chapter-1 Introduction to Switchgear

→ The greatest demand of electrical energy is a notable feature of modern civilisation.

→ The importance of electric supply in everyday life has reached such a stage that it is needed to protect the power system from harm, during fault conditions and to ensure maximum continuity of supply.

→ For this purpose, switch ON or OFF generators, transmission lines, distributors and other equipment under both normal and abnormal conditions. This is achieved by an apparatus called switchgear.

→ SWITCHGEAR :- The apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as switchgear.

→ A switchgear consists of ~~switchgear~~ switching & protecting devices such as:

(1) Switches
(2) Fuses
(3) circuit breakers
(4) Relays; etc.

→ The switchgear detects the fault and disconnects the unhealthy sections from the system.

→ Switchgear protects the system from damage and ensures continuity of supply.

→ Simplest form of switchgear

Tumbler switch + ordinary fuse.

→ Moderate form of switchgear (For high current rating)

switch + HRC (High Rupturing Capacity) fuse

→ In order to interrupt heavy fault currents, automatic circuit breakers are used.

→ ~~Circ~~ Circuit Breaker

A circuit breaker is a switchgear which can open or close an electrical circuit under both normal and abnormal conditions.

(1.1) ESSENTIAL FEATURES OF SWITCHGEAR

① Complete Reliability:

→ The switchgear is added to the power system to improve the reliability.

→ When fault occurs on any part of the power-system, the switchgear must operate to isolate the faulty section from the remainder circuit.

(ii) Absolutely certain discrimination

→ When fault occurs on any part of the power system, the switchgear must be able to discriminate between the faulty section and the healthy section.

→ This will ensure continuity of supply.

(iii) Quick Operation

→ When fault occurs on any part of the power system, the switchgear must operate quickly so that no damage is done to generators, transformers and other equipment by the short-circuit currents.

→ If fault is not cleared by switchgear quickly it is likely to spread into healthy parts, thus endangering complete shut down of the system.

(iv) Provision for manual control

→ A switchgear must have provision for manual control.

→ In case the electrical (or electronics) control fails, the necessary operation can be done through manual control.

(v) Provision for instruments

→ There must be provision for instruments which may be required.

→ These may be in the form of ammeter or voltmeter on the unit itself or the necessary voltage and current transformers for connecting to the main switchboard or a separate instrument panel.

(1.2) Switchgear Equipment

* Switchgear covers a wide range of equipment concerned with switching and interrupting currents under both normal and abnormal conditions.

It includes (1) switches
(2) Fuses
(3) circuit breakers
(4) relays and other equipments

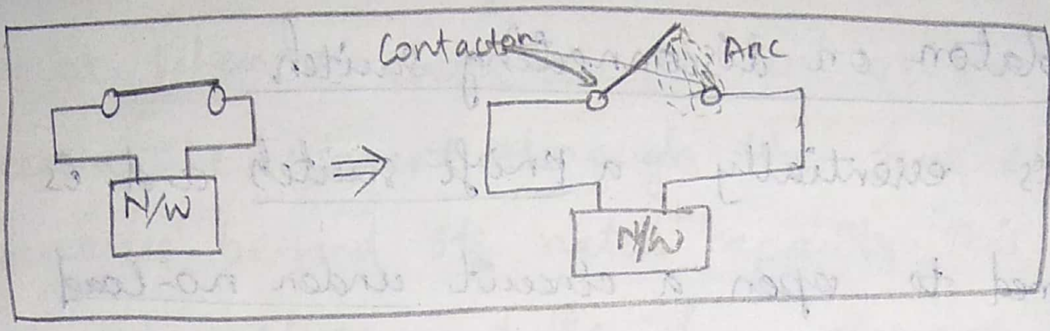
(1) SWITCHES

→ It is a device which is used to open or close an electrical circuit.

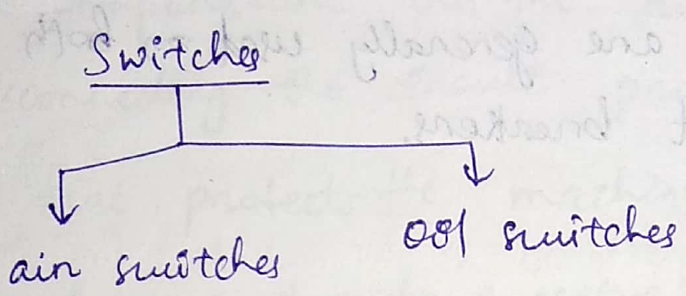
→ It can be ~~operated~~ used under full-load or no-load conditions.

→ It cannot interrupt the fault currents.

→ When the contacts of a switch are opened, an arc is produced in the air between the contacts. This is true for circuits of high voltage and current capacity.



→ Switches



(1) ~~Air switches~~ Air-break switch

Arcing horns → They are pieces of metals between which arc is formed during opening operation.

→ It is an air switch and is designed to open a circuit under load.

→ Special arcing horns are provided to quench the arc during opening the switch.

→ After open the switch, the arcing horns spreads the arc. ~~Then the ar~~ Gradually the arc is lengthened, cooled and interrupted.

→ Air break switches are generally 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.

→ Such switches are generally used on both sides of circuit breakers.

(iii) Oil switches

→ The contacts of such switches are opened under oil, usually transformer oil.

→ The effect of oil is to cool and quench the arc.

→ 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 ~~which~~ melts when excessive current flows through it for sufficient time.

→ It is connected in series with the circuit to be protected.

→ Under normal operating conditions, the fuse element is at a temperature below its melting point. When a short circuit or overload occurs, the current through the fuse element increases beyond its rated capacity. This raises the temperature and the fuse element melts, disconnecting the circuit protected by it.

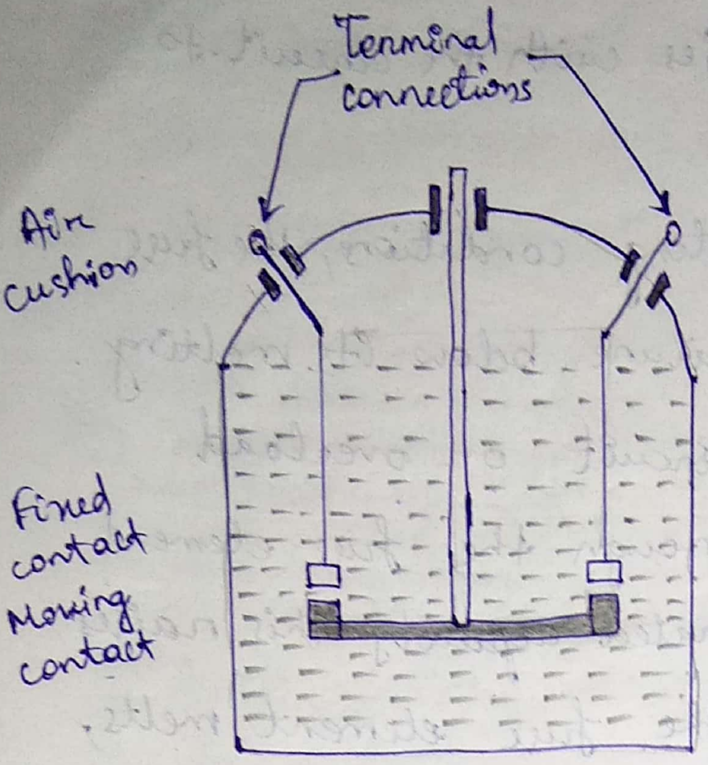
→ A fuse protects the machines and equipment from damage due to excessive currents.

NOTE
A fuse can detect/sense and break/interrupt the circuit under short-circuit or overload condition.

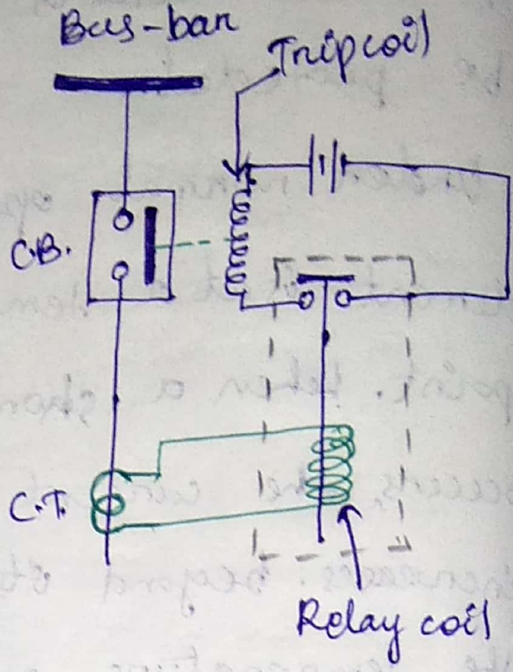
③ Circuit Breakers

→ It is an equipment which can open or close a circuit under all conditions (no-load, full-load and fault conditions)

→ It can be operated manually under normal conditions and automatically under fault conditions.



(Fig-1)



(Fig-II)

→ Fig-1 shows the parts of a typical oil circuit breaker.

→ The circuit breaker consists of moving and fixed contacts enclosed in strong metal tank and immersed in oil, known as transformer oil.

→ Fig-II shows circuit breaker control by a relay circuit.

→ <u>Operation</u>

→ Under normal operating conditions, the contacts remain closed and the circuit breaker carries the full load current continously.

→ In this condition, the emf in the secondary winding of of C.T. is insufficient to operate. the trip coil of the breaker but the contacts can be opened by manual or remote control.

→ When a fault occurs, the resulting overcurrent in the C.T. primary winding increases the secondary emf.

This energises the trip coil of the breaker and moving contacts are pulled down, thus opening the contacts. The arc produced during the opening operation is quenched by the oil.

NOTE: Hence the circuit breaker does the actual circuit interruption.

(4) RELAYS

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

→ Fig-11 shows a typical relay circuit. It can be divided into 3 parts

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

(2) The second circuit is the secondary winding of C.T. connected to the relay operating coil.

(3) The third ckt is the tripping circuit which consists of a source of supply, trip coil of ckt. breaker and the relay stationary contacts.

OPERATION

Under normal load conditions

→ secondary emf of CT is small.

→ Due to that, the relay coil is not energised or fully magnetised.

~~Under~~ When fault occurs

→ Primary current of CT increases. and secondary ~~of~~ voltage of CT increases. Then the relay coil is energised to close the trip ckt.

→ Then the trip coil will energised by the battery voltage. and hence it opens the contacts of CB.

(1.3) Bus-Bar Arrangement

Busbars → It is a copper rod or thin walled tubes 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.

NOTE All the diagrams refer to 3-phase arrangement but are shown in single-phase for simplicity.

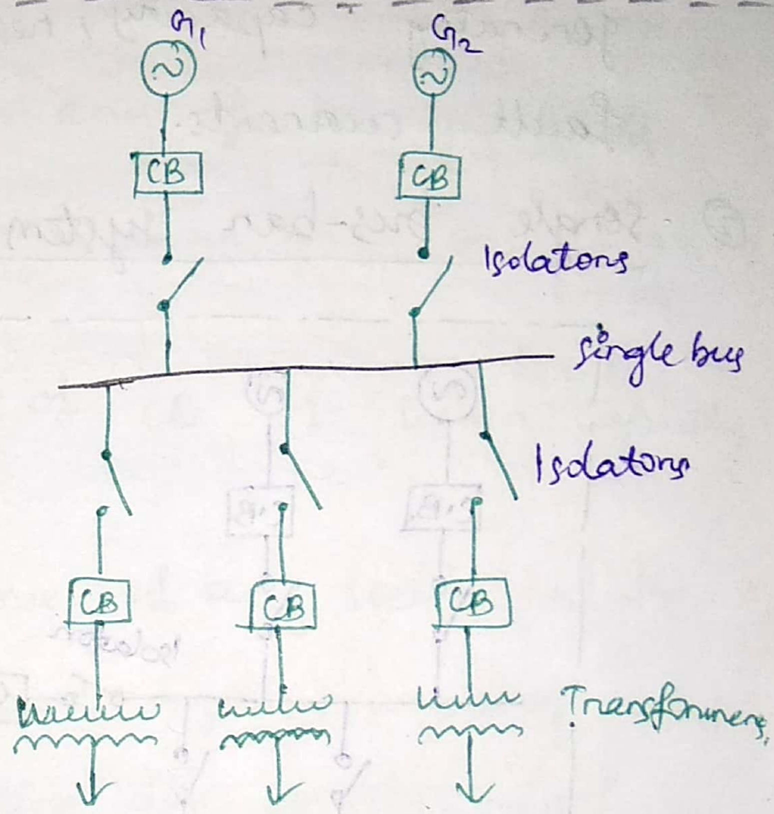
① Single Bus-bar System

→ It is used for power stations

→ It is also used in small outdoor stations having relatively few outgoing or incoming feeders and lines.

→ Fig (a) shows the single busbar system for a typical power station.

→ The Generators, outgoing lines and transformers are connected to the busbar



(Fig-a)

→ Each generator and feeder is controlled by a CB.

→ The isolator allow to isolate the generators, feeders and CB from the bus-bar for maintenance.

Advantages

→ Low initial cost

→ Less maintenance

→ simple operation.

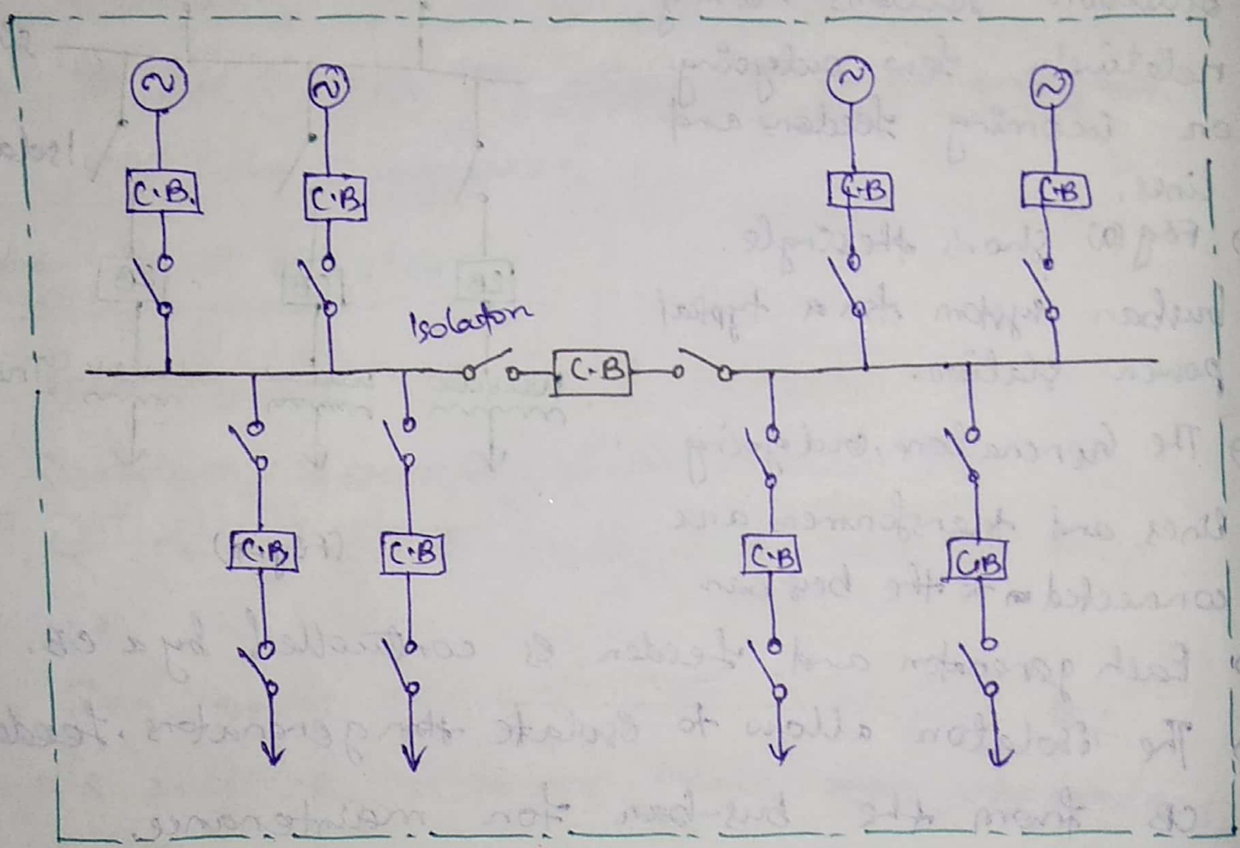
Disadvantages

→ The busbar cannot be cleared, repaired or tested without de-energising the whole system.

→ If a fault occurs on the bus-bar itself, there is complete interruption of supply.

→ Any fault on the system is fed by all the generating capacity, resulting in very large fault currents.

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.

→ The above fig. shows the bus-bars divided into two sections connected by a CB and isolators.

Advantages

(1) If a fault occurs on any section of the bus-bar, that section can be isolated without affecting the supply to other sections.

(2) If a fault occurs on any feeder, the fault current is much lower than with unsectionalised bus-bar.

This permits the use of CB of lower capacity in the feeders.

(3) Repairs and maintenance of any section of the bus-bar can be carried out by de-energising that section only, eliminating the possibility of complete shut-down.

(3) Duplicate Bus-bar system

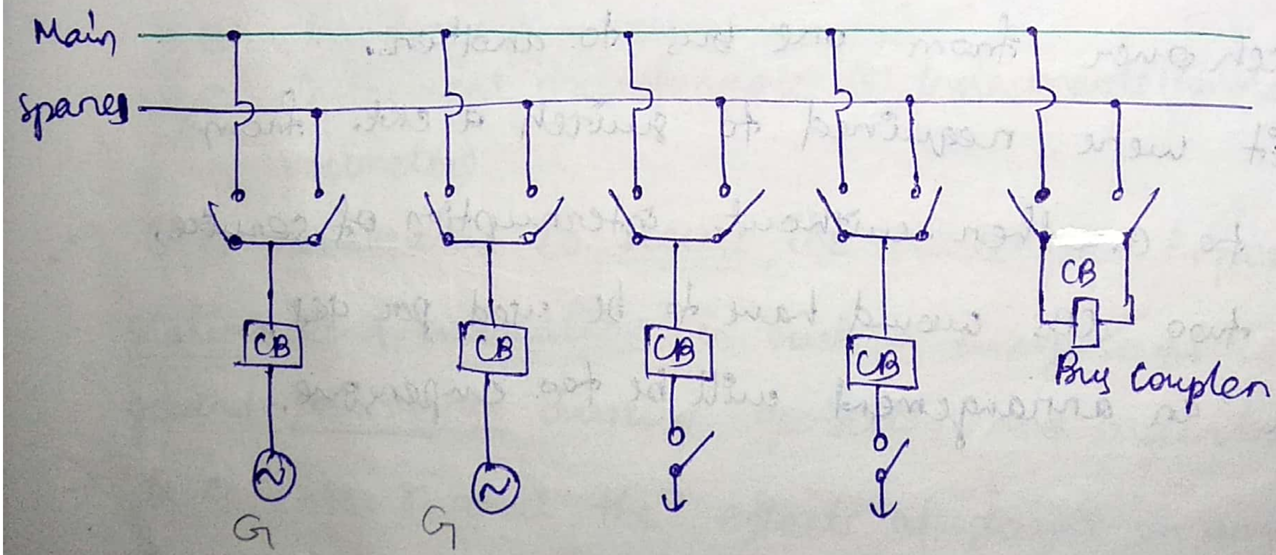


Fig (9)

→ Duplicate busbars is used to achieve the continuity of supply during breakdown & maintenance

→ It is used in important stations (Large stations)

→ This system consist of two bus-bars,

(1) Main bus-bar

(2) spare bus-bar.

→ Each generator and feeder may be connected to both main & spare bus-bar with the help of bus coupler.

→ The bus-coupler consist of circuit breaker & isolators.

→ The duplicate bus-bar system is shown in the fig (a).

→ In this scheme, service is interrupted during switch over from one bus to another.

→ If it were required to switch a ckt. from one to another without interruption of service, then two CBs would have to be used per ckt. Such an arrangement will be too expensive.

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Advantages

→ If repair and maintenance is required on the main bus, then the entire load can be transferred to the spare bus. Hence the continuity of supply need not be interrupted.

→ The testing of feeder ckt. breakers can be done by putting them on spare bus-bars, thus keeping the main bus-bar undisturbed.

→ If a fault occurs on the bus-bars, the continuity of supply to the circuit can be maintained by transferring it to the ~~main~~ other bus-bar.

1.4 SWITCHGEAR ACCOMMODATION

The main ~~component~~ components of a switchgear are

(1) CB (2) Switches

(3) bus-bars

(4) Instrument transformers. (5) Instruments (Ammeter & voltmeters)

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

→ It is ensure that the effects of fault on any section of the gear are occur to a limited region.

→ Depending upon the voltage to be handled, switchgear may be broadly classified into two types
(i) Outdoor type
(ii) Indoor type.

(1) Outdoor type

→ For voltages more than 66KV, switchgear equipment is installed outdoor.

→ It is because for such voltages, the clearance between the conductors and the space required for switches, circuit breakers, transformers & other equipment become so great that it is not economical to install all such equipment indoor.

(2) Indoor Type

→ For voltages below 66KV, switchgear is generally installed indoor because of economic considerations.

→ All live parts are completely enclosed in an earthed metal casing.

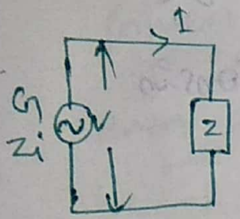
→ This switchgear is generally of metal-clad type.

1.5 SHORT CIRCUIT

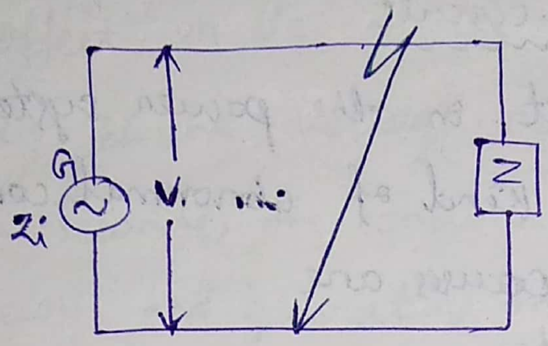
→ Whenever a fault occurs on a network, if a large current flows in one or more phases, a short-circuit is said to have occurred.

→ When a short-circuit occurs, a heavy current called short circuit current flows through the circuit.

→ Ex:-



Fig(a)



Fig(b)

The figure(a) shows a single phase generator of voltage V & internal impedance Z_i is supplying to a load Z.

Under normal conditions, the current in the ckt. is limited by load impedance Z.

If the load terminals get shorted due to any reason as illustrate in fig(b). The ckt. impedance is reduced to very low value.

Normal condition

$$I = \frac{V}{Z_i + Z}$$

Short-circuit condition

$$I = \frac{V}{Z_i} = \text{very high value}$$

because internal impedance is very low.

→ Therefore a large current flows through the circuit. This is called short-circuit current.

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

Causes of Short-circuit

A short circuit in the power system is the result of some kind of abnormal conditions in the system. The causes are

(i) Internal effects

→ Breakdown of equipment on transmission lines.

→ Defect of insulation in a generator, transformer, etc.

→ Ageing of insulation, inadequate design or improper installation.

(ii) External effects

When a short circuit occurs the current in the system increases to an abnormally high value while the system voltage decreases to a low value.

→ Insulation failure due to lightning surges.

→ Overloading of equipment causing excessive heating

→ Mechanical damage by public/human

* EFFECTS OF SHORT CIRCUIT

→ Fire or explosion due to excessive heat from over current

→ Considerable damage occurs to the system due to formation of arc

→ The voltage created by the fault has a very harmful effect on the service rendered by the power system. If the voltage remains low for even a few seconds, the consumers motors may be shut down and generators on the power system may become unstable.

1.6 SHORT-CIRCUIT CURRENTS

Most of the failures on the power system lead to short circuit fault and cause heavy current to flow in the system.

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

(1) A short circuit on the power system is cleared by a circuit breaker or a fuse. It is necessary therefore, to know the maximum possible values of short circuit currents so that switchgear of suitable rating may be installed to interrupt them.

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

(iii) The magnitudes 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 (eg:- bus-bars, CT, etc) so that they can withstand the forces that arise due to the occurrence of short circuits.

1.7 FAULTS IN A POWER SYSTEM

→ A fault occurs when two or more conductors that normally operate with a potential difference come in contact with each other.

→ These faults may be caused by sudden failure of a piece of equipment, accidental damage or short-circuit to overhead lines or by insulation failure resulting from ~~lighting~~ lightning surges.

→ Irrespective of the causes, the faults in a 3-phase system can be classified into two types.

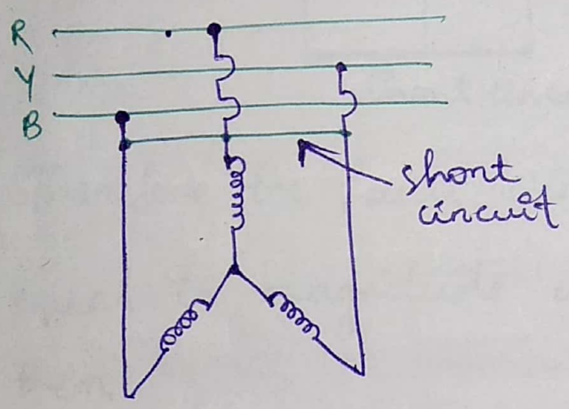
(i) Symmetrical faults

(ii) Unsymmetrical faults.

(i) Symmetrical faults

The fault which give rise to equal fault currents with 120° displacement is called a symmetrical fault.

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



(ii) Unsymmetrical faults

The fault which give rise to unequal line currents with unequal displacement are called unsymmetrical faults.

The unsymmetrical faults are 3 types

1. Single line to ground fault (L-G)
2. Line to Line (L-L) fault
3. Double line to ground (L-L-G) fault.

→ Maximum occurring fault is unsymmetrical fault.

→ But the symmetrical fault is happen very rarely but very severe.

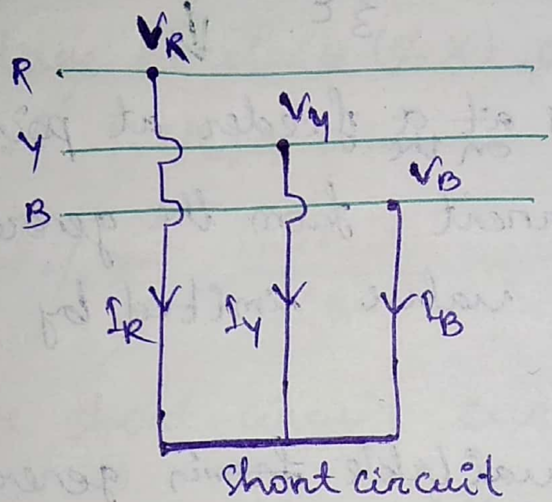
→ Most commonly single line to ground (L-G) fault occurs.

CHAPTER-02

FAULT CALCULATION

(2.1) Symmetrical faults on 3-phase system

→ The symmetrical fault occurs when all the three conductors of a 3-phase line are brought together simultaneously into a short-circuit condition.



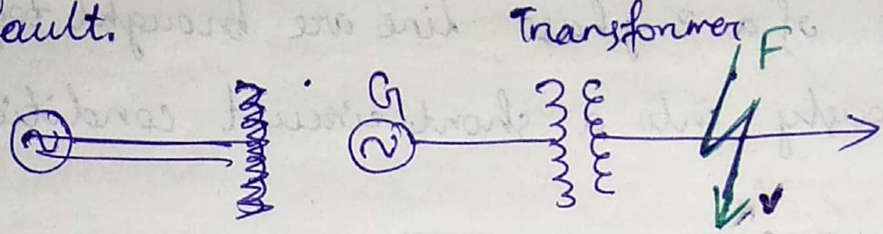
→ Therefore the fault currents I_R, I_Y, & I_B will be equal in magnitude with 120° displacement among them.

→ Because of balanced nature of fault, only one phase need be considered in calculations.

→ The symmetrical fault is the most severe and imposes more heavy duty on the circuit breaker.

(2.2) Limitation of Fault Current

→ When a short circuit occurs at any point in a system, the short circuit current is limited by the impedance of the system upto the point of fault.

→ 

If a fault occurs ~~at a~~ on the feeder at point F, then the short circuit current from the generating station will have a value limited by the impedance.

→ The impedance is available ~~from~~ in generator, transformer and the impedance of the line between the generator and the point of fault.

→ The impedances are limiting the fault current. are largely reactive.

(2.3) Percentage Reactance

→ The reactance of generator, transformers, reactors etc ~~is~~ expressed in percentage reactance to allow ~~easy &~~ quick short circuit calculations.

→ It is defined as the total phase voltage dropped in the circuit when full load current is flowing.

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

where, I = full-load current

V = phase voltage

X = reactance in ohms per phase.

→ Percentage reactance (% X) can also be expressed in terms of KVA and KV.

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

Now the short circuit current is

$$I_{sc} = \frac{V}{X} \quad \text{(If only reactance is present in the ckt)}$$

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

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

$$= \frac{(\% X) \times V \times V}{100 I \cdot \times V} \quad (\because \text{Multiply V in both numerator \& denominator})$$

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

$$X = \frac{KV \times KV \times (\% X)}{\left(\frac{KVA}{10}\right)}$$

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

⊛ Find short circuit current when 50 Amp current is flowing in the system, the percentage reactance of an element is 20%.

Soln $I = 50$ Amp.

$\% X = 20\%$

$$I_{sc} = I \times \frac{100}{\% X} = \frac{50 \times 100}{20} = 250 \text{Amp}.$$

We know, $I_{sc} = \frac{V}{X}$, $V = \frac{I \times X}{\% X}$, $I_{sc} = \frac{I \times X}{X \times (\% X)} = \frac{I}{(\% X)} = \frac{50}{\frac{20}{100}}$

$= \frac{50 \times 100}{20} = 50 \times 5 = 250$ Amp.

~~2.4 Percentage Reactance & Base KVA~~

Advantage of Using %X ~~system~~.

→ The advantage of using percentage reactance instead of ohmic reactance in short circuit calculations are.

(i) Percentage reactance values remain unchanged as they are referred through transformers, unlike ~~percentage~~ ohmic reactances which become multiplied or divided by the square of transformation ratio.

(ii) This makes the procedure simple and provide quick calculations.

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2.4 Percentage Reactance & Base KVA

→ The equation ② shows that percentage reactance of an equipment depends upon its KVA rating.

→ But the various equipments used in the power system have different KVA ratings, therefore it is necessary to find the percentage reactances of all elements on a common KVA rating.

→ This common KVA rating is known as base KVA.

