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Electrical and Electronics Engineering

IIIYEAR/VIth Semester

EE8602-Protection and Switchgear

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UNIT 02 –
– ELECTROMAGNETIC RELAY

""“How much you can learn when you fail determines how far you will go into achieving your goals.”

— Roy Bennett.

Electromagnetic relay

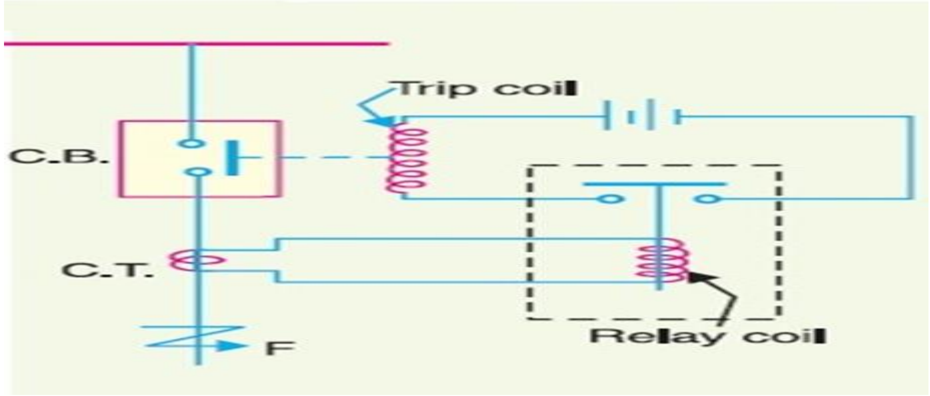
- Operating principles of relay
- The universal relay torque equation
- RX diagram
- Electromagnetic relay
- Overcurrent relay
- Directional relay
- Distance relay
- Differential relay
- Under frequency relay
- Negative sequence relay

Operating principles of Relay

- Relay is a switch which senses fault in a system and once fault is sensed by the Relay

- It issues trip command to the Circuit Breaker

- CB to isolate the faulty section of the network from the healthy section.



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Universal Relay Torque Equation

- These electromagnetic consist current and voltage windings.
- The current through the winding produces magnetic flux.
- The torque is produced by the interaction of the flux of the same winding or between the flux of both the windings.

$$Torque\ Developed\ by\ curent\ windings = K_1 I^2$$

$$Torque\ developed\ by\ voltage\ winding = K_1 V^2$$

If both the current and voltage windings are used, the torque developed by the interaction between the fluxes is given by the equation

$$= K_3 VIcos(\theta - \tau)$$

Where θ is the angle between V and I and the τ is the relay maximum torque angle.

- If the relay has current, voltage and the torque angle, the torque will be developed, and it will be given as

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

where K_1, K_2, K_3 are the tap setting or constant of V and I. The K_4 is the mechanical restraint due to spring or gravity.

The operating characteristic of all types of relays is obtained by adding and subtracting all the other constants and letting others be zero or by adding other similar terms.

$$T = K_1 I^2 - K_4$$

In over current relay the $K_2 = K_3 = 0$

for directional relay $K_1 = K_2 = 0$ and the developed torque will be

$$T = K_3 V I cos(\theta - \tau) - K_4$$

The operating characteristic of Impedance Relay

It is clear from the characteristics that if the impedance seen by the Relay lies within the circle then the Relay shall operate else it won't operate.

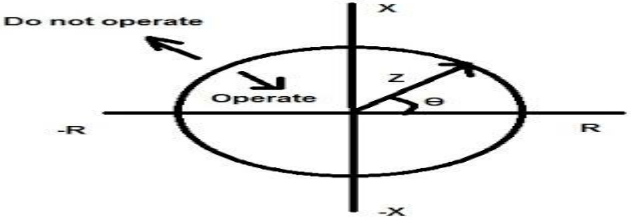
For the impedance Z as shown in figure, the current is lagging behind the Voltage by angle Ө.

If current and voltage were in phase then Z vector would have coincided with the +R axis.

