SWITCHGEAR:-

The device used for switching, controlling, regulating and protecting the electrical circuits and equipments is known as switchgear.

Essential Features of Switchgear:-

i) Complete reliability.
ii) Absolutely certain discrimination.
iii) Quick operation.
iv) Provision for manual control.
v) Provision for instruments.

Switchgear Equipment:-

The equipment associated with switching and interrupting currents under both normal and abnormal conditions, includes switches, fuses, circuit breakers, relays, CT, PT and other equipment.

1. Switches:-

→ A switch is a device which is used to open or close an electrical circuit under full load or no-load conditions but it cannot interrupt the fault currents.

→ The switches may be classified into
i) Air switches
ii) Oil switches.

→ The contacts of air switches are opened in air and that of the oil switches are opened in oil.

i) Air-break switch :- It is an air switch and is designed to open a circuit under load. It is used outdoor for circuits of medium capacity such as lines supplying an industrial load from a main transmission line or feeder.

ii) Isolator or disconnecting switch :- It is essentially a knife switch and is designed to open a circuit under no load. Its main purpose is to isolate one portion of the circuit from the other and is not intended to be opened while current is flowing in line. It is generally used on both sides of circuit breakers for repairs and replacement of CB.

iii) Oil Switches :- Here the contacts of such switches are opened under oil, usually transformer oil. These switches are used for circuits of high voltage and large current carrying capacities.

2. Fuses :-

A fuse is a short piece of wire or thin strip which melts when excessive current flows through it for sufficient time of it is inserted in series with the circuit to be protected. A fuse performs both detection and interruption functions.

3. Circuit breakers :-

A circuit breaker is a device which can open or close a circuit under all conditions i.e. no load, full load and fault conditions. It is also designed to be operated manually under normal conditions. automatically.

4. Relays:-

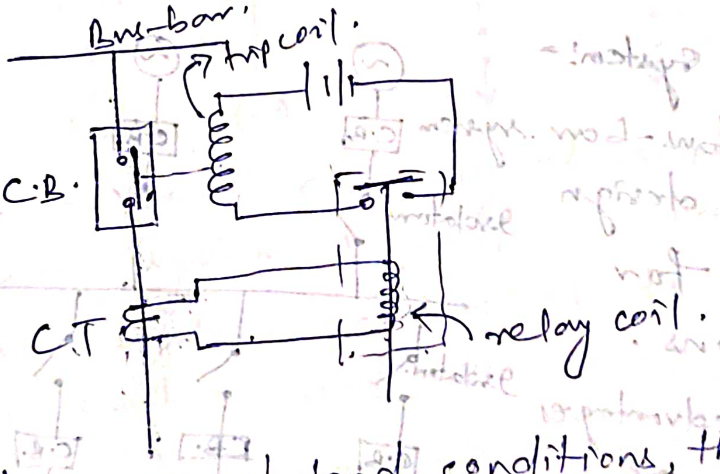
A relay is a device which detects the fault and supplies information to the breaker for circuit interruption.

It can be divided into three parts.

i) The primary winding of CT which is connected in series with the circuit to be protected. The primary winding often consists of the main conductor itself.

ii) The second circuit is the secondary winding of CT connected to the relay operating coil.

iii) The third circuit is the tripping circuit which consists of a source of supply, trip coil of CB and the relay stationary contacts.



→ Under normal load conditions, the e.m.f. of the secondary winding of C.T. is small and the current flowing in the relay operating coil is insufficient to close the relay contacts. This keeps the trip coil of the circuit breaker un-energised. Consequently, the contacts of the circuit breaker remain closed and it carries the normal load current. When a fault occurs, a large current flows through the primary of C.T. This increases the secondary emf and hence the current through the relay operating coil. The relay contacts are closed and the trip coil of the circuit breaker is energised to open the contacts of the circuit breaker.

Bus-bar Arrangements:-

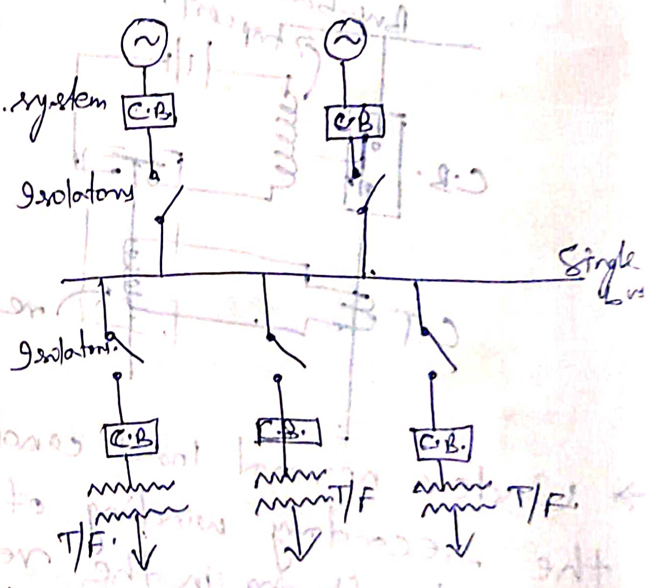
→ Bus-bars are copper rods and operate at constant voltage. When a number of generators or feeders operating at the same voltage have to be directly connected electrically, bus-bars are used as the common electrical component.

→ Some important bus-bars arrangements used for power stations and sub-stations are

1. Single bus-bar system:-

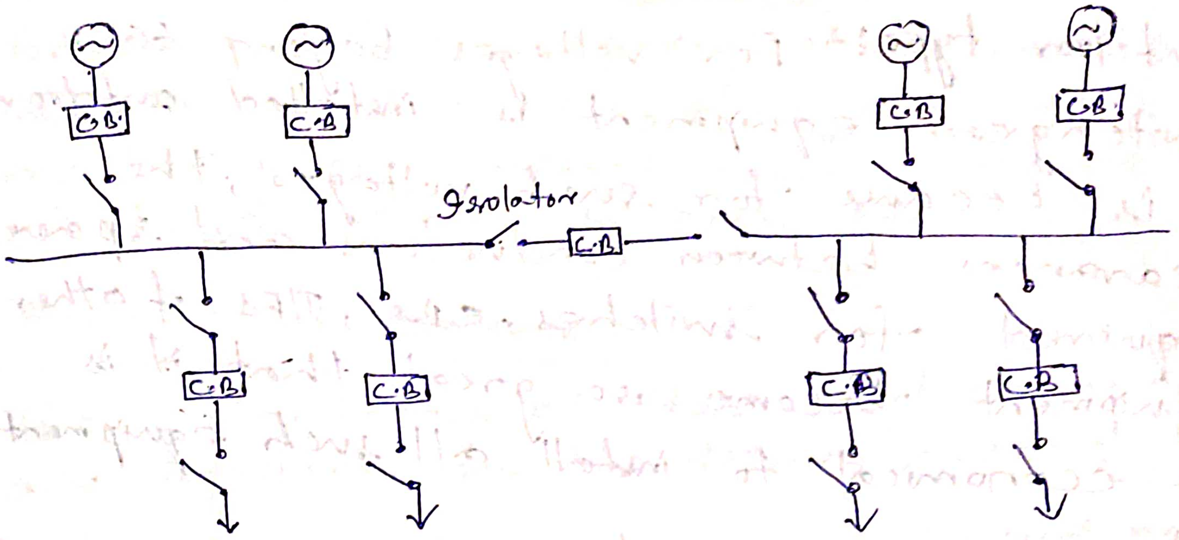
The single bus-bar system is simple in design and is used for power stations.

The chief advantages of this type of arrangement are low initial cost; less maintenance & simple operation.

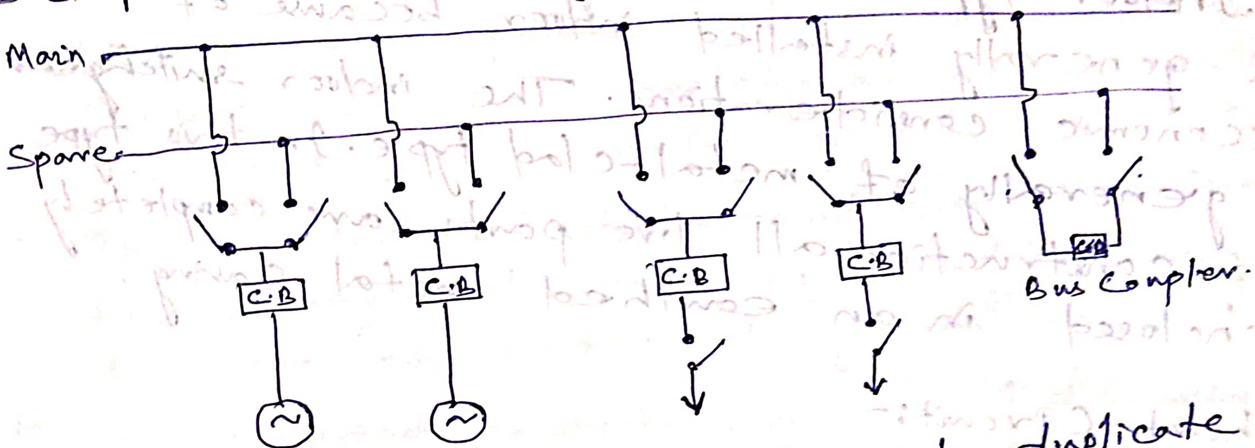


2. Single bus-bar system with sectionalisation:-

In large generating stations where several units are installed, it is a common practice to sectionalise the bus so that fault on any section of the bus-bar will not cause complete shut down.



3. Duplicate bus-bar System:-



→ To achieve continuity of supply, duplicate bus-bar system is used in important stations. This system consists of two bus-bars, 'main bus-bar' and spare bus-bar.

* Bus Coupler is a device which is used to switch from one bus to other without any interruption in power supply & without creating hazardous arcs.

Switchgear Accommodation:-

→ It is necessary to house the switchgear in power stations and sub-stations in such a way so as to safeguard personnel during operation and maintenance.

→ Depending upon the voltage to be handled, switchgear may be broadly classified into

i) Outdoor type.

ii) Indoor type.

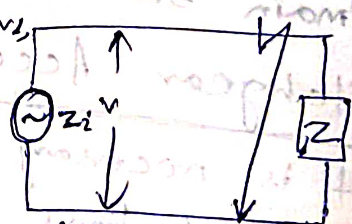
i) Outdoor type:- For voltages beyond 66KV, switchgear equipment is installed outdoor. It is because for such voltages, the clearances between conductors and space required for switches, CBs, T/Fs & other equipment become so great that it is not economical to install all such equipment indoor.

ii) Indoor type:- For voltages below 66KV, switchgear is generally installed indoor because of economic considerations. The indoor switchgear is generally of metal-clad type. In this type of construction, all live parts are completely enclosed in an earthed metal casing.

Short-Circuit:-

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

→ When a short-circuit occurs, the voltage at fault point is reduced to zero and current of abnormally high magnitude flows through the network to the point of fault.



Causes:-

It may be caused due to internal or external effects.

i) Internal effects are caused by breakdown of equipment or transmission lines, ageing of insulation in a generator, transformer etc

ii) External effects causing short circuit include insulation failure due to lightning surges, overloading of equipment causing excessive heating, mechanical damage by public etc.

Short-circuit Currents:-

The calculations of these short-circuit currents are important for the following reasons:

i) The CB or fuse clear a short-circuit on the power system. Hence it is necessary to know the maximum possible values of short-circuit current so that switchgear of suitable rating may be installed to interrupt them.

ii) The magnitude of short-circuit current determines the setting and sometimes the types and location of protective system.

iii) The magnitude of short-circuit current determines the size of the protective reactors which must be inserted in the system so that the circuit breaker is able to withstand the fault current.

iv) The calculation of short-circuit currents enables us to make proper selection of the associated apparatus (e.g. bus bars, CTs etc) so that they can withstand the forces that arise due to occurrence of short circuits.

Faults in a Power System:-

A fault occurs when two or more conductors come in contact with each other. These faults may be caused by sudden failure of equipment, short-circuit to overhead lines or by insulation failure resulting from lightning surges.

→ The faults in a 3-phase system can be classified into two main categories.

i) Symmetrical faults.

ii) Unsymmetrical faults.

i) Symmetrical faults:-

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

Ex:- When all the three conductors of a 3-phase line are brought together simultaneously into a short-circuit condition.

ii) Unsymmetrical faults:-

The fault which gives rise to unsymmetrical currents (i.e. unequal line currents with unequal displacement) are called unsymmetrical faults.

The unsymmetrical faults may take one of the following forms:

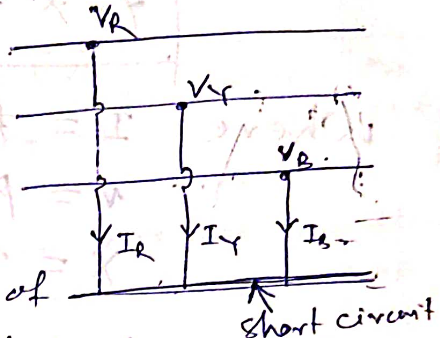
a) Single-line-to ground fault (L-G).

b) Line-to-line fault (L-L)

c) Double line-to-ground fault (L-L-G).

Symmetrical Faults on 3-phase System:-

→ The fault on the power system which gives rise to symmetrical fault currents (i.e. equal fault currents in the lines with 120° displacement) is called a symmetrical fault.



→ Fault currents I_R, I_Y and I_B will be equal in magnitude with 120° displacement among them.

→ Because of balanced nature of fault, only one phase need be considered in calculations since condition in the other two phases will also be similar.

Limitation of Fault Current:-

→ When a fault occurs on the feeder at point F, then the short circuit current from the generating station will have a value limited by the impedance of generator and transformer and the impedance of the line between the generator and the point of fault.

→ Cables and lines are mostly resistive, but in calculations except where the total reactance 3 times the resistance, so resistance is neglect

Percentage Reactance:-

The reactance of generators, transformer, reactors etc. is usually expressed in percentage reactance to permit rapid short circuit calculations.

→ The percentage reactance of a circuit is the percentage of the total phase-voltage dropped in the circuit when full-load current is flowing i.e.

$$\% X = \frac{IX}{V} \times 100 \quad \text{--- (1)}$$

Where I = full-load current.
V = phase voltage.
X = reactance in ohms per phase.

→ Alternatively,

From eqn (1), $X = \frac{(\% X) V}{I \times 100}$

$$= \frac{(\% X) V \times V}{100 \times VI}$$

$$= \frac{(\% X)\left(\frac{V}{1000}\right) \times \left(\frac{V}{1000}\right) \times 1000}{100 \times \left(\frac{V}{1000}\right) \times I}$$

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

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

Percentage Reactance and Base KVA :-

→ From eqn-(2), it is clear that percentage reactance of an equipment depends upon its KVA rating. Generally, the various equipments used in the power system have different KVA ratings. So it is necessary to find the percentage reactances of all the elements on a common KVA rating. This common KVA rating is known as base KVA.

→ The conversion of percentage reactance at rated KVA to the percentage reactance at base KVA can be made by using the following expression:

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

Ex:- If a T/F is rated for 10,000 KVA and has % reactance of 7.5% then the % reactance at base KVA of 25,000 will be $= \frac{25,000}{10,000} \times 7.5\% = 18.75\%$.