→ The value of base KVA may be

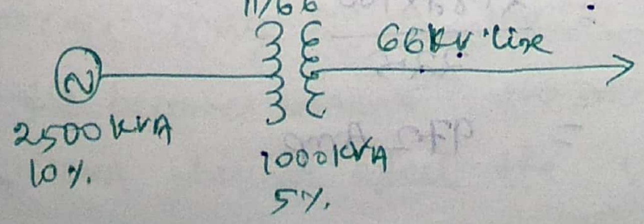
(i) Equal to that of largest plant

(ii) Equal to the total plant capacity

(iii) Any arbitrary value.

→ $\% X \text{ at base KVA} = \frac{\text{Base KVA}}{\text{Rated KVA}} \times (\% X \text{ at rated KVA})$

Ex: ① Consider a 3-phase transmission line ~~ground~~ operating at 66KV and connected through a 1000KVA transformer with 5% reactance to a generating station bus-bar. The generator is of 2500KVA with 10% reactance. The single line diagram of the system is shown in fig below,



Soln (1) ~~Suppose~~ Let we choose maxm KVA rating as the common base KVA.

Common base KVA = 2500 KVA

% reactance of t/f at 2500 KVA base

$$= \frac{2500}{1000} \times 5$$

$$= 12.5\ \%$$

%age reactance of generator at 2500 KVA base

$$= \frac{2500}{2500} \times 10$$

$$= 10\ \%$$

Total percentage reactance on the common base KVA is

$$\%X = 12.5 + 10 = 22.5\ \%$$

The FL current corresponding to 2500 KVA base at 66 KV is

$$I = \frac{\text{Base KVA}}{\sqrt{3} \times \text{Bus-bar voltage}} = \frac{2500 \times 1000}{\sqrt{3} \times 66 \times 1000} = 21.87\ \text{Amp.}$$

∴ short circuit current

$$I_{sc} = \frac{I}{\%X} = \frac{21.87}{\frac{22.5}{100}}$$

$$= \frac{21.87 \times 100}{22.5}$$

$$= 97.2\ \text{Amp.}$$

(ii) Now, suppose we choose 5000 KVA as the common base value.

% X of T/f at 5000 KVA base

$$= \frac{5000}{1000} \times 5 = 25\%$$

% X of G aton ~~common~~ 5000 KVA base value

$$= \frac{5000}{2500} \times 10 = 20\%$$

Total percentage reactance on the common base KVA value

$$\% X = 25 + 20 = 45\%$$

Full load current corresponding to 5000 KVA at 66 KV line

$$I = \frac{P}{\sqrt{3} \times V} = \frac{5000 \times 1000}{\sqrt{3} \times 66 \times 1000} = 43.74 \text{ Amp.}$$

short circuit current,

$$I_{sc} = \frac{I}{\% X} = \frac{43.74}{\frac{45}{100}}$$

$$= \frac{43.74 \times 100}{45} = 97.2 \text{ Amp.}$$

From the above ~~example~~ it is clear that, whatever may be the value of base KVA, SC current ~~is the becomes same~~, is the same. So the value of base KVA doesnot effect the short circuit current.

(2.5) 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.

Short circuit current;

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

∴ Short-circuit KVA for 3-phase circuit

$$= \frac{3 V I_{sc}}{1000}$$

$$= \frac{3 V I}{1000} \times \frac{100}{\% X} \quad \left(\because I_{sc} = \frac{I \times 100}{\% X}\right)$$

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

where, V = normal phase voltage in volts

I = FL current in amperes at base KVA

% X = percentage reactance of the system on the base KVA upto the fault point.

(2.8) Steps for Symmetrical Fault Calculations

→ In symmetrical fault, we will calculate fault current ~~for~~ of one-phase. Because the fault currents in the 3-phases are are equal in magnitude but displaced in 120° electrically from one another.

→ The steps to solve the problem are ~~given~~ given below:

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

(2) Choose a numerically convenient value of base KVA and convert all percentage reactances to this base value.

(3) Draw the reactance diagram showing one phase of the system and the neutral. ~~similar~~ Indicate the % reactances on the base KVA in the reactance diagram. The transformer in the system should be represented by a reactance in series.

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

(5) Find the FL current corresponding to the selected base KVA and the normal system voltage at the fault point. Let it be I

(6) Then the short circuit calculations are

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

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

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2.6 Reactor Control of Short-Circuit Current

→ Generally, the reactance of the system under fault conditions is low and fault currents may rise to a dangerous high value.

→ If no steps are taken to limit the value of these short-circuit currents, then not only the CB required excessive heavy duty but also damage to lines and other equipment will almost certainly occur.

→ An additional reactances known as Reactors are connected in series with the system at suitable points in order to limit the short-circuit current. Then the value of short-ckt current can handle the circuit breaker.

→ A reactor is a coil having number of turns

→ which is designed to have a large inductances as compared to its ohmic resistance.

→ The windings of reactors must be solidly braced.

→ By adding the reactor, there is very little change in the efficiency of the system due to the reactor having very small resistance.

Advantages

(i) It limit the flow of short-circuit current

(ii) It protect the equipment from over heating as well as from failure due to destructive mechanical forces

(iii) Troubles are localised or isolated at the point at where they originate without communicating their disturbing effects to other parts of the power system. This increase the chances of continuity of supply.

(iv) They permit the installation of CB of lower rating.

(2.7) Location of Reactors

Short circuit current limiting reactors may be connected in (i) series with each generator

(ii) series with each feeder

(iii) bus-bars

(i) Generator Reactors

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

In this case, the reactor may be considered as a part of leakage reactance of the generator; hence its effect is to protect the generator in the case of any short-circuit beyond the reactors.

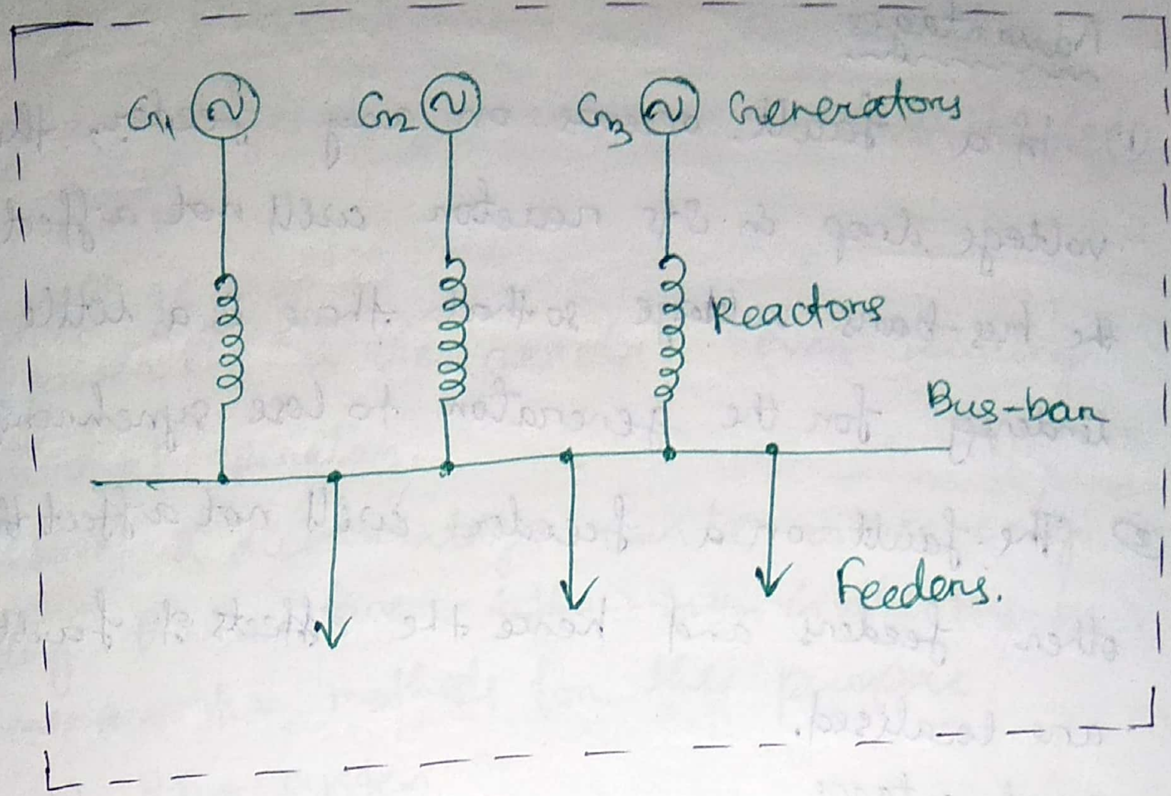
Disadvantages

(i) There is a constant voltage drop and power loss in the reactors even during normal operation

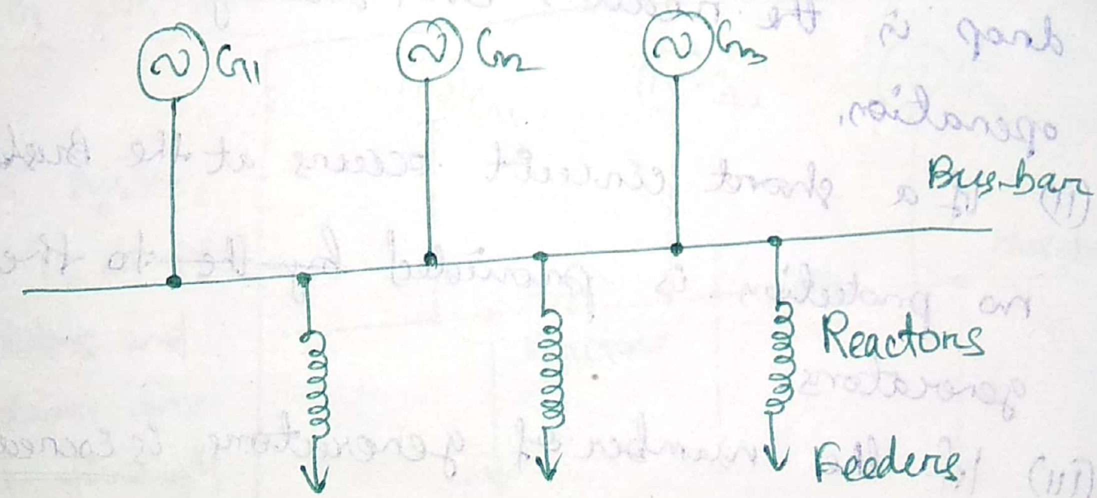
(ii) If a bus-bar or feeder fault occurs close to the bus-bar, the voltage at the bus-bar will be reduced to a low value, thereby causing the generators to fall out of step.

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

Due to these disadvantages and also since modern power station generators have sufficiently large leakage reactance to protect them against short-circuit, it is not a common practice to use separate reactors for the generators.



② FEEDER REACTORS



→ When the reactors are connected in series with each feeder, they are known as feeder reactors, which is shown in the above figure.

→ Most of the short-circuits occur on feeders, a large number of reactors are used for such circuits.

Advantages

(1) If a fault occurs on any feeder, the voltage drop in its reactor will not affect the bus-bars voltage so that there is a little tendency for the generator to lose synchronism.

(2) The fault on a feeder will not affect the other feeders and hence the effects of fault are localised.

Disadvantages

(1) There is a constant power loss and voltage drop in the reactors even during normal operation.

(ii) If a short circuit occurs at the Busbars, no protection is provided ~~by the~~ to the generators.

(iii) If the number of generators is increased, the size of feeder reactors will have to be increased. to keep the short-circuit currents within the ratings of the feeder circuit breakers.

(Agni)

③ Bus-bar Reactors

→ Disadvantages of generator reactors & feeder reactors are

① voltage drop

② power loss in the reactors even during normal operation.

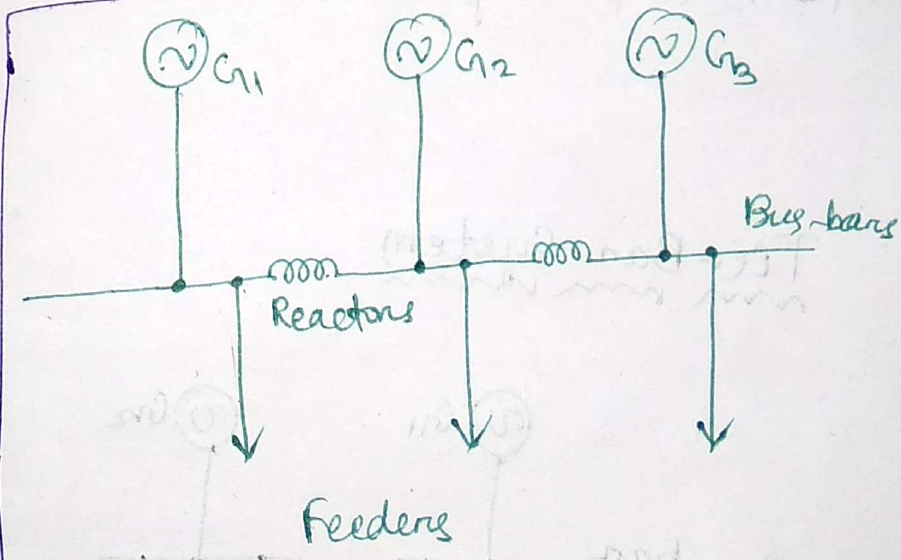
→ The above 2 disadvantages can be overcome by locating the reactors ~~in the bus~~ in the bus-bars.

→ There are two methods for this purpose.

(1) Ring system

② Tie-Bar system

① RING SYSTEM



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

→ One feeder is fed from one generator only.

→ Under normal operating conditions, each generator will supply its own section of the load and very little power will be fed by ~~the~~ other generators.

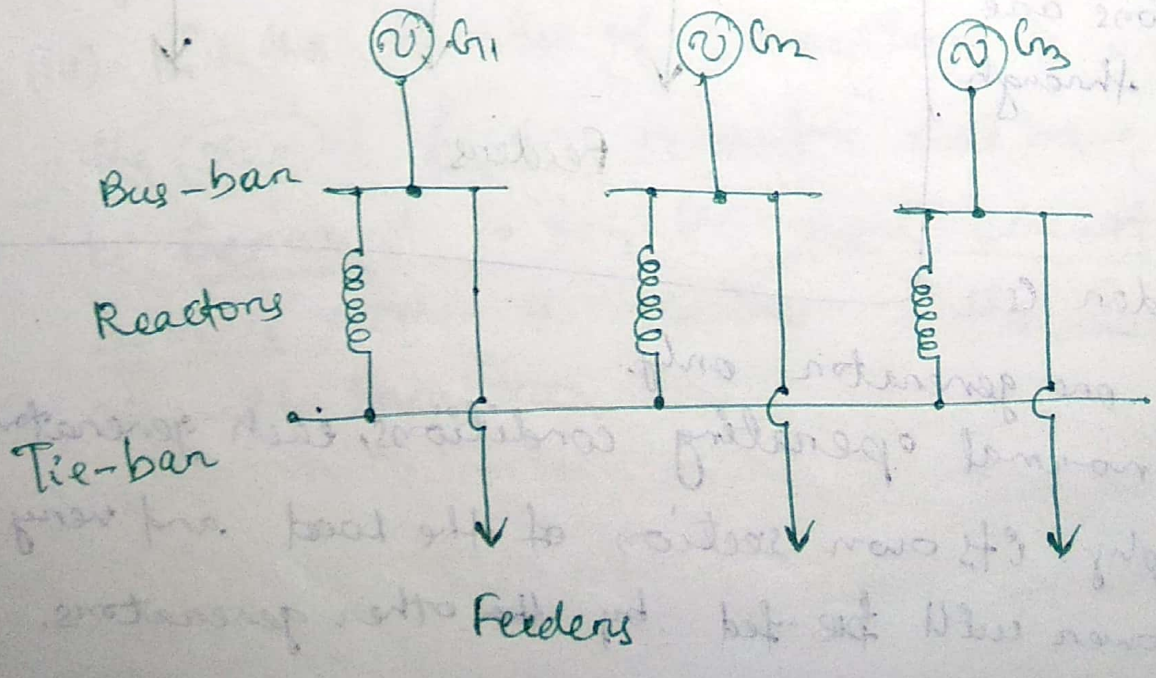
→ This results in low power loss and voltage drop in the reactors.

Advantages

① If a fault occurs on any feeder, only one generator mainly feeds the fault current while the current fed from other generators is small due to the presence of reactors.

② Therefore only ~~that~~ fault sectn of the busbar is affected to which the feeder is connected, the other sectn being able to continue in normal ~~operat~~ operation,

Tie-Bar System



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

Advantages

→ The additional generators may ~~not~~ be connected to the system without requiring changes in the existing reactors.

Disadvantages

→ It requires an additional bus-bar.
that is tie-bar.

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 ckt.

Features of fuse element

① Low melting point
② High conductivity
③ Least deterioration due to oxidation.

3.1 Desirable Characteristics of Fuse Element

- The function of a fuse is to carry the normal current without overheating but when the current exceeds its normal value, it rapidly heats up to melting point and disconnects the ckt. protected by it.

The fuse element should have the following desirable characteristics:

(i) low melting point (Ex:- tin, lead)
(ii) High conductivity (Ex:- silver, copper)
(iii) free from deterioration due to oxidation (silver)
(iv) low cost (Ex:- lead, tin, copper.

The above point reveals that no material possesses all the characteristics. Therefore, a compromise is made in the selection of material for a fuse.

(3.2) Fuse Element Materials

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

→ For small currents (upto 10 Amp)

~~upto 10A,~~ tin or an alloy of lead & tin (lead 37%, tin 63%) is used for making the fuse element

→ For larger currents

Copper or silver is employed. Because copper protect it ~~for~~ from oxidation.

→ Zinc is good but it takes more time to melt. as compared to other ~~elem~~ fuse element

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 doesnot deteriorate when used in dry air

(iii) The coefficient of expansion of silver is so small that no critical fatigue occurs, Therefore the fuse element can carry the rated current continuously for a long time.

(iv) The conductivity of silver is very high.

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

(vi) Silver vapourises at very low temperature at which its vapour will readily ionise. Therefore an arc is formed through the vapourised portion of the element, ~~having~~ having high resistance. As a result, SC current is quickly/~~rapidly~~ interrupted.

3.3 Important terms used for fuses

① Current rating of fuse element

→ It is the current at which the fuse element can normally carry without overheating/melting.

② Fusing current

→ It is ~~the~~ minimum current at which the fuse elements melts and thus disconnects the ckt ~~pro~~ and protect the ckt elements, ~~and~~ devices.

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

→ It depends ~~on~~ upon the temperature rise of the contact of the fuse holder, fuse material and the surroundings of the fuse.

→ For a round wire, the approximate relationship betn fusing current I & the diameter d of of the wire is

$$I = K d^{3/2} = Kd^{1.5}$$

where, K = constant, called fuse constant.

Its value depends upon the metal of which the fuse element is made.

→ Sir W.H. Preece found the value of K for different materials.

Material	Value of K: d in cm	Value of K: d in mm
Copper	2530	80
Aluminium	1873	59
Tin	405.5	12.8
Lead	340.6	10.8

The fusing current depends upon:

(a) Material of fuse element 

(b) length.

(c) diameter

(d) size & location of terminals

(e) Previous history

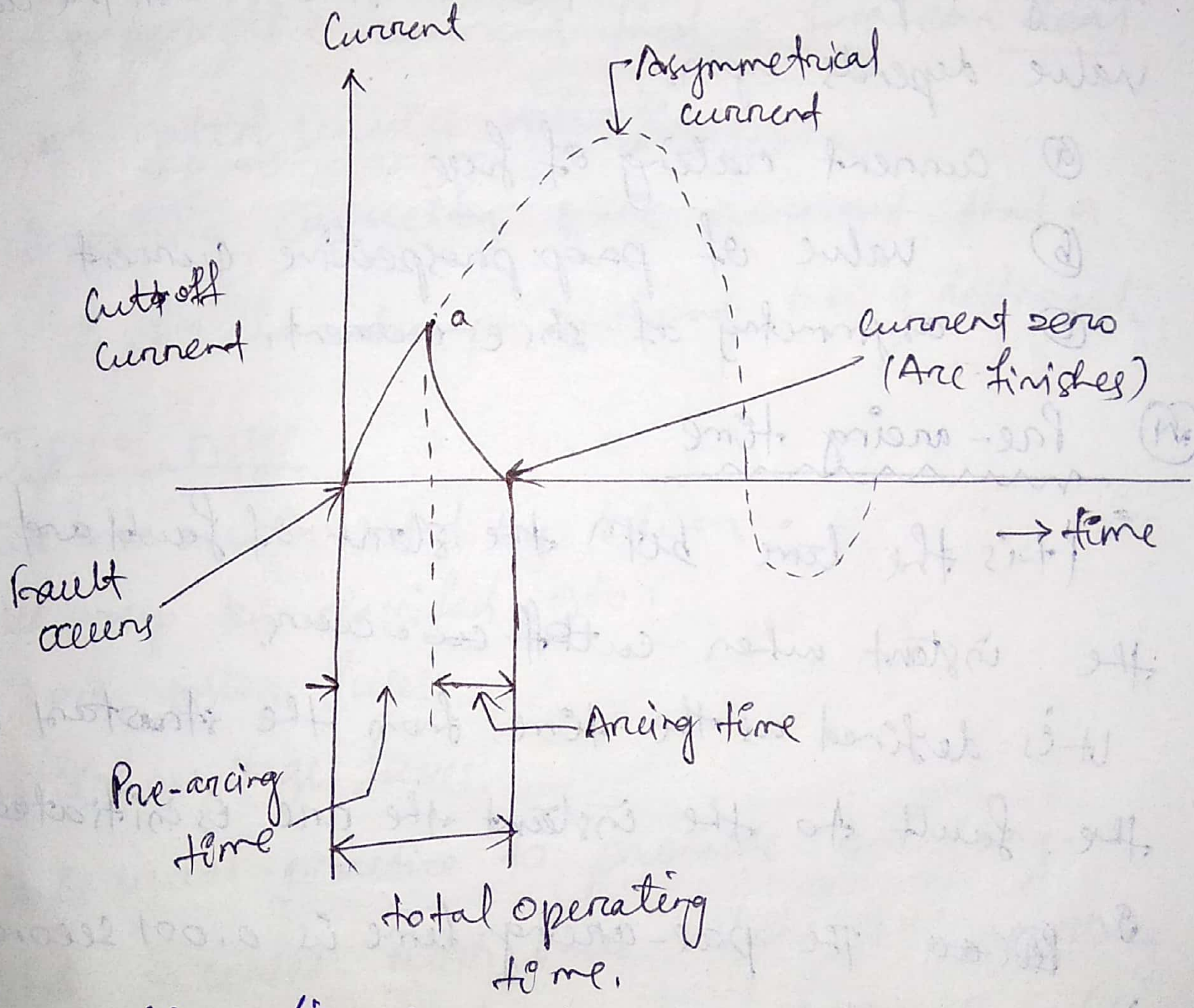
(f) type of enclosure used.

③ Fusing factor

It is defined as the ratio of minimum fusing current to the current rating of the fuse element

$$\text{Fusing factor} = \frac{\text{Min}^m \text{ fusing current}}{\text{current rating of fuse.}}$$

→ Its value is always more than one.



④ Prospective current

The rms value of the 1st loop of fault current is known as prospective current.

It is the rms value of the 1st loop of the fault current obtained if the fuse is replaced by an ordinary conductor of negligible resistance

(v) Cut-off current

It is the maxm value of fault current actually reached before the fuse melts. The current corresponding to point 'a' is the cut-off current. The cut-off value depends upon.

(a) current rating of fuse
(b) value of ~~prop~~ prospective current
(c) asymmetry of ~~ph~~ ase current.

(vi) Pre-arcing time

It is the time betn the start of fault and the instant when cutoff ~~cu~~ occurs.

It is defined as the time from the ~~sta~~ start of the fault to the instant the arc is initiated.

Ex. ~~Pre-arc~~ The pre-arcing time is 0.001 second.

(vii) Arcing time.

This is the ~~#~~ time betn 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 time & arcing times.
The operating time of a fuse is quite low (0.002sec) as compared to a CB (0.2sec).

(ix) Breaking Capacity

It is the rms value of ac component of max^m prospective current that a fuse can deal with at rated service voltage.

Breaking capacity is the current that a fuse is able to interrupt without being destroyed.

Types of fuses

Fuse wire was invented by Edison.
Fuses may be classified into:
(i) Low voltage fuses
(ii) High voltage fuses.

→ It is usual practice to provide isolating switches in series with fuses where it is necessary to permit fuses to be replaced with safety.
→ If isolations are not available the fuses must be shielded to protect the user.

(3.4) Low voltage fuse & High voltage fuse

(1) Low voltage fuse

(a) Semienclosed rewirable fuse

(b) High rupturing capacity (HRC) Catridge fuse.

(a) Semi-enclosed rewirable fuse

→ It is also called as Kit-Kat type fuse.

→ The Kit-Kat fuse is used where low value of fault current are to be interrupted.

→ It consists of a (i) base &
(ii) ~~Carrier~~ fuse carrier.

→ The base is made up of ~~pro~~ porcelain and having a fixed contact to which the incoming & outgoing phase wires are connected.

→ The fuse carrier is also of ~~pro~~ porcelain and holds the fuse element between its terminals.

→ The fuse carrier can be inserted in or taken out of the base when desired.

Operation

→ When a fault occurs, the fuse element is blown out and the circuit is interrupted.

→ The fuse carrier is taken out and the blown out fuse element is replaced by the new one.

→ The fuse carrier is then re-inserted in the base to restore the supply.

Advantages

→ The replacement of fuse element without any danger ~~co~~ of coming in contact with live parts.

→ The cost of replacement is negligible.

Disadvantages

→ There is a possibility of reneweal of fuse element of wrong size or improper material.

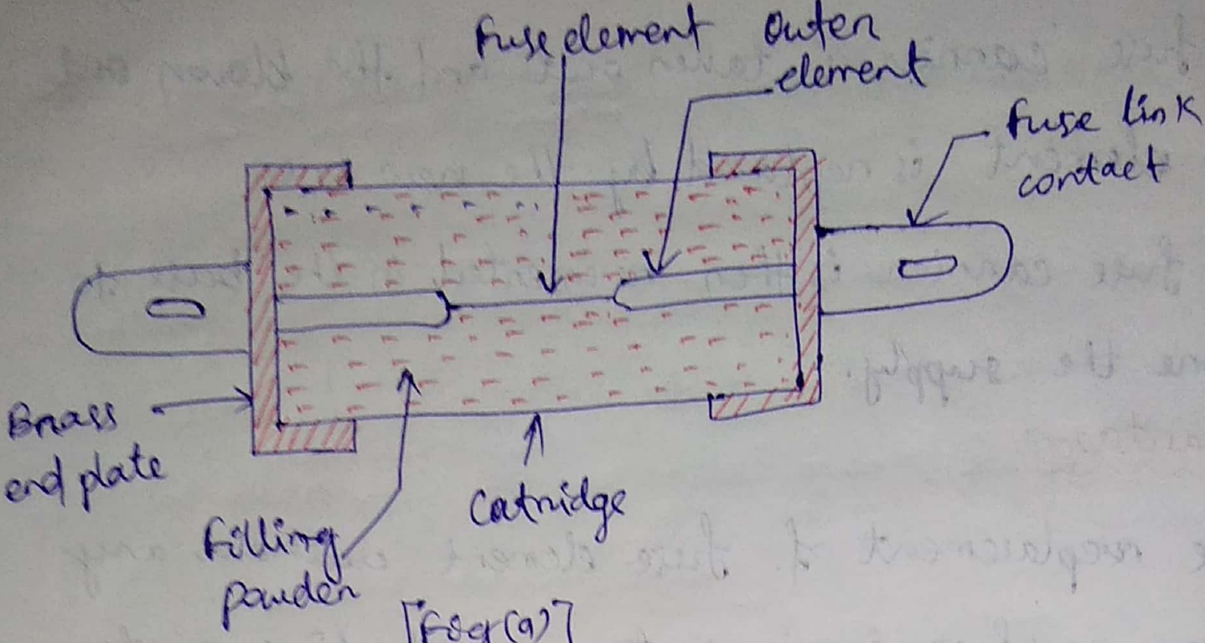
→ It cannot be used in ckts of high fault level because it has low breaking capacity.

→ Deterioration due to oxygen through the continous heating up ~~it~~ of the element. Therefore the current rating of the fuse is decreased.

→ The ~~reliability of~~ protective capacity of this fuse is uncertain or may be low ~~as it~~ due to it is affected by the ambient conditions.

(b) High-Rupturing Capacity (HRC) catridge fuse

Rupturing → breaking



[Fig (a)]

→ This fuse overcome the ~~problem of~~ disadvantage low and uncertain breaking capacity of semienclosed rewirable fuse.

→ Fig (a) shows the parts of a typical HRC catridge fuse.

→ It consists of a heat resisting ceramic body having metal end caps to which is welded silver current carrying element.

→ The surrounding of fuse element is filled by powder (chalk, plaster of paris, quartz or marble dust), which act as an arc quenching and cooling medium.

- Therefore, it carries the normal current without overheating.

→ Working or operation

→ When a fault occurs, the current increases and the fuse element melts before the fault current reaches its ~~1st~~ 1st peak.

→ Then the fuse element melts and then vapourises the melted silver element. The chemical reaction betn the silver vapour and the filling powder ~~result~~ results in the formation of a high resistance substance which helps in quenching the arc.

Advantages

1. They are capable of clearing high as well as low fault currents.
2. They ~~donot~~ do not deteriorate with age.
3. They have high speed of operation
~~4. They provide reliable discrimination.~~
~~5. They require no maintenance~~
4. Complete reliability
5. No maintenance is reqd.
6. Low cost
7. They ~~permit~~ provide consistent performance.

Disadvantages

1. They have to be replaced after each operation
* 2. Heat produced by the arc may affect the associated switches

(2) High Voltage Fuses

→ The low voltage fuse have low normal current rating and breaking capacity. Hence, they cannot be successfully used on high voltage ckts.

→ The high voltage fuse is of two types

(i) High voltage fuse

- Catridge type
- Liquid type.

(i) Catridge type

→ ~~This fuse is~~ The construction of this fuse is similar to LV catridge type except that special design features are included.

→ Some designs employ fuse element wound in the form of a helix. so as to avoid corona effects at higher voltages.

→ Some designs provided two fuse elements in parallel; one of low resistance (silver wire) and the other of high resistance (tungsten wire).

Operation

Under normal load condition, the low resistance element is blown out. and the high resistance element reduces the short ckt current and finally breaks the ckt.

