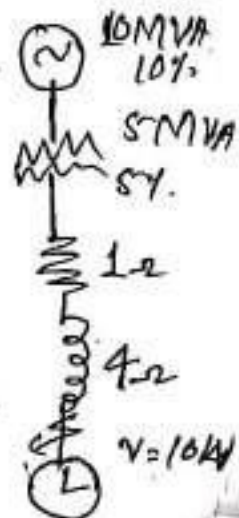
$$10 \text{ MVA} = 10,000 \text{ KVA}$$

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

$$\rightarrow \%x \text{ at generator} = \frac{15,000}{10,000} \times 10\% = 15\%$$

$$\rightarrow \%x \text{ at tlf} = \frac{15,000}{5,000} \times 5\% = 15\%$$

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



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

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

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

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

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

$$= 866 \text{ Amp}$$

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

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

$$= \frac{15,000 \times 100}{91.24} = 16,440 \text{ kVA}$$

$$= 16.44 \text{ MVA}$$

Q1)

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

Assume,

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

$\%X$ at Base kVA for X

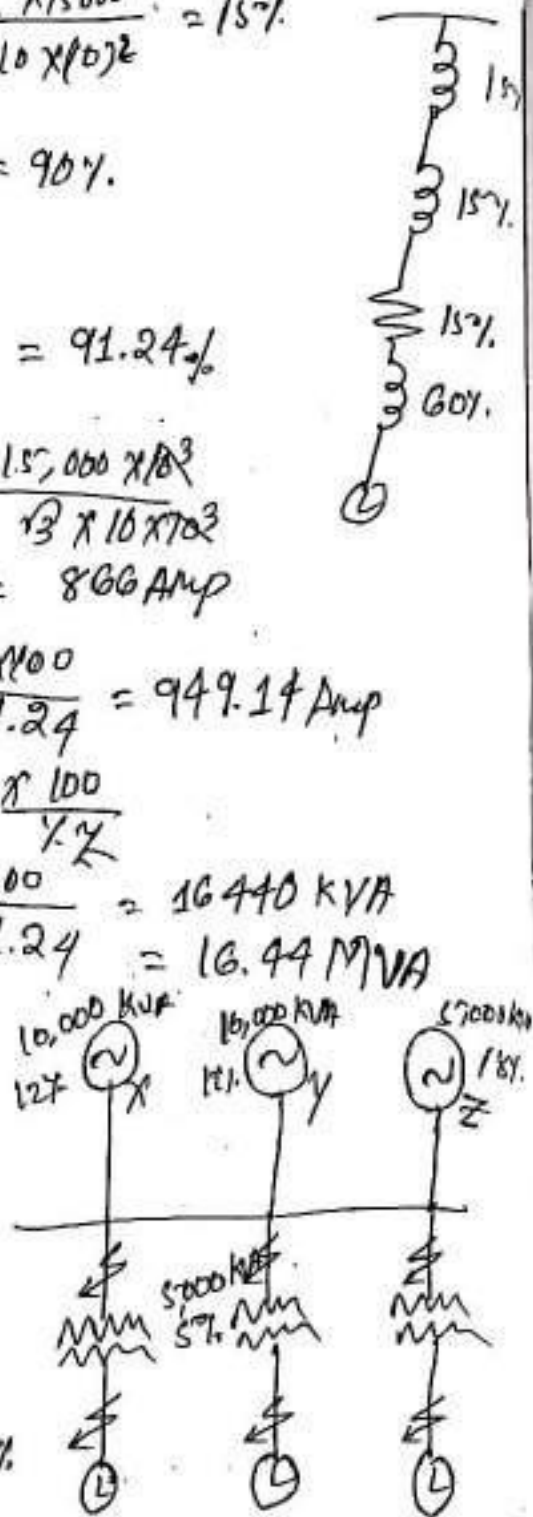
$$\text{Generator} = \frac{5,000}{10,000} \times 12\% = 6\%$$

$$\%X \text{ for Y generator} = \frac{5,000}{10,000} \times 12\% = 6\%$$

$$\%X \text{ for Z generator} = \frac{5,000}{5,000} \times 18\% = 18\%$$

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

(for T/B)



6% 6% 18%

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

$$\frac{3 \times 18}{3+18} = 2.57\% \text{ (for low voltage side)}$$

$$\begin{aligned} \text{for high voltage side} &= 2.57 + 5 \\ &= 7.57\% \end{aligned}$$

$$I = \frac{5,000 \times 10^3}{\sqrt{3} \times 11 \times 10^3} = 262.43 \text{ Amp}$$

$$I_{sc} = \frac{I \times 100}{\%X} = \frac{262.43 \times 100}{7.57} = 3466.7$$

$$\begin{aligned} \text{Short ckt kVA} &= 5,000 \times \frac{100}{7.57} = 66050.19 \text{ kVA} \\ \text{(for high voltage side)} &= 66.05 \text{ MVA} \end{aligned}$$

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

$$\begin{aligned} \text{Short ckt kVA} &= 5,000 \times \frac{100}{2.57} = 194552.5 \text{ kVA} \\ \text{(for lower voltage side)} &= 194.55 \text{ MVA} \end{aligned}$$

$$\begin{aligned} 0.2 \times 50 &= 10 \Omega = R, & 10 \text{ MVA} &= 10,000 \text{ kVA} \\ 1 \times 50 &= 50 \Omega = X, & 5 \text{ MVA} &= 5,000 \text{ kVA} \end{aligned}$$

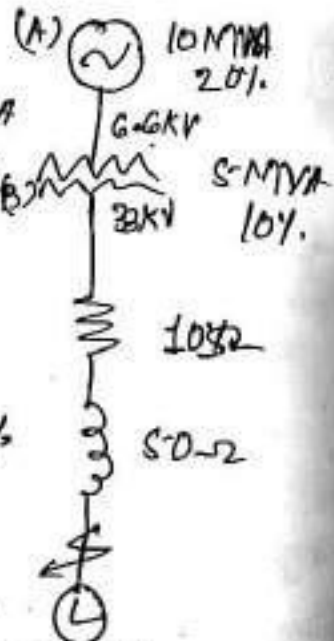
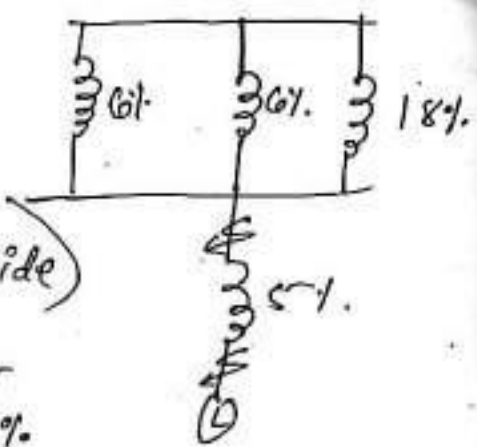
$$\text{Assume, Base kVA} = 20,000 \text{ kVA}$$

$$\begin{aligned} \%X \text{ at Base kVA} &= \frac{20,000}{10,000} \times 20\% = 40\% \\ \text{(for A)} & \end{aligned}$$

$$\begin{aligned} \%X \text{ for B} &= \frac{20,000}{5,000} = 10\% = 40\% \end{aligned}$$

$$\begin{aligned} \%X &= \frac{X \times \text{kVA}}{10 \times (\text{kV})^2} = \frac{50 \times 20,000}{10 \times (33)^2} = 91.827\% \end{aligned}$$

$$\begin{aligned} \%R &= \frac{10 \times 20,000}{10 \times (33)^2} = 18.36\% \end{aligned}$$



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

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

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

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

$$\rightarrow \text{S.C. kVA} = 20,000 \times \frac{100}{172.79} = 11548.7 \text{ kVA} \\ = 11.54 \text{ MVA}$$

Q. A 3 ϕ 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.

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

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

$$\rightarrow I_{sc} = 1154.4 \times 8 = 9234.6 \text{ Amp}$$

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

$$\Rightarrow \% X = \frac{I \times 100}{I_{sc}} = \frac{1154.4 \times 100}{9234.6} = 12.5\%$$

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

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

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

$$V_{ph} = \frac{10 \times 10^3}{\sqrt{3}} = 5773.5$$

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

Q. A 3 ϕ 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.

$$V = 33\text{kV}$$

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

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

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

$$I = \frac{30,000 \times 10^3}{33 \times 12 \times 10^3} = 5248.63 \text{ Amp}$$

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

We know,

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

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

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

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

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

$$\Rightarrow x = \frac{5 \times \frac{33000}{12}}{5248.63 \times 100} = 0.1812$$

✓

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

→ Principle of fuse:-

The fuse material generally made up of the material which having low melting point high conductivity & least deterioration due to oxidation.

→ Ex:- Silver, copper etc.

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

→ Under normal operating condⁿ 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.

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

→ In this the fuse protect the device, i.e. equipment from damage due to the excessive currents.

→ Advantage:-

→ It is the cheapest form of protection.

→ It req^r 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 breakers 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 betⁿ fuse is series can't be obtain unless there is sufficient diff^r in the sizes of the fuse.

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

* Desirable characteristic of fuse elements :-

→ The fun^{ct} 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 its melting point & disconnects the ckt protected by it.

→ In order to perform this fun^{ct} the fuse element should have following desirable characteristics.

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

2. High conducting copper & silver. ^{oxidization}

3. Free from deformation 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 = 37% & tin = 63%] is used for making the fuse element.

→ For larger current copper or silver is used.

* Important terms :-

DT-08/01/2020

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

i) 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.

ii) Fusing current :- It is minimum current at which the fuse element melts & thus disconnects the ckt protected by it.

→ Its value will be more than the current rating of the fuse element.

→ The ^{approximate} relation betⁿ 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

d) Size & location of terminal

e) Types of enclosure.

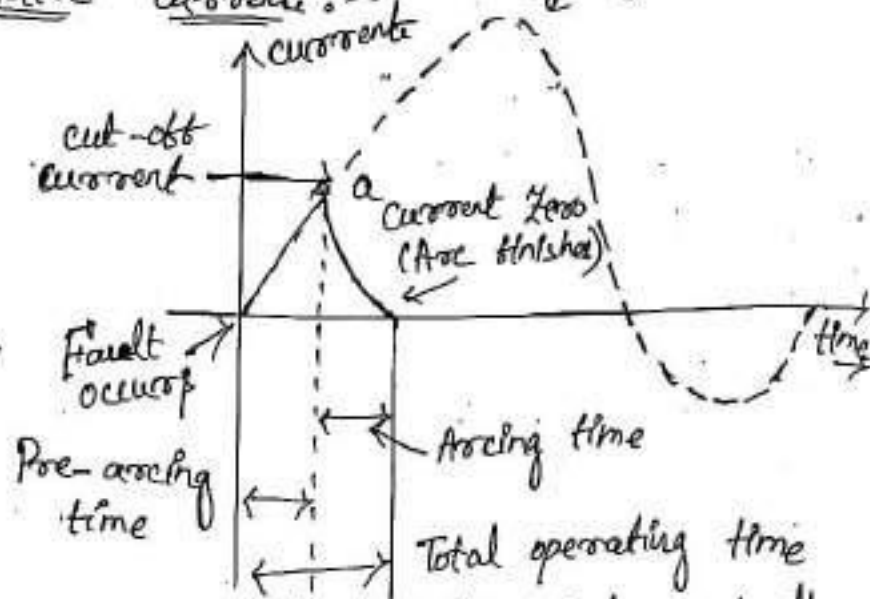
iii) Fusing factor :- It is the ratio of min^m fusing current to the current rating of fuse.

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

✓ Its value is always more than one.

✓ For cu. wire as the fuse element the multiplying 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^m 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 betⁿ 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 betⁿ the end of pre-arcing time & the instant where the arc is extinguished.

✓ Total operating time:- It is the sum of pre-arcing time & arcing time. It may be noted that the ope. 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 " "

i) Low voltage fuse :-

(a) Semi-closed rewireable fuse.

(b) High rupturing capacity cartridge fuse (HRC)

a) Semi-closed rewireable fuse :-

→ The rewireable fuse also known as type.

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

→ It consists 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 betⁿ 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 used for the circuit of high fault level.

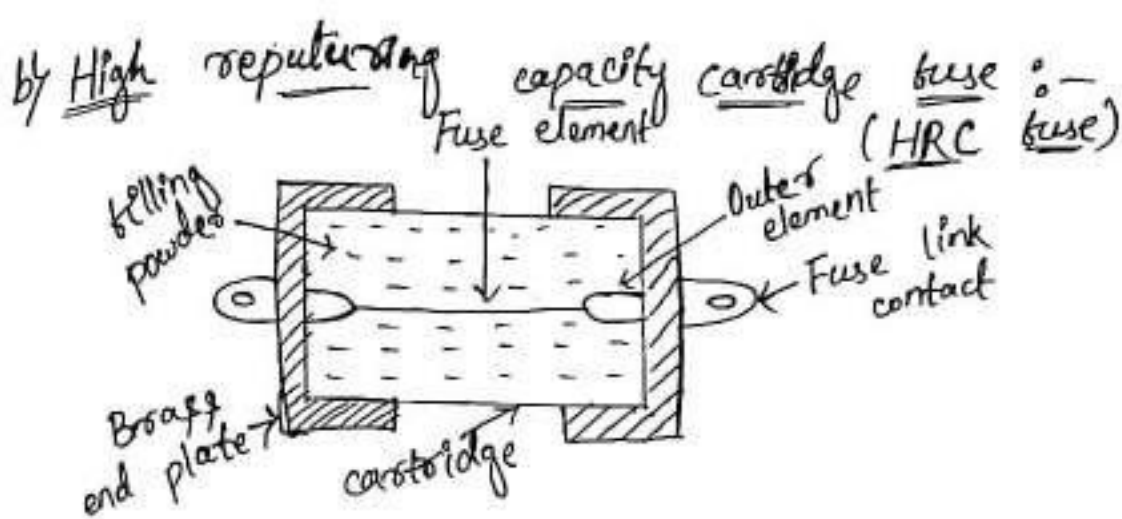
iii) The fuse element subjected to the deterioration due to oxidation through the continuous heating of the element. Therefore after some time the current rating of the fuse is decreased i.e. the fuse operates at a lower current than originally rated.

iv) The protective capacity of such fuse is

uncertain.
v) The accurate calibration of fuse wire is not possible because the fusing current very much depends upon the length of the fusing element.

