UNIT - I

PROTECTION SCHEMES

* THE ZONES OF PROTECTION IN POWER SYSTEM

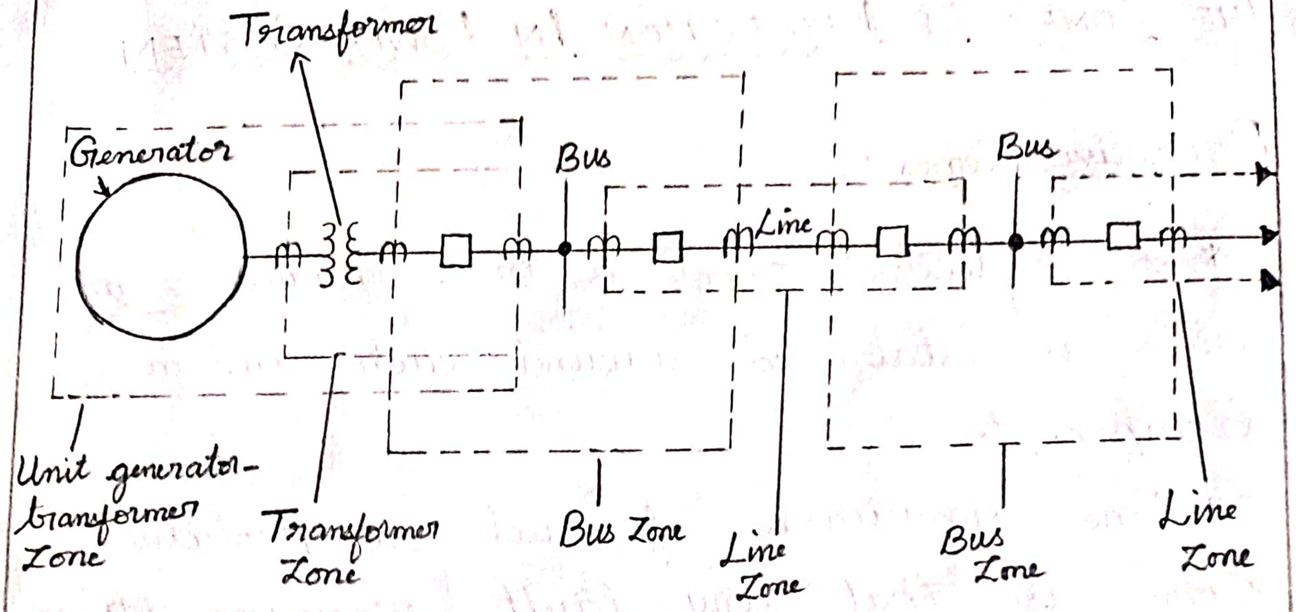
Protective Zones:

* A protective zone is the separate zone which is established around each system Components.

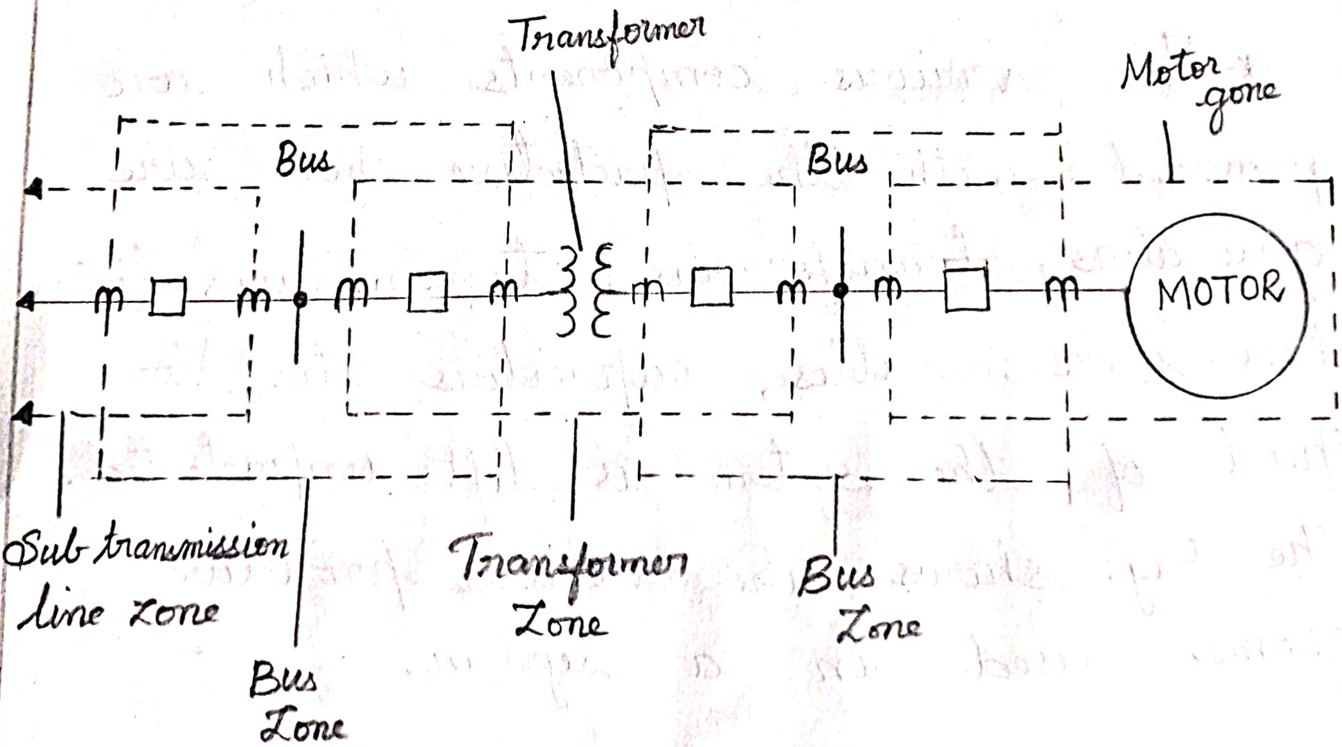
* The significance of such a protective zone is that any fault occuring within cause the tripping of relays which causes opening of all the circuit breakers within that zone.

* The various components which are provided with the protective zone are generators, transformers, transmissions lines bus bars, cables, capacitors etc. No part of the system is left unprotected. The Fig. shows the various protective zones used in a system.

FIG 1.1. PROTECTIVE ZONE



ⓐ Typical relay for generator, line and bus.



ⓑ Typical relay for motor and transformer.

* In practice, various protective zones are overlapped. The overlapping of protective zones is done to ensure complete safety of each and every element of the system.

* The zone which is unprotected is called dead spot. The zones are overlapped and hence there is no chance of existence of a dead spot in a system. For the failures within the region where two adjacent protective zones are overlapped, more circuit breakers get tripped than minimum necessary to disconnect the faulty element.

* If there are no overlaps, then dead spot may exists, means the circuit breakers lying within the zon may not trip even though the fault occurs. This may cause damage to the healthy system.

* PRIMARY AND BACKUP PROTECTION

When a fault occurs on any part of electric power system, it must be cleared quickly in order to avoid damage and/or interference, with the rest of the system. It is a usual practice to divide the protection scheme into two classes viz. primary protection and back-up protection.

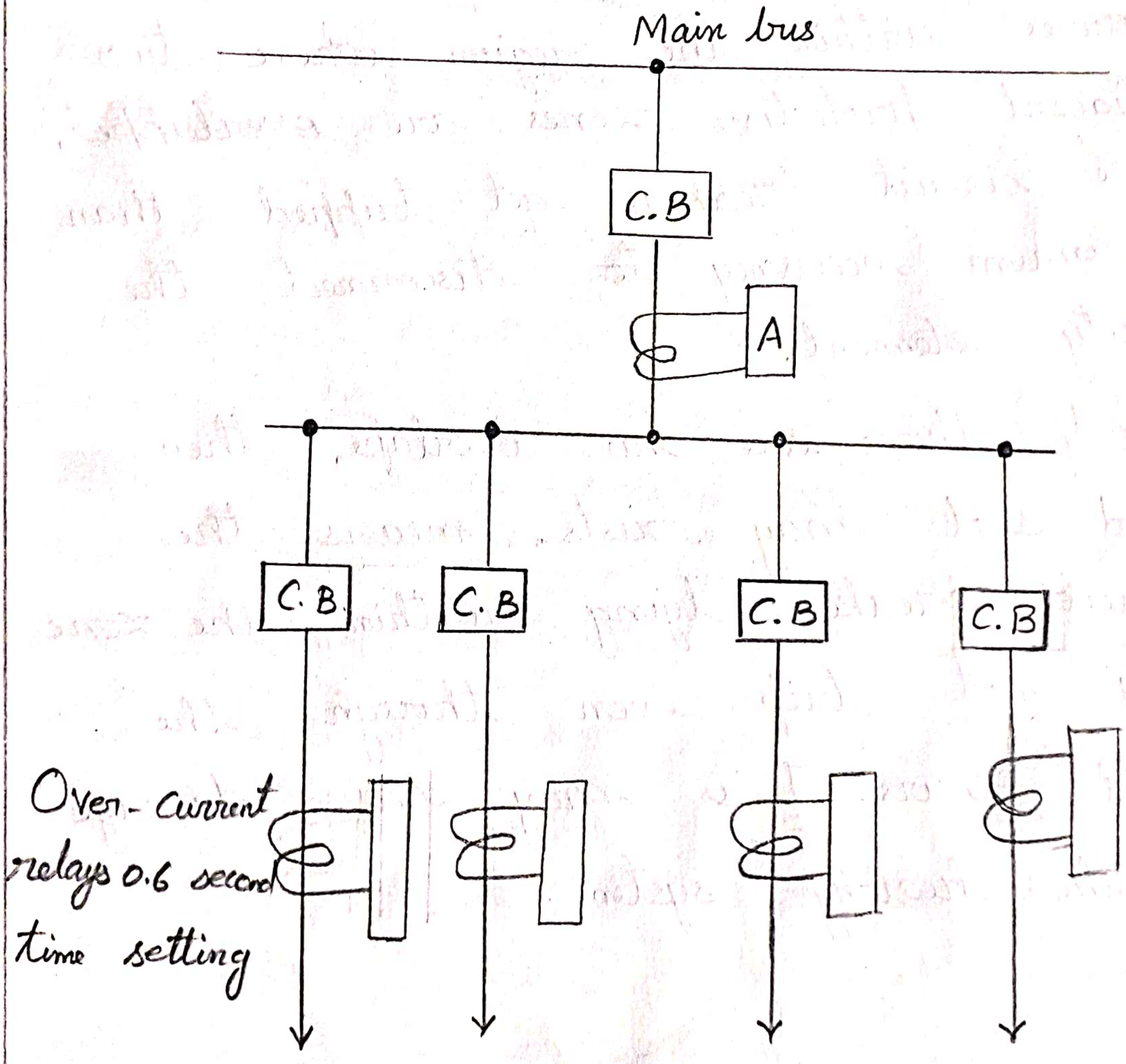


FIG. 1.2. Primary And Back up Protection

(i) Primary Protection :

* It is the protection scheme which is designed to protect the component parts of the power system. Thus referring to Fig 1.2., each line has an overcurrent relay that protects the line.

* If a fault occurs on any line, it will be cleared by its relay and circuit breaker. This forms the primary or main protection and serves as the first line of defence.

(ii) Back-up 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 does the required jobs.

* 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 primary relaying will be given enough time to function if it is able to.

* Thus referring to Fig 1.2 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.

* NATURE AND CAUSES OF FAULT

* Faults occurs normally due to breaking of conductors or failure of insulation or many other reasons. The other reasons for occurence of fault include mechanical failure, accidents, excessive internal and external stressess.

* The impendence of the path in the faul is low and the fault currents are comparatively large.

* When a fault occurs on a system the voltages of the three phases become unbalanced. As the fault currents ar large, the apparatus may gets dama

* A power system consists of generators,

transformers, switchgear, transmission and distribution circuits. There is always a possibility in such a large network that some fault will occur in some part of the system.

* The maximum possibility of fault occurence is on transmission lines due to their greater lengths and exposure to atmospheric conditions.

* The fault can not be totally eliminated from the system but their occurence can be minimized by improving system design, quality of the equipment and maintenance.

* The faults can be classified according to causes their incidence.

* The breakdown may occur at normal voltage due to deterioration of insulation.

* The breakdown may also occur due to perching of birds, accidental short circuiting by snakes, kite strings, three branches etc. The breakdown may occur at abnormal voltages due to switching surges or surges caused by lighting.

* The AC faults can also be classified as single line to ground fault, double line to ground fault, three phase fault. Following table gives us an idea as to how the faults are distributed in the various parts of the system.

S.NO	Equipment	% Total Of Fault
1.	Over head line	50
2	Switch Gear	15
3	Transformer	12
4	Cables	10
5	Miscelleneous	8
6	Control Equipment	3
7	Cts and Pts	2

* It can be seen from the above table that maximum number of faults are occuring on overhead lines.

* In case of three phase system, the breakdown of insulation between one of the phases and earth is known as line to ground fault.

* In line to line fault, there is insulation

breakdown between either of two phases. While the insulation breakdown between two phases and earth forms double line to ground fault.

* The breakdown of insulation between three phases is nothing but three phase fault. Following table gives occurance of these faults.

S.No	TYPE OF FAULT	% OCCURENCE
1	Line to Ground	85
2	Line to Line	8
3	Line to Line to Ground	5
4	Three phase fault	2 or less

* It can be seen from the above table that most of the faults are line to ground faults in case of overhead lines.

* The fault current produced by line to ground fault has considerable magnitude. So the protective system must be properly designed so as to have operation of relays under line to ground fault.

* The Line to Line to Line (L-L-L)

fault is nothing but symmetrical three phase fault which normally occurs due to carelessness of operating personnel.

* Usually the phase lines are tied together with the help of a bare conductor so as to protect the lineman working on the lines against inadvertent charging of the line.

* Sometimes after the work, if lineman forgets to remove the tie up between phase lines and if the circuit breaker is closed then three phase symmetrical fault occurs.

* VARIOUS METHODS OF NEUTRAL GROUNDING

"The process of connecting the metallic frame of electrical equipment or some electrical part of the system (e.g. neutral point in a star-connected system) to earth (i.e. soil) is called grounding or earthing."

Methods Of Neutral Grounding

(i) Solid grounding
(ii) Resistance grounding
(iii) Reactance grounding
(iv) Resonant grounding / Peterson Coil groundings

(1) Solid grounding :-

* "When the neutral point of a 3-phase system (e.g. 3-phase generator, 3-phase transformer etc) is directly connected to earth (i.e. soil) through a wire of negligible resistance and reactance, it is called solid grounding or effective grounding."

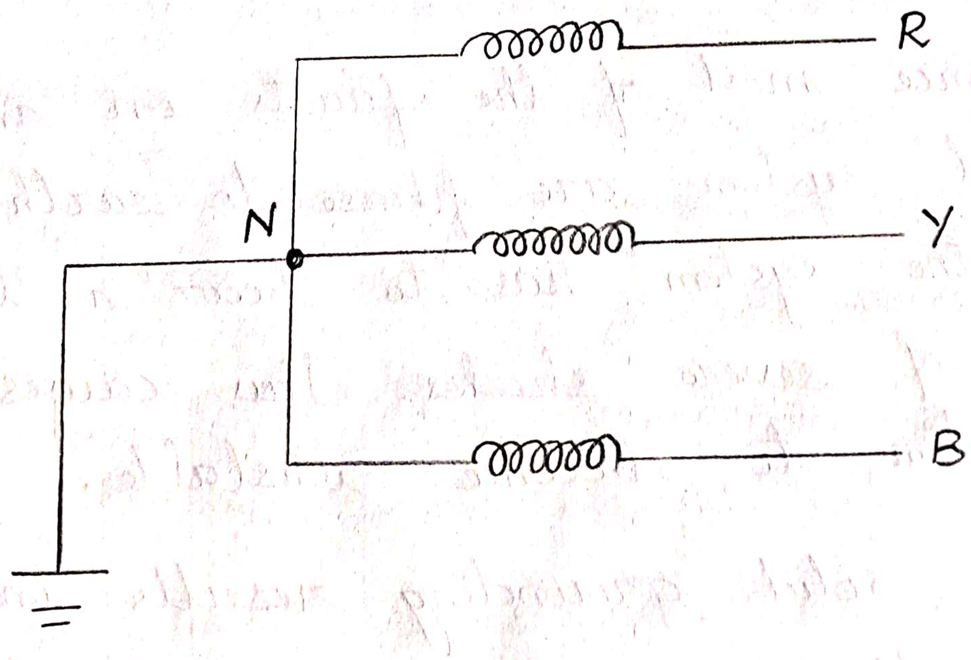


Fig. Solid Grounding

* Fig. shows the solid grounding of the neutral point. Since the neutral point is directly connected to earth through a wire, the neutral point is held at earth potential under all conditions.

* When there is an earth fault on any phase of the system, the phase to earth voltage of the faulty phase becomes zero.

* However, the phase to earth voltages of the remaining two healthy phases remain at normal phase voltage because the potential of the neutral is fixed at earth potential.

Disadvantages :-

(i) Since most of the faults on an overhead system are phase to earth faults, the system has to bear a large number of severe shocks. This causes the system to become unstable.

(ii) The solid grounding results in heavy earth fault currents. Since the fault has to be cleared by the circuit breakers, the heavy earth fault currents may cause the burning or circuit breaker contacts.

(iii) The increased earth fault current results in greater interference in the neighbouring communication lines.

2. Resistance Grounding :-

* In order to limit the magnitude of earth fault current, it is a common practice to connect the neutral point of a 3-phase system to earth through a resistor. This is called resistance grounding.

* When the neutral point of a 3-phase system (e.g. 3-phase generator, 3-phase transformer etc.) is connected to earth (i.e. soil) through a ~~resistance~~ resistor, it is called resistance grounding.

* Fig. shows the grounding of neutral point through a resistor R.

* If the earthing resistance R is very high, the system conditions become similar

to ungrounded system, If the value of earthing resistance R is very low, the earth fault current will be large and the system becomes similar to the solid grounding system.

* The value of R should neither be very low nor very high.

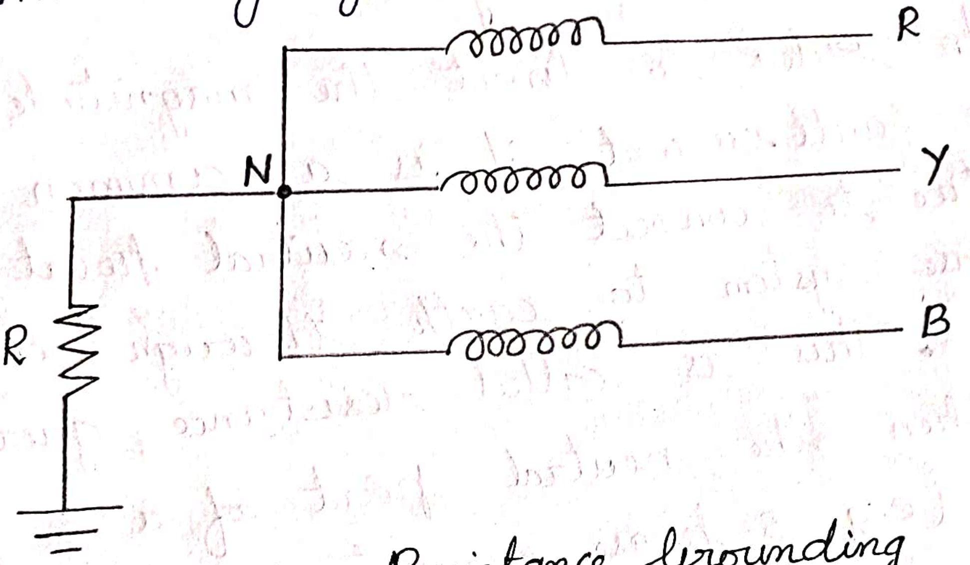


Fig. Resistance grounding

Advantages :-

* It improves the stability of the system.
* The earth fault current is small due to the presence of earthing resistance. Therefore, interference with communication circuits is reduced.
* By adjusting the value of R, the arcing grounds can be minimized.

Disadvantages :-

* A large amount of energy is produced in the earthing resistance during earth faults. Some-times it becomes difficult to dissipate this energy to atmosphere.
* This system is costlier than the solidly grounded system.
* Since the system neutral is displaced during earth faults, the equipment has to be insulated for higher voltages.

3. Reactance Grounding :-

* In this system, a reactance is inserted between the neutral and ground as shown in Fig...

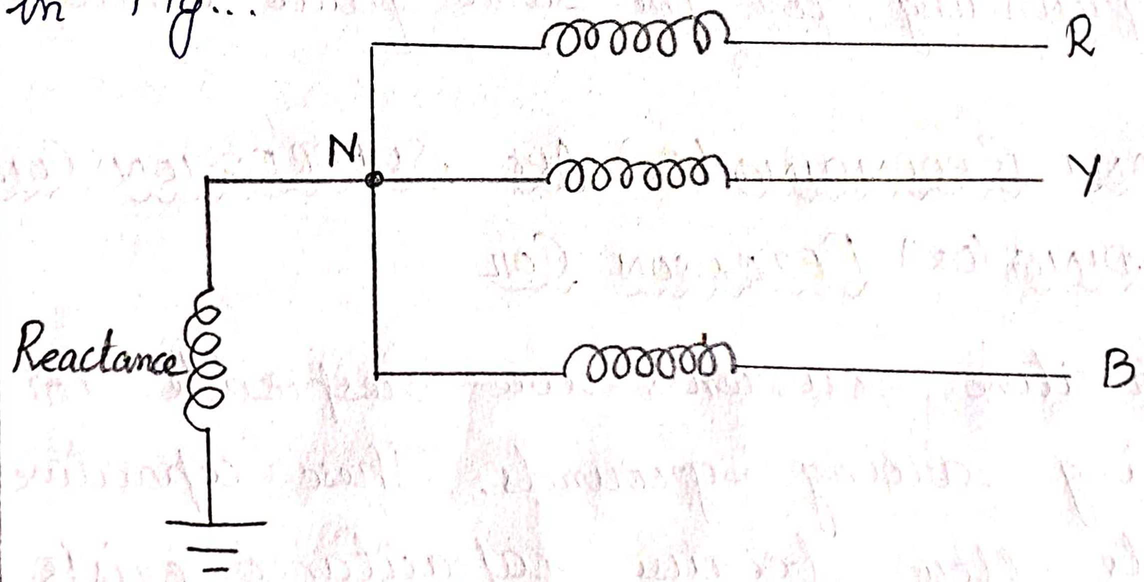


Fig. 1.7. Reactance Grounding

* The purpose of reactance is to limit the earth fault current. By changing the earthing reactance, the earth fault current can to changed to obtain the conditions similar to that of solid grounding.

* This method is not used these days because of the following disadvantages

Disadvantages :-

* High transient voltages appear under fault conditions.
* In this system, the fault current required to operate the protective device is higher than that of resistance grounding for the same fault conditions.

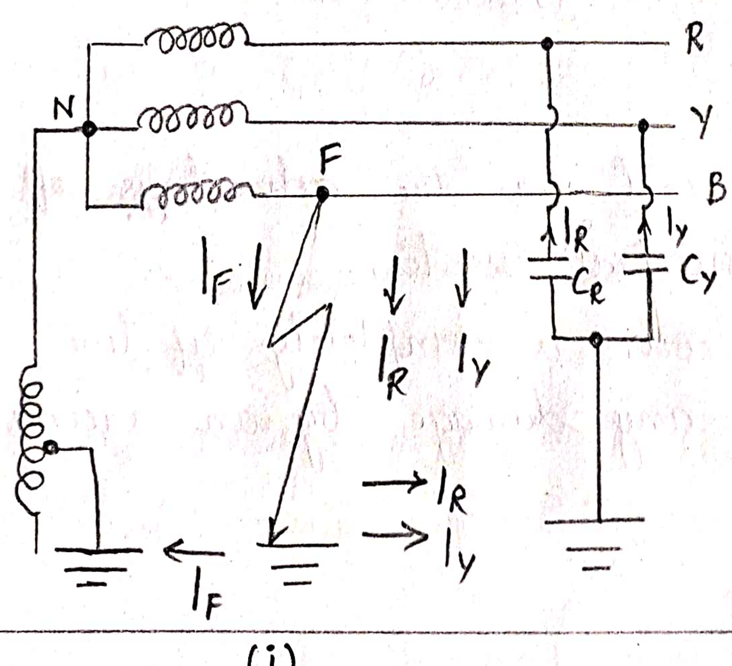
* RESONANT GROUNDING (OR) ARC SUPPRESSION COIL GROUNDING (OR) PETERSON COIL

* Capacitive currents are resposible for producing arcing grounds. These capacitive currents flow because capacitance exists between each line and earth.