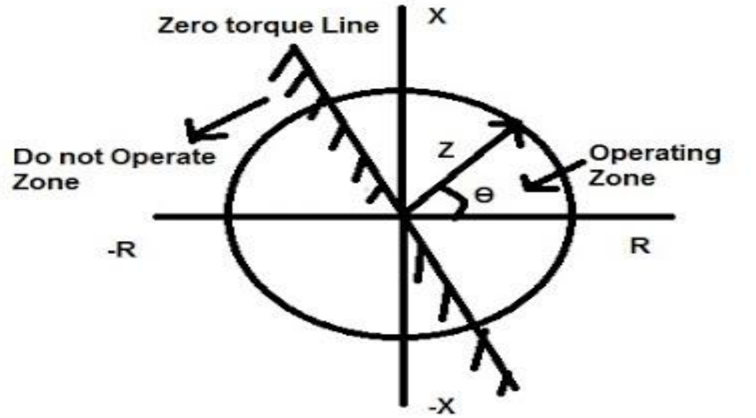
If the current leads the voltage then Z vector will be either in third or fourth quadrant.

Again in case current lags the voltage by 180 degree then Z vector coincides with –R axis.

Here it should be noted that Resistance is not negative rather it implies that current is lagging by 180 degree.



- **Impedance Relay to make it directional.**
- This means Impedance Relay will only operate if the directional unit picks up and impedance seen by relay is within the circle.
- For providing directional feature we need to draw a Zero Torque Line to separate the R-X plane in Operate and Do not Operate region as shown in fi



Electromagnetic Relay

- Electromagnetic relays are those relay which operates on the principle of electromagnetic attraction.

- It is a type of a magnetic switch which uses the magnet for creating a magnetic field.

- The magnetic field then uses for opening and closing the switch and for performing the mechanical operation.

- Types of an Electromagnetic Relay

  Electromagnetic Attraction Relay

  Electromagnetic Induction Relay

Electromagnetic Attraction Relay

- In this relay, the armature is attracted to the pole of a magnet.
- The electromagnetic force exerted on the moving element is proportional to the square of the current flow through the coil.
- This relay responds to both the alternating and direct current.
- For AC quantity the electromagnetic force developed is given as

one constant independent of time and another dependent upon time and pulsating at double supply frequency.

$$F_e = KI^2 = K(Imax\ sin\omega t)^2$$
$$= \frac{1}{2}K[1^2_{max} - I^2_{max}cos2\omega t]$$

This double supply frequency produces noise and hence damage the relay contacts.

The difficulty of a double frequency supply is overcome by splitting the flux developing in the electromagnetic relay.

- These fluxes were acting simultaneously but differ in time phase. Thus the resulting deflecting force is always positive and constant.
- The splitting of fluxes is achieved by using the electromagnet having a phase shifting networks or by putting shading rings on the poles of an electromagnet.

- **Balanced Beam Relay –** In such type of relay two quantities are compared because the electromagnetic force developed varies as the square of the ampere-turn. The ratio of an operating current for such relay is low. If the relay is set for fast operation, then it will tend to overreach on a fast operation.
- **Hinged armature relay –** The sensitivity of the relay can be increased for DC operation by adding the permanent magnet. This relay is also known as the polarized moving relay.

Electromagnetic Induction Relay

- The electromagnetic relay operates on the principle of a split-phase induction motor.

- The initial force is developed on the moving element that may be disc or another form of the rotor of the non-magnetic moving element.

- The force is developed by the interaction of electromagnetic fluxes with eddy current, that is induced in the rotor by these fluxes.
- They categorized as three types

  a . Shaded pole structure
  b. Watt-hour meter or double winding structure
  c. Induction cup structure.

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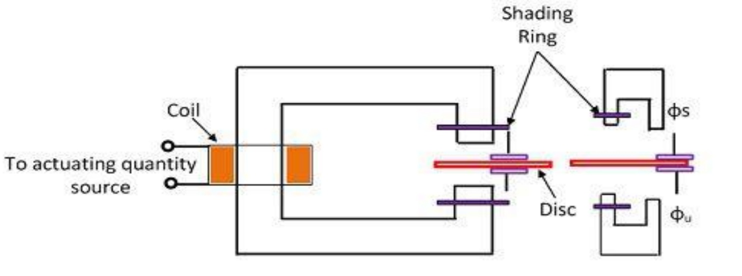
Shaded pole structure

- This coil is usually energized by current flowing in the single coil wound on a magnetic structure containing an air gap.
- The air-gap fluxes produce by the initializing current is split into two flux displace in time-space and by a shaded ring.
- The shaded ring is made up of the copper ring that encircles the part of the pole face of each pole.

