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Lecture Notes

On

POWER SYSTEMS PROTECTION

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UNIT - I

PROTECTIVE RELAYS

Introduction:

In electrical engineering, a protective relay is a relay device designed to trip a circuit breaker when a fault is detected. The first protective relays were electromagnetic devices, relying on coils operating on moving parts to provide detection of abnormal operating conditions such as over-current, overvoltage, reverse power flow, over-frequency, and under-frequency.

Microprocessor-based solid-state digital protection relays now emulate the original devices, as well as providing types of protection and supervision impractical with electromechanical relays. Electromechanical relays provide only rudimentary indication of the location and origin of a fault. In many cases a single microprocessor relay provides functions that would take two or more electromechanical devices. By combining several functions in one case, numerical relays also save capital cost and maintenance cost over electromechanical relays. However, due to their very long life span, tens of thousands of these "silent sentinels" are still protecting transmission lines and electrical apparatus all over the world. Important transmission lines and generators have cubicles dedicated to protection, with many individual electromechanical devices, or one or two microprocessor relays.

The theory and application of these protective devices is an important part of the education of a power engineer who specializes in power system protection. The need to act quickly to protect circuits and equipment often requires protective relays to respond and trip a breaker within a few thousandths of a second. In some instances these clearance times are prescribed in legislation or operating rules. A maintenance or testing program is used to determine the performance and availability of protection systems.

Based on the end application and applicable legislation, various standards such as ANSI C37.90, IEC255-4, IEC60255-3, and IAC govern the response time of the relay to the fault conditions that may occur.

NEED FOR POWER SYSTEM PROTECTION:-

The main objective of using power system protection is to detach the faulty section from the system to make the rest of the portion work without any disturbance. In addition to this, it is used for the protection of power system and prevent the flow of fault current. It can help in preventing the continuation of flow by quickly disconnecting the short circuit.

Protection relays, on the other hand, are the important characteristic of power system protection helps to isolate the faculty part of the electrical system. However, it is important for this relay to possess certain qualities that are mentioned below:

• Dependability:

This is an important aspect of the relay to possess, as it remains out of action for a long time before the fault occurs. However, if the fault occurs, the relay should respond correctly.

• Selective:

The protection relay should operate on the commissioned condition in the electrical power system. There are situations during fault which relays shouldn't be operated after a definite time limit, hence it should be capable enough to select the appropriate condition for operation.

EFFECTS OF FAULTS:-

Over current flow: When fault occurs it creates a very low impedance path for the current flow. This results in a very high current being drawn from the supply, causing tripping of relays, damaging insulation and components of the equipment's.

Danger to operating personnel: Fault occurrence can also cause shocks to individuals. Severity of the shock depends on the current and voltage at fault location and even may lead to death.

Loss of equipment: Heavy current due to short circuit faults result in the components being burnt completely which leads to improper working of equipment or device. Sometimes heavy fire causes complete burnout of the equipment's.

Disturbs interconnected active circuits: Faults not only affect the location at which they occur but also disturbs the active interconnected circuits to the faulted line.

• Electrical fires: Short circuit causes flashovers and sparks due to the ionization of air between two conducting paths which further leads to fire as we often observe in news such as building and shopping complex fires.

Fault limiting devices:

It is possible to minimize causes like human errors, but not environmental changes. Fault clearing is a crucial task in power system network. If we manage to disrupt or break the circuit when fault arises, it reduces the considerable damage to the equipment's and also property.

Some of these fault limiting devices include fuses, circuit breakers, relays, etc. and are discussed below.

Fuse: It is the primary protecting device. It is a thin wire enclosed in a casing or glass which connects two metal parts. This wire melts when excessive current flows in circuit. Type of fuse depends on the voltage at which it is to operate. Manual replacement of wire is necessary once it blowout.

Circuit breaker: It makes the circuit at normal as well as breaks at abnormal conditions. It causes automatic tripping of the circuit when fault occurs. It can be electromechanical circuit breaker like vacuum / oil circuit breakers etc., or ultrafast electronic circuit breaker.

Relay: It is condition based operating switch. It consists of magnetic coil and normally open and closed contacts. Fault occurrence raises the current which energizes relay coil, resulting in the contacts to operate so the circuit is interrupted from flowing of current. Protective relays are of different types like impedance relays, mho relays, etc.

