UNIT II

OPERATING PRINCIPLES AND RELAY CHARACTERISTICS

2.1 Electromagnetic Relay

Electromagnetic relays are those relays which are operated by electromagnetic action. Modern electrical protection relays are mainly micro processor based, but still electromagnetic relay holds its place. It will take much longer time to be replaced the all electromagnetic relays by micro processor based static relays. So before going through detail of protection relay system we should review the various types of electromagnetic relays. Electromagnetic Relay Working

Practically all the relaying device are based on either one or more of the following types of electromagnetic relays.

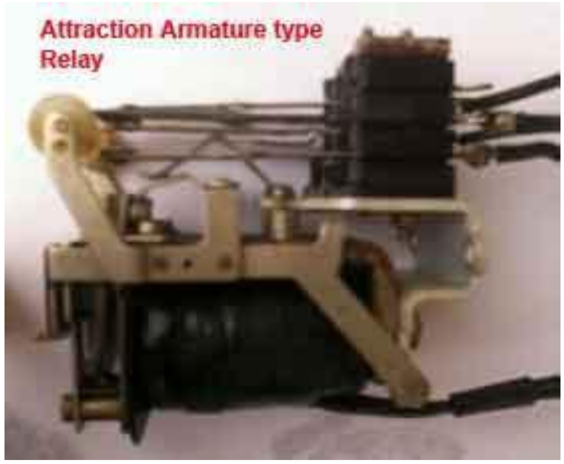
1. Magnitude measurement,
2. Comparison,
3. Ratio measurement.

Principle of electromagnetic relay working is on some basic principles. Depending upon working principle the these can be divided into following types of electromagnetic relays.

1. Attracted Armature type relay,
2. Induction Disc type relay,
3. Induction Cup type relay,
4. Balanced Beam type relay,
5. Moving coil type relay,
6. Polarized Moving Iron type relay.

Attraction Armature Type Relay

Attraction armature type relay is the most simple in construction as well as its working principle. These types of electromagnetic relays can be utilized as either magnitude relay or ratio relay. These relays are employed as auxiliary relay, control relay, over current, under current, over voltage, under voltage and impedance measuring relays.



Hinged armature and plunger type constructions are most commonly used for these types of electromagnetic relays. Among these two constructional design, hinged armature type is more commonly used.

We know that force exerted on an armature is directly proportional to the square of the magnetic flux in the air gap. If we ignore the effect of saturation, the equation for the force experienced by the armature can be expressed as,

$$F = (KI^2 - K')$$

Where F is the net force, K' is constant, I is rms current of armature coil, and K' is the restraining force.

The threshold condition for relay operation would therefore be reached when $KI^2 = K'$.

If we observe the above equation carefully, it would be realized that the relay operation is dependent on the constants K' and K for a particular value of the coil current.

From the above explanation and equation it can be summarized that, the operation of relay is influenced by

1. Ampere – turns developed by the relay operating coil,
2. The size of air gap between the relay core and the armature,
3. Restraining force on the armature.

Construction of Attracted Type Relay

This relay is essentially a simple electromagnetic coil, and a hinged plunger. Whenever the coil becomes energized the plunger being attracted towards core of the coil. Some NO-NC (Normally Open and Normally Closed) contacts are so arranged mechanically with this plunger, that, NO contacts become closed and NC contacts become open at the end of the plunger movement. Normally attraction armature type relay is dc operated relay. The contacts are so arranged, that, after relay is operated, the contacts cannot return their original positions even after the armature is de energized. After relay operation, this types of electromagnetic relays are reset manually.

Attraction armature relay by virtue of their construction and working principle, is instantaneous in operation.

Induction Disc Type Relay

Induction disc type relay mainly consists of one rotating disc.