Short-circuit KVA:-

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

Let V = normal phase voltage in volts
I = full-load current in amperes at base KVA
%X = % reactance of the system on base KVA upto the fault point.

→ If X is the only reactance element in the circuit, then short-circuit current is given by $I_{sc} = \frac{V}{X}$ ↗ putting value of X from eqn (i).

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

∴ Short-circuit KVA for 3-phase circuit

$$= \frac{3\,V I_{sc}}{1000} = \frac{3\,VI}{1000} \times \frac{100}{\%X}$$

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

Reactor Control of Short-Circuit Currents:-

→ In order to limit the short-circuit currents to a value which the circuit breakers can handle, additional reactances known as reactors are connected in series with the system at suitable points. A reactor is a coil of number of turns designed to have a large inductance as compared to its ohmic resistance.

→ Using reactors, troubles are also localised or isolated at the point where they originate without communicating their disturbing effects to other parts of the power system. This increases the chances of continuity of supply.

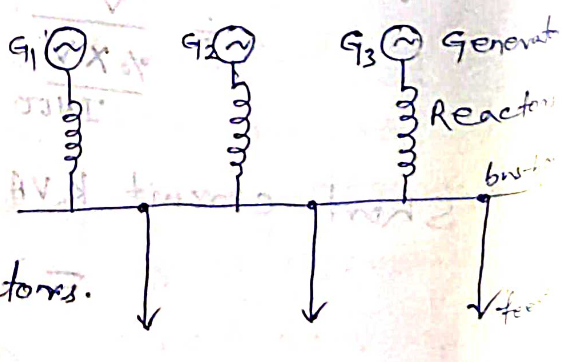
→ They also permit the installation of circuit breakers of lower rating.

Location of Reactors:-

→ Short circuit current limiting reactors may be connected i) in series with each generator.
ii) in series with each feeder.
iii) in bus-bars.

1) Generator reactors:-

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



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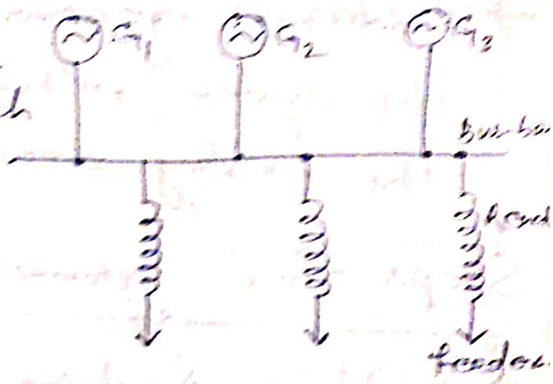
2) Feeder reactors:-

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



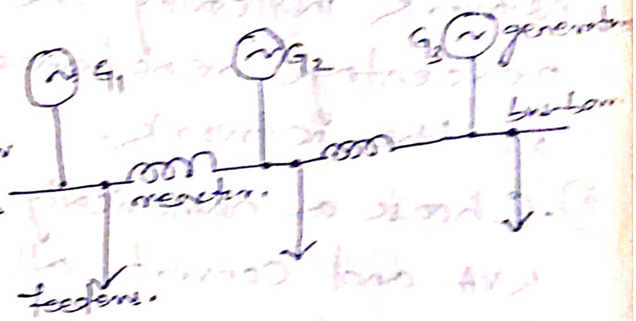
3) Bus-bar reactors:-

Due to voltage drop and power loss in the reactors even during normal operation, the reactors are located in the bus-bars.

There are two methods.

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

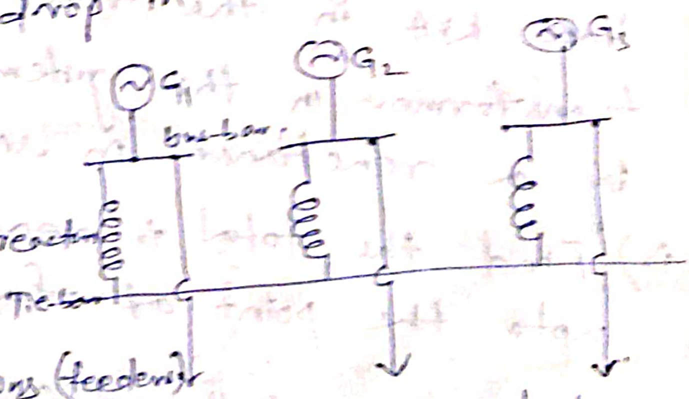
i) Ring system:-



→ In this system, bus-bar is divided into sections and these sections are connected through reactors.

→ Generally, one feeder is fed from one generator only. Under normal operating conditions, each generator will supply its own section of the load. This results in low power loss and voltage drop in the reactors.

ii) Tie-bar system:-



→ In tie-bar system, there are effectively two reactors in series between sections (feeders) so that reactors must have approximately half the reactance of those used in a comparable ring system.

→ Additional generators may be connected to the system without requiring changes in the existing reactors.

Steps for Symmetrical Fault calculations:-

→ Problems involving symmetrical faults can be solved by considering one phase only as the same conditions prevail in the other two phases. The steps are.

i) Draw a single line diagram of the complete network indicating the rating, voltage and percentage reactance of each element of the network.

ii). Choose a numerically convenient value of base KVA and convert all %. reactances to this base value.

iii). Corresponding to the single line diagram of the network, draw the reactance diagram showing one phase of the system and the neutral. Indicate the % reactances on the reactance diagram. The base KVA in the system should be represented by a transformer in the system should be represented by a reactances in series.

iv). Find the total % reactance of the network upto the point of fault. Let it be X%.

v) Find the full-load current corresponding to the selected base KVA and the normal system voltage at the fault point. Let it be I.

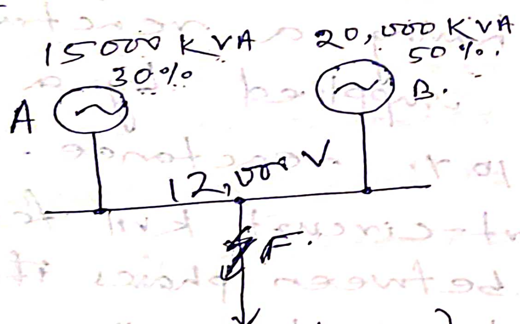
vi) Then various short-circuit calculations are:

short-circuit current, $I_{sc} = I \times \frac{100}{\%X}$

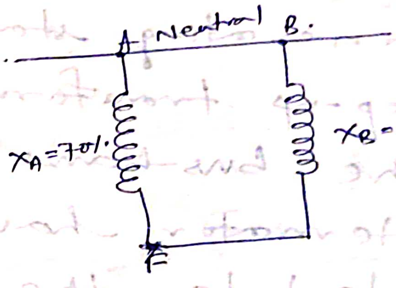
Short-circuit KVA = Base KVA $\times \frac{100}{\%X}$

Ex-4 The figure shows the single line diagram of a 3-phase system. The percentage reactance of each alternator is based on its own capacity. Find the short-circuit current that will flow into a complete 3-phase short-circuit at F.

Solution:-



(Single-line diagram)



(Reactance diagram) at 35,000 KVA

Let the base KVA be 35,000 KVA.

% reactance of alternator A at base KVA is.

$$\% X_A = \frac{35,000}{15,000} \times 30 = 70\%.$$

% reactance of alternator B at the base KVA is.

$$\% X_B = \frac{35,000}{20,000} \times 50 = 87.5\%.$$

Line Current corresponding to 35,000 KVA at 12 KV is

$$I = \frac{35,000 \times 10^3}{\sqrt{3} \times 12 \times 10^3} = 1684 \, A.$$

Total % reactance from generator neutral up to fault point is % $X = X_A \parallel X_B$

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

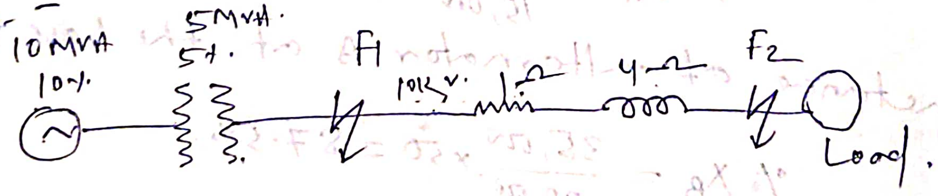
∴ Short-circuit Current, $I_{sc} = I \times \frac{100}{\%X}$

$= 1684 \times \frac{100}{38.89}$

$= 4330A$.

Ex-2. A 3-phase transmission line operating at 10kV and having a resistance of 1Ω and reactance of 4Ω is connected to the generating station bus-bars through 5MVA step-up transformer having a reactance of 5%. The bus-bars are supplied by a 10MVA alternator having 10% reactance. Calculate the short-circuit kVA fed to symmetrical fault between phases if it occurs i) at the load end of transmission line ii) at the high voltage terminals of the transformer.

Soln :-



Solution

Let 10,000 kVA be the base kVA.

% reactance of alternator on base kVA,

$\% X_A = \frac{10,000}{10 \times 10^3} \times 10 = 10\%$

% reactance of transformer on base kVA,

$\% X_T = \frac{10,000}{5 \times 10^3} \times 5 = 10\%$

The line impedance is given in ohms.

Converting into percentage impedances

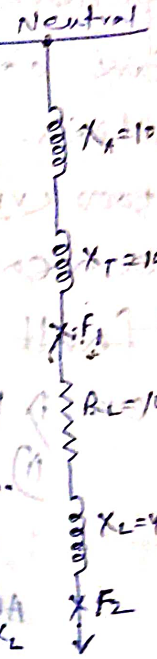
% reactance of transmission line is

$$\% X_L = \frac{(KVA) \times \text{reactance in } \Omega}{10 (KV)^2}$$

$$= \frac{10,000 \times 4}{10 (10)^2} = 40\%$$

% resistance of transmission line,

$$\% R_L = \frac{10,000 \times 1}{10 (10)^2} = 10\%$$



i) The reactance diagram of the network on the selected base KVA is shown.

For a fault at point F_2,

Total % reactance $= \% X_A + \% X_T + \% X_L$

$= 10 + 10 + 40 = 60\%$

% resistance $= 10\%$

∴ % impedance from generator neutral upto fault point F_2 $= \sqrt{60^2 + 10^2} = 60.83\%$

Short-circuit KVA $= 10,000 \times \frac{100}{60.83} = 16440$ KVA

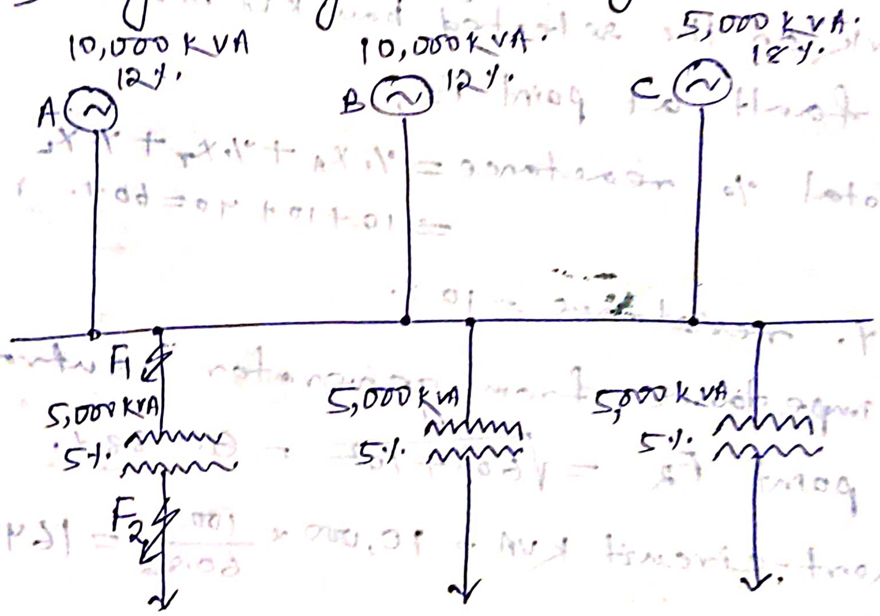
ii) For a fault at the high voltage terminals of the transformer (F_1).

Total % impedance from generator neutral upto fault point F_1

$= \% X_A + \% X_T = 10 + 10 = 20\%$

Short-circuit KVA $= 10,000 \times \frac{100}{20} = 50,000$ KVA

Ex-3 The plant capacity of a 3-phase generating station consists of two 10,000 kVA generators of reactance 12% each and one 5000 kVA generator of reactance 18%. The generators are connected to the station bus-bars from which load is taken through three 5000 kVA step-up transformers each having a reactance of 5%. Determine the maximum fault MVA which the circuit breakers on i) low voltage side ii) high voltage side may have to deal with



Soln:- Let 10,000 kVA be the base kVA.

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

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

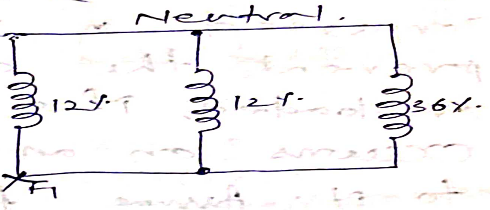
$\% X_B = 12 \times \frac{10,000}{10,000} = 12\%$

$\% X_C = 18 \times \frac{10,000}{5,000} = 36\%$

$\% X_T = 5 \times \frac{10,000}{5,000} = 10\%$

i) When the fault occurs on the low voltage side of the transformer (point F_1), the reactance diagram at the selected base KVA is shown in figure.

The total reactance upto the point of fault F_1 is the parallel combination of the reactances of the three alternators i.e.

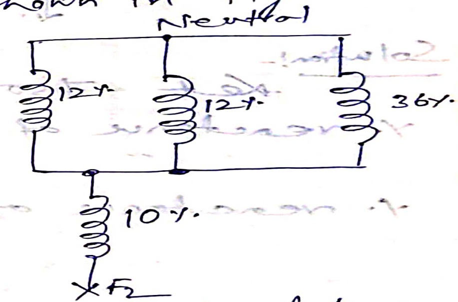


Total % reactance from generator neutral upto fault point F_1 $= \%X_A \parallel \%X_B \parallel \%X_C$

$$= \frac{1}{\frac{1}{12}+\frac{1}{12}+\frac{1}{36}} = 5.14\ \%$$

$$\text{Fault MVA} = 10,000 \times \frac{100}{5.14} \times \frac{1}{1000} = 194.5$$

ii) When the fault occurs on the high voltage side of the transformer (point F_2), the reactance diagram will as shown in figure.