→ The semi-enclosed non-renewable fuses are made up to 500 amp rated current but the breaking capacity is low i.e. on 400 volt service.

→ This type of fuse is limited to domestic & lighting load.
The use of



- To overcome the disadvantage of semi enclosed re-wirable fuse, HRC cartridge fuse is used.
- It consists of a heat resisting ceramic body having metal caps to which it 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 increases & the fuse element melts.
- The heat produced in the process vaporise the melted silver element.
- The chemical reaction between the silver vapours & the filling powder results in the formation of high resistance, which helps quenching the arc.

* Advantage :-

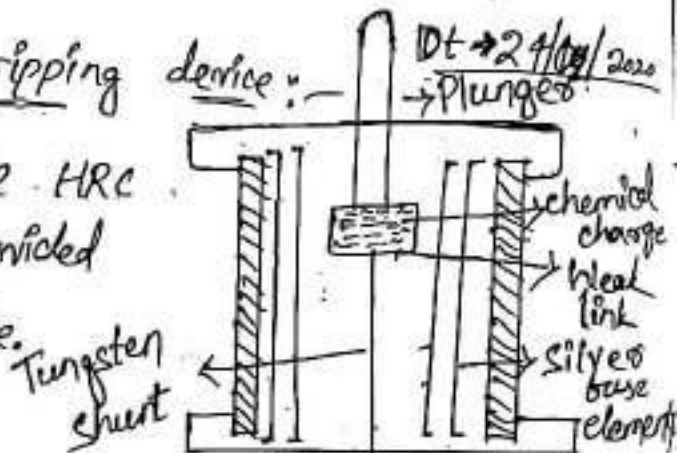
- i) These are capable of clearing high as well as low fault current.
- ii) These are not deteriorate with age.
- iii) They have high speed of operation.
- iv) They provide reliable discrimination.
- v) They req^d no maintenance.
- vi) They permit consistant performance.

* Disadvantage :-

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

* HRC bus with tripping device :-

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



- When the bus blows out under the fault condition 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 mechanism 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 1st is blown out & then the current is fed 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 plungers outwards to operate the ckt breakers.

→ Adv.:- In case of 1 ϕ fault on a 3 ϕ system the plungers operates the tripping mechanism of the C.B. to open all the 3 ϕ & 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 fuse 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 of low resistance (silvers) & the other of high R (tungsten wire)

→ Under normal load condⁿ 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.

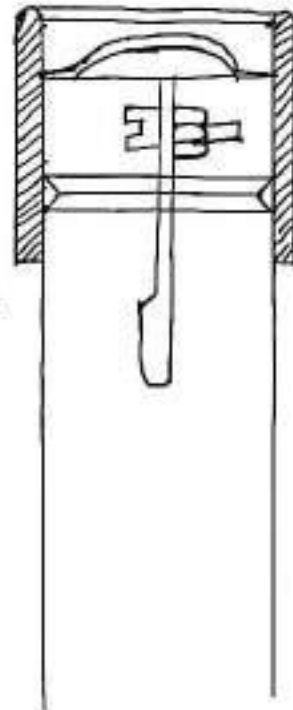
(b) Liquid type :-

→ 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 bronze spiral spring fixed at the other end of the glass tube.

→ When current exceeds the fuse wire is blown out.

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



Q) Q

$$r_1 = 0.8 \text{ mm}$$

$$I_1 = 8 \text{ Amp}$$

$$I_2 = 1 \text{ amp}$$

$$r_2 = ?$$

$$K = 1$$

$$I = K d^{3/2}$$

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

\Rightarrow Heat produced per sec = Heat loss per sec

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

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

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

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

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

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

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

$$\Rightarrow \frac{1}{64} = \frac{r_2^3}{0.514}$$

$$\frac{r_2^3}{0.514} = 8 \times 10^{-3}$$

$$r_2 = \sqrt[3]{0.008} = 0.2 \text{ mm.}$$

→ A circuit breaker is a piece of equipment which can make or break an ckt either manually or by remote control under normal conditions. Breaks 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 consist 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 apart 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 they open by the protecting system, at the instant. When the contact began to separate the contact area decrease rapidly & the large fault current cause increase large current density and hence raising temperature.

→ The heat produce and medium betⁿ contact (usually the medium is oil or air) is sufficient to ionise the air or oil.

- The ionised air or vapours act as a conductor and an arc is struck betⁿ the contact.
- The potential diff^r 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 persists.
- 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 ionisation:-

→ 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 (orignali)

(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 extinguishing.

→ The ^{main} dis. and. of this method is dissipation 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 the arc :- The R of the arc is directly proportional to its length. The length of the arc can be increased by increasing the gap between the contacts.

(b) Cooling the arc :-

→ The cooling helps in the de-ionisation of the medium between the contacts, this increases the arc R.

(c) Reducing the cross-section area of the arc :-

→ ~~large~~ The area of cross-section of the arc is reduced, the R of the arc increases. The cross-section area of the arc can be reduced 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 increased by splitting the arc into a no. of smaller arcs in series. The arc may be split by introducing some conducting plate between 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 every half cycle. At every I zero the arc extinguish for a brief moment.
- Now the medium betn the contact contain ion & electron 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 betn the contact.
 - ∴ By opening the contact rapidly higher dielectric strength can be achieved
 - * High Pressure:- If the pressure of the arc is increase 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 increase.
 - * Cooling:- The natural combination of ionise particles takes place more rapidly if they are allowed to cool.
 - ∴ dielectric strength of the medium can be increase by cooling the arc.
 - * Blast effect:- If the ionise particle betn the contact are swept away & replace by un-ionised

particle the dielectric strength of the medium can be increased & this may be achieved by a gas blast or by forcing the oil betn the contact.

* Classification of ckt breaker :-

→ There are several ways of classifying the CB. however the most general way of classification is on the basis of medium used for arc

extension.

→ Accordingly the ckt breaker may be classified into following type:-

1) Oil ckt breakers:- which employed some insulating oil for arc extension.

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

3) Sulphur hexa fluoride CB:- (SF_6) :-

In which SF_6 gas is used for arc extension.

4) Vacuum CB:- In which vacuum is used for arc extension.

5) Oil ckt breakers:-

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

→ The contact are open under oil & the arc is struck betn 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 decomposed. The oil is pushed away from the arc & an expanding H gas bubbles surround the arc region & adjacent portion of the contact.

→ The arc extension

→ ∴ The arc is extinguished & the ckt current interrupted.

⇒ Adv.:-

⇒ Oil as an arc quenching medium are:-

i) It absorbs the arc energy to decompose the oil into gases.

ii) It acts as an insulator & permits smaller clearance betn the conductors.

⇒ Dis. adv.:-

i) It is inflammable & there is a risk of fire

ii) It may form an explosive mixture with air.

⇒ Types of oil CB:-

The oil CB can be classified into following types.

(i) Bulk oil ckt breaker:-

Which use a large quantity of oil

→ The oil has to serve two purposes,

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

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

→ Such ckt breakers can be classified into 2 types

(A) Plain break oil CB

(B) Arc control " "

Q7 Low oil CB :-
 which use min 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 betn the contact is reached.

→ It has a very simple construction.

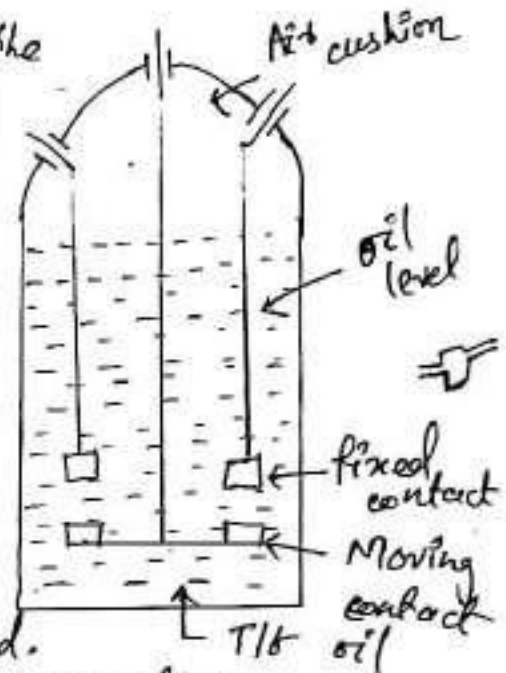
→ It consist of fixed & moving contact which is enclosed in a tank containing oil upto a certain level. and an air cushion above the oil level.

→ The air cushion provide sufficient space for allow for the reception of the arc gases without the generation of unsafe pressure.

→ Under normal operating condⁿ the fixed & moving contact remain closed & the ckt breaker carry the normal ckt current.

→ When a fault occurs the moving contact are pulled down by the protective system & an arc is strucked which vapourise the oil into hydrogen gas.

→ The arc extension is be by the following process;



ii. H^+ gas bubble generated around the arc & cools the arc.

iii. As the arc lengthens due to the separating contact, the dielectric strength of the medium if increase. 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, \therefore for successful interruption long arc length is necessary

* This breakers have long & inconsistent arcing time.

* This 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;

i) Self blast oil CB

ii) Forced blast oil CB

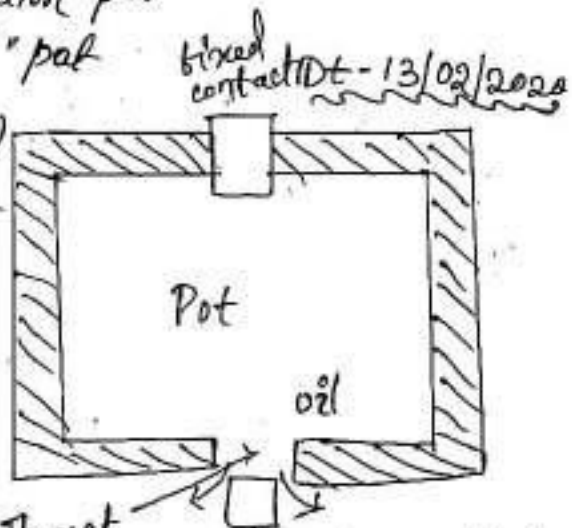
i) Self blast oil CB:- It is the CB in which arc control is provided by internal means i.e. the arc itself is employed for its own extinction efficiently.

- In this type of CB the gases produced during arcing are confined (2/10/20) 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, such breakers some time called self generated pressure oil C.B..
- There are several design of pressure chamber has been developed. These are;

- Plain explosion pot
- Cross jet explosion pot
- Self compressed pot

* Self blast oil CB (PEP)

1) 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 gets separated & 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 I_{sc} only.

if Cross 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 an arc splitter. Path of cool oil

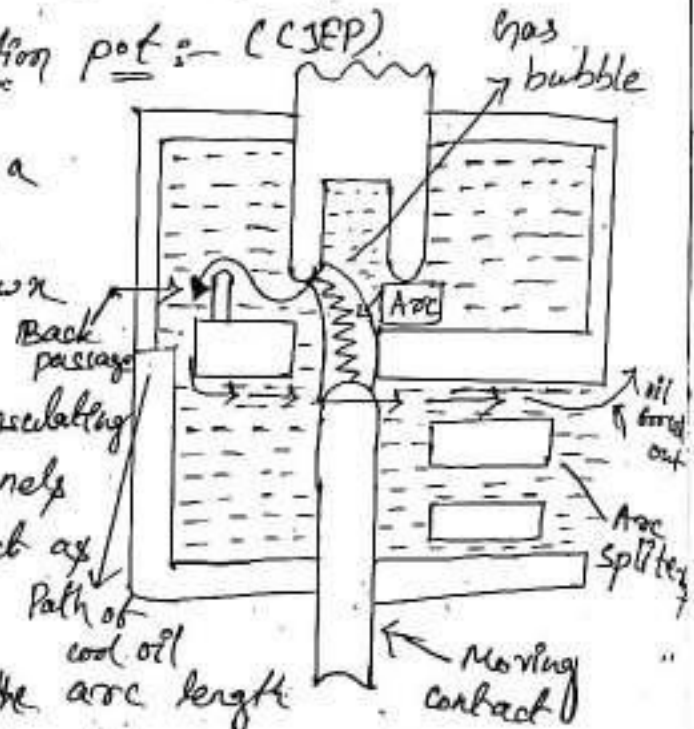
→ It helps in increasing the arc length

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, fresh oil is forced across the arc path.

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



are if extinguish:
 → This pot is quite efficient for interrupting heavy fault current.

air self compensated explosion pot:-

This type of pot is a combination of plain explosion type pot & cross jet " " " "

→ It can interrupt low as well as heavy s.c. current (I_{sc})

→ It consists of 2 chambers the upper chamber is CSEP with two arc splitter duct, while the lower one is PEP.

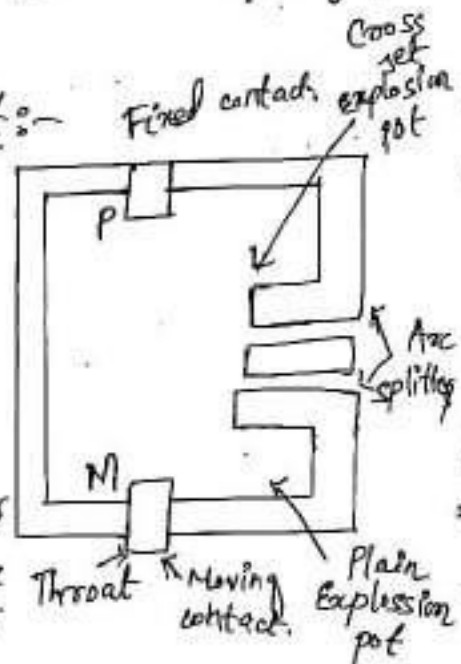
→ When I_{sc} is heavy the rate of generation of gas is very high & the device behaves as a CSEP. At when the low I_{sc} the rate of gas generation is low or small.

→ 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 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 depends on fault 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.