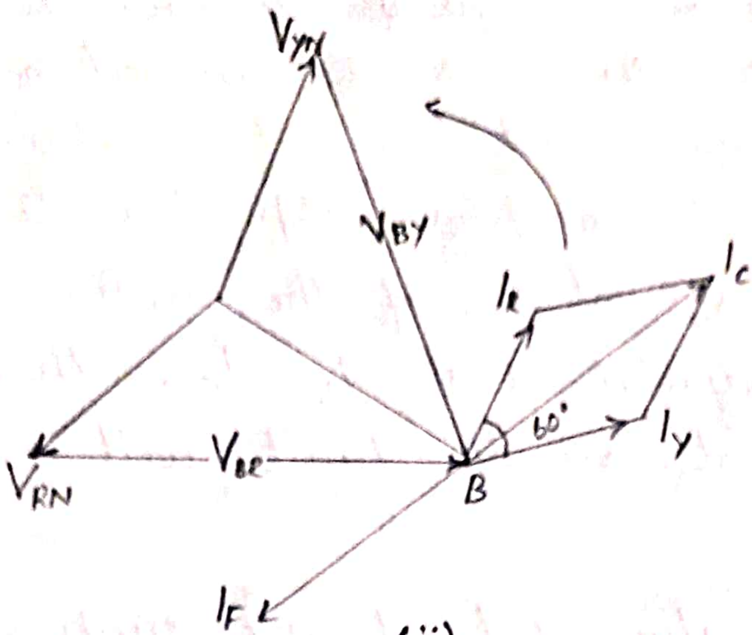
* If inductance L of appropriate value is connected in parallel with the capacitance of the system, the fault current I_F flowing through L will be in phase opposition to the capacitive current I_c of the system. If L is so adjusted that $I_L = I_C$, then resultant current in the fault will be zero.

* "When the value of L of arc suppression coil is such that the fault current I_F exactly balances the capacitive current I_c, it is called resonant grounding."

* The reactor is provided with tappings to change the inductance of the coil. By adjusting the tappings on the coil, resonant grounding can be achieved.



(i)



(ii)

Fig. 1.8. Arc Suppression Coil.

* An arc suppression coil (also called Peterson coil) is an iron-cored coil connected between the neutral and earth as shown in Fig. 1.8.

* The Peterson coil grounding has the following advantages:

Advantages:

* The Peterson coil has the advantags of ungrounded neutral system.
* The Peterson coil is completely effective in preventing any damage by an arcing ground.

* The lines should be transposed.
* Due to varying operational conditions, the capacitance of the network changes from time to time. Therefore, inductance L of Peterson coil requires readjustment.

* ESSENTIAL QUALITIES OF PROTECTIVE RELAYING:

A Protective Relaying scheme should have certain important qualities. Such an essential qualities of protective relaying are

1. Reliability
2. Selectivity and Discrimination
3. Speed and Time
4. Sensitivity
5. Stability
6. Adequateness.
7. Simplicity and Economy.

1. Reliability

* A Protective Relaying should be reliable is its basic quality. It indicates the reliability of the relay system to operate under the ~~Pe~~ Predetermined Conditions.

* The reliability of a protection system depends on the reliability of various components like circuit breakers, relays, current transformers (C.T.s), potential transformers (P.T.s), cables, trip circuit etc

* The proper maintenance also plays an important role in improving the reliable operation of The Relay.

2. Selectivity And Discrimination :

* The selectivity is the ability of the protective system to identify the faulty part correctly and disconnect that part without affecting the rest of the healthy part of system.

* The discrimination quality of the protective system is the ability to distinguish between normal condition and abnormal condition and also between abnormal condition within protective zone and elsewhere.

3. Speed And Time :

* A protective system must disconnect the faulty system as fast as possible. If the faulty system is not disconnect

for a long time then, 1. The devices carrying fault currents may get damaged. 2. The failure leads to the reduction in system voltage. 3. If fault persists for long time, then subsequently other faults may get generated.

* The total time required between the instant of fault and the instant of final arc interruption in the circuit breaker is called fault clearing time.

* It is the sum of relay time and circuit breaker time. The fault clearing time should be as small as possible.

4. Sensitivity :

* The sensitivity of the system is the ability of the relay system to operate with low value of actuating quantity.

* The relay sensitivity is the function of the volt-amperes input to the relay coil necessary to cause its operation.

* Smaller the value of volt-ampere input more sensitive is the relay. Thus 1 VA

input relay is more sensitive than the 5VA input relay.

5. Stability

* The stability is the quality of the protective system due to which the system remains inoperative and stable under certain specified conditions such as transients, disturbance, through faults etc.,

* In most of the cases time delays, filter circuits, mechanical and electrical bias are provided to achieve stable operation during the disturbances.

UNIT - II
ELECTROMAGNETIC RELAYS

* FROM THE UNIVERSAL TORQUE EQUATION - THE CONDITION OF OPERATION FOR IMPEDANCE RELAY, REACTANCE RELAY AND MHO RELAY

Universal Relay Torque Equation :-

* The torque produced by the current winding is proportional to the square of the current.
* The torque produced by voltage winding is proportional to the square of the voltage and the torque produced by both the winding is proportional to the product of voltage and current.

Mathematically we can write

Torque produced by the current coil $= K_1 I^2$

Torque produced by the Voltage coil $= K_2 V^2$

Torque produced by both the coil $= K_3 VI \cos(\theta - \phi)$

Where K_1, K_2 and K_3 = Constant θ = Angle between V & I

ϕ = Maximum torque angle

Torque produced by control spring $= K_4$

* If all the relays are present in the relay then total torque produced by all the causes can be expressed by a general equation as

$$T = K_1 I^2 + K_2 V^2 + K_3 VI \cos(\theta - \phi) + K_4$$

* In case of over current relay $K_2 = K_3 = 0$; and the spring torque is negative we get $T = K_1 I^2 - K_4$

* In case of directional relay $K_1 = K_2 = 0$ and the spring torque is negative $T = K_3 VI \cos(\theta - \phi) - K_4$

* VARIOUS TYPES OF ELECTROMAGNETIC RELAYS

Electromagnetic Attraction Type Relays :-

The electromagnetic attraction type relays operate on the principle of attraction of an armature by the magnetic force produced by undesirable current or movement of plunger in a solenoid. These can be actuated by a.c or d.c quantities. The various types of these relays are, 1. Attracted Armature Type Relay 2. Solenoid Type:

Attracted Armature Type Relay

* This relay operates on the current setting. When current in the circuit exceeds beyond the limit, the armature gets attracted by the magnetic force produced by the undesirable current.

* The current rating of the circuit in which relay is connected plays an important role in the operation of the relay. There are two types of structures available for attracted armature type relay which are

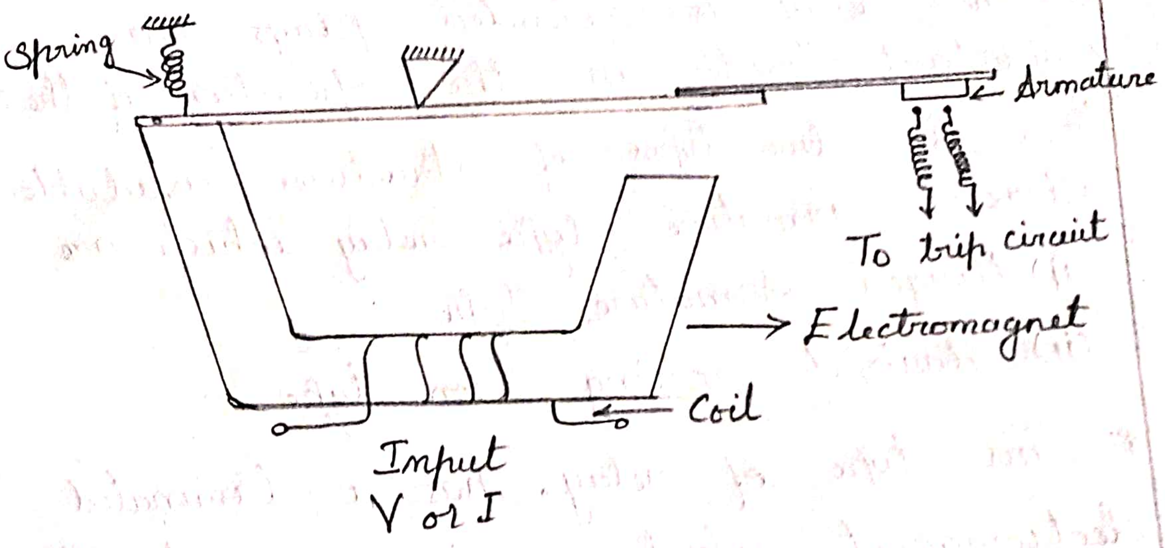
(i) Hinged Armature Type

(ii) Polarized moving iron type

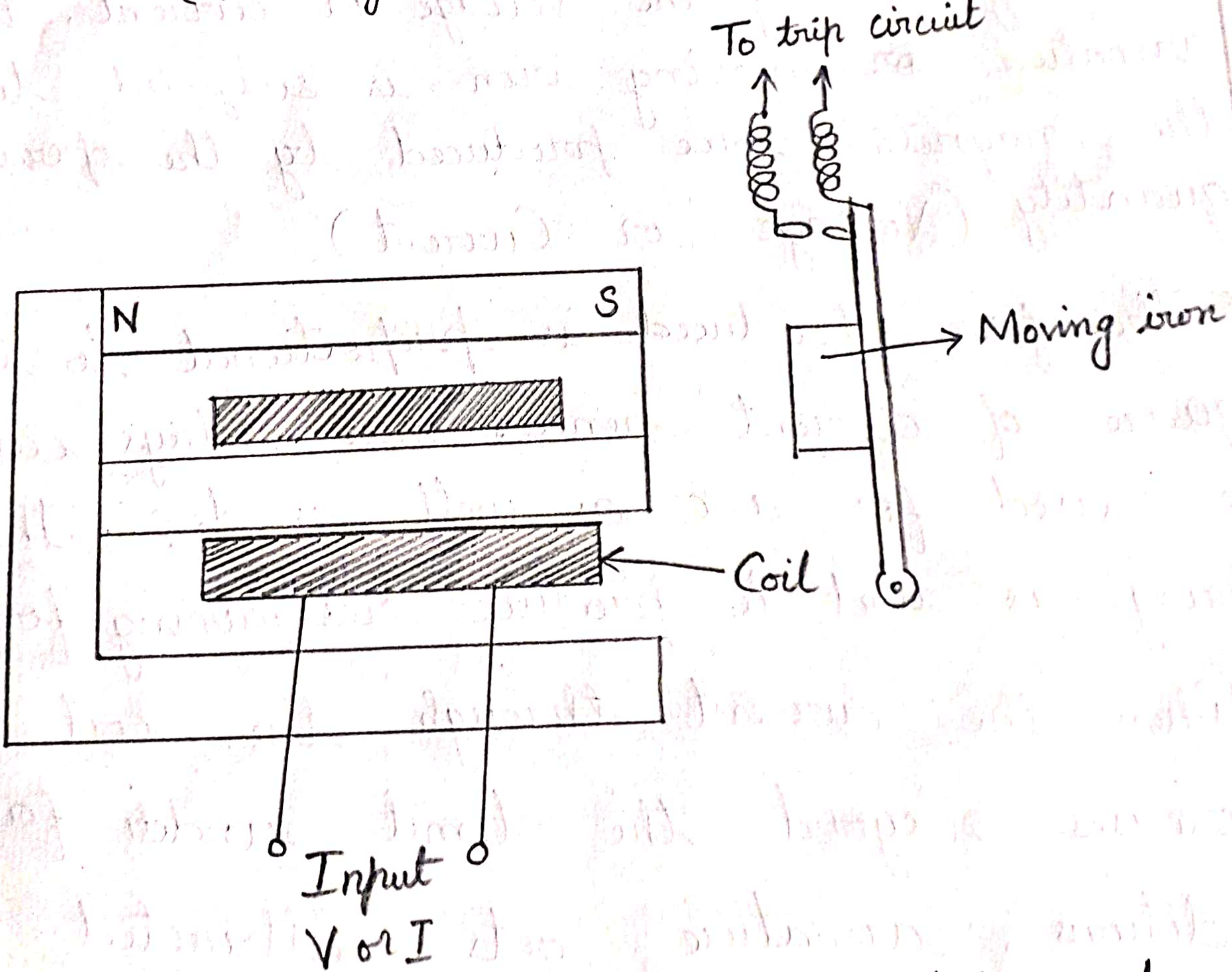
* This type of relay, has a laminated electromagnet which carries a coil. The coil is energized by the voltage or current. The armature or moving iron is subjected to the magnetic force produced by the operating quantity (Voltage or Current).

* The force produced is proportional to the square of current hence, these relays can be used for a.c as well as d.c. The spring is used to produce restraining force.

* When the current through the coil increases beyond the limit under fault conditions, armature gets attracted.



(a) Hinged Armature Type Relay



(b) Polarised moving iron type relay

Due to this it makes contact with contacts of a trip circuit which results in an opening of a circuit breaker.

* The current time characteristics of such relay is hyperbolic as shown in fig.

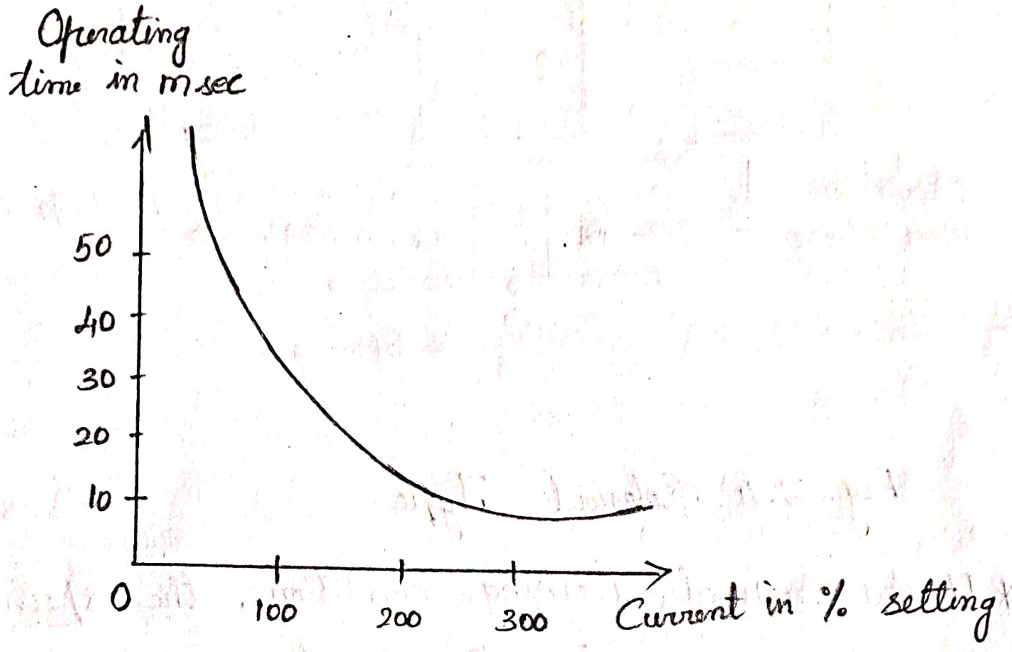


Fig. Time - Current Characteristic

Solenoid Type:

* In this relay, the plunger or iron core moves into a solenoid and the operation of the relays depends on the movement of the plunger.
* It consists of solenoid which is nothing but an electromagnet. It also consists of movable iron plunger.

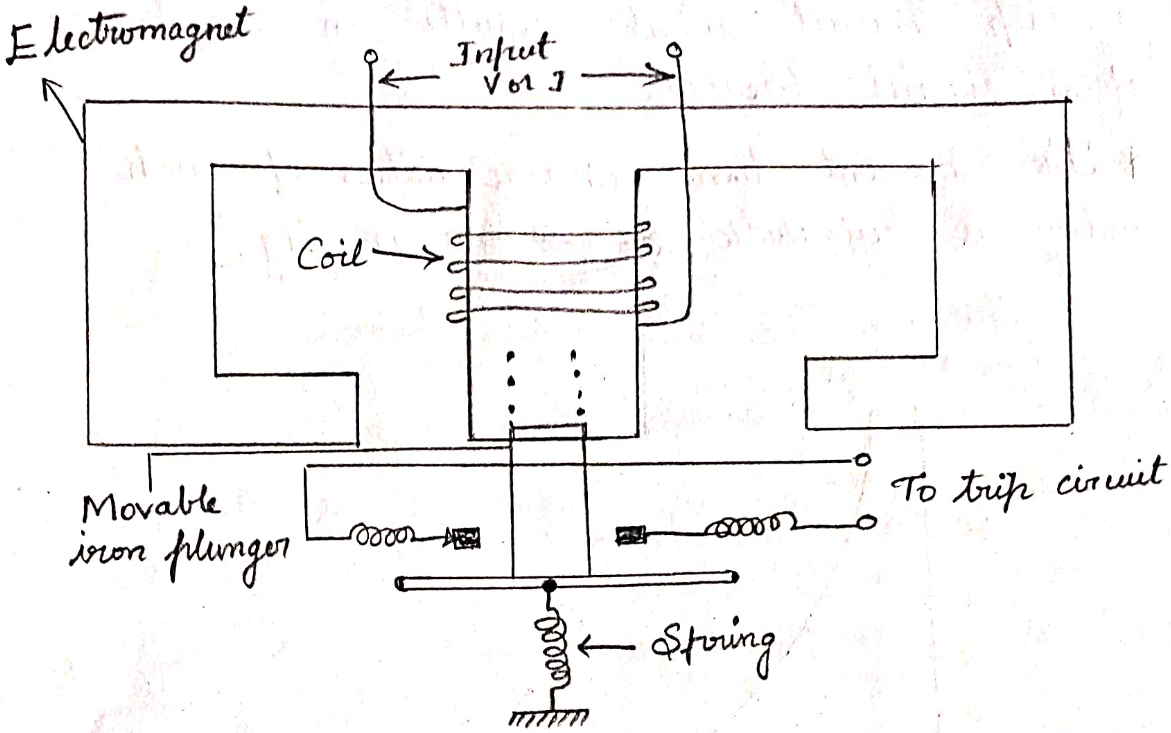


Fig. 2.4. Solenoid Type

* Under normal working condition, the spring holds the plunger in the position, such that it cannot make contact with trip circuit contacts.
* Under fault conditions when current through relay coil increases the solenoid draws the plunger upwards.
* Due to this, it makes contact with the trip circuit contacts which results in an opening of a circuit breaker.

Advantages :-

* Can be used for both a.c and d.c
* They have fast operation and fast reset.

* High Operating Speed with operating time.
* Modern relays are compact, simple, reliable and robust.

Disadvantages :-

a) The directional feature is absent.

b) The working can be affected by the transients.

c) Due to moving parts, frequent maintenance is required.

d) Due to mechanical moving parts, the life is less.

Applications :-

① The protection of various a.c and d.c equipment.

② The over/under current and over/under voltage protection of various a.c and d.c equipment.

③ For the differential protection.

④ Used as auxiliary relays in the contact system of protective relaying schemes.

* THE CONSTRUCTION AND PRINCIPLE OF OPERATION OF NON DIRECTIONAL OVER CURRENT RELAY

Non directional induction type over current relay:-

This relay is also called earth leakage induction type relay. The over current relay operates when the current in the circuit exceeds a certain present value.

Construction:-

* The induction type non directional over current relay has a construction similar to a watt hour meter, with slight modification.
* The figure 2.10 below shows the constructional of non directional induction type over current relay.
* It consists two electromagnets. The upper is E shaped while the lower is U-shaped
* The aluminium disc is free to rotate between the two magnets. The spindle of the disc carries moving contacts and when the disc rotates the moving ~~circuits~~ contacts come in contact with fixed contacts which are the terminals of a trip circuit.

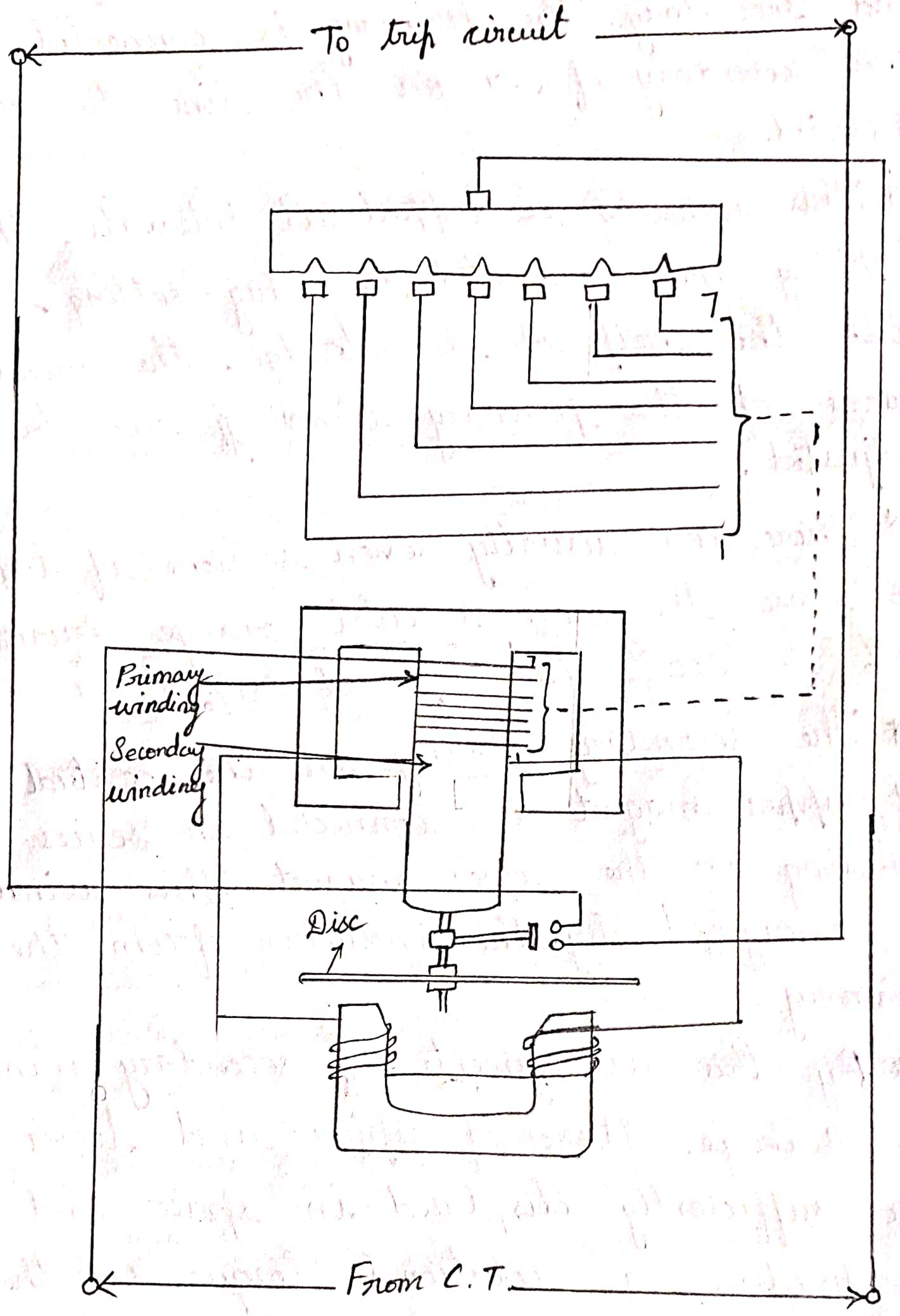


Fig. Non-Directional Over Current Relay.