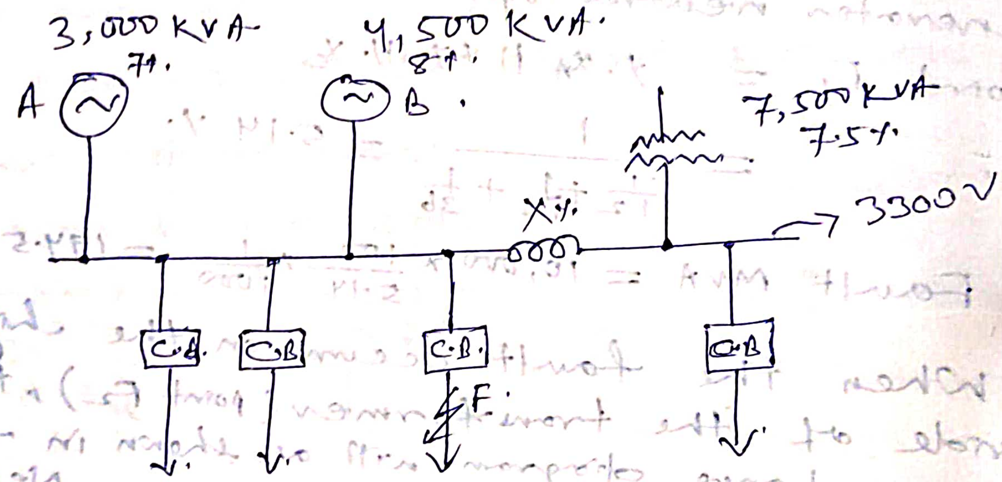


Total % reactance from generator neutral upto fault point F_2 $= 5.14 + 10 = 15.14\ \%$

$$\text{Fault MVA} = 10,000 \times \frac{100}{15.14} \times \frac{1}{1000} = 66$$

* It may be noted that circuit breakers of lower rating will be required on the high voltage side of the transformers.

Ex-4 A small generating station has two alternators of 3000 KVA and 4500 KVA and percentage reactances of 7% and 8% respectively. The circuit breakers have a rupturing capacity of 150 MVA. It is desired to extend the system by a supply from the grid via a transformer of 7500 KVA and 7.5% reactance. Find the reactance of the reactor connected in the bus-bar section to prevent the circuit breakers being overloaded, if a symmetrical short circuit occurs on an outgoing feeder connected to it. Assume the bus-voltage = 3300 V.



Solution:-

Let 7500 KVA be the base KVA.

% reactance of generator A on the base KVA

$$= 7 \times \frac{7500}{3000} = 17.5\%$$

% reactance of generator B on the base KVA

$$= 8 \times \frac{7500}{4500} = 13.34\%$$

% reactance of transformer on the base KVA

$$= 7.5 \times \frac{7500}{7500} = 7.5\%$$

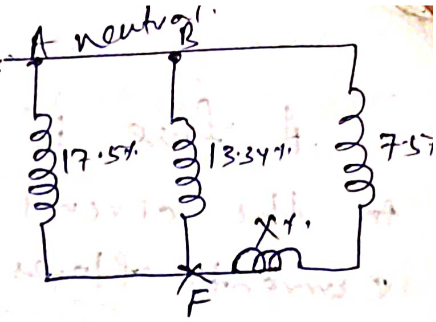
Let the percentage reactance of the bus-bar reactor be X%.

For a fault at point F, the reactance diagram will be shown in figure.

Reactances of 17.5% and 13.34% are in parallel & the equivalent reactance = $\frac{17.75 \times 1}{17.75 + 1}$

$= 7.57\%$

Total % reactance from generator neutral to fault point F.



$$= 7.57\% \parallel (X + 7.5)\%$$

$$= \frac{7.57 \times (X + 7.5)}{X + 15.07} \%$$

Short-circuit $KVA = 7{,}500 \times 100 \times \frac{X + 15.07}{7.57(X+7.5)}$

But the short-circuit KVA should not exceed 150×10^3 KVA, the rupturing capacity of the breaker.

$$150 \times 10^3 = \frac{7500 \times 100 \times (X + 15.07)}{7.57(X + 7.5)}$$

$$\Rightarrow 7.57(X + 7.5) = 5(X + 15.07)$$

$$\Rightarrow 7.57X + 56.77 = 5X + 75.35$$

$$\Rightarrow X = \frac{75.35 - 56.77}{7.57 - 5} = 7.23\%$$

The %age reactance can be converted into reactance in ohms by the following expression:

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

$$= \frac{7.23 \times 10 \times (3.3)^2}{7500}$$

$$= 0.105\,\Omega$$

FUSES

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

Characteristics of fuse element:-

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

Fuse Element Materials:-

→ The materials used for fuse element are lead, tin, copper, zinc and silver.

→ For small currents upto 10A, tin or an alloy of lead and tin is used.

→ For larger currents, copper or silver is used

The present trend is to use silver despite its high cost due to the following reasons:

i) It is comparatively free from oxidation.
ii) It does not deteriorate when used in dry air.
iii) The co-efficient of expansion of silver is so small that no critical fatigue occurs. So the fuse element can carry the rated current continuously for a long time

iv) The conductivity of silver is very high. Therefore, for a given rating of fuse element the mass of silver metal required is smaller than that of other materials.

v) Due to comparatively low specific heat, silver fusible elements can be raised from normal temperature to vaporisation quicker than other fusible elements. Consequently, operation becomes very much faster at higher currents.

vi). Silver vapourises at a temperature much lower than the one at which its vapour will readily ionise. Therefore, when an arc is formed through the vaporised portion of the element, the arc path has high resistance. As a result, short-circuit current is quickly interrupted.

Important terms used for Fuses:-

i) Current rating of fuse element:-
It is the current which the fuse element can normally carry without overheating or melting. It depends upon the temperature rise of the contacts of the fuse holder, fuse material and the surroundings of the fuse.

ii). Fusing Current:-
It is the minimum current at which the fuse element melts and thus disconnects the circuit protected by it. Obviously, its value will be more than the current rating of the fuse element.

-> For a round wire, the approximate relationship between fusing current I and diameter d of the wire is: $I = K d^{3/2}$.

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

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

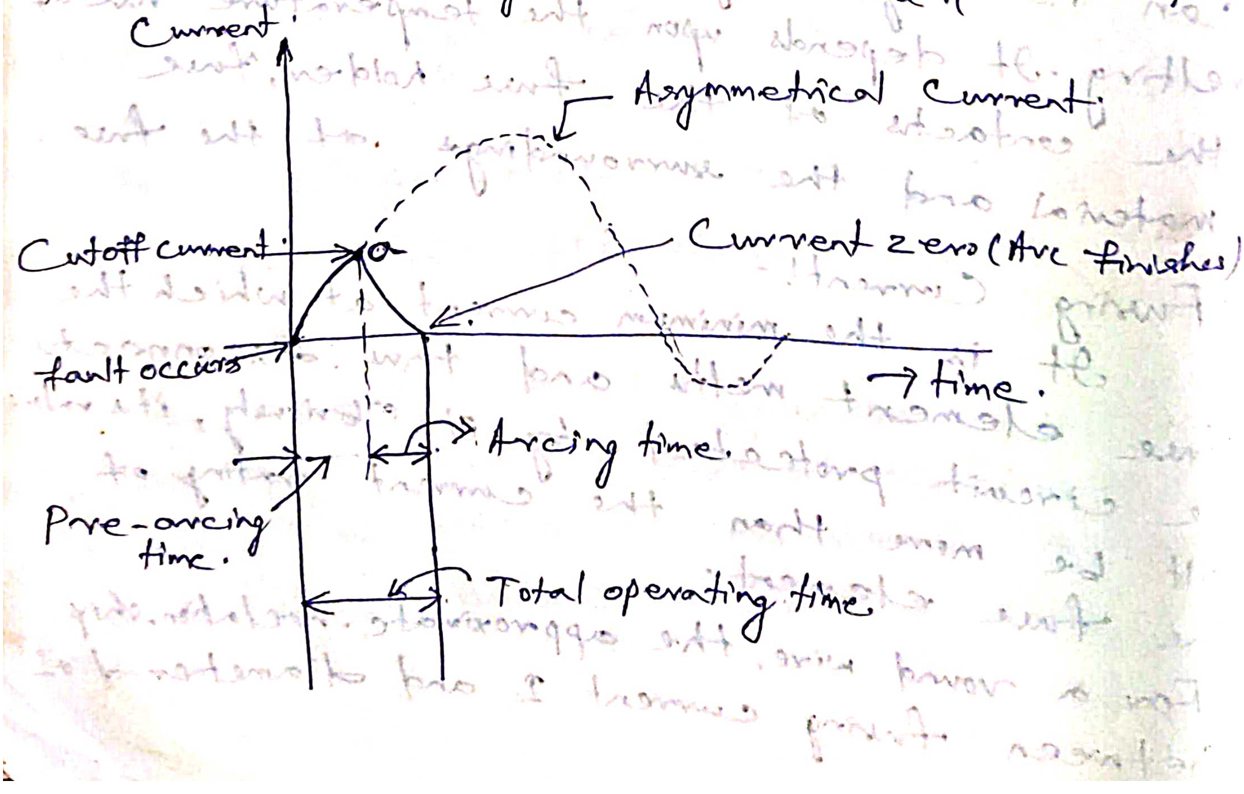
a) material of fuse element.
b) length.
c) diameter.
d) size and location of terminals.
e) previous history.
f) type of enclosure used.

(iii) Fusing factor:-

It is the ratio of minimum fusing current to the current rating of the fuse element i.e.

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

→ Its value is always more than one. (For Ensure, rate



iv) Prospective Current:-

It is the rms value of the first loop of the fault current obtained if the fuse is replaced by an ordinary conductor of negligible resistance.

v) Cut-off Current:-

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

→ The cut-off value depends upon

a) Current rating of fuse.

b) Value of prospective current.

c) asymmetry of short-circuit current.

vi) Pre-arcing time:-

It is the time between the commencement of fault and the instant when cut off occurs.

→ When a fault occurs, the fault current rises rapidly and generates heat in the fuse element. As the fault current reaches the cut off value, the fuse element melts and an arc is initiated. Typical value of pre-arcing time is <u>0.001 second</u>.

vii) Arcing time:-

This is the time between the end of pre-arcing time and the instant when the arc is extinguished.

viii). Total operating time:-

It is the sum of pre-arcing and arcing times.

→ Operating time of a fuse is generally low (say 0.002 sec) as compared to a circuit breaker (say 0.2 sec).

ix) Breaking Capacity:-

It is the rating corresponding to the rms value of the ac component of the maximum prospective current.

Types of fuses:-

→ Fuse was invented by Edison.

Fuses may be classified into

i) Low voltage fuses

ii) High voltage fuses.

i) Low Voltage Fuses:-

Low voltage fuses can be subdivided into two classes viz. rewireable fuse (Kit-Kat fu

ⓐ semi-enclosed rewireable fuse (Kit-Kat fu

ⓑ High rupturing capacity (HRC) cartridge fuse

ⓐ Semi-enclosed rewireable fuse:-

→ Rewireable fuse (Kit-Kat type) is used where low values of fault current are to be interrupted.

→ It consists of (i) a base and (ii) a fuse carrie

The base is of porcelain and carries the fixed contacts to which the incoming and outgoing phase wires are connected. The fuse carrier is also of porcelain and holds the fuse element (tinned copper wire) betwe the terminals. The fuse carrier can be inserted in or taken out of the base when desired.

Disadvantages.

→ There is a possibility of renewal by the fuse wire of wrong size.

→ It has low-breaking capacity.

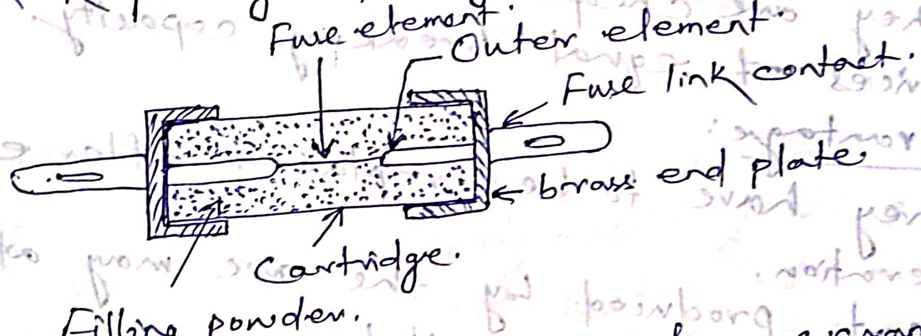
→ The fuse element is subjected to deterioration due to oxidation through the continuous heating up of the element.

→ Accurate calibration of the fuse wire is not possible because fusing current very much depends upon the length of the fuse element.

→ These fuses are made upto 500A rated current, but their breaking capacity is low e.g. on 400V service, the breaking capacity is about 400A.

→ It's use is limited to domestic and lighting loads.

(b) High Rupturing capacity (HRC) Cartridge fuse:-



→ It consists of a heat resisting ceramic body having metal end-caps to which is welded silver current-carrying element. The space within the body surrounding the element is completely packed with a filling powder. The filling material may be chalk, plaster of paris, quartz or marble dust and acts as an arc quenching and cooling medium.

→ Under normal load conditions, the fuse element is at a temperature below its melting point. Therefore, it carries the normal current without heating. When a fault occurs, the current increases and the fuse element melts before the fault current reaches its peak. The heat produced in the process vapour the melted silver element. The chemical reaction between the silver vapour and the filling powder results in the formation of a high resistance substance which helps in quenching the arc.

Advantage

→ They are capable of clearing high as well as low fault current.
→ They do not deteriorate with age.
→ They have high speed of operation.
→ Less maintenance.
→ They are cheaper than other circuit interrupt devices of equal breaking capacity

Disadvantage:

→ They have to be replaced after each operation.
→ Heat produced by the arc may affect the associated switches.
→ Low voltage H.R.C. fuses may be built with a breaking capacity of 16,000A to 30,000 at 440V.
→ They are used on low-voltage distribution system against over-load and short-circuit conditions.

High Voltage Fuses:-

Ⓐ Cartridge type:-

→ This is similar in construction to the low voltage cartridge type except that fuse elements wound in the form of a helix so as to avoid corona effects at higher voltages.

→ On some designs, there are two fuse elements in parallel; one of low resistance (silver wire) and other of high resistance (tungsten wire). When a fault occurs, the low-resistance element is blown out and the high resistance element reduces the short-circuit current and finally breaks the circuit.

→ High voltage cartridge fuses are used upto 33KV with breaking capacity of about 8700A at that voltage. Rating of the order of 200A at 6.6 KV and 11KV and 50A at 33KV are also available.

Ⓑ Liquid type:-

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

→ It is used for h.v. systems for circuits upto about 100A rated current on systems upto 132kV and may have breaking capacities of the order of 6100

© Metal clad fuses:-

Metal clad oil-immersed fuses have been developed with the object of providing a substitute for the oil circuit breaker. Such fuses can be used for very high voltage circuits and operate most satisfactorily under short-circuit conditions approaching their rated capacity.

Current Carrying Capacity of fuse element:

The current carrying capacity of a fuse element mainly depends on the metal used and the cross-sectional area but is affected also by the length, the state of surface and the surroundings of the fuse.

Heat produced per sec = heat lost per sec by convection, radiation & conduction

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

$\Rightarrow I^2(\rho \frac{l}{a}) = \text{Constant} \times d \times l$

where d = diameter of fuse element
l = length of fuse element.

$$\therefore I^2 \frac{\rho l}{\frac{\pi d^2}{4}} = \text{constant} \times d \times l.$$

$$\Rightarrow I^2 = \text{constant} \times d^3.$$

$$\boxed{\therefore I^2 \propto d^3}$$

This is known as ordinary fuse law.

Difference between a Fuse & circuit breaker:-

Fuse	Circuit breaker
→ It performs both detection and interruption functions.	→ It performs interruption function only. The detection of fault is made by relay system.
→ Inherently completely automatic.	→ Requires elaborate equipment (i.e. relays) for automatic action.
→ small breaking capacity	→ very large breaking capacity
→ Small operating time (0.002 sec)	→ large operating time (0.1 to 0.2 sec)
→ Requires replacement after every operation.	→ No replacement after operation.