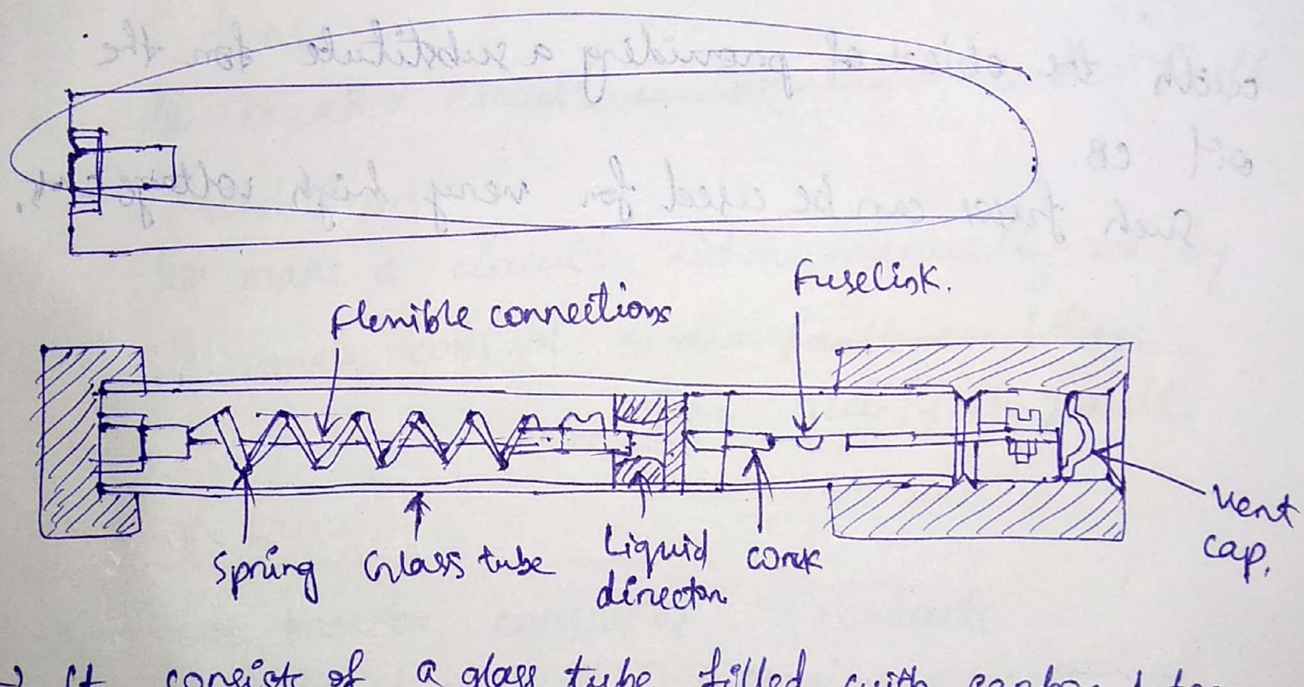
→ The HV catridge fuses are used upto 33 KV with breaking capacity of about 8700 A at that voltage.

→ Rating of the order of 200 A at 6.6 KV & 11 KV, & 50 A at 33 KV are also available.

② Liquid type

→ These fuses are filled with carbon tetrachloride and have the widest range of application to h.v. systems.

→ They may be used for ckts upto about 100A rated current on systems upto 132 KV and have breaking capacities of the order of 6100A.



→ 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 the other end of the wire is held by a strong phosphor bronze spiral spring.

Operation

→ When fault occurs the fuse element is blown out and the liquid director moves towards the liquid.

→ The small quantity of gas producing during fusion forces some part of the liquid into the passage through baffle and can effectively extinguish the arc.

Baffle → obstacle

③ Metal clad fuses

Metal clad oil-immersed fuses have been developed with the object of providing a substitute for the oil CB.

Such fuses can be used for very high voltage ckts.

(3.6) Difference betn a fuse & circuit breaker

Sl.No	Particular	Fuse	CB
1	Function	It performs both detection & interruptn functions	It performs interruption functn. The detectn of fault is made by relay system
2	Operation	Inherently completely automatic	Requires relay ckt with CT for automatic action
3	Breaking Capacity	Small	Very large
4	Operating time	Very small (0.002sec)	Comparatively large (0.1 to 0.2sec)
5	Replacement	Requires replacement after every operatn	No replacement reqd. after operatn

(3.5) Current Carrying capacity of fuse element

→ It mainly depends on the metal used and the cross-sectional area but is affected also by length, state of surface and the surroundings of the fuse.

Scanned by CamScanner

When the fuse element attains steady temperature,

Heat produced per sec = Heat lost per second by convection, radiation and conduction.

I^2R = constant × effective surface area.

$$I^2\left(\rho\frac{l}{A}\right) = \text{constant} \times d \times l$$

where, d = diameter of fuse element.

l = length of fuse element

$$I^2 \cdot \frac{\rho l}{\left(\frac{\pi d^2}{4}\right)} = \text{constant} \times d \times l$$

$$I^2 = \text{constant} \times d \times d^2 \quad \left[\because \frac{\rho}{(\pi/4)} = \text{constant}\right]$$

$$I^2 \propto d^3 \quad \text{—— (1)}$$

This expression is known as fuse law.

Problem

(1) A fuse wire of circular cross-sectn has a radius of 0.8mm. The wire blows off at a current of 8A. Calculate the radius of the wire that will blow off at a current of 1A.

Soln

$r_1 = 0.8\text{mm}$

$I_1 = 8A$, $I_2 = 1A$

$I^2 \propto d^3$, $I^2 \propto r^3$

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

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

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

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

$$= 0.2\text{mm}$$

CIRCUIT BREAKERS

(4.1) Definition & Principle of Circuit breakers

Definition:- A circuit breaker can make or break a circuit either manually or automatically under all conditions (like:- no-load, full-load and short-circuit conditions)

or

A circuit breaker is a piece of equipment which can (i) make or break a circuit either manually or by remote control under normal conditions.

(ii) break a circuit automatically under fault conditions.

(iii) make a circuit either manually or by remote control ~~under fault conditions~~. after rectify the fault.

Operating Principle:-

→ A ckt. breaker consists of 2 contacts
(i) Fixed contact & (ii) Moving contacts.
these contacts are called electrode.

→ Under normal operating conditions, these contacts remain closed.

→ The contacts can be opened manually or by remote control whenever desired/required/needed.

→ 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 ckt.

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

→ The production of arc not only delays the current interruption process but also generates ~~enomo~~ enormous heat which may damage the CB.

NOTE ✱ The main problem in a CB is to extinguish the arc. ~~within the shortest~~ within very short period of time so that heat generated by it may not reach a dangerous value.

(4.2) Arc phenomenon & principle of arc extinction

Arc Phenomenon

→ When a short circuit occurs, a heavy current flows through the contacts of the CB.

→ When the contacts begin to separate, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature.

→ The heat produced in the medium betn the contacts (oil or air medium) is sufficient to ionise the air or oil. The ionised air or oil acts as conductor and arc is struck betn the contacts.

→ The PD betn the contacts is quite small and it is sufficient to maintain the arc.

→ The arc provides a low resistance path and hence the current in the ckt remains uninterrupted as long as the arc persists.

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

→ The arc resistance depends upon 3 factors

(i) Degree of ionisation

(ii) Length of the arc

(iii) cross-section of the arc.

(i) Degree of ionisation :- the arc resistance increases with the decrease in the number of ionised particles between the contacts.

(ii) Length of the arc :- the arc resistance increases with the increase in length of the arc.

(iii) Cross-section of the arc :- the arc resistance increases with the decrease in area of X-section of the arc.

Principle of arc extinction

The factors responsible for the maintenance of arc between the contacts are

1. P.d. betn the contacts
2. ionised particles betn contacts.

→ When the contacts have a small separation, the PD between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that p.d. becomes insufficient to maintain the arc. But this method is impracticable in high voltage system where a separation of many metres may be required.

→ The ionised particles between the contacts tend to maintain the arc.

If the arc path is deionised, then the arc extinction will be facilitated.

→ This may be achieved by cooling the arc or removing the ionised particles from the space between the contacts.

4.3 Methods of arc extinction

There are two methods of extinguishing the arc in the CB.

① High resistance method

② Low resistance method (current zero method)

① High resistance method

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

→ Consequently, the current is interrupted ~~or the due~~ to arc is extinguished.

→ The disadvantages of this method is that enormous energy is dissipated in the arc. Therefore it is employed only in d.c. ckt. breakers and low capacity a.c. CB.

The resistance of the arc may be increased by:

① Lengthening the arc:

~~The length of the arc can be increased by increasing the gap~~ The resistance of the arc is directly proportional to its length. ($R \propto L$). The length of the arc can be increased by increasing the gap between contacts

(ii) Cooling the arc:

Cooling helps in the deionisation of the medium between the contacts. This increase the arc resistance.

(iii) Reducing X-section of the arc:

If the area of X-section of the arc is reduced, ($\uparrow R \propto \frac{1}{A\downarrow}$), the voltage necessary to maintain the arc is increased and the resistance of the arc path is increased.

(iv) Splitting the arc

The resistance of the arc can be increased by splitting the arc into a number of smaller arcs.

② Low resistance or Current zero method

→ This method is employed for arc extinction in a.c. ckt. only.

→ In this method, arc resistance is kept low untill current is zero where the arc extinguishes naturally.

→ All modern high power a.c. circuit breakers employ this method for arc extinction.

→ In an a.c. system, current drops to zero after every half cycle. At every current zero, the arc extinguishes for a brief moment.

→ Now the medium between the contacts contains ions and electrons so that it has small dielectric strength and can be easily broken down by the rising contact voltage.

→ If such a breakdown ~~do~~ occurs, the arc will persist for another half-cycle.

→ If immediately after current zero, the dielectric strength of the medium between contacts is built up more rapidly, then the arc fails to restrike and the current will be interrupted.

→ The rapid increase of dielectric strength of the medium near ~~zero~~ current zero can be ~~ach~~ obtained by:

(a) Causing the ionised particles in the space between contacts to recombine into neutral molecules.

(b) Sweeping the ionised particles away and replacing them by un-ionised particles.

The de-ionisation of the medium can be achieved by :
① Lengthening of the gap
② high pressure
③ cooling
④ blast effect.

② high pressure

If the pressure in the vicinity of the arc is increased, the density of the particles constituting the discharge also increases. The increased density of particles causes higher rate of de-ionisation and the dielectric medium between the contacts is increased.

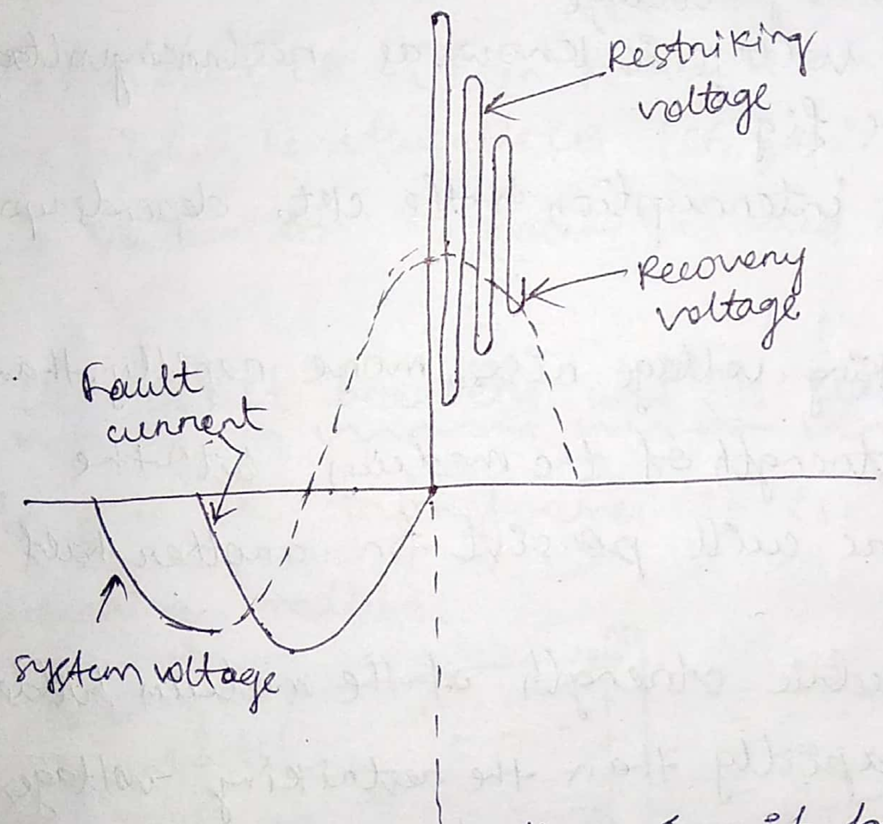
④ Blast effect

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

(4.4) Definitions of arc voltage, Re-striking voltage and recovery voltage

① Arc voltage

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



when the contacts of the circuit breaker separate, an arc is formed. The voltage that appears across the contacts during arcing period is called arc voltage.

→ ~~when~~ The ~~volt~~ arc voltage is low when current max^m.

~~But the arcing ~~current~~ voltage is high or max^m when the current is at zero.~~

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.

~~If the restriking voltage~~

The transient voltage is known as restriking voltage.

→ as shown in the fig.

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

→ If the restriking voltage rises more rapidly than the dielectric strength of the medium betn. the contacts, the arc will persist for another half cycle.

→ If the dielectric strength of the medium builds up more rapidly than the restriking voltage, the arc fails to restrike and the current will be interrupted.

(iii) **Recovery voltage**

It is the normal frequency (50Hz) rms ~~rat~~ voltage that appears across the contacts of the circuit breaker after final arc extinction.

It is approximately equal to the system voltage.

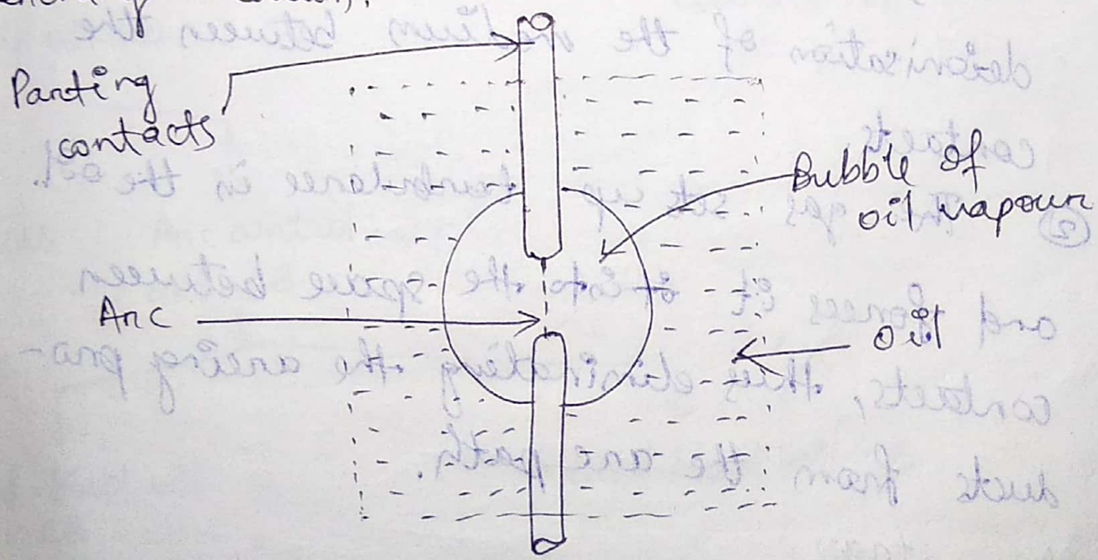
4.5 Classification of circuit breaker.

The most general way of classification of is on the basis of medium used for arc extinction. The medium used for arc extinction is usually air, oil, sulphur hexafluoride (SF_6) or vacuum.

CB
- → Oil ckt Breaker [(which employs some insulating oil) on T/f oil for arc extinction)
- → Air blast CB (high pressure air blast is used)
- → Sulphur hexafluoride CB (SF_6 gas is used)
- → Vacuum CB [Vacuum is used for arc extinction]

4.6 Oil circuit breakers and its classification

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



The contacts are opened under oil and an arc is struck between them.

→ Then the heat of the arc evaporates the surrounding oil and dissociates it into a substantial volume of gaseous hydrogen gas at high pressure.

The hydrogen gas occupies a volume about one thousand times that of the oil decomposed.

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

The arc extinction is facilitated mainly by two processes.

① The hydrogen gas has high heat conductivity and cools the arc, thus helping the deionisation of the medium between the contacts.

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

Advantages

① It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.

② It acts as an insulator and permits smaller clearance betⁿ line conductors.

③ The surrounding oil presents cooling surface in close near to the arc.

Disadvantages

① It is inflammable and there is a risk of a fire.

② It may form an explosive mixture with air

③ The arcing products (Ex: carbon) remain in the oil and its quality deteriorates with successive operations. ~~That why~~ This necessitates periodic checking and replacement of oil.

Classification of oil Circuit Breakers

- Oil CB
  - Bulk oil CB
    - Plain break oil CB
    - Arc control oil CB
      - Self-blast oil CB
      - Forced-blast oil CB
  - Low oil CB

① Bulk oil CB

→ This CB use a large quantity of oil. The oil has to serve two purposes.

① It extinguishes the arc during opening of contacts.

⑪ It insulates the current conducting parts from one another and from the earthed tank.

→ This CB is classified into two types:

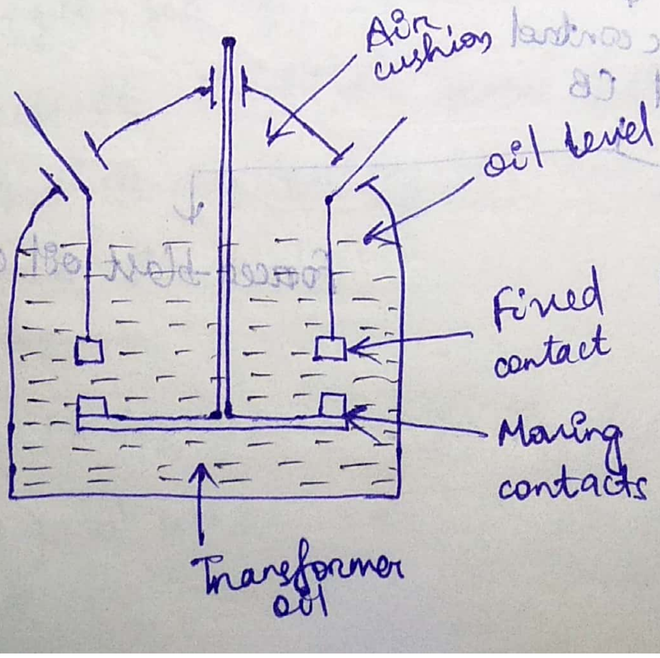
(a) Plain break oil CB.

(b) Arc control oil CB.

② Low oil circuit breakers

This CB use minimum amount of oil. oil is used for arc extinction; the current conducting parts are insulated by air or insulating material.

4.7 Plain Break Oil Circuit Breakers



→ There is no special system for arc control other ~~than the~~

→ The arc extinction occurs when a certain gap critical gap betn the contacts is reached.

→ It has a very simple construction.

→ It consists of ~~for~~ two contacts
① fixed contact & ② Moving contacts.

→ These two contacts enclosed in a ~~stro~~ tank ~~con~~ containing oil upto a certain level and an air cushion above the oil level.

→ The air cushion provides sufficient space to allow for the reception of the arc gases.

→ It also absorbs the mechanical shock of the upward oil movement.

→ Fig(a) shows a double break plain oil CB. It is called a double break because it provides two breaks in series.

Operation

→ Under normal operating conditions, the fixed & moving contacts remain closed and the breaker carries the normal ckt current.

→ When a fault occurs, the moving contacts are pulled down by the protective system and an arc is struck betn them, which vapourises the oil mainly into hydrogen gas.

→ The arc extinction is facilitated by the following processes:

① The hydrogen gas bubble generated around the arc and cools the arc.

② The gas sets up turbulence in the oil and helps in eliminating the arcing product from the arc path.

③ As the arc lengthens due to the separating contacts, the dielectric strength of the medium is increased.

The result of these 3 actions is that at some critical gap length, the arc is extinguished and the circuit current is interrupted.

Disadvantages

→ There is no special control over the arc. Therefore, for successful interruption, long arc length is necessary.

→ These breakers have long & inconsistent arcing times.

→ These breakers do not permit high speed ~~operation~~ interruption.

Note: Due to these disadvantages, plain-break oil CBs are used only for ~~to~~ low voltage applications. Its capacity for voltages not exceeding 11 kV.

(4.8) Arc control Oil Circuit Breakers

It is of two types

① Self-blast oil CB

② Forced-blast oil CB

~~① Self-blast oil CB~~

~~In this type of breakers, the~~

The circuit breakers provided the arc control is known as arc control CB.

① Self-Blast oil CB

In such CB, movements of oil into contact space is increased by the use of pressure developed by arc itself.

The high pressure produced by the arc causes an immediate flow of oil into space betn contacts after the arc current goes to zero.

→ In this CB, the gases produced during arcing are limited to a small volume by the use of an insulating rigid pressure chamber surrounding the contacts.

→ The space available for the arc gases is restricted by the chamber, a very high pressure is developed to force the oil and gas around the arc to extinguish it.

→ The magnitude of pressure developed depends upon the value of fault to be interrupted.

→ As the pressure is generated by arc itself, such breakers are ~~sometimes~~ called self-generated pressure oil circuit breakers.

→ The pressure chamber is cheap to make and gives less arcing time as compared to plain break oil CB.

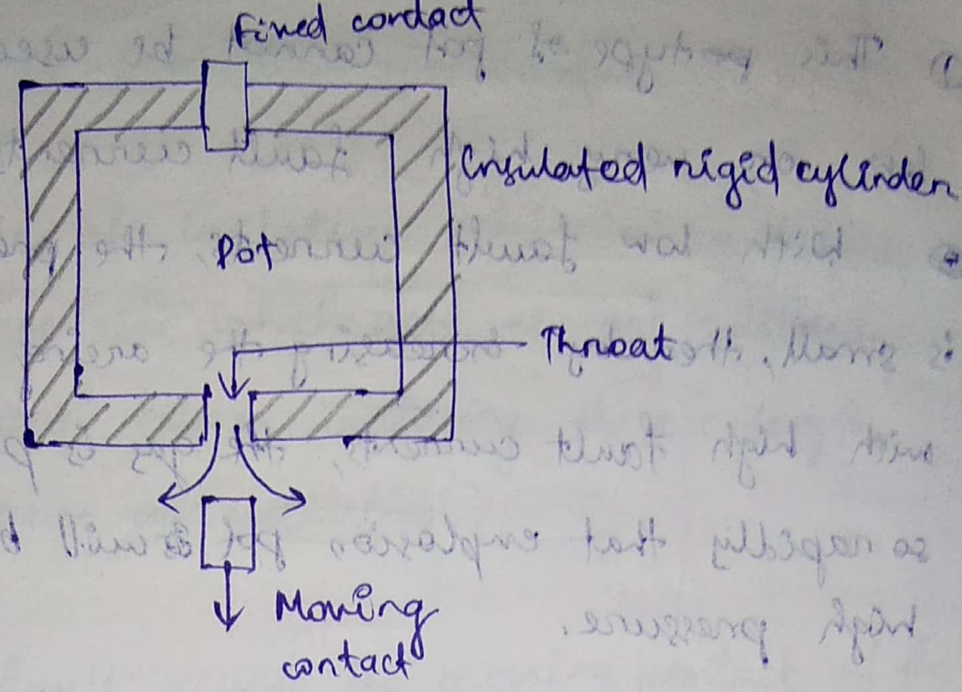
. The designs of pressure chamber are

(a) Plain explosion pot

(b) Cross jet explosion pot

(c) Self-compensated explosion pot.

(a) Plain explosion pot



→ ~~It is a~~ The plain explosion pot is shown in the figure,
→ which shows a rigid cylinder of insulating material and encloses the fixed and moving contacts. The
→ The moving contact is a cylindrical rod passing through a throat at the bottom.

Operation

→ When a fault occurs, the contacts get separated and an arc is struck between them.
→ Then the heat of the arc decomposes oil into a gas at very high pressure in the pot.
→ This ~~pass~~ high pressure forces the oil and ~~gas~~ around the arc to extinguish it.

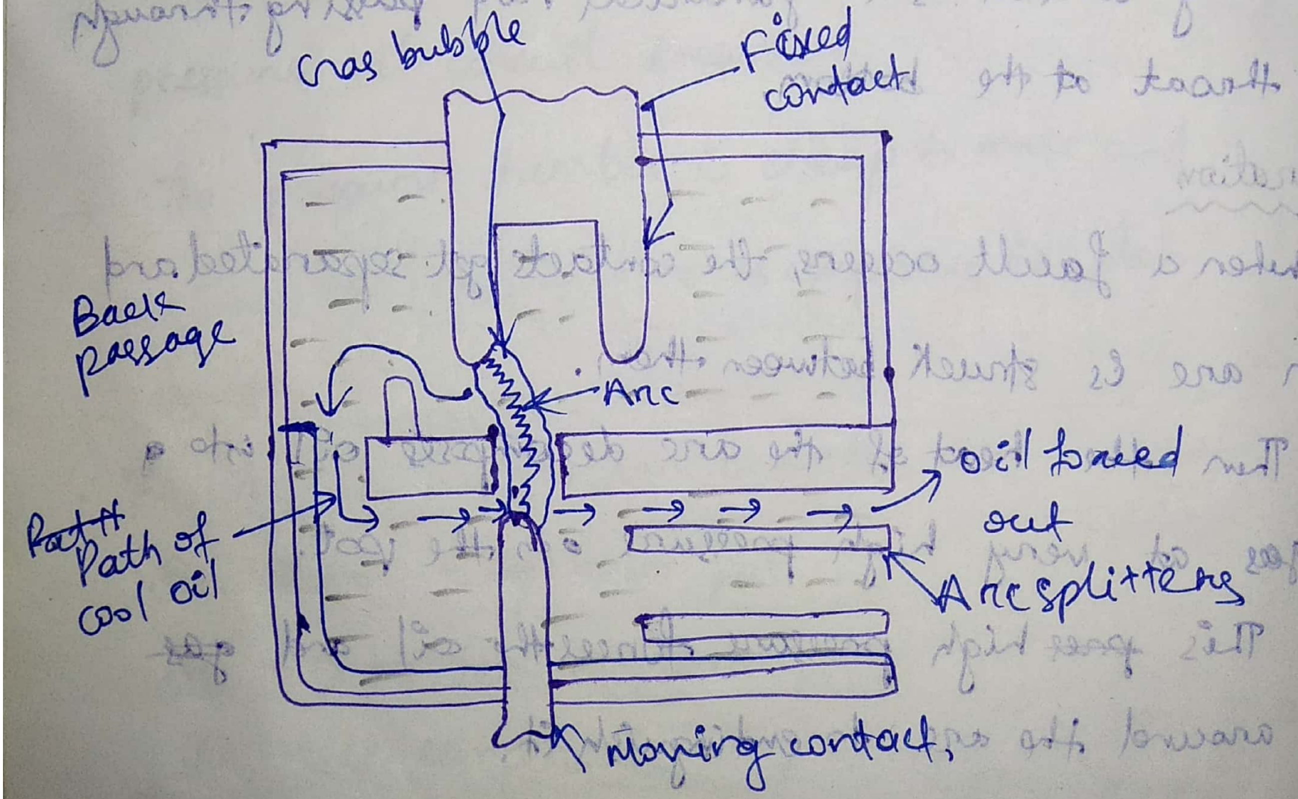
Limitation

① This type of pot cannot be used for very low or very high fault currents.

② With low fault currents, the pressure developed is small, thereby increasing the arcing time. Then with high fault currents, the gas is produced so so rapidly that explosion pot will burst due to high pressure.

Note plain explosion pot operates well on moderate short-ckt. currents only where the rate of gas evolution is moderate.

(b) Cross jet explosion pot



→ The cross jet explosion pot is shown in the fig.

→ This type of pot is a modification of plain explosion pot.

→ It is made of insulating material and has channels on one side which acts as arc splitters.

→ The arc splitters help in increasing the arc length, thus facilitating arc extinction.

→ Operation

→ When a fault occurs, the moving contact of the circuit breaker begins to separate.

→ As the moving contact is pulled down, the arc is initially struck both the contact.

→ The gas generated by the arc exert pressure on the oil in the back passage.

→ Then the arc is driven sideways into the arc splitters which increase the arc length, causing arc extinction.

Application

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

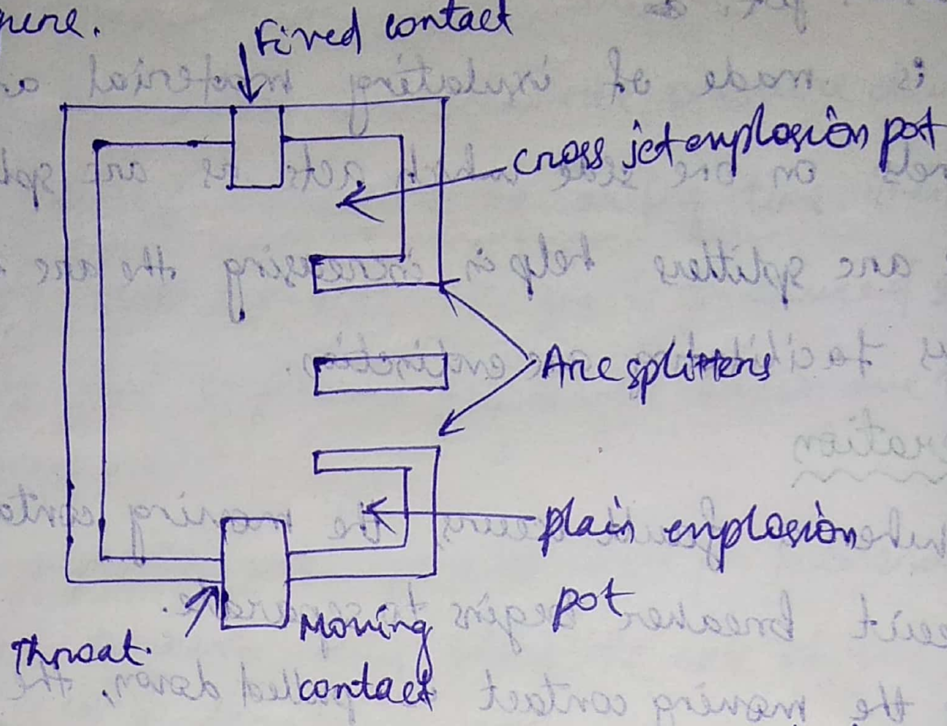
Limitation

It cannot used for low fault current.

Because, the gas pressure is small and the pot doesnot give a satisfactory operation.

© Self-compensated explosion pot

→ The self-compensated explosion pot is shown in the figure.