Lighting power protection devices: These include lighting arrestors and grounding devices to protect the system against lighting and surge voltages.

EVOLUTION OF PROTECTIVE RELAYS:-

The need for real-time process data has grown in the past decade. As the appetite for data intensified, the data's importance has increased dramatically. A changing utility environment has contributed to data importance, along with many technological advances in data collection, data storage and communication infrastructure. Advances have allowed data to be converted into valuable information used to optimize enterprise resources.

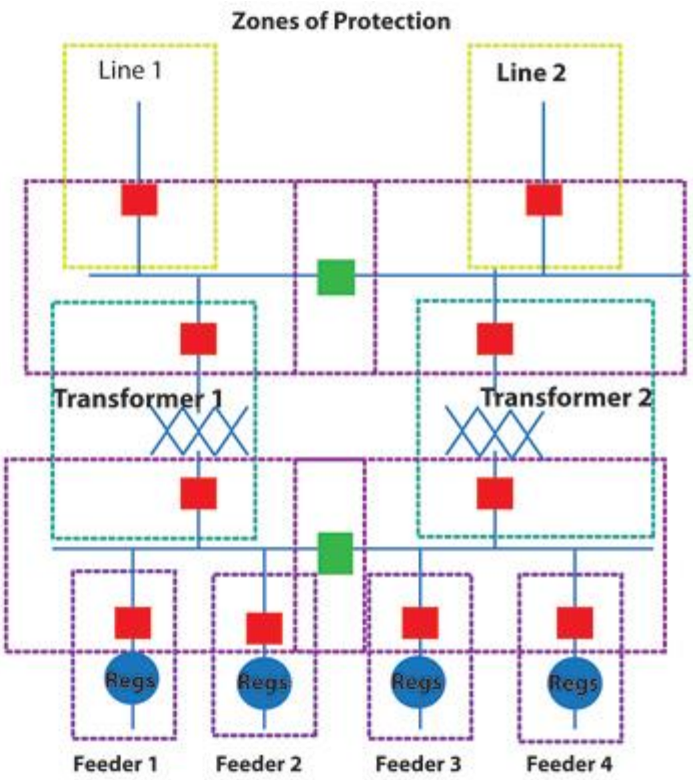
The protective relay system provides necessary power system monitoring and protection for abnormal condition detection and mitigation. Such conditions could lead to a fault and result in damage to utility-critical assets such as generators, transformers, breakers, power lines, cables and substation buses.

ZONES OF PROTECTION:-

"Zones of protection" is one strategy that can be used to provide the level of security demanded today.

Protective relay engineers keep utility grids and equipment safe from faults and system unbalances by dividing the grid into zones, each with a unique protection scheme. Overlapping zones provide backup protection. This same strategy can be used to provide communications zones of protection to address the rich information that is collected in the course of operation today. Ethernet is the best protocol for supporting that strategy.

Figure 1 is a one-line of a typical substation depicting the zones of protection within the substation. Notice that zones overlap each other to provide backup protection should a primary zone fail.



As the figure above shows, there is a zone of protection covering from each feeder breaker (Blue dotted lines), a zone covering each low-side bus, a zone covering each transformer (Green dotted lines), a zone covering each high-side bus and a zone covering each incoming transmission Line (Yellow Dotted lines). The Transformer Zone acts as a primary zone for faults internal to the transformer and a backup zone to faults on the low-side bus and feeders.

Ethernet and Physical Zones of Protection

Physical security within the substation provides an additional zone of protection through devices such as card readers installed on control house doors and outdoor cabinets such as transformer cabinets. Security cameras monitor substation access and watch over sensitive areas to guard against unauthorized penetration, copper theft and other attacks. Security data may be logged onto a substation server and also sent through the network to a central monitoring area for viewing in real-time or for archiving. When configuring communications transport for physical security data, it is important that Quality of Service (QoS) levels are set that ensure that data will be received in a timely manner.

PRIMARY & BACK-UP PROTECTION:-

Primary protection (Main protection) is the essential protection provided for protecting an equivalent/machine or a part of the power system. As a precautionary measure, addition protection is generally provided and is called Backup Protection. In this post, we will look into the difference between primary & backup protection, advantages of backup protection, and methods of backup protection.