CIRCUIT BREAKERS.

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

→ This characteristics of the circuit breaker has made it a very useful equipment for switching and protection of various parts of the power system.

Operating Principle:-

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

→ When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them. The current is thus able to continue until the discharge ceases. The production of arc not onely delays the current interruption process but it also generates heat which may cause damage to the system or to the circuit breaker itself. Therefore, the main problem in a circuit breaker is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

Arc phenomenon:-

→ When a short-circuit occurs, a heavy current flows through the contacts of the circuit breaker before they are opened by the protective system. At the instant when the contacts begin to separate, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature. The heat produced in the medium (oil or air) between contacts is sufficient to ionise the air or vapourise and ionise the oil. The ionised air or vapour acts as conductor and an arc is struck between the contacts. The p.d. between the contacts is quite small and is just sufficient to maintain the arc. The arc provides a low resistance path and the current in the circuit remains uninterrupted so long as the arc exists.

Principles of arc extinction:-

→ It is necessary to examine the factors responsible for the maintenance of arc between the contacts. These are.

1) P.d. between the contacts :-

To extinguish the arc is to separate the contacts to such a distance that p.d. becomes inadequate to maintain the arc.

ii) Ionised particles between contacts:-

To extinguish the arc, the arc path should be deionised. This may be achieved by cooling the arc or by bodily removing the ionised particles from the space between the contacts. ($Na^+ e^- \rightarrow Na^+$).

Methods of Arc Extinction:-

There are two methods of extinguishing the arc in circuit breakers viz.

1. High resistance method 2. Low resistance or current zero method.

1. High Resistance Method:-

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

→ The resistance of the arc may be increased by

i) Lengthening the arc:- The arc resistance increases with the length of the arc i.e. separation of contacts.

ii) Cooling the arc:- The arc resistance increases by cooling which helps in the deionisation of the medium between the contacts.

iii) Reducing X-section of the arc:- The resistance of the arc path is increased when the area of X-section of the arc is reduced. The cross-section of the arc can be reduced by letting the arc pass through a narrow opening or by having smaller area of contacts.

iv) Splitting the arc:- The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. The arc may be split by introducing some conducting plates between the contacts.

~~2. Low Resistance or Current zero methods~~

Disadvantage:-

→ More energy is dissipated in the arc.

Use:

→ It is employed only in d.c. circuit breakers and low-capacity a.c. circuit breakers.

2. Low resistance or Current zero method:-

→ In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally and is prevented from restriking inspite of the rising voltage across the contacts. When current is zero, the dielectric strength of the medium between contacts is built up more rapidly than the voltage across the contacts, the arc fails to restrike and the current will be interrupted. The rapid increase of dielectric strength of the medium near current zero can be achieved by causing the ionised particles in the space between contacts to recombine into neutral molecules.

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

i) lengthening of the gap:- Higher dielectric strength of the medium can be achieved by increasing the length of the gap between contacts.

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

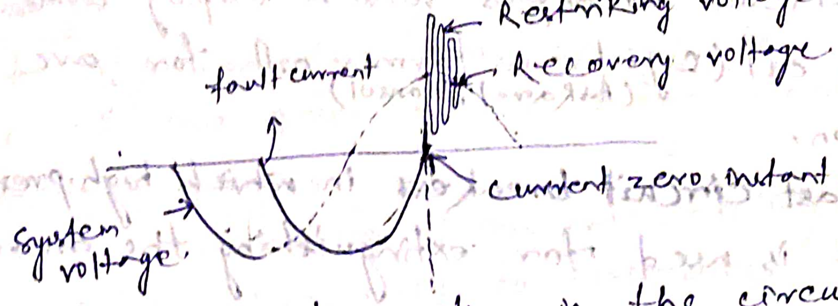
iii) Cooling:- Natural combination of ionised particles takes place more rapidly if they are allowed to cool. So, dielectric strength of the medium between the contacts can be increased by cooling the arc.

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

Important Terms:-

i) Arc voltage:-
It is the voltage that appears across the contacts of the circuit breaker during the arcing period.
→ At current zero, the arc voltage rises rapidly to peak value and this peak voltage tends to maintain the current flow in the form of arc.

ii) Restriking voltage:-
It is the transient voltage that appears across the contacts at or near current zero during arcing period.



→ The current interruption in the circuit depends upon this voltage.

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

iii) Recovery Voltage:-

It is the normal frequency (50 hz) rms voltage that appears across the contacts of the circuit breaker after final arc extinction. It is approximately equal to the system voltage.

* The power system contains an appreciable amount of inductance. At the instant of current zero point, the fault current lags behind the arc voltage by 90°. Obviously, the arc voltage must have a peak value at this instant.

Classification of Circuit Breakers:-

CBs may be classified on the basis of medium used for arc extinction. The medium used for arc extinction is usually oil, air, sulphur hexafluoride (SF_6) or vacuum. These are

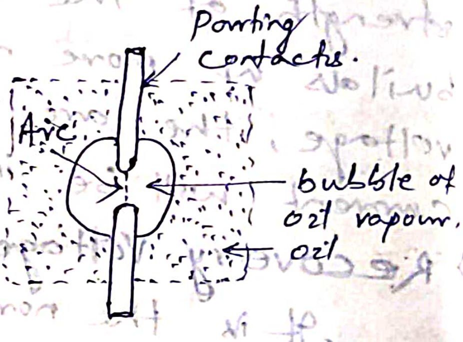
i) Oil circuit breakers which employ some insulating oil (e.g. transformer oil) (Askarrel, transol) for arc extinction.

ii) Air-blast circuit breakers in which high-pressure air-blast is used for extinguishing the arc.

iii) Sulphur hexafluoride circuit breakers in which SF_6 gas is used for arc extinction.

iv) Vacuum circuit breakers in which vacuum is used for arc extinction.

i) Oil Circuit Breakers:-



→ In this CB, some insulating oil is used as an arc quenching medium. The contacts are opened under oil and an arc is struck between them. The heat of the arc evaporates the surrounding oil and dissociates it into a substantial volume of gaseous hydrogen at high pressure. The hydrogen gas occupies a volume about one thousand times that of the oil decomposed. The oil is pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region and adjacent portions of the contacts.

→ The hydrogen gas has high heat conductivity and cools the arc and thus deionisation of the medium between contacts. So the arc is extinguished and the circuit current is interrupted.

Advantages:-

→ It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.

→ The surrounding oil presents cooling surface in close proximity to the arc.

Disadvantages:-

→ It is inflammable and there is a risk a fire.

→ It may form an explosive mixture with air.

→ The arcing products (e.g. carbon) remain in the oil and it's quality deteriorates with successive operations. This necessitates periodic checking and replacement of oil.

Types of Oil Circuit Breakers:-

These can be classified into the following types

i) Bulk oil circuit breakers:-

→ It uses a large quantity of oil. The oil has to serve two purposes.

ⓐ It extinguishes the arc during opening of contacts

ⓑ It insulates the current conducting parts from one another and from the earthed tank.

→ It may be subdivided into

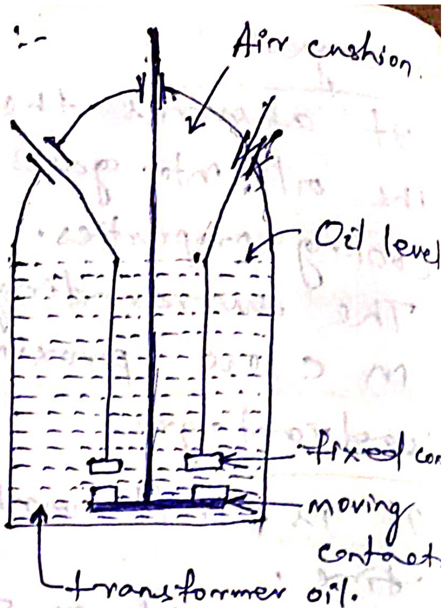
ⓐ plain break oil circuit breaker.

ⓑ Arc control oil circuit breaker.

ii) Low oil circuit breakers:-

→ It uses minimum amount of oil. Here oil is used only for arc extinction, the current conducting parts are insulated by air or porcelain or organic insulating material.

Plain Break Oil Circuit Breakers :-



→ It is very simple in construction. It consists of fixed and moving contacts enclosed in a strong weather-tight earthed tank containing oil upto a certain level and air cushion above the oil level. The air cushion provides sufficient room to allow for the reception of the arc gases without the generation of pressure. It also absorbs the mechanical shock of the upward oil movement.

→ In the figure it is called a double break because it provides two breaks in series.

→ Under normal operating conditions, the fixed and moving contacts remain closed and the breaker carries the normal circuit current. When a fault occurs, the moving contacts are pulled down by protective system and an arc is struck which vapourises the oil into hydrogen gas.

→ The arc is easily extinguished due to the reasons;

→ The hydrogen gas bubble generated around the arc cools the arc and aids the deionisation of the medium between the contacts.

→ The gas sets up turbulence in the oil and helps in eliminating the arc products from the arc path.

→ As the arc lengthens due to separating contacts the dielectric strength of the medium is increased.

→ So at a critical gap length the arc is extinguished and the circuit current is interrupted.

Disadvantages:-

→ There is no special control over the arc other than the increase in length caused by the moving contacts.

→ These breakers have long and inconsistent arcing times.

→ These breakers do not permit high speed interruption.

Uses:- Below 11kv (i.e. only for low-voltage applications)

⑥ Arc Control Oil Circuit Breaker

→ In this type of OCB, some arc control is incorporated (included) and the breakers are then called arc control circuit breaker.

These are two types.

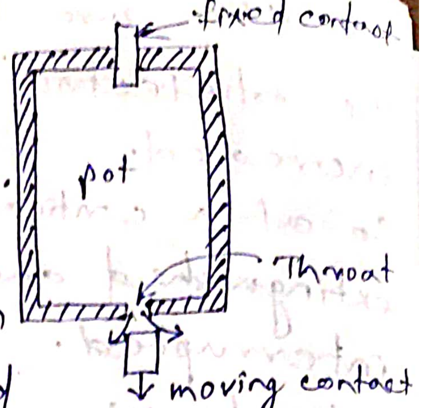
i) Self blast OCB ii) Forced-blast OCB

i) Self blast OCB:-

In this type of circuit breaker, the gases produced during arcing are confined to a small volume by the use of an insulating rigid pressure chamber or pot surrounding the contacts. The pressure is generated by the arc itself, therefore such breakers are also called self generated pressure oil circuit breaker.

. Some designs of pressure chambers (explosion pots) have been developed..

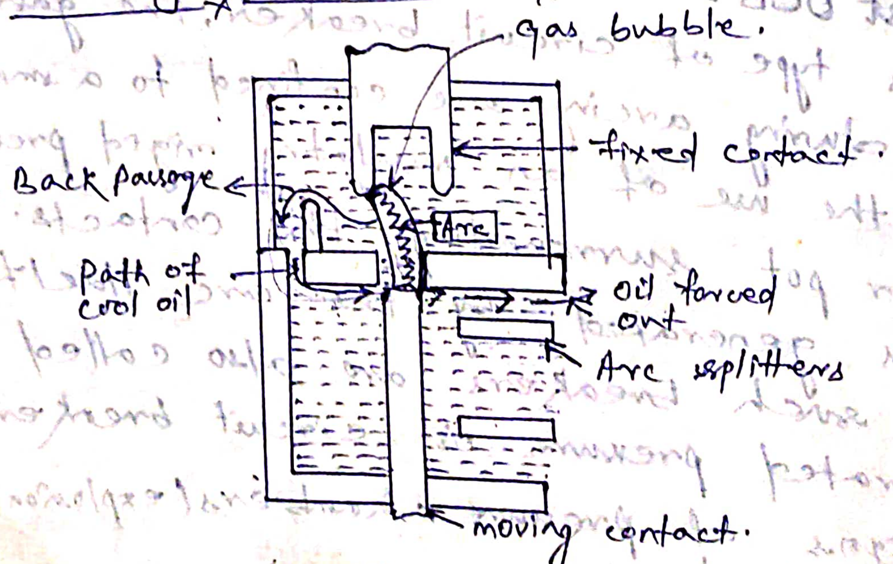
(a) Plain explosion pot:-



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

Drawback:- It is only applicable for moderate short circuit only where the rate of gas evolution is moderate.

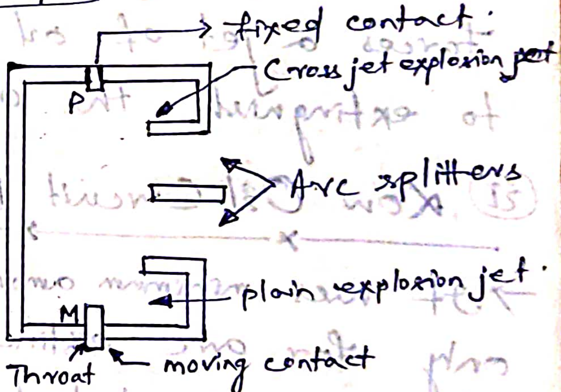
(b) Cross jet explosion pot:-



This is the modification of plain explosion pot. It is made of insulating material and has channels on one side which act as arc splitters. When a fault occurs the moving contact of the CB begins to separate. So the arc is struck in the top of the pot. The gas generated by the arc exerts a pressure on the oil in the back passage, when the moving contact uncovers the arc splitter ducts, the force oil is forced across the arc path. Here the jet of oil is forced at right angles to the arc path, this type of pot is referred to as cross jet explosion pot. The arc is driven to the arc splitters which causes arc extinction. It is quite efficient for high fault currents.

(c) Self Compensated explosion pot:-

→ This pot is the combination of plain explosion pot & cross jet explosion pot. Therefore it can interrupt low as well as heavy short circuit currents with reasonable accuracy.



→ It consists of two chambers, the upper chamber is the cross jet explosion pot with two arc splitter ducts and the lower one is the plain explosion pot.

→ When the short-circuit current is heavy, the rate of generation of gas is high & the device behaves as a cross-jet explosion pot. When the moving contact uncovers the first or second arc splitter duct, the arc is extinguished.

→ For low short-circuit currents, the rate of gas generation is small & the tip of the moving contact has the time to reach the lower chamber. During this time, the gas builds up sufficient pressure as there is very little leakage through arc splitter ducts due to the obstruction offered by the arc path & right angle bends. When the moving contact comes out of the throat, the arc is extinguished by plain pot action.

2) Forced-blast Oil Circuit Breakers:-

→ Here pressure is generated by external mechanical means independent of the fault currents to be broken. (low or moderate or high or less than low)

→ In this case, oil pressure is created by the piston-cylinder arrangement, the movement of the piston is mechanically coupled to the moving contact. When a fault occurs, the contacts get separated by the protective system and an arc is struck between the contacts. The piston forces a jet of oil towards the contact gap to extinguish the arc.

(ii) Low Oil Circuit Breakers:-

→ It uses minimum amount of oil. Here oil is used only for arc extinction & the current conducting parts are insulated by air or porcelain or organic insulating material.

Construction:-

There are two compartments separated from each other but both filled with oil. The upper chamber is called circuit breaking chamber and the lower one is called supporting chamber. The two chambers are separated by a partition so that the oil

should not mix with each other.
This arrangement provides two advantages –
→ The circuit breaking chamber requires a small volume of oil which is enough for arc extinction.
→ The amount of oil to be replaced is reduced because the oil in the supporting chamber does not get contaminated by the arc.