→ This pot is a combination of plain explosion pot and cross jet explosion pot. Therefore, it can interrupt ~~to~~ moderate as well as heavy short circuit currents. ~~with~~

→ It consists of two chambers, the upper chamber and lower chamber. The upper chamber is the cross-jet explosion pot with two arc splitters ~~duct~~ while the lower one is the plain ~~explion~~ explosion pot.

→ Operation

→ When the short-circuit current is heavy, the rate of generation of gas is very high and the device behaves as a cross-jet explosion pot.

- The arc extinction takes place, when the moving contact opens the arc splitter duct.
- However, on moderate sc-currents, the rate of gas generation is moderate and very little pressure leakage through the arc splitters and
- when the moving contact comes out of the throat the arc is extinguished by plain explosion pot action.

(II) Forced-blast oil circuit breakers

- In forced blast oil circuit breaker, oil pressure is created by the piston-cylinder arrangement.
- The movement of the piston is mechanically coupled to the moving contact.

Operation

- When a fault occurs, the contacts get separated by the protective system and an arc is struck between the contacts.
- The piston forces a stream of oil towards the contact gap to extinguish the arc.

Advantages

(a) Since oil pressure developed is independent of the fault current to be interrupted, the performance at low currents is more consistent than with self blast oil CB,

- The quantity of oil required is reduced than self oil CB,

4.9 Low oil Circuit Breakers

Bulk oil CB performs 2 function

(1) It acts as an arc quenching medium

(2) It act as a insulator.

→ But it has been found that only a small % of oil is actually used for arc extinction.

→ Large amount of oil in bulk oil CB increases the expenses, tank size and weight of the breaker but it also increases the fire risk and maintenance problems. So low oil Ckt. breaker is developed.

→ A low oil ckt breaker uses solid materials for insulation purpose and uses a small quantity of oil, which is just sufficient for arc extinction.

Construction

→ There are 2 compartments separated from each other but both filled with oil.

→ Upper chamber is Ckt. breaker chamber,
lower " " supporting chamber.

2 chamber are separated by (Division) partition & oil from one chamber is prevented from mixing with the other chamber.

This arrangement permits 2 advantages

① The OCB chamber requires a small volume of oil which is just sufficient for arc extinction.

② The amount of oil to be replaced is reduced as the oil in the supporting chamber doesnot contaminated by the arc.

① Supporting chamber

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

→ It is filled with oil for insulation purpose.

⑪ Circuit breaking chamber

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

ⓐ Upper & lower fixed contacts
ⓑ Moving contacts
ⓒ turbulator.

→ The moving contact is hollow and includes a cylinder which moves down over a fixed piston. (Vent-gate)

→ The turbulater is an arc control device and has both axial & radial vents.

→ The axial venting interrupts low currents & radial ventings interrupt heavy currents.

(iii) Top chamber

→ It is a metal chamber and is mounted on the ckt-breaking chamber.

→ It provides expansion space for the oil in the circuit-breaking compartments.

* Operations

→ Under normal operating conditions, the moving contact remains closed with the upper fixed contact.

→ When a fault occurs, the moving contact is pulled down by the tripping arrangement and an arc is struck betn the contacts

→ The heat of the arc vaporises the oil & produces gases under high pressure.

→ This high pressure forces the oil through turbulator to quench the arc.

Advantages

→ It requires less quantity of oil

→ It requires smaller space

→ There is reduced risk of fire

→ Maintenance problems are reduced.

Disadvantages

→ Due to smaller quantity of oil, the degree of carbonisation is increased.

→ Dielectric strength of the oil deteriorates rapidly due to high degree of carbonisation.

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

Arpita

4.10 Maintenance of oil circuit breaker

→ The maintenance of oil CB is generally concerned with the checking of contacts and dielectric strength of oil.

→ It is a good practice to inspect the CB at regular intervals of 3 or 6 months.

→ During inspection of the CB, the following points should be kept in view:

(i) Check the current carrying parts and arcing contacts. If the burning is severe, the contact should be replaced.

(ii) Check the dielectric strength of the oil. If the oil is badly discoloured, it should be changed or reconditioned. The oil in good condition should withstand 30kV for one minute in a standard oil testing cup with 4mm gap both electrodes.

(iii) Check the insulation for possible damage. Clean the surface and remove carbon deposits with a strong and dry fabric (cloth)

(iv) Check the oil level

(v) Check closing and tripping mechanism.

4.11 Air-Blast Circuit breaker & its classification

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 ~~also~~ cools the arc and sweeps away the arcing product to the atmosphere.

→ This rapidly increases the dielectric strength of the medium between contacts and prevents from re-establishing the arc.

→ Then the arc is extinguished & flow of current is interrupted.

Advantages

→ Risk of fire is eliminated.

→ The arcing products are completely removed by the blast.

→ The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small.

→ The arcing time is very small due to the rapid build up of dielectric strength betn contacts.

→ Due to lesser arc energy, air-blast CBs are very suitable where frequent operation is required.

→ Disadvantages

→ The air has relatively low arc extinguishing properties.

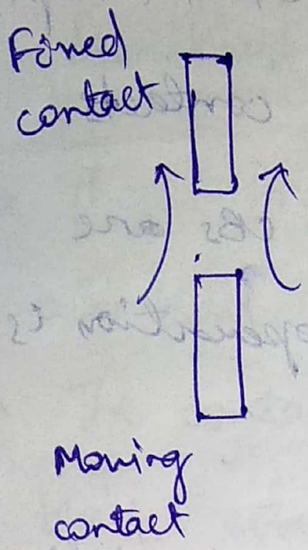
→ The air-blast CBs are very sensitive to the variation in the rate of rise of restriking voltage.

Types of Air- Blast Circuit Breakers

Depending upon the direction of ~~arc~~ air-blast in relation to the arc, air-blast CBs are classified into

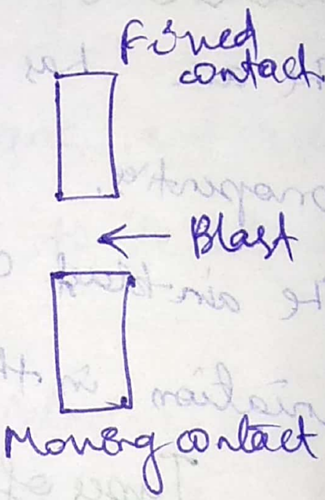
1. Axial-blast type.
2. Cross-blast type
3. Radial-blast type.

(i) Axial-blast type



Axial-blast type in which the air-blast is directed along the arc path as shown in the fig.

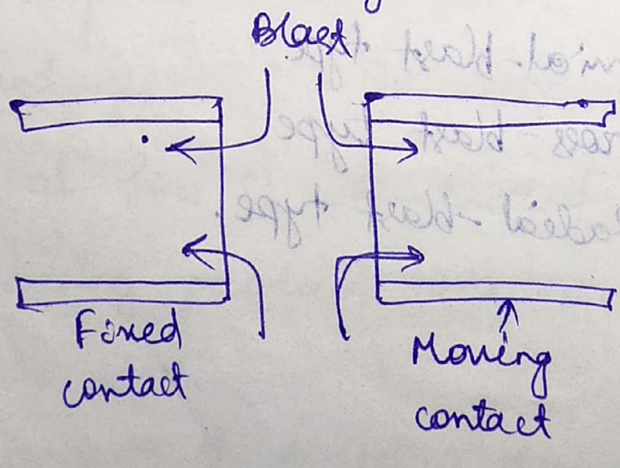
(ii) Cross-blast type



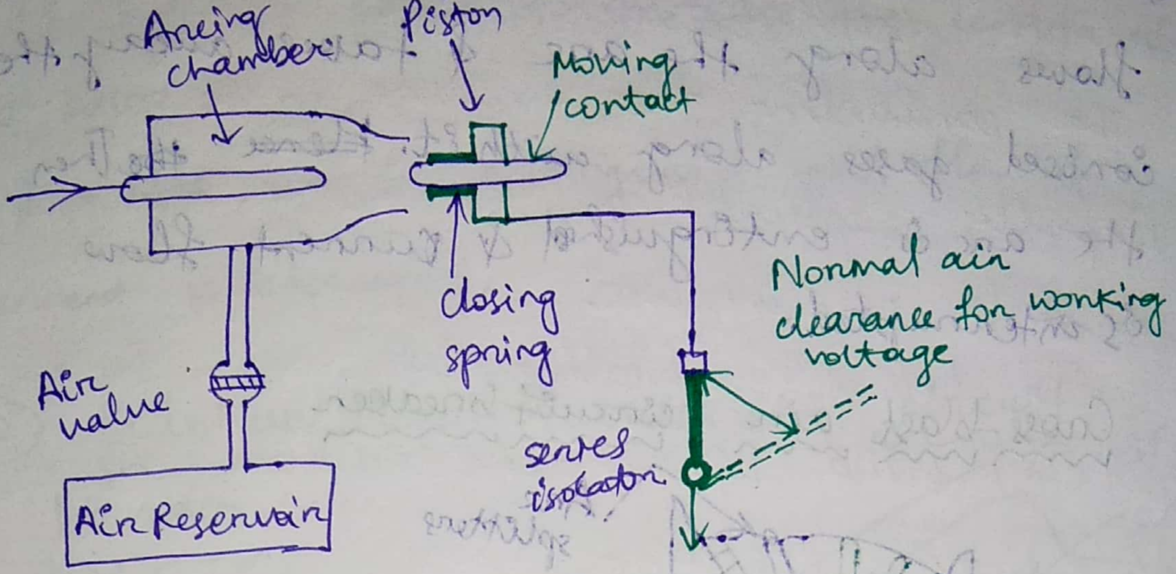
The air blast is directed at right angles to the arc path as shown in the fig.

(iii) Radial blast type

The air blast is directed radially as shown in the figure.



① Axial ~~Air~~-blast air circuit breaker



→ The fixed and moving contacts are held in the closed position by spring pressure under normal conditions.

→ The air reservoir is connected to the arcing chamber through an air valve.

→ This valve remains closed under normal conditions but opens automatically by the tripping impulse when a fault occurs on the system.

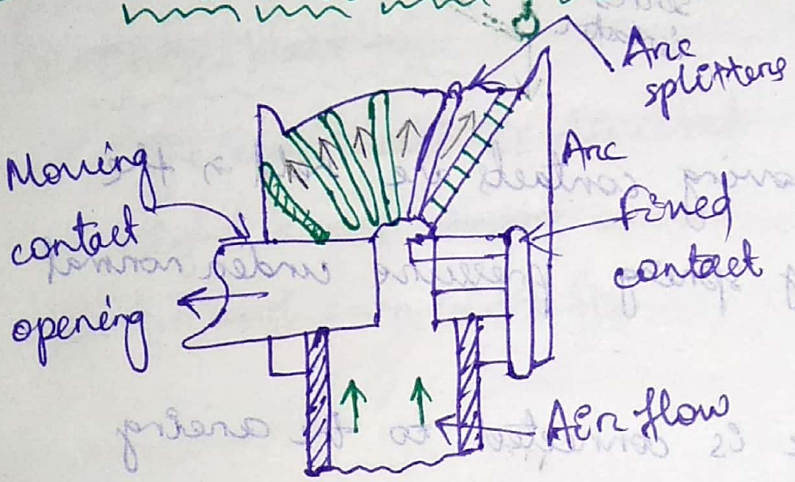
→ When a fault occurs, the tripping impulse causes opening of the air valve which connects the CB reservoir to the arcing chamber.

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

→ Now the moving contact is separated & arc is struck betn them.

→ At the same time high pressure air blast flows along the arc & takes away the ionised gases along with it. ~~Hence the~~ Then the arc is extinguished & current flow is interrupted.

(11) Cross-blast air circuit breaker



→ In this type of CB, an air-blast is directed at right angles to the arc

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

→ The typical cross blast air CB is shown in the fig.

→ Function

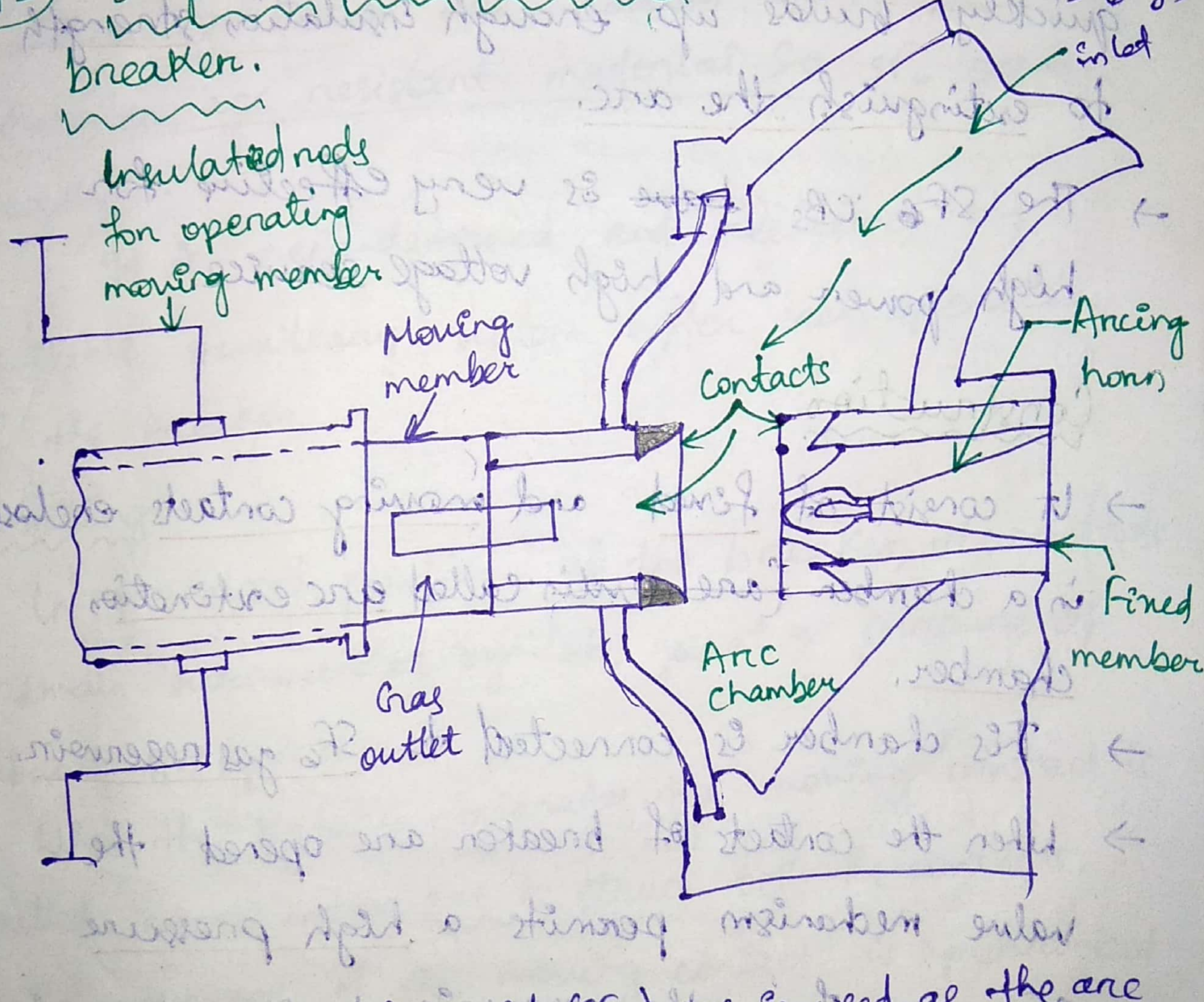
→ When the moving contact is withdrawn, an arc is struck betn the fixed and moving contacts.

→ The high pressure crossblast forces the arc into a shield consisting of arc splitters. ~~and baffles~~.

→ The splitters ~~serve~~ help to increase the length of the arc.

→ Then the arc is extinguished and flow of current is interrupted.

(4.12) Sulphur Hexa-fluoride (SF6) circuit breaker.



→ Sulphur hexafluoride (SF_6) gas is used as the arc quenching medium.

→ The SF_6 is an electro-negative gas & has a strong tendency to absorb free electrons.

→ The contacts of the breaker are opened in a high pressure flow of SF_6 gas and an arc is struck between them.

→ The conducting free electrons in the arc are rapidly captured by the gas to form relatively immobile negative ions.

This loss of conducting electrons in the arc quickly builds up enough insulation strength to extinguish the arc.

→ The SF6 CBs ~~have~~ is very effective for high power and high voltage service.

Construction:

→ It consist of fixed and moving contacts enclosed in a chamber ~~(arc extin~~ called arc extinction chamber.

→ This chamber is connected to SF_6 gas reservoir.

→ When the contacts of breaker are opened the valve mechanism permits a high pressure SF6 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 ~~arc~~ and across the arc.

→ The tips of fixed contact & moving contact and arcing horns are coated with copper-tungsten arc resistant material. So SF_6 gas is costly.

It is reconditioned and reclaimed by suitable auxiliary system after each operation of the breaker.

Working

→ In the closed position of the breaker, the contacts remain surrounded by SF_6 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 both the contacts.

→ The movement of the moving contact is synchronised with the opening of a valve which permits SF_6 gas at 14 Kg/cm² pressure from the reservoir to the arc interruption chamber.

→ The high pressure flow of SF_6 rapidly absorbs the free electrons in the arc path.

→ Then the medium between the contacts quickly builds up high dielectric strength and causes the extinction of the arc.

Advantages

→ The SF_6 CBs have many advantages over oil or air circuit breakers are.

(i) SF_6 CBs have very short arcing time.

(ii) It can interrupt much larger currents.

(iii) There is no moisture problem

(iv) There is no risk of fire in such breakers.

(v) Low maintenance cost, ~~Light fo~~

~~(vi)~~

Disadvantages

(i) SF_6 breakers are costly due to high cost of SF_6.

(ii) Additional equipment is required for reconditioned after every operation of breaker.

115kV to 230kV, power rating 10MVA to 20MVA.

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4.13 Vacuum Circuit Breakers:

* In such breakers, vacuum is used as the arc quenching medium.

Principle

~~→ When the production of arc is~~

→ When the ac 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.

→ However, the arc is quickly extinguished because 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.

Construction

→ It consists of fixed contact, moving contact & arc shield mounted inside a vacuum chamber.

→ The movable member is connected to the control mechanism by stainless steel bellows.

→ This enables the permanent sealing of the vacuum chamber so as to eliminate the possibility of leak.

→ A glass vessel or ceramic vessel is used as the outer insulating body.

→ The arc shield prevents 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 upon the material of contacts.

→ The arc is quickly extinguished because the metallic vapours, electrons & ions produced during arc are diffused in a short time.

→ Vacuum has very fast rate of recovery of dielectric strength.

→ The arc extinction in a vacuum breaker occurs with a short contact separation (0.625 cm)

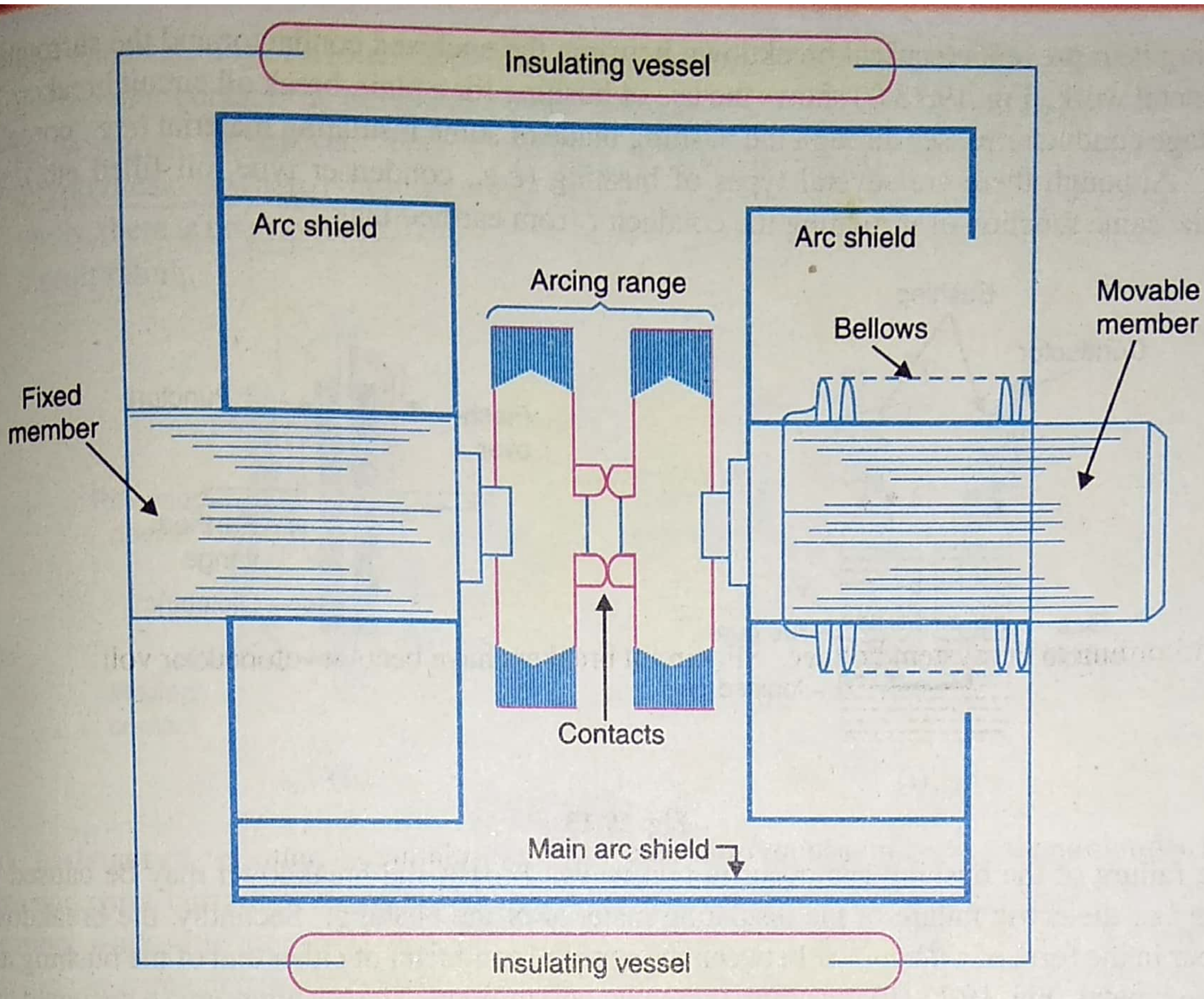


Fig. 19.12

Advantages. Vacuum circuit breakers have the following advantages :

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

(*ii*) There are no fire hazards.

(*iii*) There is no generation of gas during and after operation.

(*iv*) They can interrupt any fault current. The outstanding feature of a VCB is that it can break any heavy fault current perfectly just before the contacts reach the definite open position.

(*v*) They require little maintenance and are quiet in operation.

(*vi*) They can successfully withstand lightning surges.

(*vii*) They have low arc energy.

(*viii*) They have low inertia and hence require smaller power for control mechanism.

Applications. For a country like India, where distances are quite large and accessibility to remote areas difficult, the installation of such outdoor, maintenance free circuit breakers should prove a definite advantage. Vacuum circuit breakers are being employed for outdoor applications ranging from 22 kV to 66 kV. Even with limited rating of say 60 to 100 MVA, they are suitable for a majority of applications in rural areas.

4.14 Switchgear Component

Some important components common to most of the circuit breakers are:-

1. Bushings
2. Circuit breaker contacts
3. Instrument transformers
4. Bus-bars and conductors

1 Bushings

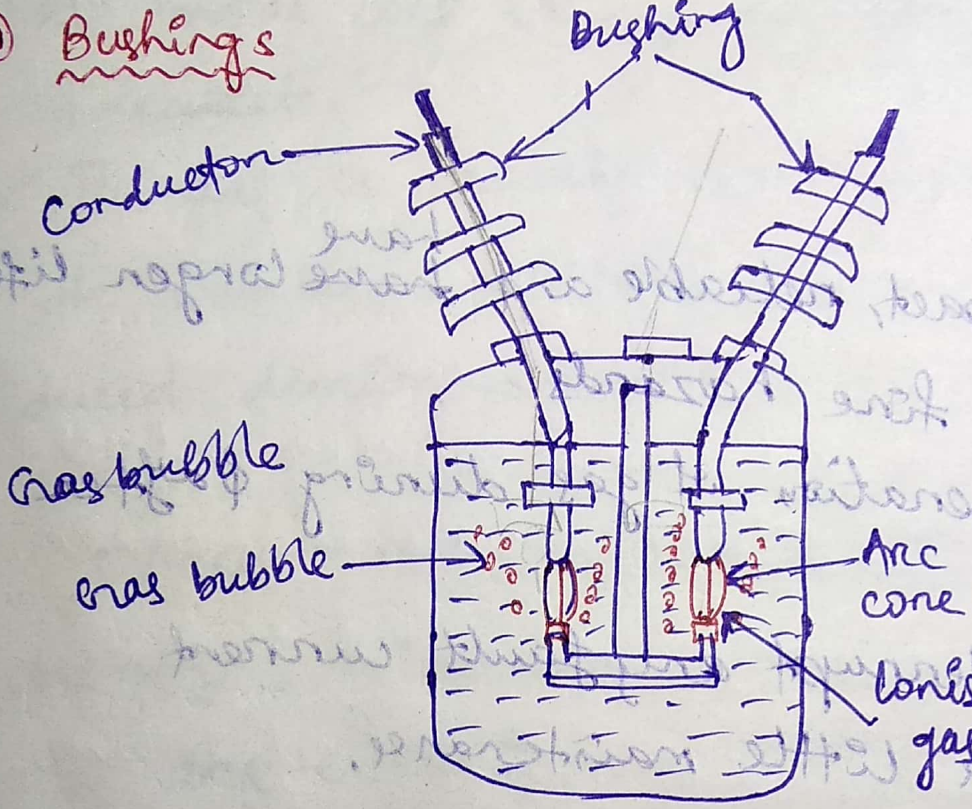


fig 1

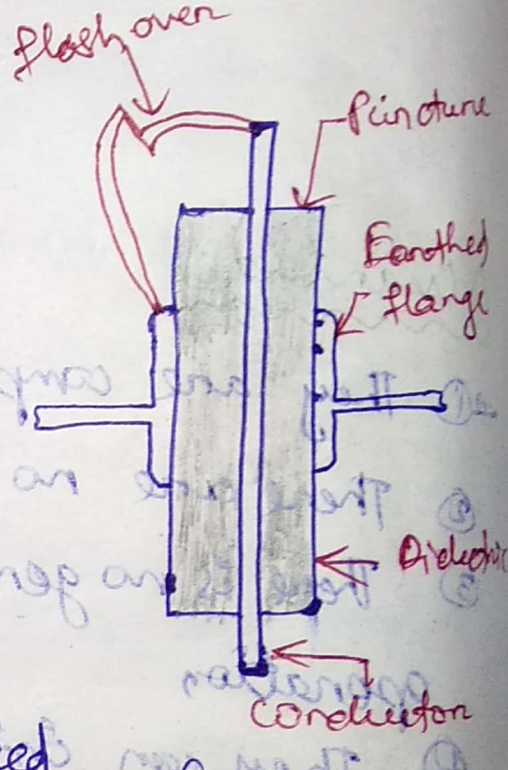


fig 2

→ When a high voltage conductor passes through a metal sheet ~~out~~ which is at earth potential, the necessary insulation is provided in the form of bushing.

→ The primary function of bushing is to prevent electrical breakdown between the enclosed conductor and the surrounding earthed metal work.

→ High voltage conductor passes through the bushing made of some insulating material (porcelain).

→ Failure of the bushing can occur in 2 ways

① The breakdown may caused by puncture. (dielectric failure of the insulating materials)

② Breakdown may occur in the form of flash-over between the exposed conductor at either end of the bushing and the earthed material.

→ Fig ② shows these two possibilities.

② Circuit breaker contacts

The circuit breaker contacts are required to carry normal as well as short-circuit current. There are 3 types of CB contacts:

ⓐ Tulip type contact

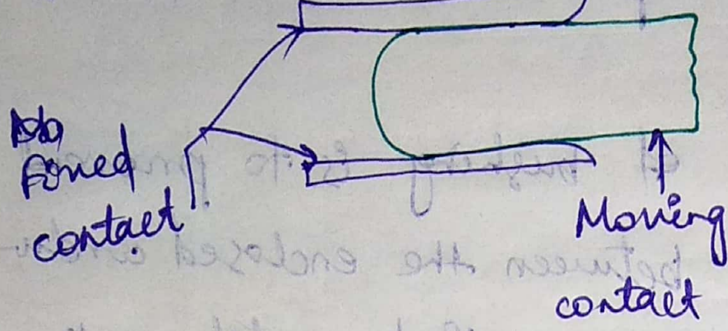
ⓑ Finger and wedge contacts

ⓒ Butt contacts.

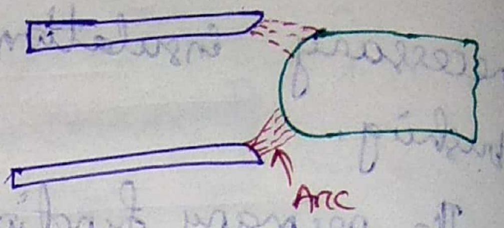
Butt → hold

wedge →

→ ① Tulip type Contacts



Fig①



Fig②

→ Fig① shows the tulip type contact.

→ It consists of moving contact which moves inside the fixed contacts.

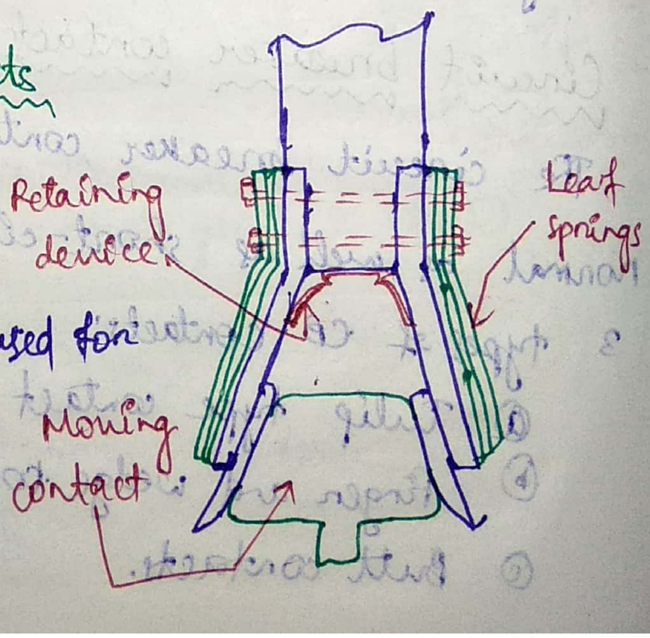
→ At contact separation, the arc is established betn the tips of fixed & moving contacts as shown in fig②.