* The upper magnet has two winding, primary and secondary. The primary is connected to the secondary of C.T on the line to be protected.

* This winding is tapped at intervals. The tapping are connected to plug setting bridge. With the help of this bridge, the number of turns of the primary winding can be adjusted.

* There are usually seven sections of tappings to have the over current range from 50% to 200% in steps of 25%.T

* The secondary winding on the central limb of upper magnet is connected in series with winding on the lower magnet. This winding is energized by the induction from the primary.

* By this arrangements of secondary winding, the leakage fluxes of upper and lower magnets are sufficiently displaced in space and time to produce a rotational torque on the aluminium disc.

* The control torque is provided by the spiral spring. When current exceeds its preset value, the disc rotates and moving contacts on

spindle make the connection with trip circuit terminals.

* The angle through which the disc rotates is between 0° to 360°. The travel of the moving contacts can be adjusted the angle of rotation of the disc.

Working :-

* The torque is produced due to induction principle. This Torque is opposed by restraining force produced by spiral springs.
* Under normal conditions, the restraining force is more than driving force hence disc remains stationary.
* Under fault conditions when the current becomes high, the disc rotates through the preset angle and makes contact with the fixed contacts of the trip circuit.
* The trip circuit opens the circuit breaker, isolating the faulty part from rest of the healthy system.

RELEVANT CONNECTION DIAGRAM AND PHASOR DIAGRAM THE DIRECTIONAL OVER CURRENT RELAY

Directional Over Current Relay :-

* The directional power relay is unsuitable for use as a directional protective relay under short-circuit conditions.

* When a short-circuit occurs, the system voltage falls to a low value and there may be insufficient torque developed in the relay to cause its operation.

* This difficulty is overcome in the Induction Type Directional Over current Relay.

* Fig 2.13 shows the constructional details of a typical Induction Type Directional Over Current Relay.

* It consists of two relay elements mounted on a common case 1. Directional Element and Non-directional element.

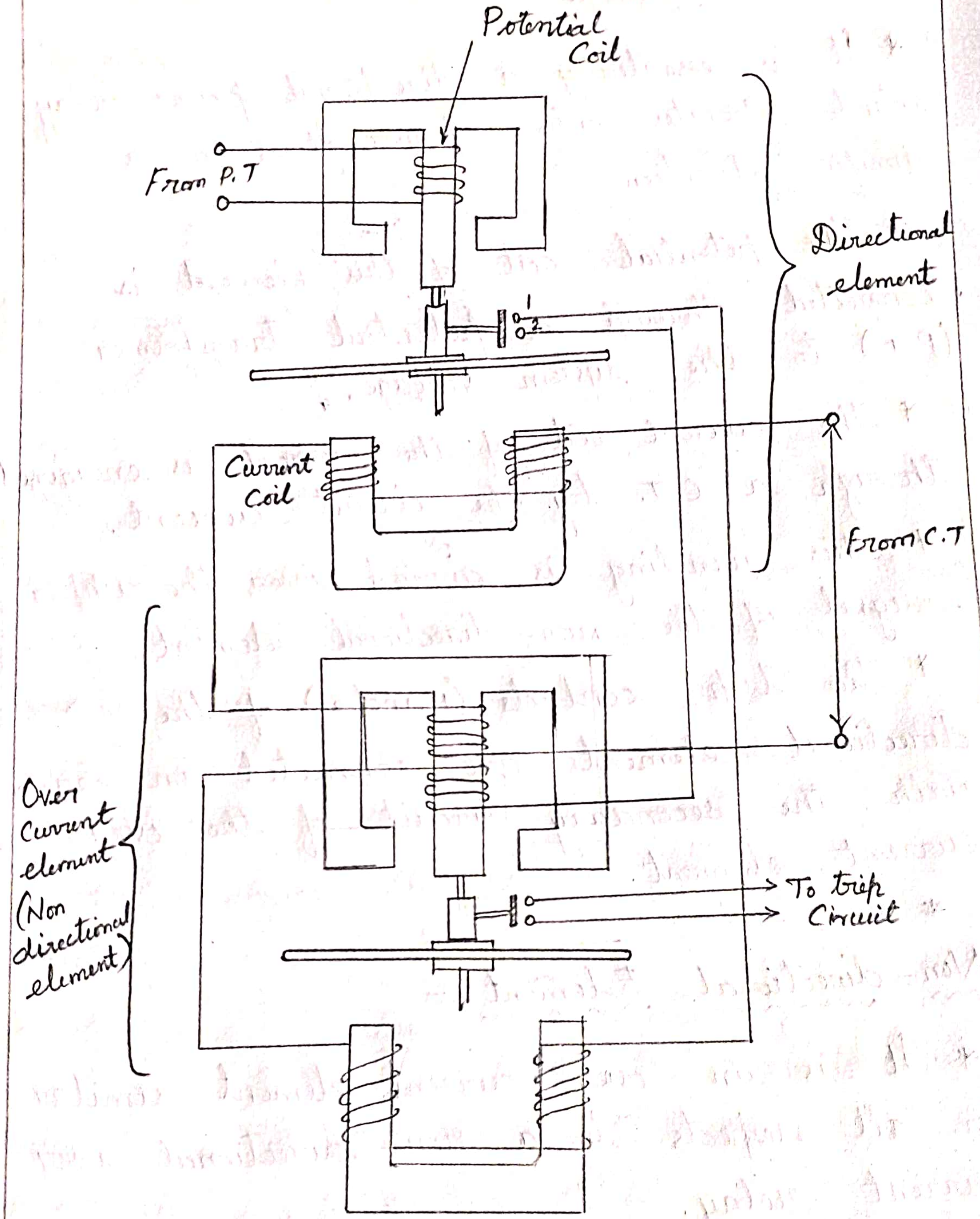


Fig. 2.13. Directional Over Current Relay

Directional Element :

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

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

* The current coil of the element is energized through a C.T. by the circuit current.

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

* The trip contacts (1 and 2) of the directional element are connected in series with the secondary circuit of the over current element.

*

Non-directional Element :-

* It is an over current 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 contacts (trip circuit contacts) after

the operation of directional element.

Operation :-

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

* Therefore, Induction Type Directional Over current Relay (upper element) does not operate, thereby keeping the over current element (lower element) unenergized.

* However, when a short-circuit occurs, there is a tendency for the current or power to flow in the reverse direction. Should this happen, the disc of the upper element rotates to bridge the fixed contacts 1 and 2.

* This completes the circuit for over current 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.

* The torque equation is given by $T = KVI \sin(\theta + \phi$ maximum torque occurs when angle is 90 degre

* Impedence Relay With Suitable R-X diagram

Distance Or Impedance Relay :-

* There is another group of relays in which the operation is governed by the ratio of applied voltage to current in the protected circuit. Such relays are called distance or impedance relays.

* In an impedance relay, the torque produced by a current element is opposed by the torque produced by a voltage element. The relay will operate when the ratio V/I is less than a predetermined value.

Classification

* The distance relays are classified as (i) Definite - distance relay (ii) Time - distance relay.

Definite - Distance Type Impedance Relay

Construction:

* Fig. shows the schematic arrangement of a definite - distance type impedance relay.

* It consists of a pivoted beam F and

two electromagnets. It energized respectively by a current and voltage transformer in the protected circuit.

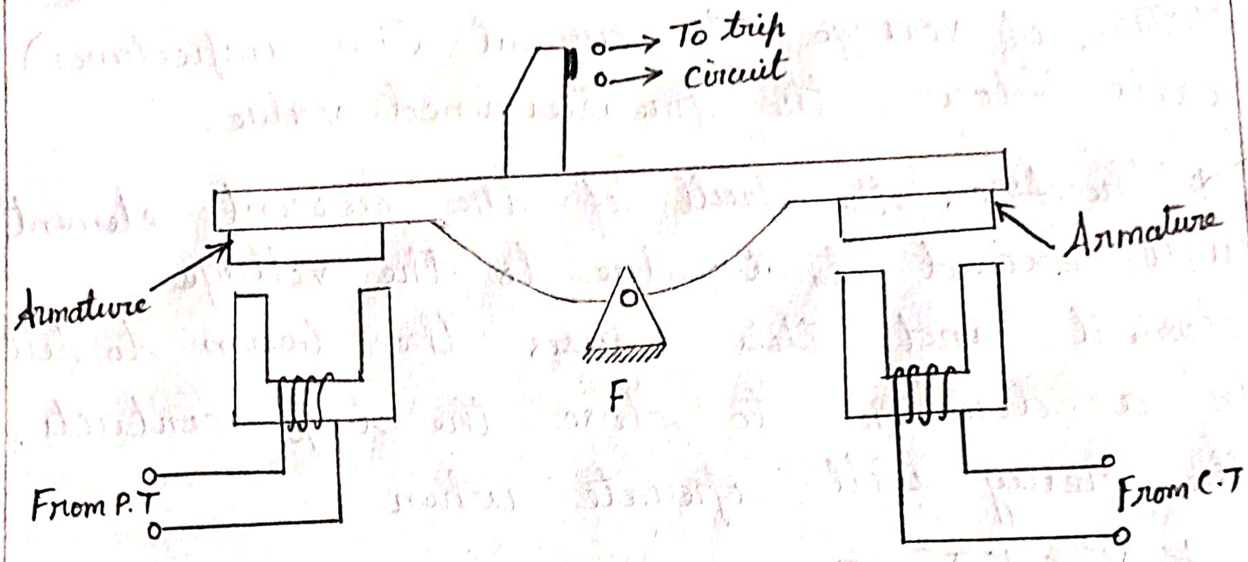


Fig. 2.15. Definite - Distance Type Impedance Relay.

* The armatures of the two electromagnets are mechanically coupled to the beam. The beam is provided with a bridging piece for the trip contacts.
* The relay is so designed that the torques produced by the two electromagnets are in the opposite direction.

Operation :-

* Under normal operating conditions, the pull due to the voltage element is greater than that of the current element. Therefore, the

relay contacts remain open.

* When a fault occurs in the protected zone, the applied voltage to the relay decreases whereas the current increases. The ratio of voltage to current (i.e. impedance) falls below the predetermined value.

* Therefore, the pull of the current element will exceed that due to the voltage element and this causes the beam to tilt in a direction to close the trip contacts. The relay will operate when

$K_1 V^2 < K_2 I^2$ or

$$\frac{V^2}{I^2} < \frac{K_2}{K_1} \; ; \; Z^2 < \frac{K_2}{K_1} \; ; \; Z < \sqrt{\frac{K_2}{K_1}}$$

Time - Distance Impedance Relay :-

* A time - distance impedance relay is one which automatically adjusts its operating time according to the distance of the relay from the fault point i.e. Operating time,

$$T \propto \frac{V}{I} \propto Z \propto \text{distance}$$

Construction :-

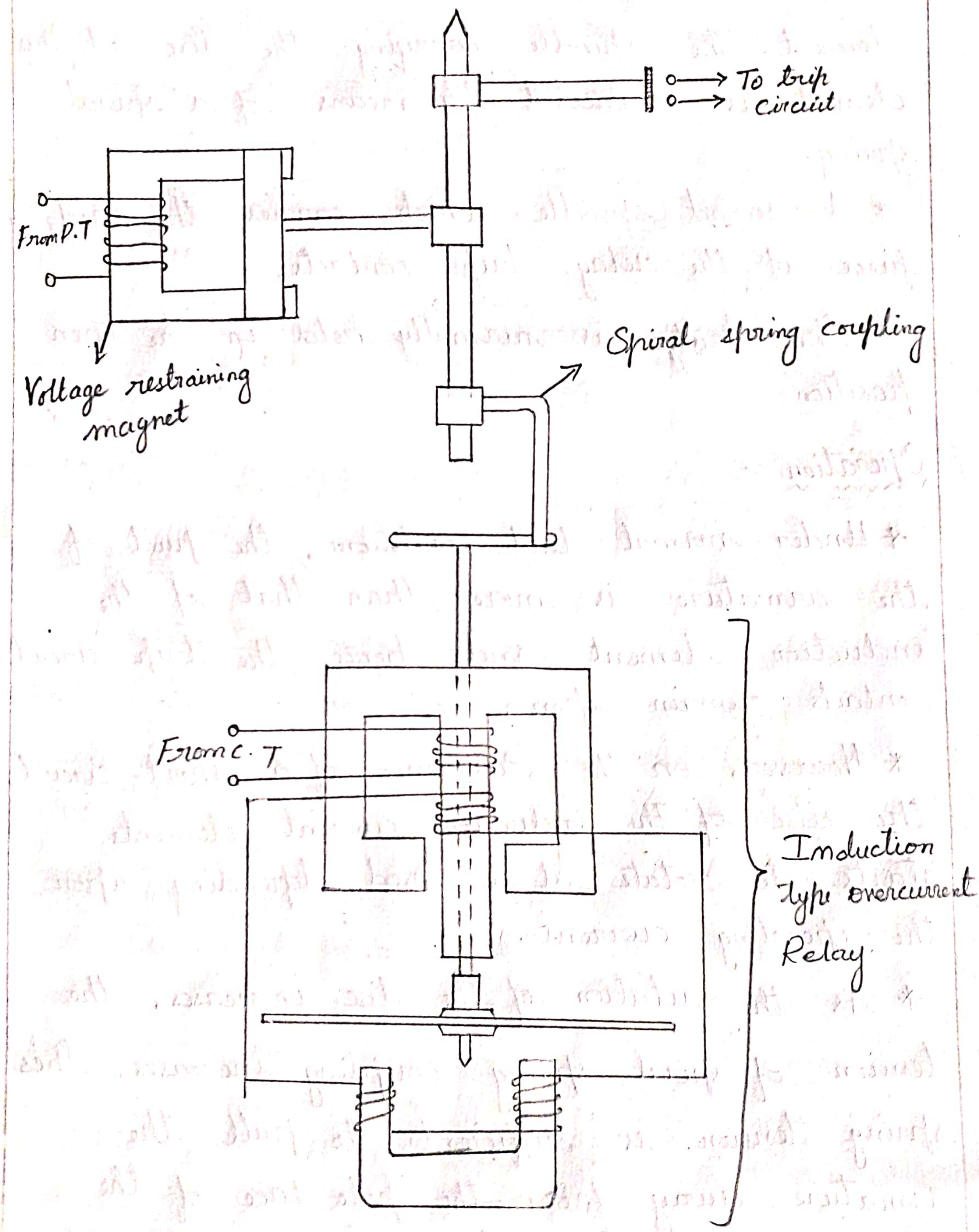


Fig. 2.16. Time - Distance Type Impedance Relay

* Fig. 2.16. shows the schematic arrangement of a typical induction type time distance impedance relay.

* It consists of a current driven induction element. The spindle carrying the disc of this element is connected by means of a spiral spring.

* A second spindle which carries the bridging piece of the relay trip contacts.

* The bridge is normally held in the open position.

Operation :-

* Under normal load conditions, the pull of the armature is more than that of the induction element and hence the trip circuit contacts remain open.

* However, on the occurrence of a short-circuit, the disc of the induction current elements starts to rotate at a speed depending upon the operating current.

* As the rotation of the disc increases, the tension of spiral spring coupling increases. This spring tension is sufficient to pull the armature away from the pole face of the voltage-excited magnet.

* Due to this trip contacts are closed. This opens the circuit breaker to isolate the faulty section.

* The speed of rotation of the disc is proportional to the operating current.

* The time of operation of the relay is directly proportional to the line voltage V at the point where the relay is connected.

* Therefore, the time of operation of relay would vary as V/I i.e. as Z or distance.

* CURRENT BALANCE DIFFERENTIAL RELAY

Differential Relay:

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

Theory :-

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

* Under normal operating conditions, the two currents are equal but as soon as a fau

occurs, the two currents become unequal.

* The difference between the incoming and outgoing currents is arranged to flow through the operating coil of the relay.

* If this differential current is equal to or greater than the pickup value, the relay will operate and open the circuit breaker to isolate the faulty section.

There are two fundamental systems of differential or balanced protection viz.

(i) Current Balance Protection
(ii) Voltage Balance Protection

Current Differential Relay:

* Fig 2.21 shows an arrangement of an over current relay connected to operate as a differential relay. A pair of identical current transformers are fitted on either end of the section to be protected (alternator winding in this case).

* The secondaries of CT's are connected in series. The operating coil of the over current relay is connected across the CT secondary circuit.

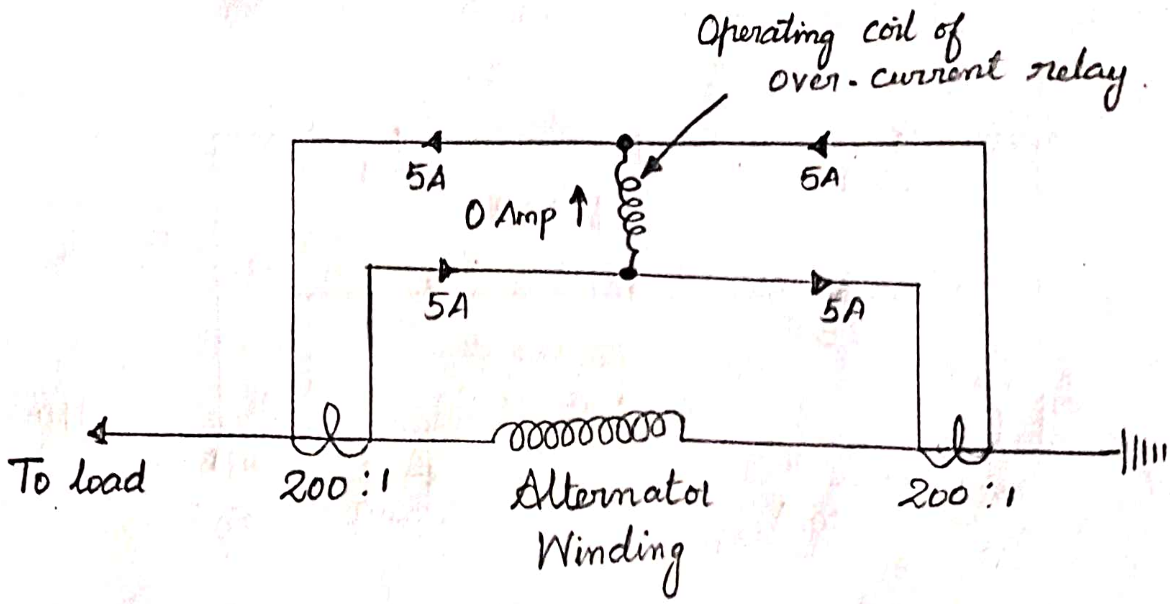


Fig 2.21 : Current Differential Relay

* The secondaries of CT's are connected in series. The operating coil of the over current relay is connected across the CT secondary circuit.

* This differential relay compares the current at the two ends of the alternator winding. Under normal operating conditions, suppose the alternator winding carries a normal current of 1000 A. Then the currents in the two secondaries of CT's are equal.

* These currents will merely circulate between the two CT's and no current will flow through the differential relay. Therefore, the relay remains inoperative.

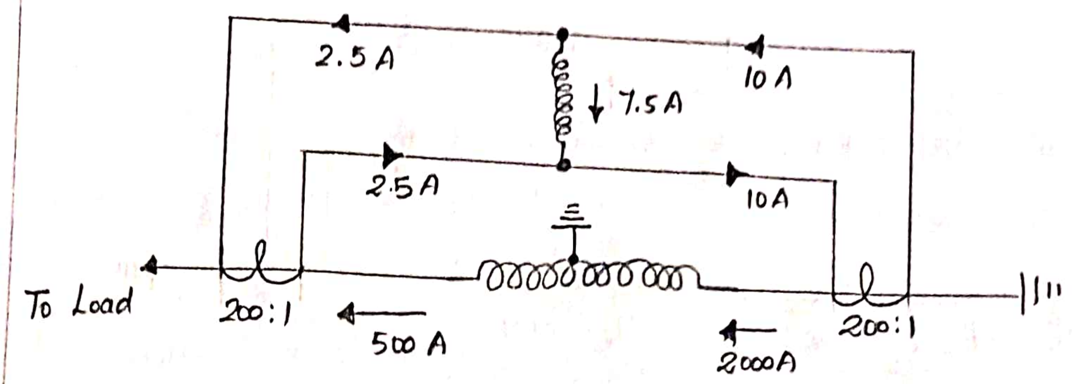


Fig 2.22. Current Differential Relay Explanation

* If a ground fault occurs on the alternator winding as shown @ in Fig. 2.22. (1) the two secondary currents will not be equal and the current flows through the operating coil of the relay, causing the relay to operate.

* The amount of current flow through the relay will depend upon the way the fault is being fed.

Disadvantages:

ⓐ The impedance of the pilot cables generally causes a slight difference between the currents at the two ends of the section to be protected.

ⓑ If the relay is very sensitive, then the small differential current flowing through the relay may cause it to operate even under no fault conditions.

ⓒ Pilot cable capacitance causes incorrect operation of the relay when a large through-current flows.

ⓓ Accurate matching of current transformers cannot be achieved due to pilot circuit impedance.

The above disadvantages are overcome to a great extent in biased beam relay.

Biased Beam Relay (or) Percentage Differential Relay

* The biased beam relay (also called percentage differential relay) is designed to respond to the differential current in terms of its fractional relation to the current flowing through the protected section.

* Fig 2.23. shows the schematic arrangement of a biased beam relay. It is essentially an over current balanced beam relay type with an additional restraining coil.

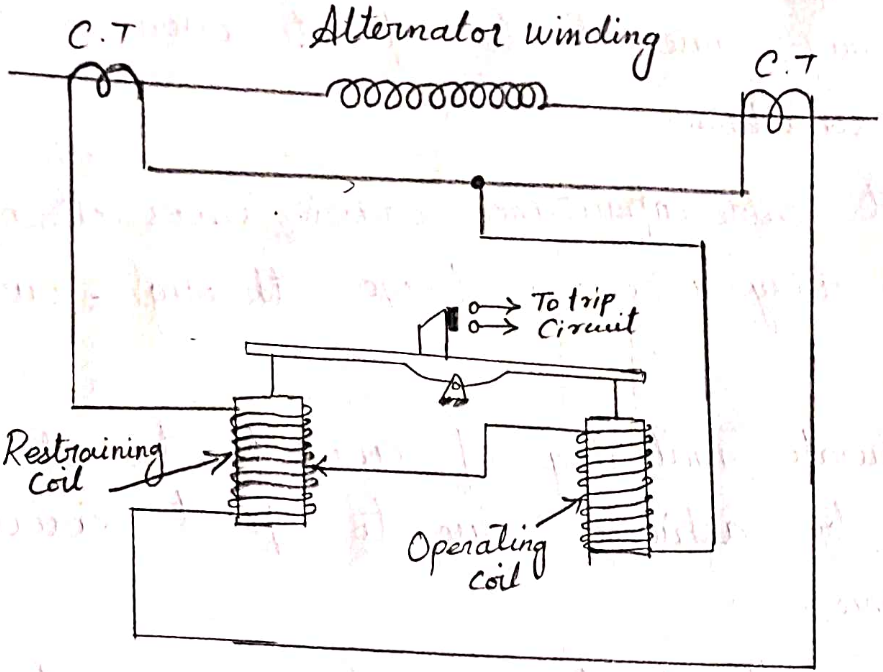


Fig: 2.23 Biased Beam Relay

* The restraining coil produces a bias force in the opposite direction to the operating force. Under normal and through load conditions, the bias force due to restraining coil is greater than the operating force.

* Therefore, the relay remains inoperative. When an internal fault occurs, the operating force exceeds the bias force. Consequently, the trip contacts are closed to open the circuit breaker.

* The bias force can be adjusted by varying the number of turns on the restraining coil.