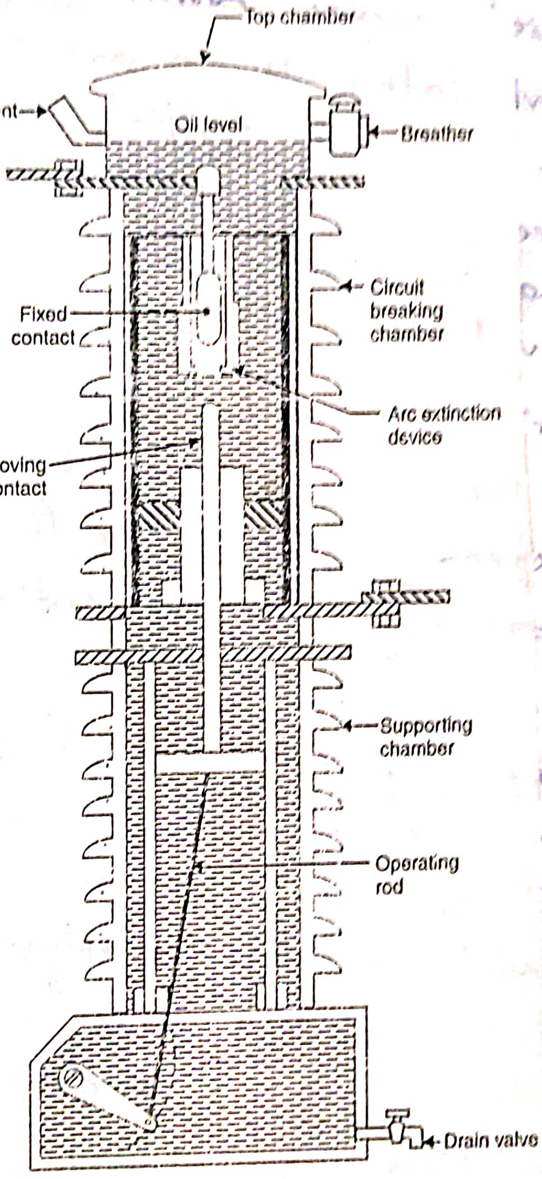


Fig. 19.7 Low-oil Circuit Breaker

(i) Supporting Chamber: It is a porcelain chamber mounted on a metal chamber. It is filled with oil and the oil inside the supporting chamber and the annular space formed between the porcelain insulation and bakelised paper is used for insulation purposes only.

(ii) Circuit Breaking Chamber:- It is a porcelain enclosure mounted on the top of the supporting compartment. It is filled with oil and contains:
→ upper & lower fixed contacts.
→ moving contact.
→ turbulator.
The moving contact is hollow and includes a cylinder which moves down over a fixed piston. The turbulator is an arc control device and has both axial and radial vents. The axial vents are used for low current interruption and radial vents for heavy current interruption.

(iii) Top chamber:- It is a metal chamber and is mounted on the circuit breaking chamber. It provides expansion space for the oil in the circuit breaking compartment.

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

Disadvantages :-

- → Due to smaller quantity of oil, the degree of carbonisation is increased.
- → The dielectric strength of the oil deteriorates rapidly due to high degree of carbonisation.

Maintenance of Oil Circuit Breakers :-

- → It is generally concerned with the checking of contacts and dielectric strength of oil.
- → Check the current carrying parts and arcing contacts. If the burning is severe, the contacts should be replaced.
- → Check the dielectric strength of the oil. If the oil is badly discoloured, it should be changed or reconditioned. The oil in good condition should withstand 30 kV for one minute in a standard oil testing cup with 4 mm gap between electrodes.
- → Check the insulation for possible damage. Clean the surface and remove carbon deposits with a strong and dry fabric.
- → Check the oil level.
- → Check closing and tripping mechanism.

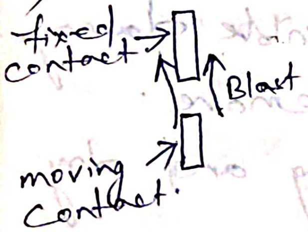
Air-Blast Circuit Breakers:-

→ These breakers employ a high pressure air blast as an arc quenching medium. The contacts are opened in a flow of air blast established by the opening of blast valve. The air blast cools the arc and sweeps away the arcing products to the atmosphere. This rapidly increases the dielectric strength of the medium between contacts and prevents from re-establishing the arc. Consequently, the arc is extinguished and the flow of current is interrupted.

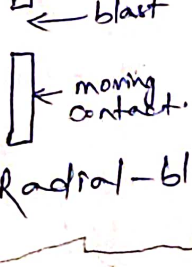
Types of Air-Blast Circuit Breakers:-

Depending upon the direction of air-blast in relation to the arc, air-blast circuit breakers are classified into:

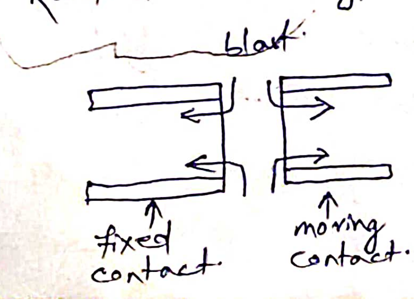
i) Axial-blast type: In which the air-blast is directed along the arc path.



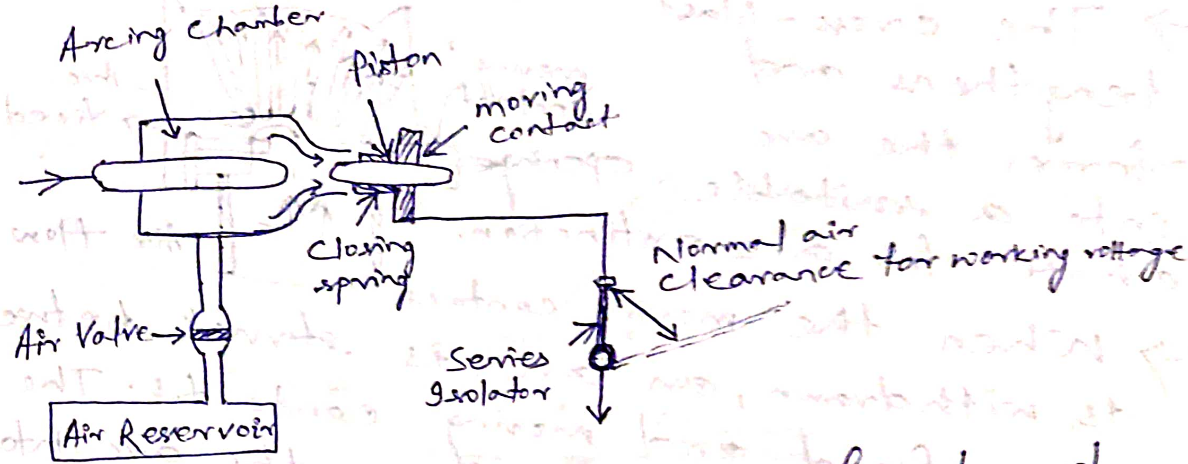
ii) Cross-blast type: In which the air-blast is directed at right angles to arc path.



iii) Radial-blast type: In which the air-blast is directed radially.



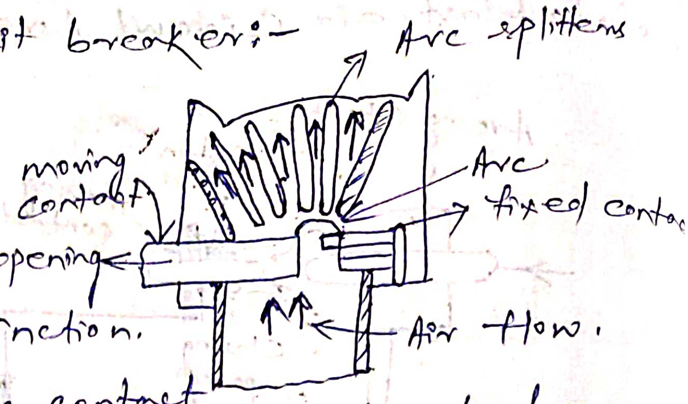
ii) Axial-blast air Circuit Breaker:-



→ Under normal conditions, the fixed and moving contacts are held in the closed position by spring pressure. The air reservoir is connected to the arcing chamber through an air valve. This valve remains closed under this conditions but opens automatically by the tripping impulse when a fault occurs on the system.

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

ii) Cross-blast air circuit breaker:-



→ The cross-blast lengthens and forces the arc into a suitable chute for arc extinction.

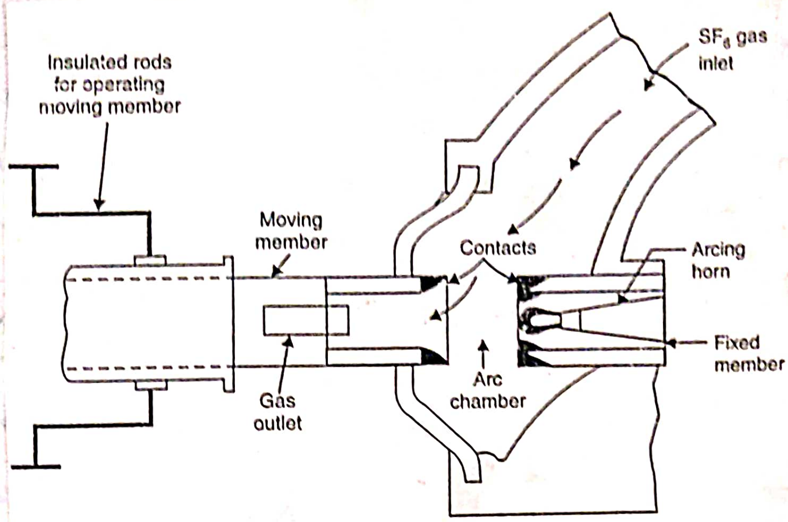
→ When the moving contact is withdrawn, an arc is struck between the fixed and moving contacts. The high pressure cross-blast forces the arc into a chute consisting of arc splitters and baffles. The splitters serve to increase the length of the arc and baffles give improved cooling. The result is that arc is extinguished and flow of current is interrupted.

→ Since blast pressure is same for all currents the inefficiency at low currents is eliminated.

Sulphur Hexaflouride (SF_6) Circuit Breakers:-

→ Here SF_6 gas is used as the arc quenching medium. The SF_6 gas is an electro-negative gas and to absorb free electrons. The contacts of the breaker are opened in a high pressure flow of SF_6 gas and an arc is struck between them. The conducting free electrons in the arc are captured by the gas to form immobile negative ions. This loss of conducting electrons in the arc quickly builds up enough insulation strength to extinguish the arc.

Construction:-



→ It consists of fixed and moving contacts enclosed in a chamber containing SF_6 gas. This chamber is connected to SF_6 gas reservoir. When the contacts of breaker are opened, the valve mechanism permits a high pressure SF_6 gas from the reservoir to flow towards the arc interruption chamber. The fixed contact is a hollow cylindrical current carrying contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides to permit the SF_6 gas to let out through these holes after flowing along and across the arc. The ~~tips~~ of fixed contact, moving contact and arcing horn are coated with copper-tungsten arc resistant material.

Working :-

→ In the closed position of the breaker, the contacts remain surrounded by SF6 gas at a pressure of about 2·8 kg/cm². When the breaker operates, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronised with the opening of a valve which permits SF6 gas at 14 kg/cm² pressure from the reservoir to the arc interruption chamber. The high pressure flow of SF6 absorbs the free electrons to form immobile negative ions which are ineffective as charge carriers. The result is that the medium between the contacts quickly builds up high dielectric strength and causes the extinction of the arc. After arc extinction, the valve is closed by the action of a set of springs.

Advantages

→ Short arcing time.
→ Since the dielectric strength is 2 to 3 times that of air, such breakers can interrupt much large currents.
→ No risk of fire.
→ No Carbon deposits.
→ Low maintenance cost.
→ Suitable where explosion hazard exists e.g. coal mines

Disadvantages

→ Costly due to high cost of SF6.
→ SF6 gas has to be reconditioned after every operation of the breaker.

Applications:-

A typical SF_6 circuit breaker consists of interruptor units each capable of dealing with currents upto 60KA and voltages in the range of 50-80KV. A no. of units are connected in series according to the system voltage. SF_6 circuit breakers have been developed for voltages 115KV to 230KV, power ratings 10 MVA to 20MVA.

Vacuum Circuit Breakers :-

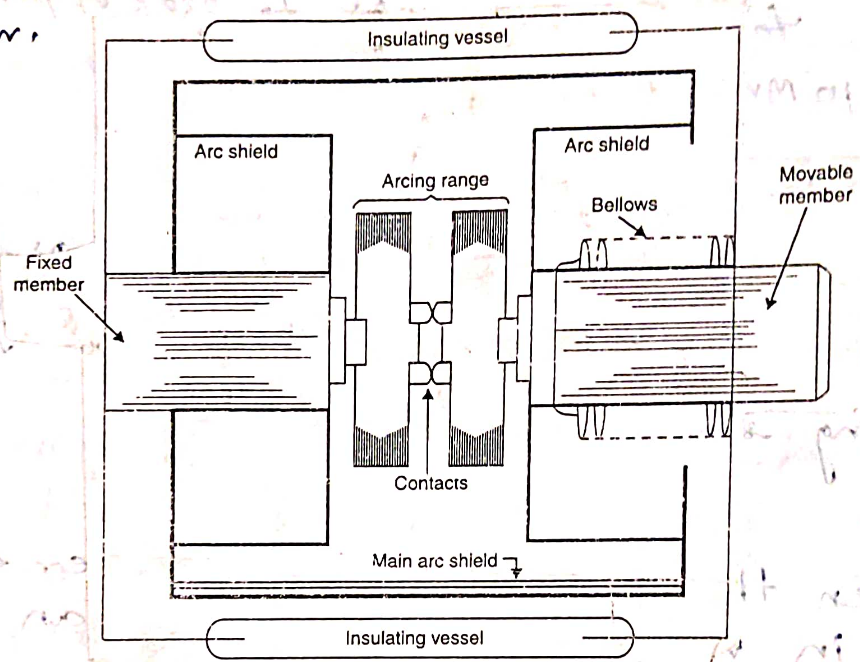
→ In such breakers, vacuum is used as the arc quenching medium. It offers the highest insulating strength.

Principle:-

When the contacts of the breaker are opened in vacuum (10^{-7} to 10^{-5} torr), an arc is produced between the contacts by the ionisation of metal vapours of contacts. The metallic vapours, electrons and ions produced during arc, rapidly condense on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength and the arc is quickly extinguished.

Construction:-

→ It consists of fixed contact, moving contact and 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 possibility of leak. A glass vessel or ceramic vessel is used as the outer insulating body. The arc shield prevent the deterioration of the internal dielectric strength by preventing metallic vapours falling on the inside surface of the outer insulating cover.



Working:-

When the breaker operates, the moving contact separates from the fixed contact and an arc is struck between the contacts. The production of arc is due to the ionisation of metal ions and depends very much upon the material of contacts. The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in a short time and seized. ~~by the~~ Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker occurs with a short contact separation (say 0.625 cm).

