INTRODUCTION TO SWITCHGEAR

* Switchgear-

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

* Essential Features of Switchgear-

1) Complete reliability.
2) Absolutely certain discrimination
3) Quick-operation
4) Provision for manual control.
5) Provision for instruments.

Complete reliability

Switch gear 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 fault section from the remainder circuit.

Absolutely certain discrimination

When fault occurs on any section of the power system the switchgear must be able to discriminate between the fault section and the healthy section. It should isolate the fault section from system without affecting the healthy section. This will ensure continuity of supply.

Quick operation

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

Provision for manual control

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

Provision for Instruments

The provision for instruments is required which may be in the form of ammeter or voltmeter
on the ckt itself
(or) the necessary CT & PT for connecting to the main switchboard.
(or) a separate instrument panel.

* Switchgear Equipment

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

-> It includes switches, fuses, circuit breakers, relays and other equipment.

⇒ Switches

- Switch
  - Air-switches
    - Air-break switch
    - Isolator
  - Oil switches

i) **Air-break switch**

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

ii) Isolaton

It is a knife switch and is designed to open a circuit under no load.

→ Its main purpose is to isolate one portion of the circuit from the other and is not intended to be opened while current is flowing in the line.

→ These switches are used on both sides of the circuit breaker in order that repairs and replacement of C.B. can be made w/o any danger.

iii) Oil switches

The contacts of these switches are opened under oil, (usually transformer oil). The effect of oil is to cool and quench the arc that tends to form when the circuit is opened.

→ used for circuits of high voltage and large current carrying capacities.

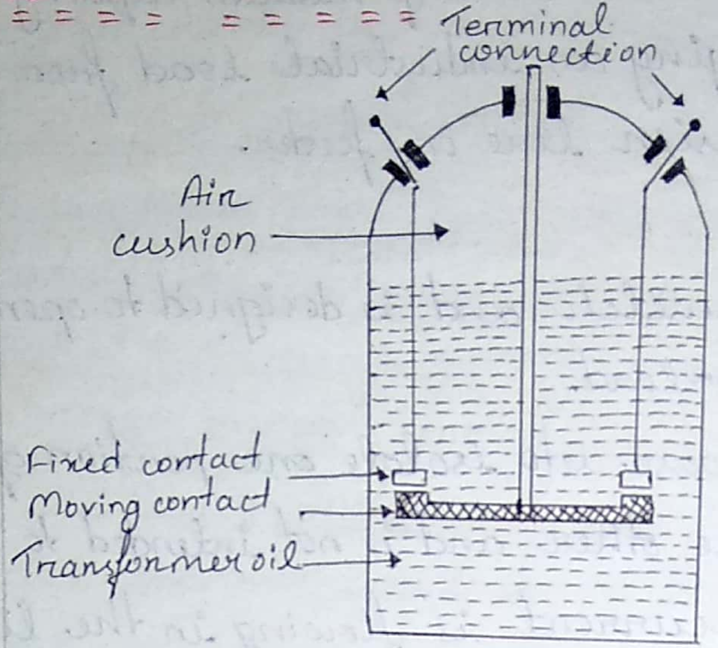
⇒ Fuses

A fuse is a short piece of wire or thin strip which melts when excessive current flows through it for sufficient time.

→ Fuse is inserted in series with the circuit to be protected.

→ A fuse performs both detection and interruption functions.

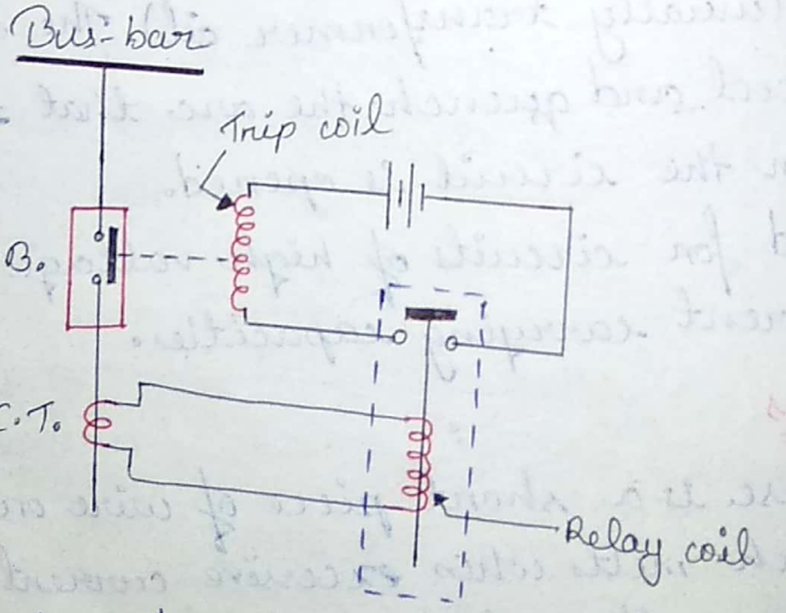
Circuit Breakers



A circuit breaker is an equipment which can open or close a circuit under all conditions viz. no load, on load and fault conditions.

→ It is so designed that it can be operated manually under normal conditions and automatically under fault conditions.

Relays



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

It can be devided into three 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.

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

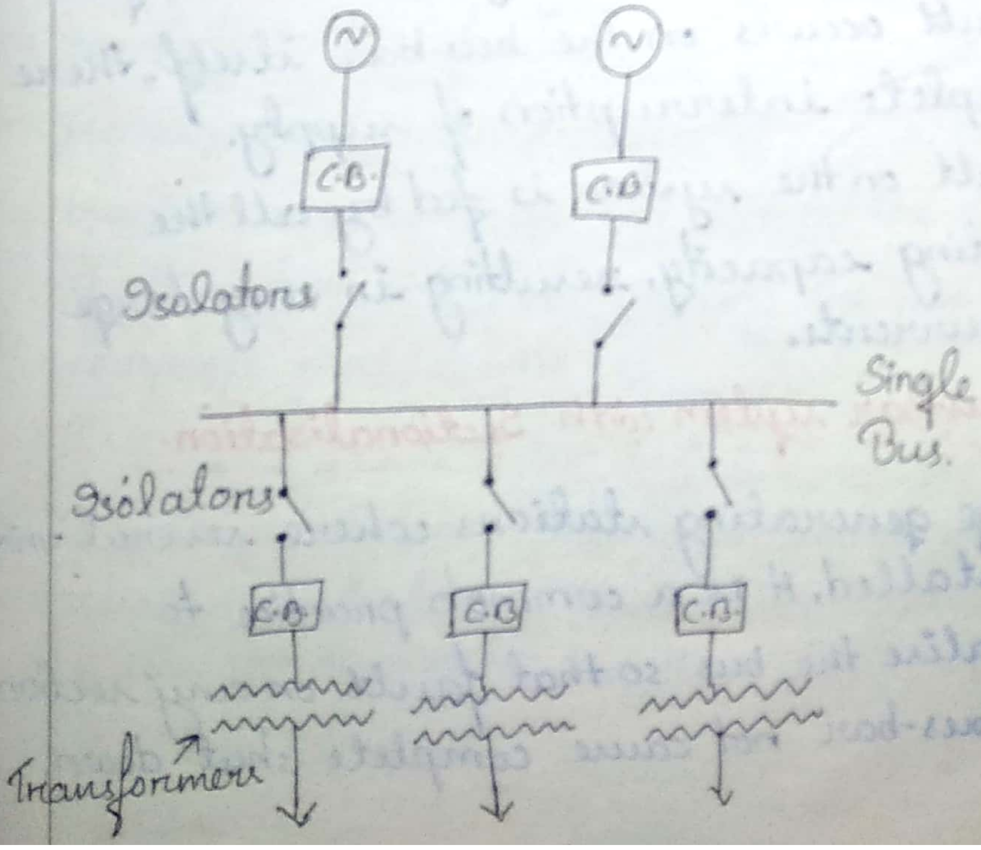
iii) The third circuit is the tripping circuit which consists of a source of supply, trip coil of circuit breaker and the relay stationary contacts.

* Bus-bar arrangements

When a number of generators or feeders operating at the same voltage have to be directly connected electrically, bus-bars are used as the common electrical field.

→ Bus-bars are copper rods or thin walled tubes and operate at constant voltage.

Single Bus bar System.



-> simplest construction
-> used for power systems.
-> used ~~for~~ in small outdoor stations having relatively few outgoing or incoming feeders and lines.
-> Each generator and feeder is controlled by a circuit breaker. The isolators permit to isolate generators, feeders and circuit breakers from the bus-bar for maintenance.

Advantage

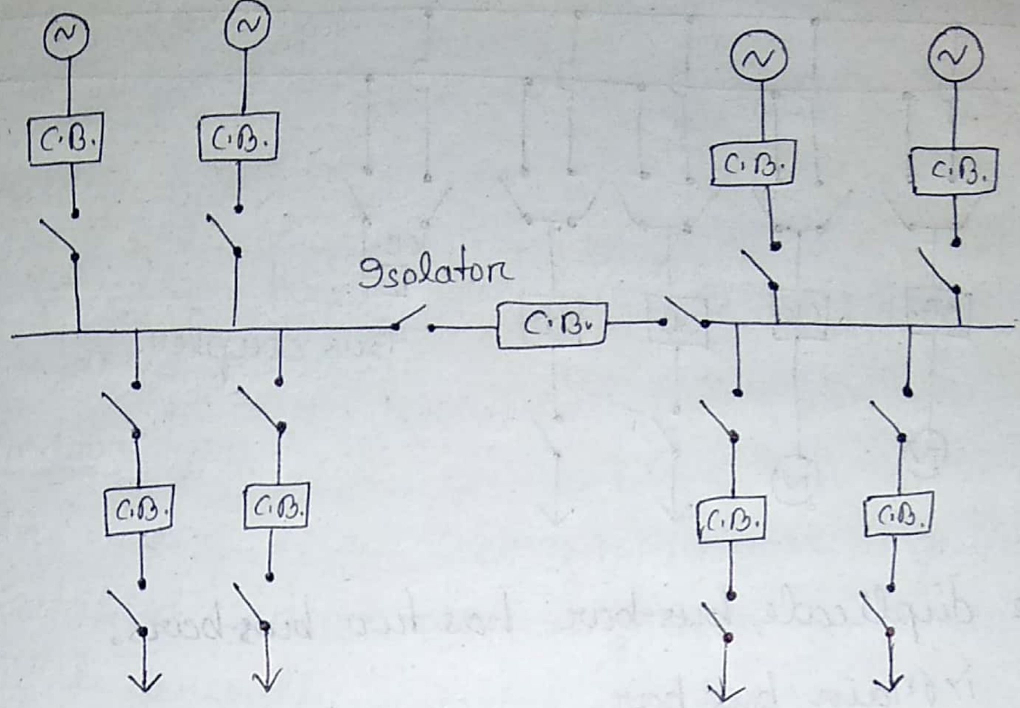
-> low initial cost
-> less maintenance
-> simple operation.

Disadvantage

i) The bus-bar can not be cleaned, repaired or tested without de-energising the whole system.
ii) If a fault occurs on the bus-bar itself, there is complete interruption of supply.
iii) Any fault on the system is fed by all the generating capacity, resulting in very large fault currents.

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 not cause complete shut down.



Advantage

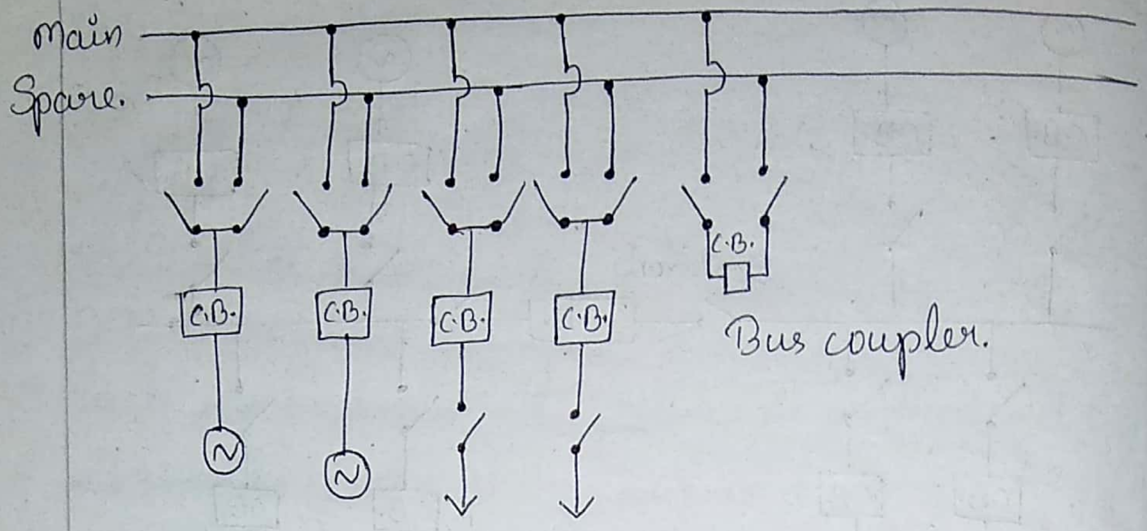
-> If a fault occurs on any section of bus-bar, that section can be isolated without affecting the supply to other sections.

-> If a fault occurs on any feeder, the fault current is much lower than with unsectionalised bus-bar. This permits the use of circuit breakers of lower capacity in the feeders.

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

Duplicate bus-bar system-

In large stations, breakdown and maintenance should interfere as little as possible with continuity of supply. For this purpose duplicate bus-bar is used.



The duplicate bus-bar has two bus-bars.

1) Main bus-bar
2) Spare bus-bar.

→ Each generator and feeder may be connected to bus-bar with the help of BUS-COUPLER which consists of a circuit breaker and isolators.

Advantage

→ If repair and maintenance is to be carried on the main bus, the supply need not to be interrupted as the entire load can be transferred to the spare bus.

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

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

* Switch Accommodation

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

i) Outdoor type.
ii) Indoor type.

i) Outdoor type

For voltage beyond 66kV, switchgear equipment is installed outdoor.

ii) Indoor type

For voltage below 66kV, switchgear is generally installed indoor because of economic considerations.

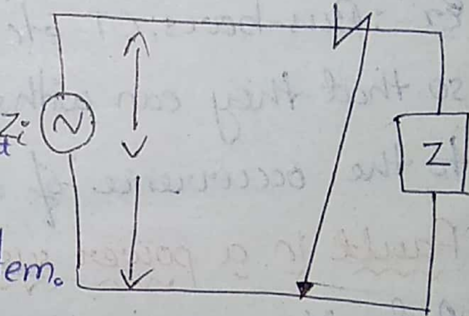
→ It is generally of metal-clad type.

* Short-circuit

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

Causes of short-circuit

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



1) Internal effects

→ caused by the breakdown of equipment or transmission lines, from deterioration of insulation in a generator, transformer etc. Such troubles may be due to ~~aging~~ ageing of insulation, inadequate design or improper installation.

2) External effects

→ causing short-circuit include installation failure due to lightning surges, over loading of equipment causing excessive heating; mechanical damage by public etc.

* Short-Circuit Currents

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

i) 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 current so that switchgear of suitable rating may be installed to interrupt them.

ii) The magnitude of short-circuit current determines the setting and sometimes the types and location of protective system. It determines the size of the protective reactors which must be inserted in the system so that the C.B. is able to withstand the fault current.

iii) The calculation of short-circuit current enables us to make proper selection of the associated apparatus. Ex-: Bus-bars, CT etc. so that they can withstand the forces that arise due to the occurrence of short circuits.

* Fault 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.

Cause

-> sudden failure of a piece of equipment
-> accidental damage
-> short-circuit to overhead lines
-> insulation failure resulting from lightning surges.

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

(i) Symmetrical faults
(ii) Unsymmetrical faults

i) Symmetrical faults

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

ii) Unsymmetrical faults

Those faults which give rise to unsymmetrical currents (i.e. unequal line currents with unequal displacement) is called unsymmetrical faults.

The unsymmetrical fault may take one of the following forms:

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

CIRCUIT BREAKERS

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

(or)

A circuit breaker is an equipment which can open or close a circuit under all conditions viz. no-load, on-load, fault condition.

* Operating principle

A circuit breaker essentially consists of fixed and moving contacts called electrodes.

→ Under normal operating conditions, there contacts remain closed and will not open automatically until and unless the system has some fault. The contacts can be opened manually or by remote control whenever desired.

→ When a fault occur on any part of the system, the trip coil of the circuit breaker get energized and the moving contacts are pulled apart by some mechanism, thus opening the circuit. When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them.

* Arc phenomenon

The ionised air or vapour between the contacts of the circuit breaker (at the time of separate process takes place) acts as conductor and an arc is struck between the contacts.

→ 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 depend upon following factors:

i) Degree of ionisation :-

the arc resistance increases with the decrease in the number of ionised particles between the contacts.

ii) Length of the arc:-

the arc resistance increases with the length of the arc i.e. separation of contacts.

iii) Cross-section of arc:-

the arc resistance increases with the decrease in area of x-section of arc.

* Principles of Arc Extinction

1) P.d. between the contacts.

When the contacts have a small separation, the p.d. between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that p.d. becomes inadequate to maintain the arc.

2) ionised particles between contacts

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

* Methods of Arc extinction

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

1) High resistance method

Arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc.

The resistance of arc may be increased by:

a) Lengthening the arc :-
The resistance of arc is directly proportional to its length. The length of the arc can be increased by increasing the gap between the contacts.

b) Cooling the arc :-
Cooling helps in deionisation of the medium betwen the contacts, whic increase the arc resistance.
→ cooling can be done by gas blast directed along arc.

c) Reducing X-section of arc :-
if X-secting of arc is reduced, then arc path resistance is increased.
→ This reducing of X-section can be done by passing the arc through a narrow opening or by having smaller area of contacts.

d) Splitting the arc
The arc may be split by introducing some conducting plates between the contacts.

Scanned with CamScanner

b) Low resistance or current zero method-

-> This method is used for arc extinction in ac circuit only.

-> Arc resistance is kept low until current is zero where the arc extinguishes naturally and is prevented from restriking inspite of the rising voltage across the contacts.

The rapid increase of dielectric strength of the medium near current zero can be achieved by:

a) causing the ionised particles in the space between contact 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-

a) lengthening of the gap

b) high pressure

c) cooling

d) blast effect.