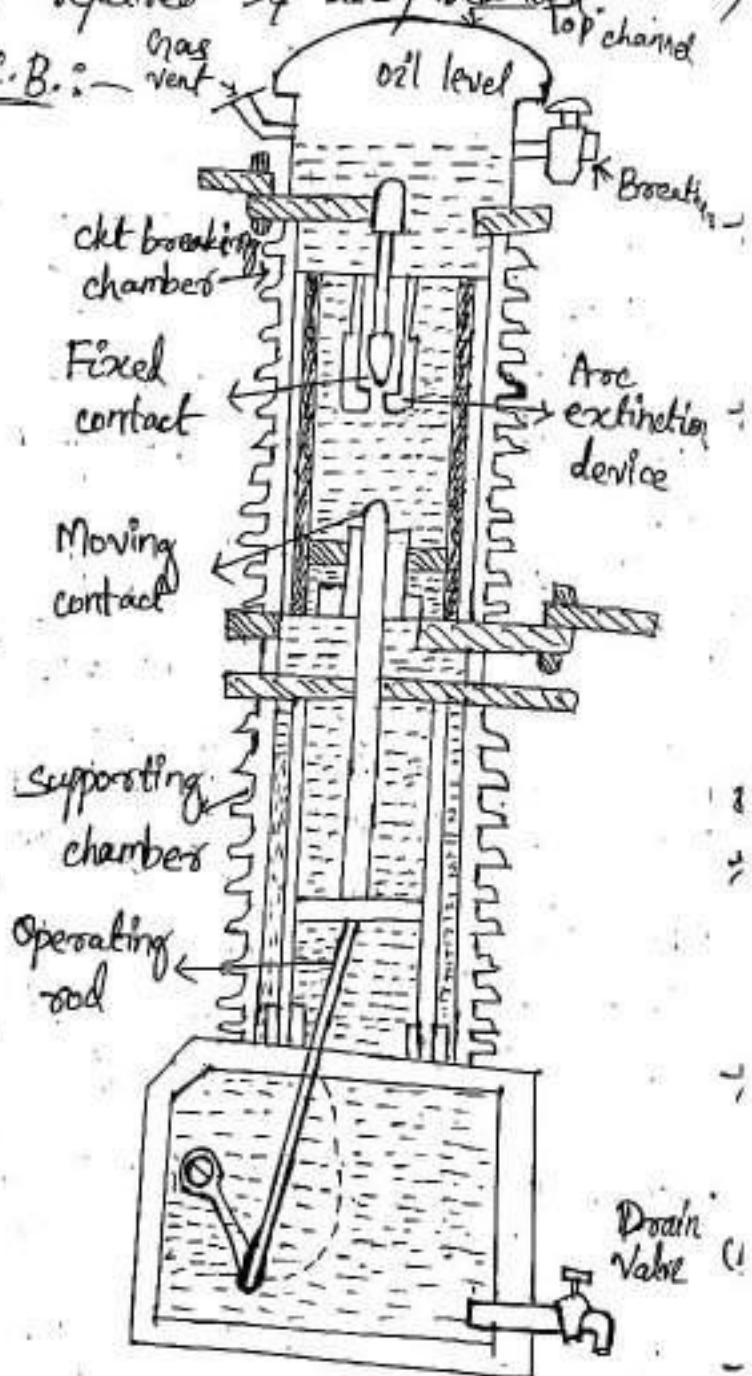


→ When a fault occurs the contact separated by the protective system & an arc is struck betⁿ the fixed contact & moving contact. The piston forces a jet of oil toward the contact gap to extinguish the arc.

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

→ Quantity of oil required is low/reduced.

* Low oil C.B.:-



→ 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 compartment separated from each others 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 chamber.

→ This arrangement permits 2 adv.;

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 replace is 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 bakelised paper is employed for insulation

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

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

(2) Upper & lower fixed contact

(ii) Moving contact

(iii) Turbulator

→ The moving contact is a hollow cylinder which moves down over a fixed piston & 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 condⁿ the moving contact remains closed with the fixed contact. & when a fault occurs the moving contact is pulled down & an arc is struck between the fixed contact & moving contact.

→ The arc energy vaporise the oil & produces gasous under high pressure. This action constrains 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 turbulence which is used to successively quenching the arc.

* Adv.: - (i) A Low oil ckt breaker has following adv. over a bulk oil CB;
(2) It req^s lesser quantity of oil, & it req^s 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 several 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 extinguished & the flow 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 product is completely removed by the air blast whereas the oil deteriorates with successive ops.
3. The arcing time is very small.
4. The energy supply for arc extinction is obtained from high pressure air & is independent of the I to be interrupted.

* 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:-

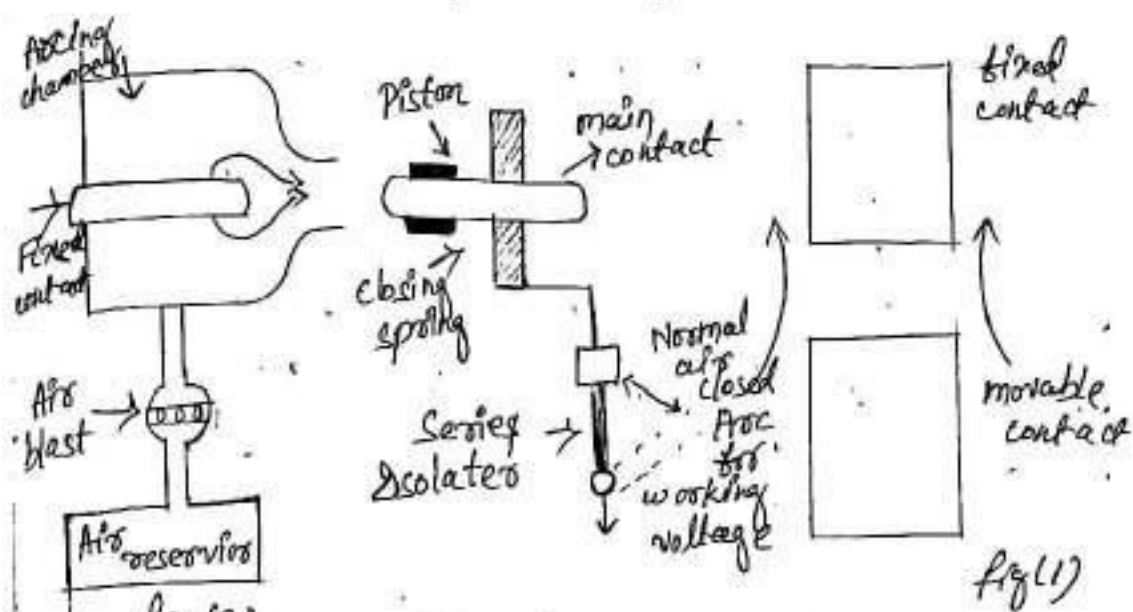
Depending upon the direction of the air blast to the arc, the air blast CB can be classified into 3 types; (a) Axial blast type

(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 CB. The fixed & moving contact are held in the close position by the spring under normal condn.



→ The air reservoir is connected to the arcing chamber through an air valve. The air valve remains closed under normal operating conditions but it opens automatically by tripping mechanism when a fault occurs in the system.

→ When a fault occurs the tripping impulse causes opening of air valve which connects the air reservoir to the arcing chamber.

→ The high pressure air entering the arcing chamber pushes away the moving contact against spring pressure.

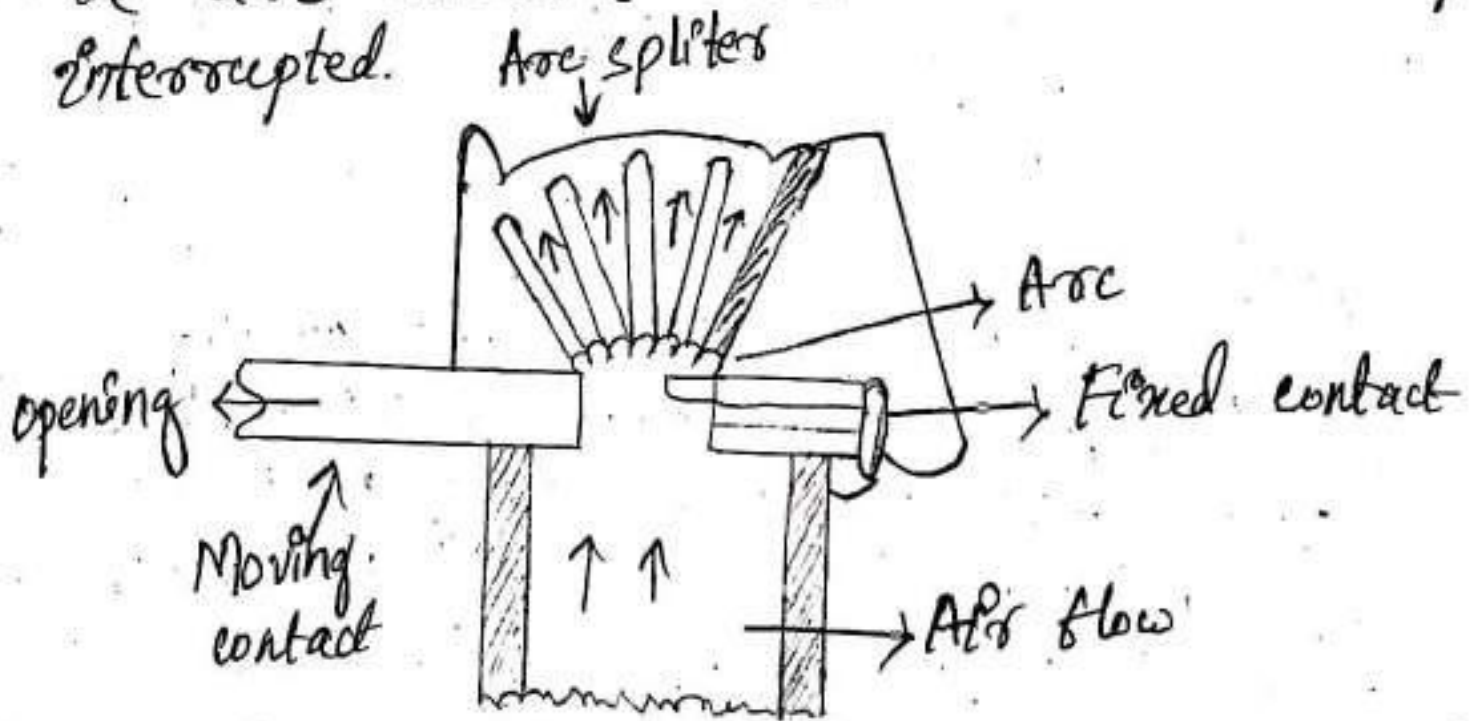
→ The moving contact is separated & an arc is produced and at the same time high pressure air blast flows along the arc and therefore, the arc is extinguished and the current flow is interrupted.

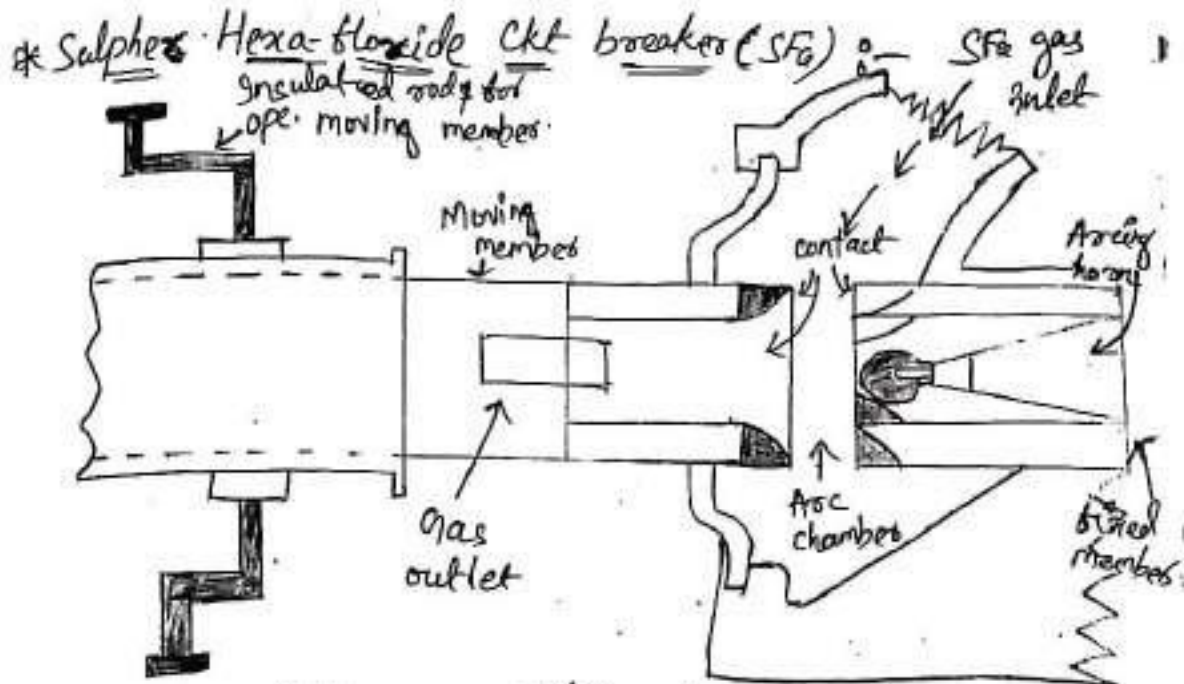
(b) Cross blast air blast CB:-

→ In this type of CB air blast is directed at right angle to the arc.

→ The cross blast lengthens and forces the arc for arc extension.

- When the moving contact is separated, an arc is produced between fixed & moving contact.
- The high pressure cross blast forces the arc into an arc splitter. The splitter serves to increase the length of the arc. This results in the arc extension & the flow of current is interrupted.





→ A CB - which uses sulphur hexafluoride or SF_6 gas as arc extinguish medium is known as SF_6 CB.

→ The SF_6 gas is a very good dielectric material which can resist high potential.

* SF_6 is an electro negative ^(-ve) gas & has a strong tendency to absorb free electrons, whenever the CB opens its contact an arc will be formed between the 2 contacts at the same time a high pressure SF_6 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_6 CB are very effective for high power or high voltage app.

* Construction - The SF_6 CB consist of a fixed contact and a moving contact & closed in an arc interruption chamber which contain SF_6 gas.

- This chamber is conn to the SF_6 gas reservoir.
- When the contact of CB are open the valve mechanism permit a high pressure SF_6 gas from the reservoir to blow toward arc interruption chamber. The fix contact & moving contact are hollow cylindrical arrangement. The moving contact contain rectangular holes in the side to permit the SF_6 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_6 is costly, it is recycled & reused by the suitable auxiliary system after each use of the ckt breaker.