* The equivalent circuit of a biased beam relay is shown in Fig. 2.24

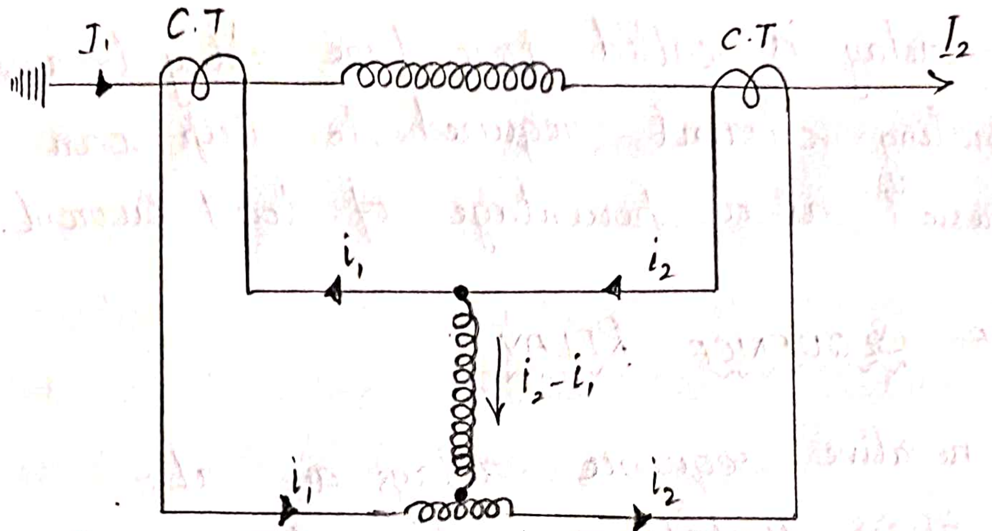


Fig. 2.24. Equivalent Circuit of Biased Beam Relay

* The differential current in the operating coil is proportional to $i2 - i1$ and the equivalent current in the restraining coil is proportional to $(i1 + i2)/2$ since the operating coil is connected to the mid-point of the restraining coil.

* It is clear that greater the current flowing through the restraining coil, the higher the value of current required in the

operating winding to trip the relay.

* Thus under a heavy load, a greater differential current through the relay operating coil is required for operation than under light load conditions.

* This relay is called percentage relay because the operating current required to trip can be expressed as a percentage of load current.

* NEGATIVE SEQUENCE RELAY :

* The negative sequence relays are also called phase unbalance relays because these relays are provide protection against negative sequence component of unbalanced currents existing due to unbalanced loads or phase to phase faults.

* Negative sequence relays are generally used to give protection to generators and motors against unbalanced currents.

Construction :-

* Fig 2.27 shows the scheme used for negative phase sequence relay. A network consisting

of four impedance Z_1, Z_2, Z_3 and Z_4 of equal magnitude connected in a bridge formation is energized from three CTs.

* A single pole relay having an inverse-time characteristic is connected across the circuit.

* Z_1 and Z_3 are non-inductive resistors while Z_2 and Z_4 are composed of both resistance and inductance. The value of Z_2 and Z_4 are so adjusted that currents flowing through them lag behinds those in impedance's Z_3 and Z_1 by 60°.

* The relay is assumed to have negligible impedance. The current from phase R at junction A is equally divided into two branches as I_1 and I_4 but I_4 will lag behind I_1 by 60°.

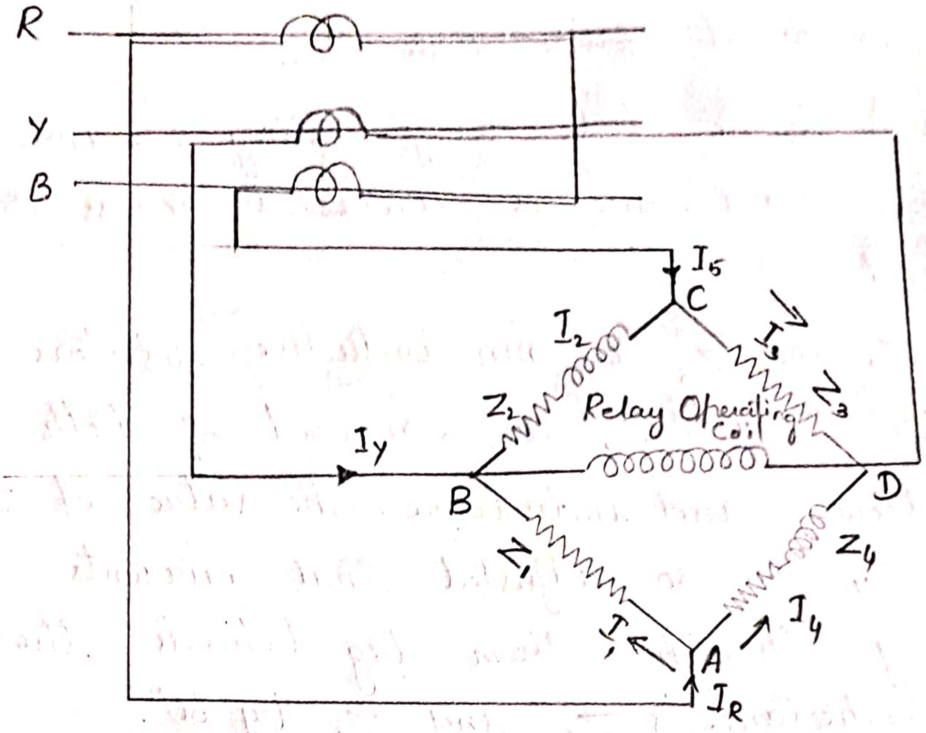


Fig. 2.27. Negativesequence Relay.

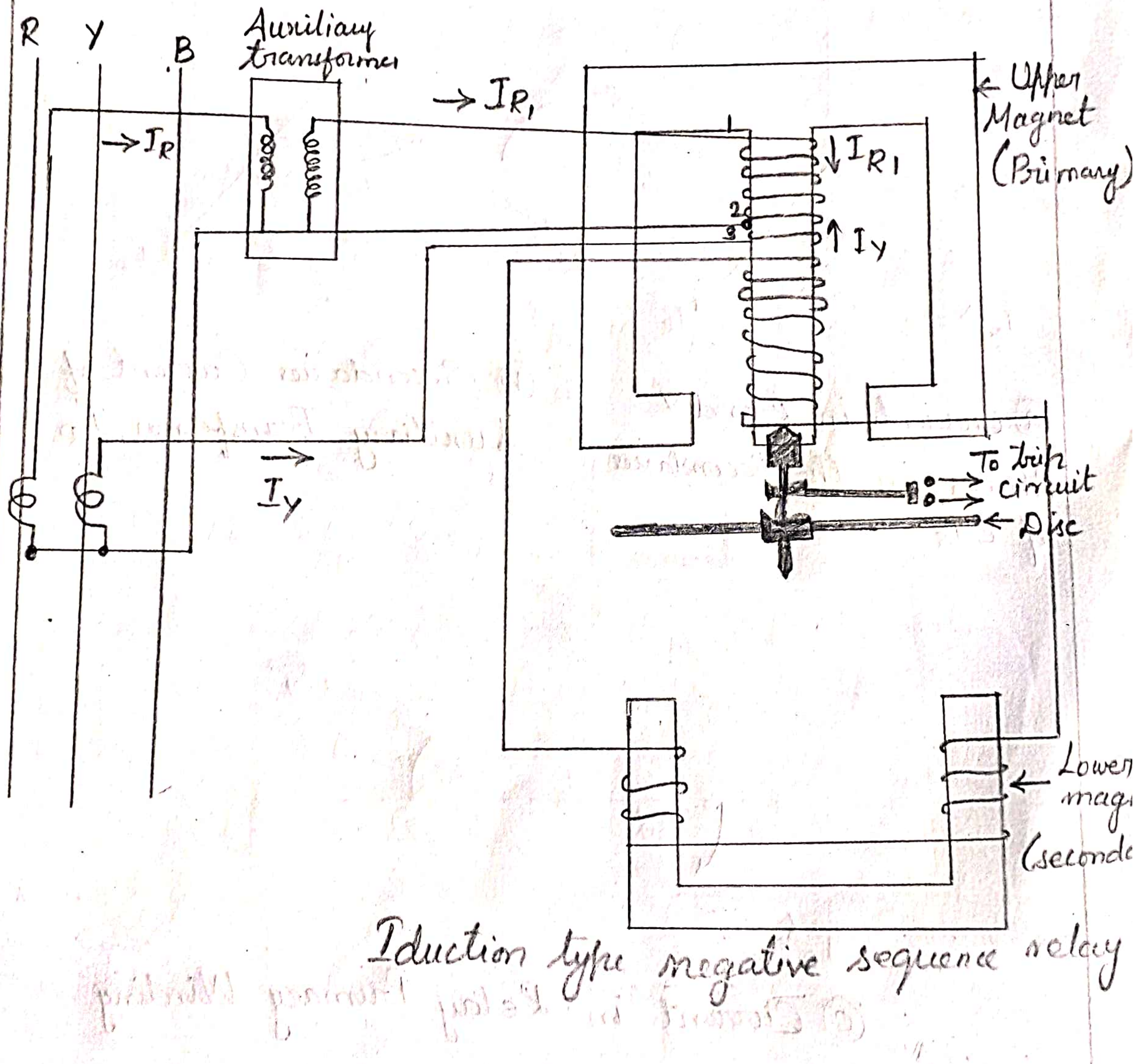
Types Of Negative Phase Sequence Relay:

1. Induction Type Negative Phase Sequence Relay:

* This type of relay has similar construction as that of an induction type over current relay. The difference lies only in the primary winding provided with a central tap resulting into three terminals 1, 2 and 3 of this winding
* The upper half is energized from phase R through CT and an auxiliary transformer

while lower half is energized from phase Y through CT.

* The auxiliary transformer has special construction (provided with an air gap in its magnetic circuit) in order that the output current of this transformer lags by 120° instead of usual 180° from the input, as illustrated in Fig 2.28(a).

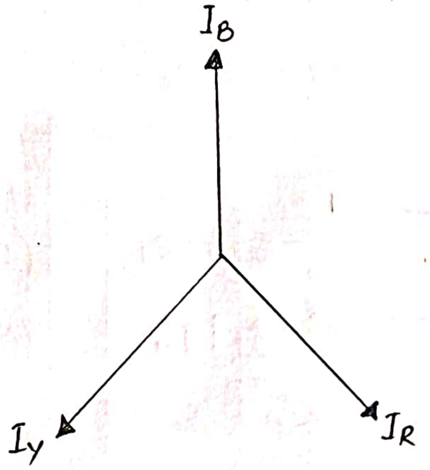


Induction type negative sequence relay

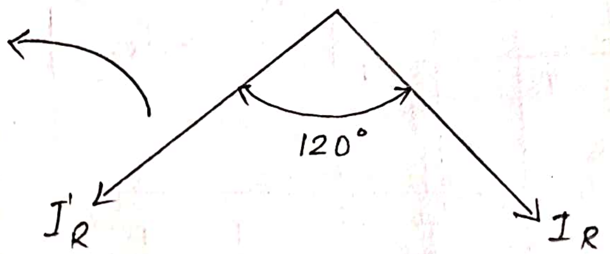
Operation for Positive Sequence Currents:

* From Fig 2.29 it is obvious that the currents I_R and I_Y flowing through the primary winding of the relay are in opposition, the auxiliary transformer is so arranged that I'_R and I_Y are of equal magnitude. Thus the relay remains inoperative for a balanced system.

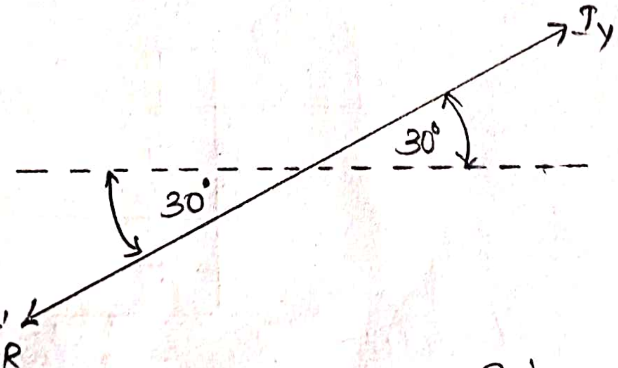
Fig. 2.29 Sequence Currents



(a) Currents in R and Y Phases in the Secondaries of CTs



(b) Secondaries Current of Auxiliary Transformer, I'_R



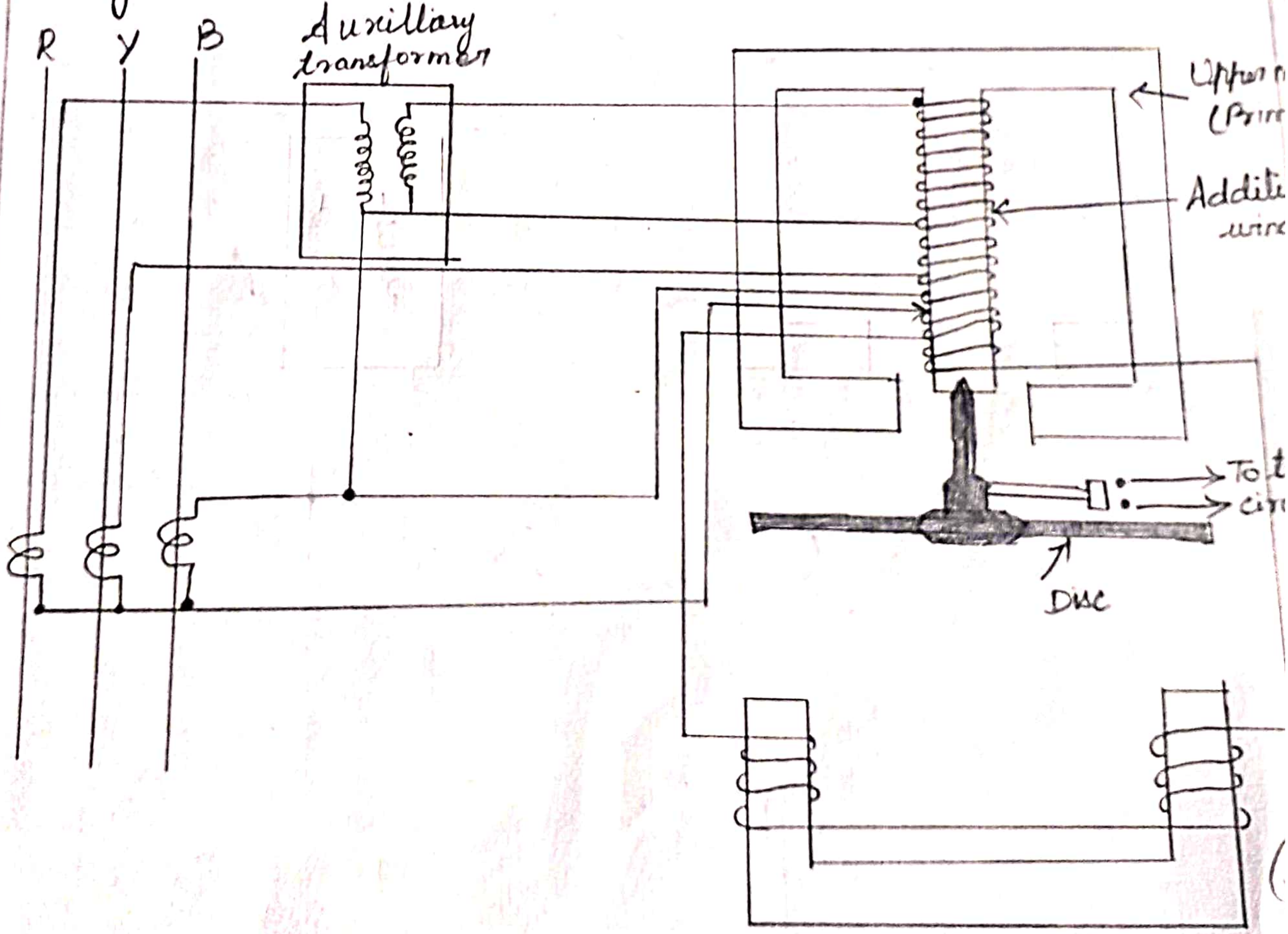
(c) Current in Relay Primary Winding

Operation For Negative Sequence Current:

* When there is a fault on the system resulting into a negative phase sequence current there is a flow of current I through the primary winding of the relay, as illustrated in Fig. (c)

* When the current flowing through the relay primary exceeds the relay setting, the relay operates and trips the circuit.

2. Induction Type Negative And Zero Sequence Current Relay :-



* This type of relay is similar to that of negative phase sequence relay discussed above. The relay is made to respond to the flow of zero sequence currents also by providing another winding on the central limb of the upper electromagnet, connected in the residual circuit of three lines CTs, as illustrated in Fig 2.30.

UNIT III
APPARATUS PROTECTION

* CT AND PT AND ITS APPLICATION TO POWER SYSTEM

* In heavy currents and high voltage circuits, the measurements can not be done with the help of low range meters.

* In such case the specially designed transformer which is called as Instrument Transformers are used to measure the high voltage and high currents.

* These transformers are not only extend the range of the low range instruments, but also isolate them from high current and high voltage a.c. circuits.

* They are generally clasified as (i) Current Transformer (ii) Potential Transformer.

Current Transformer :-

* The large alternating current which cannot be sensed or passed through normal ammeters and current coils of wattmetors, energy meters can easily be measured by use of current transformer along with normal low range instruements.

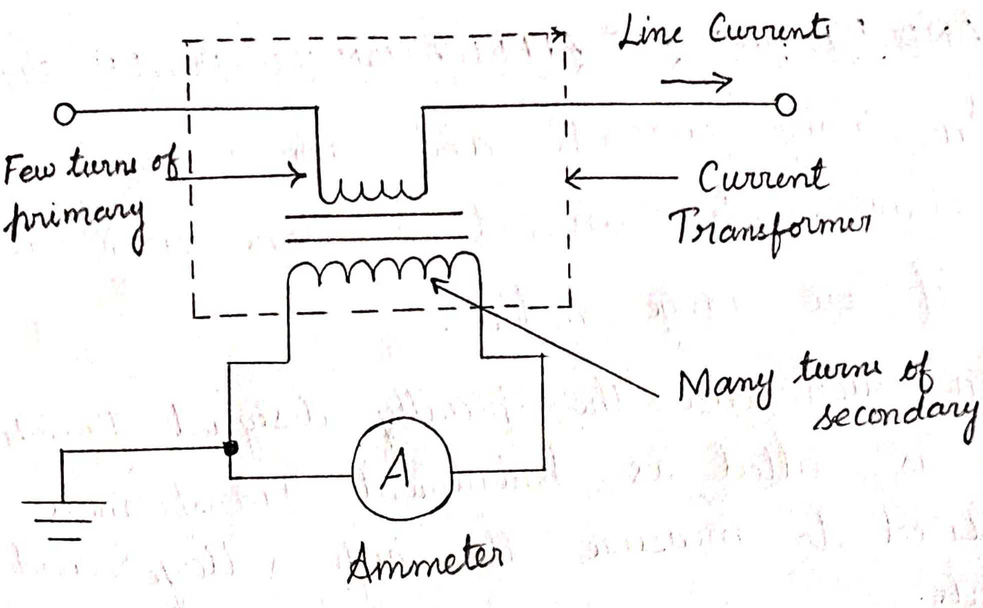


Fig. 3.1 Current Transformer.

* The large alternating current which cannot be sensed or passed through normal ammeters and current coils of wattmeters, energy meters can easily be measured by use of current transformer along with normal low range instruments.

* A transformer is a device which consists of two windings called primary and secondary.

* A current transformer basically has a primary coil of one or more turns of heavy cross sectional area.

* This is connected in series with the line carrying high current.

* The secondary of transformer is made up of a large number of turns of fine wire having small cross sectional area. It is usually rated for 5A. This is connected to the coil of normal range ammeter.

Working Principle :-

* These Transformers are basically step up transformer, i.e., stepping up a voltage from primer to secondary. Thus the current reduces from primary to secondary.

Let N_1 = Numbers of turns of Primary
N_2 = Numbers of turns of secondary
I_1 = Primary Current
I_2 = Secondary Current

*For a Transformer $\frac{I_1}{I_2} = \frac{N_2}{N_1}$. As N_2 is very high compared to N_1. the ratio I_1 to I_2 is also very high for current transformers. Such a current ratio is indicated for representing the range of current transformer.

Potential Transformer :

* The basic principle of these transformers is same as current transformers. The high alternating voltage are reduced in a fixed proportion for

the measurements purpose with the help of potentnial transformers.

* The construction of these transformers is similar to the normal transformers.

* These are step down transformers. The windings are low power rating winding.

* Primary windings consists of large no. of turns while secondary has less no. of turns and usually rated for 110V.

* The primary is connected to the high voltage line while secondary is connected to the low range voltameter coil.

* The connections are shown in fig. As a normal transformer the ratio can be specified as $\frac{V_1}{V_2} = \frac{N_1}{N_2}$

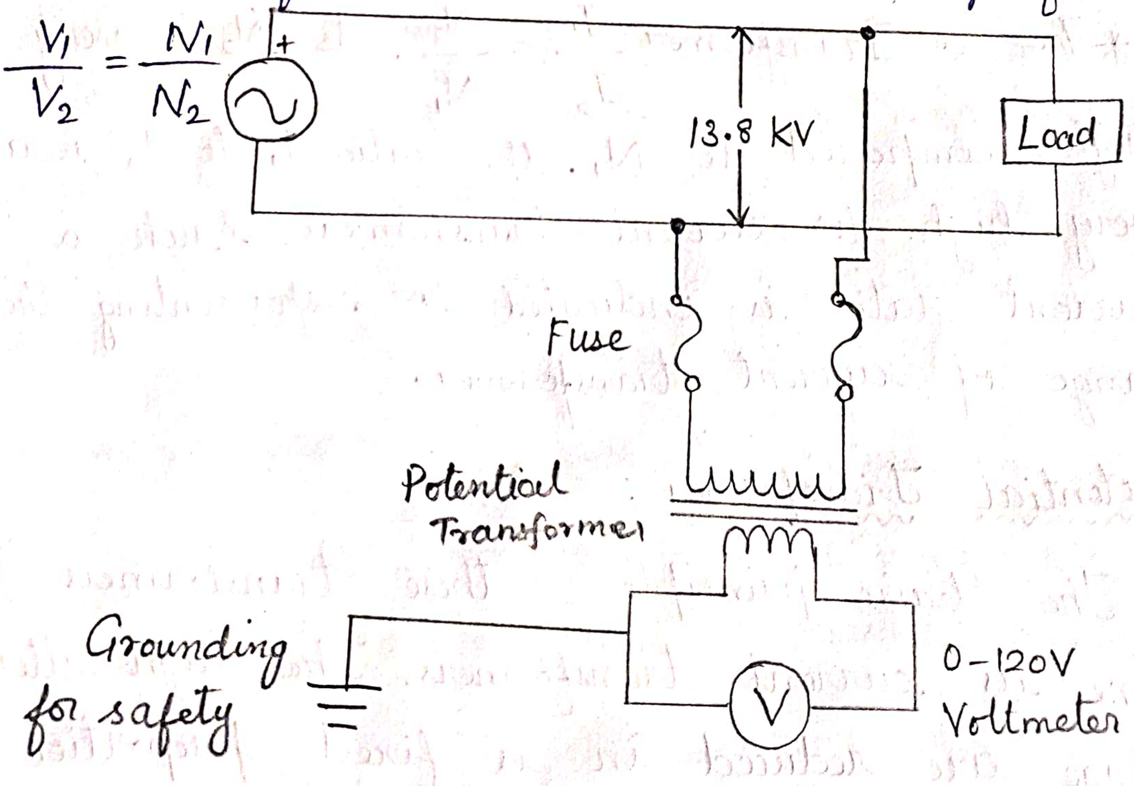


Fig. 3.4. Potential Transformer

FAULTS AND PROTECTION OF TRANSFORMER

Protection Of Transformer :

* Transformer is a static device which is used to step up or step down the voltage. Transformer plays a very vital role in transferring power from source to load. These transformers must be protected against the faults.

* The different faults which is occured in transformers are (i) over heating (ii) winding faults (iii) Open Circuits (iv) Through faults (v) Over fluxing.

(i) Over Heating :-

* The over heating of transformer are basically caused by overloads and shorts circuits. The overloading which continues for longer time is dangerous as it causes overheating of the transformers.

* Generally thermal overload relays and temperature relays sounding the alarms are used to provide the protection against overheatin

(ii) Winding Faults :

* The winding faults are called internal faults. These faults are (i) Phase to Phase faults (ii) Earth faults (iii) Interturn faults.

* When such an internal faults occurs, the transformer must be quickly disconnected from the circuit.