Induction Disc type Relay Working

Every induction disc type relay works on the same well known Ferraries principle. This principle says, a torque is produced by two phase displaced fluxes, which is proportional to the product of their magnitude and phase displacement between them. Mathematically it can be expressed as-

$$T = K\phi_1\phi_2 \sin\theta$$

Induction Disc Type Relay

The induction disc type relay is based on the same principle as that of an ammeter or a volt meter, or a wattmeter or a watt hour mater. In induction relay the deflecting torque is produced by the eddy currents in an aluminium or copper disc by the flux of an ac electromagnet. Here, an aluminium (or copper) disc is placed between the poles of an AC magnet which produces an alternating flux φ lagging from I by a small angle. As this flux links with the disc, there must be an induced emf E_2 in the disc, lagging behind the flux φ by 90^o. As the disc is purely resistive, the induced current in the disc I_2 will be in phase with E_2. As the angle between φ and I_2 is 90°, the net torque produced in that case is zero. As,

$$T = \phi I_2 \cos 90^\circ = 0$$

In order to obtain torque in induction disc type relay, it is necessary to produce a rotating field.

Pole Shading Method of Producing Torque in Induction Disc Relay

In this method half of the pole is surrounded with copper ring as shown. Let φ_1 is the flux of unshaded portion of the pole. Actually total flux divided into two equal portions when the pole is divided into two parts by a slot.

$$Total\ flux,\ \phi = \phi_1 + \phi_2$$

As the one portion of the pole is shaded by copper ring. There will be induced current in the shade ring which will produce another flux φ_2' in the shaded pole. So, resultant flux of shaded pole will be vector sum of & phi;$_1$ and φ_2. Say it is φ_2, and angle between φ_1 and φ_2 is θ. These two fluxes will produce a resultant torque,

$$T = K\phi_1\phi_2\sin\theta$$

There are mainly three types of shape of rotating disc are available for induction disc type relay. They are spiral shaped, round and vase shaped, as shown. The spiral shape is done to compensate against varying restraining torque of the control spring which winds up as the disc rotates to close its contacts. For most designs, the disc may rotate by as much as 280°. Further, the moving contact on the disc shift is so positioned that it meets the stationary contacts on the relay frame when the largest radius section of the disc is under the electromagnet. This is done to ensure satisfactory contact pressure in induction disc type relay.

Where high speed operation is required, such as in differential protection, the angular travel of the disc is considerably limited and hence circular or even vane types may be used in induction disc type electromagnetic relay.

Some time it is required that operation of an induction disc type relay should be done after successful operation of another relay. Such as inter locked over current relays are generally used for generator and bus bar protection. In that case, the shading band is replaced by a shading coil. Two ends of that shading coil are brought out across a normally open contact of other control device or relay. Whenever the latter is operated the normally open contact is closed and makes the shading coil short circuited. Only after that the over current relay disc starts rotating.

One can also change the time / current characteristics of an induction disc type relay, by deploying variable resistance arrangement to the shading coil.

Induction disc relay fed off a negative sequence filter can also be used as Negative-sequence protection device for alternators.

Induction Cup Type Relay

Induction cup type relay can be considered as a different version of induction disc type relay. The working principle of both type of relays are more or less some. Induction cup type relay are used where, very high speed operation along with polarizing and/or differential winding is requested. Generally four pole and eight pole design are available. The number of poles depends upon the number of winding to be accommodated.

The inertia of cup type design is much lower than that of disc type design. Hence very high speed operation is possible in induction cup type relay. Further, the pole system is designed to give maximum torque per KVA input. In a four pole unit almost all the eddy currents induced in the cup by one pair of poles appear directly under the other pair of poles – so that torque / VA is about three times that of an induction disc with a c-shaped electromagnet.

Induction cup type relay is practically suited as directional or phase comparison units. This is because, besides their sensitivity, induction cup relay have steady non vibrating torque and their parasitic torque due to current or voltage alone are small.

Induction Cup Type-Directional or Power Relay

It in a four pole induction cup type relay, one pair of poles produces flux proportional to voltage and other pair of poles produces flux proportional to current. The vector diagram is given below,

The torque $T_1 = K\varphi_{vi}.\varphi_i.\sin(90° - \theta)$ assuming flux produced by the voltage coil will lag 90° behind its voltage. By design, the angle can be made to approach any value and a torque equation $T = K.E.I.\cos(\varphi - \theta)$ obtained, where θ is the E - I system angle.