* Working:-

- In the closed position: at the breaker the contact remain surrounded by SF_6 gas at a pressure of 2.8 to 3.2 kg/cm²
- When the breaker open the moving contact is separated from the fix contact & the arc is struck betw the contacts.
- The movement of moving contact is synchronised with the opening of valve which permits SF_6 gas at pressure of 14 kg/cm² from the reservoir to arc interruption chamber.
- The high pressure blow of SF_6 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 SF₆ gas, the SF₆ CB have many adv. over oil or air ckt breakers these are;

1. Due to the superior arc quenching property of SF₆ gas such CB have very short arcing time.
2. Since the dielectric strength of SF₆ gas is 2 to 3 times of air such breakers can interrupt large current.
3. The SF₆ gas CB give noise less operation.
4. The closed gas enclosures keep the interior dry so that there is no moisture problem.

5. There is no risk of fire in such breakers bcoz SF₆ gas is non-inflammable.

6. The SF₆ CB have low maintenance cost and require min^m auxiliary equipment. Since SF₆ CB are totally enclosed & sealed from atmosphere, they are particularly suitable where explosion hazard exists.

* Dis-advantage:-

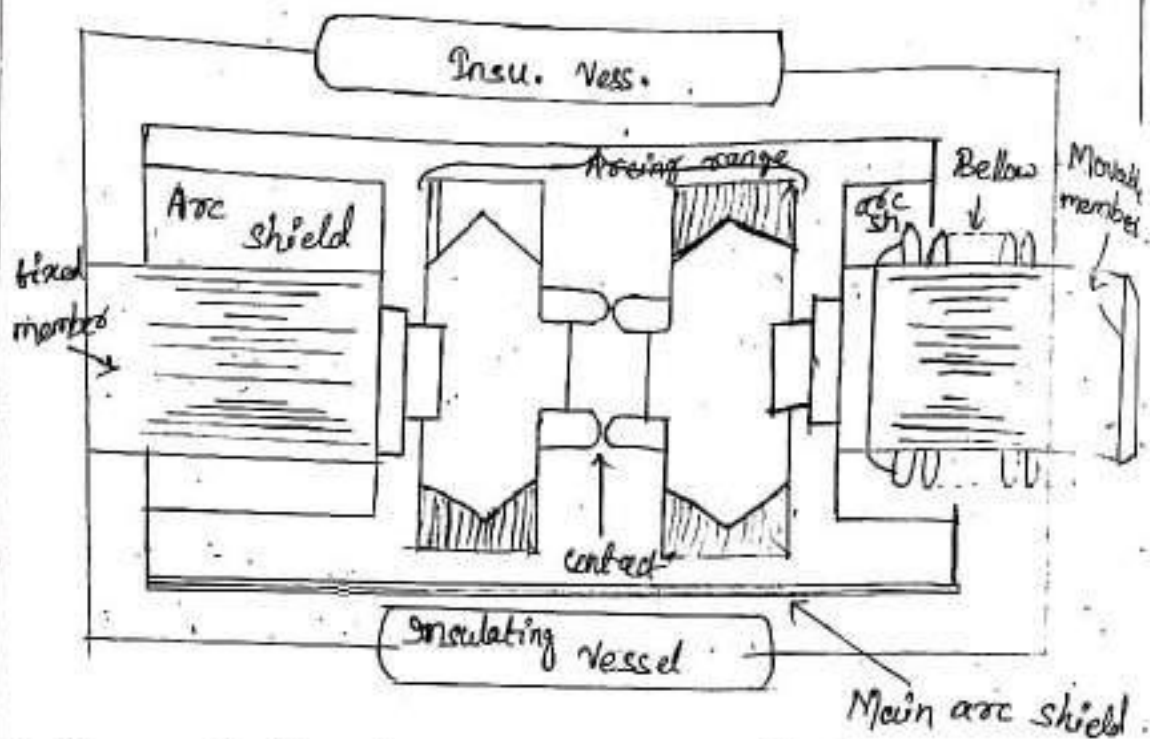
→ The SF₆ CB are costly due to the high cost of SF₆ gas.
→ Since SF₆ gas has to be reuse or recondⁿ after every operation, additional equipment is req^d for this purpose.

* Application:-

→ The SF₆ 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 insulation strength it has superior arc ^{highest} quenching property than any other medium.

→ For ex. when contact of CB are opened in vacuum, the interruption occurs at 1st I_{ext} with dielectric strength betⁿ the contacts 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 betⁿ the contact by the ionisation of metal at the contact. However the arc is quickly extinguished by the metallic vapour, electrons & ion produced during ^{arc} rapidly condense on the surfaces 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 prevents the deterioration of the internal dielectric strength.

* Adv.:— The vacuum CB have the following adv.

(i) They are compact, reliable & have longer life.

(ii) There are no fire hazards.

(iii) They need little maintenance.

(iv) They can successfully withstand the lightning surge.

(v) They have low arc energy.

(vi) 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 occur 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 ampere 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 cost, 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 armature 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 laminated electro-magnet (M), carrying a coil (C) & a laminated armature.

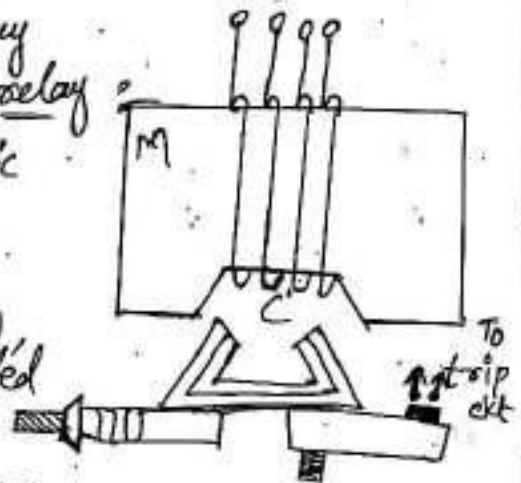
→ The armature is balanced by a counter weight & carries a pair of spring contact at its free end.

→ Under normal operating condition the current through relay coil is such that the counter weight holds the armature in the \downarrow ve as shown in fig.

→ However when a short ckt occur the through relay coil is increase & the relay armature is attracted upward.

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

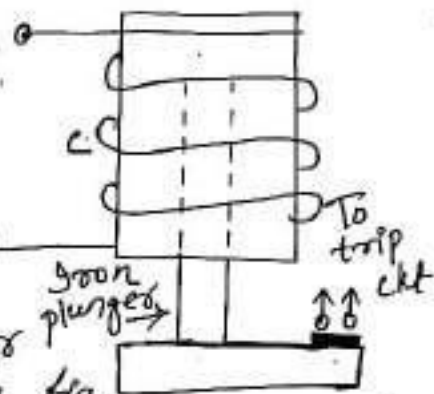
→ The minimum current at which the relay armature is attracted to close the trip ckt is called as peak-up current.



ii) 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 by the spring as shown in fig.



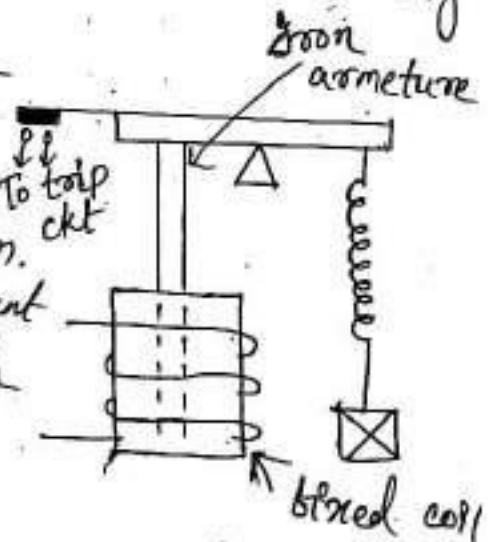
→ When the fault occurs the current through the relay coil becomes more than the peak up value causing the plunger to be attracted to the solenoid.

→ The upward movement of the plunger closes the trip ckt & thus the CB opens & the faulty section can be disconnected from the healthy section.

iii) Balanced beam type relay :-

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

→ Under normal condition the current through the relay coil is such that the beam is at its 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 the coil, this causes the closing of the trip ckt, which causes the opening of the circuit breaker to isolate the faulty section.

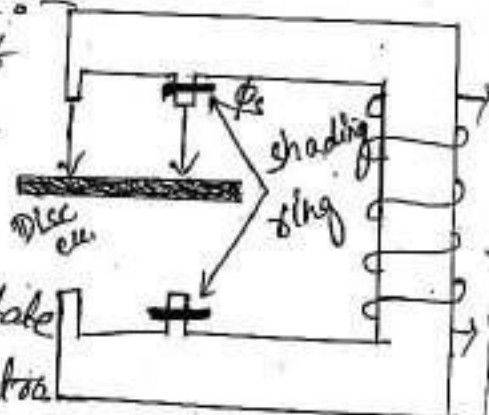
2. Electromagnetic Induction type relay :-

- * This type of relay operates on the principle of the electro-magnetic induction.
- * This type of relay mainly used for the purpose of AC quantity.
- * This relay basically operates when an aluminium disc betⁿ 2 alternating magnetic field which has same frequency but separate phase displacement betⁿ 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.

Shaded pole structure :-

- * The general arrangement of shaded pole structure is shown fig.



- * It consists of an aluminium disc which is free 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.

- * The alternating flux Φ_s in the shading portion will produce the current in the ring lags behind the flux Φ_u in the unshaded portion by an angle.

' α ', so the torque produced is given by

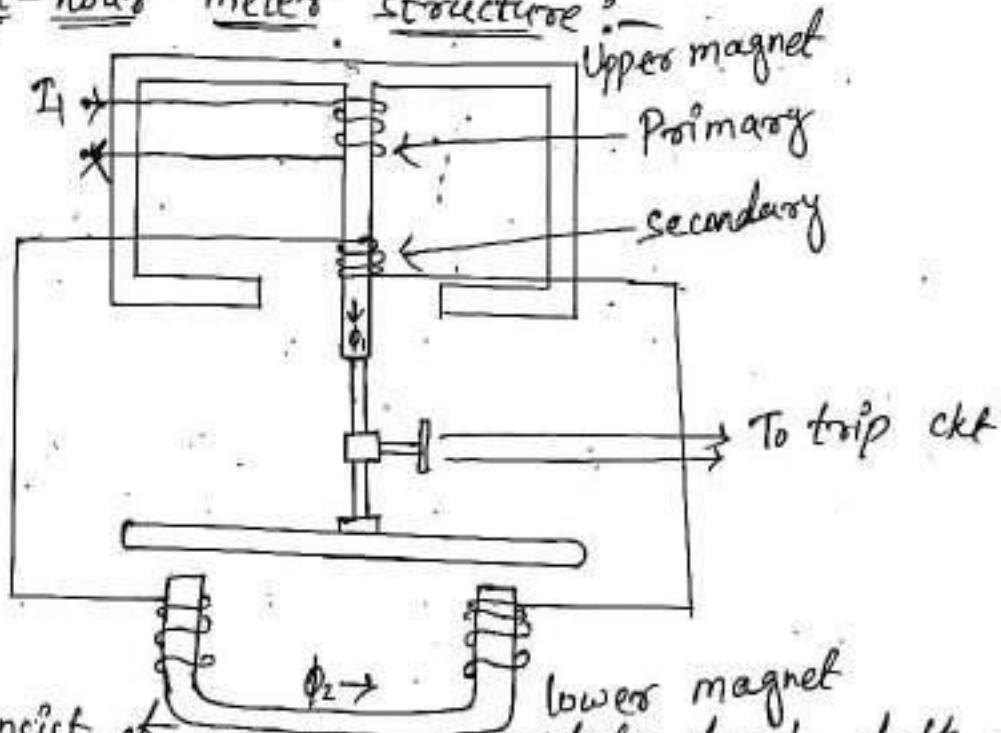
$$T \propto \phi_s \phi_u \sin \alpha$$

→ The fluxes ' ϕ_s ' & ' ϕ_u ' are directly proportional to the current ' I ' in the relay coil.

$$T \propto I^2 \sin \alpha$$

$$I \propto \phi_c, I \propto \phi_u.$$

ii) Watt-hour meter structure:-



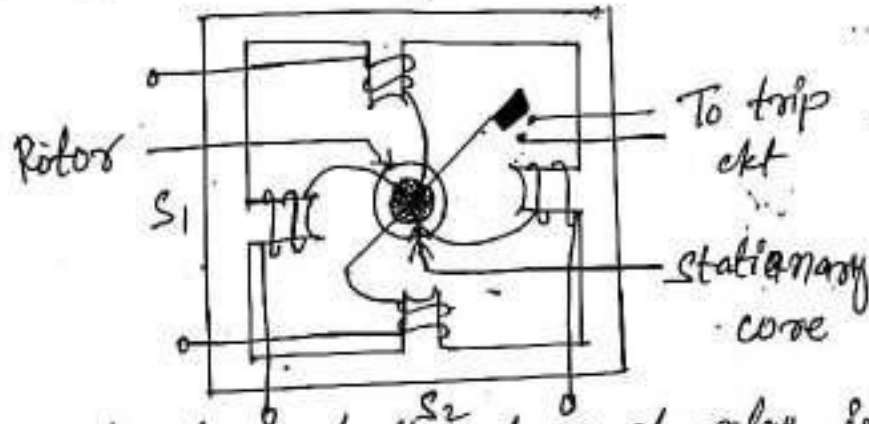
→ It consists of an arrangement to rotate freely between the poles of 2 electro-magnets. The upper magnet carries 2 windings i.e. the primary & secondary.

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

→ The primary current induced emf in the secondary wind & so current (I_2) circulates in it. The flux (ϕ_2) induced in the lower magnet by the current (I_2) in the secondary winding of the upper magnet.

→ Flux ' ϕ_2 ' lags behind the ' ϕ_1 ' by an angle ' α ', the 2 fluxes ' ϕ_1 ' & ' ϕ_2 ' differ in phase by ' α ' which produces the net torque on the disc.