* Arc voltage

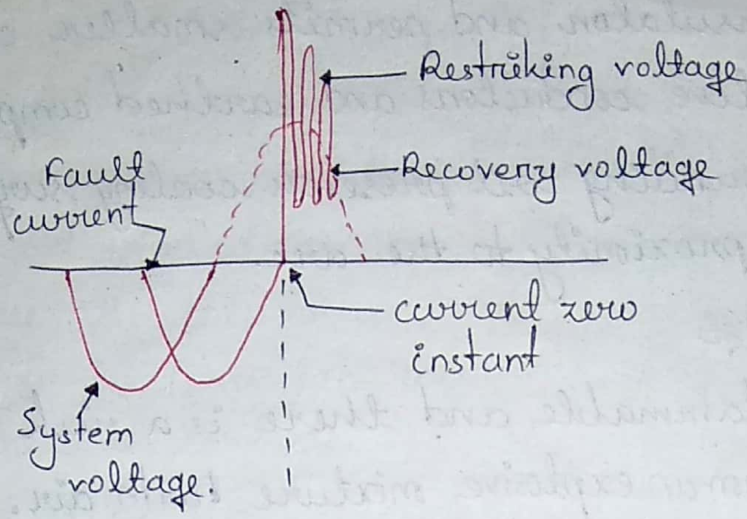
It is the voltage that appears across the contacts of the circuit breaker during the arcing period.

* Restriking voltage

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

* Recovery voltage

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

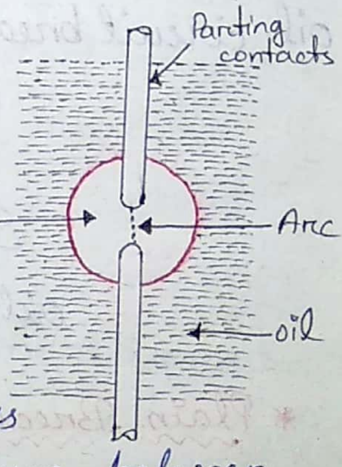


* Classification of circuit breakers

Circuit breaker
- Oil circuit breakers.
- Air-blast circuit breakers.
- Sulphur hexafluroide circuit breakers.
- Vaccum circuit breakers.

* Oil Circuit Breakers

In oil circuit breakers, some insulating oil is used as oil quenching medium. Here the arc extinction is done by two process.



1) The hydrogen gas i.e. produced by the evaporation of the surrounding oil of the arc, has high heat conductivity and cools the arc, thus aiding the de-ionisation of the medium between the contacts.

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

Advantage

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

ii> acts as an insulator and permits smaller clearance between live conductors and earthed components.

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

Disadvantage

i> It is inflammable and there is a risk of fire.

ii> It may form an explosive mixture with air.

* Types of Oil Circuit Breaker

- Oil circuit breaker.
  - Bulk oil circuit breaker
    - Plain break oil circuit breakers
    - Arc control oil circuit breakers.
      - Self-blast oil circuit breakers.
      - Forced-blast oil circuit breakers
  - Low oil circuit breaker

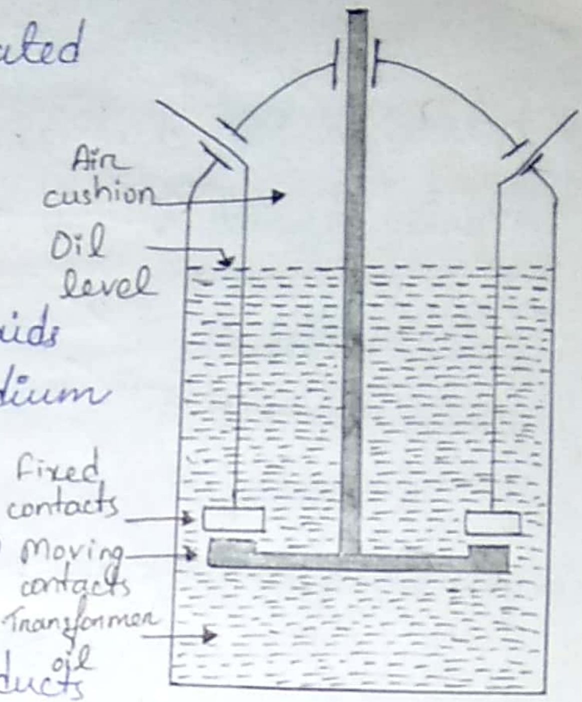
* Plain Break Oil Circuit Breakers

The plain break oil circuit breaker involves the simple process of separating the contacts under the whole of the oil in the tank. The arc control is done by increasing the length by separting the contacts. The arc extinction occurs when a certain critical gap between the contacts is reached.

→ This circuit breaker is used for low-voltage application (not exceeding 11kV).

The arc extinction is facilitated by the following process:

i) The hydrogen gas bubble generated around the arc cools the arc column and aids the de-ionisation of the medium between the contacts.



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

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

Disadvantage

i) no other process is there for arc control. So for successful interruption, long arc length is necessary.

ii) These breakers have long and inconsistent arcing times.

iii) These breakers do not permit high speed interruption.

* Arc control Oil Circuit Breakers

i) Self-blast oil circuit breaker.

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

* Forced-Blast oil circuit breaker

in which arc control is provided by mechanical means external to the circuit breaker.

-> In a 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 contacts.

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

Note

The oil pressure produced does not depend upon the fault current to be broken.

Advantages

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

ii> The quantity of oil required is reduced considerably.

* Low oil circuit breakers

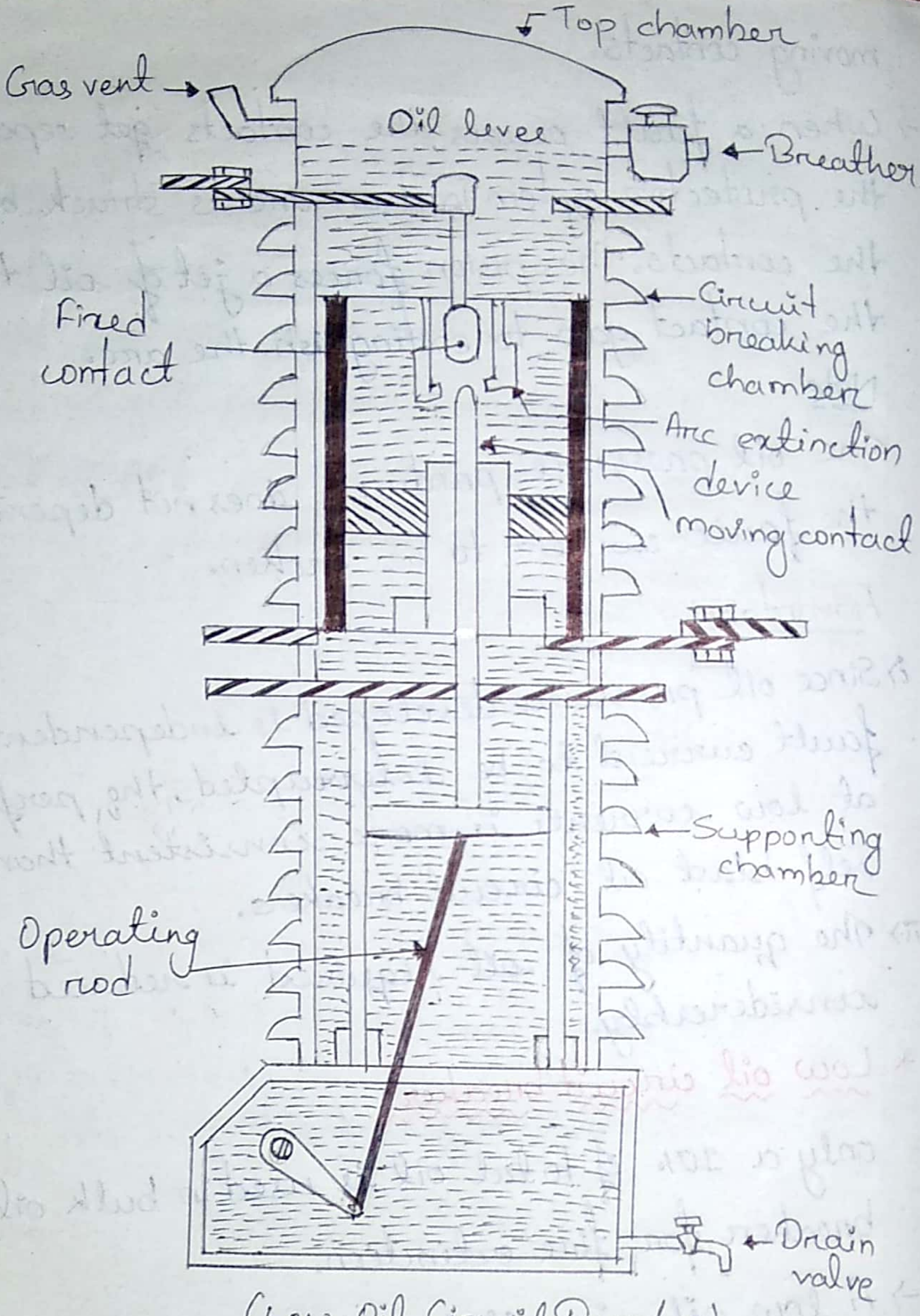
only a 10% of total oil is used in bulk oil circuit breaker for fire extinction.

-> A low oil circuit breaker employs solid materials for insulation purpose and uses a small quantity of oil which is just enough for arc extinction.

Construction :-

There are two compartments (in the Fig) separated from each other & filled with oil.

-> The upper one -> circuit breaking chamber
lower one -> supporting chamber.



(Low Oil Circuit Breaker)

As there is a partition between 2 chambers, the oil from one chamber is prevented from mixing with the other chamber.

-> Two advantages of this arrangement are-

1) The circuit breaking chamber requires a small volume of oil for arc extinction.

2) The amount oil to be replaced is reduced as the oil in the supporting chambers does not get

contaminated by the arc.

a) Supporting chamber-

-> It is a porcelin chamber mounted on a metal chamber.

-> The oil inside it and annular space between the porcelin insulation and bakelised paper is used for insulation purpose.

b) Circuit breaking chamber-

-> It is a porcelin enclosure.

-> It has the following parts.

a) upper and lower fixed contacts
b) moving contacts
c) turbulator.

The turbulator is an arc extinction device.

It has axial vents -> used for interruption of low currents

& radial vents -> used for interruption of heavy currents.

c) Top chamber-

-> a metal chamber i.e. mounted on circuit breaking chamber.

-> provides space for expansion of oil in the circuit breaking chamber.

Advantage

-> requires lesser quantity of oil.
-> requires smaller space.
-> reduced risk of fire.
-> reduced maintenance problem.

Disadvantage

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

-> There is a difficulty of removing the gasses from the contact space in time.

-> dielectric strength of the oil deteriorates rapidly due to high degree of carbonisation.

* Maintenance of Oil Circuit Breakers

This is done for checking of contacts and dielectric strengh of oil.

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

ii) Check the dielectric strength of oil. If the oil is badly discoloured, it should be changed or reconditioned. The oil in good condition should withstand 30kV for 1 min. in a standard oil testing cup with 4mm gap in electrodes.

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

iv) Check the oil level.

v) Check closing and tripping mechanism.

* Air Blast Circuit Breakers

-> employ a high pressure air-blast as an arc quenching medium.

-> The air blast cools the arc and sweeps away the arcing products to the atmosphere.

Advantages

→ The risk of fire is eliminated.

→ The arcing products are completely removed by the blast so the expense of regular oil replacement is avoided.

→ The growth of dielectric strength is so raped that final contact gap needed for arc extinction is very small. This reduces the size of the device.

→ The arc energy is ~~smal~~ only a fraction of that in oil circuit breakers, thus regulating in less burning of contacts.

→ Due to lesser arc energy, these are used where frequent operation is required.

→ The energy supplied for arc extinction is obtained from high pressure air and is independent of the current to be interrupted.

Disadvantages

→ The air has relatively inferior arc extinguishing properties.

→ The air-blast circuit breakers are very sensitive to the variations in the rate of rise of restriking voltage.

→ Considerable maintenance is required for the compressor plant which supplies air-blast.

Use

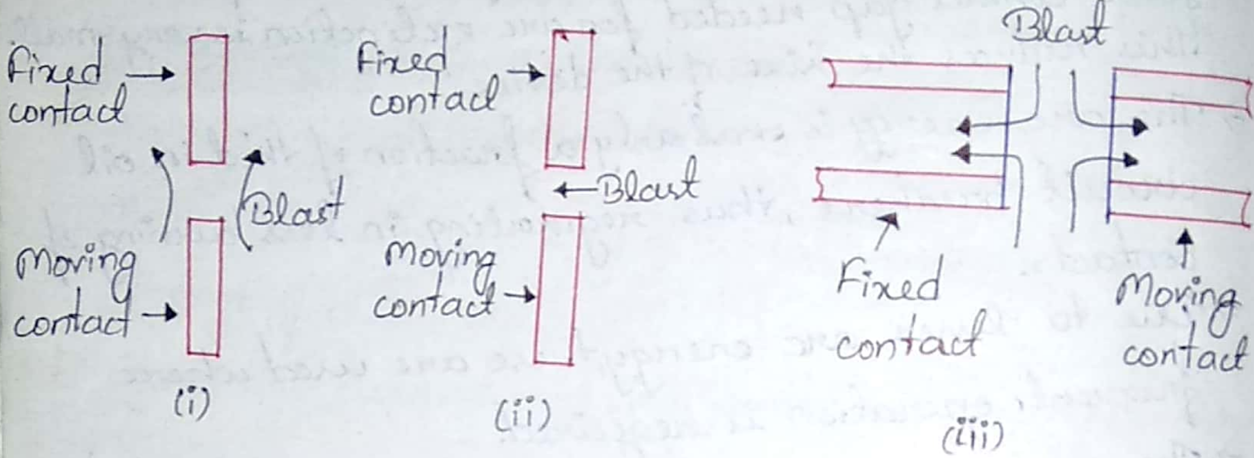
→ high voltage installation. (voltage beyond 110 kV).

* Types of air-blast Circuit Breakers

i) Axial-blast type - in which the air blast is directed along the arc path. [Fig. (i)]

ii) Cross-blast type- in which the air-blast is directed at right angle to the arc path. [Fig(ii)]

iii) Radial-blast type- in which the air-blast is directed radially. [Fig(iii)]



* Sulphur Hexaflouride (SF6) Circuit Breakers

→ SF6 is used as arc quenching medium.

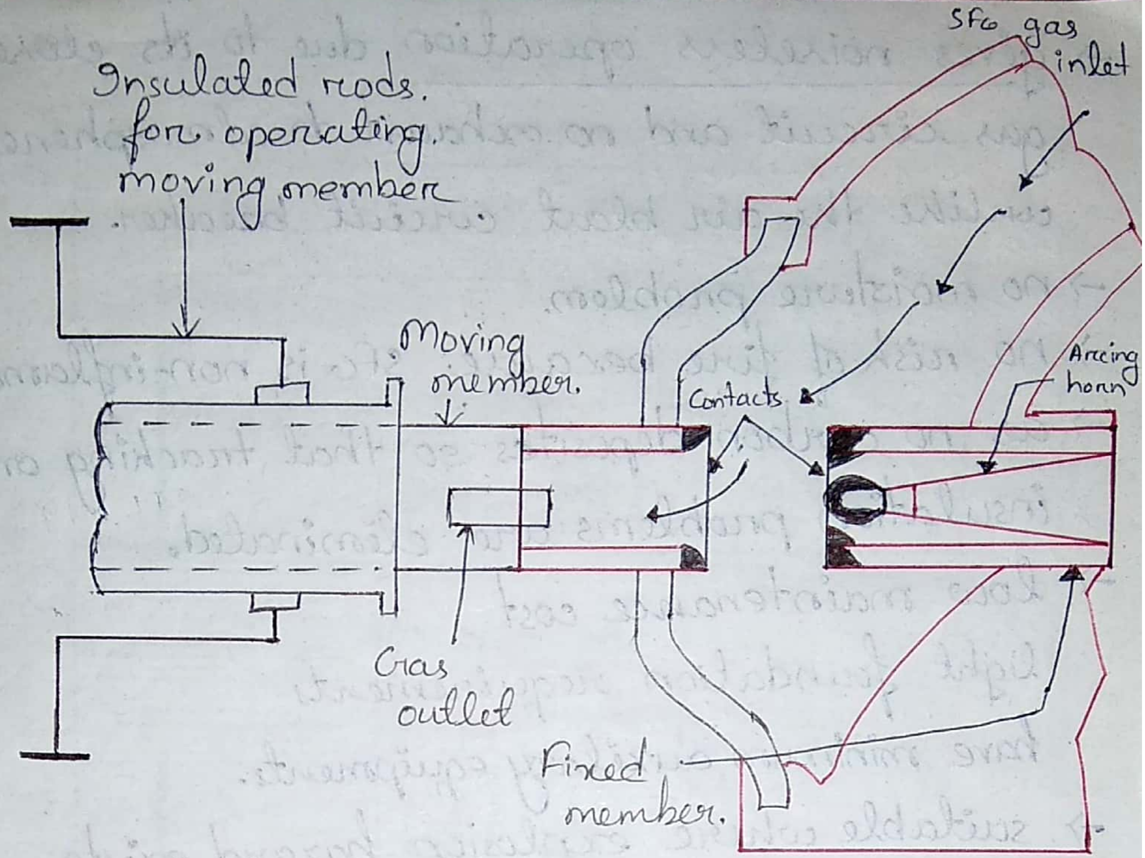
→ When arc is produced the conducting free electrons are rapidly captured by the electro-negative gas (SF6) to form relatively immobile negative ions. and thus insulation strength is build up for extinguishing arc.

→ use ⇒ high power and high voltage service.

Construction

→ consist of fixed and moving contacts enclosed in a chamber containing SF6 gas; connected to SF6 gas reservior.

→ fixed contact is a hollow cylindrical current carrying contact fitted with an arc horn.



→ The tips of fixed contact, moving contact and arcing horn are coated with COPPER-TUNGSTEN arc resistant material.

Working

When the breaker is closed, the contacts remain surrounded by SF_6 gas at pressure of about 2.8 kg/cm².

→ When the moving contact starts moving it is synchronized with the opening of valve which permits SF_6 gas from reservoir to arc interruption chamber at 14 kg/cm² pressure.

→ After the arc extinction, the valve is closed by the action of a set of springs.

Advantage

→ have very short arcing time.

→ as the dielectric strength of SF_6 is 2 to 3 times that of air, such breakers can interrupt much larger currents.

→ gives noiseless operation due to its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker.
→ no moisture problem.
→ no risk of fire because SF_6 is non-inflammable.
→ as no carbon deposites so that tracking and insulation problems are eliminated.
→ low maintenance cost
light foundation requirements
have minimum auxilary equipments.
→ suitable where explosion hazard exists. e.g. coal mines.