Accordingly, induction-cup type relay can be designed to produced maximum torque When system angle θ = 0° or 30° or 45° or 60°. The former is known as power relays as they produce maximum torque when θ = 0° and latter are known as directional relays – they are used for directional discrimination in protective schemes under fault conditions, as they are designed to produce maximum torque at faulty conditions.

2.2 Over Current Relay Working Principle Types

In an over current relay or o/c relay the actuating quantity is only current. There is only one current operated element in the relay, no voltage coil etc. are required to construct this protective relay.

Working Principle of 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 increased, the magnetic effect increases, and after 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.

Although there are different **types of over current relays but basic working principle of over current relay** is more or less same for all.

Types of Over Current Relay

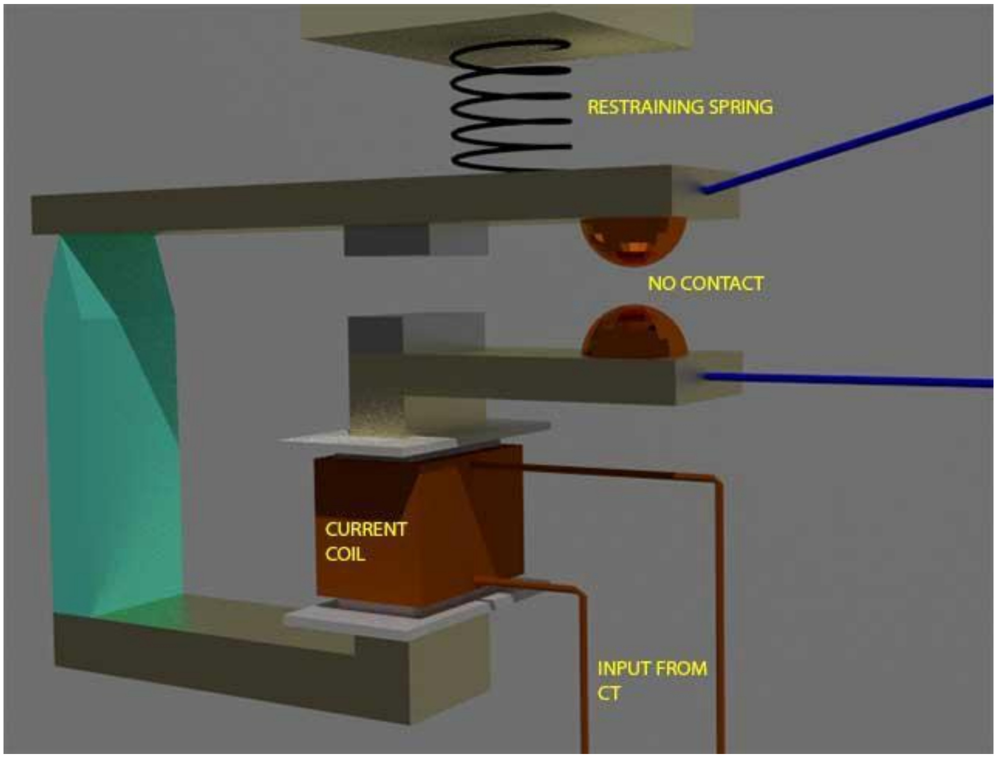
Depending upon time of operation, there are various **types of OC relays**, such as,

1. **Instantaneous over current relay**.
2. **Definite time over current relay**.
3. **Inverse time over current relay**.

Inverse time over current relay or simply inverse OC relay is again subdivided as inverse definite minimum time **(**IDMT**),** very inverse time**,** extremely inverse time over current relay or OC relay**.**

Instantaneous Over Current Relay

Construction and working principle of **instantaneous over current relay quite simple.**



Here generally a magnetic core is wound by current coil. A piece of iron is so fitted by hinge support and restraining spring in the relay, that when there is not sufficient current in the coil, the NO contacts remain open. When current in the coil crosses a present value, the attractive force becomes sufficient to pull the iron piece towards the magnetic core and consequently the No contacts are closed.