- The torque produce 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.
- iii) Induction cup structure:-



- The construction of this type of relay is similar to the construction of induction motor.
- The stator wind is supplied from the actuating quantity.
- The rotor core is kept stationary only the rotor conductor portion being move freely.
- The moving element is a hollow cylinder rotor which turns on its axle.
- The rotating field is produced by 2 pair of coil on the 4-poles.
- The rotating field induced the current & provided the necessary torque.
- If Φ_1 & Φ_2 represent the flux produced by the respective pair of coil.
- Then the torque produce is proportional to $\Phi_1 \Phi_2 \sin \alpha$ where, α = phase difference betw the 2 flux
- The induction cup structure is more efficient torque producers, 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 Ampere.

→ Current setting :- A relay can be made to operate at different peak-up current by providing tapping 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 of 25%.

* Peak up current = rated secondary current of CT \times 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 is PSM time; get the actual operating time.

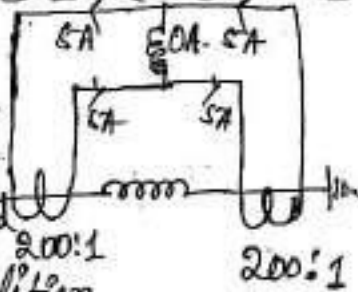
→ TSM generally expressed in second.

* Differential Relay:-

- This is the relay which operates the phasor difference at the 2 or more similar electrical quantity exceeds a predetermined value.
- This type of relay is used where more sensitivity to 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.

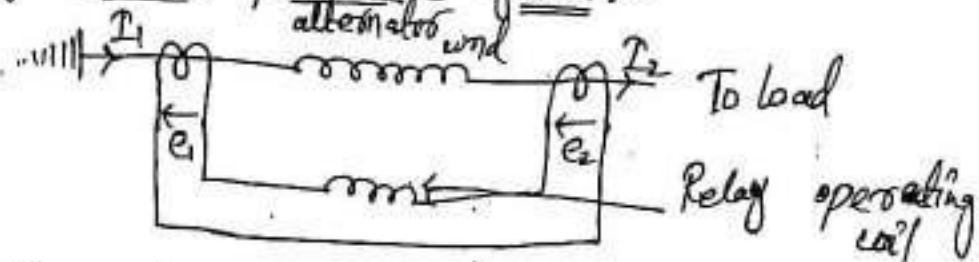
1) Current balance protection system:-

- 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 overcurrent relay is connected to the CT secondary ckt. To load.
 - Under normal operating condition a normal current flows through the both the CT. i.e. the current flows through the 2 C.T. are equal.
 - As the current at the 2 C.T. 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.

2/ 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 CT₂. Therefore the secondary voltage of the CT are balanced to each other so no current flows through the relay operating current.

→ When the fault occurs the protected one of the primary of the C.T. will differ from each other & the current flows through the relay operating coil which closes the trip ckt.

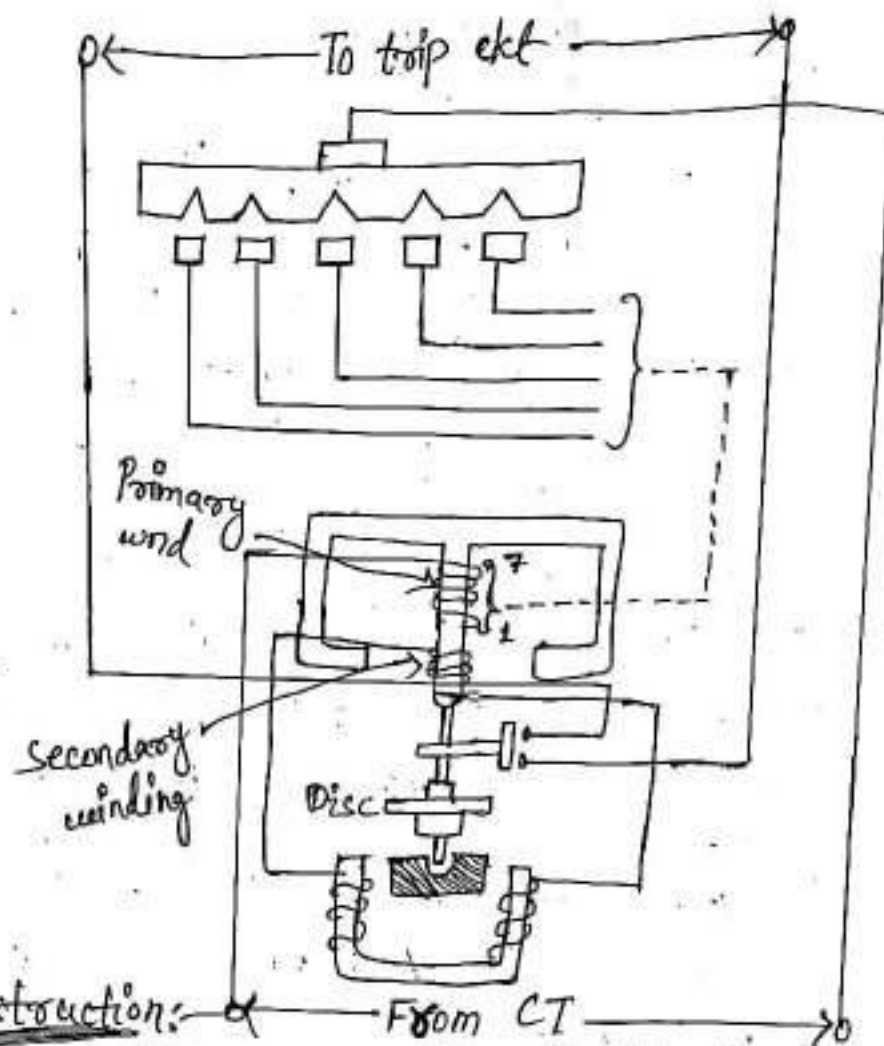
* Difference type of functional relay:-

→ Relay can be classified into the following type according to their function.

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

1/ Induction type over current relay (Non-direction):-

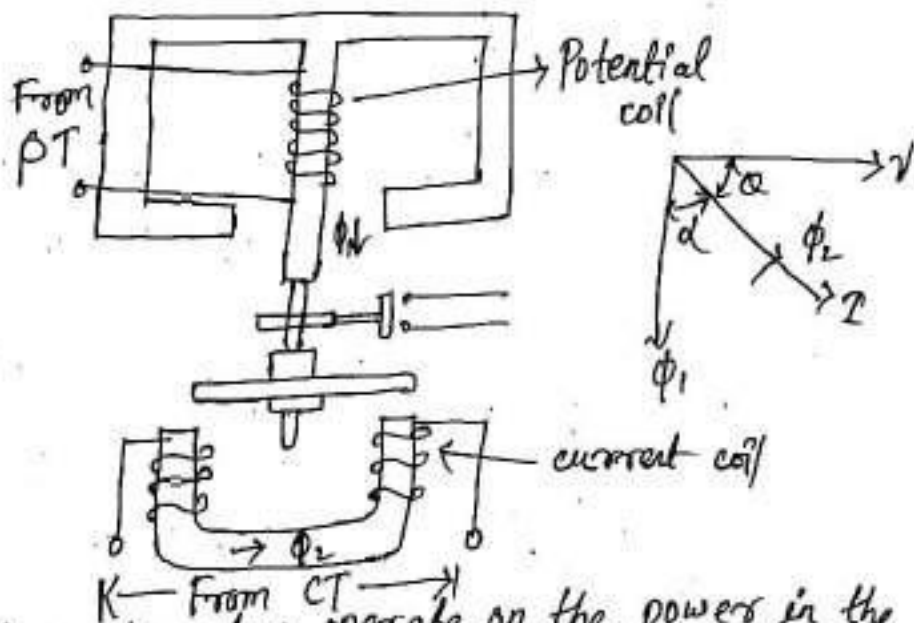
→ This type of relay operates on the induction principle. These relays are used in AC ckt only & can be operate for the fault current flow in either direction.



* Construction:

- It consists of a metallic disc (Aluminium) which is free to rotate. In betⁿ the poles of 2 electromagnets 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^d to a plug setting by which the no. of active turns of the relay operating coil varying for giving the desired 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 powers in the ckt close in specific direction.

- * Construction:-
- It consist of aluminium disc which is free to rotate in betn of poles 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.

* Operation:— From the phasor diagram the flux ϕ_1 due to the current in the potential coil will be nearly 90° lagging behind the applied voltage V .
→ The flux ϕ_2 due to the current coil will be nearly in phase with an operating current I .

$$\begin{aligned} T &\propto \phi_1 \phi_2 \sin \alpha \\ &\propto VI \sin(90^\circ - \alpha) \\ &\propto VI \cos \alpha \end{aligned}$$

$T \propto$ 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.

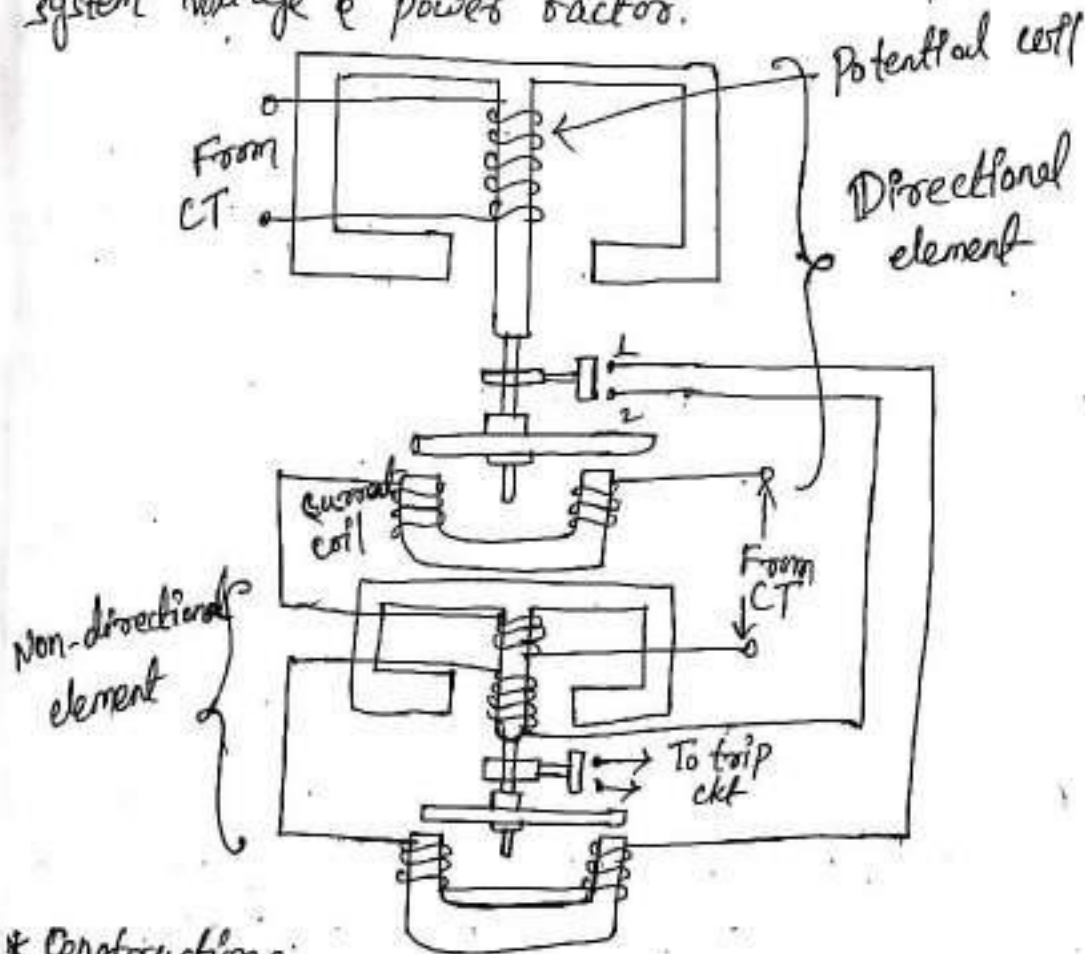
→ When the power on the ckt flows in the normal direction the relay is inoperative.

→ 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 used 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 difficulty 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) at the directional element are connected in series with the secondary ckt of the over current element. Therefore the directional element must operate first 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 at the disc of this element carries a moving contact which closes the trip ckt contact after the operation of directional element.

* 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 completes 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 isolates the faulty / unhealthy section.

* Types of Protection :-

→ When a fault occurs on any part of electric power system it must be cleared quickly in 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 "

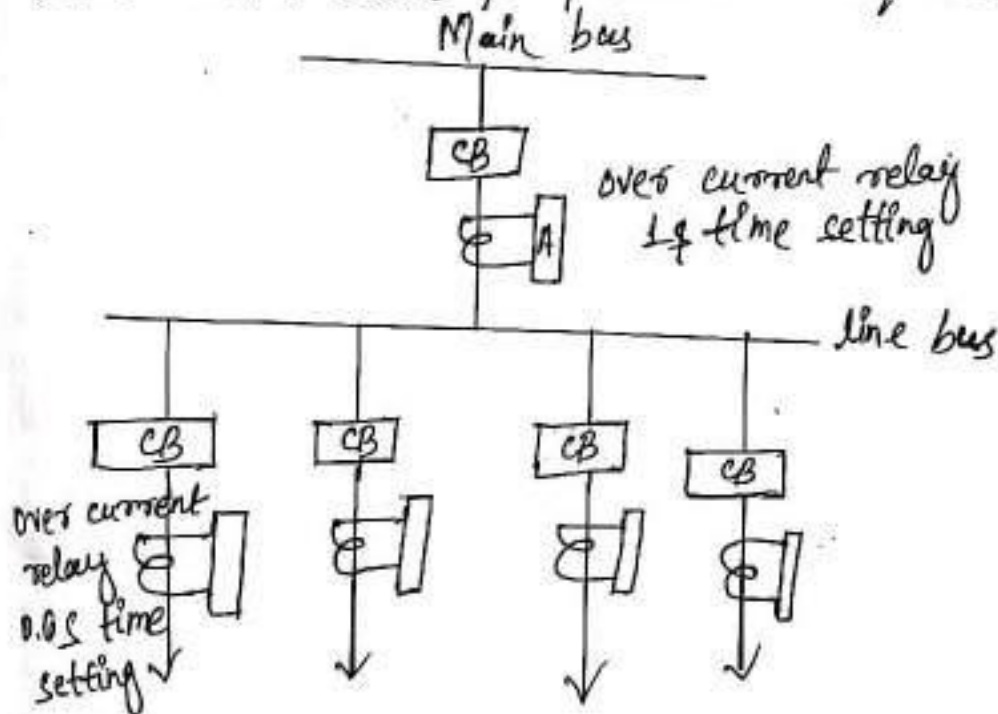
* Primary Protection :-

→ It is the protection scheme which is design 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 breakers. 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. backup protection required.