Disadvantages

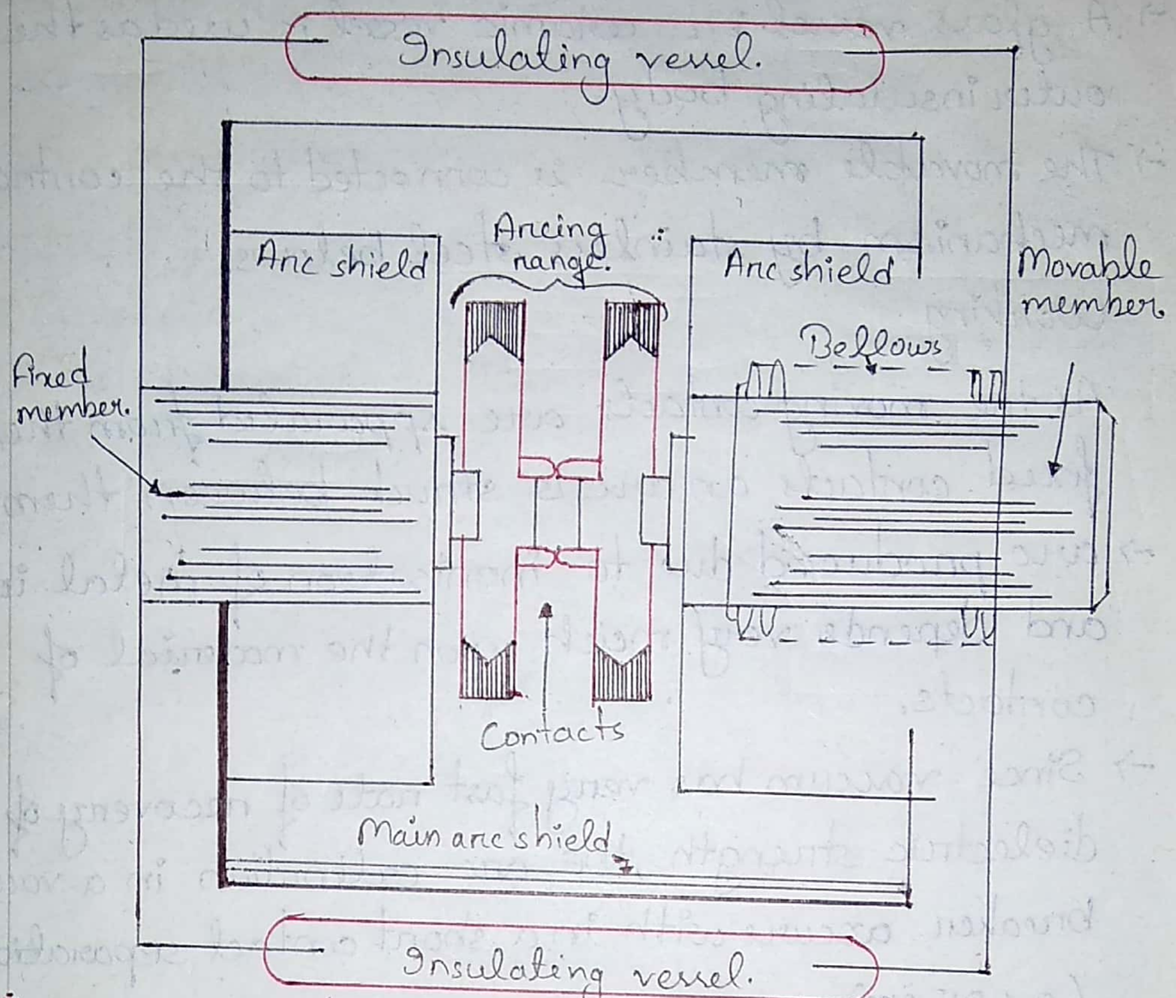
→ costly due to higher cost of SF_6.
→ Since SF_6 gas has to be reconditioned after every operation of the breaker, additional equipment is required for this purpose.

Application

current upto 60 kA
voltage in the range 50-80 kV } interrupter units.

→ These have been developed
for voltages 115-230 kV
power ratings 10-20 MVA.
and interrupting times less than 3 cycles.

* Vacuum Circuit Breakers



-> vacuum used as arc quenching medium.

-> ~~so~~ vacuum has highest insulating strength, it has far superior arc quenching properties.

Principle

When the contacts of the breaker are opened in vacuum (10^{-7} to 10^{-5} torr) an arc is produced ~~by~~ between the contacts by the ionization of metal vapours of contacts. As soon as the arc is produced in vacuum, it is quickly extinguished due to the fast rate of recovery of dielectric strength in vacuum.

Construction

-> consist of fixed contact, moving contact and arc shield mounted inside a vaccum chamber.

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

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

Working

As the moving contacts are sepparated from the fixed contacts an arc is struck between them.

→ arc produced due to inonisation of metal ions and depends very much upon the material of contacts.

→ Since vaccum has very fast rate of recovery of dielectric strength, the arc extinction in a vaccum breaker occurs with in a short contact separation (0.625 cm).

Advantages

→ compact, reliable and have longer life.

→ no fire hazards.

→ no generation of gas during and after operation.

→ can break any heavy fault current before the contacts reach the definite open position.

→ require little maintenance and are quilet in operation.

→ they can successfully withstand lightening surges.

→ have low arc energy.

→ have low inertia, so require smaller power for control mechanism.

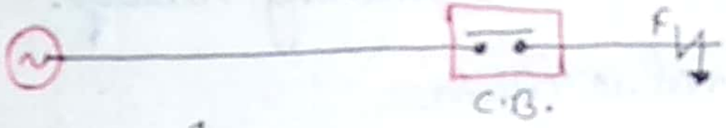
Application -

→ outdoor applications ranging from 22kV to 66kV.

* Switch-gear components.

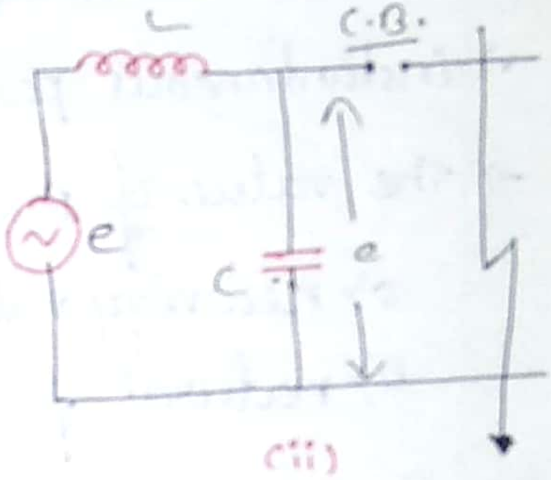
1) Bushing
2) Circuit breaker contacts.
3) Instrument transformers.
4) Bus-bars and conductors.

* Problems of current interruption



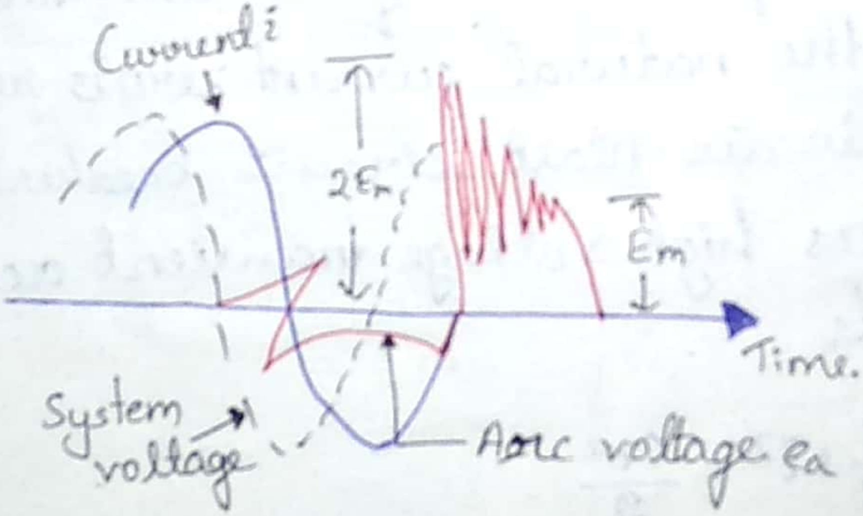
$e = E_m \sin \omega t$

(i)



(ii)

i) Rate of rise of re-striking voltage.



It is the rate of increase of restriking voltage and is abbreviated by R.R.R.V..

voltage ⟶ in KV
time ⟶ in microsecond } ⟹ R.R.R.V. ⟶ in KV/μsec.

→ Before current interruption, the 'C' is short-circuited by the fault and the short-circuit current through the breaker is limited by inductance 'L' of the system. (i.e. the entire generator voltage appears across the 'L').

→ After the arc extinguishes, the generator voltage 'e' is applied to 'L' and 'C' in series; this forms an oscillatory circuit and produces a transient of frequency:

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

→ transient voltage a.k.a. re-striking voltage.

→ instantaneous peak value ⇒ $2E_m$.

(2 × ph-neutral voltage).

→ The value of R.R.R.V. depends upon

a) recovery voltage.

b) natural frequency of oscillation.

ii) Current chopping.

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

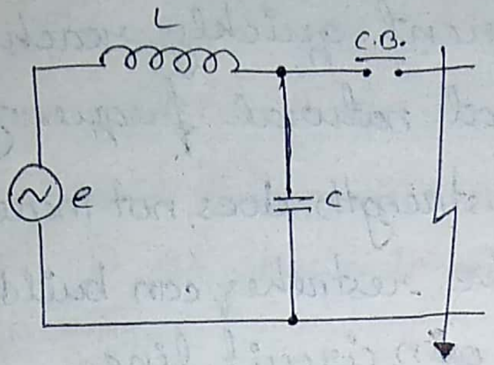
→ occurs in air-blast circuit breakers.

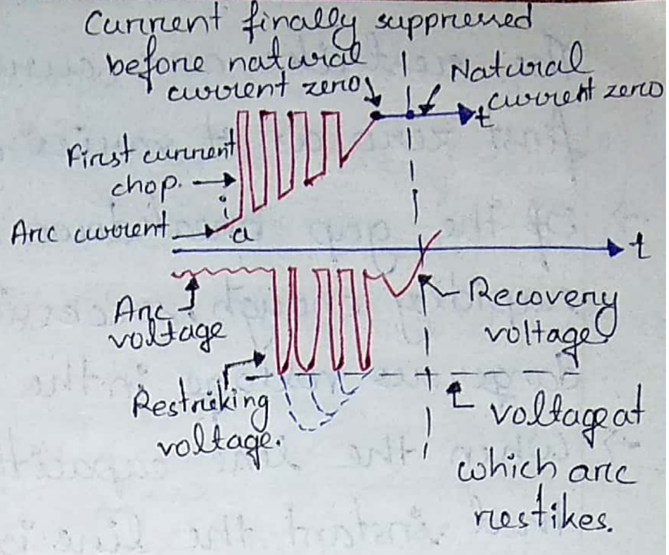
→ produces high voltage transient across the contacts.

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

$$\Rightarrow e = i\sqrt{\frac{L}{C}} \text{ volt}$$

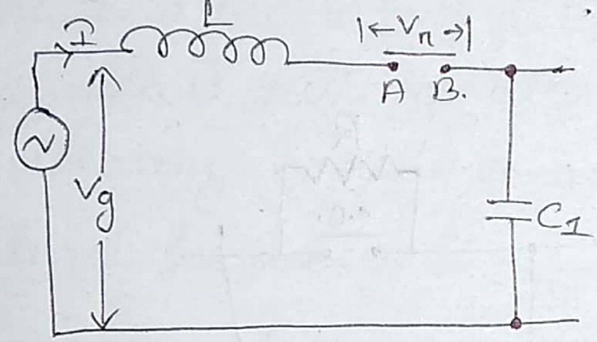
Excessive voltage surges due to current chopping are prevented by shunting the contacts with a resistor.

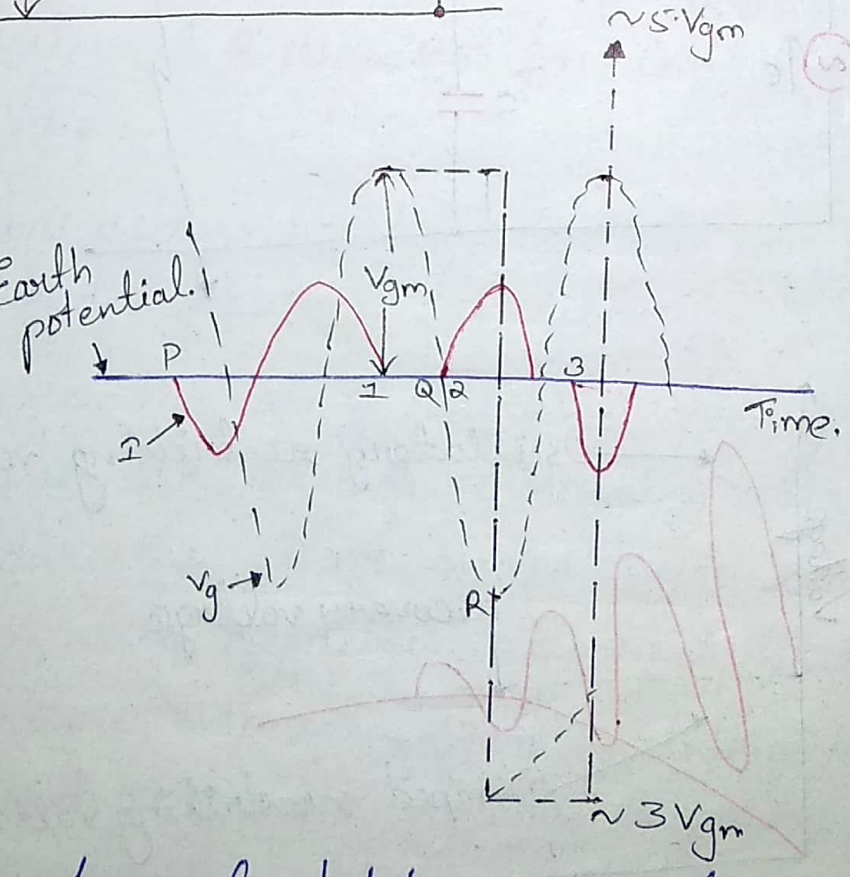




* ~~Resistance switching.~~

ii) Capacitive current breaking.





-1) opening of an unloaded transmission line.

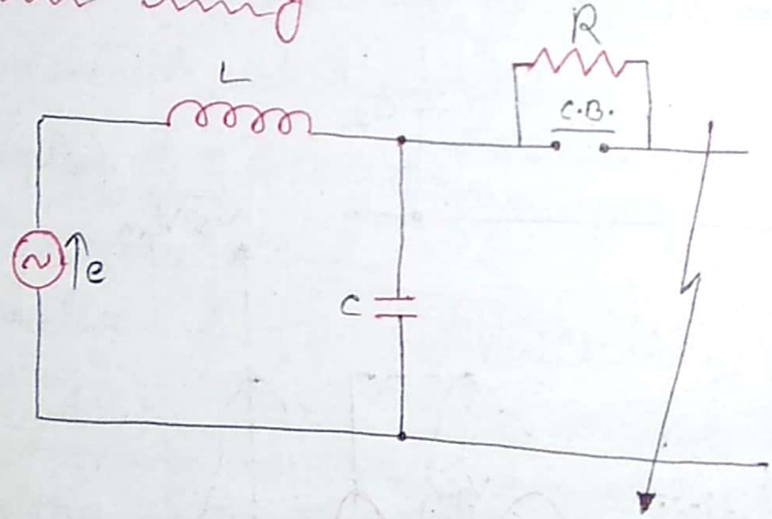
2) disconnecting a ~~pa~~ capacitor used for power factor improvement.

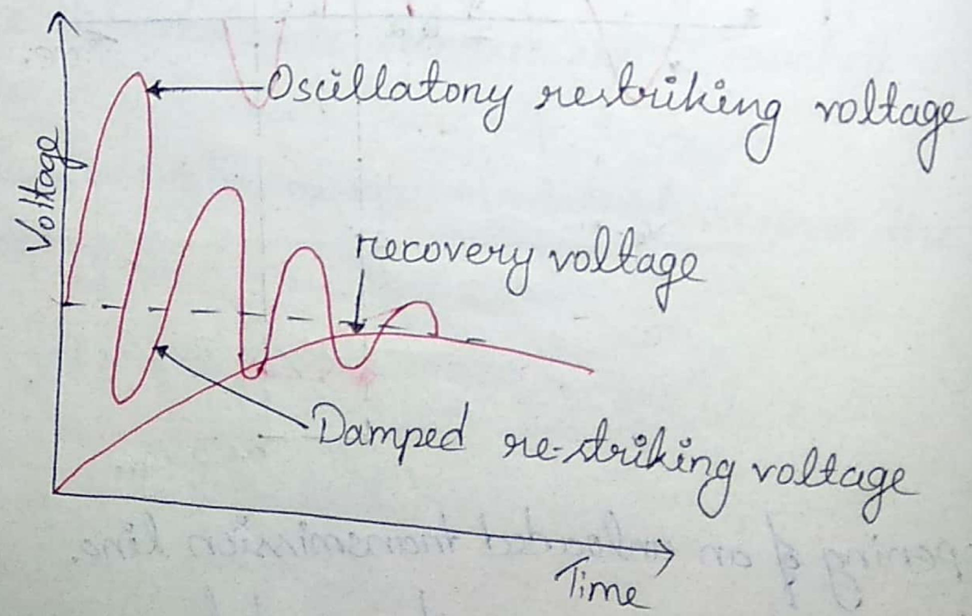
The restrike arc current quickly reaches its first zero as it varies at natural frequency.

→ If the gap breakdown strength does not increase rapidly enough, successive restrikes can build up a dangerous voltage in the open circuit line.

→ When the line capacitive current is zero at that instant the line is opened by the circuit breaker (as shown in Fig.). At this instant, the generator voltage V_g will be maximum (i.e. V_{gm}) lagging behind the current by 90°.

* Resistance switching





The 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 Fig. This is known as resistance switching.

→ When the arc is produced, a part of arc current flows through the shunt resistance 'R' i.e. connected across the contacts.

→ This help in decrease in the arc current and an increase in the rate of de-ionisation of the arc path.

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

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

→ The value of 'R' required for critical damping is $0.5\sqrt{\frac{L}{C}}$.

Resistors across breaker contacts may be used to perform the following functions:-

i) To reduce the rate of rise of re-striking voltage and the peak value of re-striking voltage.

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

iii) To ensure even sharing of re-striking voltage transient across the various breaks in multi-break circuit breakers.

* Circuit Breaker ratings

Under fault condition, a circuit breaker is required to perform the following three duties:

i) It must be capable of opening the faulty circuit and breaking the fault current.

ii) It must be capable of being closed to a fault.