- The two rings have the current induced in them by
- the alternating flux of the electromagnetic.

- The magnetic field develops from the current



Shaded Pole Construction of Induction Disc Relay

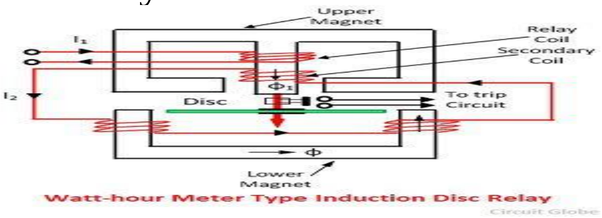
produces the flux in the portion of the iron ring surrounded by the ring to lag in phase by 40° to 50° behind the flux in the un shaded portion of the pole

Watt-hour Meter Structure

- This structure consists E shape electromagnet and a U shape electromagnet with a disc-free to rotate in between them.

- The phase displacement between the fluxes produced by the electromagnet is obtained by the flux generated by the two magnets having different resistance and inductance for the two circuits.

- The primary winding carries relay current I_1 while the secondary current induces the emf in the secondary and so circulate the current I_2 in it.



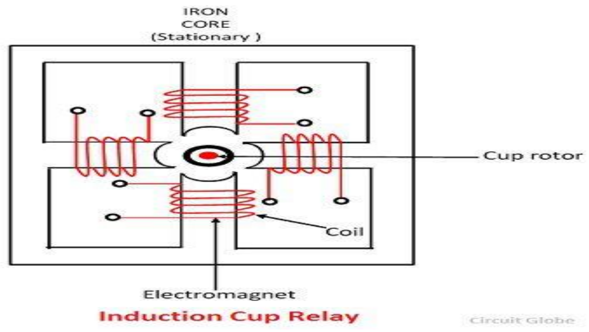
- The flux φ_1 induces in the E shed magnet,

and the flux φ induces in the U-shaped magnet.

- These fluxes induced in the upper and lower magnetic differs in phase by angle θ which will develop a driving torque on the disc proportional to $\varphi_1\varphi \sin\theta$.

Induction Cup Relay

- The relay which works on the principle of electromagnetic induction is known as the induction cup relay.
- The relay has two or more electromagnet which is energized by the relay coil.
- The static iron core is placed between the electromagnet as shown in the figure below.



- The coil which is wound on the electromagnet generates the rotating magnetic field.
- Because of the rotating magnetic field, the current induces inside the cup. Thus, the cup starts rotating.
- The direction of rotation of the cup is same as that of the current.
- The relay is fast in operation and their operating time is very less approximately 0.01 sec.

Over Current Relay

- In an **over current relay**, there would be essentially a current coil.
- When normal current flows through this coil, the magnetic effect generated by the coil is not sufficient to move the moving element of the relay, as in this condition the restraining force is greater than deflecting force.
-
- But when the current through the coil increases, the magnetic effect increases, and after a certain level of current, the deflecting force generated by the magnetic effect of the coil, crosses the restraining force.
- As a result, the moving element starts moving to change the contact position in the relay.

Types of Over Current Relay

- **Instantaneous over current relay**.

- **Definite time over current relay**

- **Inverse time over current relay**.

- **Inverse definite minimum time** (IDMT),
  V**ery inverse time,**
  E**xtremely inverse time over current relay**

Instantaneous Over Current Relay

- The relay has no intentional time delay for operation. The contacts of the relay are closed instantly when the current inside the relay rises beyond the operational value.
- The time interval between the instant pick-up value and the closing contacts of the relay is very less.
- The most significant advantage of the instantaneous relay is that it has low operating time.
- It starts operating instantly when the value of current is more than the relay setting.
- This relay operates only when the impedance between the source and the relay is less than that provided in the section.
- The most important feature of the relay is their speed of operation. The relay protects the system from earth fault and also used for protecting the system from circulating current. The instantaneous overcurrent relay is placed in the outgoing feeder.