Backup Protection :-

- It is the second line defence in case of failure of the primary protection.
- It is design 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 breakers, the relay 'A' will operate after a definite time delay and clear the fault.

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// equipment and lines }

→ The electric power system consist of several equipments & these are alternator, t/b, busbar, transmission line & other equipments.

→ It is desirable & necessary to protect each element from a variety of fault conditions.

* Protection of t/b:- The t/b are the static device and totally enclosed and generally oil immersed. There is a chance of fault occurring on them. So, there is necessity to provide the adequate automatic protection for t/b against any possible fault.

→ Common t/b fault:- The power t/b may suffer from:-

→ open ckt, over heating and short ckt etc.

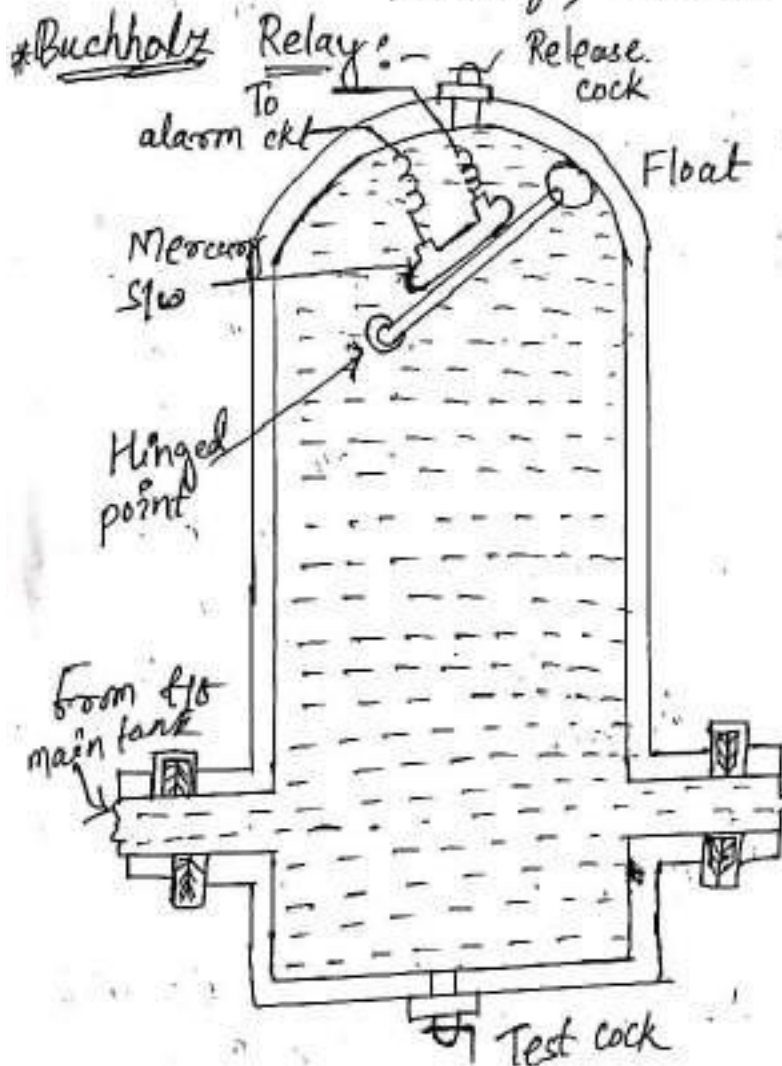
→ An open ckt in 1 ϕ or a 3 ϕ t/b may cause undesirable heating. On the occurrence of such fault the t/b can be disconnected manually from the system.

→ The short ckt on the t/b arise (come) from deterioration (loss) of insulation due to over heating. When an internal fault occurs the t/b must be disconnected quickly from the system. ∴ the relay protection is necessary for internal fault.

→ Protection system for t/b:- The principle relays and systems used for t/b protection are;
→ Earth fault relay (providing the protection against arc fault only)

- ↳ Over I relay - (Providing the protection against phase to phase fault & over loading)
- ↳ 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 of the wind, core heating, fall of oil level.)

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➤ This relay is a gas actuated relay installed in ~~the~~ oil immersed t/b 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 t/b and it can be disconn^d from the t/b in the event of severe internal fault.

- It is usually installed in the pipe connecting to the conservator to main tank.
- The buchholz relay is used in the oil immersed t/f having the rating an exceeds 450 KV.

* Construction:-

- It takes the form of a domed vessel placed in the connecting pipe betn the main tank & conservator.
- It has 2 elements. The upper element consist of a mercury type SW attached to a float.
- The lower element contain a mercury switch mounted on a hinge type flap located in the direct path of the flow of oil from the t/f to the conservator tank.
- The upper element closes an alarm ckt during the slow developing slot where as the lower element is arrang 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 70% of the Hydrogen-gas.

- The H₂-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 sw attached to it. This complete the alarm ckt to sound an alarm.

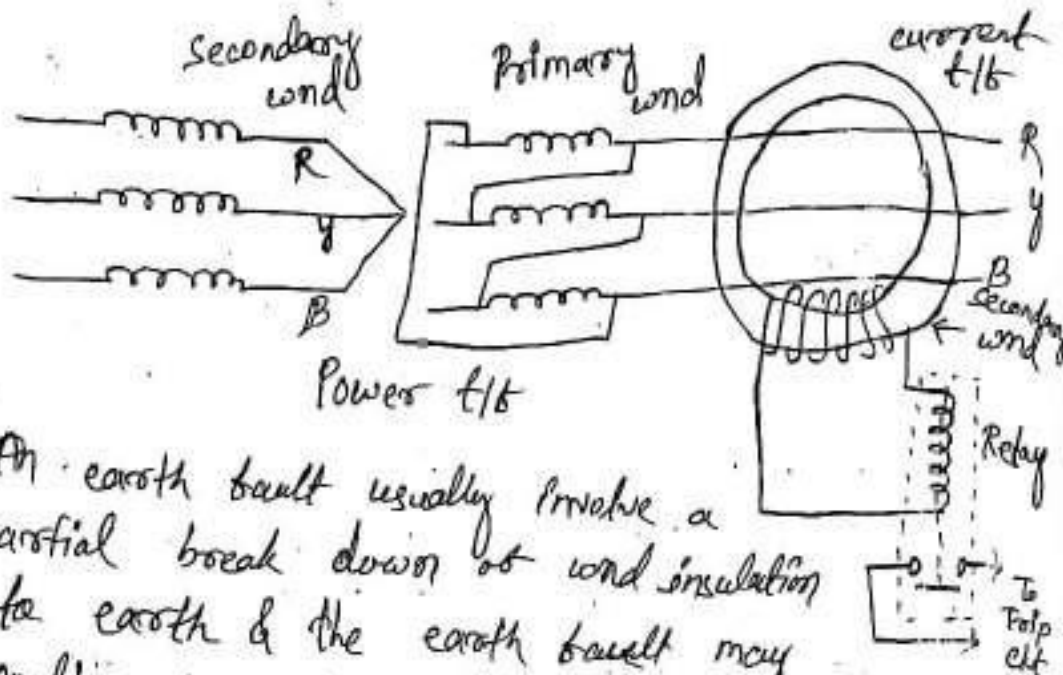
If a severe fault occurs in the t/b an enormous ^{high} amount of gas is generated in or main tank, & the oil in the main tank rushes towards the conservator via the buchholts relay and in doing so tilt the flap to close the contact of mercury sw. This complete the trip ckt to open the ckt breakers which controlling the t/b.

* Advantage :- 1. It is the simplest form of t/b protection.
2. It detect incipient (slow developing) fault at a stage much earlier than other form of protection.

- Disadvantage :-
1. It can only used with oil immersed t/b equipped with conservator tank.
2. The device can detect only fault below oil level in the t/b.

* Earth fault or leakage protection :-

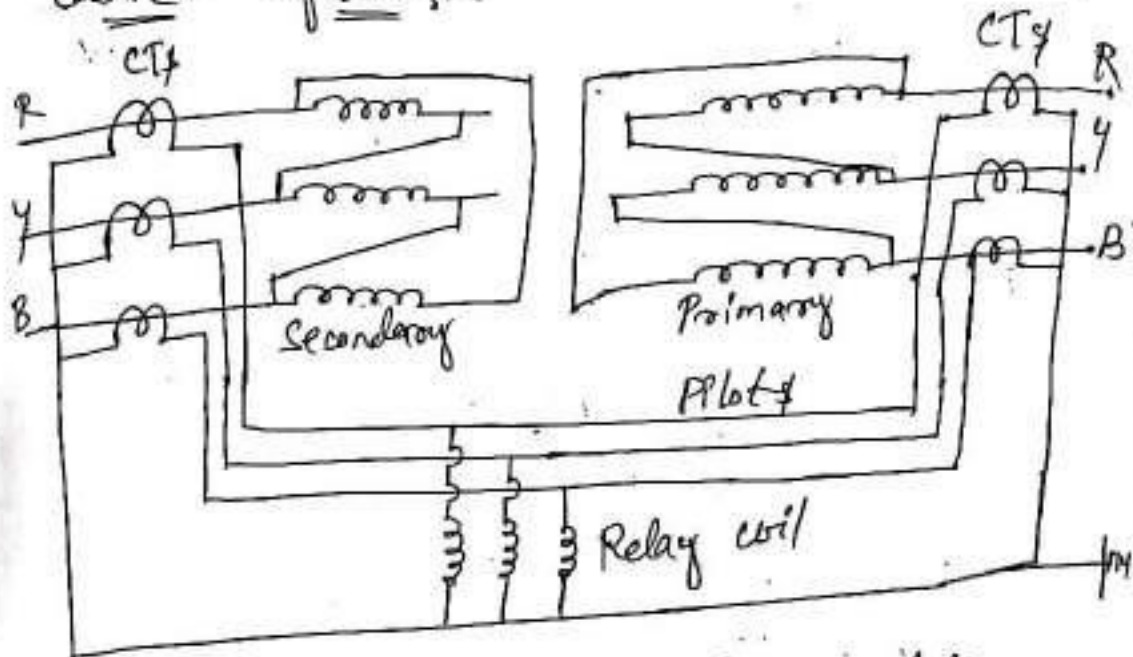
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- An earth fault usually involve a partial break down of wind insulation to earth & the earth fault may continue for a long time & cause considerable damage before it develop the short ckt & remove from the system.
- Under this case it is profitable to employ earth fault relay in order to ensure the disconn of 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 t/t.
- In this method the 3 lead of primary wmd of the power t/t are taken through the core of a current t/t.
- The operating coil of the relay is conn to the secondary wmd of the current t/t.
- Under normal condⁿ the vector sum of the 3 ϕ current is zero. & there is no resulting flux in the core of the current t/t.
 \therefore no current flows through the relay & it remains inoperative.

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

* Differential protection system or circulating current system :-



→ The fig. shows the more precise circulating current scheme. For the protection of a 3 ϕ delta-delta t/b against phase to ground & ϕ to ϕ faults.

→ The CTs on the 2 sides of the t/b are connected in star this compensates for the ϕ difference between the power t/b primary & secondary.

→ The CTs on the 2 sides are connected by pilot wires & one relay is used for each pair of CT. During the normal op. condⁿ the secondary of CTs carry identical current.

∴ The current entering & leaving the pilot wires at both ends are same & no.

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

* 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:-

i) Failure of Prime-movers
ii) Failure of field winding

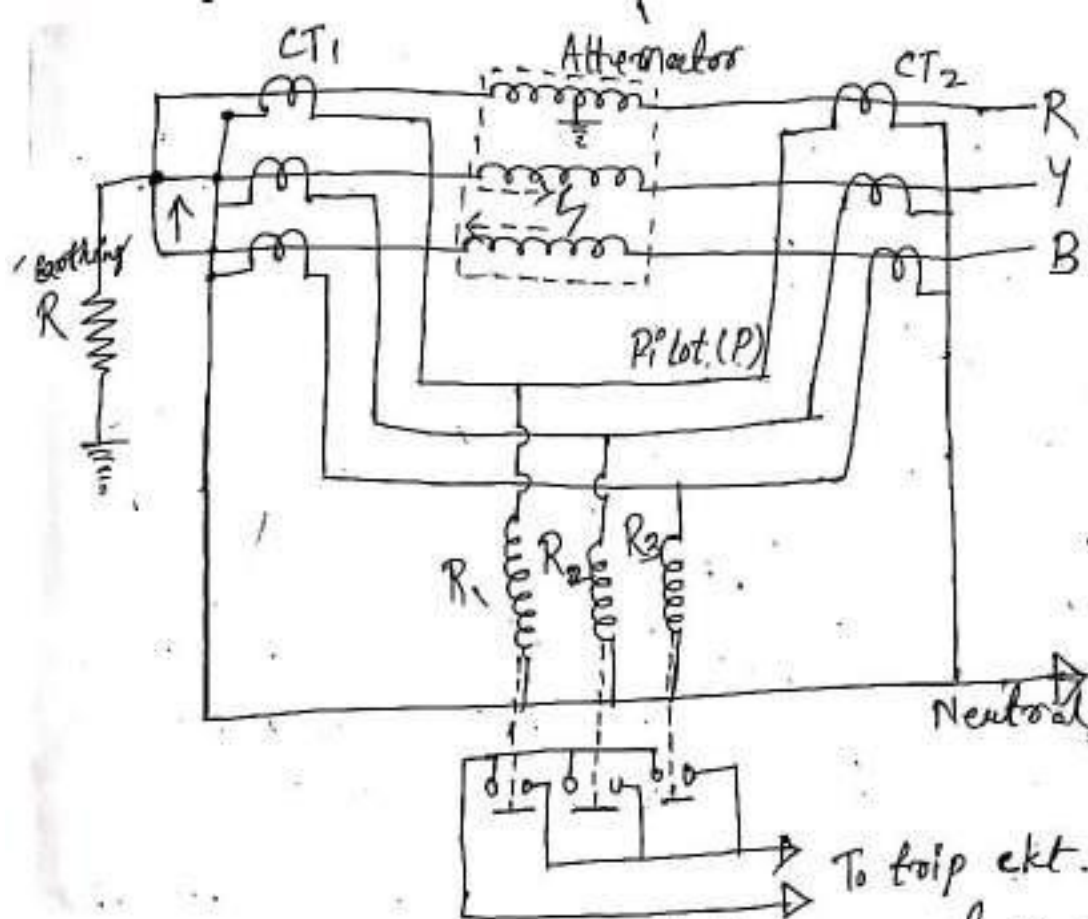
iii) Over current
iv) Over speed
v) Over voltage
vi) Unbalanced loading
vii) Stator wind fault.