The preset value of current in the relay coil is referred as pick up setting current. This relay is referred as instantaneous over current relay, as ideally, the relay operates as soon as the current in the coil gets higher than pick up setting current. There is no intentional time delay applied. But there is always an inherent time delay which can not be avoided practically. In practice the operating time of an instantaneous relay is of the order of a few milliseconds. Fig.

2.3 Directional Over Current Relays

1. When fault current can flow in both the directions through the relay, at its location. Therefore, it is necessary to make the relay respond for a particular defined direction, so that proper discrimination is possible. This can be achieved by introduction of directional control elements.

2. These are basically power measuring devices in which the system voltage is used as a reference for establishing the relative phase of the fault current.

Basically, an AC directional relay can recognize certain difference in phase angle between two quantities, just as a D.C. directional relay recognize difference in polarity

The polarizing quantity of a directional relay

1. It is the reference against which the phase angle of the other quantity is compared. Consequently the phase angle of the polarizing quantity must remain fixed when other quantity suffers wide change in phase angle.

2. The voltage is chosen as the "polarizing" quantity in the current-voltage induction type directional relay.

3. Four pole induction cup construction is normally used.

2.4 Distance relay

Distance relay is used for the protection of transmission line & feeders In a distance relay, instead of comparing the local line current with the current at far end of line, the relay compares the local current with the local voltage in the corresponding phase or suitable components of them

Principle of operation of distance relay

1. The basic principle of measurement involves the comparison of fault current seen by the relay with the voltage at relaying point; by comparing these two quantities.

2. It is possible to determine whether the impedance of the line up to the point of fault is greater than or less than the predetermined reach point impedance

There are two types of torques

1. Restraining torque

$$T_r \alpha V_F^2$$

2. Operating torque

$$T_0 \alpha I_F^2$$

The relay trips when T_0 greater than T_r

$$KI_F^2 > V_F^2$$

$$\frac{V_F}{I_F} < \sqrt{K}$$

The constant K depends on the design of the electromagnets.

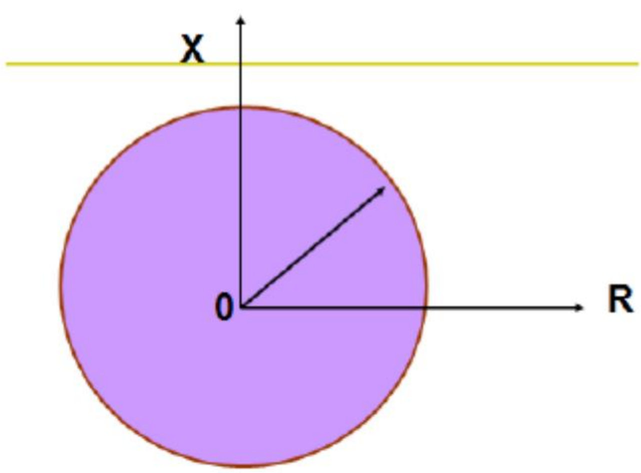
Types of distance relay Distance relays are classified depending on their operating characteristic in the R-X plane

• Impedance Relay
• Mho Relay
• Reactance Relay

2.5 IMPEDANCE RELAY:

The torque equation T, for such a relay the current actuates the operating torque and the voltage actuates the restraining torque, with the usual spring constant K4.

$$T = K_1 I^2 + K_2 V^2 + K_4$$



Considering K2 to be negative (as it produces the restraining torque) and neglecting the torque component due to spring, the equation represents a circle in the R-X plane.