Advantages:-

→ They are compact, reliable and have longer life.
→ No risk of fire.
→ They can interrupt any fault current.
→ Need little maintenance.
→ withstand lighting surges.
→ They have low inertia and hence require smaller power for control mechanism.

Applications:-

→ It is used where distances are quite large and accessibility to remote areas difficult.
→ VCBs are employed for outdoor applications ranging from 22KV to 66KV.

Switchgear Components:-

The components are
i) Bushings.
ii) circuit breaker contacts.
iii) Instrument transformers.
iv) Bus-bars and conductors.

i) Bushings:-

→ It provide insulation between the high voltage conductor and the surrounding earthed metal tank.
→ Bushing made of porcelain or steatite and there are several types of bushing (e.g. condenser type, oil filled etc).

ii) Circuit breaker Contacts:-

→ Contacts are required to carry normal as well as short-circuit current.
→ During normal current, temp. should not rise above the specified limits of low voltage drop at the point of contact.

→ During breaking and making short-circuit currents, the effects to be dealt with are melting and vapourisation by the heat of the arc & those due to electromagnetic forces.

→ Types are
a) Tulip type contacts.
b) Finger & wedge contacts.
c) Butt contacts.

iii) Instrument Transformers:-

→ The function of instrument transformer is to transform voltages or currents in the power lines to values which are convenient for the operation of measuring instruments & relay.

→ There are two types
a) Current transformer (C.T)
b) Potential transformer (P.T).

→ Advantages:

→ They isolate the measuring instruments and relays from high-voltage power circuits.

→ The leads in the secondary circuits carry relatively small voltages and currents. This permits to use wires of smaller size with minimum insulation.

iv) Bus-bars and Conductors:-

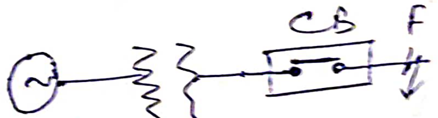
The current carrying members in a CB consist of fixed and moving contacts and the conductors connecting these to the points external to the breaker. If the switchgear is of outdoor type, these connections are connected directly to the overhead lines. In case of indoor switchgear, the incoming conductors to the circuit breaker are connected to the bus-bars.

Problems of Circuit Interruption:-

→ The power system contains an appreciable amount of inductance and some capacitance.

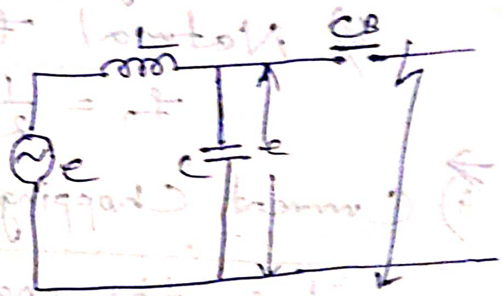
→ When a fault occurs, the energy stored in the system can be considerable. Interruption of fault current by a circuit breaker will result in most of the stored energy dissipated within the circuit breaker, the remainder being dissipated during oscillatory surges in the system.

→



e = Em sin ωt

(fig-1)

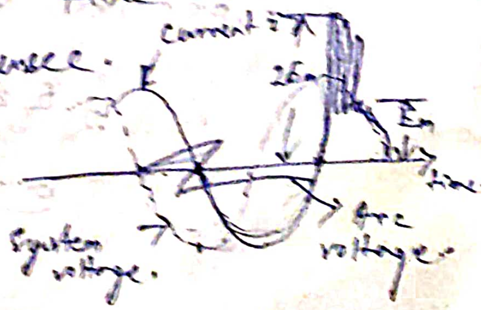


(fig-2)

→ Fig ①. shows a short-circuit occuring on the transmission line. Fig ② shows its equivalent circuit where L is the inductance per phase of the system upto the point of fault and C is the capacitance per phase of the system. The resistance of the system is neglected as it is generally small.

(i) Rate of Rise of Restriking Voltage (RRRV)

→ It is the rate of increase of restriking voltage and is abbreviated by RRRV. Usually the voltage is in kV and time in microseconds so that RRRV is in kV/μsec.



→ RRRV decides whether the arc will restrike or not. If RRRV is greater than rate of rise of dielectric strength between the contacts, the arc will restrike. If RRRV is less than rate of increase of dielectric strength between the contacts of the breaker, then the arc will fail to restrike.

→ RRRV depends upon:

a) Recovery voltage.

b) Natural frequency of oscillations.

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

ii) Current Chopping:-

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

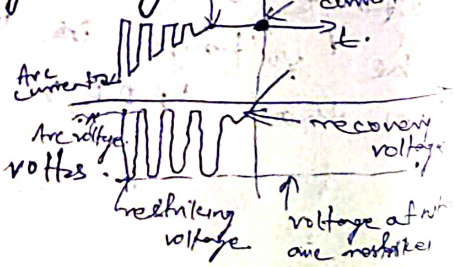
→ The effects is production of high voltage transient across the contacts of the circuit breaker.

→ Suppose the arc current is 'i' when it is chopped down to zero value.

→ As the chop occurs at current i, therefore, the energy stored in inductance is $Li^2/2$. This energy will be transferred to the capacitance C, charging the latter to a prospective voltage e given by

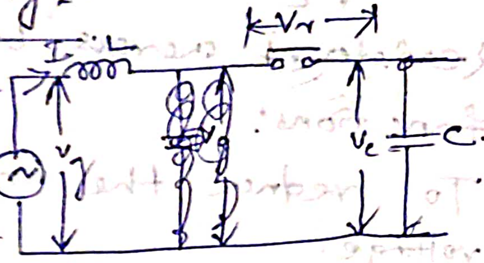
$$\frac{1}{2}Li^2 = \frac{Ce^2}{2}$$

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



→ The prospective voltage e is very high as compared to the dielectric strength gained by the gap so that the breaker restrikes.

ii) Capacitive Current Breaking:-

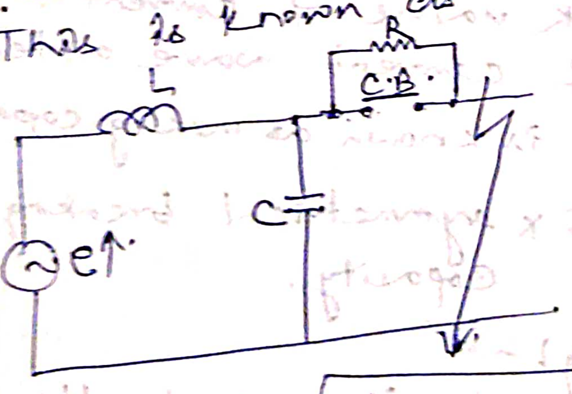


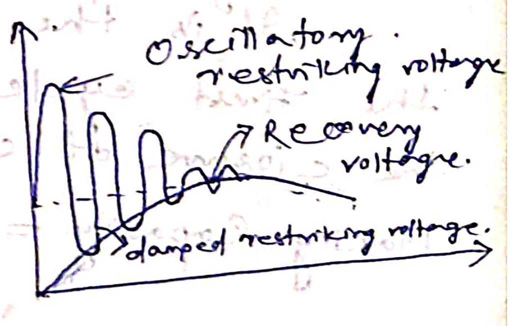
→ Another cause of excessive voltage surges in the circuit breakers is the interruption of capacitive currents.

→ Examples of such instances are opening of an unloaded long transmission line, disconnecting a capacitor bank used for power factor improvement etc

Resistance Switching:-

→ The current chopping, capacitive current breaking etc give rise to severe voltage oscillations. These excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R connected across the circuit breaker contacts. This is known as resistance switching.





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

→ The effect of shunt resistance R is to prevent the oscillatory growth of re-striking voltage and cause it to grow exponentially upto recovery voltage. This is being most effective when the value of R is so chosen that the circuit is critically damped. The value of R required for critical damping is $0.5\sqrt{\frac{L}{C}}$.

→ Resistors across breaker perform following functions:

i) To reduce the rate of rise of restriking voltage

ii) To reduce the voltage surges due to current chopping and capacitive current breaking.

Circuit Breaker Ratings:-

C.B.s have three ratings

1) Breaking Capacity:-

It is the rms current that a C.B. is capable of breaking at given recovery voltage and under specified conditions (e.g. power factor, RRRV).

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

2) Making Capacity:-

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

Making Capacity $= 2.55 \times$ symmetrical breaking capacity.

3) Short time Rating:-

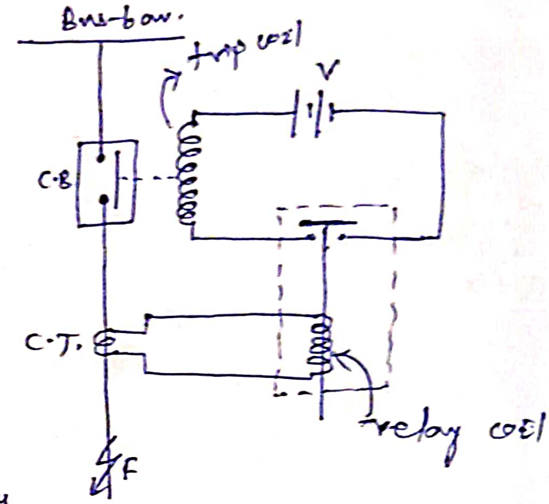
It is the period for which the C.B. is able to carry fault current while remaining closed for short intervals without tripping.

Normal Current Rating:-
It is the rms value of current which the CB is capable of carrying continuously at its rated frequency under specified conditions.

PROTECTIVE RELAYS.

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

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



Fundamental Requirements of Protective Relaying

i) Selectivity:-
It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system.

ii) Speed:-
The relay system should disconnect the faulty section as fast as possible.

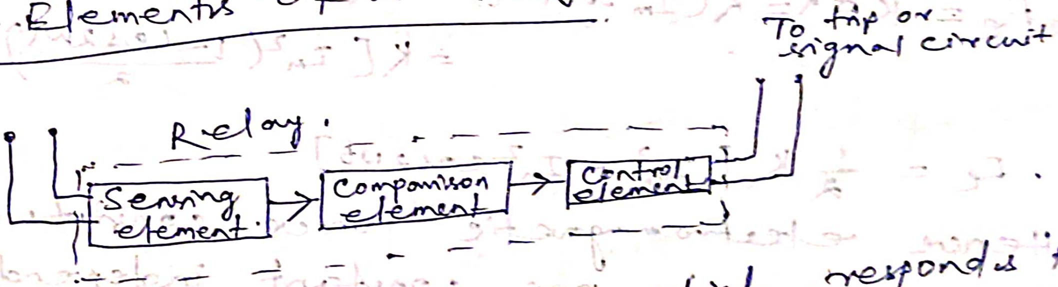
iii) Sensitivity:-
It is the ability of the relay system to operate with low value of actuating quantity.

iv) Reliability:-
It is the ability of the relay system to operate under pre-determined conditions. Without reliability, the protection would be ineffective.

v) Simplicity:-
The relaying system should be simple so that it can be easily maintained. The simpler the protection scheme, the greater will be its reliability.

vi). Economy:-
The most important factor in the choice of particular protection scheme is the economic aspect. As a rule, the protective gear should not cost more than 5% of total cost.

Basic Elements of a Relay:-



1) Sensing or measuring Element:- which responds to the change in the actuating quantity.

2) Comparing element:- It compare the action of the actuating quantity on the relay with a pre-selected relay setting.

3) Control element:- accomplishes a sudden change in the control quantity such as closing of the operative current circuit.

→ Relay used in power system operate by virtue of current and/or voltage supplied by C.T. and V.T connected in various combinations to the system element that is to be protected.

Operating Principle of Protective Relays:-

The main principle employed in the operation of the relay is either electromagnetic attraction or electromagnetic induction.

Electromagnetic Attraction Relays:-

→ Electromagnetic attraction relays operate by virtue of an armature being attracted to the poles of an electromagnet or a plunger being drawn into a solenoid. Such relays may be actuated by dc or ac quantities.

→ In case of ac quantity the electromagnetic force developed is given as

$$F_e = KI^2 = K(I_m \sin\omega t)^2 = K[I_m^2 \sin^2\omega t]$$
$$= K[I_m^2(\frac{1-\cos 2\omega t}{2})]$$

$$F_e = \frac{1}{2}K[I_m^2 - I_m^2\cos 2\omega t]$$

→ Hence electromagnetic force consists of two components, one constant independent of time $(\frac{1}{2}KI_m^2)$ and another dependent upon time and pulsating at double the supply frequency $(\frac{1}{2}KI_m^2\cos 2\omega t)$

→ The total electromagnetic force pulsate at double the supply frequency. Due to this relay causes noise and also damages to the relay contacts.

→ To overcome this, the flux developing the electromagnetic force is splitted into two fluxes acting simultaneously but differing in time phase so that the resultant deflecting force is always positive & constant.

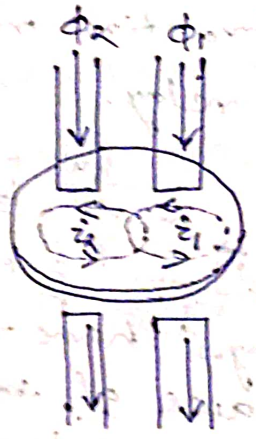
→ Types of electromagnetic attraction relays
  i) Attracted armature type relay.
  ii) Solenoid type relay.
  iii) Balanced beam relay.

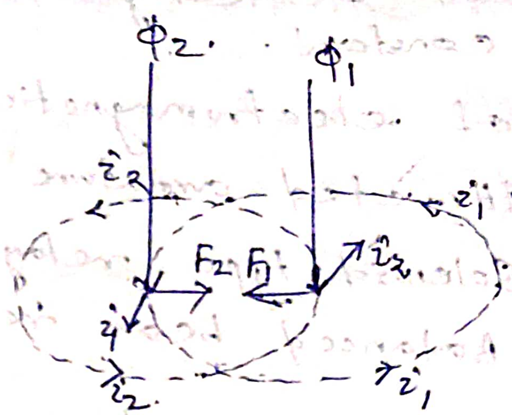
* The attraction armature relays have fast operation and fast reset because of small length of travel and light moving parts.
* These relays are operate on dc as well as ac and they are affected by transients.
* Attraction armature relays are sensitive to starting current, load fluctuations and current surges.

Electromagnetic Induction Relay :-

→ Electromagnetic induction relays operate on the principle of induction motor. and are widely used for protective relaying purposes involving only ac quantities. these relays operate on the principle of split phase induction motor.

→ In the figure two ac fluxes ϕ_2 and ϕ_1 differs in phase by an angle 'α' induce emf's in the disc and cause the circulation of eddy currents i_2 and i_1 respectively. These currents lag behind their respective fluxes by 90°.





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

$\phi_2 = \phi_{2max} \sin(\omega t + \alpha)$.

Where ϕ_1 and ϕ_2 are instantaneous values of fluxes and ϕ_2 leads ϕ_1 by an angle α.

→ Assuming negligible self-inductance, the rotor currents will be in phase with their voltages.

$$i_1 \propto \frac{d\phi_1}{dt} \propto \frac{d}{dt}(\phi_{1max} \sin\omega t).$$

$$\propto \phi_{1max} \cos\omega t.$$

& $i_2 \propto \frac{d\phi_2}{dt} \propto \phi_{2max} \cos(\omega t + \alpha)$.