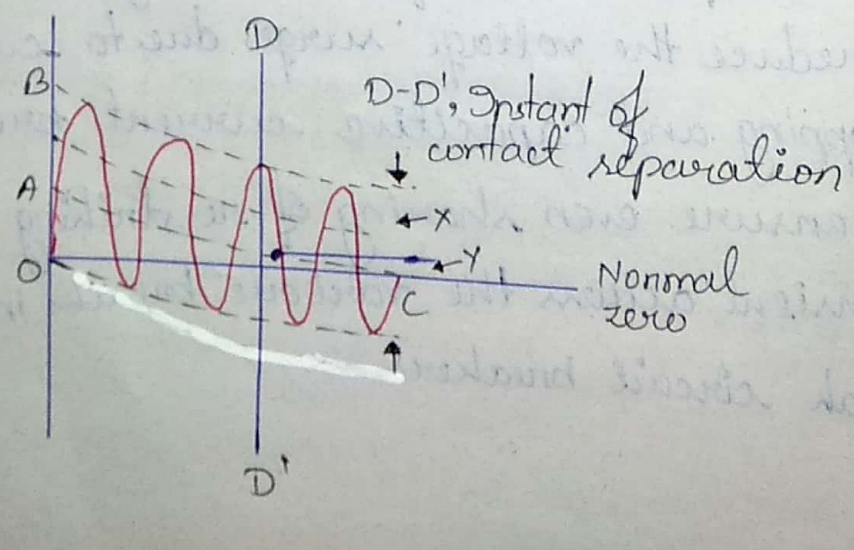
iii) It must be capable of carrying fault current for a short time while another circuit breaker is clearing the fault.

→ The circuit breakers have three ratings:-

i) Breaking capacity
ii) Making capacity
iii) Short-time capacity

i) Breaking capacity

It is the current (r.m.s.) that a circuit breaker is capable of breaking at given recovery voltage and under specified conditions (e.g. power factor, rate of rise of re-striking voltage).



As per the above Fig the contact are separated at DD'. At this, the fault current has

x = maximum value of a.c. component

y = d.c. component.

∴ Symmetrical breaking current = r.m.s. value of a.c. component = $\frac{x}{\sqrt{2}}$

Asymmetrical breaking current = r.m.s. value of total current

$$= \sqrt{\left(\frac{x}{\sqrt{2}}\right)^2 + y^2}$$

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

→ The agreed international standard of specifying breaking capacity is defined as the rated symmetrical breaking current at a rated voltage.

ii) Making capacity

The peak value of current (including dc. component) during the first cycle of current wave after the closure of circuit breaker is known as making capacity.

Making capacity = 2.55 × Symmetrical breaking capacity

$[\sqrt{2} \times 1.8 = 2.55]$.

iii) Short time rating.

It is the period for which the circuit breaker is able to carry fault current while remaining closed.

→ If the fault persists for a duration longer than the specified time limit, the circuit breaker will trip, disconnecting the fault section.

→ The short-time rating of a circuit breaker depends upon its ability to withstand
a) electro magnetic force effects
b) the temperature rise

Natural current rating

It is the rms value of the current which the circuit breaker is capable of carrying continuously as its rated frequency under specified conditions.

FUSES

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

→ The time required to blow out the fuse depends upon the magnitude of excessive current. The greater the current, the smaller is the time taken by the fuse to blow out.

Advantages

→ It is the cheapest form of protection available.

→ require no maintenance.

→ can break heavy short-circuit currents without noise or smoke.

→ The inverse time-current characteristics of a fuse makes it suitable for overcurrent protection

→ as compared to C.B. the minimum time of operation can made much shorter.

Disadvantage

→ considerable time is lost in rewiring or replacing a fuse after operation.

→ The current-time characteristics of a fuse cannot always be co-related with that of the protected apparatus.

* Desirable Characteristics of Fuse element

A fuse should have the following characteristics:

i) low melting point; e.g. tin, lead.

ii) high conductivity; e.g. silver, copper.

iii) free from deterioration due to oxidation; e.g. silver

iv) low cost; e.g. lead, tin, copper.

* Fuse Element Materials

-> commonly used material -> lead, tin, copper, zinc, silver.

-> small current (10A) -> tin or alloy of lead (37%) and tin (63%)

-> large currents -> coppor / silver.

* Important terms

i) Current rating of fuse element:

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

ii) Fusing current

Fusing current is the minimum current at which the fuse melts and and disconnects the circuit protected by it.

-> Fusing current > current ~~carrying~~ rating of fuse element.

$$I = kd^{\frac{3}{2}}$$

$k \rightarrow$ fuse constant

$d \rightarrow$ diameter of element

$I \rightarrow$ current (fusing)

Sl. no.	Material	value of k (d in cm.)	value of k (d in mm)
1	Copper	2530	80
2	Aluminium	1873	59
3	Tin	405.5	12.8
4	Lead	340.6	10.8.

The fusing current depends on the following factors.

i) material of fuse element

ii) length- the smaller the length the greater the current

iii) diameter

iv) size and location of terminals.

v) previous history

vi) type of enclosure used.

iv) Fusing Factor

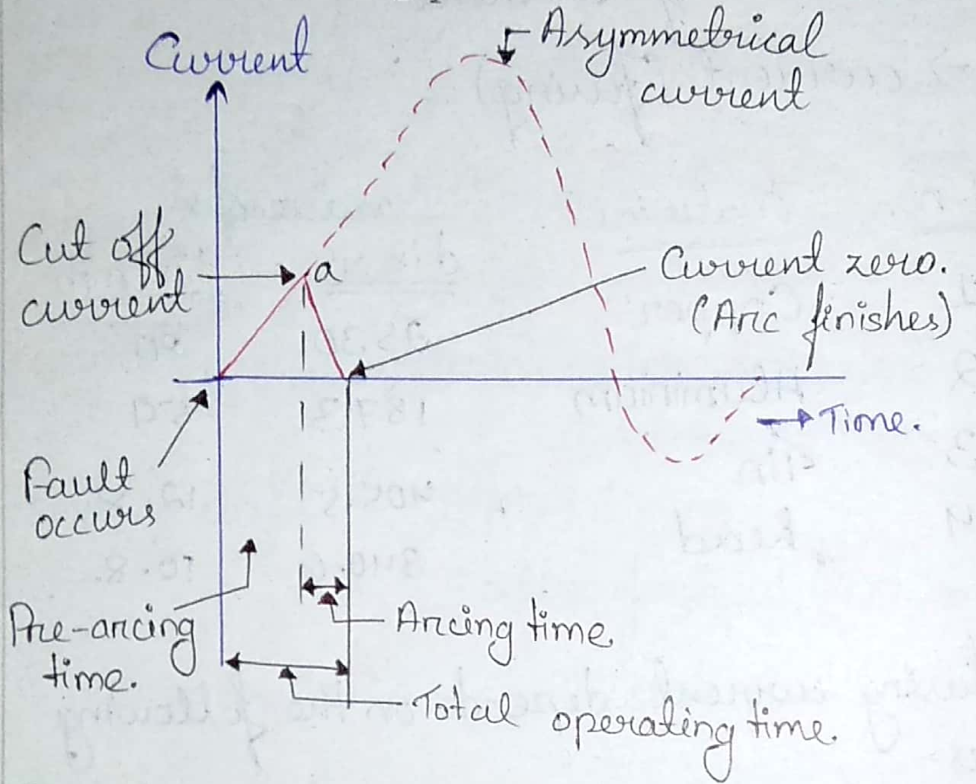
$$\text{Fusing factor} = \frac{\text{Minimum fusing current}}{\text{Current rating of fuse.}}$$

Fusing factor >1.

Scanned with CamScanner

-> Fusing factor is 2 for a semi-enclosed or rewirable fuse which employs copper wire.

iv) Prospective current -



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

v) Cut-off current :-

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

-> The cut-off value depends upon:-

i) current rating of fuse

ii) value of prospective current

iii) asymmetry of short-circuit current

vi) Pre-arcing time-

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

-> The pre-arcing time is generally small : a typical value being 0.001 second.

vii) **Arcing time-**

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

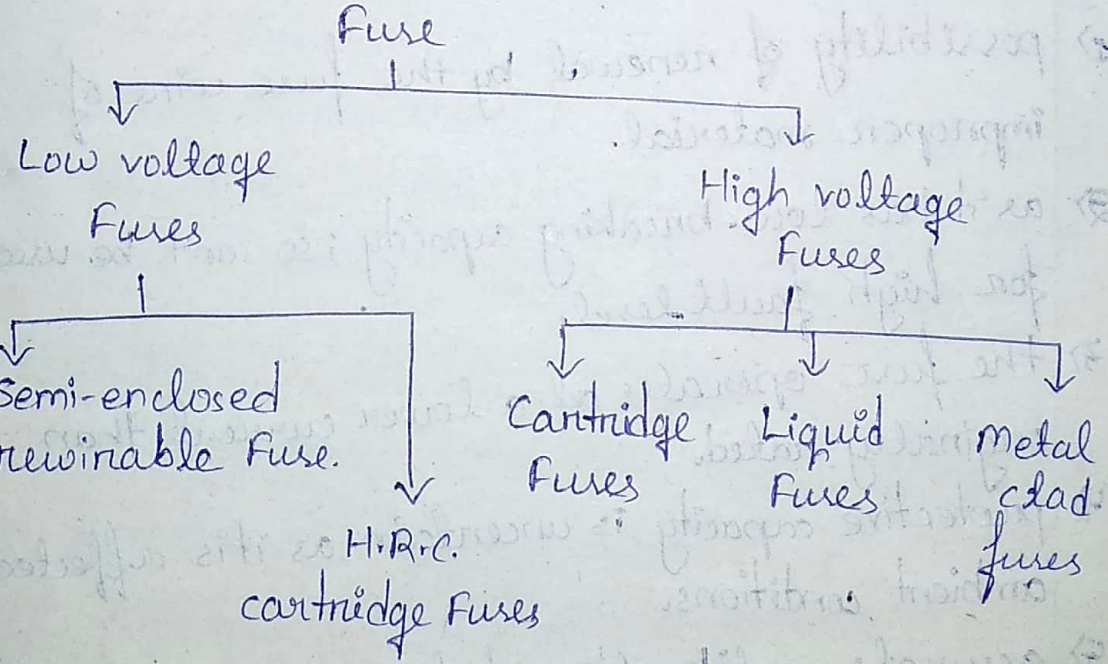
viii) **Total operating time-**

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

ix) **Breaking capacity:-**

It is the rms value of a.c. component of maximum prospective current that a fuse can deal with at rated service voltage.

* Types of Fuse



* Low voltage Fuses

i) **Semi-enclosed rewireable Fuse:-**

-> a.k.a. kit-kat type.

-> used where low value of fault current is to be interrupted.

→ consist of i) a base - porcelain
ii) a fuse carrier - fixed contacts to which the phase wire are connected.

→ when the circuit is interrupted; the fuse carrier is taken out and the blown out fuse element is replaced by a new one.

Advantage

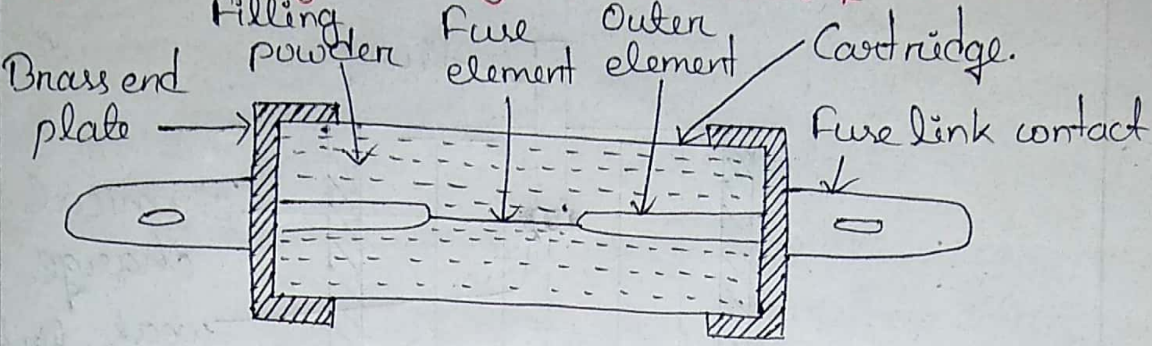
1) the detachable fuse carrier permits the replacement of fuse element without any danger of coming in contact with live parts.
2) the cost of replacement is negligible.

Disadvantage

1) possibility of renewal by the fuse wire of improper material.
2) as it has low-breaking capacity; so can't be used for high fault level.
3) the fuse operates at a lower current than originally rated.
4) protective capacity is uncertain as it is affected by ambient conditions.
5) accurate calibration of fuse wire is not possible because the fusing current depends upon the length of the fuse element.

→ These Fuse are made upto 500A rated current, breaking capacity is 400V, 4000A.
→ use :- domestic and lighting loads.

2) High-Repturing capacity (H.R.C) cartridge Fuse-



-> consist of heat resisting ceramic body.

-> The space within the body surrounding the element is packed with filling power.(may be chalk, plaster of paris, quartz or marble) & acts as arc quenching and cooling medium.

-> when fault occurs, the current increase and fuse element melts before the fault current reaches its first peak.

-> The chemical reaction between the silver element and the filling powder results in forming a high resistance substance. which quenches the arc.

Advantage

-> capable of clearing both high & low fault currents

-> no deterionation with age.

-> high speed operation.

-> no maintenance.

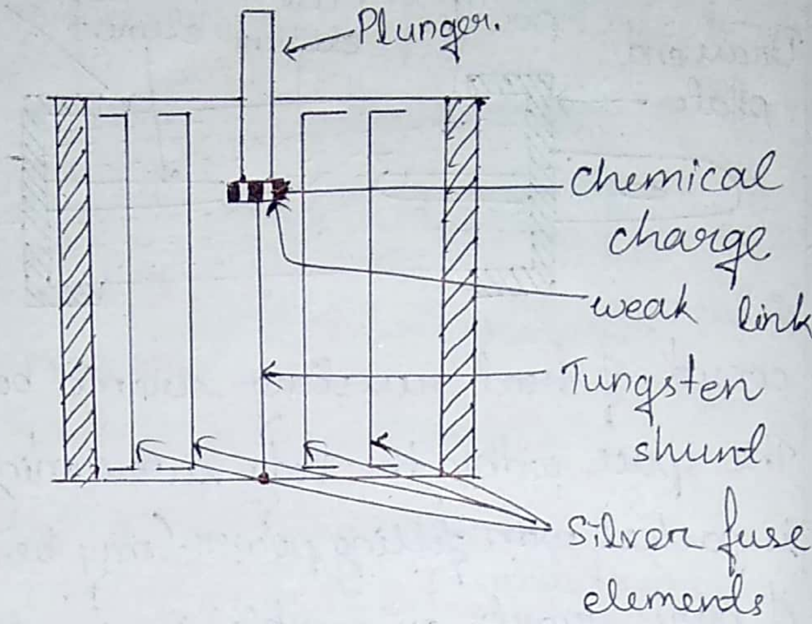
-> cheaper. than other of same capacity.

Disadvantage

-> need of replacement after each operation

-> heat produced by arc may affect the associated switches.

3) HRC fuse with tripping device.



When the fuse blows out under fault conditions, the tripping device causes the circuit breaker to operate.

→ When a fault occurs, the silver fuse elements are the first to be blown out and then current is transferred to the tungsten wire.

→ Then weak link gets fused and causes the chemical charge to be detonated. This force the plunger outward to operate the circuit breaker.

Low voltage HRC fuse may have a breaking capacity of 16KA to 30KA at 440V.

→ used on low-voltage distribution system against over-load and short-circuit conditions.

Scanned with CamScanner

* ## High voltage fuses

i) Cartridge type

there are two fuse elements in parallel.

1) low resistance - (silver wire) - operate under normal condition

2) high resistance - (tungsten wire) - operate under fault condition.

-> breaking capacities

1) 33kV -> 8700A

2) 6.6kV (& 11kV) -> 200 A

3) 11kV -> 50 A.

ii) Liquid type

-> filled with carbon tetrachloride

-> used for 100A rated current on the system upto 132kV and breaking capacity of 6100A.

iii) Metal clad type.

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

* ## Current carrying capacity of Fuse element.

The current carrying capacity of a fuse element mainly depends on the metal used and the cross-sectional area. ~~bad~~

when the fuse element attains steady temperature,

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

$\Rightarrow I^2R$ = Costant x effective surface area.

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

where, d → diameter of fuse element
l → length of fuse element

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

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

$\Rightarrow \boxed{I^2 \propto d^3}$ ⟶ ordinary fuse law.

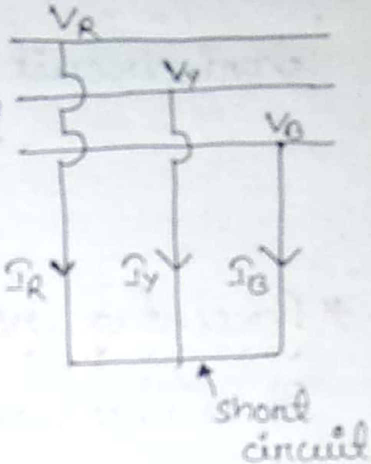
* Difference between Fuse and Circuit Breaker.

SL No	Particular	Fuse	Circuit Breaker
1.	Function	both detection & interruption operation.	only interruption operation
2.	Operation.	Inherently completely automatic.	Requires relay for automatic operation.
3.	Breaking capacity.	Small	very large
4.	Operating time	Very small	Comparatively large
5.	Replacement	Require replacement after each operation.	No replacement after operations

FAULT CALCULATION

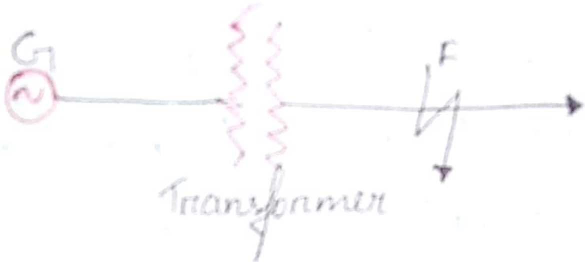
* Symmetrical faults on 3-phase system

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



$\Rightarrow I_R = I_Y = I_B$ (in magnitude in 120° displacement)

* Limitation of Fault current



→ Fault can be limited by the impedance of the system upto the point of fault.

→ The impedances limiting the fault current are largely reactive, such as tranformer, reactors and generators.

* Percentage reactance

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

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

$I \rightarrow$ full-load current

$X \rightarrow$ reactance in ohms per phase.