Inverse-Time Overcurrent Relay

- The relay operates only when the magnitude of their operating current is inversely proportional to the magnitude of the energize quantities.

- The operating time of relay decreases with the increases in the current. The operation of the relay depends on the magnitude of the current

- The characteristic curve for the relay is shown in the figure below. The relay will not operate when the value of current is less than the pick value.
- The relay is used for the protection of the distribution lines. The inverse time relay is of three types.

Inverse Definite Minimum Time Relay

- The relay whose operating time is approximately proportional to the fault current is known as the IDMT relay.

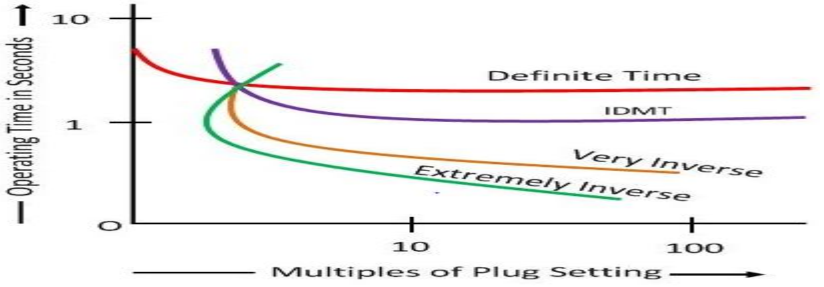
- The operating time of the relay is maintained by adjusting the time delay setting.

- The IDMT relay uses the electromagnetic core because it can easily saturate for the current having larger magnitude than pick up current.

- The relay is used for the protection of the distribution line.

Very Inverse Relay

- The inverse characteristic of the relay is more than the IDMT. Such type of relay is used in the feeder and on long transmission lines.
- The relay is used in the places where there the magnitude of the short-circuit current fall rapidly because of the large distance from the source.
- It is used for sensing the fault current which is free from the fault location.



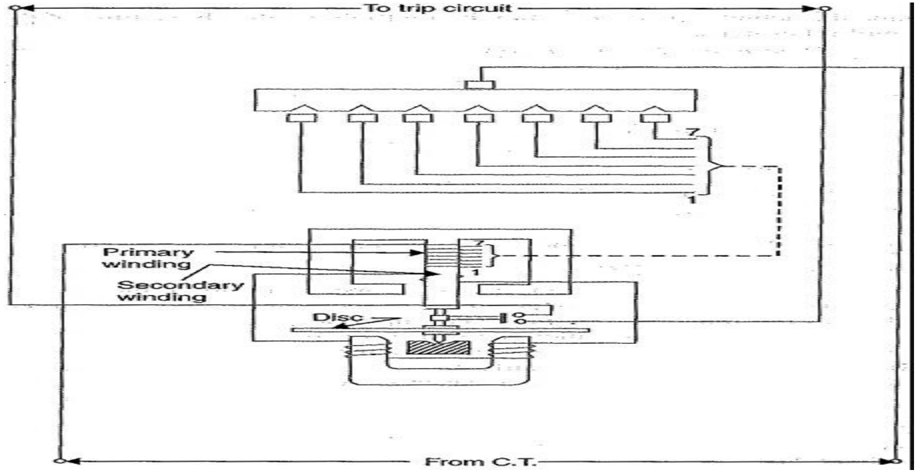
Characteristic of Various Overcurrent Relay

Extremely Inverse Relay

- The characteristic time of the relay is extremely large as compared to the IDMT and the Very inverse relay.
- This relay is used for protecting the cable, transformer, etc.
- The relay can operate instantly when the pickup value of the current is more than the relay setting time.
- The relay provides faster operation even under the fault current.
- It is used for sensing the overheating of the machines.
- The inverse time relay is used in the distribution networks and the power plants.
- The relay gives the fast operation in the fault conditions because of their fault time characteristic.

Induction Type Overcurrent Relay(Non-Directional):

- This Induction Type Overcurrent Relay works on the induction principle and initiates corrective measures when current in the circuit exceeds the predetermined value.
- The actuating source is a current in the circuit supplied to the relay from a current transformer. These relays are used on a .c. circuits only and can operate for fault current flow in either direction.