→ The stator wind fault 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 alternator against such fault, differential protection also known as mho-protection system is most commonly employed.

→ Differential protection of Alternator:- Dt-13/03/2

→ 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 differential 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-price circulating current scheme.

* Schematic arrangement:

The fig. shows the schematic arrangement of differential protection for a 3 ϕ alternator.
 → Here the identical current t/t placed CT₁ & CT₂ are placed on either side of each phase of the stator winding.

- The secondary wind of each set of CT are conn in stars and the two neutral points & the corresponding terminal of the 2 stars 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 stars the neutral point being conn to the CT common neutral & the outer ends are connected each to the 3 pilot wire.
- The relays are conn across the equip-potential point of the 3 pilot wire & these points are naturally located at the middle of the pilot wire.
- * Operation:- Under the normal operating condn the current at both end of each wind 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^s 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 affected phase (R) will flow through the core & frame of the m/c to earth.

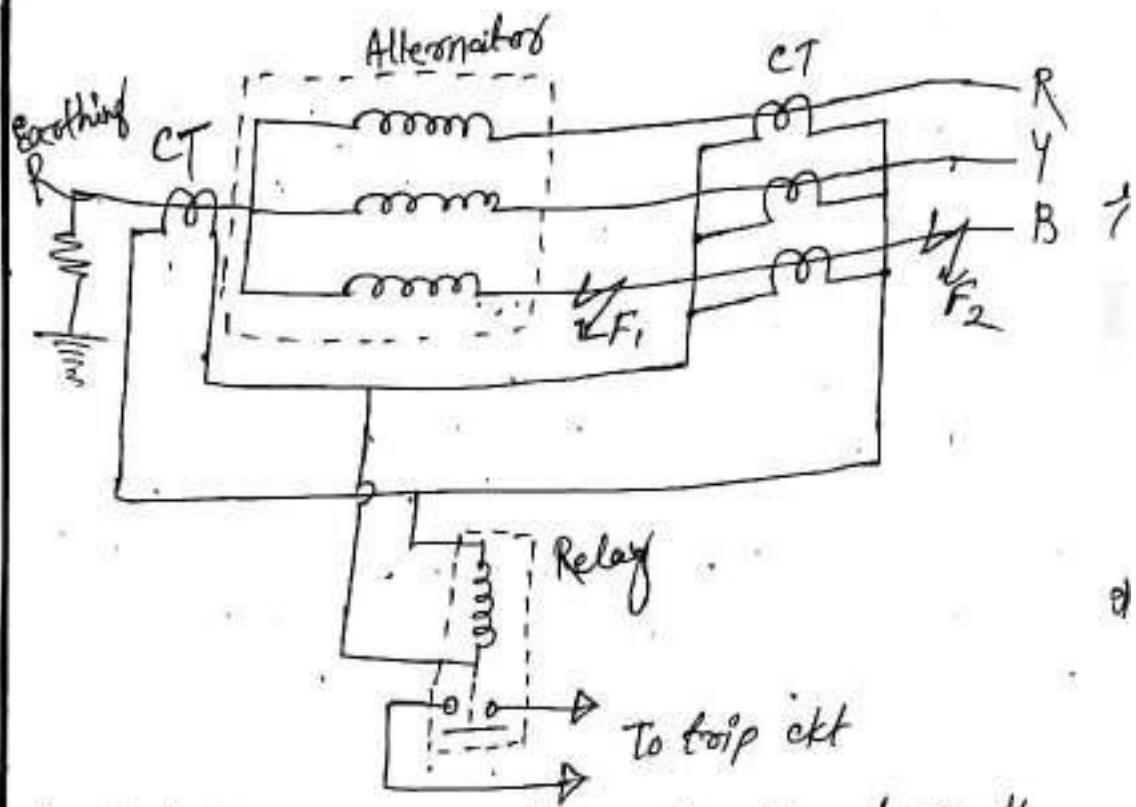
* Then the ckt. being completed through the neutral earthing R. The I in the secondary of the CT in phase R will become unequal and the difference of the 2 currents will flow through the corresponding relay coil (R_1) & then the relay operated to trip the ckt breakers.

* Suppose now a short ckt fault occurs betw 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 CT in each affected phase (Y & B) will become unequal & the diff I will flow through the operating coils of the relays (R_2 & R_3) conn in these phase. Their relay close the contact of trip coil to close the ckt breaker.

* Balanced earth fault protection system:-

In small size alternator the neutral of the 3 ϕ wind are conn internally for a single terminal, \therefore it is not possible to use the zero-sequence circulating I system, but 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 ϕ alternator.

* It consists of 3 line CT, one mounted in each phase having their secondary connⁿ in || with the single CT in the conductor joining the star point of the alternator to earth.

→ A relay is connⁿ 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 CT will be zero and no I flows through 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 conn. & hence no current flows through the relay.

→ When a earth fault occurs in F_1 or within the protected zone, these current will no longer be equal & the differential I flows through the operating coil of the relay & the relay then close its contacts to disconnect the alternator from the system.

* Protection of busbars :-

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

→ The busbars in the generating station & substation form an imp. link betⁿ 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^s equipments conn^d to that section must be trip to give the complete isolation.

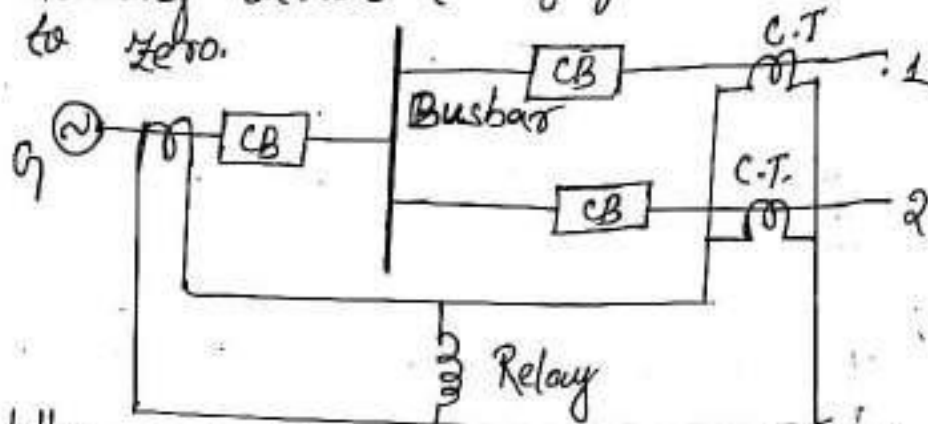
→ There are 2 most commonly used methods for the busbar protection are :-

(a) Differential protection

(b) Fault bus

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

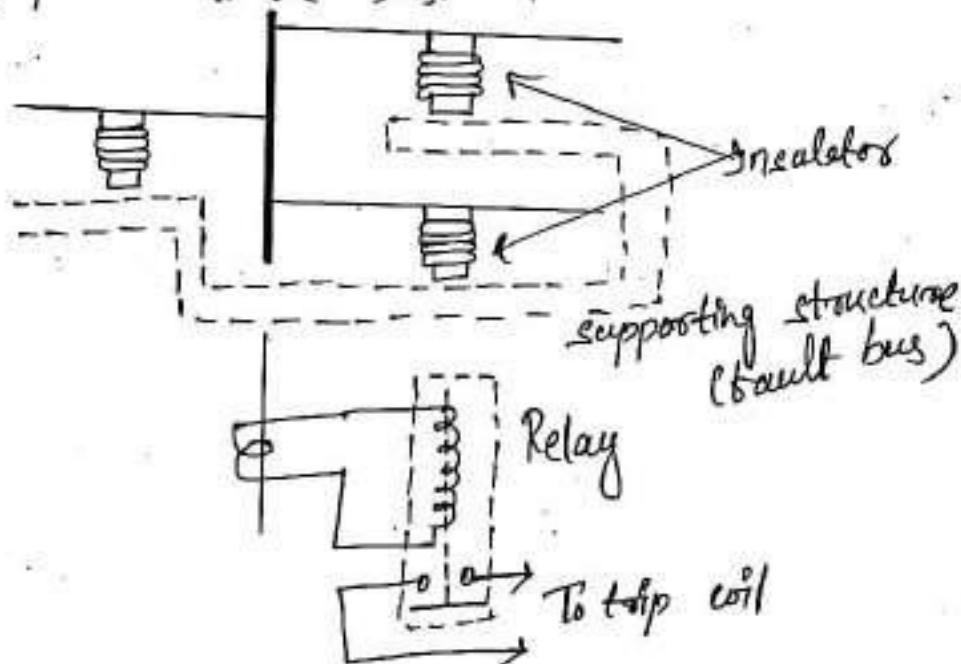
- In this scheme the current entering & leaving the bus are totalised.
- During normal operating condition the sum of incoming current & outgoing currents is equal to zero.



- 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 generator and supplies load to two lines.
- The secondaries of CT in generator load, line 1 & line 2 are conn^d in parallel.
- The protective relay is connected across this parallel connection.
- Under normal condⁿ the sum of the currents 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 directing 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 betⁿ a conductor & earthed supporting structure will result in current flow to ground through the fault bus which causes the relay to operate.
- The op. 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 condⁿ the current entering one end of a line is equal to that leaving the other.

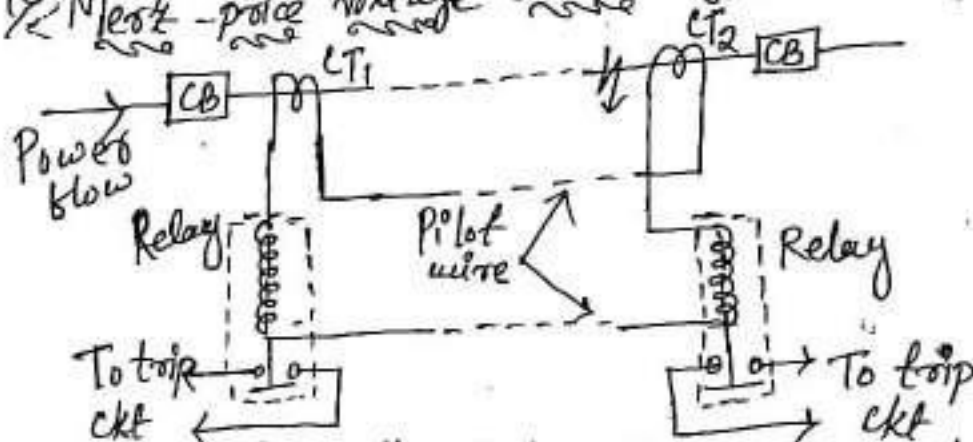
* But when fault occurs betⁿ the 2 ends, the diffⁿ betⁿ incoming & outgoing current flow through the relay which operate the ckt breaker to isolate the faulty line.

* There are 2 types of differential protection scheme

1) Meryz-price voltage balance system.

2) Transly scheme.

1) Meryz-price voltage balance system:-



* The fig. shows the single line diagram of meryz-price voltage balance system for the protection of a 3 ϕ line.

* Identical current tlbz are placed in each phase at both ends of the line.

* The pairs of CTz in each line is connected in series with a relay in such a way that under normal condⁿ 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.

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

* Advantage:-

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

* Disadvantage:-

- i) Accurate matching of current t/b is very essential.
- ii) If there is a break in the pilot wire ckt the system will not operate.
- iii) This system is very expensive.
- iv) This system can't be used for line voltage beyond 33KV because of constructional difficulties in matching the current transformers.

ch-8

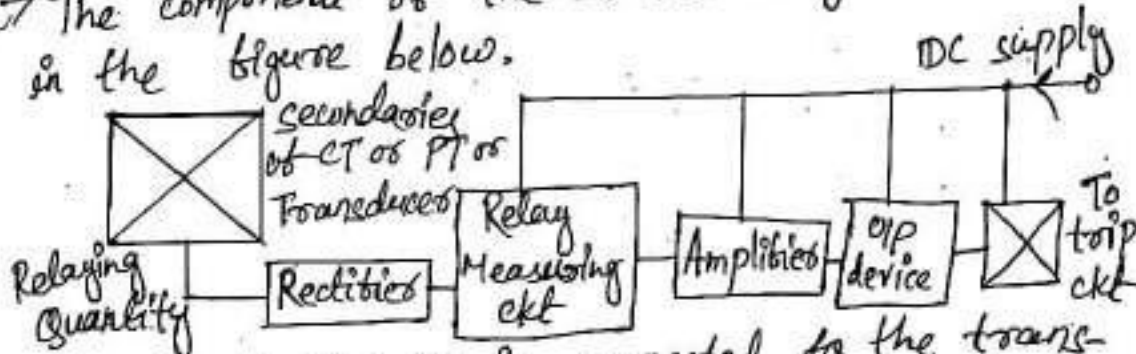
Static Relay

* 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 consists static & electromagnetic relay also called as static relay because the static unit obtains the response & the electromagnetic relay is only used for switching ops.

→ The components of the static relay are shown in the figure below.



→ The i/p of the CT is connected to the transducer, and their o/p is given to the rectifier.

→ The rectifier was rectifying the i/p signal & pass it to the relaying measuring unit.

→ The rectifying measuring unit has the comparators level detector & logic circuits.

→ 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 amplifier.

→ The amplifier amplifies the signal & gives the o/p to the o/p device.

→ The o/p device activates 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 signal.

→ 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 electronic 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 & 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 as the current in the coil gets higher than the preset current.

PROTECTION AGAINST OVER VOLTAGE AND LIGHTENING

Voltage surge

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

Cause of over voltage

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

- i) Internal cause
- ii) External cause.