If any fault occurs in the protected area, the primary protection act first. If primary protection fails to act, the back-up protection comes into action and removes the faulty part from the health system.

Advantages of Back-up Protection

Back-up protection is provided for the following reasons

- If due to some reason, the Main protection fails, the Back-up protection serves the purpose of protection.
- Main protection can fail due to failure of one of the components in the protective system such as a relay, auxiliary relay Current Transformer, PT, trip circuit, circuit-breaker, etc. If the primary protection fails, there must be an additional protection, otherwise, the fault may remain uncleared, resulting in a disaster.
- When main protection is made inoperative for the purpose of maintenance, testing, etc. the Back-up protection acts like main protection.
- As a measure of the economy, Back-up protection is given against short-circuit protection and generally not for other abnormal conditions. The extent to which back-up protection is provided depends upon economic and technical considerations,

The cost of back-up protection is justified on the basis of the probability of failure of individual component in the protection system, cost of the protected equipment, the importance of protected equipment, location of protected equipment, etc.

Methods of Back-up Protection:-

- The methods of back-up protection can be classified as follows :
- Relay Back-up
- Breaker Back-up
- Remote back-up
- Centrally Coordinated Back-up
- Relay Back-up
- Same breaker is used by both main and back-up protection, but the protective systems are different. Separate trip coils may be provided for the same breaker.
- Breaker Back-up
- Different breakers are provided for main and back-up protection, both the breakers being in the same station
- Remote back-up
- The main and back-up protections provided at different stations and are completely independent.
- Centrally Coordinated Back-up
- The system having central control can be provided with centrally controlled back-up. Central control continuously supervises the load flow and frequency in the system. The information about load flow and frequency are assessed continuously.

- If one of the components in any part of the-system fails, (e.g. a fault on a transformer, in some station) the load flow in the system is affected. The central coordinating station receives information about the abnormal condition through high-frequency carrier signals.

- The stored program in the digital computer determines the correct switching operation, as regards severity of fault, system stability,

ESSENTIAL QUALITIES OF PROTECTION:-

1. Selectivity or Discrimination:

The selectivity or discrimination of a protective relay refers to how well it can distinguish between a fault in a protected section and the normal condition. The protective relay should have the ability to distinguish if a fault is within its zone of protection or outside it. It is desirable to isolate only the faulty part of a power system when a fault occurs. It is important that no healthy part of the system is deprived of electrical power and is, therefore, left intact. The relay should be able to differentiate between faults and transient conditions such as inrush of a transformer's magnetizing current or power surges.

2. Sensitivity:

It is important that the power system equipment be sufficiently sensitive so that equipment can operate reliably when the fault condition is just crossing the predefined limit.

3. Reliability:

In quantitative terms, reliability can be expressed as a probability of failure. Components present in the protective system are also prone to failure. Thus, every component and circuit in the fault clearance process must be regarded as a potential failure source. Normally, a relay remains inoperative for a long time before it develops a fault.

4. Stability:

Protective systems should remain stable even when a large current is flowing through their protective zones as a result of an external fault that is not in their zone. The concerned circuit breakers should clear the fault immediately. Although the protective system will not wait indefinitely if the zone in which the fault occurs is unable to detect the fault. A relay will operate after a predetermined delay to trip the circuit breaker.

5. Fast operation:

It is essential that a protective system is fast enough to isolate the faulty element of a system as soon as possible to minimize damages to the equipment and to ensure system stability. A protective system operating time should not exceed the critical clearing time to prevent loss of synchronism. If fault currents are carried for a long time, electrical equipment may be damaged. The voltage will drop gradually resulting in crawling and overloading of industrial drives with a persistent fault. Because of these reasons, protective relays need to be quick-acting.

As the fault persists for a shorter period of time, a greater amount of load can be transferred between two points on the power system without loss of synchronism.

CLASSIFICATION OF PROTECTIVE RELAYS & SCHEMES:-

Types of protection relays are mainly based on their characteristic, logic, on actuating parameter and operation mechanism.

Based on operation mechanism protection relay can be categorized as electromagnetic relay, static relay and mechanical relay. Actually, a relay is nothing but a combination of one or more open or closed contacts. These all or some specific contacts the relay change their state when actuating parameters are applied to the relay. That means open contacts become closed and closed contacts become open. In an electromagnetic relay, these closing and opening of relay contacts are done by the electromagnetic action of a solenoid.