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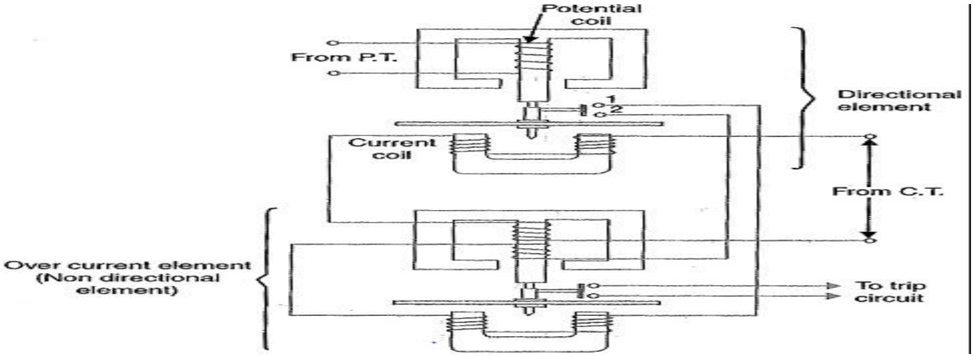
- The driving torque on the aluminum disc is set up due to the induction principle
- This torque is opposed by the restraining torque provided by the spring.
- Under normal operating conditions, restraining torque is greater than the driving torque produced by the relay coil current, Therefore, the aluminum disc remains stationary.
- However, if the current in the protected circuit exceeds the pre-set value, the driving torque becomes greater than the restraining torque.
- Consequently, the disc rotates and the moving contact bridges the fixed contacts when the disc has rotated through a pre-set angle.
- The trip circuit operates the circuit breaker which isolates the faulty section.

Induction Type Directional Overcurrent 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 Overcurrent Relay which is designed to be almost independent of system voltage and power factor



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Induction Type Directional Overcurrent Relay:

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

- Under normal operating conditions, power flows in the normal direction in the circuit protected by the relay
- Induction Type Directional Overcurrent Relay (upper element) does not operate, thereby keeping the overcurrent element (lower element) un energized.
- when a short-circuit occurs, there is a tendency for the current or power to flow in the reverse direction. \
- The disc of the upper element rotates to bridge the fixed contacts 1 and 2. This completes the circuit for overcurrent element.

Differential Relay:

- **A differential relay is one that operates when the phasor difference of two or more similar electrical quantities exceeds a pre-determined value.**
- Thus a current differential relay is one that compares the current entering a section of the system with the current leaving the section.
- Under normal operating conditions, the two currents are equal but as soon as a fault occurs, this condition no longer applies.
- The difference between the incoming and outgoing currents is arranged to flow through the operating coil of the relay.

Current balance protection

Voltage balance protection

Current 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 secondary's of CT's are connected in series in such a way that they carry the induced currents in the same direction.
- The operating coil of the over current relay is connected across the CT secondary circuit.
- This differential relay compares the current at the two ends of the alternator winding.

Current Differential Relay:

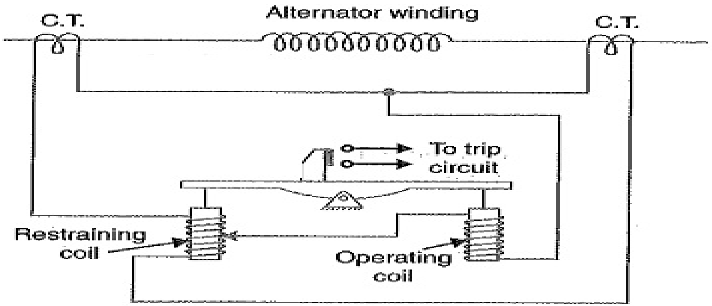
- Under normal operating conditions, suppose the alternator winding carries a normal current of 1000 A. Then the currents in the two secondary's of CT's are equal .
- These currents will merely circulate between the two CT's and no current will flow through the differential relay.
- Therefore, the relay remains inoperative. If a ground fault occurs on the alternator winding
- 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 of Current Differential Relay:

- 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
- Pilot cable capacitance causes incorrect operation of the relay when a large through-current
- 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:

- 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.
- It is essentially an overcurrent balanced beam relay type with an additional restraining coil.
- The restraining coil produces a bias force in the opposite direction to the operating force.