* If such faults remains for long time, there is possibility of oil fire. The differential protection is commonly used to provide protection against such faults.

(iii) Open Circuits :

* The open circuit in one of the three phases is dangerous as it causes the undesirable heating of the transformer.

* These type of faults are much harmless compared to other faults. Hence no separate relay is provided.

* In case of such faults the transformer can be manually disconnected.

(iv) Through Faults :-

* Through faults are the external faults which occur outside the transformer zone. Through

faults are not detected by the differential protection.

* Over current relays with undervoltage blocking, zero sequence protection and negative sequence protection are used to give protection against through faults.

(V) Overfluxing :-

* The flux density in the transformer core is proportional to the ratio of voltage to the frequency i.e., V/F.

* In the generator transformer unit, if full excitation is applied before generator reaches its synchronous speed, due to high V/f, the overfluxing of core may result.

* Higher core flux means core loss and overheating of the core. The V/f relay called volts/hertz relay is provided to give the protection against overfluxing operation.

* PROTECTION OF TRANSFORMER USING DIFFERENTIAL PROTECTION WHICH INCLUDES ASSOCIATED FAULTS:

Differential Protection For Transformer (or) Merz-Price Protection:

* This system gives protection against phase to to phase faults and phase to ground faults to the power transformers.
* The principle of differential protection scheme is the comparision of the currents entering and leaving the ends of a transformer.
* In normal conditions the two currents at the two ends of the transformer are equal and balance is maintained. So, no current flows through the operating coil of the relay and relay is inoperative.
* But when there is phase fault or phase to ground fault, this balance gets disturbed.

* The difference current flows through the operating coil due to which relay operates, tripping the circuit breaker.

Merz - Price Protection For Star - Delta Transformer:-

* The primary of the power transformer is star connected while the secondary is delta connected. Hence to compensate for the phase difference, the C.T secondaries on primary side must be connected in delta while the C.T. secondaries on delta side must be connected in star.
* The star point of the power transformer primary as well as the star connected C.T secondaries must be grounded. The circuit diagram of the scheme is shown in the Fig 3.5
* The restraining coils are connected across the C.T secondary windings while the operating coils are connected between the tapping points on the restraining coils and the star point of C.T. secondaries.
* With the proper selection of turns ratio of C.T.S the coils are under balanced condition during normal operating conditions. The C.T. secondaries carry equal currents which are in phase under normal conditions.

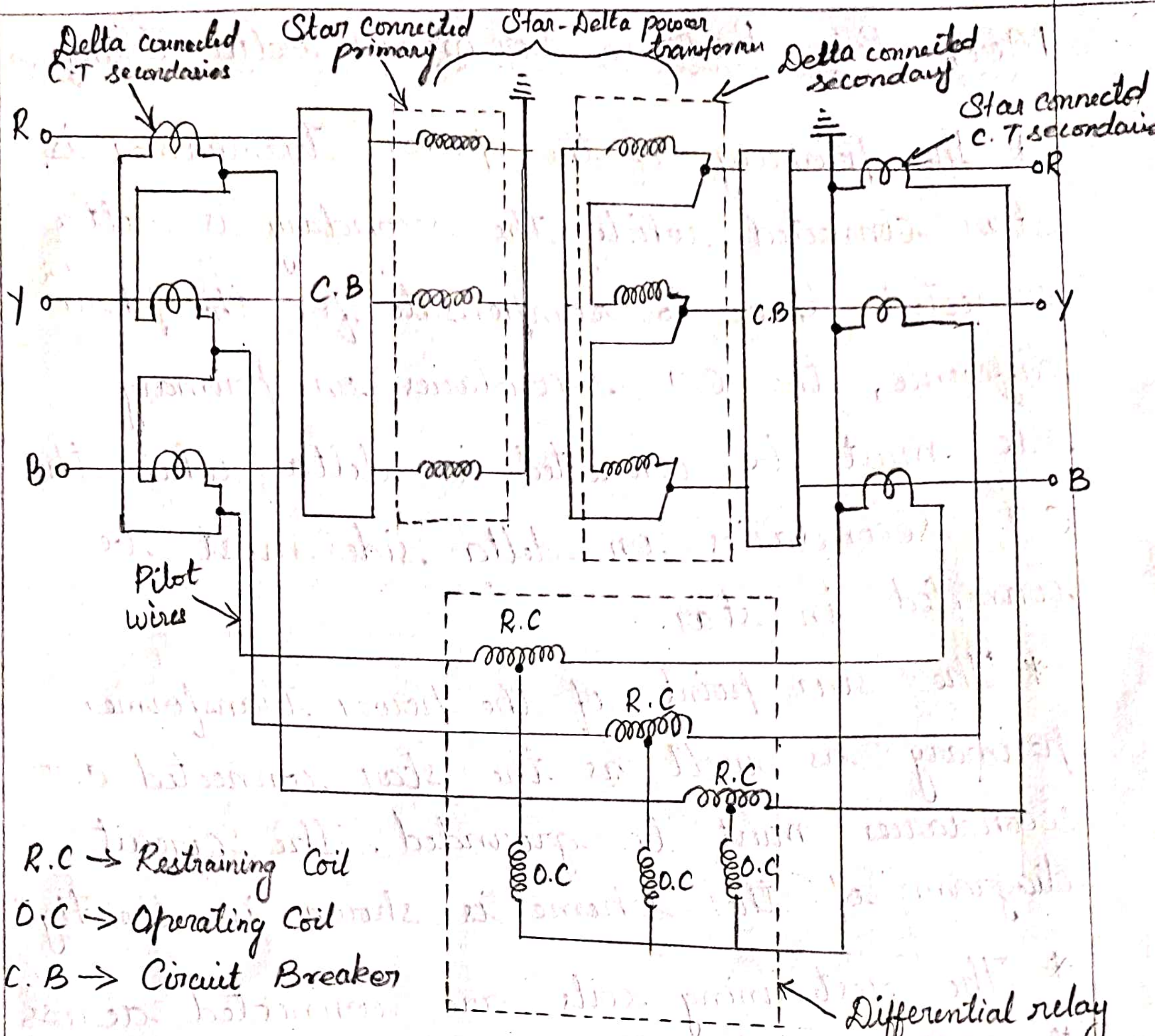


Fig 3.5 Merz - Price Protection Of Star Delta Transfo

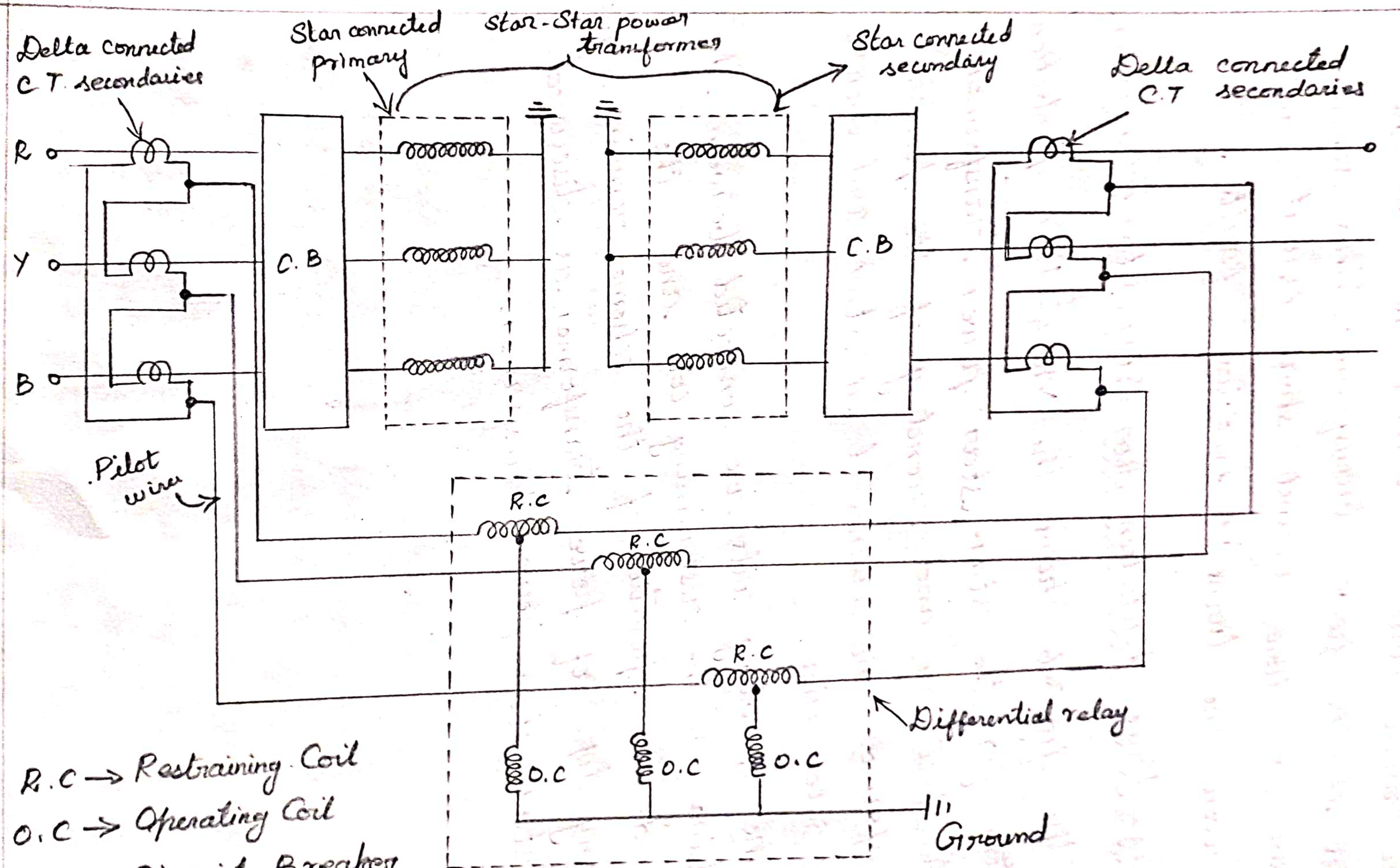
* So no current flows through the relay and the relay is inoperative. With an internal fault in power transformer windings, the balance in the C.T.s get disturbed. The operating coils of differential relay carry currents proportional to the difference of current between the two sides of a power transformer.

* This causes the relay operation which trips the main circuit breakers on both the sides of the power transformer. This scheme gives protection against short circuit faults between the turns i.e interturn faults also.

Merz - Price Protection For Star - Star Transformer :-

* The fig 3.6 shows the Merz - Price protection system for the star-star power transformer. Both primary and secondary of the power transformer are connected in star and hence C.T. secondaries.

* The operating coils are connected between the tapping on the restraining coil and the ground. The operation of the scheme remains same for any type of power transformer as discussed for star - star power transformer.



R.C → Restraining Coil

O.C → Operating Coil

C.B → Circuit Breaker

* BUCHHOLZ RELAY FOR THE PROTECTION OF INCIPIENT FAULTS IN TRANSFORMER:

BUCHHOLZ RELAY:

* The Buchholz relay is a gas operated relay used for the protection of oil immersed transformers against all the types of internals fault. It is named after its inventor, Buchholz.
* The slow developing faults called incipient faults in the transformer tank below oil level operate Buchholz relay which gives an alarm. If the faults are severe it disconnects the transformers from the supply.
* The construction feature of Buchholz relay is shown in the fig. 3.8 Under normal conditions, the Buchholz relay is full of oil, It consists of a cast housing containing a hinged hollow float. A mercury switch is attached to a float.
* The float being rotated in the upper part of the housing. Another hinged flap valve is located in the lower part which is directly in the path of the oil between

the decomposition of oil in the main tank starts due to which the gases are generated.

* As mentioned earlier, major component of such gases is hydrogen. The hydrogen tries to rise up towards conservator but in its path it gets accumulated in the upper part of the Buchholz relay. Through passage of the gas is prevented by the flap valve.

* When gas gets accumulated in the upper part of housing. The oil level inside the housing falls. Due to which the hollow float tilts and close the contacts of the mercury switch attached to it.

* This completes the alarm circuit to sound an alarm. Due to this operator knows that there is some incipient fault in the transformer. The transformer is disconnected and the gas sample is tested. The testing results give the indication, what type of fault is started developing in the transformer. Hence transformer can be disconnected before grows into a serious one.

* If a serious fault such as internal short circuit between phases, earth fault inside the tank etc. occurs then the considerable amount of gas gets generated.

* Thus due to fast reduce level of oil, The pressure in the tank increases. Due to this the oil rushes towards the conservator.

* While doing so its passes through the relay where flap value is present. The flap valve gets deflected due to the rushing oil. Due to this the ~~memory~~ mercury switch contacts gets closed. This energizes the trip circuit which opens the circuit breaker. Thus transformer is totally disconnected from the supply.

Advantages :-

The various advantages of the Buchholz relay are

1. Normally a protective relay does not indicate the appearance of the fault. It operates when fault occurs. But Buchholz relay gives an indication of the fault at very early stage. by anticipating the fault and operating the alarm circuit.

2. Thus the transformer can be taken out of service before any type of serious damage occurs.

3. It is the simplest protection in case of transformers.

Limitations :

The various limitations of the Buchholz relay are,

1. Can be used only for oil immersed transformers having conservator tanks.
2. Only faults below oil level are detected.
3. Setting of the ~~memory~~ mercury switches can not be kept too sensitive otherwise the relay can operate due to bubbles, vibration, earthquakes mechanical shocks etc.
4. The relay is slow to operate having minimum operating time of 0.1 seconds and average of time of 0.2 seconds.

Applications :

The following types of transformer faults can be protected by the Buchholz relay and are indicated by alarm :

1. Local Overheating
2. Entrance of air bubbles in oil

* The Fig. 3.9 shows a schematic arrangement of Merz - Price protection scheme for a star connected alternator.

* The differential relay gives protection against short circuit fault in the stator winding of a generator.

* The C.T.S are connected in star and are provided on both, the outgoing side and machine winding connections to earth side. The restraining coils are energized from the secondary connection of C.T.S in each phase, through pilot wires. The operating coils are energized by the tappings from restraining coils and the C.T. neutral earthing connection.

Operation :-

* This is most commonly used protection scheme for the alternator stator windings. The scheme is also called biased differential protection and percentage differential protection.

* In this method, the currents at the two ends of the protected section are sensed using current transformer secondaries are called pilot wires.

* Under normal conditions, when there is no

fault in the windings, the currents in the pilot wires fed from C.T. secondaries are equal. The differential current $i_1 - i_2$ through the operating coils of the relay is zero. Hence the relay is inoperative and system is said to be balanced.

* When fault occurs inside the protected section of the stator windings, the differential current $i_1 - i_2$ flows through the operating coil of the relay. Due to this current, the relay operates.

* This trips the generator circuit breaker to isolate the faulty section.

*

* THE PROTECTION SCHEME FOR MOTORS.

INDUCTION MOTOR PROTECTION:

Single Phasing Preventer :-

* If one of the supply line is disconnected due to open circuit or improper contact in ~~sb~~ switch then still the motor continues to run. The power is then supplied to the remaining windings.

* The current in the other phases increases to about √3 times its normal value. This is called single phasing which results in unbalanced stator currents.

* Thus major damage to motor may take place due to single phasing if proper precaution is not taken.

* For small motors separate protection against single phasing is normally not provided as thermal relays sense the increased current in remaining phases due to single phasing and provides the sufficient protection.

* A separate single phasing protection circuit is required in case of large induction motors as even a small unbalance can cause damage to motor winding and rotor.

* The single phasing preventer is shown in the fig. 3.15. As shown in the figure, it consists of C.Ts connected in each phase. The output of control circuit is fed to the level detector which sense the ~~t~~ magnitude of unbalance.

* Depending on this output from the control circuit the tripping command to the

forms the earth fault.

* These faults are relatively frequent and hence protection is required against these which is provided with the help of Earth leakage circuit breaker.

* The schematic of ELCB is shown in Fig. 3.16.
As shown in the Fig ELCB consists of a small current transformer surrounding line and neutral wire.

* The secondary winding of current transformer is connected to relay circuit which can trip the circuit breaker which is connected in the circuit.

* Under normal conditions, the current in line and neutral conductor is same so the net current ($I_L - I_N$) flowing through the core is zero. So the breaker does not trip.

* If there is a fault due to leakage from line wire to earth or a person by mistake touching to the live terminal then the net current through the core will no longer remain as zero but equal to $I_L - I_N$ or I, which will set up flux and emf in CT.

* As per the preset value the unbalance in current is detected by C.T. and relay coil is energized which will give tripping signal for the circuit breaker.

* BUS BAR PROTECTION:

* Busbar in the generating stations and sub-stations from important link between the incoming and outgoing circuits. If a fault occurs on a busbar, considerable damage and disruption of supply will occur unless some form of quick-acting automatic protection is provided to isolate the faulty busbar.

* The two most commonly used schemes for busbar protection are:

(i) Differential Protection

(ii) Fault bus protection

(i) Differential Protection:

* The basic method for busbar protection is the differential scheme in which currents entering and leaving the bus are totalised.

* During normal load condition, the sum of these currents is equal to zero.

* When a fault occurs, the fault current produces a differential current to operate a relay.

Schematic Arrangement :-

* Fig 3.18 shows the single line diagram of differential current method for a station busbar. The busbar is fed by a generator and supplies load to two lines.

* The secondaries of current transformers in the generator lead, in line 1 and in line 2 are all connected in parallel.

* The protective relay is connected across this parallel connection.

UNIT - IV

STATIC RELAYS AND NUMERICAL PROTECTION

Static relays - Phase, Amplitude Comparators - Synthesis of various relays using Static comparators Block diagram of Numerical relays - Overcurrent protection, transformer differential protection, distant protection of transmission lines.

* THE OPERATION OF STATIC RELAY - WITH BLOCK DIAGRAM:

* Static Relays:

* Static relay is an Electrical relay in which the response is developed by Electronic/Magnetic/optical or other components without the mechanical motion of components.
* Static relay employs semiconductor devices for their operation. A protective system is formed by static relays and electromechanical auxiliary relays.
* Fig. 4.1 illustrates the Essential Components in a static relays. The output of CT's of PT's or transducer is rectified in Rectifiers.

* The other forms of inputs such as heat, light, magnetic field, travelling waves etc., can be converted into equivalent analogue or digital signals and then fed to the static relay.

Advantages:

① Low Power Consumptions:-

Static relays provide less burden on CTs and PT's compared to conventional relays. The consumption of 1mW is quite common in static overcurrent relay. Whereas an equivalent electromechanical can have consumption of about 2 watts.

② Resetting Time And Overshoots:-

By using special circuits, the Resetting Time and Overshoots can be reduced thereby the selectivity can be improved.

③ No Moving Contacts:-

There is no moving contacts. Therefore, the associated problems of arcing, contacts bounce, erosion, Replacement of contacts etc., can be eliminated.

④ Single Relay for several functions:

By combining various functional circuits a single static relay can replace several conventi-onal relays.

⑤ Compactness :-

Static relay are compact. A Single relay performs several functions. A single microprocessor based system can substitute several independent protection and control relay units.

Disadvantages:

a) Auxiliary Voltage Requirement
b) Electrostatic discharges.
c) Voltage Transients
d) Temperature dependance of static relays.

Application :-

* Used in Ultra high speed protection schemes of EHV- AC lines utilising distance protection.
* Overcurrent Protection.
* Earth fault Protection schemes.

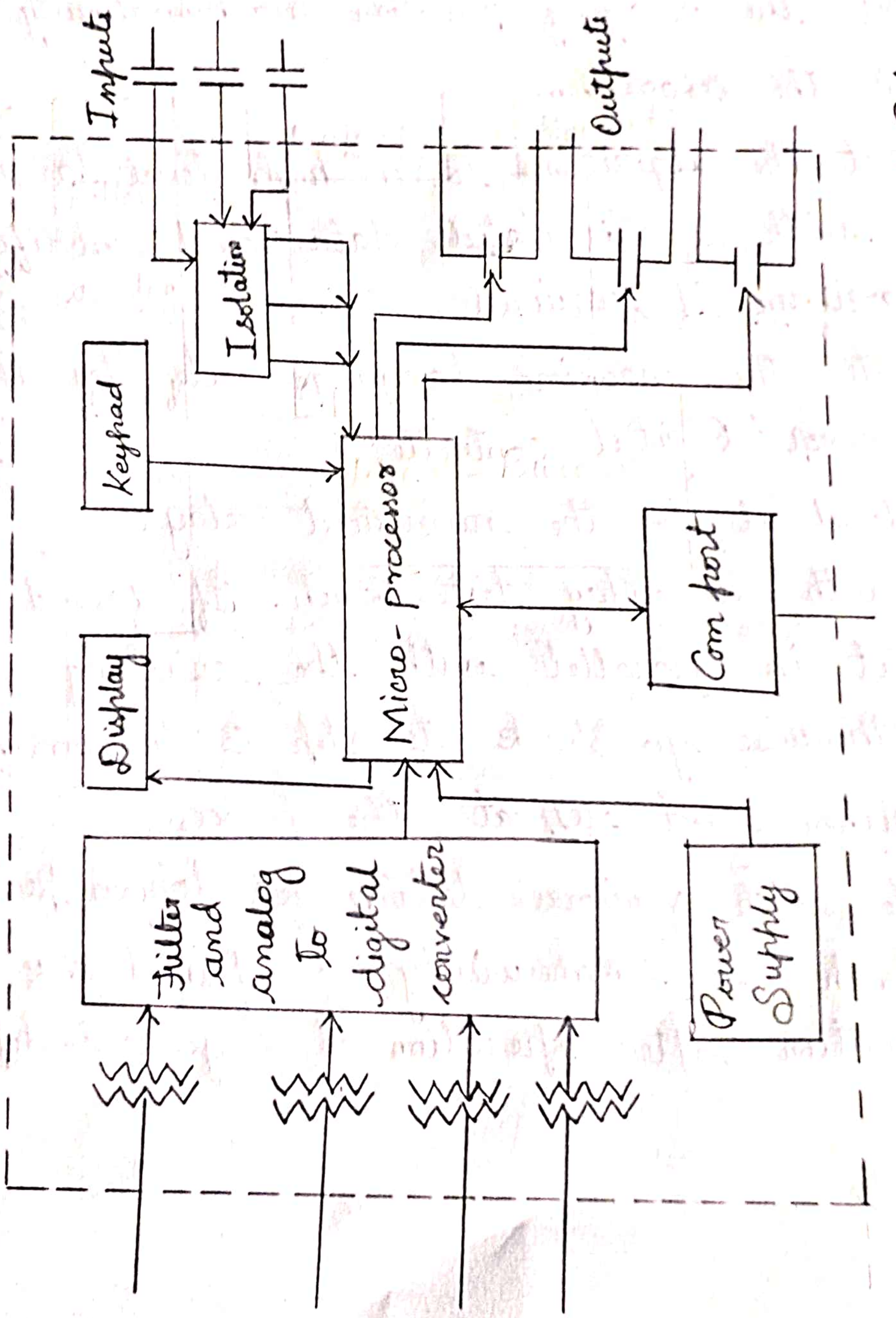
* BLOCK DIAGRAM OF NUMERICAL RELAY

Numerical Protection :-

Numerical relays are technically superior to the conventional type relays. Their general characteristic are :

* Reliability
* Self diagnosis
* Event And Disturbance Records
* Adaptive Protection
* Integration Of Digital Systems.

Typical Architecture Of Numerical Relays:



General Arrangement Of Numerical Relays

Numerical relays are made up from modules with well defined functions. The use of algorithm of fault diagnosis, with the help of numerical relays can be understood clearly from the following development steps.

* State the relaying problem.
* Model the relaying problem mathematically.
* Write the algorithm.
* Convert the algorithm to a high level language.
* Test with a stimulated data and modify the algorithm if required.
* Generate the machine language code for the Microprocessor / Digital controller
* Download it for the numerical relay.
* Test with a relay test bench. If found O.K install it in parallel with the existing relay. Otherwise go back to step 3 to modify the algorithm and repeat the process.
* Evaluate with various testing for longer period and launch it commercially if found O.K in its operation after operation of 2 years independently.