DISADVANTAGE OF IMPEDANCE RELAY

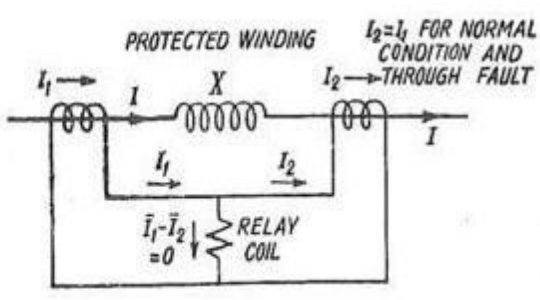
1. It is not directional.
2. It is affected by the Arc resistance
3. It is highly sensitive to oscillations on the power system, due to large area covered by its circular characteristic

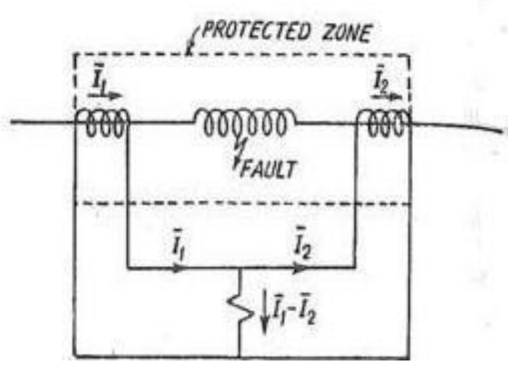
2.6 Differential Relay

One of the most prevalent and successful method of protecting a circuit is to arrange relays to compare the currents entering and leaving it, which should be the same under normal conditions and during an external fault. Any difference current must be flowing in to a fault within the protected circuit

Principle of circulating current differential (MERZ-PRIZE) protection

The figure below illustrates the principle of differential protection of generator and transformer, X is the winding of the protected machine. Where there is no internal fault, the current entering in X is equal in phase and magnitude to current leaving X. The CT's have such a ratio that during the normal conditions or for external faults (Through Faults) the secondary current of CT's are equal. These current say I1 and I2 circulate in the pilot wire. The polarity connections are such the current I1 and I2 are in the same direction of pilot wire during normal condition or external faults. Relay operation coil is connected at the middle of pilot wires. Relay unit is of over current type





During normal condition and external fault the protection system is balanced and the CT's ratios are such that secondary currents are equal. These current circulate in pilot wires. The vector differential current I1- I2 which flow through the relay coil is zero. I1-I2 = 0 (normal condition or external faults) This balance is disturbed for internal faults. When fault occurs in the protected zone, the current entering the protected winding is no more equal to the leaving the winding because some current flows to the fault. The differential I1-I2 flows through the relay operating coil and the relay operates if the operating torque is more than the restraining torque. The current I1 and I2 circulate in the secondary circuit. Hence CT's does not get damaged. Polarities of CT's should be proper, otherwise the currents I1 and I2 would add up even for normal condition and mal operate the relay.

Differential Protection current balance

• When this system is applied to electrical equipment (Generator stator windings, Transformer, Bus bars etc.) it is called differential current protection.

• When it is applied to lines and cables it is called pilot differential protection because pilot wires or an equivalent link or channel is required to bring the current to the relay from the remote end of the line.

The CTs at both ends of the protected circuit connected so that for through load or through fault conditions current circulates between the interconnected CTs. The over-current relay is normally connected across equipotential points and therefore doesn‟t operate.

• Circulating current balance methods are widely used for apparatus protection where CTs are within the same substation area and interconnecting leads between CTs are short (e.g. generator stator windings, Transformer, Bus bars etc.)

• The circulating current balance method is also called longitudinal differential protection or Merz-Price differential protection system.

• The current in the differential relay would be proportional to the phasor difference between the currents that enter and leave the protected circuit. If the current through the relay exceeds the pick-up value, then the relay will operate.

Demerits of a Differential Relay(Merz Price Scheme)

- **Unmatched characteristics of C.T.s** :

Though the saturation is avoided, there exist difference in the C.T. characteristics due to ratio error at high values of short circuit currents. This causes an appreciable difference in the secondary currents which can operate the relay. So the relay operates for through external faults. This difficulty is overcome by using percentage differential relay. In this relay, the difference in current due to the ratio error exists and flows through relay coil. But at the same time the average current (I1 + I2/2) flows through the restraining coil which produces enough restraining torque. Hence relay becomes inoperative for the through faults.