→ The advantage of this type of contact is that arc is limited to the tip of the contact & not spread to whole portions of the contacts.

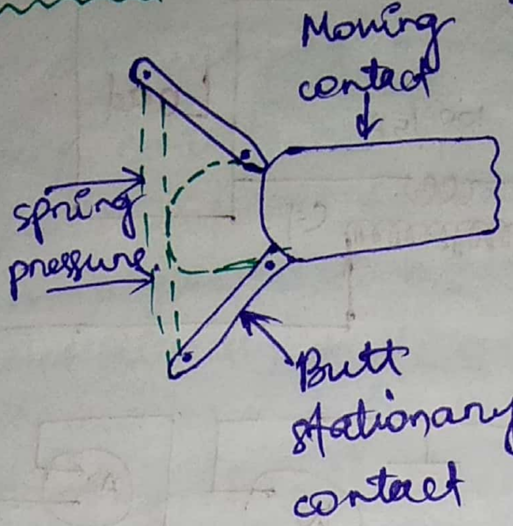
② Finger & Wedge contacts

→ Finger & wedge type contact is shown in the figure

→ This type of contact is largely used for low voltage oil CB.



ⓒ Butt contacts



→ Butt type contact is shown in the figure.

→ It possesses two advantages

① spring pressure is available to assist contact separation.

②

This is useful in single-break oil CBs and air blast CBs, where small loop forces are available to assist in opening.

② It is suitable for higher short-circuit current rating because it has no grip force.

(iii) Instrument transformers

→ The measuring instruments and protective devices cannot work satisfactorily if connected directly on the power lines.

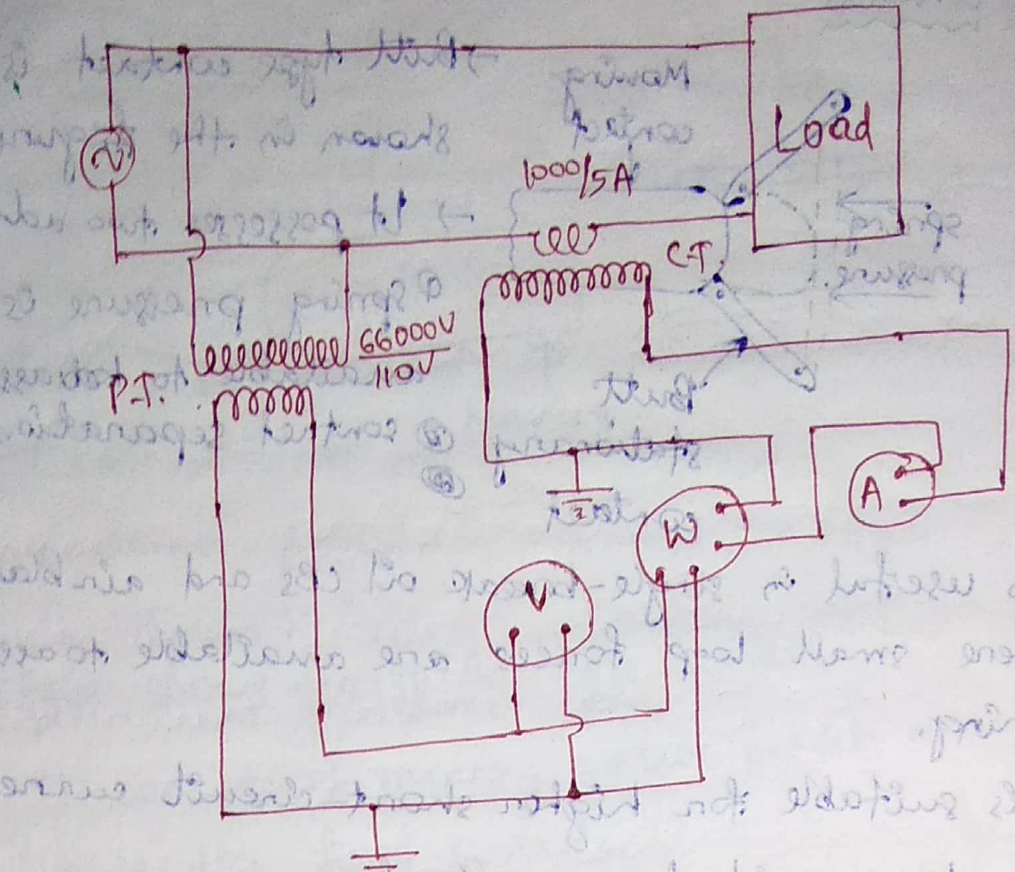
→ This difficulty is overcome by installing instrument transformers on the power lines.

→ The function of these instrument t/fs is to transform voltages or currents in the power lines to low voltage or current lines for the operation of measuring instruments & relays.

→ Instrument transformers are of 2 types.

① Current transformer (C.T.)

② Potential transformer (P.T)



→ The primary ~~winding~~ of CT & PT are connected in the power line. (iii)

→ The secondary of CT & PT provides low values of current & voltage (constant fraction) to be measured in ~~voltmeter~~ measuring instruments (Voltmeter, Ammeter & ~~Po~~ watt meter).

→ The above fig. shows the use of instrument transformers.

	Primary	Secondary
C.T. rating	1000A	5A
PT rating	66,000V	110V

→ The primary voltage of P.T & primary current of CT can be found out by ~~applying~~ the use of transformation ratio. But the secondary reading should require for calculation,

(iv) Bus-bars & 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 CB are connected to the bus-bars.

(4.15) Problems of Circuit Interruption

→ When a fault occurs, the energy stored in the system can be considerable. Interruption of fault current by a circuit breaker and will result in most of the stored energy dissipated within the CB.

→ Therefore, the CB must be designed to dissipate as much of the stored energy as possible.

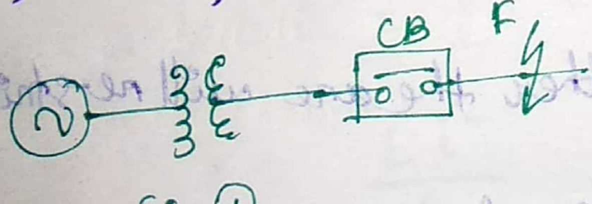


Fig ①

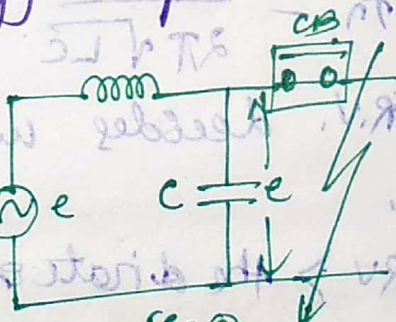


Fig ②

→ Fig ① shows a short-circuit occurring on the transmission line.

→ Fig ② shows the equivalent ckt, where L & C are the per phase inductance & capacitance of the system.

→ The resistance of the system is neglected as it is small.

① Rate of rise of re-striking voltage.

→ It is denoted by/abbreviated by R.R.R.V.

→ It is the rate of increase of re-striking voltage. Usually the voltage is in KV & time in microseconds so that R.R.R.V. is in KV/μsec.

→ When the contacts are opened and the arc is formed, when current reaches zero at π radian, the generator voltage suddenly applied to the inductance & capacitance in series.

→ This L-C combination forms an oscillatory circuit and produces a transient of frequency.

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

→ The R.R.R.V. decides whether the arc will re-strike or not.

If RRRV > the rate of rise of dielectric strength between the contacts, the arc will re-strike.

If RRRV < rate of rise of dielectric strength, then the arc will fail to re-strike.

→ The value of RRRV depends upon:

ⓐ Recovery voltage

ⓑ natural frequency of oscillations.

→ For a SC occurring near the power station bus-bars, C being small, the f_n will be high, Hence, RRRV will attain a large value.

(ii) Current Chopping:-

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

→ Current chopping mainly occurs in air-blast CBs. Because they retain the same extinguishing power irrespective of the magnitude of the current to be interrupted.

→ As the chop occurs at current i, therefore, the energy stored in inductance is $\frac{1}{2}Li^2$. This energy will be transferred to the capacitance C.

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

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

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

Ex:- If L & C are 4mH & 0.001 μF. A current chop of magnitude 50A. would induce a voltage of

$$e = i\sqrt{\frac{L}{C}} = 50\sqrt{\frac{4\times10^{-3}}{0.001\times10^{-6}}}$$

$$= 100\times10^3 \text{ Volts} = 100\text{ kV}.$$

* Excessive voltage surges due to current chopping are prevented by shunting the contacts of the breaker with a resistor (Resistance switching)

plained in Art

***(iii)* 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. Consider the simple equivalent circuit of an unloaded transmission line shown in Fig. 19.20. Such a line, although unloaded in the normal sense, will actually carry a capacitive current I on account of appreciable amount of capacitance C between the line and the earth.

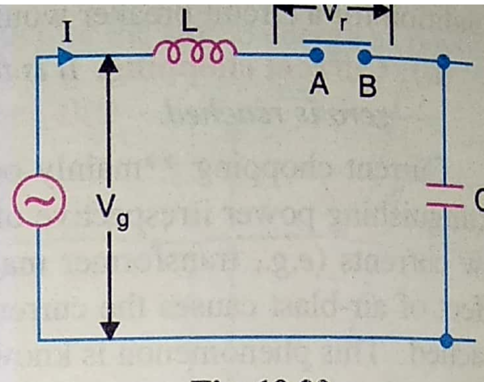


Fig. 19.20

Let us suppose that the line is opened by the circuit breaker at the instant when line capacitive current is zero [point 1 in Fig. 19.21]. At this instant, the generator voltage V_g will be maximum (*i.e.*, V_{gm}) lagging behind the current by 90°. The opening of the line leaves a standing charge on it (*i.e.*, end B of the line) and the capacitor C_1 is charged to V_{gm}. However, the generator end of the line (*i.e.*, end A of the line) continues its normal sinusoidal variations. The voltage V_r across the circuit breaker will be the difference between the voltages on the respective sides. Its initial value is zero (point 1) and increases slowly in the beginning. But half a cycle later [point R in Fig. 19.21], the potential of the circuit breaker contact 'A' becomes maximum negative which causes the voltage across the breaker (V_r) to become 2 V_{gm}. This voltage may be sufficient to restrike the arc. The two previously separated parts of the circuit will now be joined by an arc of very low resistance. The line capacitance discharges at once to reduce the voltage across the circuit breaker, thus setting up high frequency transient. The peak value of the initial transient will be twice the voltage at that instant *i.e.*, – 4 V_{gm}. This will cause the transmission voltage to swing to – 4 V_{gm} to + V_{gm} *i.e.*, –3V_{gm}.

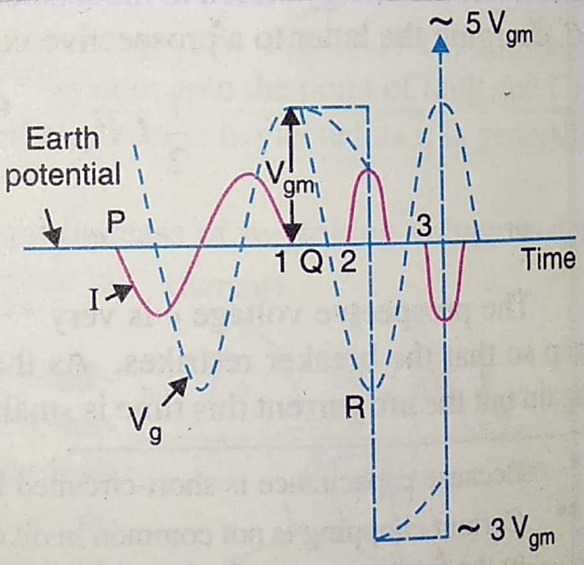


Fig. 19.21

Scanned by CamScanner

The re-strike arc current quickly reaches its first zero as it varies at natural frequency. The voltage on the line is now $-3V_{gm}$ and once again the two halves of the circuit are separated and the line is isolated at this potential. After about half a cycle further, the aforesaid events are repeated even on more formidable scale and the line may be left with a potential of $5V_{gm}$ above earth potential. Theoretically, this phenomenon may proceed infinitely increasing the voltage by successive increment of 2 times V_{gm}.

While the above description relates to the worst possible conditions, it is obvious that if the gap breakdown strength does not increase rapidly enough, successive re-strikes can build up a dangerous voltage in the open circuit line. However, due to leakage and corona loss, the maximum voltage on the line in such cases is limited to 5 V_{gm}.

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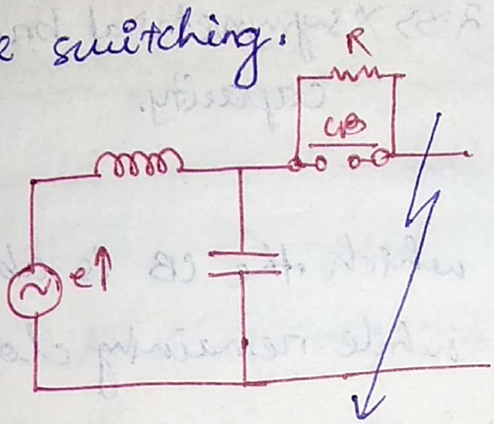
4.16 Resistance Switching

→ The current chopping, capacitive current breaking etc give rise to severe voltage oscillations.

→ These ~~volen~~ excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R connected across the circuit breaker contacts as shown in the fig (a). This is known as resistance switching.



→ The shunt resistor also helps in limiting the oscillatory growth of re-striking voltage.

→ The shunt resistor reduce the voltage surges due to current chopping and capacitive current breaking.

4.17 Circuit Breaker Rating

→ The CBs have three ratings

1. Breaking capacity
2. making capacity
3. short-time capacity.

① Breaking capacity

It is the rms ~~curr~~ value of current that a CB is capable of breaking at given recovery voltage and RRR voltage.

→ If I is the rated breaking current in amperes and V is the rated service line voltage in volts, then

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

(ii) Making capacity

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

Making capacity = 2.55 × symmetrical breaking capacity.

(iii) Short-time rating

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

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

ⓐ the electromagnetic force effects

ⓑ temperature rise.

chapter-05 Protective Relays

5.1 Definition of 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.

5.2 Fundamental Requirement of protective relay.

It should have the following qualities:

① selectivity ② speed ③ sensitivity

④ reliability ⑤ simplicity ⑥ economy

① 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.

② Speed

The relay system should disconnect the faulty section as fast as possible for the following reasons.

① Electrical apparatus may be damaged if they are made to carry the fault currents for a long time.

②

(ii) A failure in the system leads to a great reduction in the system voltage. If the faulty section is not disconnected quickly, then the low voltage created by the fault may shut down consumer's motors and generators on the system may become unstable.

(iii) The high speed relay system decreases the possibility of development of one type of fault into the other more severe type.

③ Sensitivity

It is the ability of the relay system to operate with low value of actuating quantity.

ex:- A 1VA relay is more sensitive than a 3VA relay.

④ Reliability

→ It is the ability of the relay system to operate under the pre-determined conditions.

→ Without reliability, the protection would be ineffective.

⑤ 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.

⑥ Economy

. The protective system should not cost more than 5% of total cost. So the most importante factor is the choice of a particular protection system in the economic aspects.

(5.3) Basic Relay operation

→ Most of the relays in service on electric power system today are of electro-mechanical type.

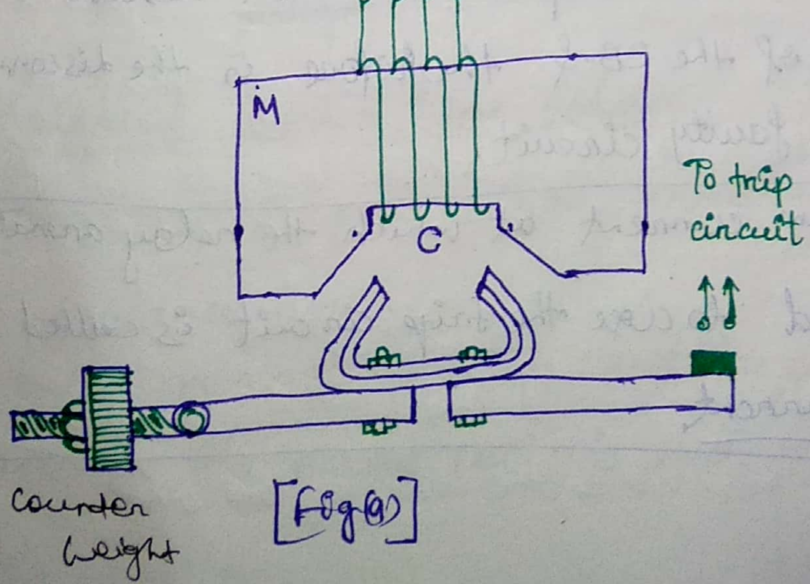
→ They work on the following operating principles:

① Electromagnetic attraction

② Electromagnetic induction.

(a) Electromagnetic Attraction type

① Attracted armature type relay



[Fig (a)]

→ Fig (a) shows the schematic arrangement of an attracted armature type relay.

→ It consists of a laminated electromagnet M carrying a coil C and a pivoted laminated armature.

→ The armature is balanced by a counterweight and carries a pair of spring contact fingers at its free end.

Operation

→ Under normal operating conditions, the current through the relay coil C is such that counter weight holds the armature in the initial position.

→ When a short-circuit occurs, the current through the relay coil increases sufficiently and the relay armature bridge a pair of stationary contacts attached to the relay.

→ This completion the trip ckt. which results in the opening of the CB. & therefore in the disconnection of the faulty circuit.

→ The minimum current at which the relay armature is attracted to close the trip circuit is called pickup current.

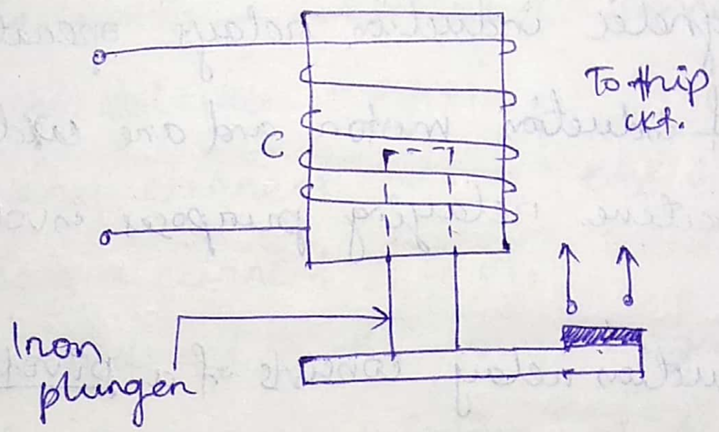
(ii) Solenoid type relay

→ It consists of a solenoid and movable iron plunger arranged with trip circuit.

→ Under normal operating conditions, the current through the relay coil 'C' is such that it holds the plunger by spring in the initial position.

→ Operation: On the occurrance of a fault, the current through the relay coil becomes more than the pick-up value, then the plunger to be attracted to the solenoid.

→ The upward movement of the plunger closes the trip circuit, thus opening the CB & disconnecting the faulty circuit.



(iii) Balanced Beam type relay

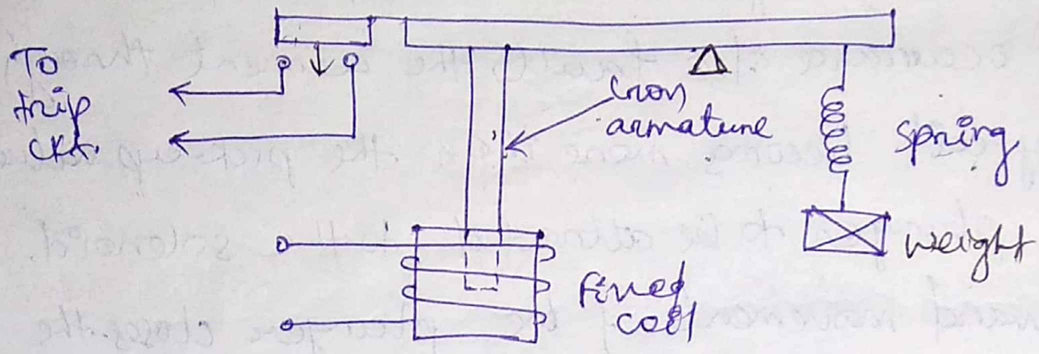
→ It consisted of an iron armature connected to a balance beam.

→ Under normal operating conditions, the current through the relay coil is such that the beam is held in the horizontal position by the spring.

Operation

→ When a fault occurs, the current through the relay coil becomes greater than the pickup value and beam is attracted to close the trip ckt.

→ This causes the opening of the CB to isolate the faulty circuit.



(11) Induction Relays

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

→ An induction relay consists of a pivoted aluminium disc placed in two alternating magnetic fields of the same frequency but displaced in time & space.

→ The torque is produced in the disc by the interaction of one of the magnetic fields with the currents induced in the disc by the other,

→ Three types of structures are commonly used for the operating torque in induction relays.

① shaded pole structure
② watthour-meter or double winding structure
③ induction cup structure.

* Watt-Hour-meter structure

→ It is used in watthour meters.

→ It consists of a pivoted aluminium disc arranged to rotate freely between the poles of two electromagnets.

→ The upper electromagnets carries two windings; the primary and the secondary

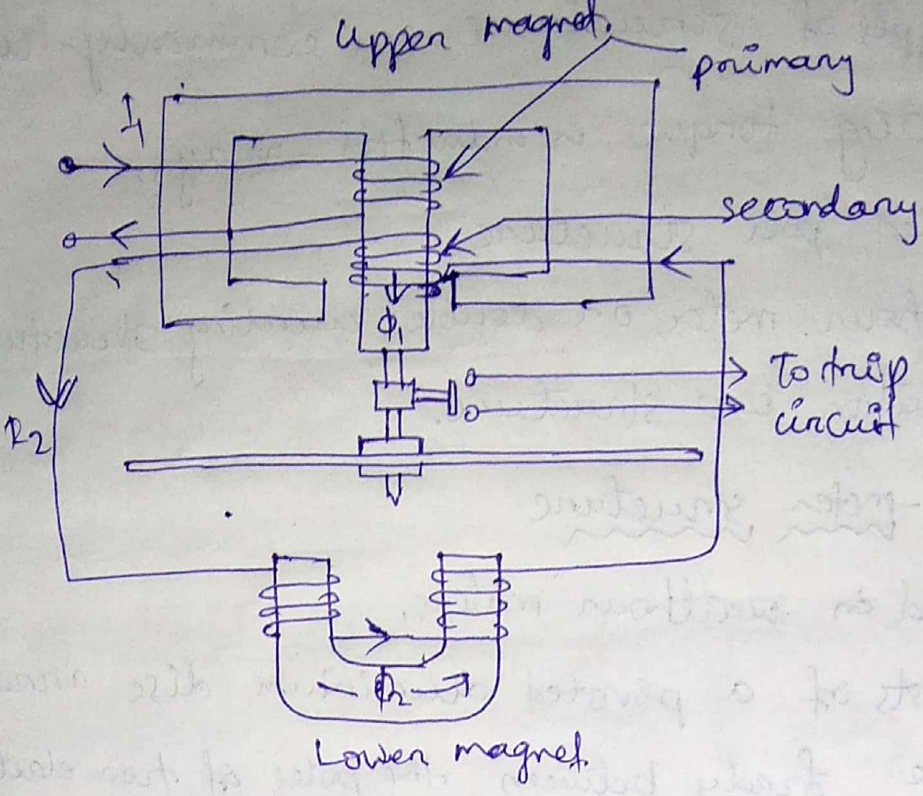
→ The primary winding carries the relay current I_1 while the secondary winding is connected to the winding of the lower magnet.

→ 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 by the current in the secondary winding of the upper magnet will lag behind ϕ_1 by an angle α.

→ The two fluxes ϕ_1 & ϕ_2 differs in phase by α will produce a driving torque on the disc proportional to $\phi_1 \phi_2 \sin\alpha$.

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



5.4 Definition of following important terms

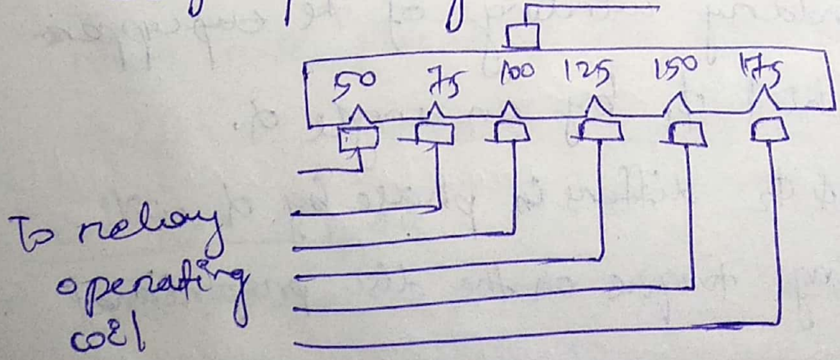
(a) Pick-up current :-

It is the minimum current in the relay coil at which the relay stands to operate.

(b) Current setting

→ The adjustment of pickup current to any required value is called current setting.

→ This is achieved by the use of tappings on the relay operating coil.



(c) Plug setting multiplier (P.S.M).

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

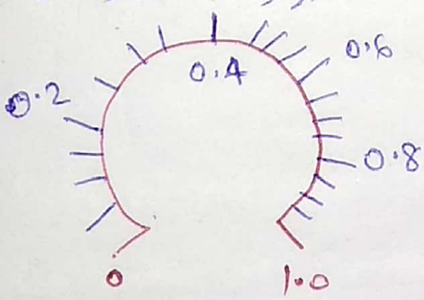
$$P.S.M = \frac{\text{Fault current in relay coil}}{\text{pick-up current}}$$

Pickup current = Rated secondary current of C.T. × current setting.

(d) Time-setting multiplier

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

→ the time setting dial is calibrated from 0 to 1. in steps of 0.05 sec. as shown in the fig.



→ If time setting is 0.1 & time obtained from the time/P.S.M curve is 3 seconds,

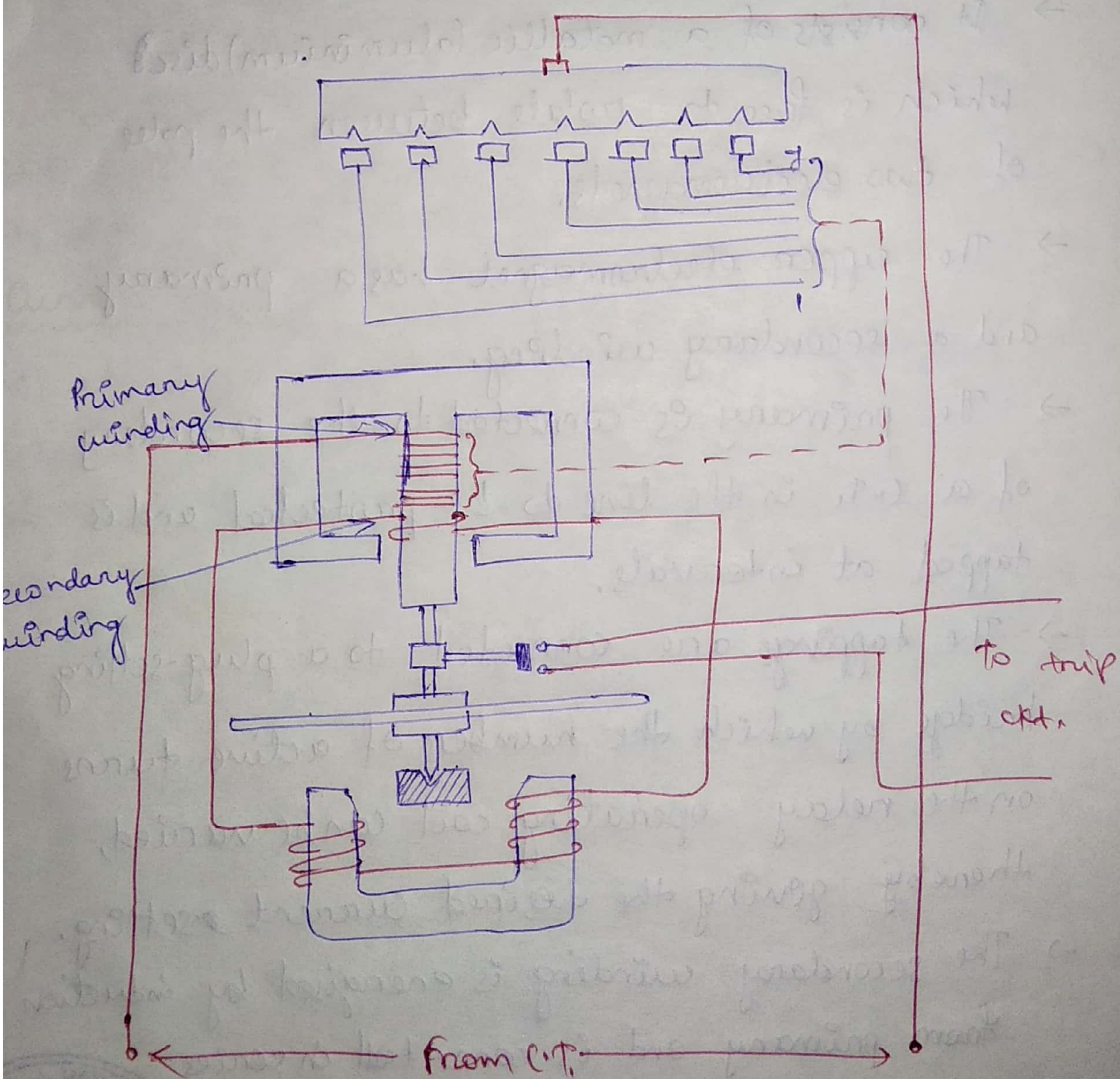
Actual relay operating time is = 3 × 0.1 = 0.3 second.

5.6 Classification of functional Relays

→ There are several types of special function relays, the important types of relays are

1. Induction type overcurrent relays
2. Induction type power relays
3. Distance relays
4. Differential relays
5. Translay scheme.

5.7 Induction type over current relay (Non-directional)



→ A relay which recognises over current in a circuit and initiates corrective measures could be termed as an overcurrent relay.

→ These relays are used on A.C. circuits only & can operate for fault current flow in either direction.

Construction

→ The typical non-directional induction type over-current relay is shown in the figure.

→ It consists of a metallic (aluminium) disc which is free to rotate between the poles of two electromagnets.

→ The upper electromagnet has a primary and a secondary winding.

→ The primary is connected to the secondary of a C.T. in the line to be protected and is tapped at intervals.

→ The tappings are connected to a plug-setting bridge by which the number of active turns on the relay operating coil can be varied, thereby 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.