* AMPLITUDE AND PHASE COMPARATORS :-

Amplitude Comparators:

* The amplitude comparator has two inputs, S_0 and S_r and a trip output. Both the inputs are phasors.
* The input phasor S_0 is called the operating quantity and the input phasor S_r is called the restraining quantity.
* The amplitude comparator follows the simple law. If $|S_0 > |S$ then trip ; else restrain

Fig. 4.2 Amplitude Comparator responds only to amplitude and is blind to the phase angle between the inputs.

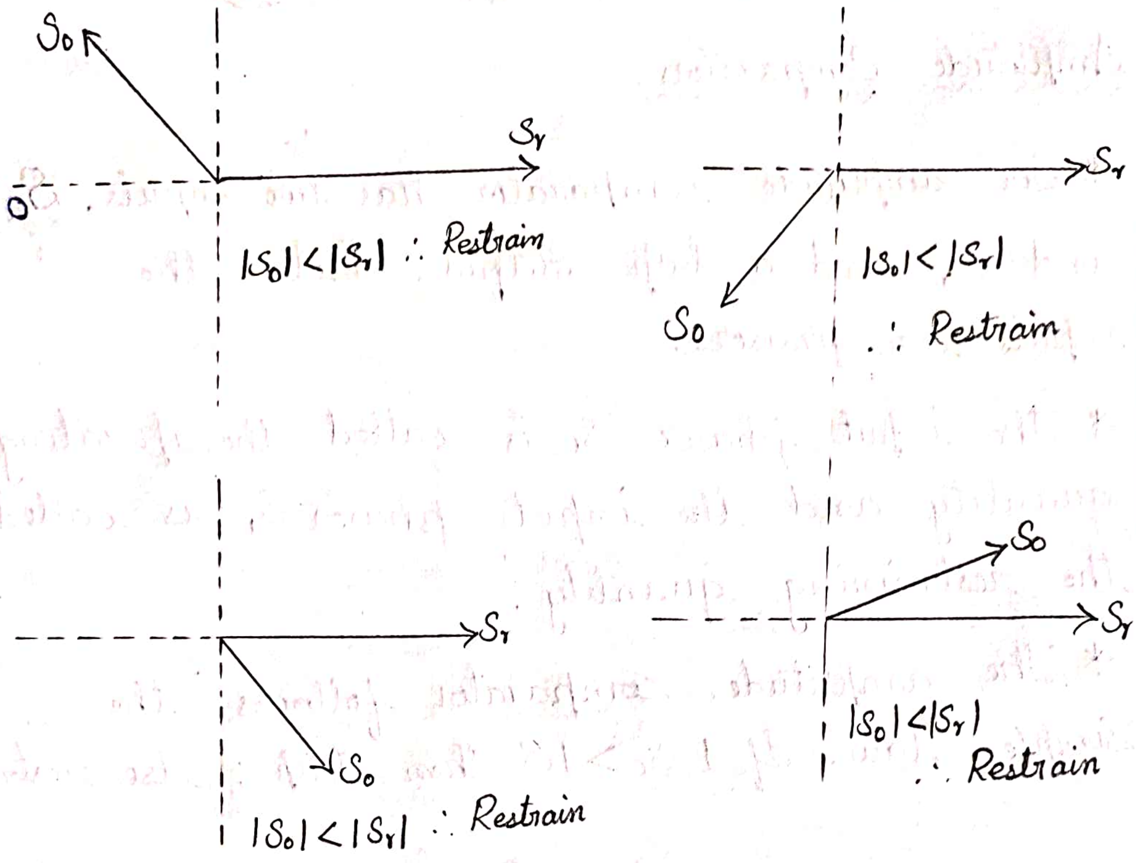


Fig. 4.3 Inputs to amplitude Comparator Causing it to restrain

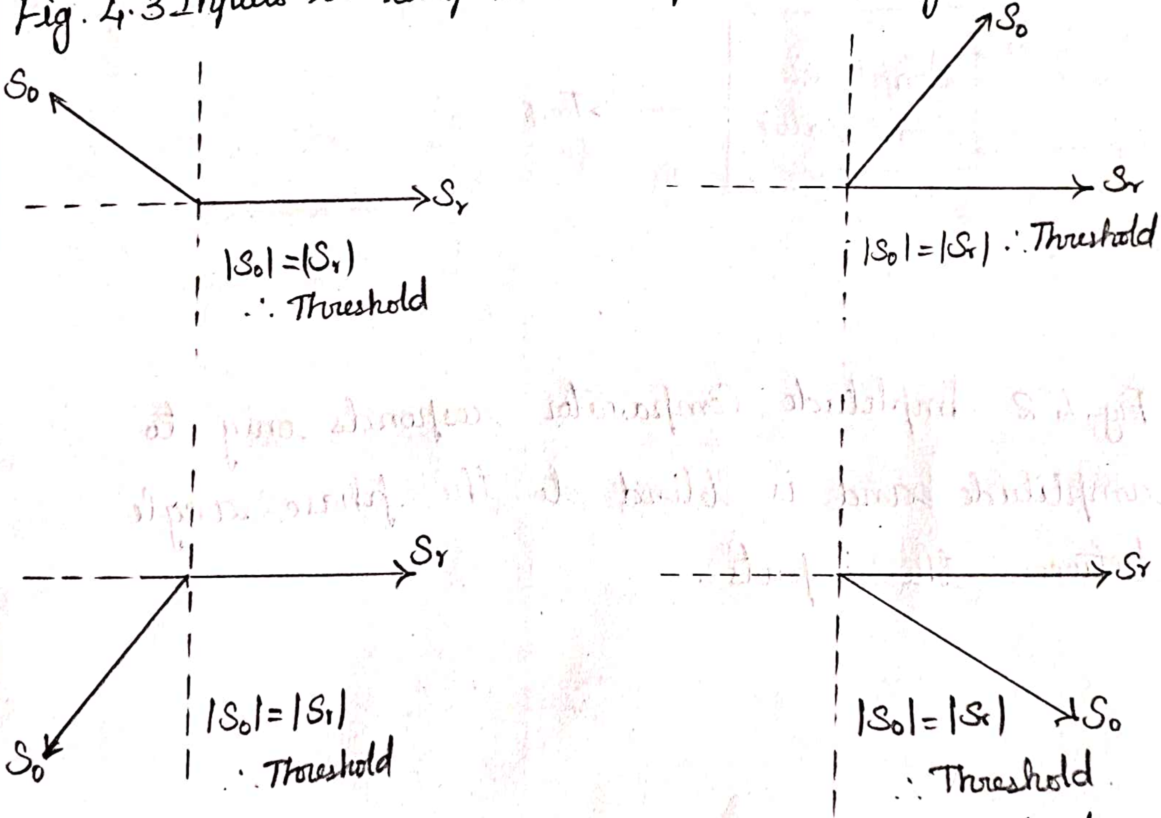


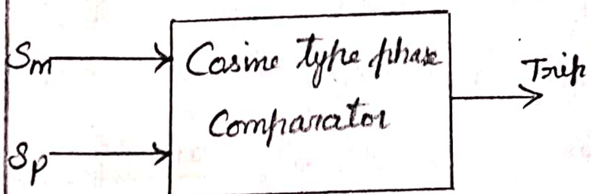
Fig 4.4. Inputs to Amplitude Comparator causing it to be on the threshold.

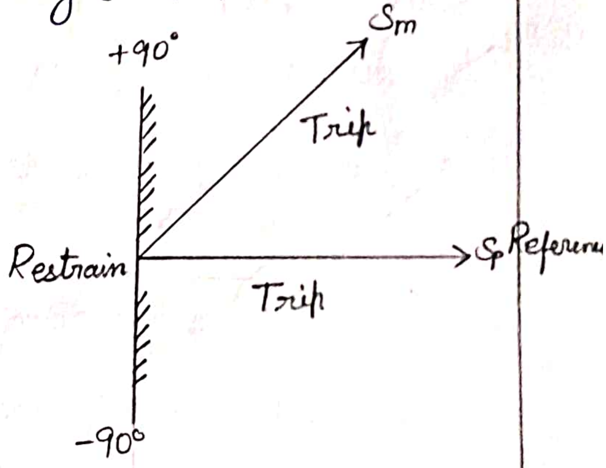
Phase Comparator :

Phase comparators are of two types : the cosine type and sine type

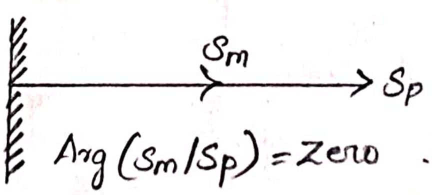
Cosine - type phase Comparator :

* The cosine - type phase comparator has two phasors S_p and S_m, at its inputs and has a trip output.
* The input - phasor, designated as S_p is the polarizing or reference input. The input-phasor, designated as S_m, is called the measured input.
* The cosine - type phase comparator follows the trip law : If $-90° < Arg(S_m/S_p) < +90°$ then trip; else restrain.

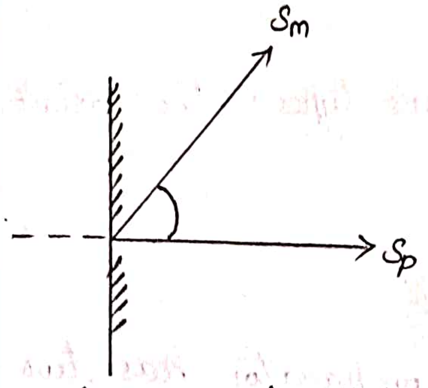




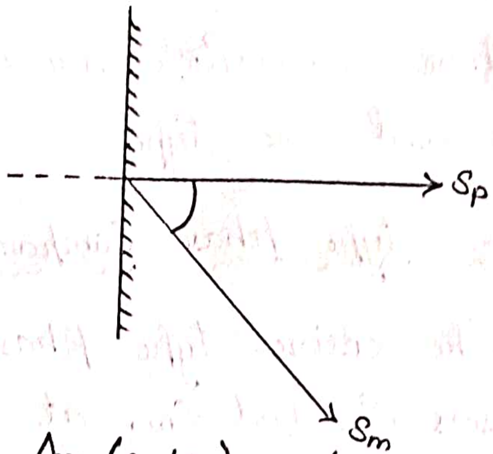
* Phase comparator responds only to phase angle and is blind to the relative amplitude of the two inputs.



$Arg(S_m/S_p) = \text{Zero}$ ∴ Trip

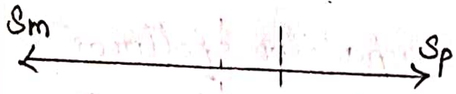


Arg (Sm/Sp) < 90° ∴ Trip

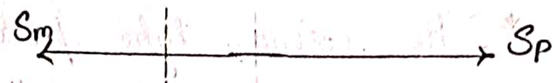


Arg (Sm/Sp) > -90° ∴ Trip

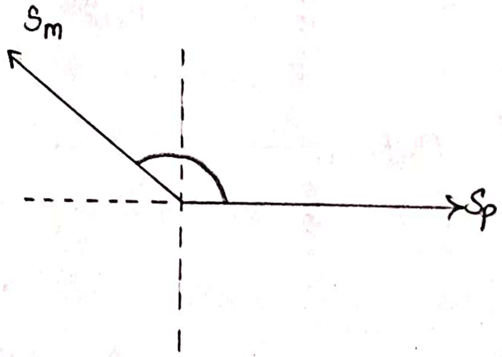
Fig. 4.5. Inputs to cosine-type phase comparator resulting in trip output



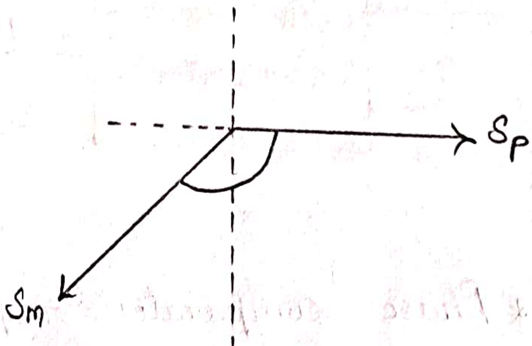
Arg (Sn/Sp) = 180° ∴ Restrain



Arg (Sm/Sp) = 180° ∴ Restrain



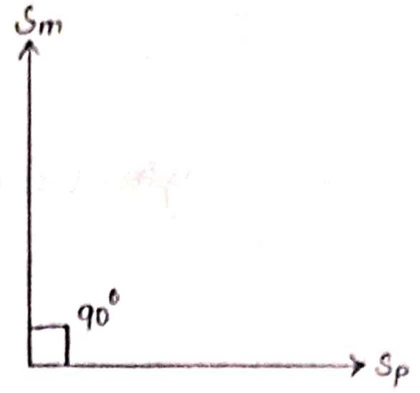
Arg (Sm/Sp) > 90° ∴ Restrain



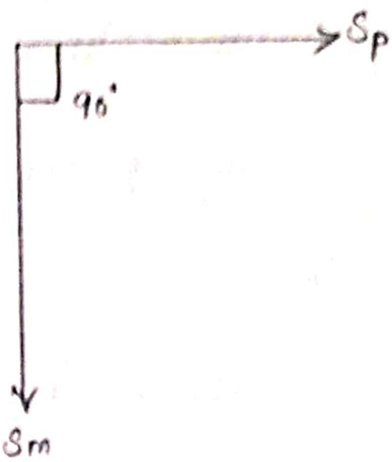
Arg (Sm/Sp) > -90° ∴ Restrain

Fig ~~4.5~~. ~~Inputs~~ to ~~co~~

Fig 4.6. Inputs to cosine-type phase comparator causing it to restrain



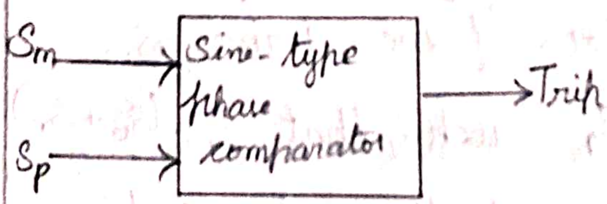
$Arg(S_m/S_p) = +90°$: Threshold

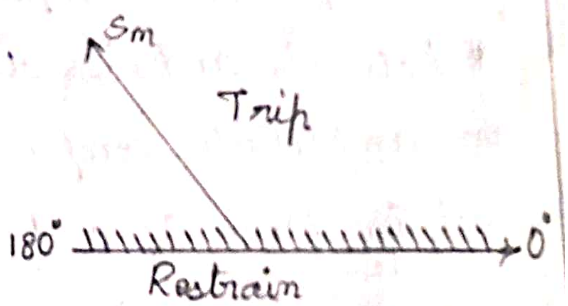


$Arg(S_m/S_p) = -90°$ ∴ Threshold

Sine-type phase Comparator :

* The sine-type phase comparator has two phasors S_p and S_m, at its input and has a trip output.
* The input phasor, designated as S_m is the polarizing or reference input. The input phasor, designated as S,, is called the measured input
* The sine-type phase comparator follows the trip law : If $0'' < Arg(S_m/S_p) < 180''$ then trip ; else restrain.





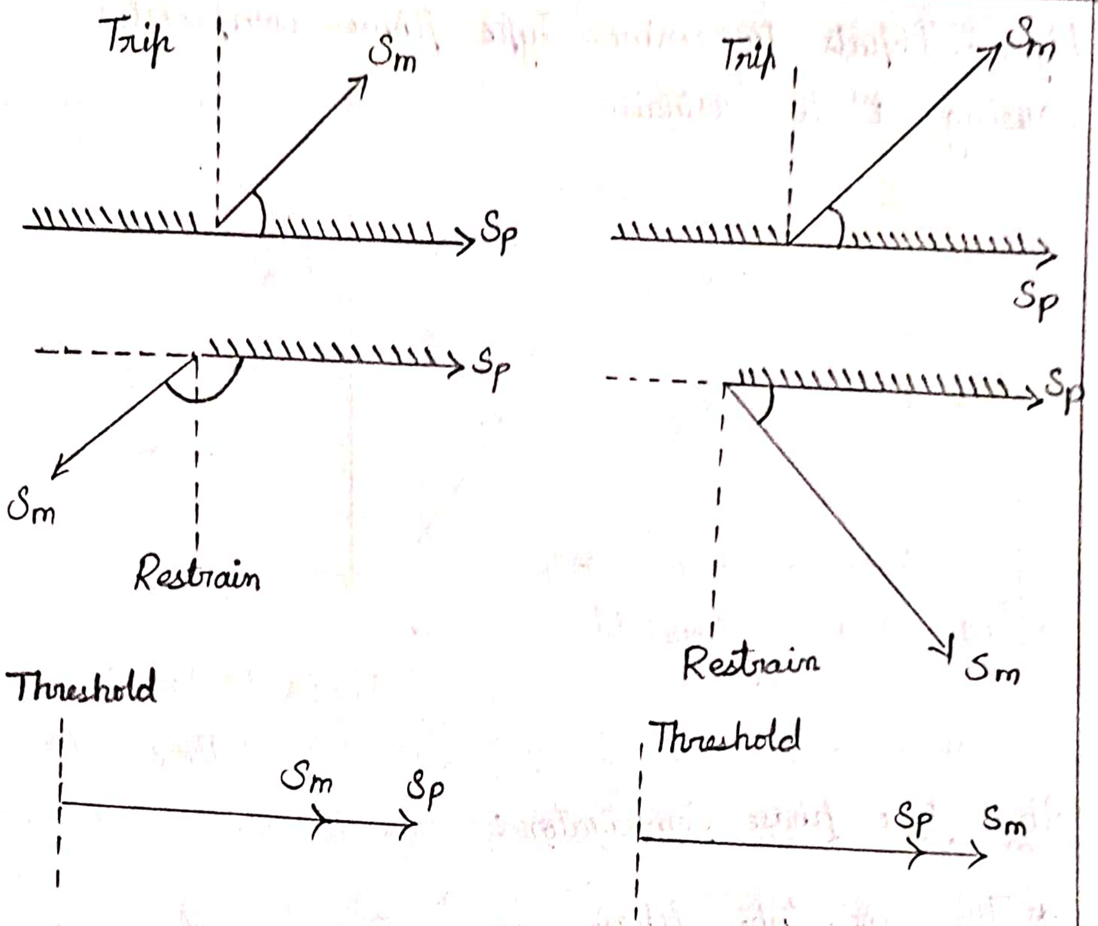
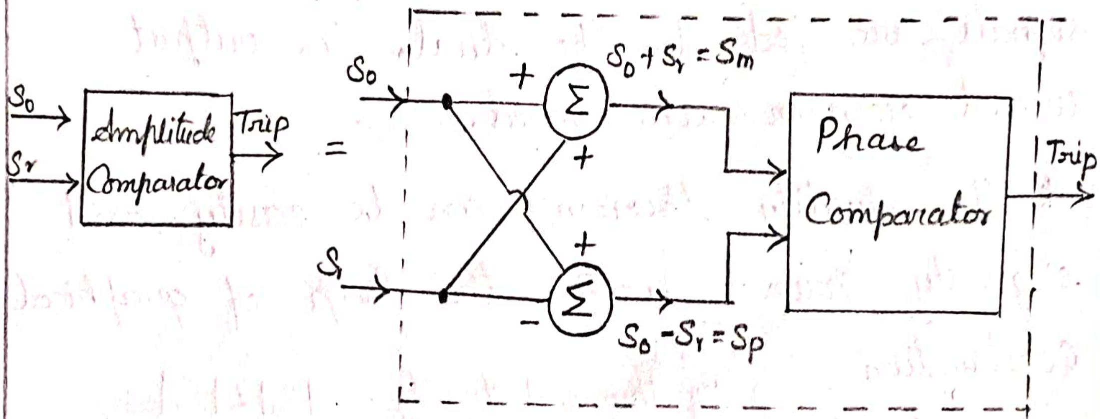


Fig. 4.7 Sine-type phase comparator: trip, restrain and threshold conditions.

Duality Between Amplitude and phase comparators:

* If the inputs of an amplitude comparator are modified according to the theorem of duality then they become suitable as inputs for a phase comparator and vice versa.
* Lets S_o and S_r be the original inputs to an amplitude comparator. If we derive S_m and S_p from S_o and S_r such that $S_m = (S_o + S_r)$ and $S_p = (S_o - S_r)$ and feed these to a phase

comparator, then the output of the phase comparator would be exactly the same as that of the original amplitude comparator.



* Similarly, let S_m and S_p be the original inputs to a phase comparator, then if we derive S_0 and S_r from S_m and S_p such that $S_0 = (S_p + S_m)$ and $S_r = (S_p - S_m)$ and feed these to an amplitude comparator, then the output of the amplitude comparator, would be exactly the same as that of the original phase comparator.

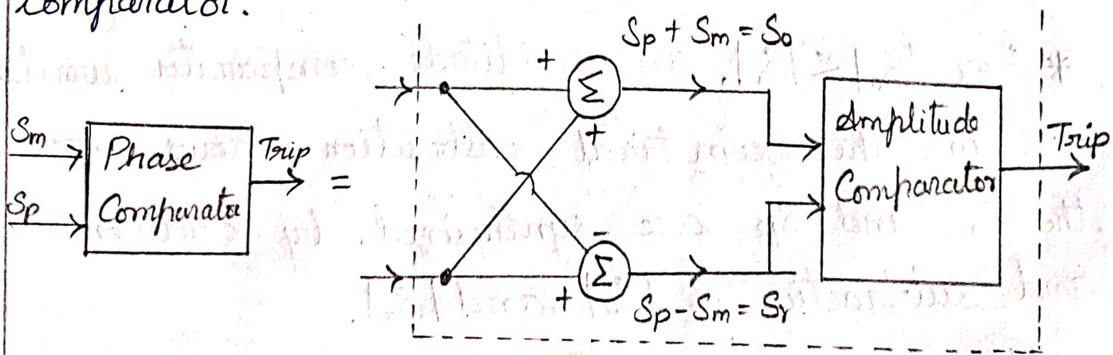


Fig. 4.8 Duality between phase and amplitude Comparator.

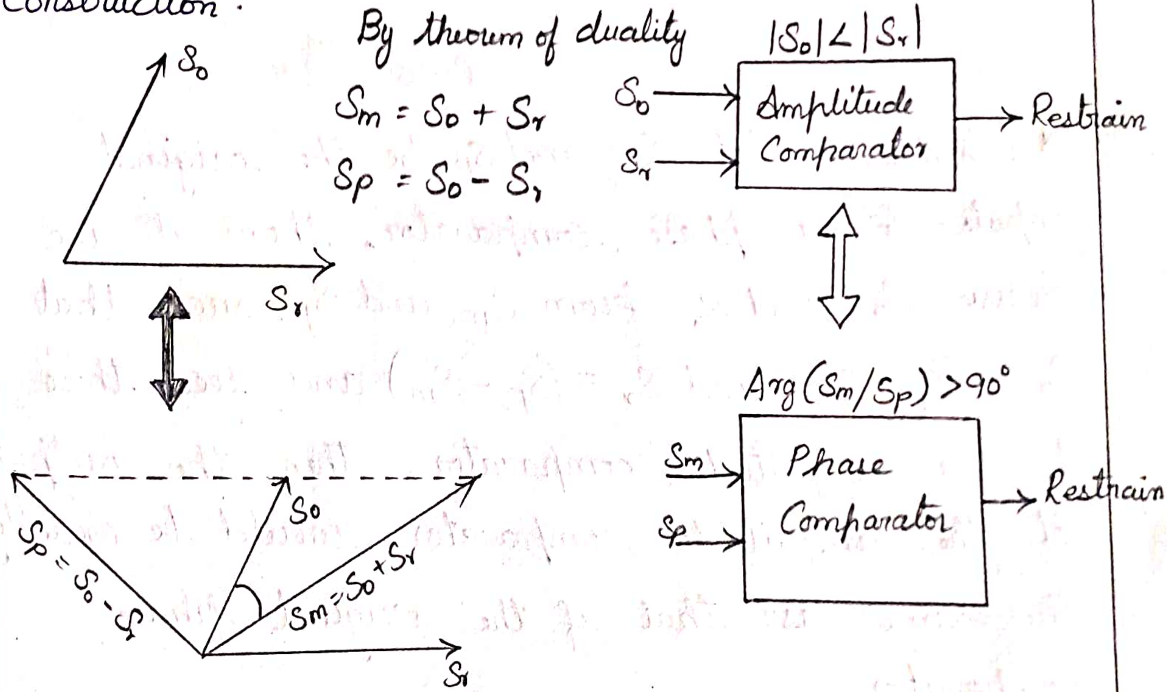
* The two signal, obtained by adding and subtracting the inputs to a comparator, are the inputs suitable for its dual. If such signals are fed to the dual, the output would remain unchanged.