$V \rightarrow$ phase voltage

$$\% X = \frac{(kVA) X}{10 (kV)^2}$$

$X \rightarrow$ reactance in ohms.

short-circuit current = $I_{sc} = \frac{V}{X}$

$$= I \times \left[\frac{100}{\% X}\right]$$

* Percentage reactance and Base kVA

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

→ base kVA may be

i> equal to that of the largest plant

ii> equal to the total plant capacity

iii> any orbitary value.

$$\text{at base kVA } \% X = \frac{\text{Base kVA}}{\text{Rated kVA}} \cdot \% X \text{ at rated kVA}$$

* 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.

V → normal phase voltage in volts

I → full-load current in amperes at base kVA.

% X → % reactance of the system on base kVA upto the fault point.

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

Scanned with CamScanner

short-circuit kVA for 3-phase point $= \frac{3 V I_{sc}}{1000}$

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

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

* Reactor Control of Short-Circuit Currents

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

→ Due to very small resistance of reactors, there is very little change in the efficiency of the system.

Advantage

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

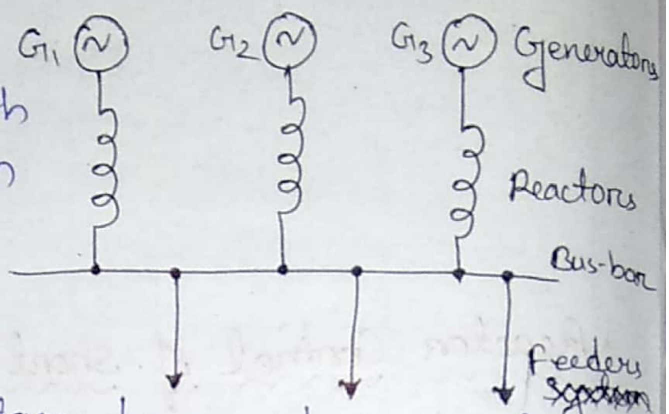
→ Reactors limit the flow of short-circuit currents and thus protect the equipment from over heating as well as from failure due to destructive mechanical forces.

* Location of reactors

i) in series with each generator
ii) in series with each feeder
iii) in bus-bars.

1) Generator reactors

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



Disadvantage

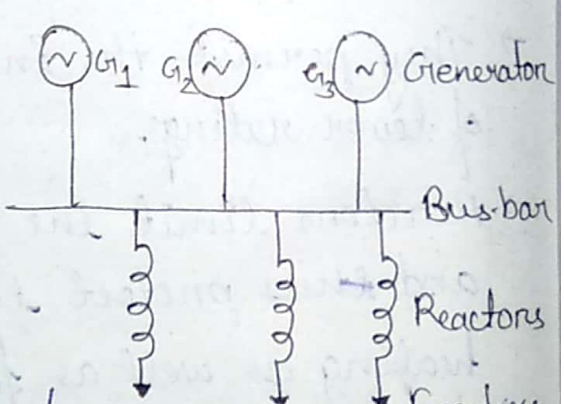
-> There is a constant voltage drop and power loss in the reactors even during normal operation.

-> continuity of supply is to be affected when fault occurs on any feeder.

-> if fault occurs on busbar of feeder, it causes the generator to fall out of step.

2) Feeder reactor

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



Advantage

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

-> fault on a feeder will not affect other feeder & the effects of fault are localised.

Disadvantage

-> constant power loss and voltage drop in reactors during normal conditions.

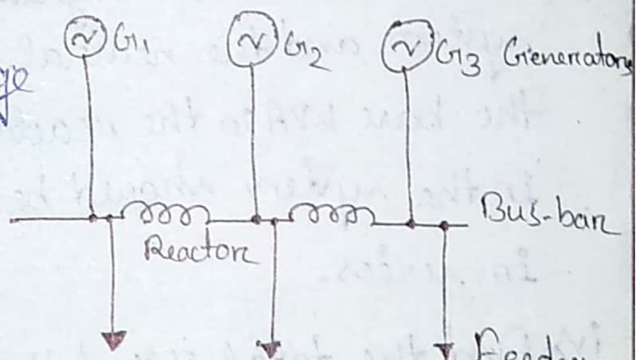
→ when short-circuit occurs at the bus-bars, no protection is provided to the generators.

→ number of generator ↑, feeder reactors size also ↑, to keep the short-circuit currents within the ratings of the feeder circuit breakers.

3) Bus-bar reactors

i) Ring system
ii) Tie-bar system.

i) Ring system

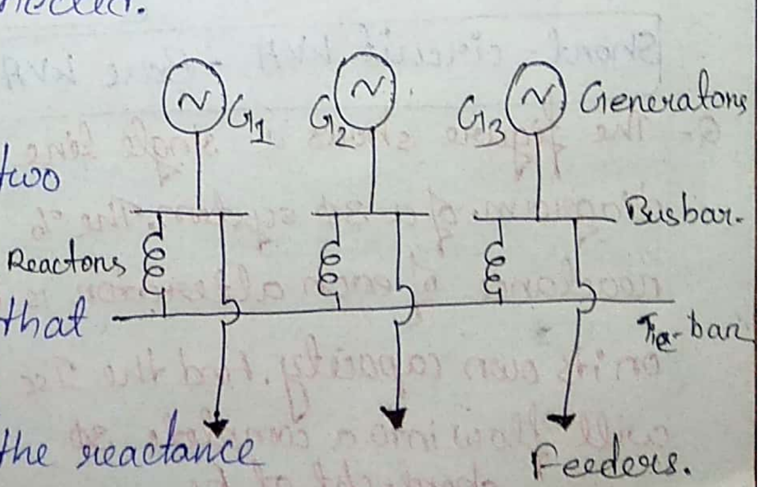


→ low power loss and voltage drops.

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

∴ only that section of bus-bar is affected to which the feeder is connected.

ii) 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.

→ it requires an additional bus-bar i.e. tie-bar (disadv.)

* Steps for symmetrical fault calculations.

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

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

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

iv) Find the total %X of the network upto the fault point.

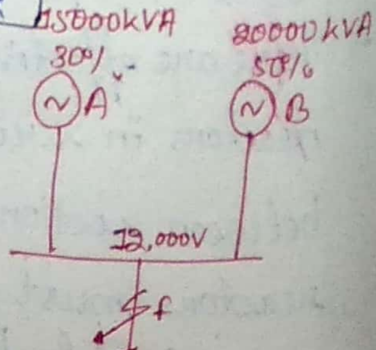
v) Find the full-load current corresponding to the selected base kVA and the normal system voltage at the fault point. Let it be I.

vi) The various short-circuit calculations are:

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

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

Q- The figure shows a single line diagram of a 3ϕ system. The % reactance of each alternator is based on its own capacity. Find the I_{sc} that will flow into a complete 3ϕ short-ckt at F.

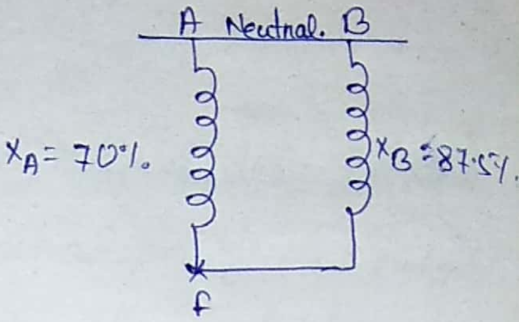


Single line diagram.

Let the base kVA = 35000kVA.

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

$$= 70\%$$



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

$$= 87.5\%$$

I_L corresponding to 35000 kVA at 12kV is

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

$$\text{Total } \% X = X_A \parallel X_B$$

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

$$I_{SC} = I \times \frac{100}{\% X} = 1684 \times \frac{100}{38.89} = 4330A.$$

PROTECTIVE RELAYS

* Definition

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.

* Fundamental Requirements of Protective Relaying

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.

→ To provide selectivity to the system, we have to divide the entire system into several protection zones.

a) generator
b) low-tension switchgear.
c) transformers.
d) high tension switchgears.
e) transmission lines

2) Speed

The relay should disconnect the fault section from the system as soon as possible.

a) Electrical apparatus may be damaged if they are made to carry fault current for long time.

b) It decreases the possibility of increase in the fault.

3) Sensitivity

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

-> The smaller the volt-ampere input required to cause relay operation, the more sensitive is the relay.

4) Reliability

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

5) Simplicity

The relaying system should be simple so that it can be easily maintained.

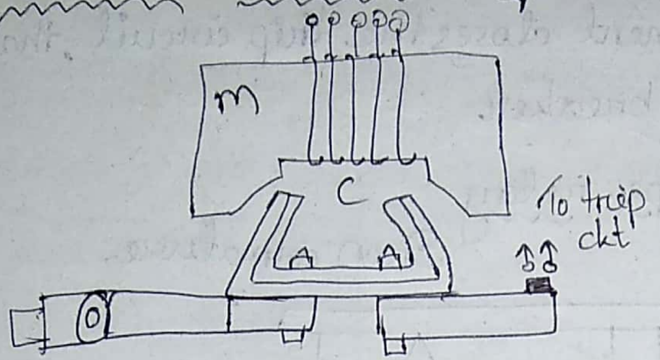
* Basic relays

1) Electromagnetic attraction
2) Electromagnetic Induction.

* Electromagnetic attraction relays

Electro magnetic attraction relays operate by virtue of an armature being attracted to the poles of an electromagnet or a plunger being drawn into a Solenoid.

i) Attracted armature type relay.

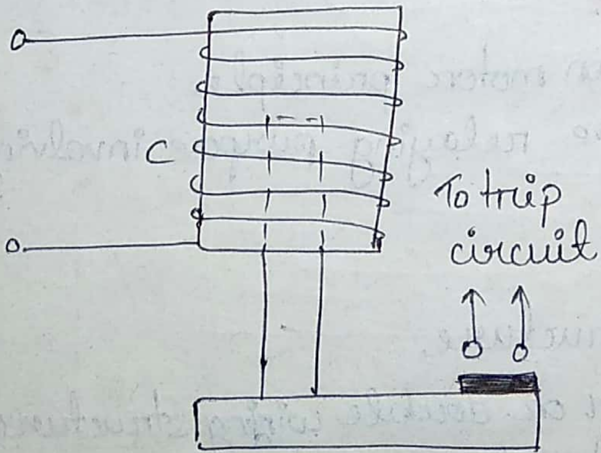


-> consist of a laminated electromagnet m carrying a coil c.

-> When a short circuit occurs, the current through the relay coil increases sufficiently and the relay armature is attracted upwards.

-> The contacts on the relay armature bridge a pair of stationary contacts attatched to the relay frame. This completes the trip circuit which results in the opening of the circuit breaker.

ii) Solenoid type relay



-> consist of solenoid and movable iron plunger.

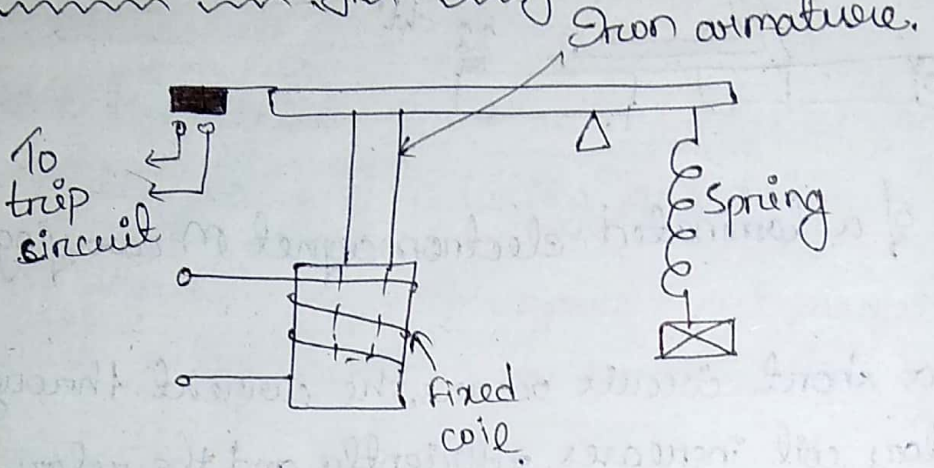
-> under fault condition, the current through the relay coil becomes more than the pickup value,

Scanned with CamScanner

causing the plunger to be attracted to the solenoid.

-> This upward movement closes the trip circuit, that opens the circuit breaker.

iii) Balanced beam type relay



-> consist of an iron armature fastened to a balance beam.

-> under normal condition the current through relay coil is such that the beam is held in the horizontal position by the spring.

-> ~~when~~

* Induction relays

-> works on induction motor principle.

-> used for protective relaying purpose involving a.c quantities.

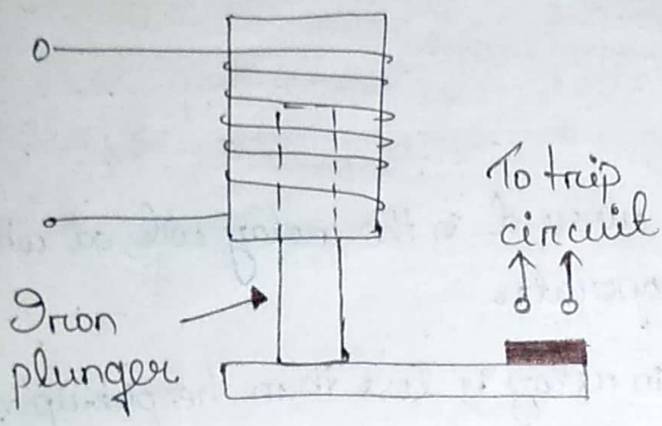
(i) shaded-pole structure.

(ii) watthour-meter or double winding structure

(iii) induction cup structure.

* Relay timing

i) Instantaneous relay



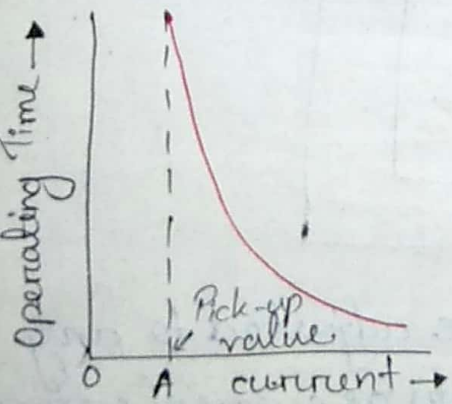
-> no intentional time delay is provided.

-> has operating time [<0.1 second].

-> The operating time of instantaneous relay is sometimes expressed in cycles based on power-system frequency

e.g. one-cycle would be $\frac{1}{50}$ second in a 50-cycle system.

ii) Inverse-time relay



-> The operating time is approximately inversely proportional to the magnitude of the actuating quantity.

-> At values of current less than pickup, the relay never operates.

Scanned with CamScanner

iii) Definite time lag relay

-> There is definite time elapse between the instant of pickup and the closing of relay contacts.

* Important terms

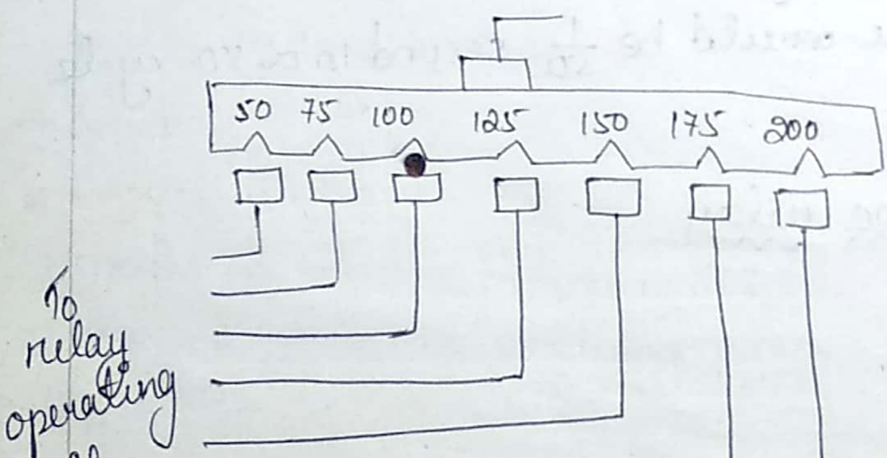
i) Pickup current

-> It is the minimum current in the relay coil at which the relay starts to operate.

-> When the current in relay is less than the pick-up value, the relay does not operate.

-> when the current is equals to or greater than pick-up value the relay operates to energise the trip coil which opens the circuit breaker.

2) Current setting



-> The pick-up current can be adjusted to any required value. This is known as current setting.

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

Example

current setting = 125%

connected to a supply circuit through a current transformer of $\frac{400}{5}$.

rated secondary current = 5 Amp.

pick up value = 5 × 1.25

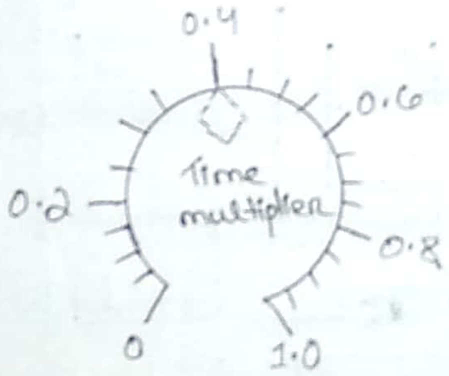
= 6.25 A.

iii) Plug-setting multiplier (P.S.M.)