→ This angle can be adjusted to any value between 0° to 360°.

→ By adjusting this angle, the travel of the moving contact can be adjusted and hence the relay can be given any desired time setting.

Operation

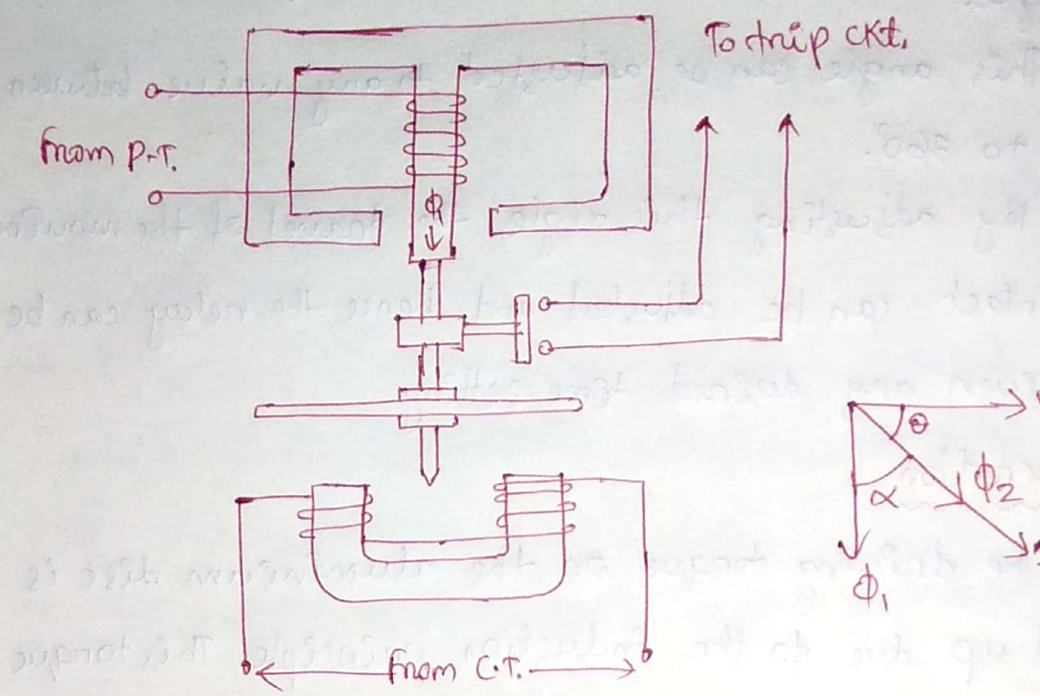
→ The driving torque on the aluminium disc is set up due to the induction principle. This torque is opposed by the ~~restrai~~ restraining torque provided by the spring.

→ Under normal operating conditions, restraining torque is greater than the driving torque produced by the relay coil current. Therefore the aluminium disc remains stationary.

→ When fault occurs, the current in the protected circuit exceeds the pre-set value, the driving torque becomes greater than the restraining torque.

→ Then aluminium dis rotates and the moving contact bridges the fixed contacts when the disc has rotated through a pre-set angle. Then the trip circuit operates the circuit breaker which isolates the faulty section.

5.8 Induction type directional power relay



→ It operates when power in the circuit flows in a specific direction.

Construction

→ The above figure shows the parts of a typical induction type directional power relay.

→ It consists of an aluminium disc is free to rotate in between the poles of two electromagnets.

→ The upper electromagnet carries a winding is called potential coil on the central limb which is connected through a potential transformer (P.T.) to the circuit voltage source.

→ The lower electromagnet has a separate winding (called current coil) 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.

Operation

→ The flux ϕ_1 due to current in the potential coil will be nearly 90° lagging behind the applied voltage V.

→ The flux ϕ_2 due to current coil will be nearly in phase with the operating current I.

→ The interaction of fluxes ϕ_1 & ϕ_2 with the eddy currents induced in the disc produces a driving torque ~~gre~~ is:

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

$$\phi_1 \propto V, \quad \phi_2 \propto I$$

$$\alpha = 90 - \theta$$

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

$$\propto VI \cos\theta$$

$\propto$ power in the circuit.

→ Therefore, the direction of driving torque on the disc depends upon the direction of power flow in the circuit to which the relay is associated.

→ When the power in the circuit flows in the normal direction, the driving torque and the restraining torque help each other to run away the moving contact from the fixed contacts.

→ 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. Then the circuit breaker operates and disconnects the faulty section.

5.9 Induction type directional Overcurrent Relay

Construction

→ It consists of 2 relay elements mounted on a common case:-

① directional element
② Non-directional element

① Directional element

→ It is a directional power relay which operates when power flows in a specific direction.

→ The potential coil of the element is connected through a potential transformer (P.T.) to the system voltage.

→ The current coil of the element is energised through a C.T. by the circuit ~~breaker~~ current.

→ This winding is carried over the upper magnet of the non-directional element.

→ The trip contacts (1 & 2) of the directional element are connected in series with the secondary circuit of the overcurrent element.

→ Therefore, the later element cannot start to operate until its secondary circuit is completed.

→ In other words, the directional element must operate first (i.e., contacts 1 & 2 should close) in order to operate the overcurrent element.

② Non-directional element

→ It is an overcurrent element similar in all respects to a non-directional over-current relay.

→ The spindle of the disc of this element carries a moving contact which closes the fixed contact (trip circuit contact) after the operation of directional element.

→ It may be noted that plug setting bridge is also provided in the relay for current setting but has been omitted in the figure for clarity and simplicity.

→ The tappings are provided on the upper magnet of overcurrent element and are connected to the bridge.

Operation

→ Under normal operating conditions, power flows in the normal direction in the circuit protected by the relay.

→ Therefore, directional power relay (upper element) doesnot operate, thereby keeping the overcurrent element (lower element) unenergised.

→ When a short circuit occurs, there is a tendency for the current or power to flows in the reverse direction.

→ ~~When the~~ Then the disc of the upper magnet rotates to bridge the fixed contacts 1 & 2.

→ This completes the circuit for overcurrent element

→ The disc of this element rotates and the moving contact attached to it closes the trip circuit.

→ This operates the circuit breaker which isolates the faulty section.

(5.10) Differential Relay

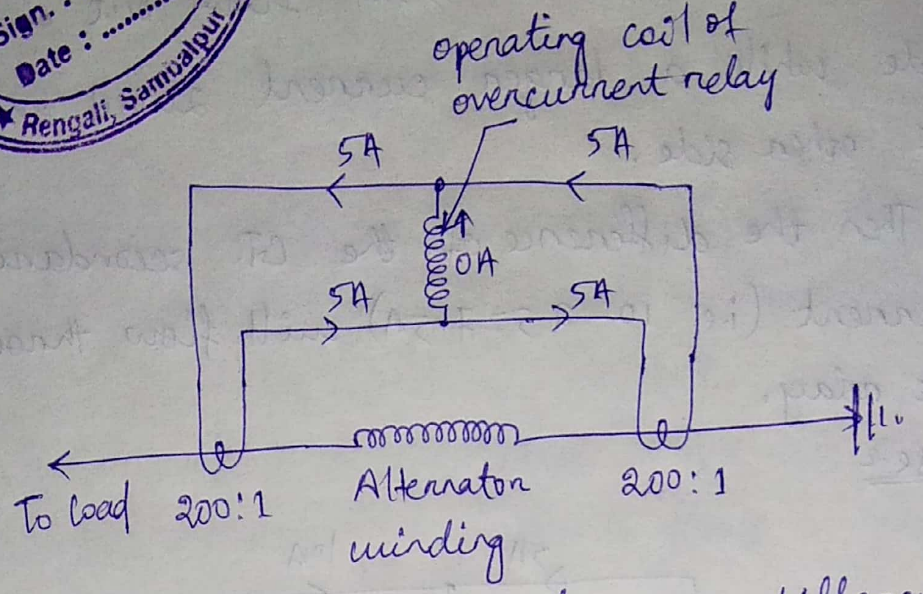
A differential relay is one that operates when the phasor difference of two or more similar electrical quantities exceeds a pre-determined value.

There are two fundamental systems of differential or balanced protection.

① Current differential relay

② Voltage balance differential

(a) Current Differential Relay



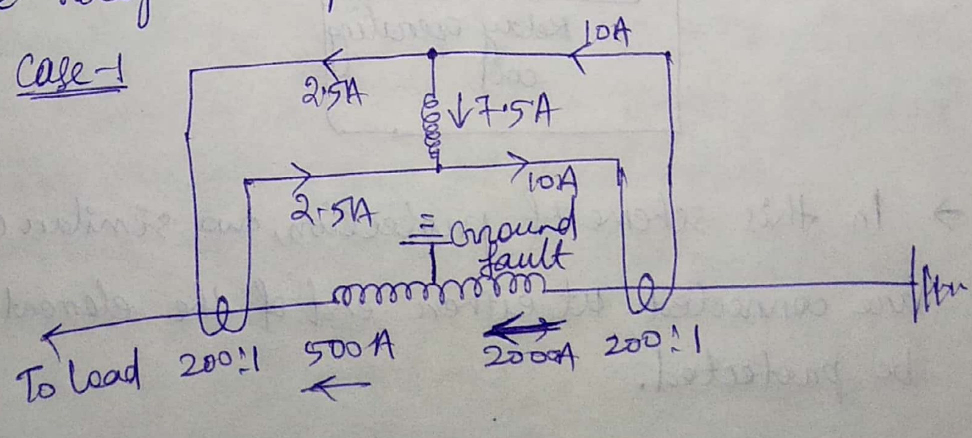
→ Overcurrent relay operates as a differential relay.

→ During normal operating condition; there is no fault currents in the two C.T.s secondaries are equal & relay operating coil therefore does not carry any current.

→ During fault conditions, there will be a differential current flows through the differential relay operating coil.

→ If this current exceeds the pick-up value, the relay will operate.

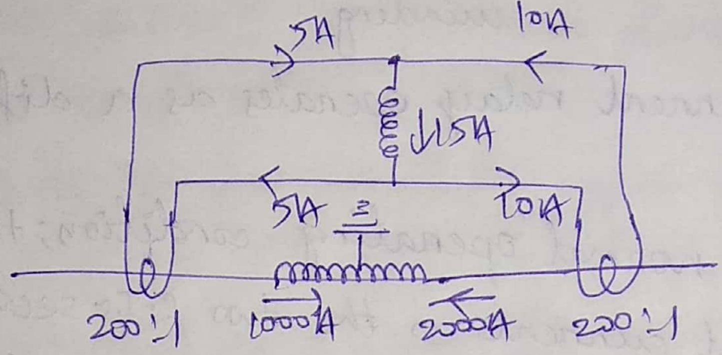
→ Case-1



→ If some current 500A flows out of one side while a larger current 2000A enters the other side.

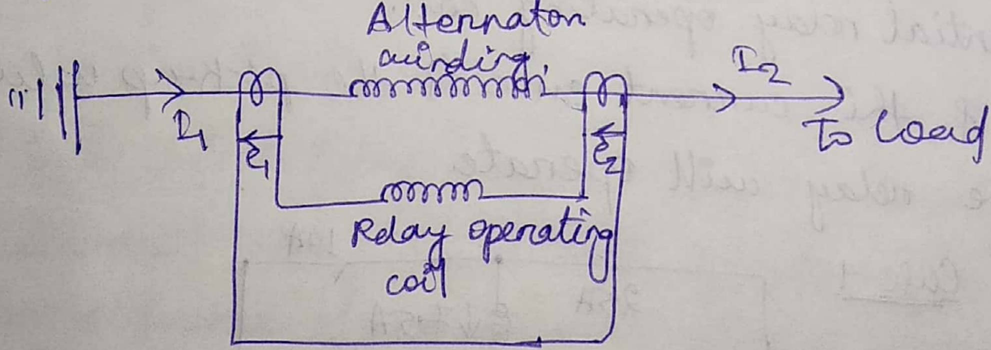
→ Then the difference of the C.T. secondary current (i.e. 10 − 2.5 = 7.5A) will flow through the relay.

Case-2



→ If current flows to the fault from both sides, then sum of C.T. secondary currents (i.e. 10 + 5 = 15A) will flow through the relay.

ⓑ Voltage Balance Differential Relay



→ In this scheme of protection, two similar CTs are connected at either end of the element to be protected.

→ The secondaries of CTs are connected in series with a relay in such a way that under normal conditions, their induced emfs are in opposition.

→ Under healthy conditions, equal currents ($I_1 = I_2$) flows in both primary windings.

→ Therefore, the secondary voltages of the two CTs are balanced against each other and no current will flow through the relay operating coil.

→ When a fault occurs in the protected zone, the currents in the two primaries will differ from one another ($I_1 \neq I_2$) and their secondary voltages will no longer be in balance.

→ This voltage difference will cause a current to flow through the operating coil of the relay which closes the trip circuit.

5.11 Types of protection

→ When a fault occurs on any part of electric power system, it must be cleared quickly in order to avoid damage with the rest of the system.

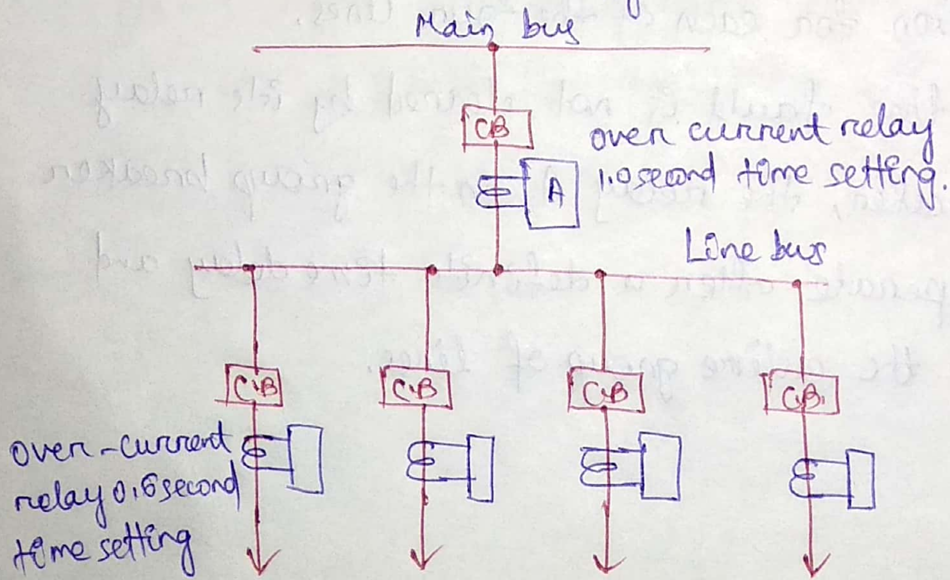
→ The protection scheme is divided into 2 classes

① Primary Protection
② Back-up Protection.

① Primary Protection

→ It is designed to protect the component parts of the power system.

→ Each line has an overcurrent relay that protects the line as shown in the fig.



→ If a fault occurs on any line, it will be cleared by its relay & circuit breaker.

→ This forms the primary protection

→ Sometimes faults are not cleared by primary relay system because of trouble within the relay, wiring system or breaker.

→ Under such conditions, back-up protection performs the required job.

(ii) Back-up Protection

→ It is the second line of defence in case of failure of the primary protection.

→ It is designed to operate with sufficient time delay, so that the primary relaying will have enough time to operate, if possible.

→ In the above figure, relay A provides back-up protection for each of the four lines.

→ If a line fault is not cleared by its relay and breaker, the relay A on the group breaker will operate after a definite time delay and clear the entire group of lines.

Chapter-06

Protection of Electrical Power Equipments & Lines

(6.1) Protection of Alternators

The generating unit, especially the larger ones, are relatively few in number and higher in individual cost than most other equipments. Therefore, it is necessary to provide protection to cover the wide range of faults which may occur in the modern generating plant.

Some of the important faults which may occur on an alternator are:

(1) Failure of prime-mover.

→ When input to the prime-mover fails, the alternator runs as a synchronous motor and draws some current from the supply system. This motoring conditions is known as "inverted running".

(a) In case of turbo-alternator sets, failure of steam supply may cause inverted running.

→ If the steam supply is gradually restored, the alternator will pick up load without disturbing the system.

→ If the steam failure is likely to be prolonged, the machine can be safely isolated by the control room attendant since this condition is relatively harmless. Therefore, automatic protection is not required.

(b) In case of hydro-generator sets, protection against inverted running is achieved by providing mechanical devices on the water-wheel.

→ When the water flow drops to an insufficient rate to maintain the electrical output, the alternator is disconnected from the system. Therefore in this case also electrical protection is not necessary.

(c) Diesel engine driven alternators, when running inverted, draw a considerable amount of power from the supply system and it is a usual practice to provide protection against motoring in order to avoid damage due to possible mechanical seizure.

→ This is achieved by applying reverse power relays to the alternators which isolate the latter during their motoring action.

(2) Failure of field

→ The chances of field failure of alternators are undoubtedly very rare. Even if it does occur, no immediate damage will be caused by permitting the alternator to run without a field for a short period.

→ It is sufficient to rely on the control room attendant to disconnect the faulty alternator manually from the system bus-bars.

→ Therefore, an automatic protection is not necessary.

③ Overcurrent:-

→ It occurs mainly due to partial breakdown of winding insulation or due to overload on the supply system.

→ Overcurrent protection for alternators is not necessary because the modern tendency is to design alternators with very high values of internal impedance so that they will stand a complete short-circuit at their terminals for sufficient time without serious overheating.

→ On the occurrence of an overload, the alternators can be disconnected manually.

④ Overspeed:-

→ The main cause of overspeed is the sudden loss of major part of load on the alternator.

→ Modern alternators are usually provided with mechanical centrifugal devices mounted on their driving shafts to trip the main valve of the prime-mover when a dangerous overspeed occurs.

⑤ Over-voltage:

→ The field excitation system of modern alternators is so designed that over voltage conditions at normal running speeds cannot occur. However, overvoltage in an alternator occurs when speed of the prime-mover increases due to sudden loss of alternator load.

→ The over-voltage relays are operated from a voltage supply derived from the generator terminals.

→ The relays are so arranged that when the generated voltage rises 20% above the normal value, they operate to

ⓐ trip the main CB to disconnect the faulty alternator from the system.

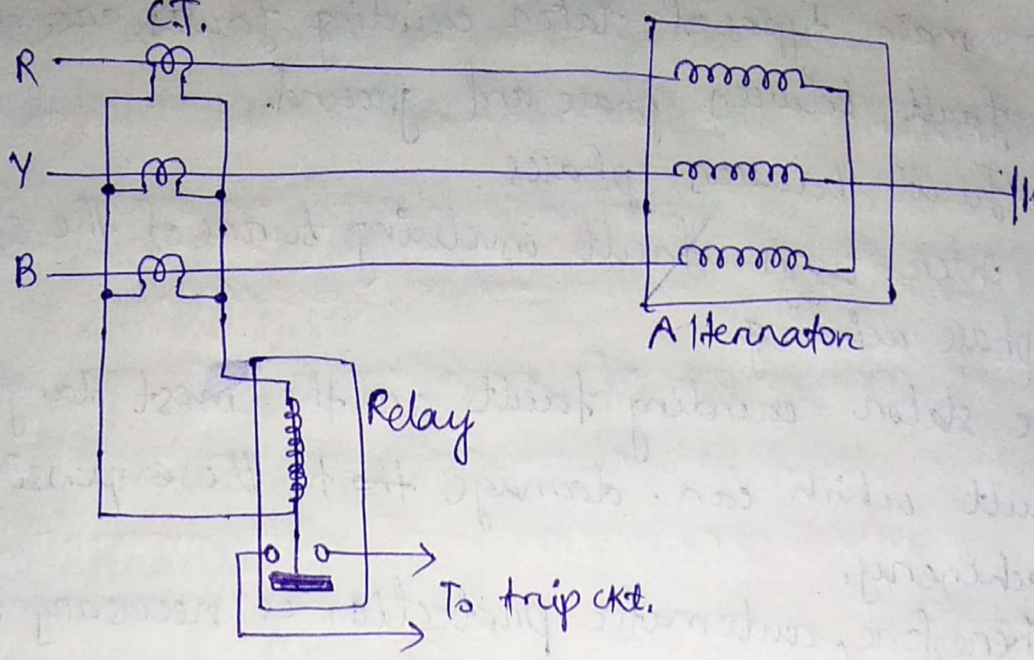
ⓑ disconnect the alternator field circuit.

⑥ Unbalanced Loading →

→ Unbalanced loading means there are different phase currents in the alternator.

→ Unbalanced loading arises from faults to earth or faults between phases on the ckt. external to the alternator.

→ The unbalanced currents, if allowed to persist, may damage the field winding.



→ The above figure shows the arrangement for the protection of alternator against unbalanced loading.

→ Under normal operating conditions, equal currents flow through the different phases of the alternator and their algebraic sum is zero.

→ Therefore, the sum of the currents flowing in the secondaries is also zero and no current flows through the operating coil of the relay.

→ If unbalancing occurs, the currents induced in the secondaries will be different and the resultant of these currents will flow through the relay. Then the operation of the relay will trip the CB to disconnect the alternator from the system.

⑦ Stator winding faults:-

These faults occur mainly due to the insulation failure of the stator windings.

The main types of stator winding faults are

ⓐ fault between phase and ground.

ⓑ fault between phases

ⓒ inter-turn fault involving turns of the same phase winding.

→ The stator winding faults are the most dangerous fault which can damage ~~the~~ to the expensive machinery.

→ Therefore, automatic protection is necessary to clear such faults.

→ For protection of Alternators against such faults, differential method of protection (also known as Merz-Price system) is most commonly employed due to its greater sensitivity and reliability.

(6.2) Differential Protection of Alternators

→ The most common system used for the protection of stator winding faults employs circulating - current principle.

→ In this scheme of protection, currents at the two ends of the protected section are compared.

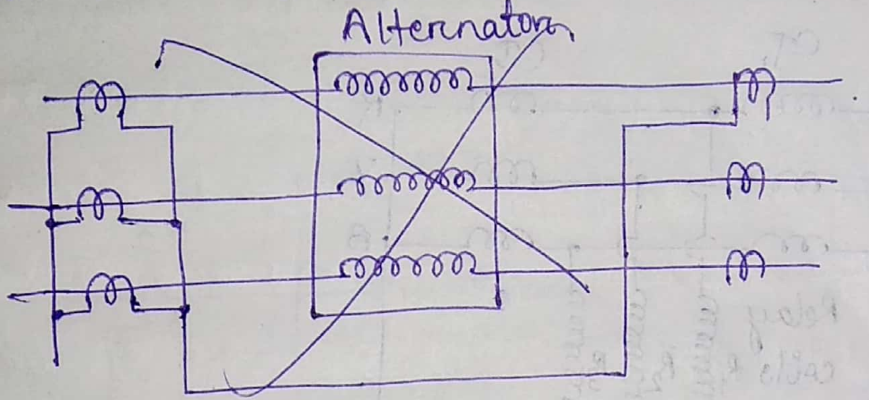
→ Under normal operating conditions, these currents are equal but may become unequal on the occurance of a fault in the protected section.

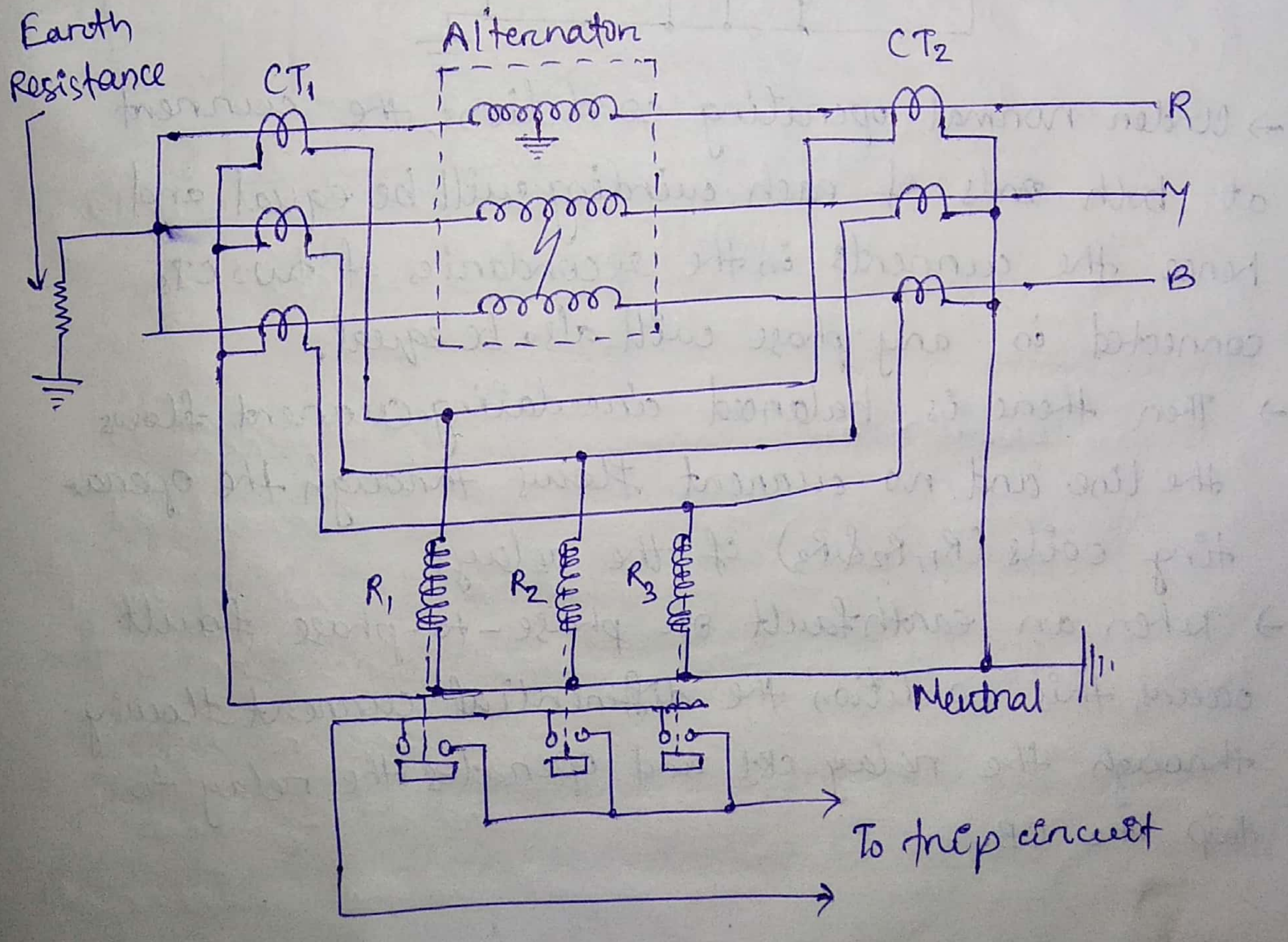
→ The difference of the currents under fault conditions is arranged to pass through the operating coil of the relay.

→ The relay then closes its contacts to isolate protected section from the system.

→ This form of protection is also known as <u>Merz-Price circulating current scheme</u>.

Schematic Arrangement





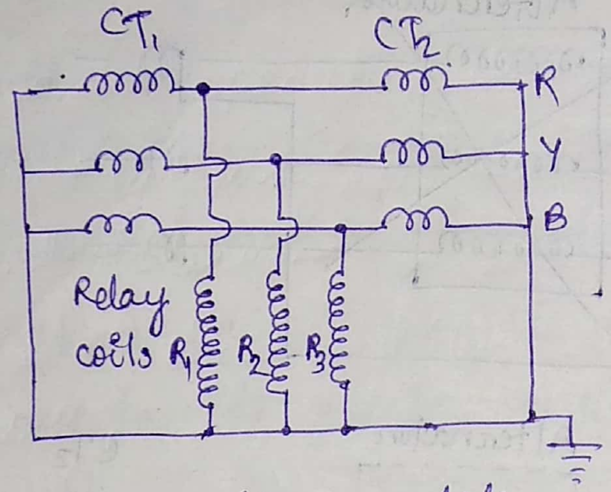
→ The above figure shows the arrangement of current differential protection for a 3-phase alternator.

→ Identical CT pairs are placed on either side of each phase of the stator windings.

→ The secondaries of each set of CTs are connected in star & the relay coils are connected in star.

→ The relays are generally of electromagnetic type.

Operation



→ Under normal operating conditions, the current at both ends of each winding will be equal and hence the currents in the secondaries of two CTs connected in any phase will also be equal.

→ Then there is balanced circulating current flows the line and no current flows through the operating coils (R_1, R_2 & R_3) of the relays.

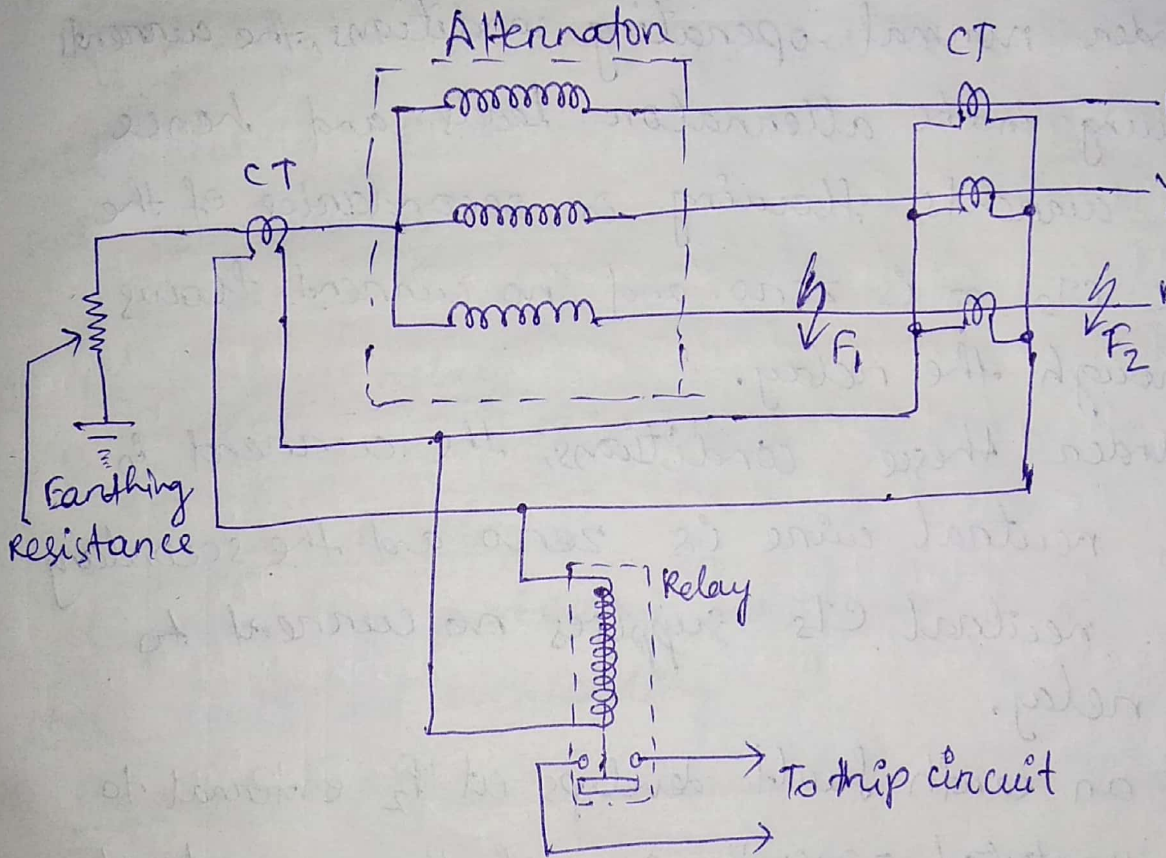
→ When an earth fault or phase-to-phase fault occurs, this condition the differential current flowing through the relay ckt. and operates the relay to trip the CB.