In the mechanical relay, these closing and opening of relay contacts are done by mechanical displacement of different gear level system.

In static relay it is mainly done by semiconductor switches like thyristor. In digital relay on and off state can be referred as 1 and 0 state.

Based on Characteristic the protection relay can be categorized as:

1. Definite time relays
2. Inverse time relays with definite minimum time(IDMT)
3. Instantaneous relays.
4. IDMT with inst.
5. Stepped characteristic.
6. Programmed switches.
7. Voltage restraint over current relay.

Based on of logic the protection relay can be categorized as-

1. Differential.
2. Unbalance.
3. Neutral displacement.
4. Directional.
5. Restricted earth fault.
6. Over fluxing.
7. Distance schemes.
8. Bus bar protection.
9. Reverse power relays.
10. Loss of excitation.
11. Negative phase sequence relays etc.

Based on actuating parameter the protection relay can be categorized as-

1. Current relays.
2. Voltage relays.

3. Frequency relays.
4. Power relays etc.

Based on application the protection relay can be categorized as-

1. Primary relay.
2. Backup relay.

Primary relay or primary protection relay is the first line of power system protection whereas backup relay is operated only when primary relay fails to be operated during a fault. Hence backup relay is slower in action than primary relay. Any relay may fail to be operated due to any of the following reasons,

1. The protective relay itself is defective.
2. DC Trip voltage supply to the relay is unavailable.
3. Trip lead from relay panel to the circuit breaker is disconnected.
4. The trip coil in the circuit breaker is disconnected or defective.
5. Current or voltage signals from Current Transformers (CTs) or Potential Transformers (PTs) respectively is unavailable.

As because backup relay operates only when primary relay fails, backup protection relay should not have anything common with primary protection relay.

Some examples of Mechanical Relay are:

1. Thermal
- OT trip (Oil Temperature Trip)
- WT trip (Winding Temperature Trip)
- Bearing temp trip etc.
2. Float type
- Buchholz
- OSR
- PRV
- Water level Controls etc.
3. Pressure switches.
4. Mechanical interlocks.
5. Pole discrepancy relay.

CURRENT TRANSFORMER:-

A Current Transformer (CT) is used to measure the current of another circuit. CTs are used worldwide to monitor high-voltage lines across national power grids. A CT is designed to produce an alternating current in its secondary winding that is proportional to the current that it is measuring in its primary.

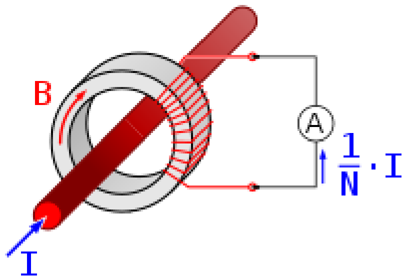
OPERATIONAL HAZARDS:

Operational hazards can occur if the secondary circuit of a CT is left open whilst the primary is energised. Open circuit conditions can happen inadvertently through routine maintenance of the burden or damage to the leads of the secondary circuit. High voltage transients may be generated in these situations and damage the CT winding insulation; possibly rendering it inoperable. In addition, these transients can cause high eddy currents in the CT core. These may be detrimental to the magnetising characteristics of the CT and result in errors in the measurement accuracy.

WORKING:-

A current transformer has a primary winding, a core, and a secondary winding, although some transformers, use an air core. While the physical principles are the same, the details of a "current" transformer compared with a "voltage" transformer will differ owing to different requirements of the application. A current transformer is designed to maintain an accurate ratio between the currents in its primary and secondary circuits over a defined range.

The alternating current in the primary produces an alternating magnetic field in the core, which then induces an alternating current in the secondary. The primary circuit is largely unaffected by the insertion of the CT. Accurate current transformers need close coupling between the primary and secondary to ensure that the secondary current is proportional to the primary current over a wide current range. The current in the secondary is the current in the primary (assuming a single turn primary) divided by the number of turns of the secondary. In the illustration on the right, 'I' is the current in the primary, 'B' is the magnetic field, 'N' is the number of turns on the secondary, and 'A' is an AC ammeter.