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

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

iv) Time-setting multiplier

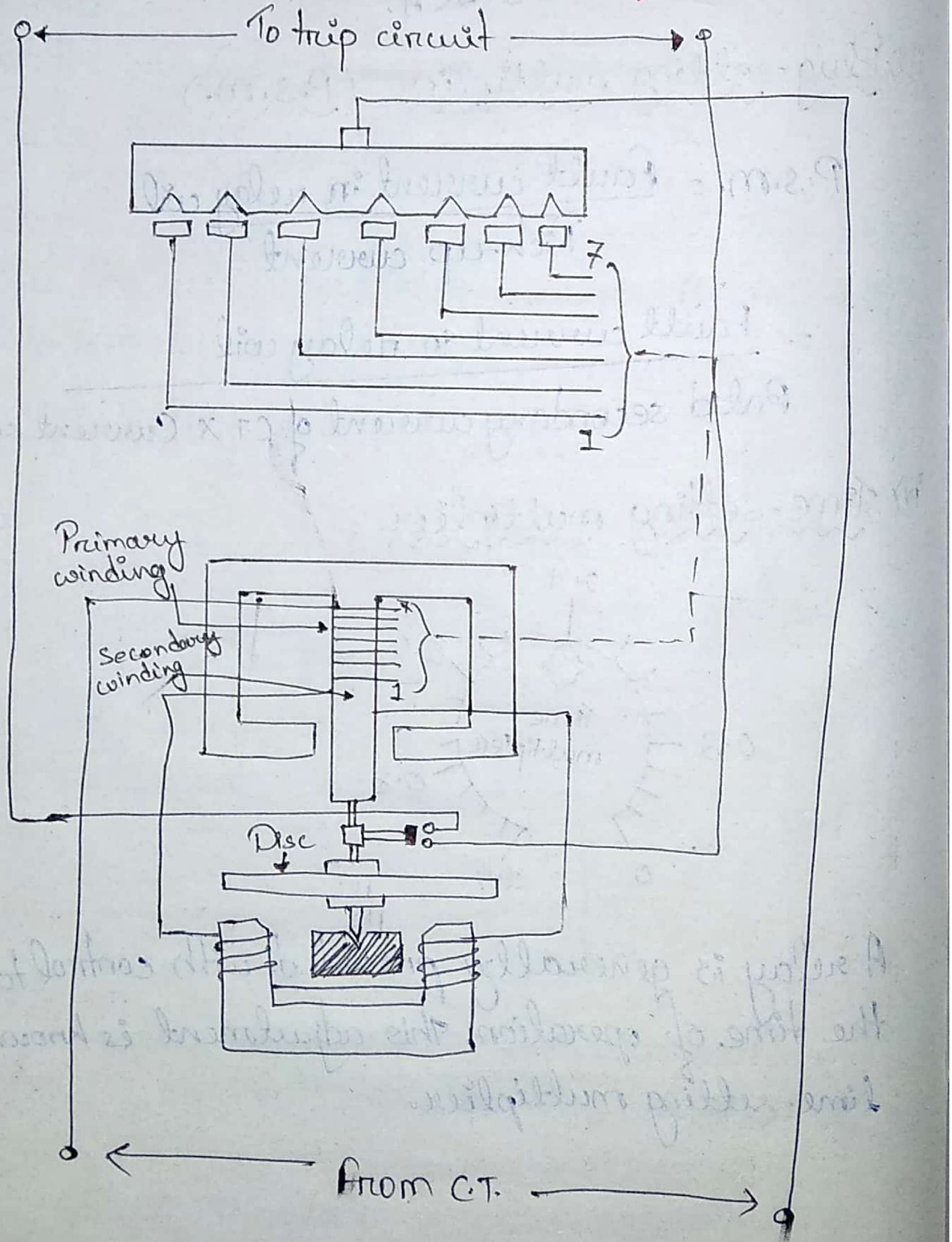


A relay is generally provided with control to adjust the time of operation. This adjustment is known as time-setting multiplier.

* Classification of functional relay

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

* Induction Type Overcurrent Relay (non-directional)



Construction

-> consist of a metallic disc which is free to rotate inbetween the poles of two electromagnets.

-> upper electromagnet has a primary & secondary winding.

-> primary is connected to the secondary of a CT & tapped at intervals.

-> secondary winding is energised by induction from primary and is connected in series with the winding of lower magnet.

-> controlling torque provided by a spiral spring.

Operation

-> The driving torque is opposed by the restraining torque provided by the spring.

-> normal condition

restraining torque > driving torque

=> aluminium disc - stationary

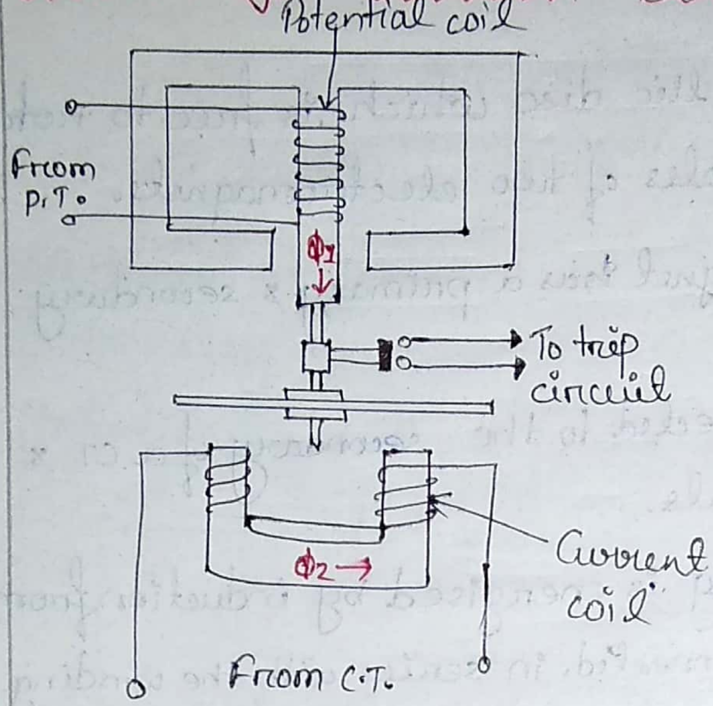
-> fault condition (exceed pre-set value)

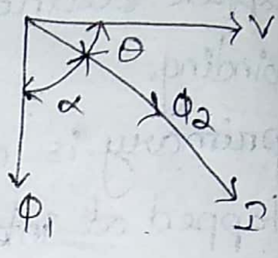
driving torque > restraining torque

=> disc rotates

∴ The trip circuit operates the circuit breaker which isolates the fault section.

* Induction Type Directional Power Relay.





Construction

-> consist of an aluminium disc i.e. free to rotate inbetween poles of two electromagnet.

-> The upper electromagnet carries the potential coil which is connected through PT on the central limb.

-> The lower magnet is consist of current coil i.e. connected to secondary of CT.

-> The restraining torque is provided by a spiral spring.

-> By adjusting the pre-set angle, the travel of the moving disc can be adjusted and hence desired time-setting can be given to the relay.

Operation

-> ϕ_1 due to current in potential coil will nearby 90° lagging behind the applied voltage V.

-> ϕ_2 due to current in current coil is in phase with the operating current I.

→ interaction of ϕ_1 & ϕ_2 with eddy current in disc produces a driving torque.

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

Since $\phi_1 \propto V$

$\phi_2 \propto I$

and $\alpha = 90° - \theta$

$$T \propto \phi_1 \phi_2 \sin(90° - \theta)$$

$$\propto \phi_1 \phi_2 \cos\theta$$

$$\propto VI \cos\theta$$

$\propto$ power in the circuit.

→ in normal condition the relay remains inoperative.

→ under the reversed driving torque condition, the disc rotates in reverse direction and the moving contacts closes the trip circuit. Hence the circuit breaker disconnects the fault section.

* Induction Type Directional Overcurrent Relay

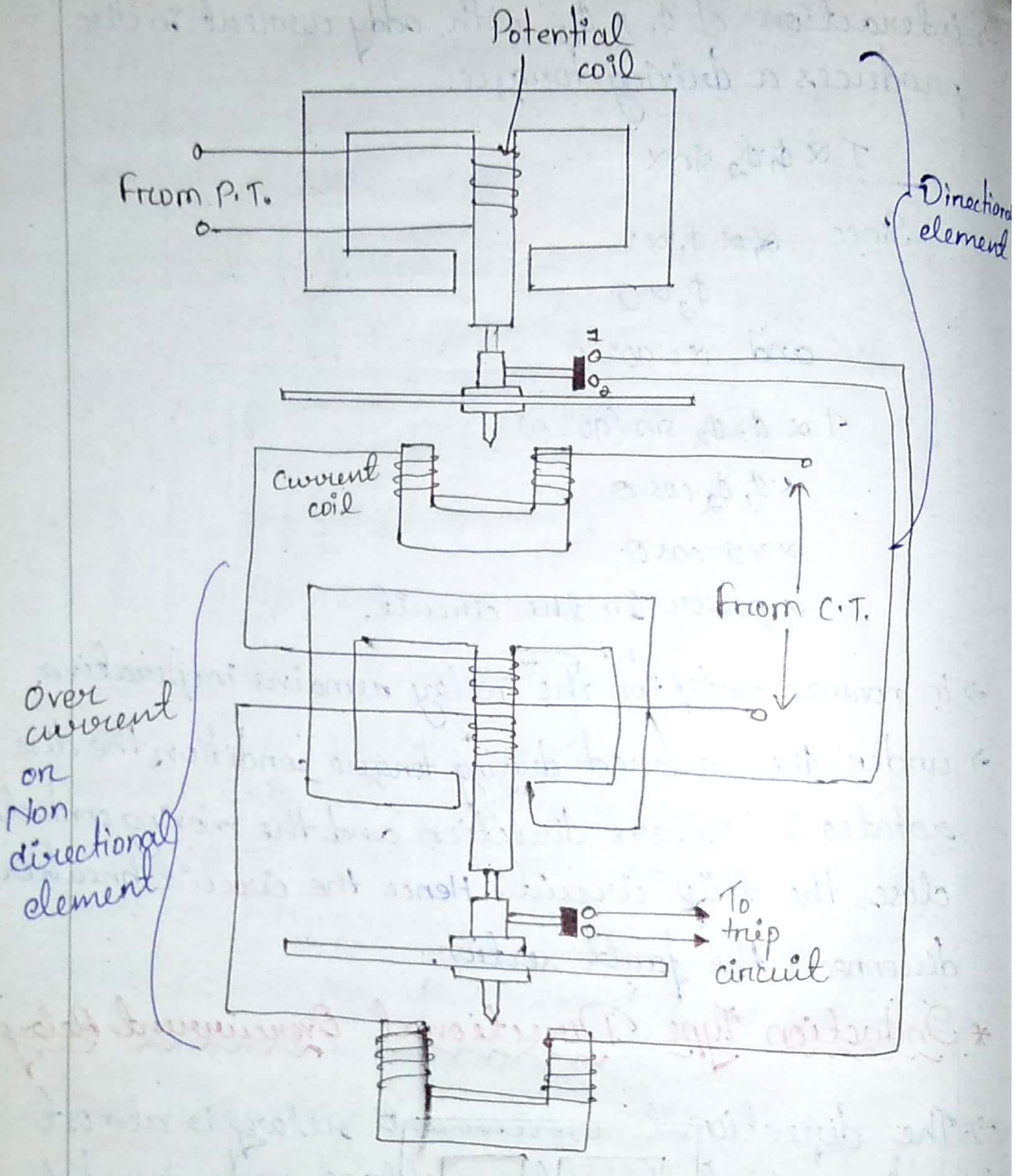
→ The directional overcurrent relay is almost independent of system voltage and power factor.

Construction

consist of two relay elements mounted on a common case.

i) DIRECTIONAL ELEMENT

ii) NON-DIRECTIONAL ELEMENT.



i) DIRECTIONAL ELEMENT

-> potential coil of this element is connected through a PT to the system voltage.

-> The current coil i.e. connected to the upper magnet of non-directional element is energised through CT.

-> Trip circuit is connected in series with the secondary circuit of non-directional element.

ii) NON-DIRECTIONAL ELEMENT

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

=> plug-setting bridge is provided for current setting in the relay.

Operation

Normal condition

directional power relay (upper magnet) does not operate, thereby keeping the overcurrent element (lower element) unenergised.

Short circuit condition

disc of upper magnet starts rotating. Through 1 & 2 contacts circuit completes for overcurrent element.

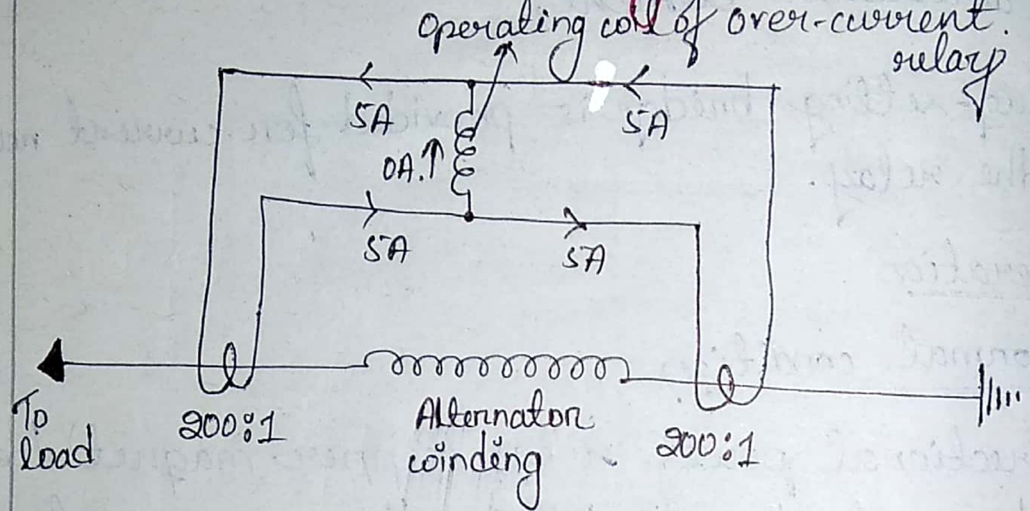
hence the disc of overcurrent element rotates and it closes the trip circuit.

* 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.

2 fundamental systems
1) Current balance protection
2) Voltage balance protection.

a) Current Differential Relay



→ A pair of identical CT are connected on the either side of the section to be protected.

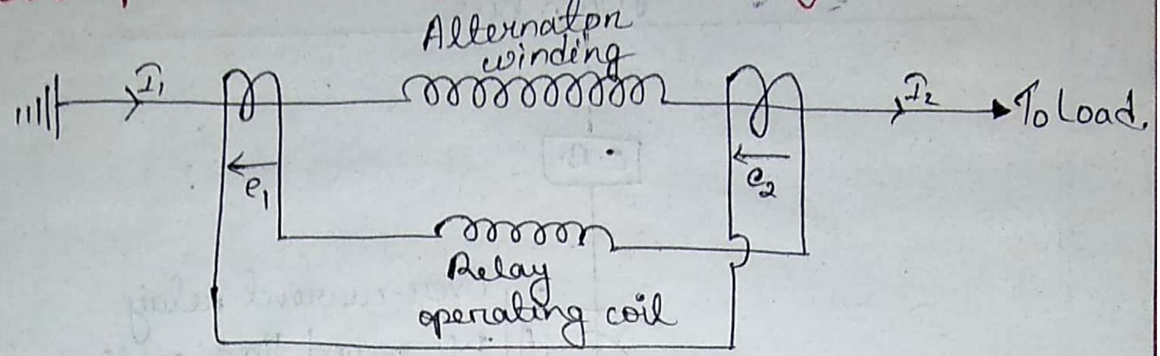
→ The secondary of CT are connected in such a way that they can carry the induced current in the same direction.

→ The operating coil of the overcurrent relay is connected across the CT secondary circuit.

→ under normal condition, the secondary currents of CT's are equal.

→ under fault condition, the current amount flow through the relay will depend upon the way the fault being fed.

b) Voltage balance differential relay



-> Two similar current transformers are connected at either end of the element to be protected. by means of pilot wires.

-> under healthy condition equal current flows in both primary windings.

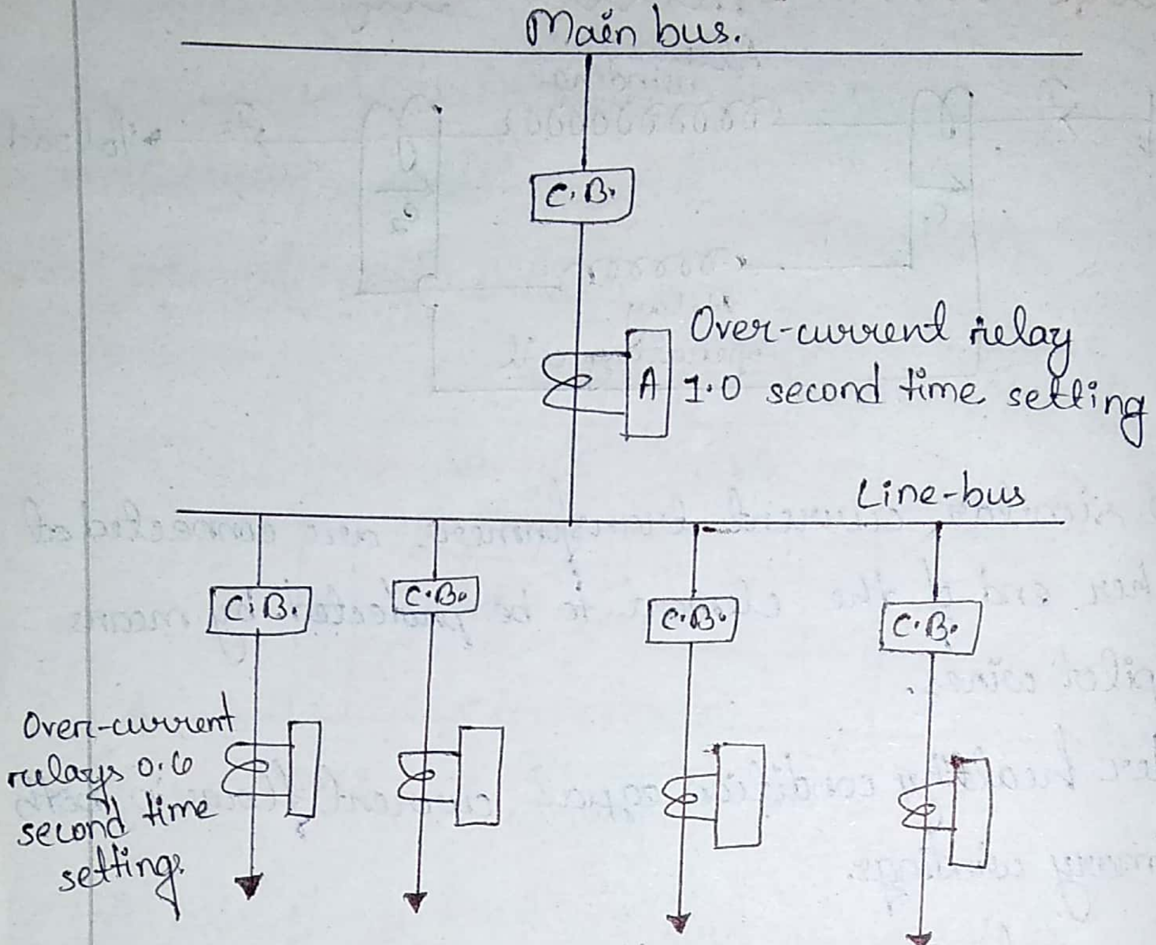
-> When a fault occurs in the protected zone, the current in two primaries will not equal and their secondary voltage will no longer in balance. This voltage difference will cause a current to flow through the operating coil of the relay which closes the trip circuit.

* Types of protection

i) Primary protection

It is the protection scheme which is designed to protect the component parts of the power system.

-> If a fault occurs on any line, it will be cleared by its relay and circuit breaker. This forms the primary or main protection.



ii) Back-up protection

-> Sometimes fault are not cleared by primary relay system because of trouble within the relay, wiring system or breaker. Under such conditions back-up protection does the required job.

-> When back-up relaying functions, a larger part is disconnected than when primary relaying functions correctly.