Now $F_1 \propto \phi_1 i_2$ & $F_2 \propto \phi_2 i_1$. $F = BINA$

Here two forces are in opposition.

∴ Net force F at the instant is

$$F \propto F_2 - F_1$$

$$\propto \phi_2 i_1 - \phi_1 i_2.$$

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

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

$$F \propto \phi_{1max}\, \phi_{2max} \sin\alpha.$$

$$\propto \phi_1 \phi_2 \sin\alpha.$$

where ϕ_1 & ϕ_2 are the r.m.s. values of the fluxes.

→ The greater the phase angle 'α' between the fluxes, the greater is the net force applied to the disc. The maximum force will be produced when two fluxes are 90° out of phase.

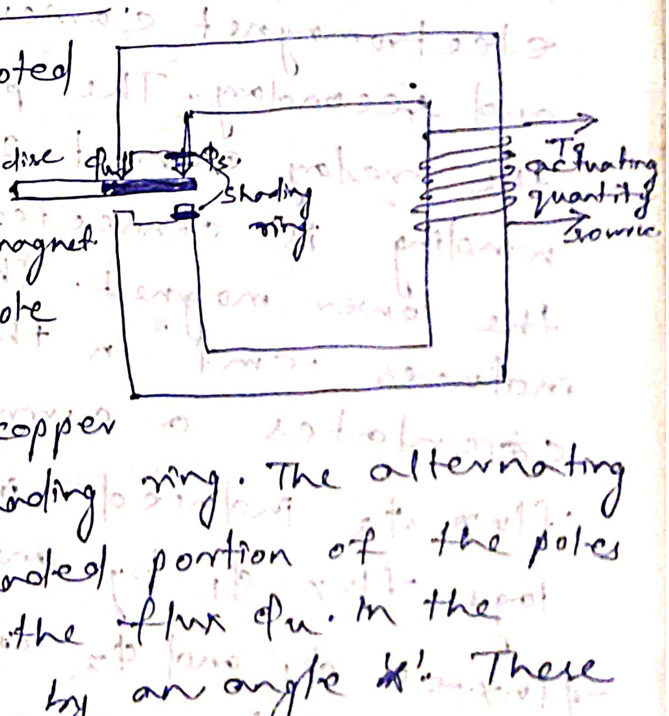
→ The direction of net force and hence the direction of motion of the disc depends upon which flux is leading.

⊛ There are three structures used for obtaining the phase difference in the fluxes and hence the operating torque.

i) Shaded-pole structure.
ii) Watthour-meter structure.
iii) Induction cup structure.

i) **Shaded-pole structure:-**

→ It consists of a pivoted aluminium disc free to rotate in the air gap of an electromagnet. One half of each pole of the magnet is surrounded by a copper band known as shading ring. The alternating flux ϕ_s in the shaded portion of the poles will lag behind the flux ϕ_u in the unshaded portion by an angle 'α'. These two fluxes differing in phase will produce the necessary torque to rotate the disc.



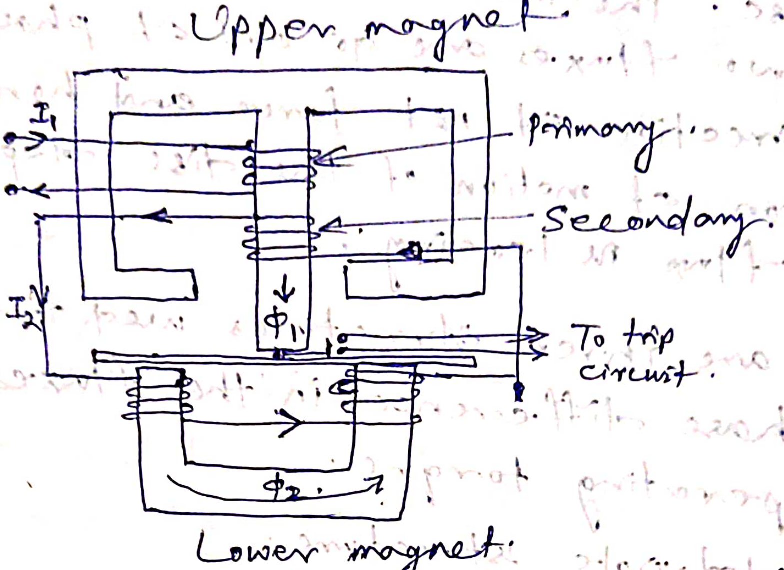
$$T \propto \phi_s \phi_u \sin\alpha.$$

$$\phi \propto I.$$

$$\boxed{T \propto I^2 \sin\alpha}$$

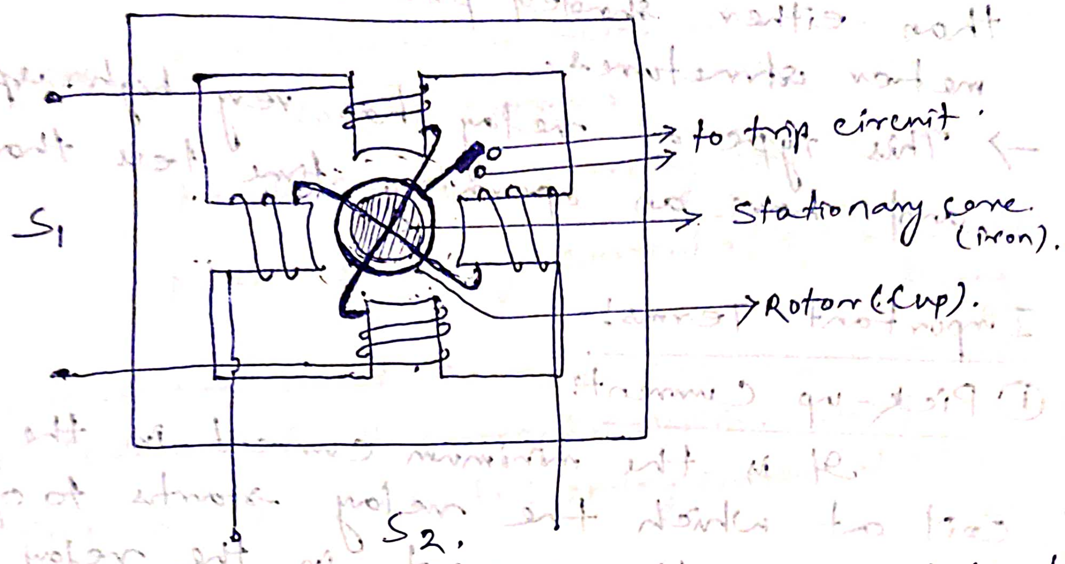
The driving torque is proportional to the square of current in the relay coil.

ii) Watthour meter Structure:-



→ It consists of a pivoted aluminium disc
arranged to rotate freely between the
poles of two electromagnet. The upper
electromagnet carries two windings - primary
and secondary. The primary winding carries
the relay current I_1 while the secondary
winding is connected to the winding of
the lower magnet. The primary current
induces emf in the secondary and
circulates a current I_2 in it. The
flux ϕ_2 induced in the lower magnet
lags flux ϕ_1 by an angle α. The two
fluxes ϕ_1 and ϕ_2 differing in phase by
α will ~~will~~ produce a driving torque
on the disc proportional to $\phi_1 \phi_2 \sin\alpha$.

iii) Induction Cup Structure:-



→ It resembles to induction motor., except that the rotor iron is stationary, only the rotor conductor (cup) being free to rotate. The rotor is a hollow metallic cylindrical cup rotate between the electromagnet and the stationary iron core. The rotating field is produced by two pairs of coils wound on four poles. The rotating field induces currents in the cup to provide the necessary driving torque.

→ If ϕ_1 and ϕ_2 represent the fluxes produced by the respective pairs of poles, then torque produced is proportional to $\phi_1\phi_2 \sin\alpha$ where α is the phase difference between the two fluxes.

→ A control spring and the back stop for closing of the contacts carried on an arm are attached to the spindle of the cup to prevent continuous rotation.

Advantage:-

-> There are more efficient torque producers than either shaded pole or the watthour meter structures.

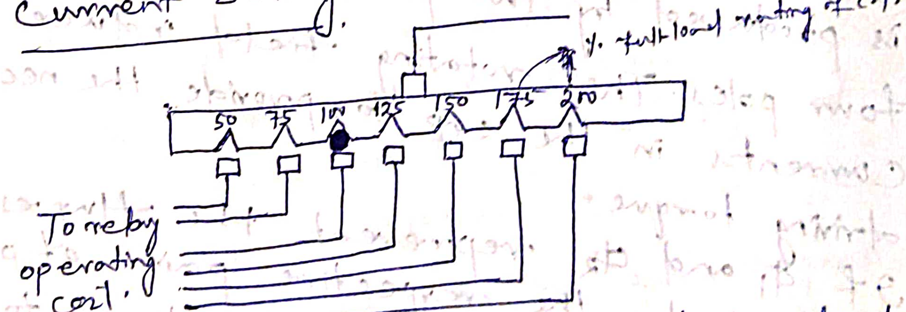
-> This type of relay has very high speed and have an operating time less than 0.1s.

Important Terms:-

① Pick-up Current:-

It is the minimum current in the relay coil at which the relay starts to operate. So long as the current in the relay is less than the pick-up value, the relay does not operate. However when the relay coil current is equal to or greater than the pick-up value, the relay operates to energise the trip coil which opens the circuit breaker.

② Current Setting:-



The pick-up current is adjusted according to the required value. This is known as current setting and is achieved by the use of tapping on the relay operating coil. The taps are brought out to a plug bridge. Changes of number of turns on relay coil, changes the torque on the disc of the time of operation of the relay.

Pick-up Current = Rated secondary current of C.T × current setting.

(3) Plug-setting multiplier (PSM) :-

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

$$PSM = \frac{\text{Fault current in relay coil}}{\text{Pick-up current}}$$

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

Ex:- Relay is connected to 400/5 C.T & set at 150%. with primary fault current of 2400A. PSM = ?

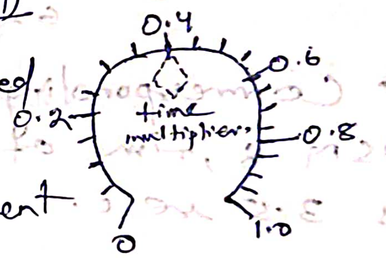
Soln. Pick-up value = Rated secondary current of C.T. × Current setting

$= 5 \times 1.5 = 7.5\,A$

fault current in relay coil $= 2400 \times \frac{5}{400} = 30A$.

$$P.S.M = \frac{30}{7.5} = 4$$

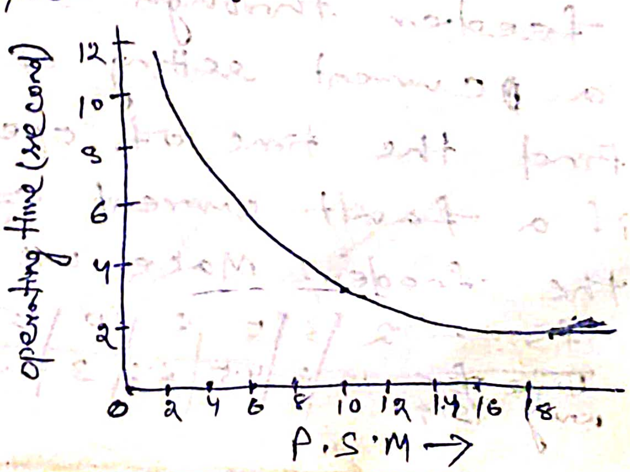
(4) Time setting multiplier (TSM)



A relay is generally provided with control to adjust the time of operation. This adjustment is known as time setting multiplier.

The time setting dial is calibrated from 0 to 1 in steps of 0.05 sec. The actual time of operation is calculated by multiplying the time setting multiplier with the time obtained from time/PSM curve of the relay.

Time/PSM curve



- Determine the time of operation of a 5A, 3-second overcurrent relay having a current setting of 125% and a time setting multiplier of 0.6 connected to supply circuit through a 400/5 current transformer when the circuit carries a fault current of 4000 A.

Solution:- Rated secondary current of CT = 5A

Pickup current $= 5 \times 1.25 = 6.25A$.

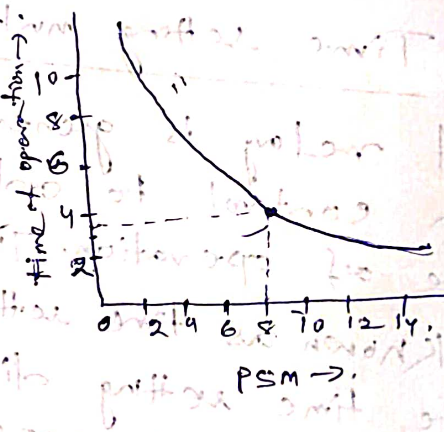
Fault current in relay coil $= 4000 \times \frac{5}{400} = 50A$.

(Fault current in relay coil $= \frac{\text{fault current}}{\text{CT ratio}}$).

$$PSM = \frac{\text{fault current in relay coil}}{\text{pickup current}}$$

$$= \frac{50}{6.25} = 8$$

→ Corresponding to the PSM 8, time of operation is 3.5 sec.



Actual relay operating time = 3.5 × time setting

$= 3.5 \times 0.6$

$= 2.1$ sec

Ex:- An over current relay is used to protect a feeder through 500/1 A CT. The relay has a current setting of 125% and TSM = 0.3. Find the time of operation of the said relay if a fault current of 5000 A flows through the feeder. Make use of the following characteristic

PSM	2	3	5	8	10	15
Time for unity TSM	10	6	4.5	3.2	3	2.5

Soln :- Pick up current = 1·25 × 1 = 1·25 A
∴ fault current = 5000 A
fault current in relay coil = $5000 \times \frac{1}{500} = 10$ A

$PSM = \frac{10}{1.25} = 8$.

Time corresponding to PSM of 8, data given is 3.2
So actual operating time = 3.2 × time setting multiplier
= 3.2 × 0.3
= 0.96 sec.

Relay Types :-

* Relay which recognise overcurrent - Overcurrent relay.
Relay which recognise overvoltage - Over voltage relay.

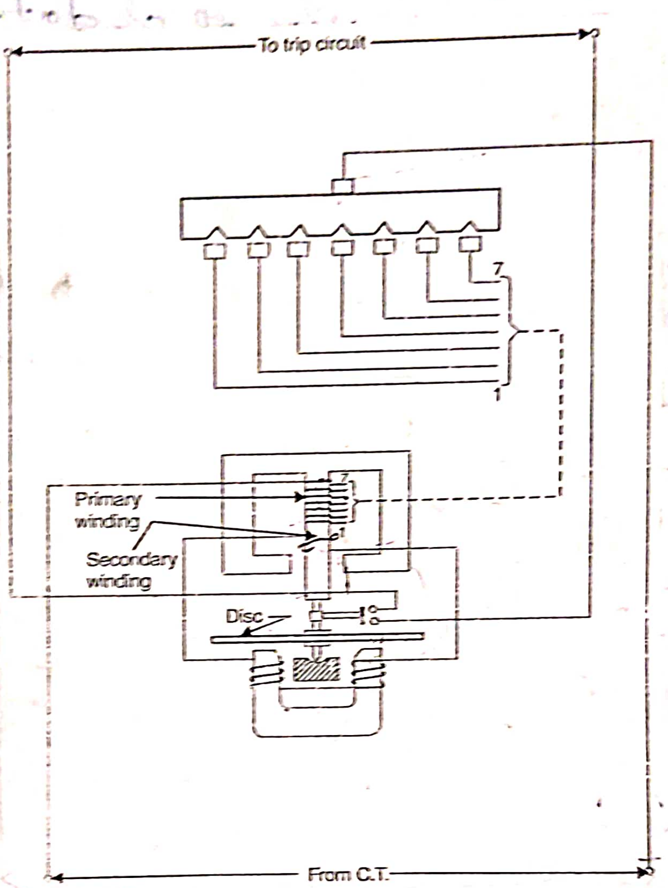
Induction Type Overcurrent Relay (Non-directional)

→ The actuating source is a current in the circuit supply to the relay from a CT.
→ Used on a.c circuits only & can operate for fault current flow in either direction.