(6.3) Balanced Earth-fault Protection

→ It is necessary to provide protection against earth-faults only by the use of balanced earth-fault protection scheme.

→ This scheme provides no protection against phase-phase faults, until they develop into earth-faults.

Schematic Arrangement



→ The above figure shows the arrangement of a balanced earth-fault protection for a 3-phase alternator.

→ It consists of three line CTs, one mounted in each phase, having their secondaries connected in parallel with that of a single current transformer in the conductor joining the star point of the alternator to earth.

→ A relay is connected across the transformers secondaries.

→ The protection against earth faults is limited to the region betn the neutral & the line CTs.

Operation

→ Under normal operating conditions, the currents flowing in the alternator leads and hence the currents flowing in secondaries of the line CTs is zero. and no current flows through the relay.

→ Under these conditions, the current in the neutral wire is zero and the secondary of neutral CTs supplies no current to the relay.

→ If an earth-fault develops at F_2 external to the protected zone, the sum of the currents at the terminals of the alternator is exactly equal to the current in the neutral connection and hence no current flows through the relay.

→ When an earth fault occurs at F_1, these currents are no longer equal and the differential current flows through the operating coil of the relay. Then the relay closes its contacts to disconnect the alternator from the system.

6.4 Protection Systems for Transformers

→ The principal relays and systems used for transformer protection are:

① Buchholz devices
② Earth-fault relays
③ Over current relays
④ Differential system.

① Buchholz devices

It providing protection against all kinds of incipient (initiatory) faults, i.e. slow developing faults such as insulation failure of windings, core heating, fall of oil level due to leaky joints etc.

② Earth-fault relays

It providing protection against earth-faults only.

③ Overcurrent relay

It providing protection mainly against phase-to-phase faults and overloading.

④ Differential system (or circulating current system)

It providing protection against both earth and phase faults.

→ The complete protection of transformer usually requires the combination of these systems.

→ Choice of a particular combination of systems may depend upon several factors such as:

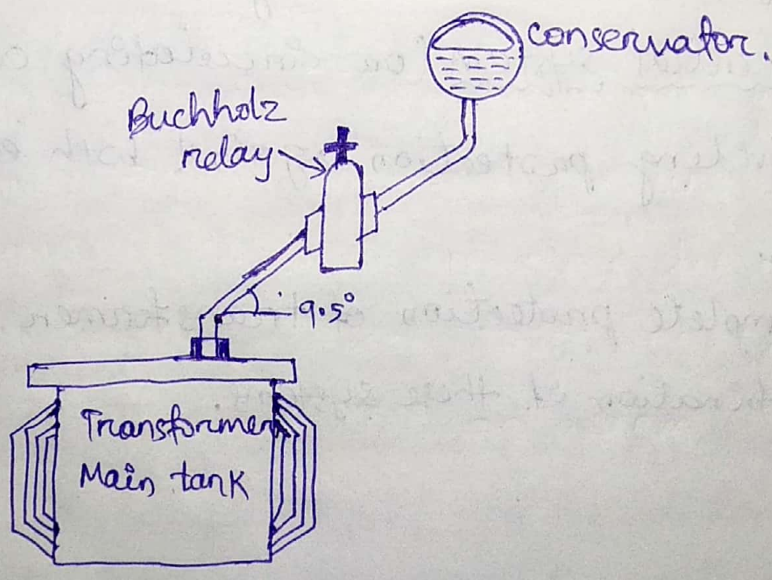
(a) size of transformer
(b) type of cooling
(c) location of transformer in the network.
(d) nature of load supplied and
(e) importance of service for which transformer is required.

6.5 Buchholz Relay

→ Buchholz relay is a gas actuated relay installed in oil immersed transformers for protection against all kinds of faults.

→ It is used to give an alarm in case of incipient (slow developing) faults in the transformer and to disconnect the transformer from the supply in the event of severe internal faults.

→ It is installed in the pipe connecting the conservator to the main tank as shown in the fig(1)



Fig(1)

→ It is used in all such oil immersed transformers having ratings of in excess of 750KVA.

Construction

→ Fig② shows the constructional details of a Buchholz relay.

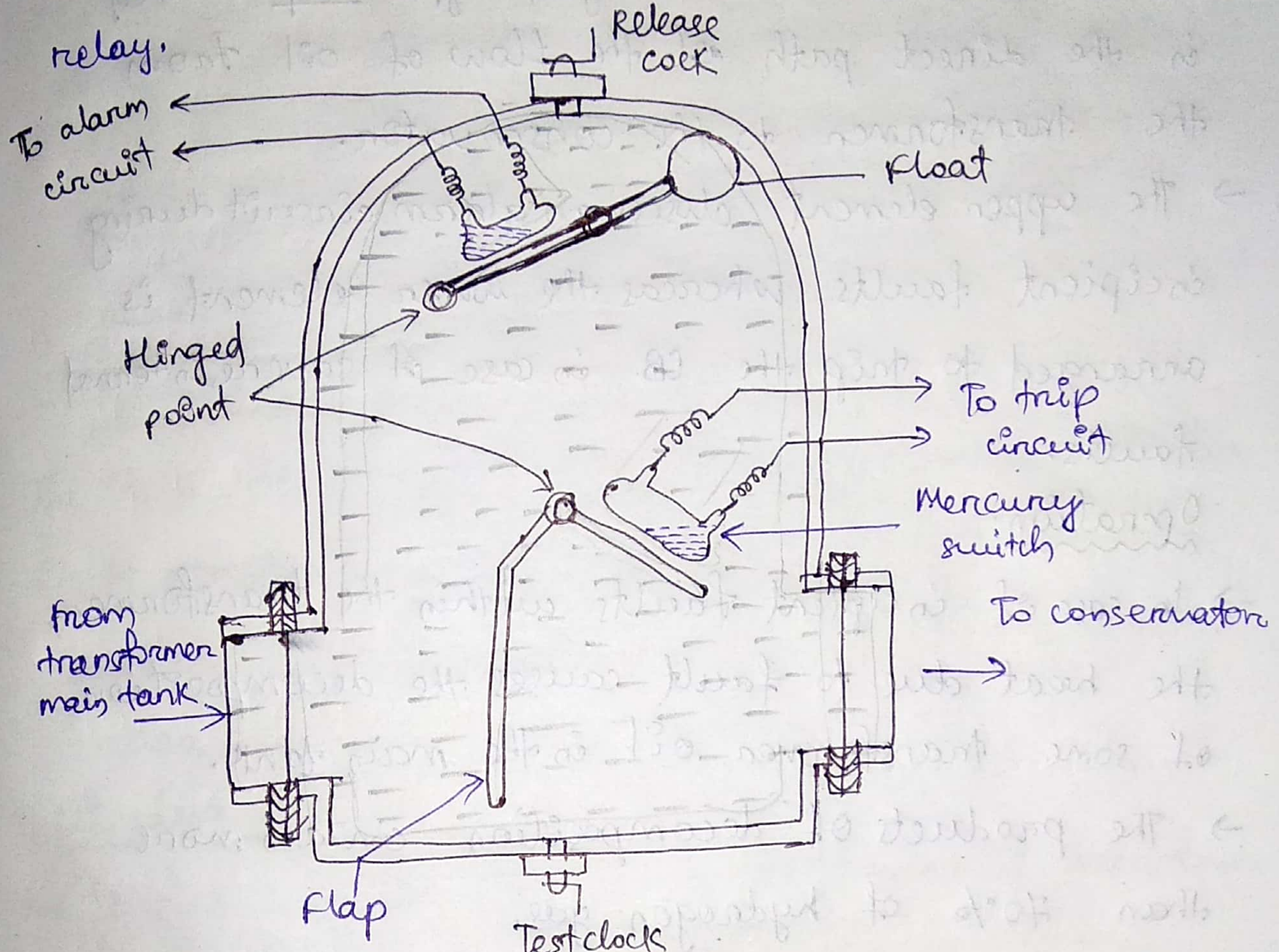


Fig.②

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

→ The device has two elements

① The upper element &

② The lower element.

→ The upper element consist of a mercury type switch attached to a float.

→ The lower element contains a mercury switch mounted on a hinged type flap located in the direct path of the flow of oil from the transformer to the conservator.

→ The upper element closes an alarm circuit during incipient faults whereas the lower element is arranged to trip the CB in case of severe internal faults.

Operation:

→ In case of incipient faults within the transformer, the heat due to fault causes the decomposition of some transformer oil in the main tank.

→ The products of decomposition contain more than 70% of hydrogen gas.

→ The hydrogen gas being light and tries to go into the conservator.

→ When a pre-determined amount of gas gets accumulated, it exerts sufficient pressure on the float to cause it to bend and close the contacts of mercury switch attached to it. This completes the alarm circuit to sound an alarm.

→

→ If a serious fault occurs in the transformer, an enormous amount of gas is generated in the main tank.

→ The oil in the main tank rushes towards the conservator via the Buchholz relay and the flap to close the contacts of mercury switch. This completes the trip circuit to open the circuit breaker controlling the transformer.

Advantages

① It is the simplest form of transformer protection.

② It detects the incipient faults at a stage much earlier than is possible with other forms of protection.

Disadvantages

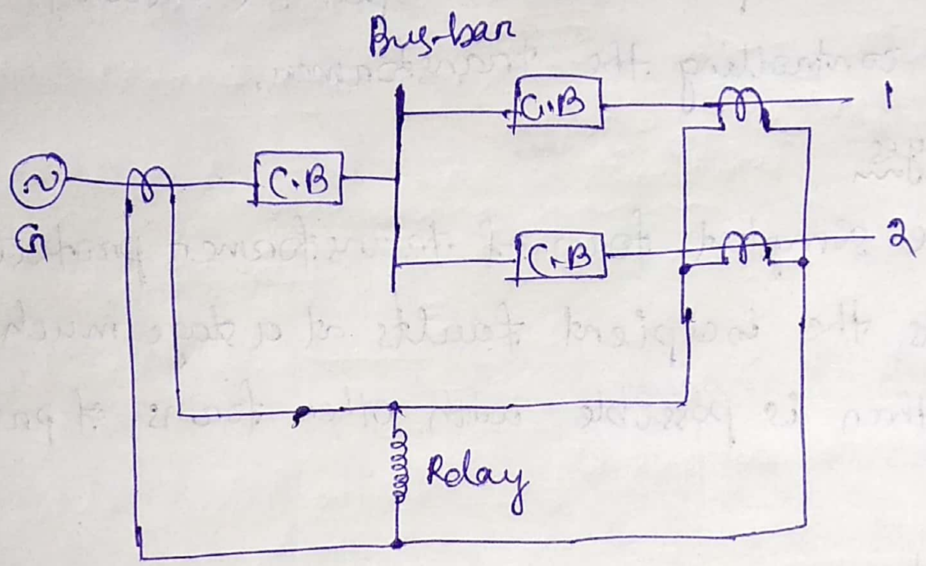
→ It can only be used with oil immersed transformers equipped with conservator tanks.

6.6 Protection of Busbar

→ If a fault occurs on a busbar, considerable damage and disruption of supply will occur unless some form of quick-acting automatic protectn is provided to isolate the faulty busbar.

→ The two most commonly used schemes for busbar protection are
① Differential protection
② Fault bus protection.

① Differential protection



→ This is the basic method for busbar protection.
→ The differential protection scheme is shown in the above fig.
→ The busbar is fed by a generator and supplies load to two lines.
→ The secondaries of CTs in the generator lead, in line 1 & in line 2, are all connected in parallel.
→ The protective relay is connected across this parallel connection.

→ All CTs must be of the same ratio.

→ Under normal load conditions, the sum of the currents entering the bus is equal to those leaving it and no current flows through the relay.

→ If a fault occurs within the protected zone, the current entering the bus will no longer be equal to those leaving it.

→ The difference of these currents will flow through the relay and then the circuit breaker operates.

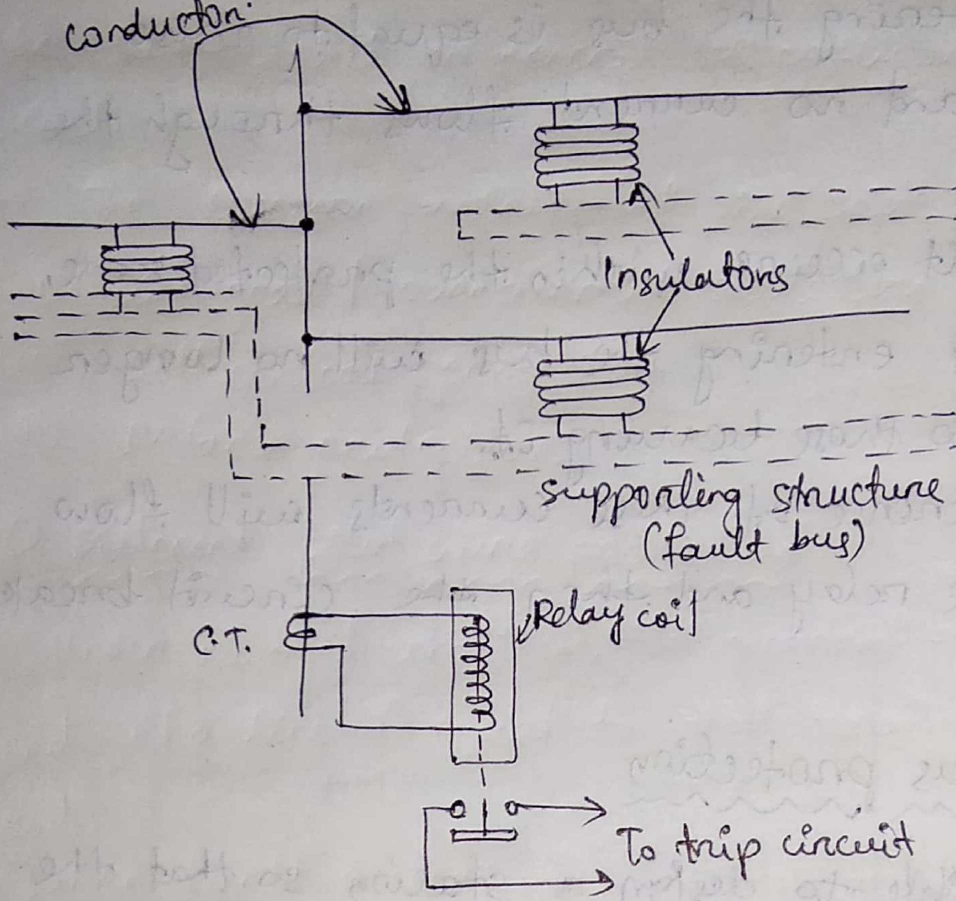
② Fault Bus protection

→ It is possible to design a station so that the faults that develop are mostly earth faults. This can be achieved by providing earthed metal barrier (known as fault bus) surrounding each conductor throughout its entire length in the bus structure.

→ In this arrangement, every fault that might occur must involve a connection betn a conductor and an earthed metal part.

→ By directing the flow of earth fault current, it is possible to detect the faults and determine their location.

→ This type of protection is known as fault bus protection.



→ The above fig. shows the schematic arrangement of fault bus protection.

→ The metal supporting structure or fault bus is earthed through a current transformer.

→ A relay is connected across the secondary of this CT.

→ Operation

→ Under normal operating conditions, there is no current flow from fault bus to ground and the relay remains inoperative.

→ When a fault involving a connection between a conductor and earthed supporting structure will result in current flow to ground through the fault bus, causing the relay to operate.

→ The operation of relay will trip all breakers connecting equipment to the bus.

6.7 Protection of Transmission Line

→ The probability of faults occurring on the lines is much more due to their greater length and exposure to atmospheric conditions.

→ The requirements of line protection are:

(i) In the event of a short-circuit, the circuit breaker closest to the fault should open, all other circuit breakers remaining in a closed position.

(ii) In case the nearest breaker to the fault fails to open, back-up protection should be provided by the adjacent circuit breakers.

(iii) The relay operating time should be just as short as possible in order to preserve system stability, without unnecessary tripping of circuits.

→ ~~While~~ Differential protection is ideal method for lines, it is much more expensive to use.

→ The two ends of a line may be several kilometers apart and to compare the two currents a costly pilot-wire circuit is required. This expense may be justified but in general less costly methods are used.

→ The common methods of line protection are

(i) Time-graded overcurrent protection

(ii) Differential protection

(iii) Distance protection.

(6.8) Different pilot wire protection

→ Under normal conditions, the current entering one end of a line is equal to that leaving the other end.

→ When fault occurs betⁿ the two ends, this condition no longer holds and the difference of incoming incoming and outgoing currents is arranged to flow through a relay which operates the circuit breaker to isolate the faulty line.

(i) Merz-Price voltage balance system

→ Fig(a) shows the single line diagram of Merz-Price voltage balance system for the protection of a 3-phase line.

→ Identical current transformers are placed in each phase at both ends of the line.

→ The pair of CTs in each line is connected in series with a relay. ~~in such a way that~~

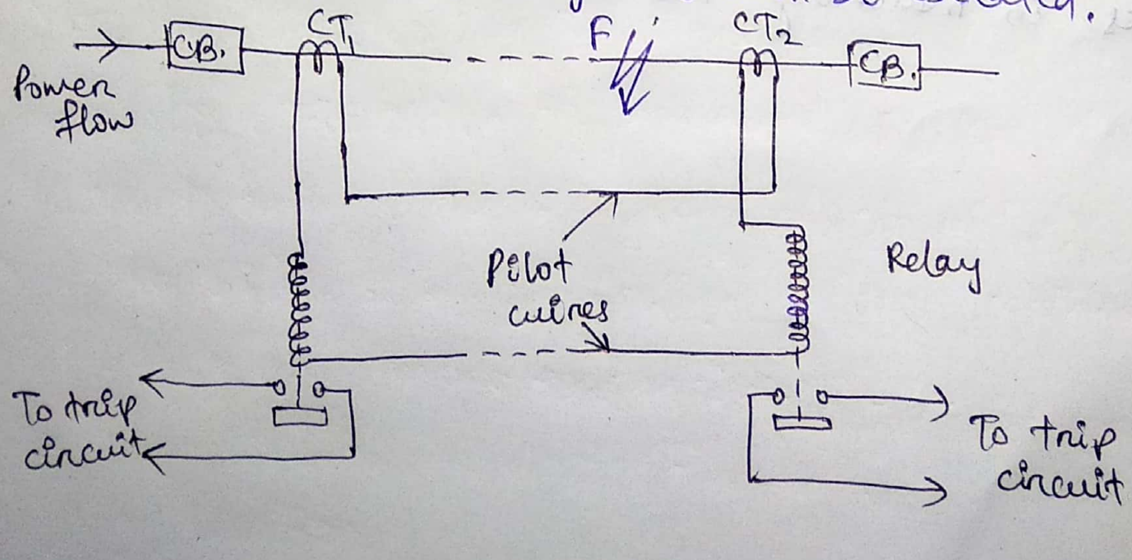
→ Under normal operating conditions, their secondary voltages are equal and in opposition i.e. they balance each other.

→ Under healthy conditions, current entering the line at one-end is equal to that leaving it at the other end.

→ Therefore, equal and opposite voltages are induced in the secondaries of the CTs at the two ends of the line. The result is that no current flows through the relays.

→ When a fault occurs at point F on the line, then a greater current to flow through CT_1 than through CT_2.

→ Consequently, their secondary voltages become unequal and circulating current flows through the pilot wires and relays. Then the CB at both ends of the line will trip out and the faulty line will be isolated.



Advantages

(i) This system can be used for ring mains as well as parallel feeders.

(ii) This system provides instantaneous protection for ground faults. This decrease the possibility of these faults involving other phases.

(iii) This system provides instantaneous relaying which reduces the amount of damage to overhead conductors resulting from arcing faults.

Disadvantages

(i) Accurate matching of current transformers is very essential.

(ii) If there is a break in the pilot-wire circuit, the system will not operate.

(iii) This system is very expensive due to the greater length of pilot wires required.

(iv) This system cannot be used for line voltages beyond 33KV because of constructional difficulties in matching the current transformers.

Chapter-07

Protection against overvoltage & Lightning

7.1 Voltage surge & causes of over voltage

Voltage surge

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

Causes of over voltage

The causes of overvoltage are due to switching surge or transients and lightning ~~surge~~/strike.

Causes of overvoltages

- Internal causes
  - Switching surges
  - Insulation failure
  - Arcing ground
  - Resonance.
- External causes (Lightning)

7.2 Internal cause of over voltage

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

① Switching surges

The overvoltages produced on the power system due to switching operations are known as switching surges.

② Insulation failure

The most common case of insulation failure in a power system is the grounding of conductor. (i.e. insulation failure betn line and earth)

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

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

④ Resonance

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

→ Under resonance, the impedance of the circuit is equal to resistance of the circuit and the p.f is unity.

→ Resonance causes high voltages in the electrical system.

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

→ If generator emf. wave is ~~distored~~ distorted, the trouble of resonance may occur due to 5th or higher order harmonics and in case of underground cables too.

(7.3) External cause of overvoltage (lightning)

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

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

(7.4) Mechanism of lightning discharge.

An electric discharge between cloud and earth, between clouds or between the charge centres of the same cloud is known as lightning.

→ Lightning is a huge spark and takes place when clouds are charged to such a high potential (+ve or −ve) with respect to earth or a neighbouring cloud. that the dielectric strength of neighbouring medium is destroyed.

→ The uprush of warm moist air from earth, the friction between the air and the tiny particles of water causes the building up of charges.

→ When drops of water are formed, the larger drops become positively charged and the smaller drops become negatively charged.

→ When the drops of water accumulate, they form clouds, and hence cloud may possess either a positive or a negative charge, depending upon the charge of drops of water they contain.

→ The charge on a cloud may become so great that it may discharge to another cloud or to earth and we call this discharge as lightning.

→ As the charge acquired by the cloud increases, the potential between cloud and earth increases. and therefore, gradient in the air increases.

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

the lightning stroke starts. The stroke mechanism is as under :

(*i*) As soon as the air near the cloud breaks down, a streamer called *leader streamer* or *pilot streamer* starts from the cloud towards the earth and carries charge with it as shown in Fig. 24.4 (*i*). The leader streamer will continue its journey towards earth as long as the cloud, from which it originates feeds enough charge to it to maintain gradient at the tip of leader streamer above the strength of air. If this gradient is not maintained, the leader streamer stops and the charge is dissipated without the formation of a complete stroke. In other words, the leader streamer will not reach the earth. Fig. 24.4 (*i*) shows the leader streamer being unable to reach the earth as gradient at its end cloud not be maintained above the strength of air. It may be noted that current in the leader streamer is low (<100 A) and its velocity of propagation is about 0·05% that of velocity of light. Moreover, the luminosity of leader is also very low.

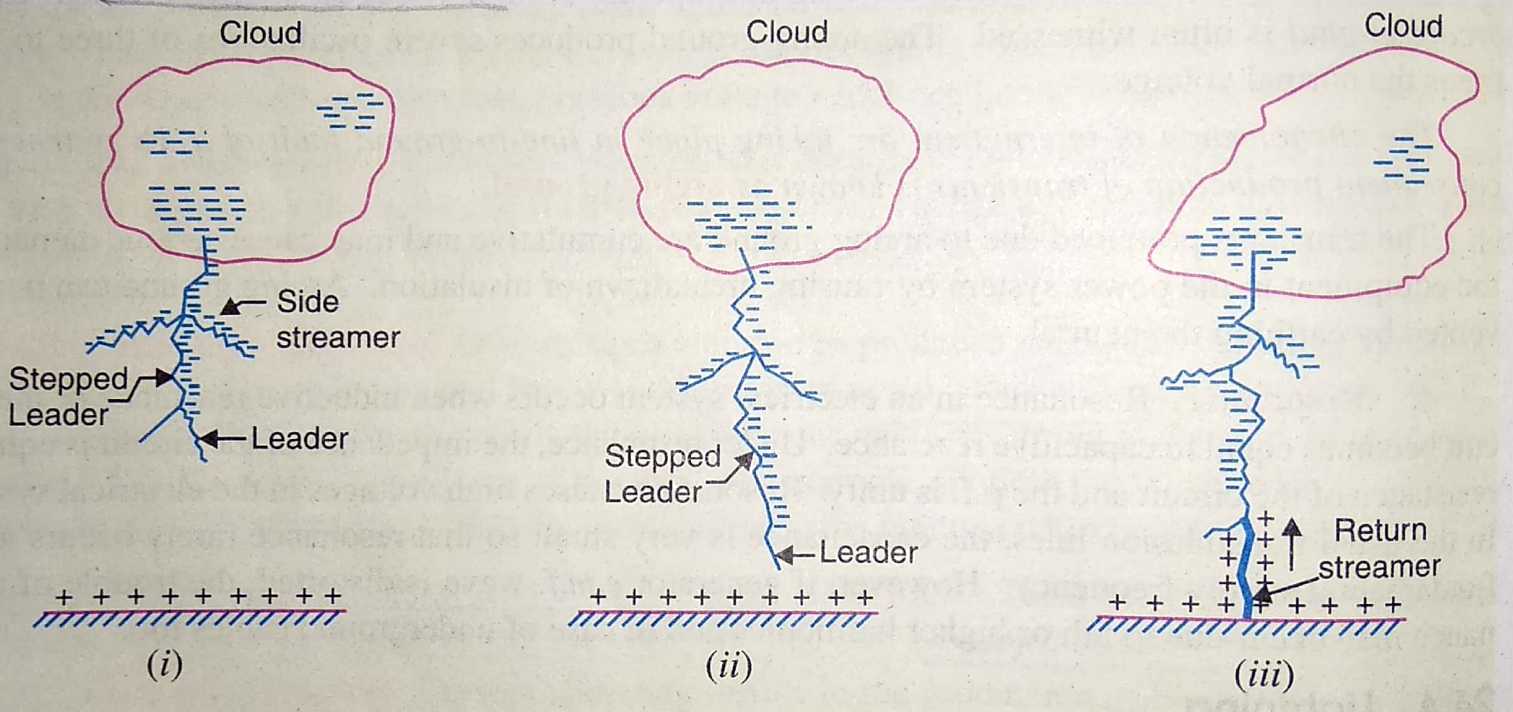


Fig. 24.4

(*ii*) In many cases, the leader streamer continues its journey towards earth [See Fig. 24.4 (*ii*)] until it makes contact with earth or some object on the earth. As the leader streamer moves towards earth, it is accompanied by points of luminescence which travel in jumps giving rise to stepped leaders. The velocity of stepped leader exceeds one-sixth of that of light and distance travelled in one step is about 50 m. It may be noted that stepped leaders have sufficient luminosity and give rise to first visual phenomenon of discharge.

(*iii*) The path of leader streamer is a path of ionisation and, therefore, of complete breakdown of insulation. As the leader streamer reaches near the earth, a *return streamer* shoots up from the earth [See Fig. 24.4 (*iii*)] to the cloud, following the same path as the main channel of the downward leader. The action can be compared with the closing of a switch between the positive and negative terminals; the downward leader having negative charge and return streamer the positive charge. This phenomenon causes a sudden spark which we call lightning. With the resulting neutralisation of much of the negative charge on the cloud, any further discharge from the cloud may have to originate from some other portion of it.

The following points may be noted about lightning discharge :

(*a*) A lightning discharge which usually appears to the eye as a single flash is in reality made up of a number of separate strokes that travel down the same path. The interval between them varies from 0·0005 to 0·5 second. Each separate stroke starts as a downward leader from the cloud.

(*b*) It has been found that 87% of all lightning strokes result from negatively charged clouds and only 13% originate from positively charged clouds.

(*c*) It has been estimated that throughout the world, there occur about 100 lightning strokes per second.

(*d*) Lightning discharge may have currents in the range of 10 kA to 90 kA.

24.6 Types of Lightning Strokes

There are two main ways in which a lightning may strike the power system (*e.g.* overhead lines, towers, sub-stations etc.), namely;

1. Direct stroke   2. Indirect stroke

1. **Direct stroke.** In the direct stroke, the lightning discharge (*i.e.* current path) is directly from the cloud to the subject equipment *e.g.* an overhead line. From the line, the current path may be over the insulators down the pole to the ground. The overvoltages set up due to the stroke may be large enough to flashover this path directly to the ground. The direct strokes can be of two types *viz.* (*i*) Stroke *A* and (*ii*) stroke *B*.