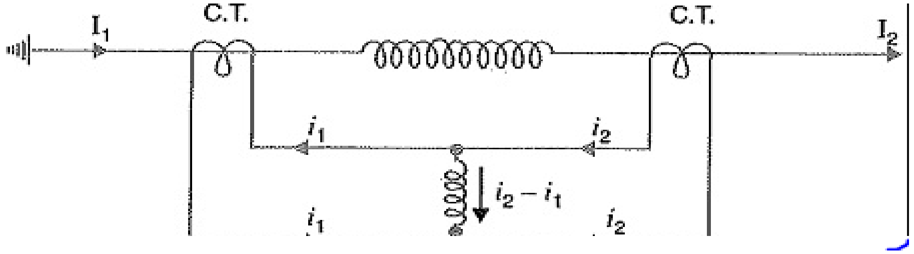


- Under normal and through load conditions, the bias force due to restraining coil is greater than the operating force.
- Therefore, the relay remains inoperative. When an internal fault occurs, the operating force exceeds the bias force.
- Consequently, the trip contacts are closed to open the circuit breaker.
- The bias force can be adjusted by varying the number of turns on the restraining coil.
- The differential current in the operating coil is proportional to $i_2 — i_1$ and the equivalent current in the restraining coil is proportional to $(i_1 + i_2)/2$ 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.

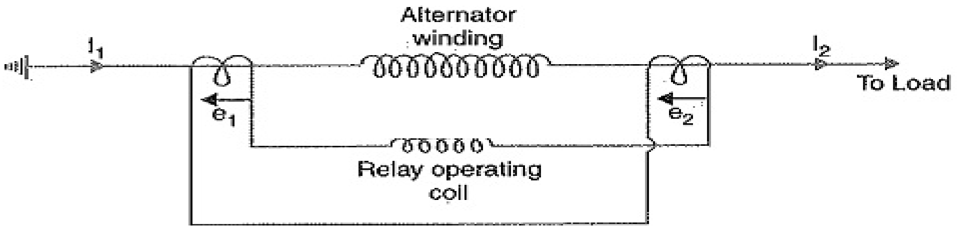
- Thus under a heavy load, a greater differential current through the relay operating coil is required for operation than under light load conditions.

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



Voltage Balance Differential Relay:

- In this scheme of protection, two similar current transformers are connected at either end of the element to be protected (e.g. an alternator winding) by means of pilot wires.
- The secondary's of current transformers are connected in series with a relay in such way that under normal conditions, their induced e.m.f's are in opposition.



- Under healthy conditions, equal currents $I_I = I_2$ flow in both primary windings.

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

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

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

Disadvantages in Voltage Balance Differential Relay:

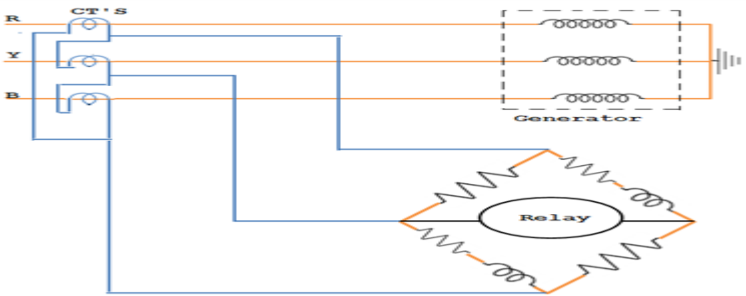
- The voltage balance system suffers from the following drawbacks:
- A multi-gap transformer constriction is required to achieve the accurate balance between current transformer pairs.
- The system is suitable for protection of cables of relatively short lengths due to the capacitance of pilot wires.
- On long, cables, the charging current may be sufficient to operate the relay even if a perfect balance of current transformers is attained.