= X =

Scanned with CamScanner

PROTECTION OF ELECTRICAL POWER EQUIPMENT AND LINES

* Protection of Alternator

Faults that may occure on an alternator :-

i) Failure of prime-mover.
ii) Failure of field
iii) overcurrent
iv) overspeed
v) overvoltage
vi) unbalanced loading
vii) stator winding faults

i) Failure of prime mover

The alternator runs as a synchronous motor and draws some current from the ~~sys~~ supply system when the prime mover fails.
This motoring condition is known as 'INVERTED RUNNING'.

ii) Failure of field

-> no immediate damage
-> the alternator can run without field for a short span of time.
∴ by using relay disconnection of faulty alternator from system bus-bar is easily possible.

iii) Overcurrent

-> due to partial breakdown of winiding insulation.

-> due to overload on supply system

iv) Overspeed

-> due to sudden loss of major part of load on the alternator

-> alternators are provided with mechanical centrifugal devices mounted on their driving shaft to trip the main valve of the prime-mover when overspeed occurs.

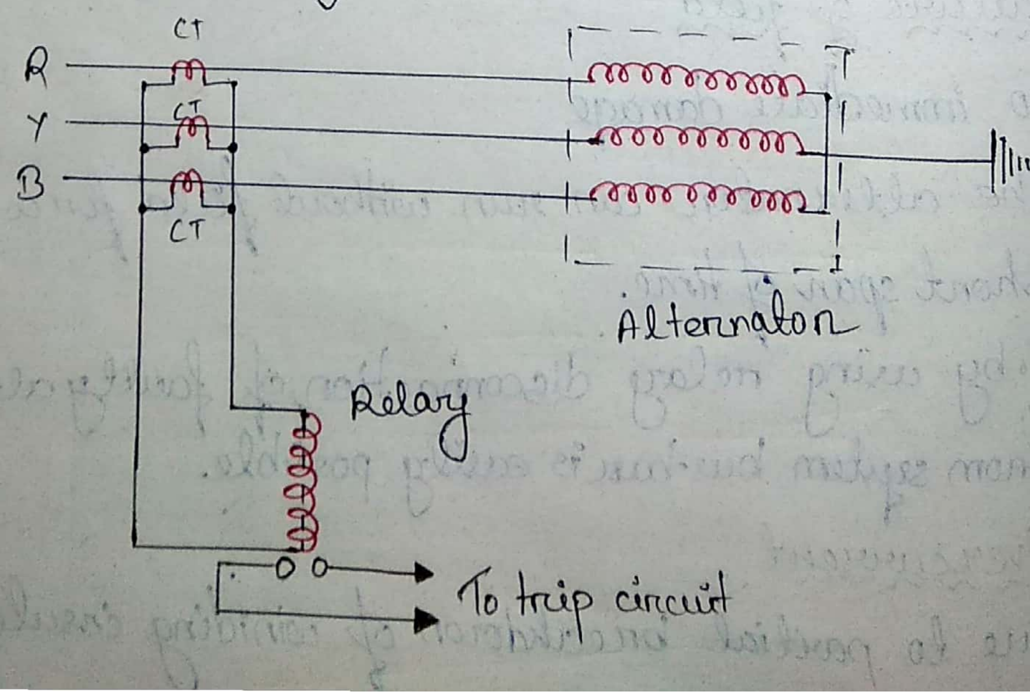
v) Overvoltage

-> field excitation is designed in alternator to avoid the occurance of overvoltage at normal running speed.

-> due to increase in speed of prime mover bcz of sudden loss in load of alternator.

-> overvoltage protection is not provided in turbo-alternator.

vi) Unbalanced loading



-> different phase currents in the alternator.

-> arises from i> fault to earth,

ii> fault betweens phases on the circuit external to the alternator.

-> it may cause damage in mechanical fixing of the rotor core

-> damage in feeld winding.

-> According to the above Fig. in unbalancing occurs, the currents induced in the secondaries will be different and the resultant of these currents will flow through the relay. The operation of relay will trip the CB to disconnect the alternator from the system.

viii> Stator winding faults

-> due to insulation failure of stator winding.

-> occurs due to.

i> Fault between phase and ground.

ii> Fault between phases

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

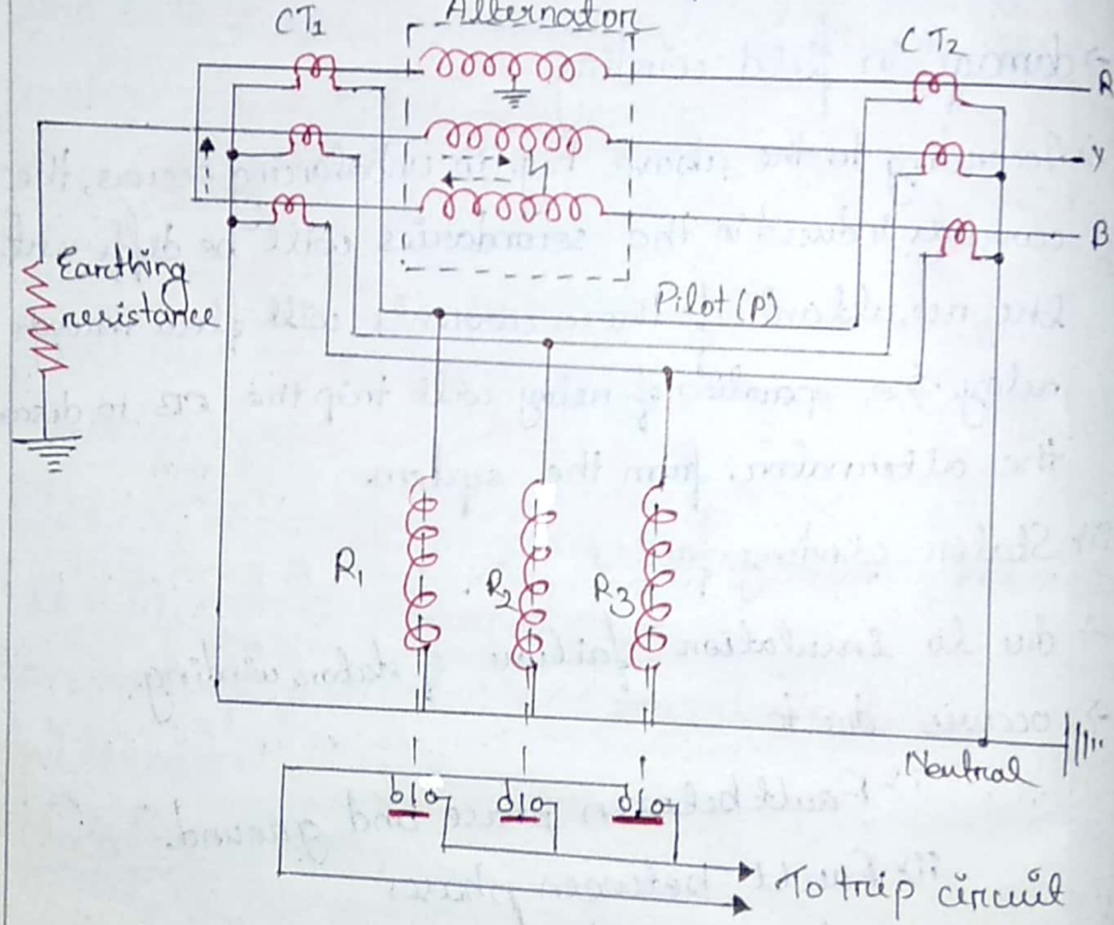
* Differential protection of alternators.

Schematic arrangement

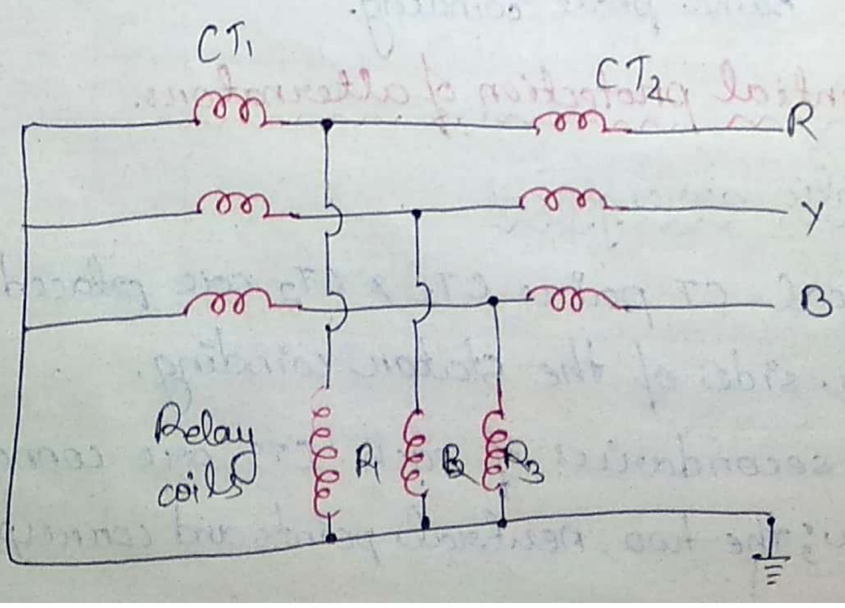
Identical CT pairs CT_1 & CT_2 are placed on either side of the stator winding.

-> The secondaries of each CTs are connected in star; the two neutral points and corresponding terminals of the two star groups being connected together by means of a four-core pilot cable.

→ The relays are electromagnetic type and are arranged for instantaneous action since fault should be cleared as soon as possible.



Operation



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

→ balanced circulating current in the pilot wires and no current flows through operating coil of relays.

→ Under fault condition, a differential current will flow through the operating coil and it operates the relay circuit to trip the circuit breaker.

→ Energising of relay circuit causes

i) opening of breaker connecting the alternator to the bus-bar.

ii) opening of the field circuit of the alternator.

Limitations

→ use of neutral earthing resistance in order to limit the destructive effects of earth-fault currents.

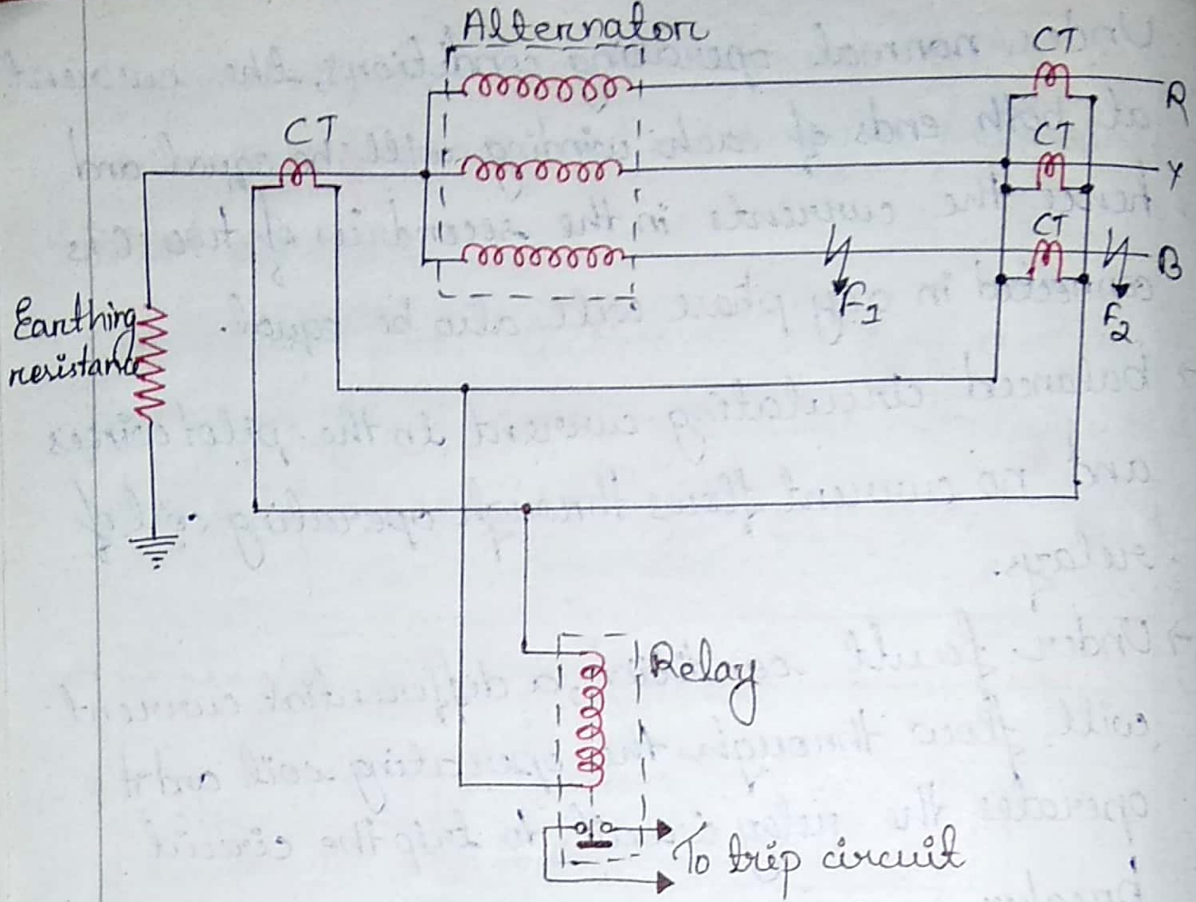
* Balanced Earth-fault Protection

Schematic arrangement

→ It is the diagram for balanced earth-fault protection for a 3-phase alternator.

→ consist of 3 line of CTs, one mounted on each phase.

→ secondries are connected in parallel with a single CT in the conductor joining the star point of the alternator to earth.



→ relay is connected across the transformer secondries.

Operation

i) normal operating condition

→ current flowing in the alternator leads & current flowing in secondries add to zero.

⇒ no current in relay.

ii) when F_2 fault occurs

it is outside of the protected zone,

⇒ sum of currents at terminals of alternator = current in neutral connection.

⇒ no current flows through relay.

iii) when F_1 fault occurs

differential current flows the operating coil of the relay.

* Protection of Transformers

Common Transformer faults

1) Open circuits
2) Overheating
3) Winding short-circuits
e.g. earth-faults, phase-to-phase faults and inter-turn faults

* Protection Systems for Transformers

The principal relays and systems used for transformer protection are:

1) BUCHHOLZ DEVICES.
providing protection against all kinds of incipient faults i.e. slow-developing faults such as insulation failure of windings, core heating, fall of oil level due to leaky joints

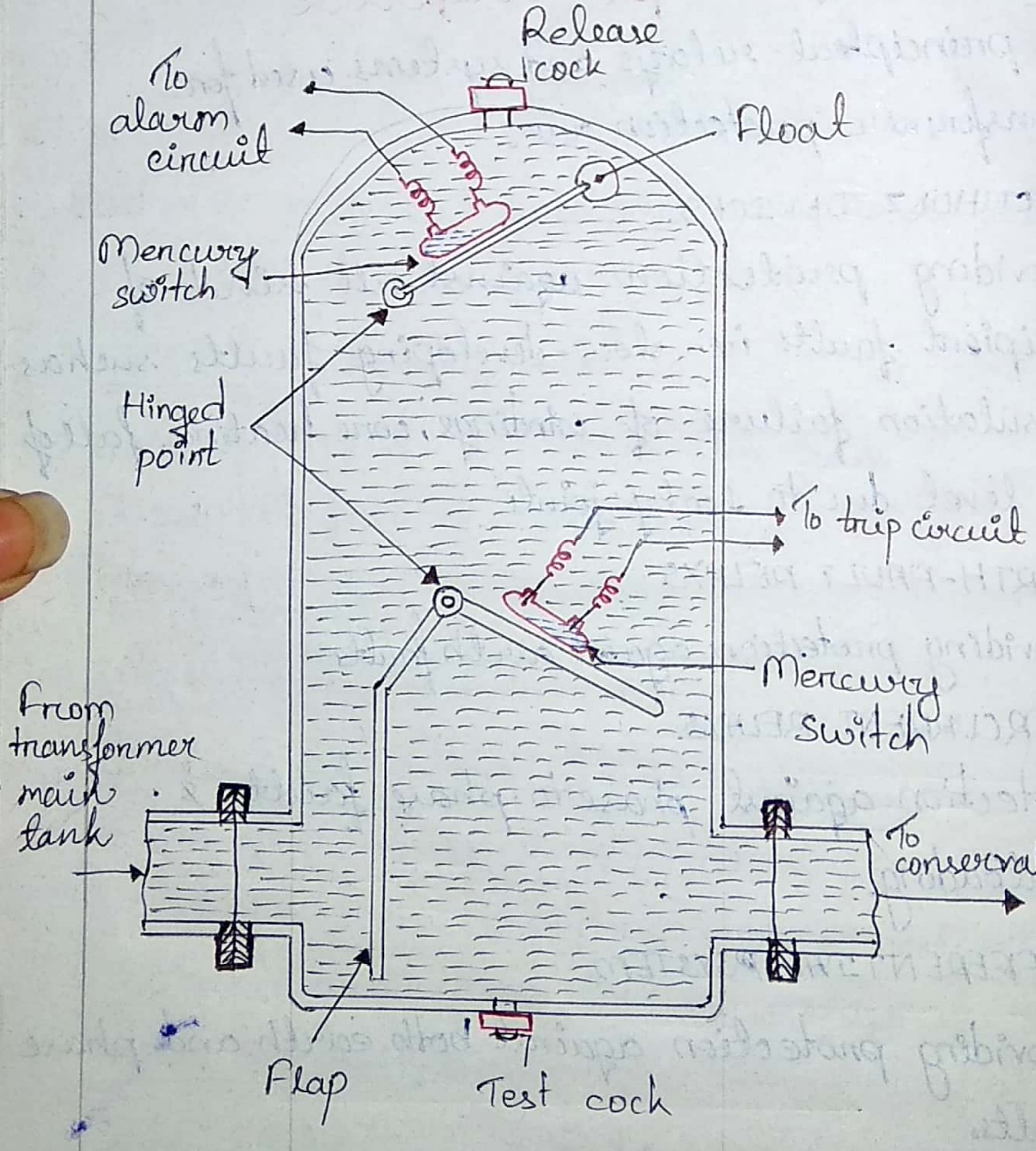
2) EARTH-FAULT RELAYS
providing protection against earth faults

3) OVERCURRENT RELAYS.
protection against phase-to-phase faults & overloading.

4) DIFFERENTIAL SYSTEM
providing protection against both earth and phase faults.

→ Choice of a particular combination of system may depends on the factors
i) size of transformer
ii) types of cooling
iii) location of transformer in the network
iv) nature of load supplied
v) importance of service for which transformer is required.

* Buchholz Relay



→ Buchholz relay is used on the oil immersed transformer having rating in excess of 750kVA.