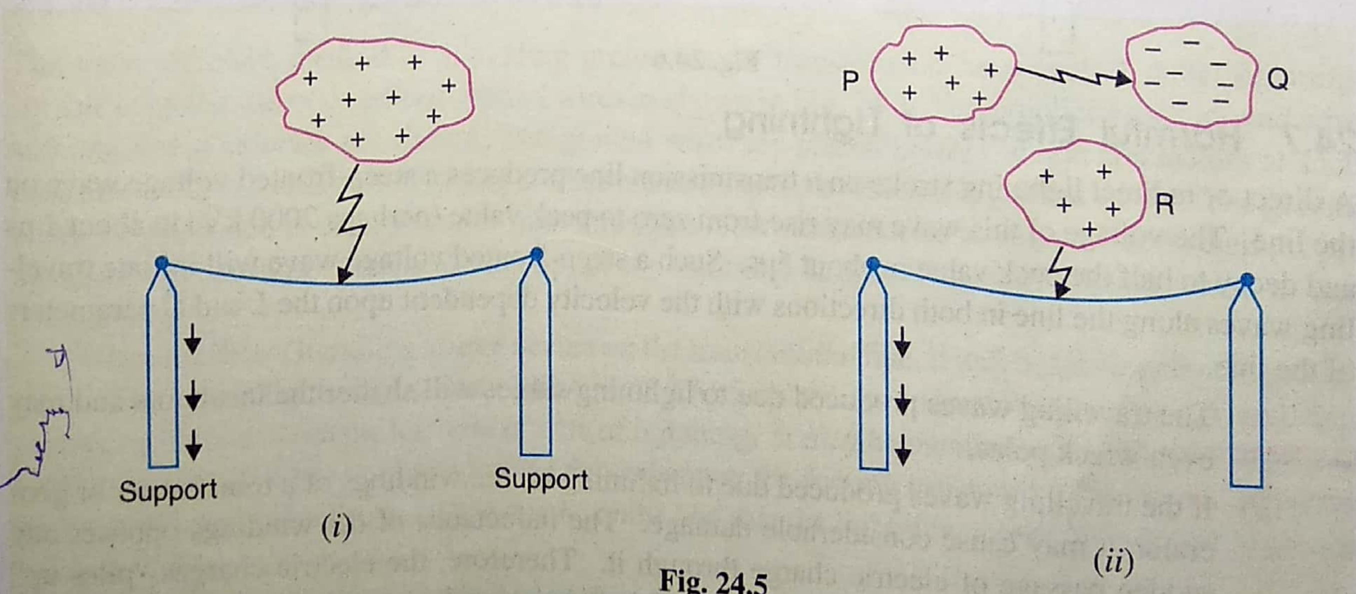


Fig. 24.5

(*i*) In stroke *A*, the lightning discharge is from the cloud to the subject equipment *i.e.* an overhead line in this case as shown in Fig. 24.5 (*i*). The cloud will induce a charge of opposite sign on the tall object (*e.g.* an overhead line in this case). When the potential between the cloud and line exceeds the breakdown value of air, the lightning discharge occurs between the cloud and the line.

(ii) In stroke *B*, the lightning discharge occurs on the overhead line as a result of stroke *A* between the clouds as shown in Fig. 24.5 *(ii)*. There are three clouds *P*, *Q* and *R* having positive, negative and positive charges respectively. The charge on the cloud *Q* is bound by the cloud *R*. If the cloud *P* shifts too near the cloud *Q*, then lightning discharge will occur between them and charges on both these clouds disappear quickly. The result is that charge on cloud *R* suddenly becomes free and it then discharges rapidly to earth, ignoring tall objects.

Two points are worth noting about direct strokes. Firstly, direct strokes on the power system are very rare. Secondly, stroke *A* will always occur on tall objects and hence protection can be provided against it. However, stroke *B* completely ignores the height of the object and can even strike the ground. Therefore, it is not possible to provide protection against stroke *B*.

2. **Indirect stroke.** Indirect strokes result from the electrostatically induced charges on the conductors due to the presence of charged clouds. This is illustrated in Fig. 24.6. A positively charged cloud is above the line and induces a negative charge on the line by electrostatic induction. This negative charge, however, will be only on that portion of the line right under the cloud and the portions of the line away from it will be positively charged as shown in Fig. 24.6. The induced positive charge leaks slowly to earth *via* the insulators. When the cloud discharges to earth or to another cloud, the negative charge on the wire is isolated as it cannot flow quickly to earth over the insulators. The result is that negative charge rushes along the line is both directions in the form of travelling waves. It may be worthwhile to mention here that majority of the surges in a transmission line are caused by indirect lightning strokes.

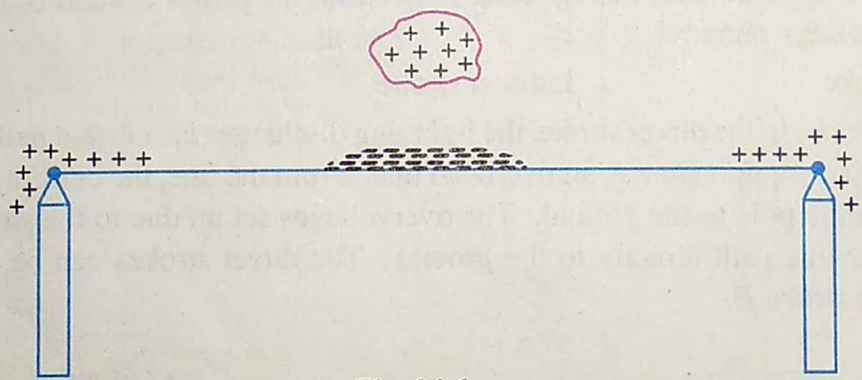


Fig. 24.6

24.7 Harmful Effects of Lightning

A direct or indirect lightning stroke on a transmission line produces a steep-fronted voltage wave on the line. The voltage of this wave may rise from zero to peak value (perhaps 2000 kV) in about 1 μs and decay to half the peak value in about 5μs. Such a steep-fronted voltage wave will initiate travelling waves along the line in both directions with the velocity dependent upon the *L* and *C* parameters of the line.

(i) The travelling waves produced due to lightning surges will shatter the insulators and may even wreck poles.

(ii) If the travelling waves produced due to lightning hit the windings of a transformer or generator, it may cause considerable damage. The inductance of the windings opposes any sudden passage of electric charge through it. Therefore, the electric charges "piles up" against the transformer (or generator). This induces such an excessive pressure between the windings that insulation may breakdown, resulting in the production of arc. While the normal voltage between the turns is never enough to *start* an arc, once the insulation has

broken down and an arc has been started by a momentary overvoltage, the line voltage is usually sufficient to *maintain* the arc long enough to severely damage the machine.

(*iii*) If the arc is initiated in any part of the power system by the lightning stroke, this arc will set up very disturbing oscillations in the line. This may damage other equipment connected to the line.

24.11 Lightning Arresters

The earthing screen and ground wires can well protect the electrical system against direct lightning strokes but they fail to provide protection against travelling waves which may reach the terminal apparatus. The lightning arresters or surge diverters provide protection against such surges.

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

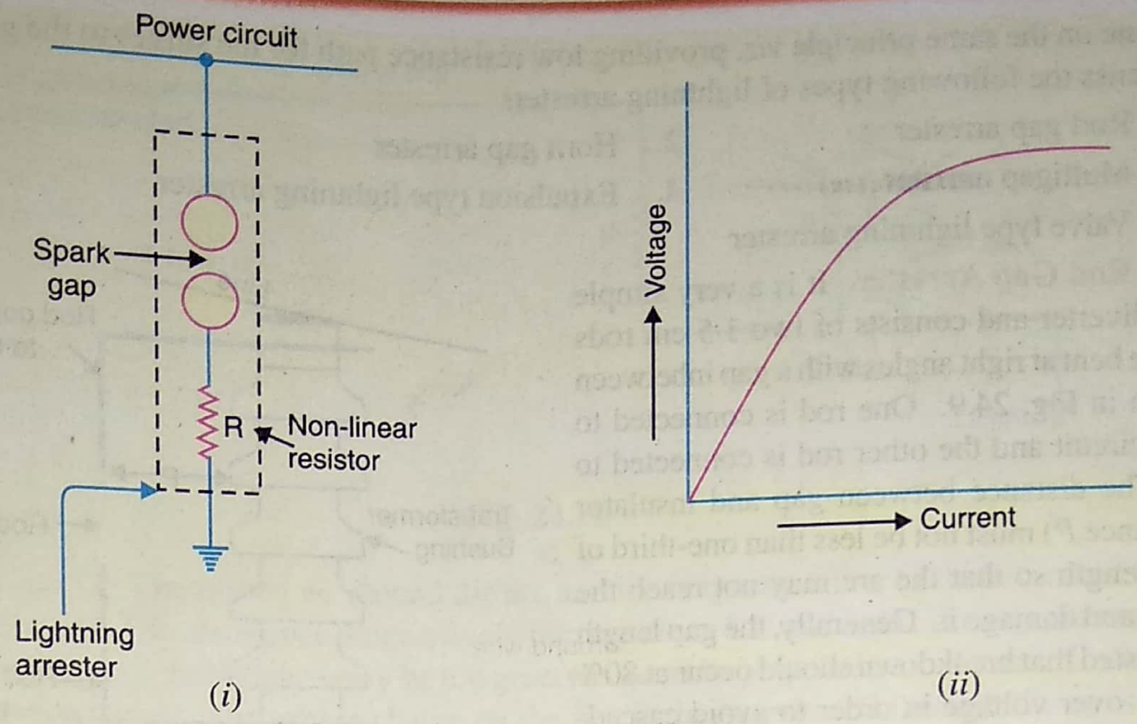


Fig. 24.8

Fig. 24.8 (*i*) shows the basic form of a surge diverter. It consists of a spark gap in series with a non-linear resistor. One end of the diverter is connected to the terminal of the equipment to be protected and the other end is effectively grounded. The length of the gap is so set that normal line voltage is not enough to cause an arc across the gap but a dangerously high voltage will break down the air insulation and form an arc. The property of the non-linear resistance is that its resistance decreases as the voltage (or current) increases and vice-versa. This is clear from the *volt/amp characteristic of the resistor shown in Fig. 24.8 (*ii*).

Action. The action of the lightning arrester or surge diverter is as under :

(*i*) Under normal operation, the lightning arrester is off the line *i.e.* it conducts **no current to earth or the gap is non-conducting.

(*ii*) On the occurrence of overvoltage, the air insulation across the gap breaks down and an arc is formed, providing a low resistance path for the surge to the ground. In this way, the excess charge on the line due to the surge is harmlessly conducted through the arrester to the ground instead of being sent back over the line.

(*iii*) It is worthwhile to mention the function of non-linear resistor in the operation of arrester. As the gap sparks over due to overvoltage, the arc would be a short-circuit on the power system and may cause power-follow current in the arrester. Since the characteristic of the resistor is to offer high resistance to high voltage (or current), it prevents the effect of a short-circuit. After the surge is over, the resistor offers high resistance to make the gap non-conducting.

Two things must be taken care of in the design of a lightning arrester. Firstly, when the surge is over, the arc in gap should cease. If the arc does not go out, the current would continue to flow through the resistor and both resistor and gap may be destroyed. Secondly, IR drop (where I is the surge current) across the arrester when carrying surge current should not exceed the breakdown strength of the insulation of the equipment to be protected.

24.12 Types of Lightning Arresters

There are several types of lightning arresters in general use. They differ only in constructional details but operate on the same principle *viz.* providing low resistance path for the surges to the ground. We shall discuss the following types of lightning arresters :

1. Rod gap arrester
2. Horn gap arrester
3. Multigap arrester
4. Expulsion type lightning arrester
5. Valve type lightning arrester

1. Rod Gap Arrester. It is a very simple type of diverter and consists of two 1·5 cm rods which are bent at right angles with a gap inbetween as shown in Fig. 24.9. One rod is connected to the line circuit and the other rod is connected to earth. The distance between gap and insulator (*i.e.* distance *P*) must not be less than one-third of the gap length so that the arc may not reach the insulator and damage it. Generally, the gap length is so adjusted that breakdown should occur at 80% of spark- over voltage in order to avoid cascading of very steep wave fronts across the insulators. The string of insulators for an overhead line on the bushing of transformer has frequently a rod gap across it. Fig. 24.9 shows the rod gap across the bushing of a transformer.

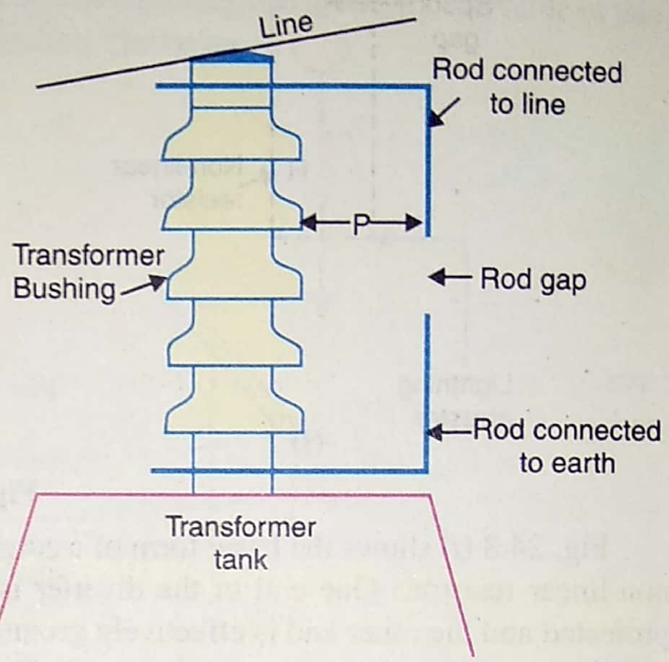


Fig. 24.9

Under normal operating conditions, the gap remains non-conducting. On the occurrence of a high voltage surge on the line, the gap sparks over and the surge current is conducted to earth. In this way, excess charge on the line due to the surge is harmlessly conducted to earth.

Limitations

(*i*) After the surge is over, the arc in the gap is maintained by the †normal supply voltage, leading to a short-circuit on the system.

(*ii*) The rods may melt or get damaged due to excessive heat produced by the arc.

(*iii*) The climatic conditions (*e.g.* rain, humidity, temperature etc.) affect the performance of rod gap arrester.

(*iv*) The polarity of the surge also affects the performance of this arrester.

Due to the above limitations, the rod gap arrester is only used as a 'back-up' protection in case of main arresters.

2. Horn Gap Arrester. Fig. 24.10 shows the horn gap arrester. It consists of two horn shaped metal rods *A* and *B* separated by a small air gap. The horns are so constructed that distance between them gradually increases towards the top as shown. The horns are mounted on porcelain insulators. One end of horn is connected to the line through a resistance *R* and choke coil *L* while the other end is effectively grounded. The resistance *R* helps in limiting the follow current to a small value. The choke coil is so designed that it offers small reactance at normal power frequency but a very high reactance at transient frequency. Thus the choke does not allow the transients to enter the apparatus to be protected. The gap between the horns is so adjusted that normal supply voltage is not enough to cause an arc across the gap.

Under normal conditions, the gap is non-conducting *i.e.* normal supply voltage is insufficient to initiate the arc between the gap. On the occurrence of an overvoltage, spark-over takes place across

† The normal supply voltage may not be able to initiate the arc across the gap. But once the arc is started by

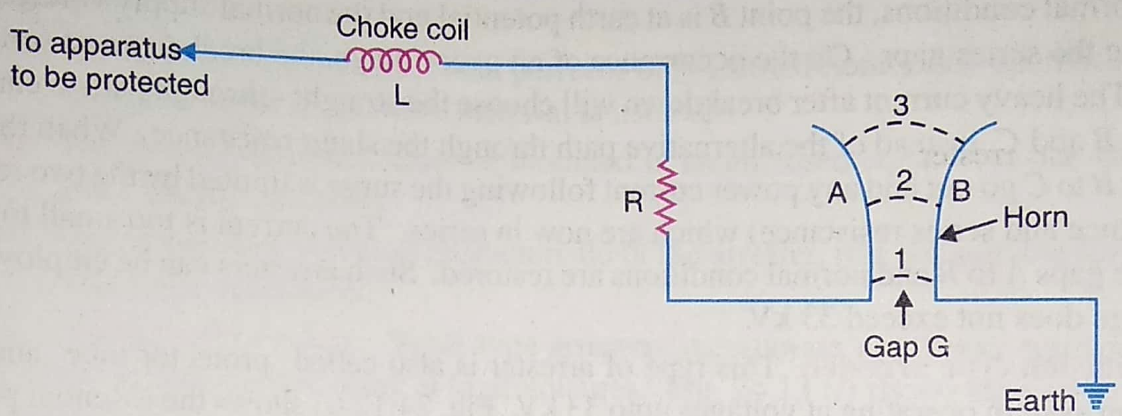


Fig. 24.10

the *small gap *G*. The heated air around the arc and the magnetic effect of the arc cause the arc to travel up the gap. The arc moves progressively into positions 1, 2 and 3. At some position of the arc (perhaps position 3), the distance may be too great for the voltage to maintain the arc. Consequently, the arc is extinguished. The excess charge on the line is thus conducted through the arrester to the ground.

Advantages

(*i*) The arc is self-clearing. Therefore, this type of arrester does not cause short-circuiting of the system after the surge is over as in the case of rod gap.

(*ii*) Series resistance helps in limiting the follow current to a small value.

Limitations

(*i*) The bridging of gap by some external agency (*e.g.* birds) can render the device useless.

(*ii*) The setting of horn gap is likely to change due to corrosion or pitting. This adversely affects the performance of the arrester.

(*iii*) The time of operation is comparatively long, say about 3 seconds. In view of the very short operating time of modern protective gear for feeders, this time is far long.

Due to the above limitations, this type of arrester is not reliable and can only be used as a second line of defence like the rod gap arrester.

expensive equipment.

5. **Valve type arrester.** Valve type arresters incorporate non-linear resistors and are extensively used on systems operating at high voltages. Fig. 24.13 (*i*) shows the various parts of a valve type arrester. It consists of two assemblies (*i*) series spark gaps and (*ii*) non-linear resistor discs (made of material such as thyrite or metrosil) in series. The non-linear elements are connected in series with the spark gaps. Both the assemblies are accommodated in tight porcelain container.

(*i*) The spark gap is a multiple assembly consisting of a number of identical spark gaps in series. Each gap consists of two electrodes with a fixed gap spacing. The voltage distribution across the gaps is linearised by means of additional resistance elements (called grading resistors) across the gaps. The spacing of the series gaps is such that it will withstand the normal circuit voltage. However, an overvoltage will cause the gap to breakdown, causing the surge current to ground via the non-linear resistors.

(*ii*) The non-linear resistor discs are made of an inorganic compound such as Thyrite or Metrosil. These discs are connected in series. The non-linear resistors have the property of offering a high resistance to current flow when normal system voltage is applied, but a low resistance to the flow of high-surge currents. In other words, the resistance of these non-linear elements decreases with the increase in current through them and *vice-versa*.

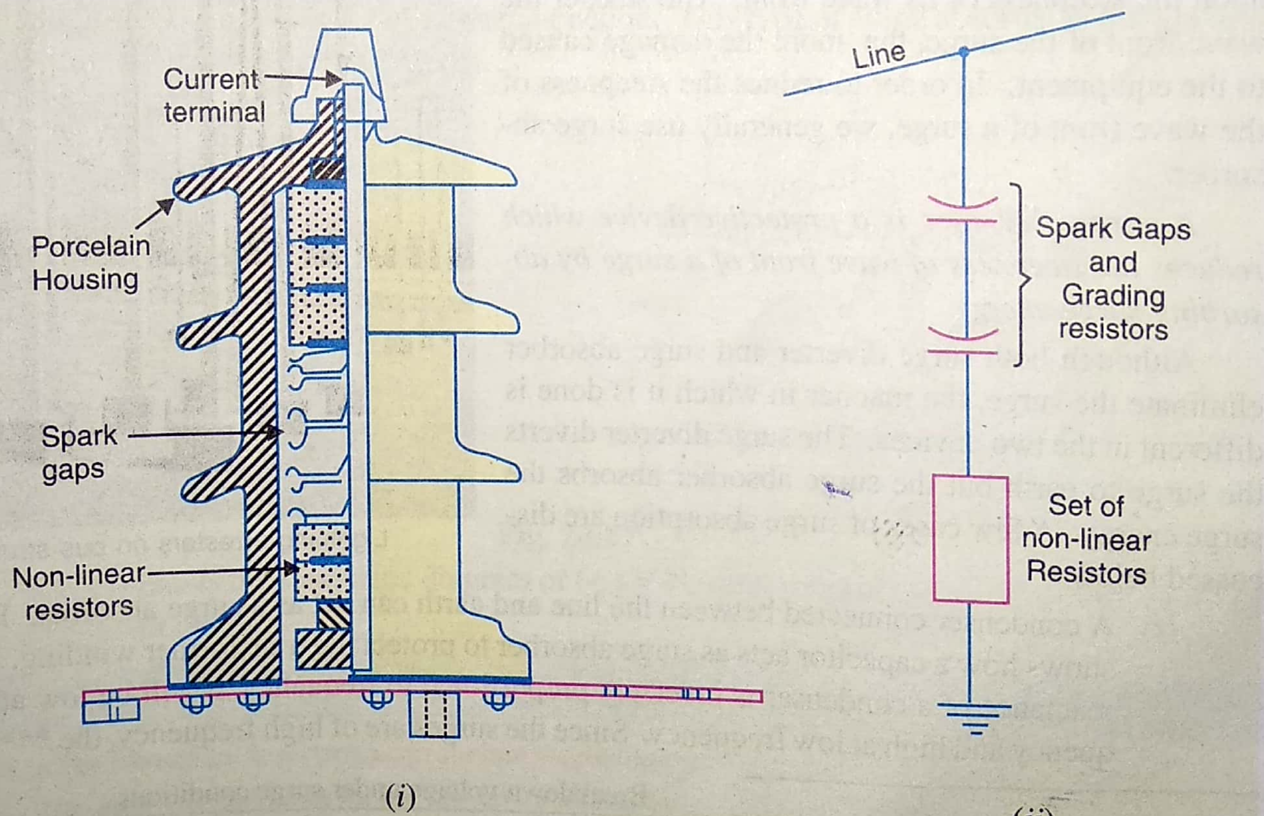


Fig. 24.13

Working. Under normal conditions, the normal system voltage is insufficient to cause the breakdown of air gap assembly. On the occurrence of an overvoltage, the breakdown of the series spark gap takes place and the surge current is conducted to earth *via* the non-linear resistors. Since the magnitude of surge current is very large, the non-linear elements will offer a very low resistance to the passage of surge. The result is that the surge will rapidly go to earth instead of being sent back over the line. When the surge is over, the non-linear resistors assume high resistance to stop the flow of current.

Advantages

(*i*) They provide very effective protection (especially for transformers and cables) against surges.

(*ii*) They operate very rapidly taking less than a second.

(*iii*) The *impulse ratio is practically unity.

Limitations

(*i*) They **may fail to check the surges of very steep wave front from reaching the terminal apparatus. This calls for additional steps to check steep-fronted waves.

(*ii*) Their performance is adversely affected by the entry of moisture into the enclosure. This necessitates effective sealing of the enclosure at all times.

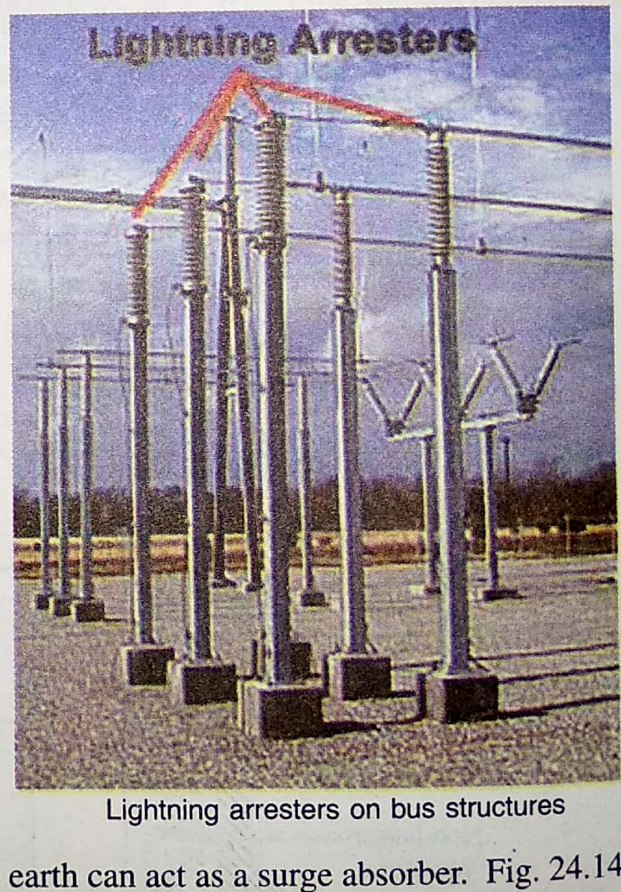
Applications. According to their application, the valve type arresters are classified as (*i*) station type and (*ii*) line type. The station type arresters are generally used for the protection of important equipment in power stations operating on voltages upto 220 kV or higher. The line type arresters are also used for stations handling voltages upto 66 kV.

24.13 Surge Absorber

The travelling waves set up on the transmission lines by the surges may reach the terminals apparatus and cause damage to it. The amount of damage caused not only depends upon the amplitude of the surge but also upon the steepness of its wave front. The steeper the wave front of the surge, the more the damage caused to the equipment. In order to reduce the steepness of the wave front of a surge, we generally use surge absorber.

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

Although both surge diverter and surge absorber eliminate the surge, the manner in which it is done is different in the two devices. The surge diverter diverts the surge to earth but the surge absorber absorbs the surge energy. A few cases of surge absorption are discussed below :



Lightning arresters on bus structures

(*i*) A condenser connected between the line and earth can act as a surge absorber. Fig. 24.14 shows how a capacitor acts as surge absorber to protect the transformer winding. Since the reactance of a condenser is inversely proportional to frequency, it will be low at high frequency and high at low frequency. Since the surges are of high frequency, the ***capacitor acts as a short circuit and passes them directly to earth. However, for power frequency, the reactance of the capacitor is very high and practically no current flows to the ground.

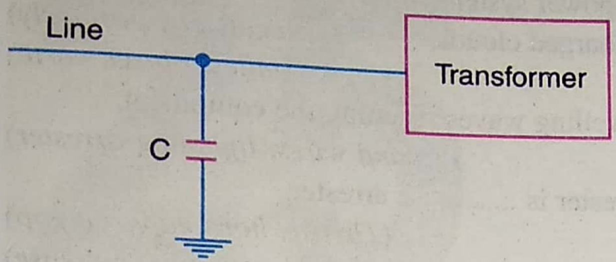


Fig. 24.14

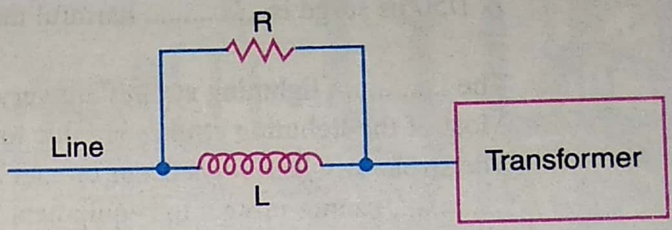


Fig. 24.15

(*ii*) Another type of surge absorber consists of a parallel combination of choke and resistance connected in series with the line as shown in Fig. 24.15. The choke offers high reactance to surge frequencies $(X_L = 2\pi f L)$. The surges are, therefore, forced to flow through the resistance R where they are dissipated.

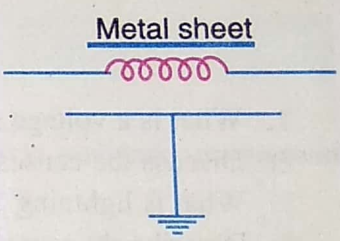
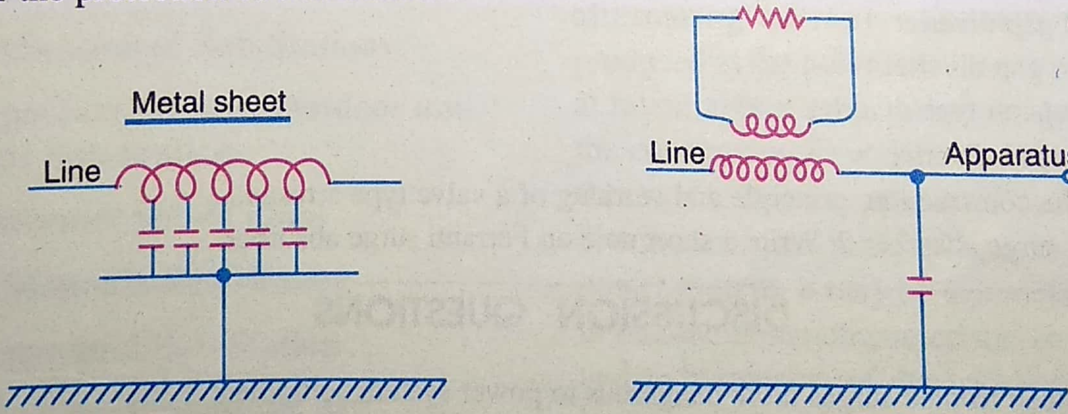


Fig. 24.16

(*iii*) Fig. 24.16 shows the another type of surge absorber. It is called Ferranti surge absorber. It consists of an air cored inductor connected in series with the line. The inductor is surrounded by but insulated from an earthed metallic sheet called dissipator. This arrangement is equivalent to a transformer with short-circuited secondary. The inductor forms the primary whereas the dissipator forms the short-circuited secondary. The energy of the surge is used up in the form of heat generated in the dissipator due to transformer action. This type of surge absorber is mainly used for the protection of transformers.



(*i*) (*ii*)

Fig. 24.17

Fig. 24.17 (*i*) shows the schematic diagram of 66 kV Ferranti surge absorber while Fig. 24.17 (*ii*) shows its equivalent circuit.

Chapter-08 Static Relay

The relay which doesnot contain any moving parts is known as the static relay. In such types of relays, the output is obtained by the static components like magnetic and electronic circuit, etc..

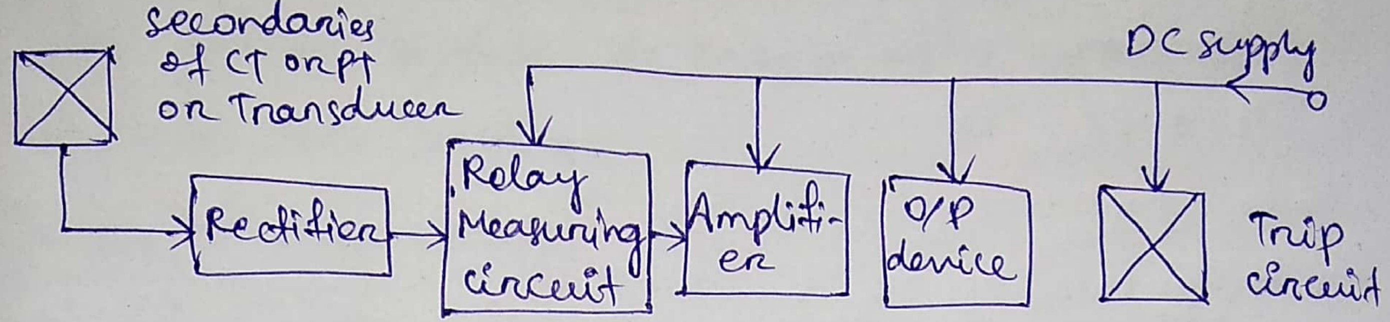


fig. [Block diagram of static relay]

8.1 Advantages of Static Relay

1. It consumes very less power
2. It gives quick response, long life, high reliability and accuracy and it is shockproof.
3. The reset time of the relay is very less.
4. The relay amplifies the input signal which increases their sensitivity.
5. The chance of unwanted tripping is less in this relay.
6. The static relay can easily operate in earthquake-prone areas because they have high resistance to shock.