Construction :-
→ It consists of a metallic (aluminium) disc which rotate in between the poles of two electromagnet.
→ Upper magnet has a primary and a secondary winding. Primary is connected to the secondary of a C.T. in the line to be protected and is tapped at intervals. Tapping are used for giving the desired current setting. The secondary winding is energised by induction from primary and is connected in series with the winding on the lower magnet.
→ The controlling torque is provided by a spiral spring.

→ The spindle of the disc carries a moving contact which bridges two fixed contacts (connected to trip circuit) when the disc rotates through a pre-set angle.

Operation :-



→ The driving torque (T_D) on the aluminium disc is set up due to the induction principle. This torque is opposed by the restraining torque (T_R) provided by the springs.

→ Under normal operating conditions,

$T_R > T_D$

Hence aluminium disc remains stationary.

→ If the current in the protected circuit exceeds the pre-set value, $T_D > T_R$. Hence the disc rotates and the moving contact bridges the fixed contacts when the disc has rotated ~~rotated~~ through a pre-set angle. The trip circuit operates the CB which isolates the faulty section.

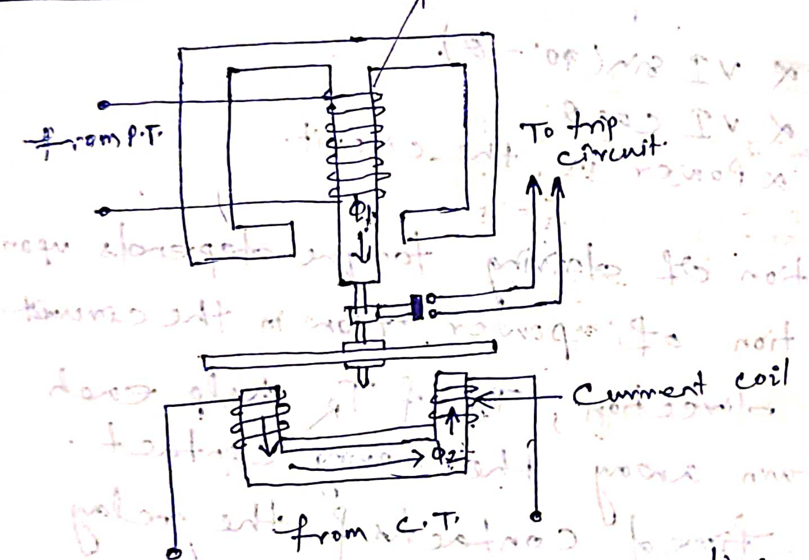
Induction Type Directional Power Relay:-

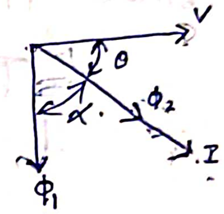
→ This type of relay operates when power in the circuit flows in a specific direction.

→ A directional power relay is so designed that it obtains its operating torque by the interaction of magnetic fields derived from both voltage and current source of the circuit it protects.

→ This type of relay is essentially a wattmeter.

Construction:-





→ It consists of an aluminium disc rotate in between the poles of two electromagnet.

→ The potential coil is connected through a PT to the circuit voltage source. The current coil is connected to the secondary of C.T. in the line to be protected. The current coil is provided with a number of tappings connected to the plug-setting bridge. This permits to have any desired current setting. The restraining torque is provided by a spiral spring.

→ The spindle of the disc carries a moving contact which bridges two fixed contacts when the disc has rotated through a preset angle

Operation:-

→ ϕ_1 lags behind applied voltage V by 90°.

→ ϕ_2 will be nearly in phase with operating current I.

→ The interaction of fluxes ϕ_1 and ϕ_2 with the eddy currents induced in the disc produces a driving torque given by.

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

Since $\phi_1 \propto V$, $\phi_2 \propto I$, $\alpha = 90 - \theta$.

$$T \propto VI \sin(90° - \theta).$$

$$\propto VI \cos\theta.$$

$\propto$ Power in the circuit.

→ The direction of driving torque depends upon the direction of power flow in the circuit

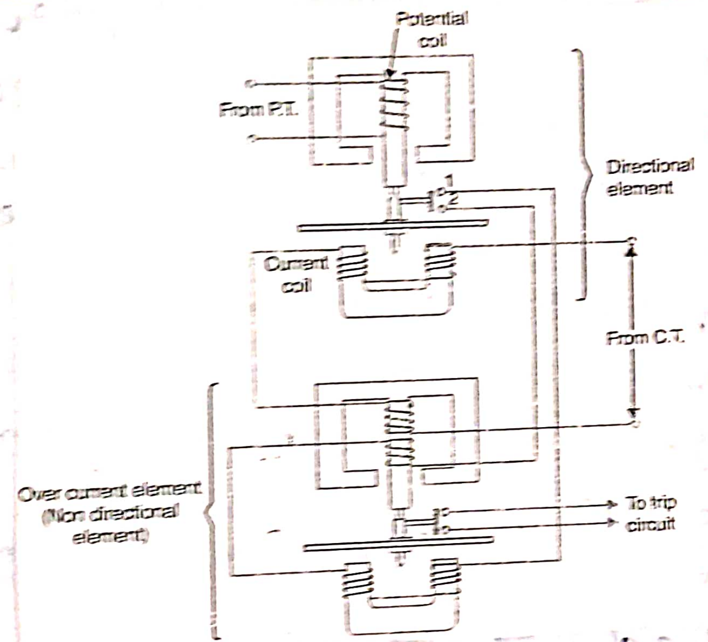
→ In normal direction, T_D & T_R help each other to turn away the moving contact from the fixed contacts & the relay remains inoperative

→ The reversal of current in the circuit reverses the direction of driving torque on the disc. When the reversed driving torque is large enough, the disc rotates in the reverse direction and the moving contact closes the trip circuit. This causes the operation of the circuit breaker which disconnects the faulty section.

Induction Type Directional Overcurrent Relay :-

→ When a short circuit occurs, the system voltage falls to a low value and torque developed in the relay is not sufficient to cause its operation. This difficulty is overcome in this relay which is designed to be almost independent of system voltage and power factor.

Construction :-



It consists of two relay elements mounted on a common case.

i) Directional element :-

→ It operates when power flows in a specific direction. The PC is connected through P.T. to the system voltage. The CC is energised through a C.T. by circuit current. The CC is carried over the upper magnet of the non directional element.

→ The trip contacts 1 & 2 are connected in series with the secondary circuit of over current element. So non-directional element cannot start to operate until its secondary circuit is completed.

ii) Non-directional element:-

The spindle of the disc of this element carries a moving contact which closes the fixed contacts after the operation of directional element.

Operation:-

→ Under normal operating conditions, directional power relay does not operate, so keeping the overcurrent element unenergised.

→ But when a short-circuit occurs, there is a tendency for the current or power to flow in the reverse direction. The disc of the upper element rotates to bridges the fixed contacts 1 & 2. This completes the circuit for over current element. The disc of lower element rotates and moving contact attached to its closes the trip circuit. This operates the CB which isolates the faulty section.

Differential Relays:-

Most of the relays operate on excess of current. Such relays are less sensitive as they can't make correct distinction between heavy load conditions and minor fault conditions. So to overcome this problem, differential relays are used.

→ A differential relay is one that operates when the phasor difference of two or more similar electrical quantities exceeds a pre-determined value.

There are two types.

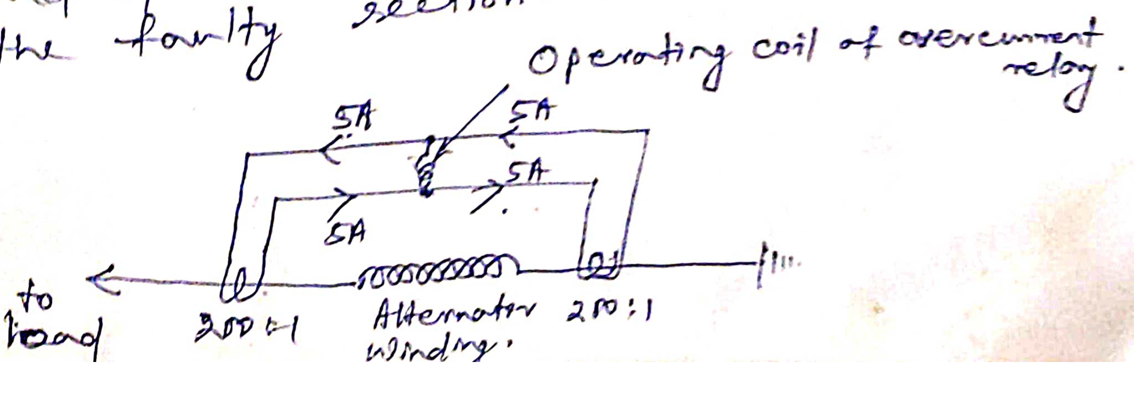
i) Current balance protection.

2) Voltage balance protection.

i) Current balance Differential Relay:-

A current differential relay is one that compares the current entering a section of the system with the current leaving the section.

→ Under normal operating conditions, the two currents are equal but as soon as a fault occurs, this condition no longer applies. The difference between the incoming and outgoing currents is arranged to flow through the operating coil of the relay. If this differential current is equal to or greater than pick-up value; the relay will operate and open the circuit breaker to isolate the faulty section.



→ A pair of identical current transformers are fitted on either end of the section to be protected. The secondaries of C.T's are connected in series in such a way that they carry the induced currents in the same direction. The operating coil of the over current relay is connected across the CT secondary circuit.

→ This differential relay compares the current at the two ends of the alternator winding.

→ Under normal operating conditions, suppose the alternator winding carries a normal current of 1000A. Then the current in the two secondaries of CT's are equal. So there will be no current flow through the differential relay.

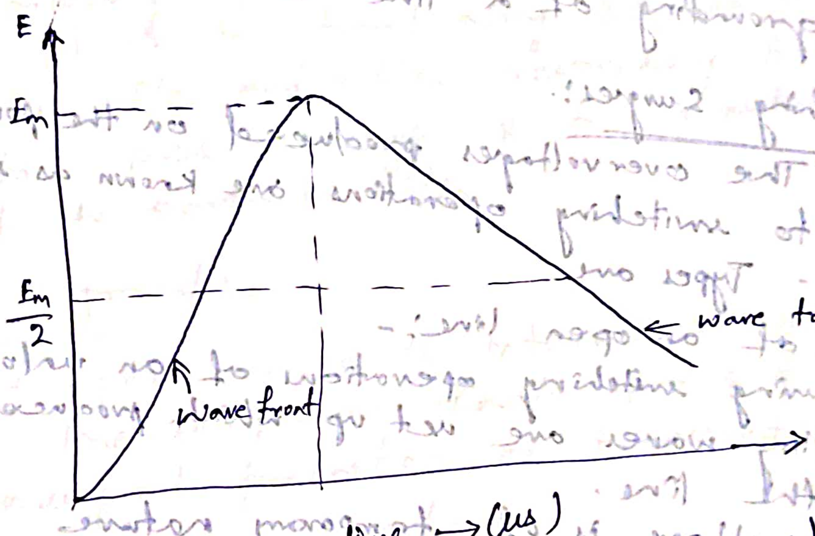
Protection Against Overvoltages.

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

-> surge due to lightning, opening of a CB, grounding of conductor etc.

-> When lightning strikes a line, the surge rushes along the line. Such surges may cause the line insulators to flash over and may damage the near by T/Fs, generators or other equipment.

->



(wave form of a lightning surge)

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

-> lightning introduces a steep-fronted wave.

-> The steeper the wave front, the more rapid is the build up of voltage.

Causes of Overvoltage:-

It is divided into two categories

i) Internal causes

a) Switching surges b) insulation failure

c) Arcing ground d) Resonance

ii) External cause: lightning.

→ Surges due to internal cause increase the system voltage to twice the normal va[lue]

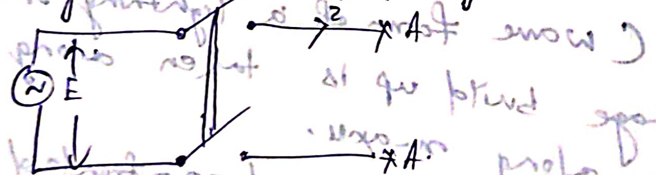
→ Surges due to lighting may increase the system voltage to several times the normal system voltage value.

Internal Causes of Overvoltages:

→ Over voltage is due to oscillations set up by the sudden changes in circuit conditions. Circuit change may be a normal switching operation such as opening of a circuit breaker, or grounding of a line conductor.

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

2) Case of an open line:-
→ During switching operations of an unloaded line, travelling waves are set up which produces overvoltage on the line.
→ Overvoltage is of temporary nature.



ii) Case of a loaded line:-
Overvoltage produce due to sudden interruption of a loaded line.

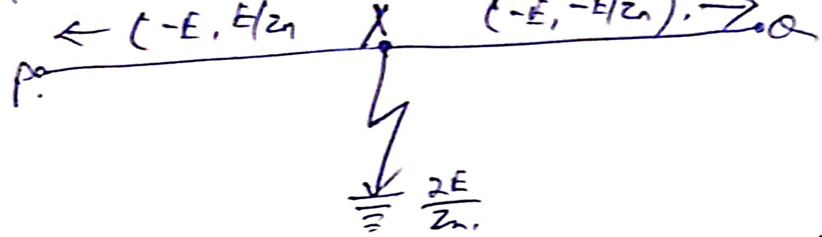
iii) Current Chopping:-
→ Current chopping results in the production of high voltage transients across the contacts of the air blast circuit breaker.
→ When breaking low current with air-blast breaker, the powerful deionizing effect of air blast causes the current to fall abruptly to zero

well before the natural current zero is reached. This is called current chopping

→ Over voltage due to current chopping are prevented by resistance switching

2. Insulation failure:-

Over voltage in the system is due to insulation failure between line & earth.



→ Suppose a line at potential E is earthed at point X. The earthing of the line causes two equal voltages of -E to travel along XQ and XP containing currents -E/Zn and +E/Zn respectively. Both these currents pass through X to earth so that current to earth is 2E/Zn.

3. Arcing ground:-

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

→ The over voltage is 3 to 4 times the normal voltage.

→ Arcing ground can be prevented by earthing the neutral.

4. Resonance:-

→ Resonance causes high voltages in the electrical system. Resonance occurs when inductive reactance is equal capacitive reactance.

→ In the usual transmission lines, the capacitance is very small so that resonance rarely occurs at the fundamental supply frequency.