Internal cause

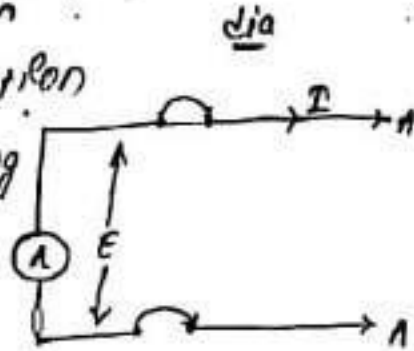
- > The internal cause do not produce surge of large magnitude.
- > The surge due to internal cause increase the system voltage to above normal voltage.
- > The internal cause of over voltage on the power system can be produce by the suddenly change in ckt condition.

Switching surge

The over voltage produce on the power system due to switching operation are known as switching surge.

a) Increase of unloaded line :-

- > During the switching operation of unloaded line travelling 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 is set up which travel along the line.
- > on reaching the terminal point 'A' it is reflected back to the supply with out change of its 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 air blast cut breaker, the powerful deionization effect of air blast 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 ckt equal to capacitive reactance.
- > Under resonance condⁿ the impedance of the ckt is equal resistance of the ckt & power factor is unity 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 centres 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 spot that 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 up rush 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 drops become 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.

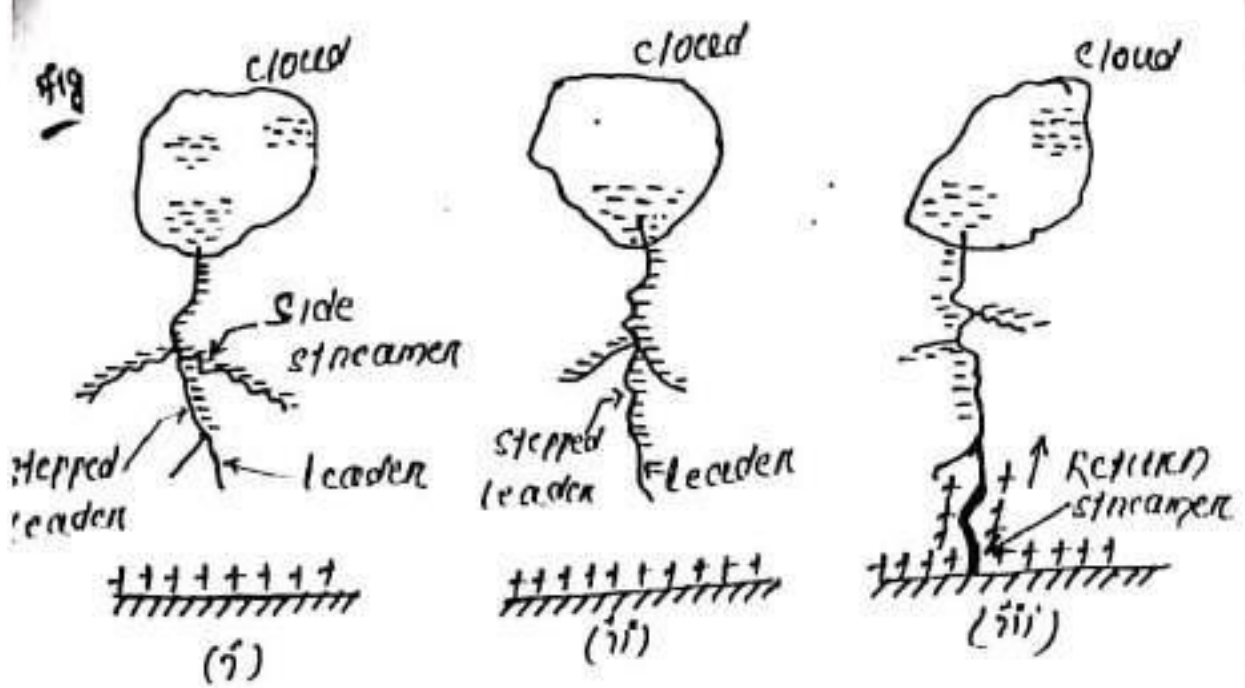
Mechanism of lightning discharge :-

→ 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 betⁿ cloud & earth increases and therefore potential gradient in the air increases.

→ When the potential gradient is sufficient (5 kV/cm to 10 kV/cm) to break down the surrounding air the lightning stroke starts.



Types of lightning stroke II-

There are two main ways in which a lightning strike the power system, these are

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

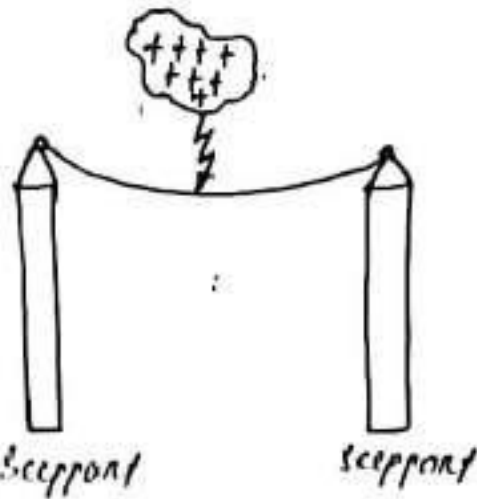
Direct stroke

In the direct lightning strokes, the cloud attains 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 ionize the neighbouring air, the air breaks down and discharge takes place between the cloud and the object.

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

Fig

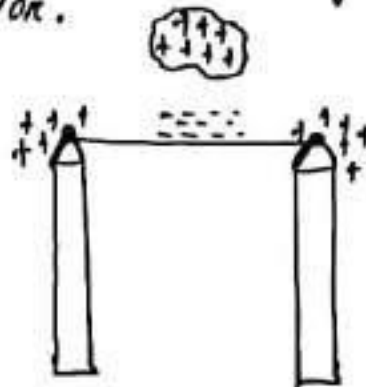


Indirect strokes II-

Indirect strokes result from the electrostatically induced charges on the conductors due to the presence of charged clouds.

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

Fig



Harmful effect of lightning :-

- A direct or indirect lightning stroke on a transmission line produces a steep-fronted (rise & fall sharply) voltage wave on the line
- > The voltage of this wave may rise from zero to peak value (about 2000kV) in $1\mu s$ & 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, this 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 device 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 the normal line voltage can't enough to cause an arc.
- > The property of the non-linear resistance is that its resistance decrease & voltage increase vice versa.
- > Under normal condⁿ 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
- horn-gap arrester
- multi-gap arrester
- Expulsion type arrester
- Valve type arrester

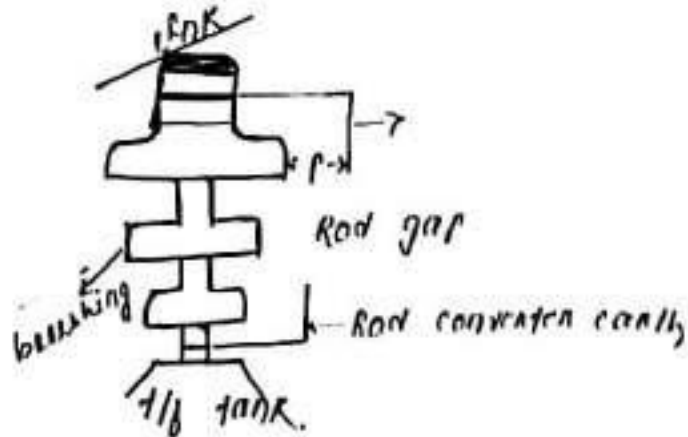
i) Rod-gap Arrester

- > It is very simple type of diverter & it consists of two 1.5 cm rod which are send at

right angle with a gap in betⁿ them.

- > one rod is connected to the line cat & the other rod is connected to earth.
- > under normal operating condition the gap remains non-conducting, on the occurrence of a high voltage on one of the rods the surge current is conducting to the earth in its way the excess charge on the line harmlessly conducted to the earth.

fig



Limitation 1-

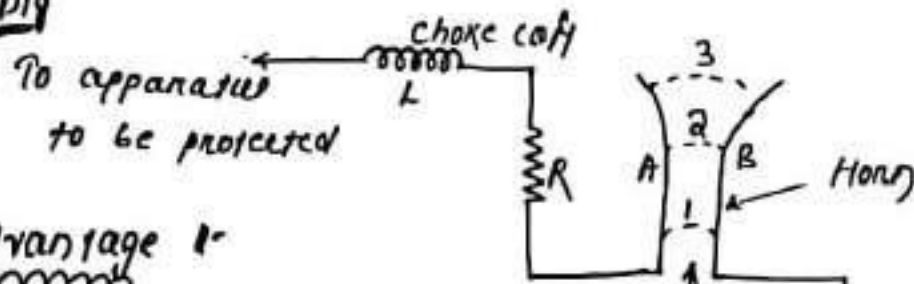
- > After the surge is over the arc in the gap of rods trapped by normal supply voltage which is large to short ckt on system.
- > The rod may melt or get damaged due to excessive heat produced by the arc.
- > The arcing condⁿ effect the performance of rod gap lightning arrester.
- > Due to the above limitation the rod gap arrester is only used as a backup protection 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 betⁿ the two horns gradually incre-
ased 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 condⁿ the gap is non-conducting i.e the normal
is insufficient to produce the gap betⁿ horns.
- > On the occurrence of overvoltage an arc is produced betⁿ the horns.
- > The arc moves progressively into the position 1, 2, 3.
- > At the position 3 the distance betⁿ the horns too large for the voltage to maintain, the earth so the arc is extinguish.

Fig



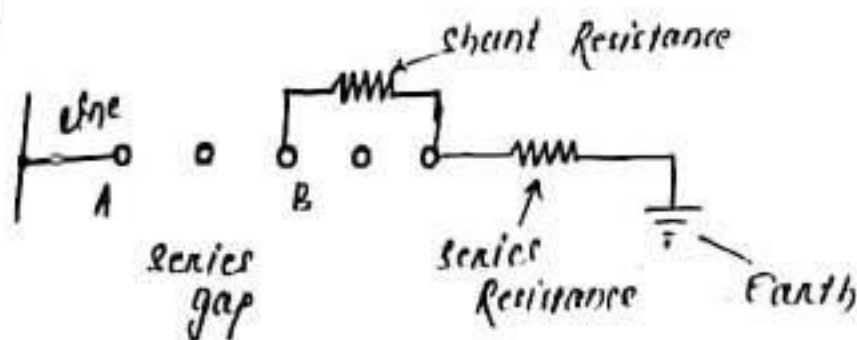
Advantage :-

- > The arc is self cleaning therefore this type of arrester does not cause short ckt after the surge is
- > 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.

Multi gap Arrester

- It consist of a series of metallic cylinders insulated from one another & separated by small interval 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 condⁿ the normal supply voltage is unable to breakdown the gaps.
- On the occurrence of over voltage the breakdown of the gaps letⁿ 'I_zP' occurs
- The heavy current after breakdown will flow to the earth through the gap letⁿ 'I_{gc}'
- When the surge is over the arc letⁿ the 'B_{tor}' goes out & any current flowing through the circuit can be limited by the two resistance.
- This arrester can be employed where the system voltage does not exceed 32 kV.

Dia



Valve type Arrester

- Valve type arrester use the non-linear resistor
- It consist 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 a no. of identical spark gap in series each gap consist of two electrode with a fixed gap.

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

→ The non-linear resistor 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 condⁿ the system voltage is in sufficient to cause the breakdown of air gap

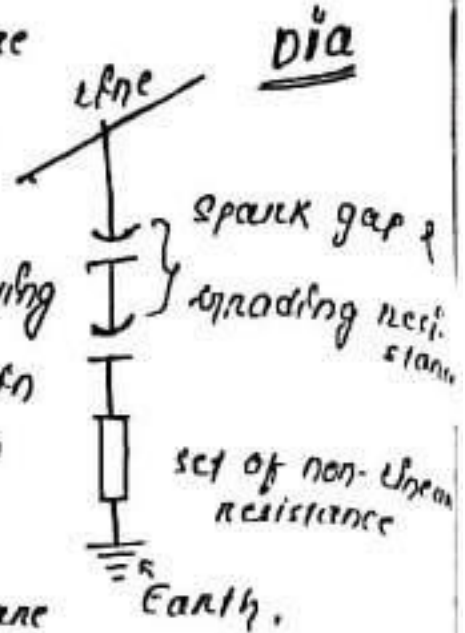
→ On occurrence of over voltage an arc is produced & the surge current conducted to earth through the non-linear resistance.

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

Advantage:-

→ It provide very effective protection against the surge

→ It operate very rapidly taking less than 1 sec.



Dis-Advantages :-

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

Application :-

- > This type of arrester are generally use for the protection of important equipment in power station operating on the voltage upto 220 kV or higher.

Surge Absorber.

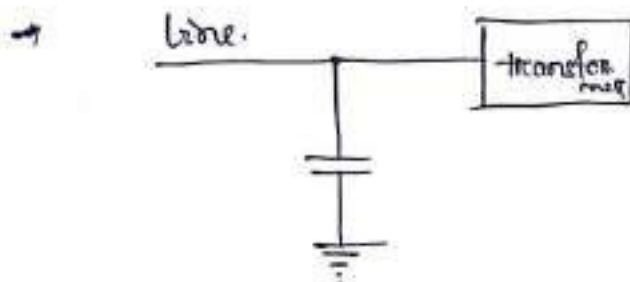
→ The travelling waves set up on the transmission lines by the surge may reach the terminals of the apparatus and cause damage to it.

→ To reduce it we use surge absorbers.

→ 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.

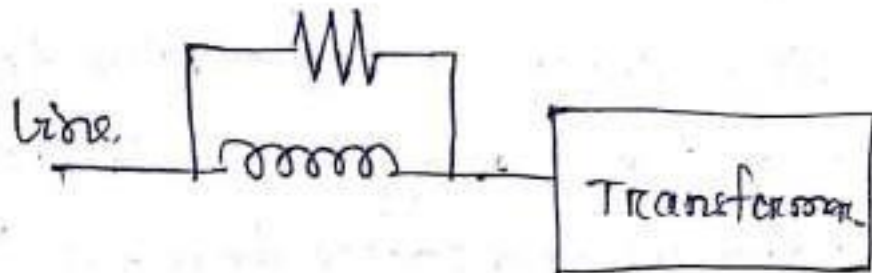
→ The figure shows a capacitor act as a surge absorber, to protect the transformer winding.



→ Since the reactance 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.