* The duality theorem can be easily and elegantly proved with the help of graphical Construction.

By theorum of duality

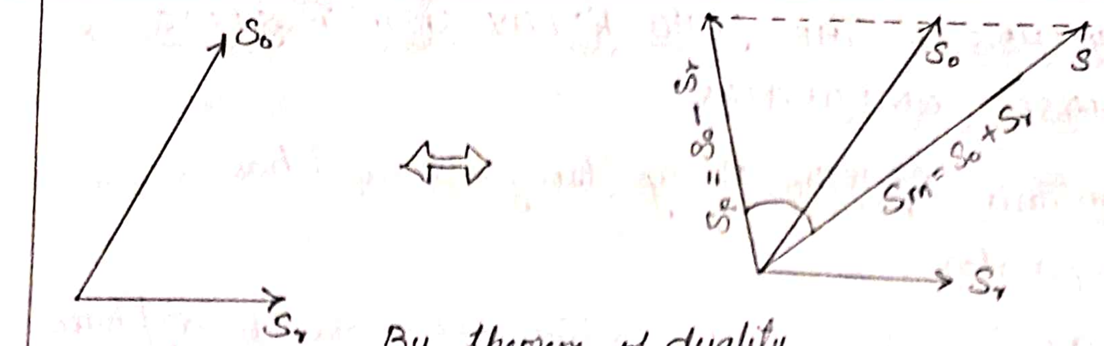
$S_m = S_o + S_r$

$S_p = S_o - S_r$



* For $|S_o| < |S_r|$, an amplitude comparator would restrain. The geometrical construction shows, how the S_m and S_p are synthesized, by addition and subtraction of $|S_o|$ and $|S_r|$.

* It can also be easily seen that since $Arg[(S_o+S_r)/(S_o-S_r)] > 90$, the dual-phase comparator would also restrain if fed with such signals.



By theorem of duality

$S_m = S_o + S_r$

$S_p = S_o - S_r$

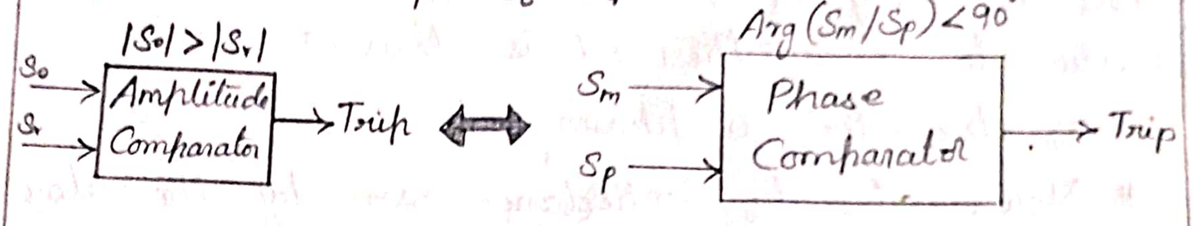
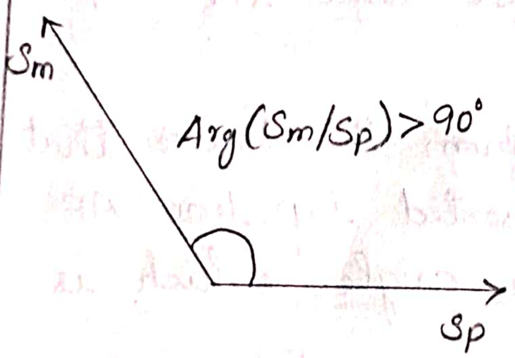
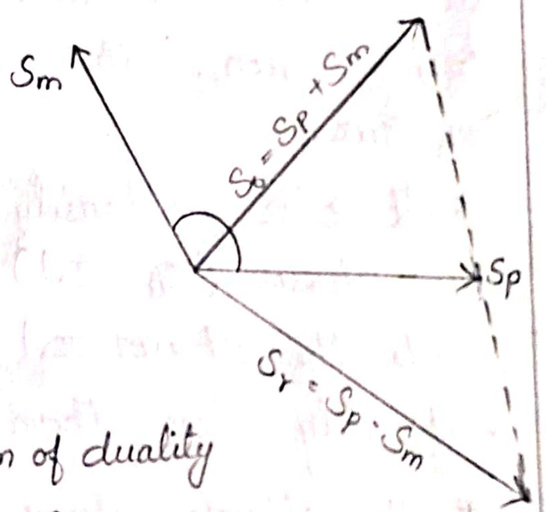


Fig. 4.9 Duality between amplitude and phase comparators for $S_o > S_r$.





By theorem of duality

$S_o = S_p + S_m$

$S_r = S_p - S_m$

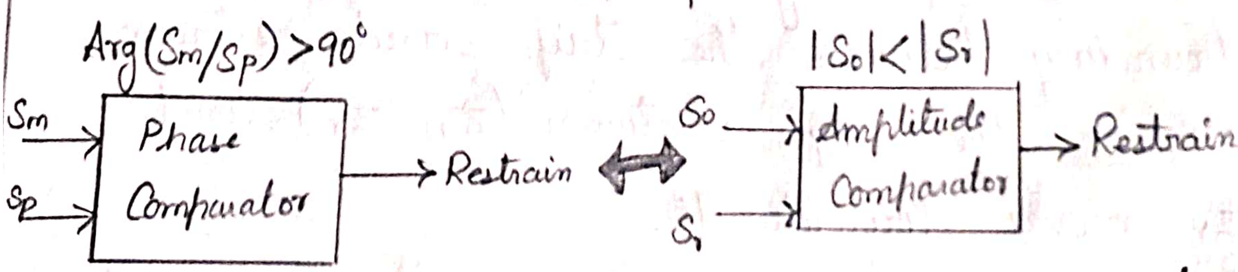


Fig. 4.10 Duality between phase comparator and amplitude comparator for arg $(S_m/S_p) > 90$

* SYNTHESIZE THE MHO RELAY USING STAIC PHASE COMPARATOR

Synthesis Of Mho Relay Using Static Phase Comparator:-

* The synthesis of a mho relay using a phase comparator. The mho relay to be synthesized has a setting of z_n at angle. The characteristic to be synthesized is thus a circle with diameter as phasor Z_n.

* Now, let the impedance seen by the relay be Z_{rl} represented by point A. in figure. Since the impedance phasor lies within the trip region, the relay must issue the trip output.

* It can be easily seen from the figure that the phasor $(Z_n - Z_{rl})$, represented by line AP leads the phasor Z_{rl} by an angle which is definitely less than 90°.

* The figure shows that as the impedance seen by the relay moves towards the boundary between the trip and restrain regions, the angle between $(Z_n - Z_r)$ and Z_r moves towards 90.

* When the phasor representing the impedance seen by the relay, lies on the boundary, this angle is exactly 90° (for example, the angle between PB and OB = 90°).

* For all impedances lying outside the trip region, i.e. in the restraining region, the angle between $(Z_n - Z_r)$ and Z_r is always greater than 90° (for example, the angle between CP and CD).

$OA = |Z_{r1}| \rightarrow$ Trip

$OB = |Z_{r2}| \rightarrow$ Threshold

$OC = |Z_{r3}| \rightarrow$ Restrain

$AP = |Z_n - Z_{r1}|$

$BP = |Z_n - Z_{r2}|$

$CP = |Z_n - Z_{r3}|$

$$\text{Arg}\frac{|Z_n - Z_{r1}|}{|Z_{r1}|} = \angle BAP < 90^\circ \Rightarrow \text{Trip}$$

$$\text{Arg}\frac{|Z_n - Z_{r2}|}{|Z_{r2}|} = \angle CBP = 90^\circ \Rightarrow \text{Threshold}$$

$$\text{Arg}\frac{|Z_n - Z_{r3}|}{|Z_{r3}|} = \angle DCP > 90^\circ \Rightarrow \text{Restrain}$$

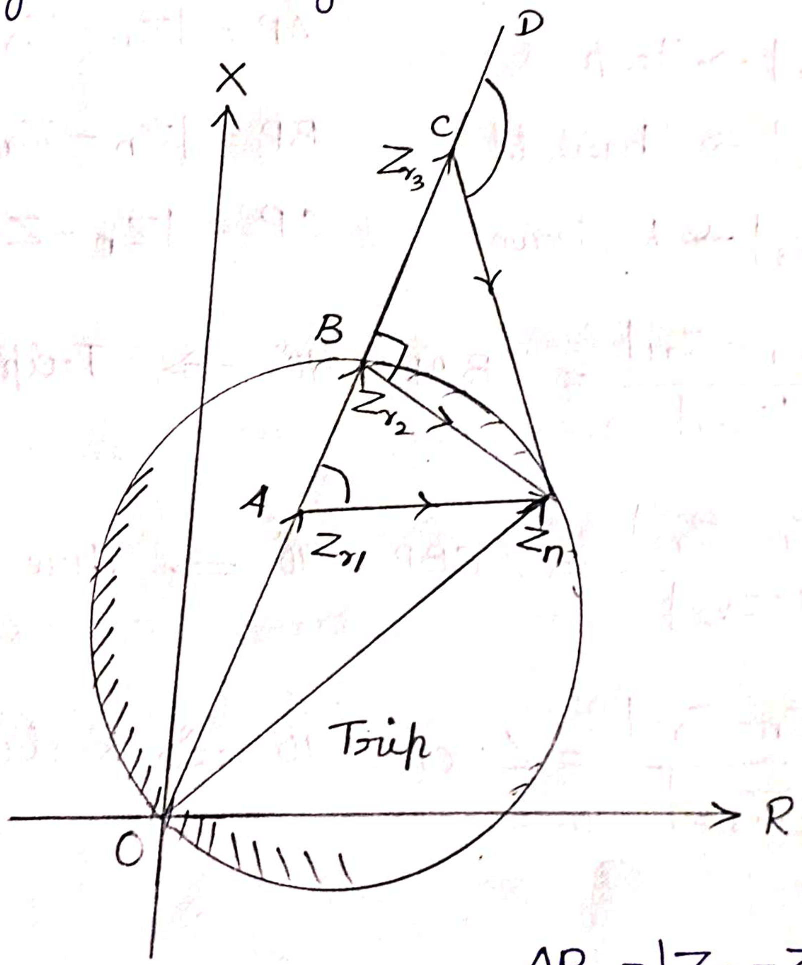
Trip law:

$$\text{If } \text{Arg}\frac{|Z_n - Z_r|}{|Z_r|} < 90^\circ \text{ ; then trip}$$

Fig 4.11. Synthesis of mho relay using cosine-type pha Comparator.

* Similar analysis shows that even if the impedance seen by the relay is on the other side of Z_n as shown in fig. as long as it is in the trip region, the angle between $(Z_n - Z_r)$ and Z_r is always greater than $-90°$.

* The angle hits 90° for boundary conditions and becomes less than $-90°$ as the impedance seen by the relay moves into the restraining Region



$OA = |Z_{r1}| \rightarrow$ Trip

$OB = |Z_{r2}| \rightarrow$ Threshold

$OC = |Z_{r3}| \rightarrow$ Restrain

$AP = |Z_n - Z_{r1}|$

$BP = |Z_n - Z_{r2}|$

$CP = |Z_n - Z_{r3}|$

$$Arg \frac{|Z_n - Z_{r1}|}{|Z_{r1}|} = \angle PAB > -90° \rightarrow \text{Trip}$$

$$Arg \frac{|Z_n - Z_{r2}|}{|Z_{r2}|} = \angle PBC = 90° \rightarrow \text{Threshold}$$

$$Arg \frac{|Z_n - Z_{r3}|}{|Z_{r3}|} = \angle PCD < -90° \rightarrow \text{Restrain}$$

Trip law:

If $Arg \frac{|Z_n - Z_r|}{|Z_r|} > -90°$; then trip.

Fig. 4.12. Synthesis of mho relay using phase comparator.

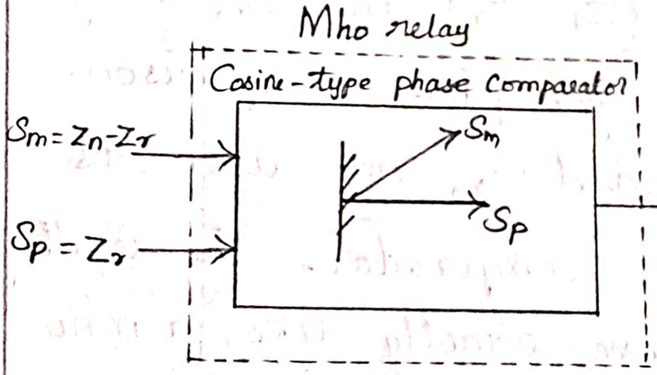
* Thus, the phasor $(Z_n - Z_r)$ and Z_r, obey the law of cosine-type phase comparison. Therefore, if $(Z_n - Z_r)$ and Z_r, are used as inputs to a cosine comparator, the resulting entity would ~~to~~ behave exactly like a mho relay.

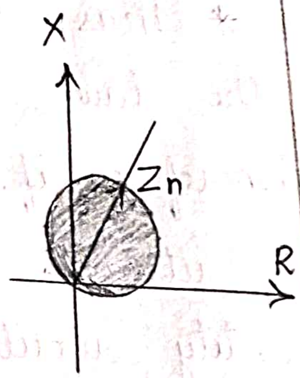
* However, there is a practical problem here. The problem is that the electronic circuit of the comparator accepts only voltage signals at its inputs. We, therefore, need

to convert these two impedance phasors into voltage signals.

* If we multiply both $(Z_n - Z_r)$ and Z_r, by the current at the relay location I_r then we get $(I_r Z_n - I_r Z_n)$ and $Z_r I_r$. Note that $Z_r I_r$, is nothing but the voltage at the relay location V_r. The two modified signals therefore are : $(I_r Z_n - V_r)$ and V_r.

* Thus, we find that $(I_r Z_n - V_r)$ and V_r, are the two voltage signals which can be fed to a cosine-type comparator for synthesis of a mino relay with a setting of Z_n.





$$(Z_n - Z_r) I_r = Z_n I_r - V_r = S_m$$

$$Z_r I_r = V_r = S_p$$

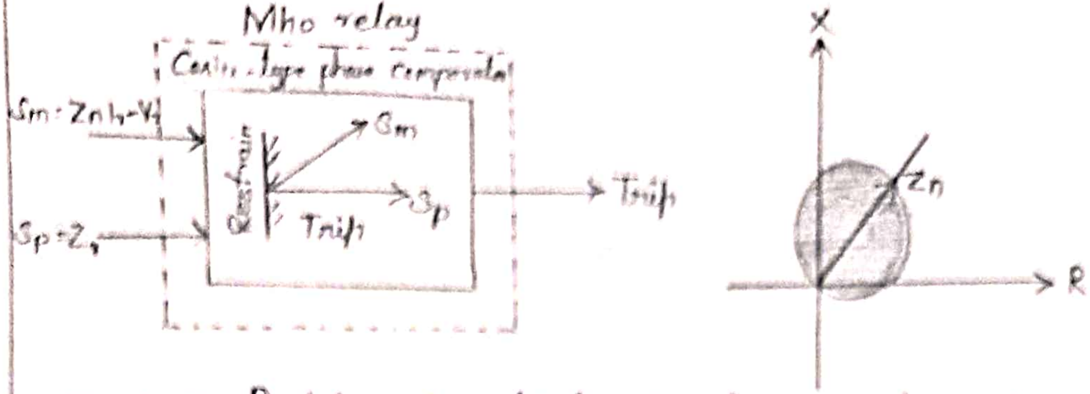


Fig. 4.13 Deriving practical signals for mho relay synthesis

* **COMPARE STATIC RELAY OVER ELECTROMAGNETIC RELAY**

Comparision Of Different Relays:

S. No	Characteristic	Electromechanical Realy	Static Relay	Digital Relay	Numerical Relay
1.	Technology Standard	1st generation	2nd Generation	Present Generation	Present Generation.
2.	Operating Principle	Electromagnetic Principle	Transistors and IC's used	It uses Microprocessor	It uses Microprocessor
3.	Relay Size	Bulky	Small	Small	Small
4.	Speed of Response	Slow	Fast	Fast	Very fast
5.	Maintenance	Frequent	Frequent	Low	Very low
6.	Resistance	100 milli ohm	10 ohms	10 ohms	10 ohms.
7.	Measuring Elements	Induction disc, Electromagnets, etc.	R, L, C Transistors	Microprocessor Digital IC etc.	Microprocessor Digital IC etc,
8.	Measuring Methods	Mechanical force, Torque etc.,	Level detector	A/D Conversion, Numerical Algorithm	A/D Conversion Numerical Algorithms.

UNIT - V

CIRCUIT BREAKERS

* **METHODS OF ARC EXTINCTION :**

There are two methods of extinguishing the arc in circuit breakers viz. 1. High resistance method 2. Low resistance or current zero method

* **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 arc is extinguished.

The resistance of the arc may be increased by:

(i) Lengthening the arc :-

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

(ii) Cooling the arc :

* Cooling helps in the deionization of the medium between the contacts. This increases the arc resistance.

* Efficient cooling may be obtained by a gas blast directed along the arc.

iii) Reducing cross-section of the arc:

* If the area of cross-section of the arc is reduced, the resistance of the arc path is increased.
* The cross-section of the arc can be reduced by allowing the arc through a narrow opening or by having smaller area of contacts.

iv) Splitting the arc:-

* The resistance of the arc can be increased by splitting the arc into a number of smaller arc in series.
* Each one of these arc experiences the eff of lengthening and cooling.
* The arc may be split by introducing s conducting plates between the contacts.

Disadvantage:

@ Enormous energy is dissipated in the

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

* Low resistance or Current zero method:

* This method is employed for arc extinction in a.c. circuit only. In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally.

* All modern high power a.c. circuit breakers employ this method for arc extinction. In 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 known as restriking voltage.

* If such a breakdown does occur, 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 than the voltage across the contacts, the arc fails to restri[ke] and the current will be interrupted.

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

(a) causing the ionized particles in the space between contacts to recombine into neutral molecules.

(b) sweeping the ionized particles away and replacing them by unionized particles.

The deionization of the medium can be achieved by:

(i) Lengthening of the gap:

* The dielectric strength of the medium is proportional to the length of the gap between contacts.

* Therefore, by opening the contacts rapidly, higher dielectric strength of the medium can be achieved.

(ii) high pressure:

* If the pressure in the arc is increased, the density of the particles also increases.

* The increased density of particles causes

higher rate of deionization.

* The dielectric strength of the medium between contacts is increased.

(iii) Cooling

* Natural combination of ionized particles takes place more rapidly if they are allowed to cool.

* Therefore, dielectric strength of the medium between the contacts can be increased by cooling the arc.

(iv) blast effect.

* If the ionized particles between the contacts are swept away and replaced by unionized particles, the dielectric strength of the medium can be increased considerably.

* This may be achieved by a gas blast directed along the discharge or by forcing oil into the contact space.

CONSTRUCTIONAL AND OPERATIONAL ASPECTS OF CROSS BLAST AND AXIAL BLAST AIR CIRCUIT BREAKER

Air Blast Circuit-breaker :-

A circuit breaker can make or break a

circuit either manually or automatically under all conditions viz., no-load, full-load and short-circuits.

* These breakers employ a high pressure air-blast as an arc quenching medium. The contacts are opened in a flow of air-blast established by the opening of blast valve.

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

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

* Consequently, the arc is extinguished and flow of current is interrupted.

Advantages:

(i) The risk of fire is eliminated.

(ii) The arcing products are completely removed by the blast.

(iii) The growth of dielectric strength is so rapid.

(iv) The arcing time is very small due to the rapid build up of dielectric strength between contacts.

(v) Due to lesser arc energy, air-blast circuit breakers are very suitable for conditions where frequent operation is required.

Disadvantages:

(i) The air has relatively inferior arc extinguishing properties.

(ii) The air-blast circuit breakers are very sensitive to the variations in the rate of rise of re striking voltage.

(iii) Considerable maintenance is required for the compressor plant which supplies the air-blast.

Types Of Air-Blast Circuit Breakers:-

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

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

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

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

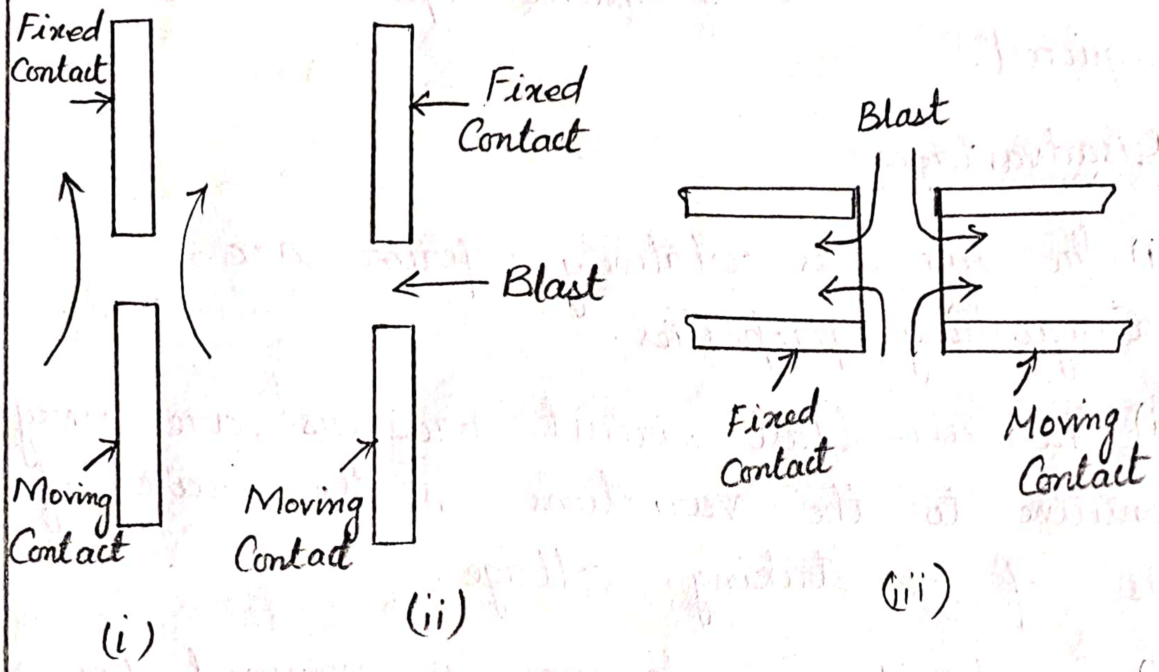


Fig. 5.7. Types of Air Blast Circuit-breaker.

<u>Axial-blast air circuit breaker</u> :-

* Fig. 5.8 shows the essential components of a typical axial 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.