- **Ratio change due to tap change**:

To alter the voltage and current ratios between high voltage and low voltage sides of a power transformer, a tap changing equipment is used. This is an important feature of a power transformer. This equipment effectively alters the turns ratio. This causes unbalance on both sides. To compensate for this effect, the tapping can be provided on C.T.s also which are to be varied similar to the main power transformer. But this method is not practicable. The percentage differential relays ensure relays ensure the stability with respect to the amount of unbalance occurring at the extremities of the tap change range.

- **Difference in lengths of pilot wires**:

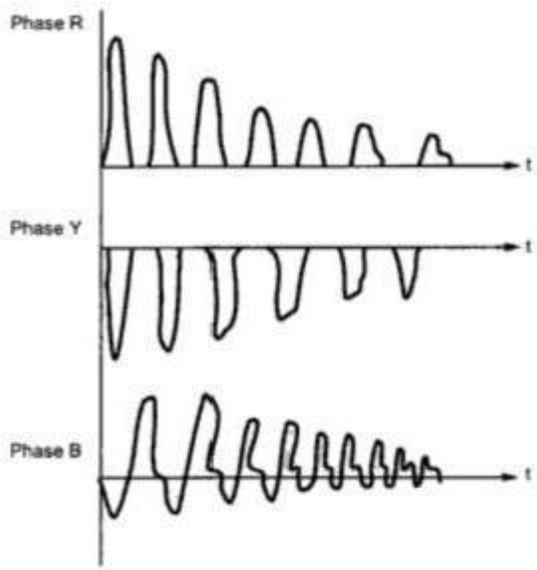
Due to the difference in lengths of the pilot wires on both sides, the unbalance condition may result. The difficulty is overcome by connecting the adjustable resistors in pilot wires on both sides. These are called balancing resistors. With the help of these resistors, equipotential points on the pilot wires can be adjusted. In percentage differential relays the taps are provided on the operating coil and restraining coil to achieve an accurate balance.

- **Magnetizing current inrush**:

When the transformer is energized, the condition initially is of zero induced E.m.f. A transient inflow of magnetizing current occurs in to the transformer. This current is called magnetizing inrush current. This current may be as great as 10 times the full load current of the transformer. This decays very slowly and is bound to operate differential protection of the transformer falsely, because of the temporary difference in magnitude of the primary and secondary currents.
The factors which affect the magnitude and direction of the magnetizing inrush current can be one of the following reasons.

a. Size of the transformer.
b. Size of the power system
c. Type of magnetic material used for the core.
d. The amount of residual flux existing before energizing the transformer.
e. The method by which transformer is energized.

If the transformer is energized when the voltage wave is passing through zero, the magnetizing current inrush is maximum. At this instant, the current and flux should be maximum in highly inductive circuit. And in a half wave flux reversal must take place to attain maximum value in the other half cycles. If the residual flux exists, the required flux may be in same or opposite direction. Due to this magnetizing current inrush is less or more. If it is more, it is responsible to saturate the core which further increases its component. This current decays rapidly for first few cycles and then decays slowly. The time constant L/R of the circuit is variable as inductance of circuit varies due to the change in permeability of the core. The losses in the circuit damp the inrush currents. Depending on the size of the transformer, the time constant of inrush current varies from 0.2 sec to 1 sec. The waveforms of magnetizing inrush current in three phases are shown in the figure below.



2.7 Static relays

Advantages of static relays

• Due to the amplification of energizing signals obtainable, the sources need only provide low power. Therefore the size of the associated current and voltage transformers could be reduced.
• Improved accuracy and selectivity.
• Fast operation of relays and hence fast clearance of faults.
• Flexibility of circuitry would allow new and improved characteristics.
• The relays would be unaffected by the number of operations.

Basic circuits employed

• Timers
• Phase comparators
• Amplitude Comparator
• Level detectors
• Integrators
• Polarity detectors

High reliability operational amplifiers are used for realizing the basic components of static relays.