Construction

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

-> The device has two elements.

i) The upper ~~em~~ element consists of a mercury type switch attatched to a float.

ii) The lower element contains a mercury switch mounted on a hinged type flap.

-> The upper element closes an alarm circuit in incipient faults where as the lower element is arranged to trip the circuit breaker.

Operation

-> The heat causes ~~dabarsé~~ decomposition of transformer oil in main tank. As the hydrogen gas (products of decomposition) is less in weight it will try to go into conservator tank via Buchholz relay.

-> It exerts the sufficient pressure on the float to move and closes the mercury switch, i.e. completes the alaram circuit to sound alarm.

-> When huge amount of gas is generated in main tank, the oil in main tank rushes towards the conservator via the Buchholz relay. During this it moves the flap to close the contacts of mercury switch. This completes the trip circuit and open the circuit breaker controlling the transformer.

Advantage

-> simplest form.

-> detects the incipient faults at a stage much earlier than is possible with other form of protection.

Disadvantage

-> only used with oil immersed transformers equipped with conservator tanks.

-> can only detect fault below oil level in the transformer.

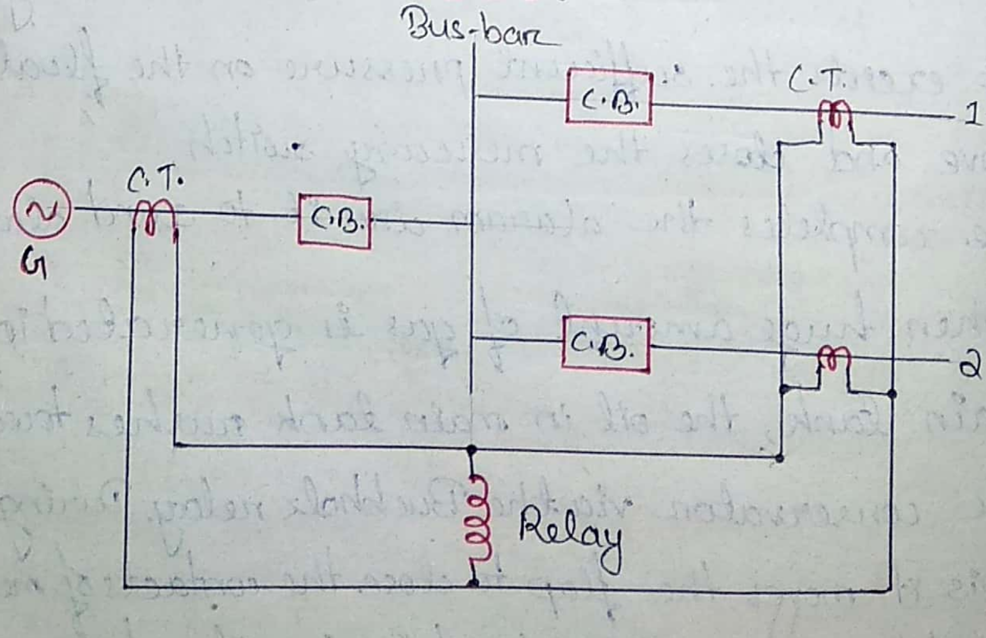
* Protection of Bus bar

The two common methods used for bus-bar protection :-

1) Differential protection

2) Fault bus protection.

1) DIFFERENTIAL PROTECTION



→ current incoming and leaving is totalised.

→ normal condition

sum of currents = 0. incoming = leaving

→ fault condition

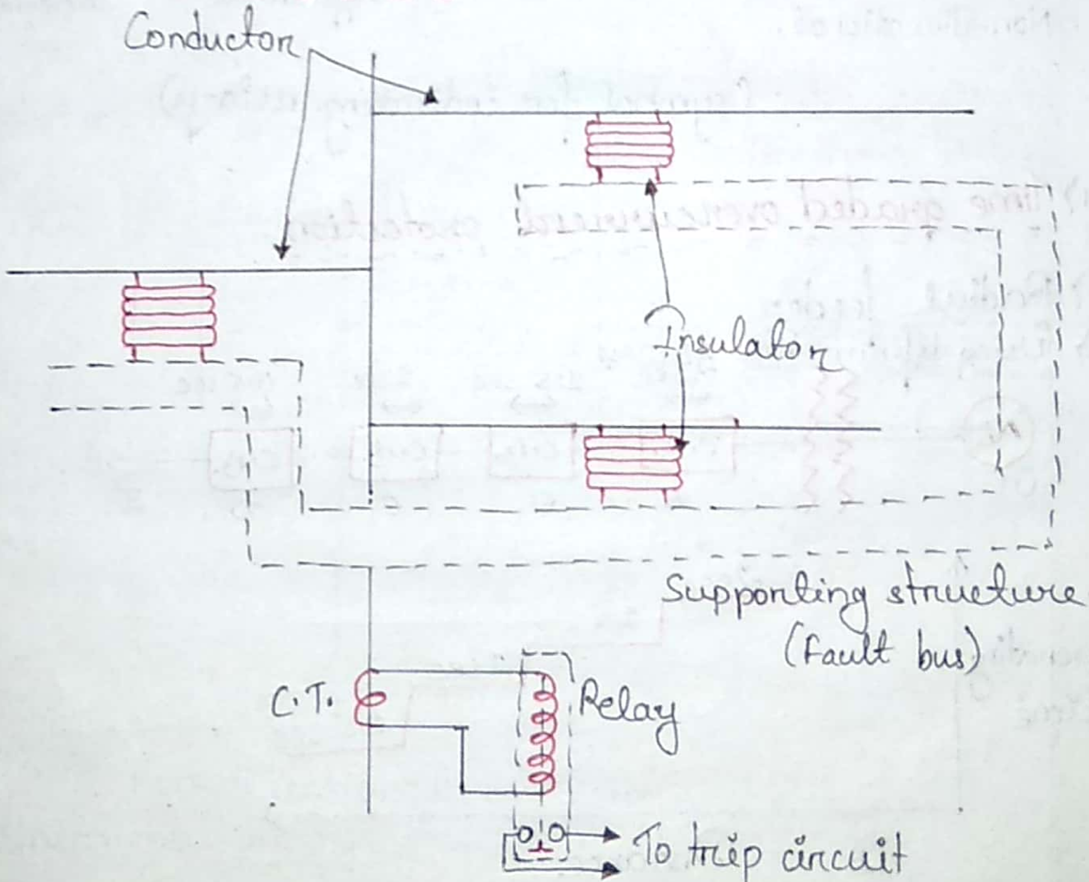
fault current upsets the balance

a differential current is produced to operate relay.

incoming current ≠ out going current

The relay cause the opening of generator circuit breaker and lines (1,2) circuit breaker.

2) FAULT BUS PROTECTION



→ Fault bus is earthed through CT.

→ relay is connected across secondary of CT.

→ normal condition

no current from fault bus to ground.

relay is inoperative.

→ Fault condition

current flow to ground through fault bus.

relay operates and trip breakers connecting equipment to the bus.

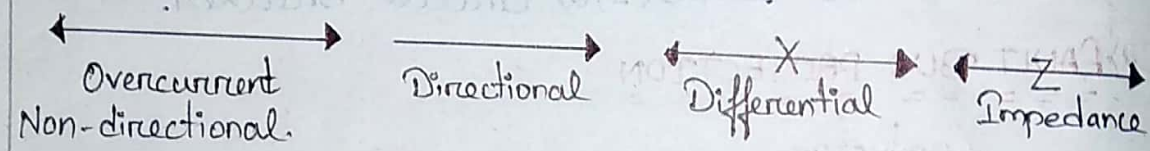
* Protection of Transmission line

Methods for protection of line:

i) Time-graded overcurrent protection

ii) Differential protection

iii) Distance protection

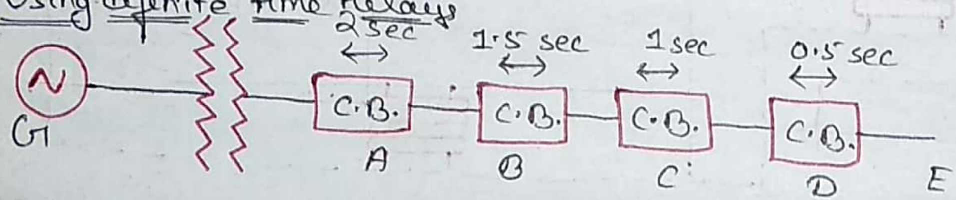


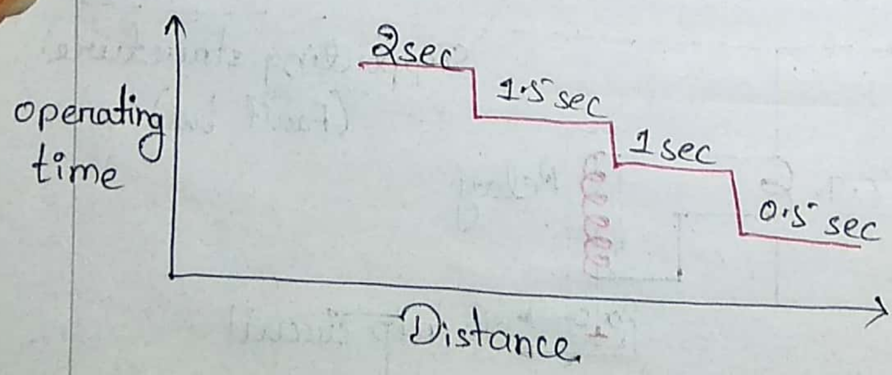
(symbol for indicating relays)

1) Time graded overcurrent protection

i) Radial feeder

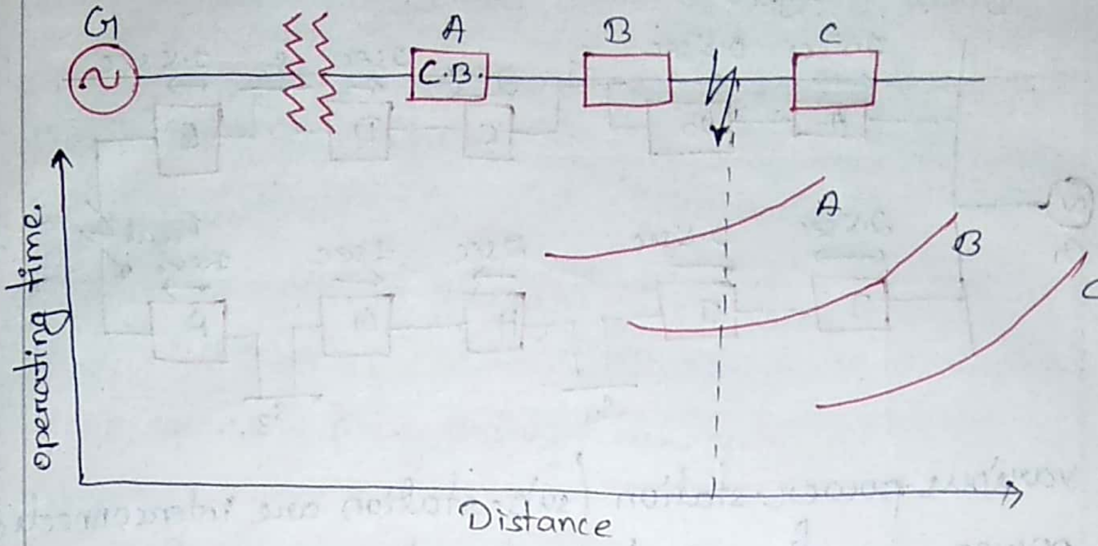
a) Using definite time relays





→ Time of operation of each relay is fixed and independent of the operating current.

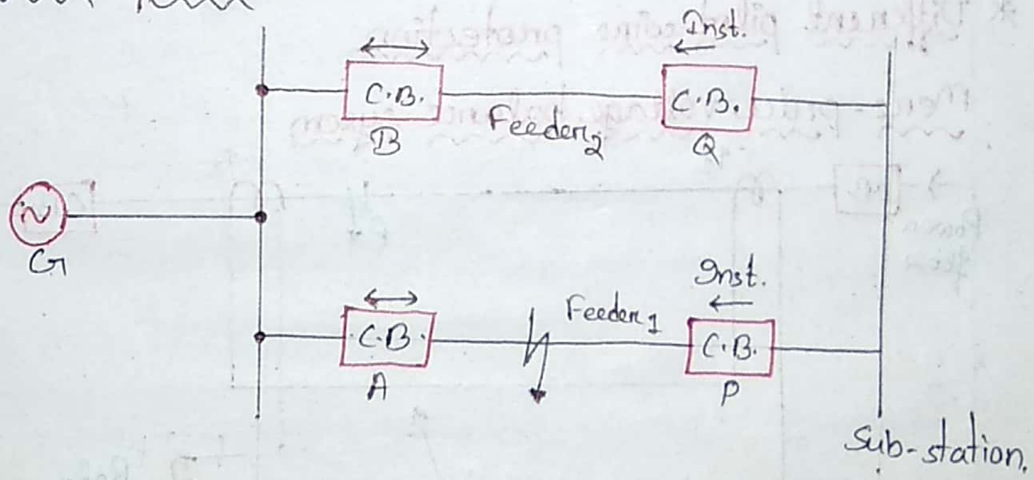
ii) Using inverse time relays



-> operating time is inversely proportional to the operating current.

-> the farther the circuit breaker from the generating station, the shorter is its relay operating time.

iii) Parallel feeder



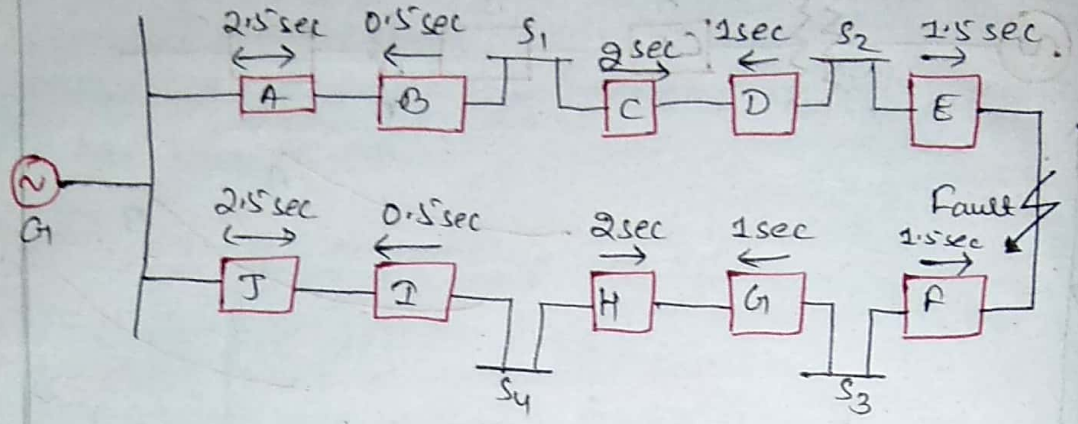
-> Both non-directional overcurrent relay and directional relays are used.

-> The protection of this system requires

i) each feeder has a non-directional overcurrent relay at the generator end. & should have inverse-time characteristics.

ii) each feeder has a directional relay at the substation end. These should be of instantaneous type and operate when power flows in reverse direction.

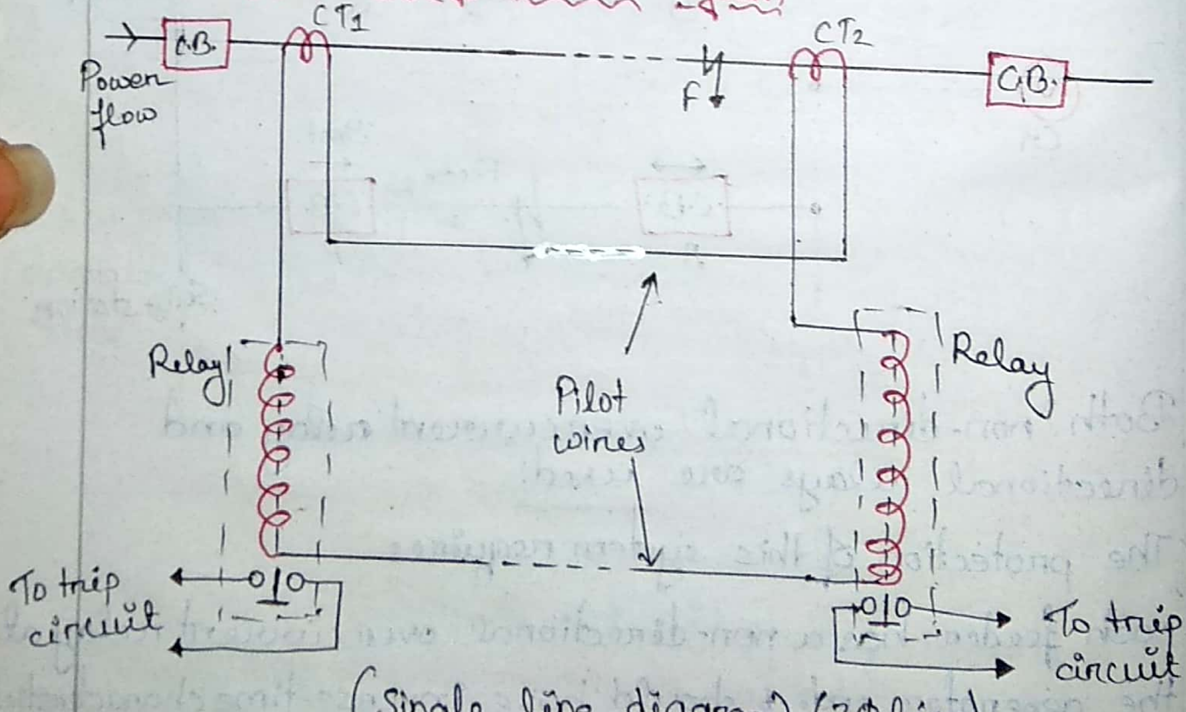
3) Ring main system



-> various power-station / sub-station are interconnected
-> power can flow in both direction under fault condition.
-> The two lines leaving the generator station should be equiped with non-directional overcurrent relay (A, J).
-> at each substation directional relays should be placed in both incoming and outgoing lines (B, C, D, E, F, G, H, I).

* Different pilot-wire protection

Merz-price voltage balance sysem



(Single line diagram). (3ϕ line).

-> Identical CTs are connected in each phase at both the ends of the line.

→ The pair of CTs in each line is connected to a relay in series in such a way that under normal conditions, secondary voltages are equal and in opposite direction i.e. they balance each other.

→ healthy condition

entering current at one end = leaving current at other end

⇒ no current flows through relay.

Advantage

→ used for ring main, parallel feeders.

→ provides instantaneous protection for ground faults.

Disadvantage

→ accurate matching of CT is essential.

→ in case of break in pilot wire circuit, system will not operate.

=X=