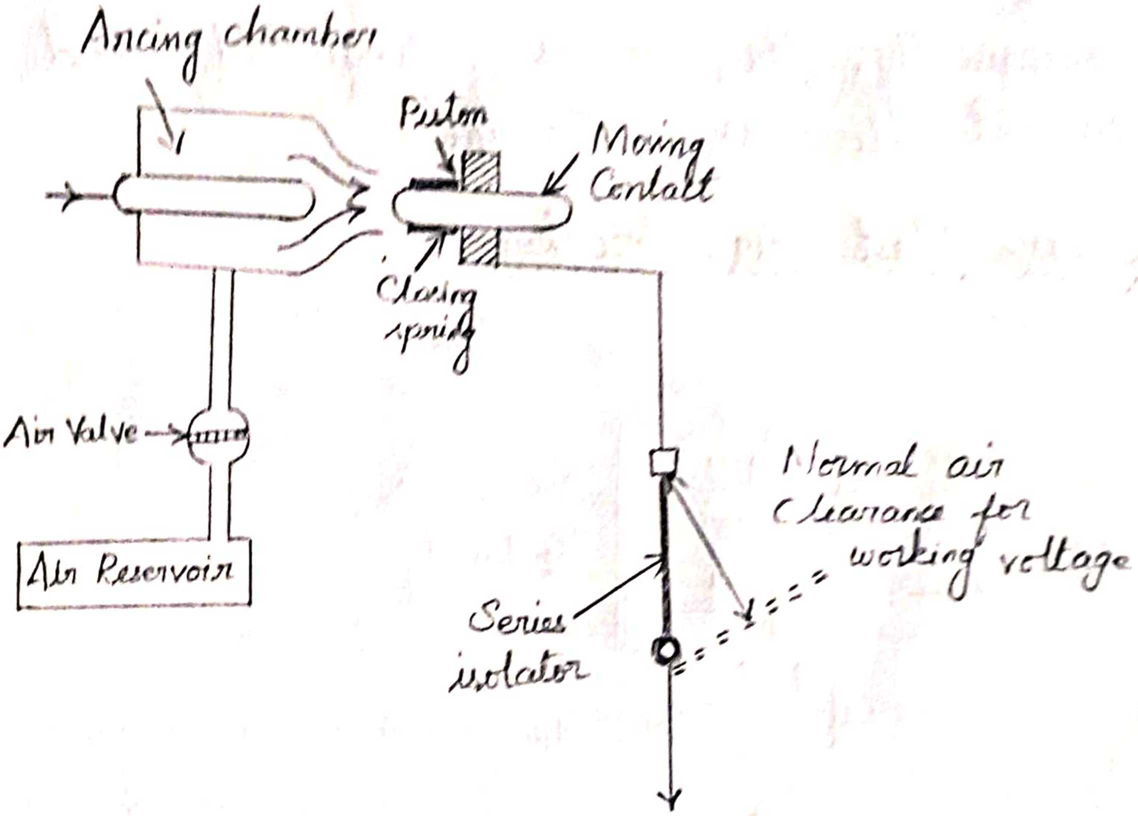


Fig. 5.8. Axial Blast C.B

* When a fault occurs, the tripping impulse causes opening of the air valve which connects the circuit breaker reservoir to the arcing chamber. The high pressure air entering the arcing chamber pushes away the moving contact against spring pressure. The moving contact is separated and arc is struck.

* At the same time, high pressure air blast flows along the arc and takes away the ionized gases along with it. Consequently, the arc is extinguished and current flow is interrupted.

Cross-blast air breaker:

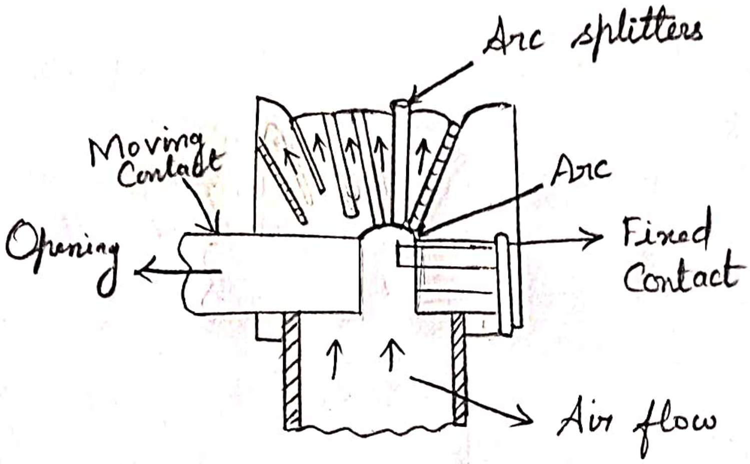


Fig. 5.9 Cross Jet C.B

* In this type of circuit breaker, an air-blast is directed at right angles to the arc. Fig. 5.9. shows the essential parts of a typical cross-blast air circuit breaker.

* When the moving contact is withdrawn an arc is struck between the fixed and moving contacts.

* The high pressure cross-blast forces the arc into a chute consisting of arc splitters and baffles.

* The splitters serve to increases the length of the arc and baffles give improved cooling.

* The result is that arc is extinguished and flow of current is interrupted.

* PRINCIPLE OF VACUUM CIRCUIT BREAKER :

Vacuum Circuit Breakers (VCB)

* In such breakers, vacuum (degree of vacuum being in the range from 10-7 to 10-5 torr) is used as the arc quenching medium.

* Since vacuum offers the highest insulating strength, it has far superior arc quenching properties than any other medium.

* For example, when contacts of a breaker are opened in vacuum, ~~(10-7 to 10-5 torr)~~, the interruption occurs at first current zero with dielectric strength between the contacts building up at a rate thousands of times higher than that obtained with other

circuit breakers.

Principle :-

* The production of arc in a vacuum circuit breaker and its extinction can be explained as follows:

* When the contacts of the breaker are opened in vacuum (10-7 to 10-5 torr), an arc is produced between the contacts by the ionisation of metal vapours of contacts.

* However, the arc is quickly extinguished because the metallic vapors, electrons and ions produced during arc rapidly condense on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength.

* 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 :-

* Fig. 5.11. shows the part of a typical vacuum circuit breaker.

* It consists of fixed contact, moving

contact and arc shield mounted inside a vacuum chamber.

* The movable member is connected to the control mechanism by stainless steel bellows. This enables the permanent sealing of the vacuum chamber so as to eliminate the possibility of leak.

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

* The arc shield prevents the deterioration of the internal dielectric strength by preventing metallic vapors falling on the inside surface of the outer insulating cover.

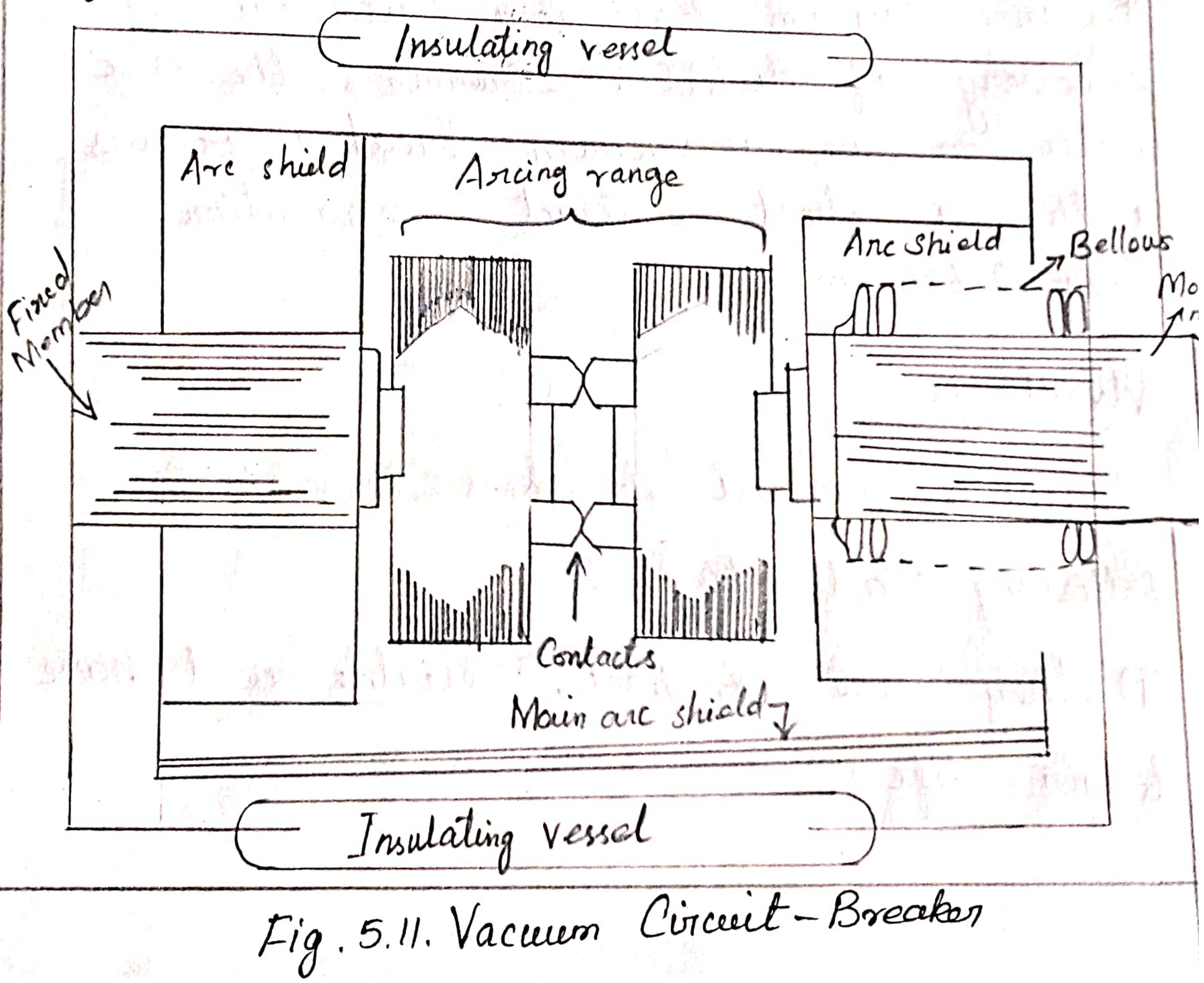


Fig. 5.11. Vacuum Circuit-Breaker

Working :-

* When the breaker operates, the moving contact separates from the fixed contact and arc is struck between the contacts.

* The production of arc is due to the ionisation of metal ions and depends very much upon the material of contacts.

* The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in a short time and seized by the surfaces of moving and fixed members and shields.

* Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker occurs with a short contract separation (say 0. 625 cm).

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 require little maintenance and are quiet in operation.

(v) They can successfully withstand lightning surges.

(vi) They have low arc energy.

Applications :

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.

* CONSTRUCTION AND WORKING OF AIR BREAK CIRCUIT BREAKER

Air Break Circuit Breaker :-

* In air break circuit breakers the atmospheric pressure air is used as an arc extinguishing medium.

* The principle of high resistance interruption is employed for such type of breakers.

* This type of circuit breakers is employed in both a.c and d.c type of circuit upto 12 kV. These are normally indoor type and installed in vertical panels.

Construction:

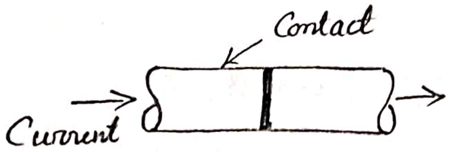
* It consists of two set of contacts:
1) Main Contacts 2) Arcing Contacts.

* During the normal operation the main contacts are closed. They are having low resistance with silver plating.

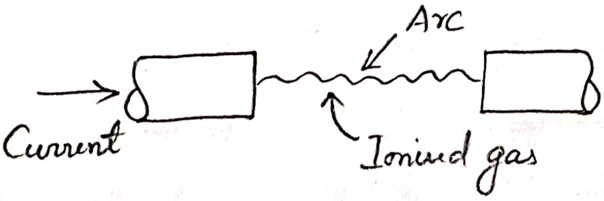
* The arcing contacts are very hard, heat resistant. They are made up of copper alloy. Arc runners are provided at the one end of arcing contact. On the Upper side are splitter plates are provided.

Working :-

* As seen from the Fig. 5.12. The contacts remain in closed position during normal condition. Whenever fault occurs, the tripping signal makes the circuit breaker contacts open.



(a) Contact closed



(b) Contacts Separated

* The arc is developed in between the contacts. Whenever the arc is struck between the contacts, the surrounding air gets ionised. The arc is then cooled to reduce the diameter of the arc core.
* Due to lengthening and cooling, arc resistance increases which will reduce fault current and will not allow to reach at high value. With increases in arc resistance the drop across it will go on increasing.

passed through arc runners with the help of blow out coils which provide a magnetic field due to which it will experience a force as given by electromagnetic theory. ($F = BIL$).

* This force will assists in moving the arc upwards. This magnetic field produced is insufficient to extinguish the arc. For system having low inductances arc gets extinguished before reaching the extremity of runners because lengthening of arc will increases the voltage drop which is insufficient to maintain the arc.

* For high inductances circuits if its not extinguished while travelling through the arc runners then it is passed through arc splitters where it is cooled. This will make the effective deionization by removing the heat from arc.

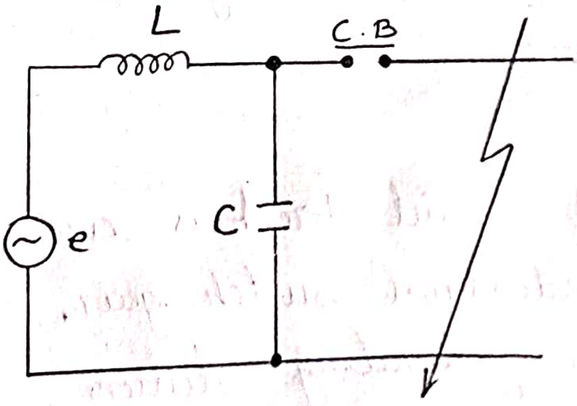
Applications:

* This type of circuit breakers are commonly employed for industrial switch gear, auxiliary switch gear in generating stations.

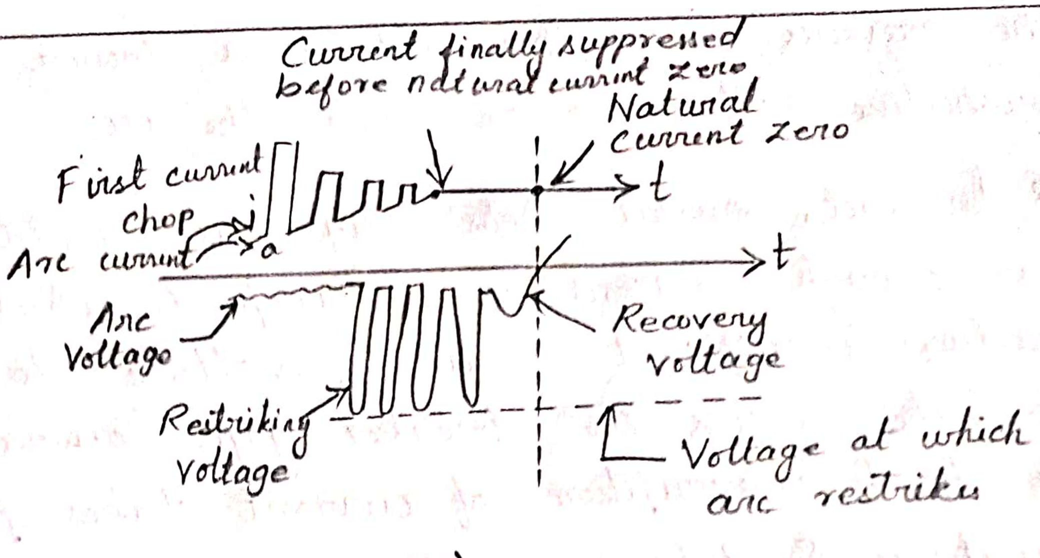
* CURRENT CHOPPING AND RESISTANCE SWITCHING

Current Chopping:

* It is the phenomenon of current interruption before the natural current zero is reached.
* Current chopping mainly occurs in air-blast circuit breakers because they retain the same extinguishing power irrespective of the magnitude of the current to be interrupted.
* When breaking low currents (e.g. transformer magnetizing current) with such breakers, the powerful de-ionising effect of air-blast causes the current to fall abruptly to zero well before the natural current zero is reached. This phenomenon is known as current chopping.
* It results in the production of high voltage transient across the contacts of the circuit breaker as discussed below:



(i)



(ii)

Fig. 5.13. Current Chopping

* Consider the Fig. 5.13 (i) Suppose the arc current is i when it is chopped down to zero value as shown by point a in Fig. 5.13. (ii)
* 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. then voltage e given by :

$$\frac{1}{2}Li^2 = \frac{1}{2}Ce^2 \; ; \text{ or } \; e = i\sqrt{\frac{L}{C}}$$

* The voltage e is very high as compared to the dielectric strength gained by the gap so that the breaker re strikes.
* As the de-ionising force is still in action, therefore, chop occurs again but the arc current this time is ~~similar~~ smaller than

the previous case. This induces a lower prospective voltage to re-ignite the arc.

* In fact, several chops may occur until a low enough current is interrupted which produces insufficient induced voltage to re-strike across the breaker gap. Consequently, the final interruption of current takes place.

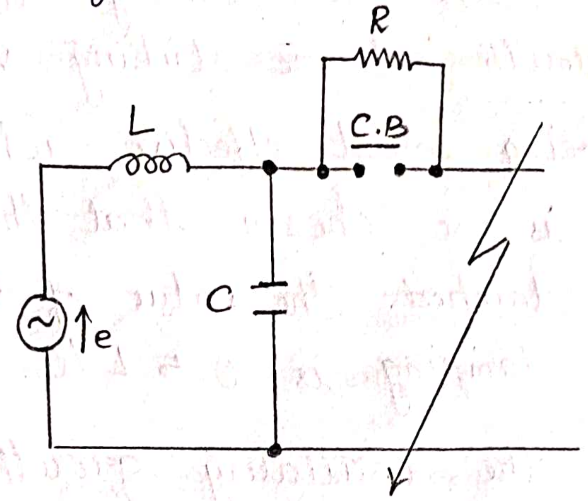
Resistance Switching:

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

* Referring to Fig 5.16 when a fault occurs, the contacts of the circuit breaker are opened and an arc is struck between the contacts. Since the contacts are shunted by resistance R, a part of arc current flows through this resistance.

* This results in the decrease of an arc current and an increase in the rate of

deionisation of the arc path. Consequently, the arc resistance is increased. The increased arc resistance leads to a further increase in current through shunt resistance.



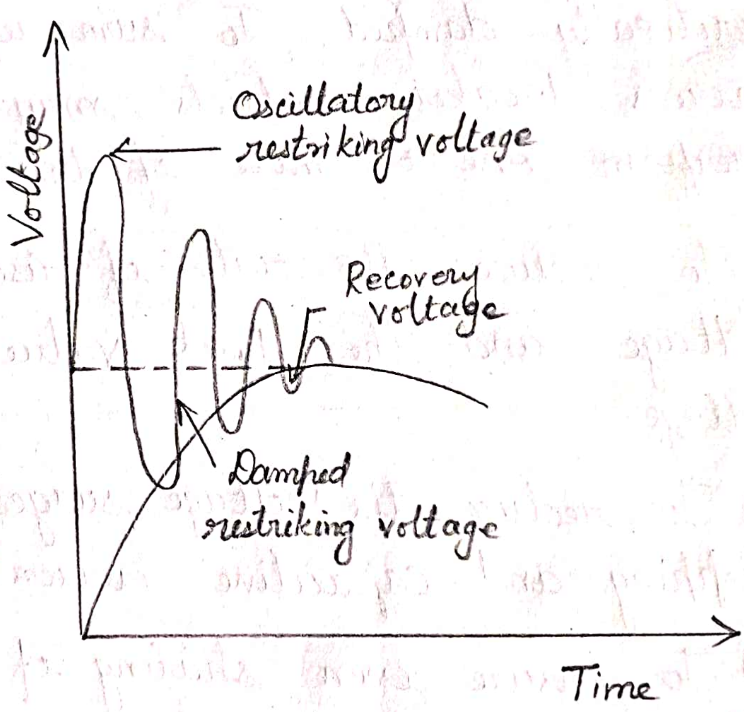


Fig. 5.16 Resistance Switching.

* This process continues until the arc current becomes so small that it fails to maintain the arc. Now, the arc is extinguished and circuit current is interrupted. The shunt resistor also helps in limiting the oscillatory growth of re-striking voltage.

* This is being most effective when the value of R is so chosen that the circuit is critically damped. The value of R required for critical damping is 0.5 L/C.

* Fig. shows the oscillatory growth and exponential growth when the circuit is critically damped. To sum up, resistors across breaker contacts may be used to perform one or more of 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.

* DIFFERENT TYPES OF CIRCUIT BREAKERS

Comparison Of Different Circuit Breakers:

S. No	Type	Medium	Voltage Breaking Capacity	Design Feature	Remarks
1.	Air-Break Circuit-Breaker	Air at atmospheric Pressure	430-600V, 35 MVA etc	Incorporates Arc Runners, Arc Splitters.	Used for Medium and low Voltages.
2.	Tank type oil C.B	Dielectric oil	12-36 kV etc.,	Arc Control device	Used upto 12 kV, 500 MVA.
3.	Minimum oil C.B	Dielectric oil	3.6-245 kV etc.,	Small size arc control device used	Outdoor: 36-245 kV
4.	Air Blast C.B	Compressed air	245 MVA, 1100 kV, etc.	Auxillary compressed air system required	Suitable for all EHV applications.
5.	SF6 C.B	SF6 Gas	7500 kV, 145 MVA, etc.,	Single Pressure type preferred	Suitable for SF6 switch gear, EHV C.B, Maintenance Free
6.	Vacuum C.B	Vacuum	36 kV, 750 MVA	Variety of designs, long life	Applications from 3.6 - 36 kV

* 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. 5.14

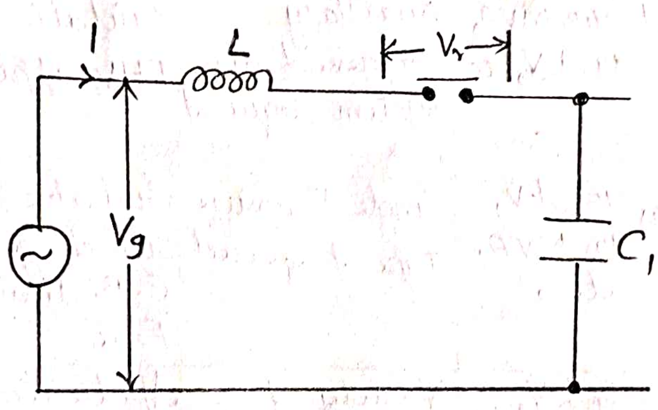


Fig. 5.14. Unloaded Transmission Line.

* This unloaded line will carry a capacitive current I on account of appreciable amount of capacitance C between the line and the earth.

* 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 5.15]

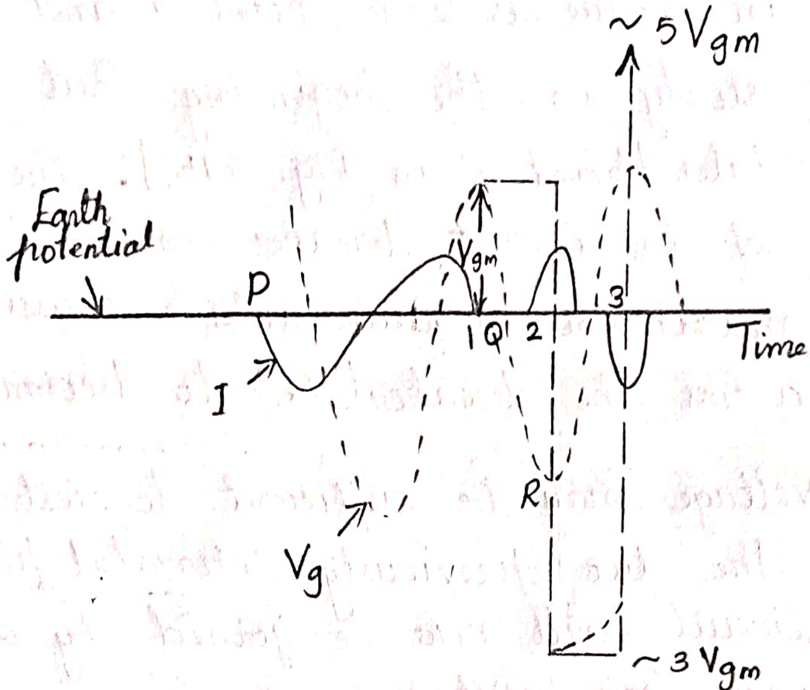


Fig 5.15. Capacitive Current Breaking.

* At this instant, the generator voltage V_g will be maximum (i.e., V_{gm}) lagging behind the current by 90°.

* On because of this some charges will present at end B of the line. Therefore 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 respectives sides.

* Its initial value is zero (point 1) and increases slowly in the beginning. But half a cycle later [point R in Fig. 5.15], the potential of the circuit breaker contact 'A' becomes maximum negative which causes the voltage across the breaker (V_r) to become $2V_{gm}$.

* 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.
* After about half a cycle further, the aforesaid events are repeated. 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}.

* 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 Vgm