Under Frequency Relay

- Frequency based relays can either be ***under frequency relay*** or ***over frequency relay***.
- The frequency relays are normally used in **generator** **protection** and for **load-frequency control**.
- The frequency of induced e.m.f. of synchronous generator is maintained constant by constant speed.
- Over speeding of the generator occurs due to loss of load and under speeding occurs due to increase in load. In both the cases, the frequency varies from normal value.
- *Under frequency relay* trips the feeder on load at set value of frequency, so as to give relief to the generator, thereby saving the unit.

Negative Sequence Relay

- **Negative sequence relays** are used to **protect electrical machines** against overheating due to **unbalance currents in stator**.
- These unbalance currents cause heating of rotor and damage it.
- Unbalance three-phase currents have negative sequence components.
- These components rotate at synchronous speed in a direction opposite to the direction of rotation of rotor, including double frequency currents in the rotor.



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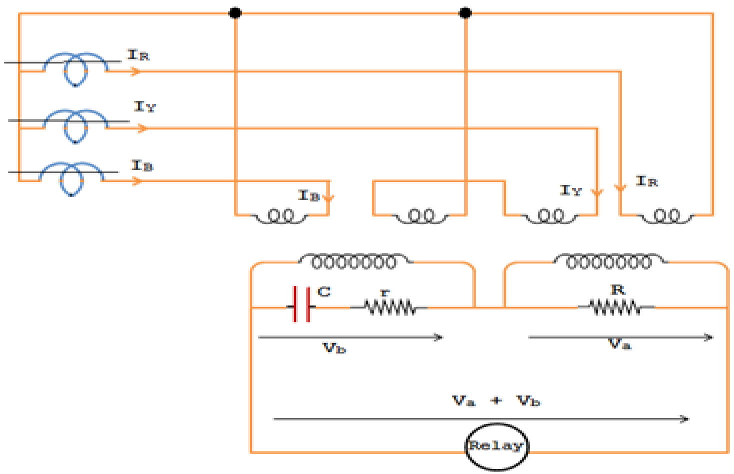
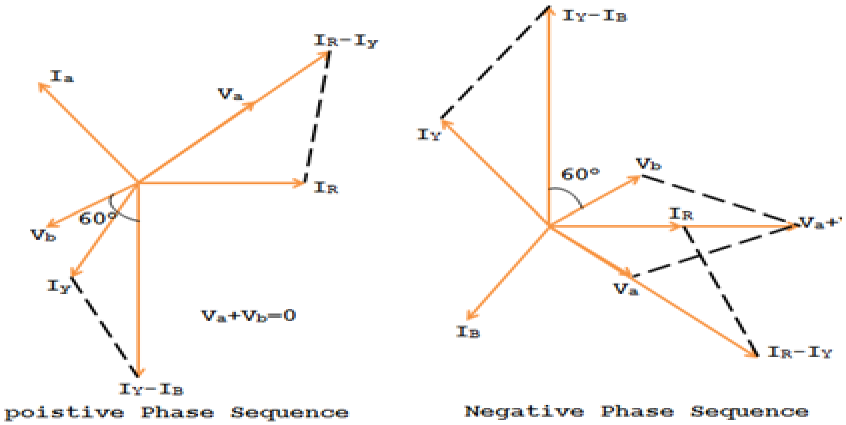
- The relay is connected in parallel across the current transformer secondary's.
- Under normal conditions, as equal current flows in all the three phases, their algebraic sum is zero.
- Hence no current flows through the relay.
- But, if unbalancing occurs, the secondary currents will be different and the resultants current flows through the relay and the **operation of the relay** trips the **circuit breaker** to disconnect the generator from the system.

- For unbalanced conditions or **unsymmetrical faults**, negative phase sequence network are used



- The values of c and r are such as to give a phase shift 60°.
- It can be seen from the vector diagrams that for the positive sequence currents the output voltage $V_a + V_b$ applied to the relay is zero shown in fig-a below where for the negative sequence currents,
- The output voltage $V_a + V_b$ is of considerable magnitude to operate the relay shown in fig



The negative sequence relay has the **inverse square law characteristic**.

i.e., $I_2^2 t = K$, a constant. I_2 is the negative sequence component of the current.

$t = K / I_2^2$ i.e., $t \alpha 1/I_2^2$.

The relay will trip the generator main breaker.