USE:-

Current transformers are used extensively for measuring current and monitoring the operation of the power grid. Along with voltage leads, revenue-grade CTs drive the electrical utility's watt-hour meter on many larger commercial and industrial supplies.

SAFETY:-

Current transformers are often used to monitor high currents or currents at high voltages. Technical standards and design practices are used to ensure the safety of installations using current transformers.

The secondary of a current transformer should not be disconnected from its burden while current is in the primary, as the secondary will attempt to continue driving current into an effective infinite impedance potentially generating high voltages and thus compromising operator safety. For certain current transformers, this voltage may reach several kilovolts and may cause arcing.

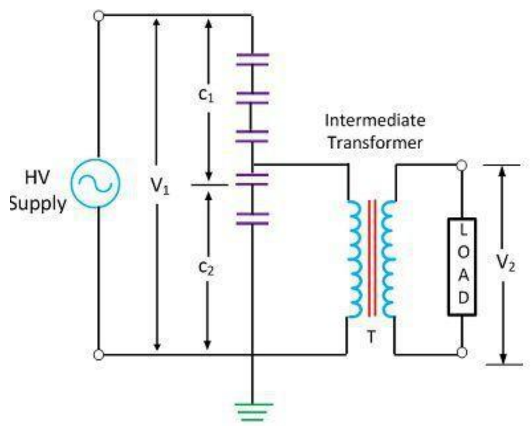
POTENTIAL TRANSFORMER:-

Voltage transformers (VT), also called potential transformers (PT), are a parallel-connected type of instrument transformer. They are designed to present a negligible load to the supply being measured and have an accurate voltage ratio and phase relationship to enable accurate secondary connected metering.

The PT is typically described by its voltage ratio from primary to secondary. A 600:120 PT will provide an output voltage of 120 volts when 600 volts are impressed across its primary winding. Standard secondary voltage ratings are 120 volts and 70 volts, compatible with standard measuring instruments.

ACCURACY & BURDEN:-

Burden and accuracy are usually stated as a combined parameter due to being dependent on each other. Metering style PTs are designed with smaller cores and VA capacities than power transformers. This causes metering PTs to saturate at lower secondary voltage outputs saving sensitive connected metering devices from damaging large voltage spikes found in grid disturbances. A small PT (see nameplate in photo) with a rating of 0.3W, 0.6X would indicate with up to W load (12.5 watts) of secondary burden the secondary current will be within a 0.3 percent error parallelogram on an accuracy diagram incorporating both phase angle and ratio errors



BASIC RELAY TERMINOLOGY:-

AC Operated Relays

Relay that is operated from an AC Voltage source. These type of relays incorporate a shading ring on the pole face. A shading ring is a shorted turn surrounding a portion of the pole of an AC electromagnet. This delays the change of the magnetic field in that part of electromagnet, thereby tending to prevent chatter and reduce hum.

Armature

The moving magnetic member of an electromagnetic relay structure.

Break

The opening of closed contacts to interrupt an electric circuit.

Coil

An assembly consisting of one or more windings with terminals and any other required parts such as a sleeve or slug. The windings may be self-supporting but usually are wound around an insulated iron core or on a bobbin.

Contact

1. A conductive connection of two elements.
2. A contact piece designed to ensure reliable current passage either in the form of a rivet or welded assembly.

Contact Bounce

The uncontrolled opening and closing of the contacts due to forces within the relay/contactor. Contact bounce is dependent on, and an inherent part of, the design of the relay/contactor. The closing velocity of the contacts, the initial contact force, the mass of the contacts, and mechanical resonances in the contact system all impact the level of contact bounce.

Contact Chatter

The uncontrolled opening and closing of contacts due to external forces. Contact chatter is extended contact bounce that is not an inherent part of the relay. Contact chatter usually occurs because of either shock or vibration to the relay or an improper control signal to the relay.

Contact Force

The force which two contacts exert against each other in the closed position.

Contact Forms

Denotes the contact mechanism and number of contacts in the contact circuit.

Contact Life

The number of operations for a given contact load under specified conditions (e.g. duty cycle, maximum operating rate) without leading to permanent contact failure (e.g. contact welding, excessive contact wear/resistance or contact locking when switching DC loads). **Contact Operate Time**

Time from initial energization of the coil to first opening of closed contact or first closing of open contact, prior to contact bounce.

Contact Rating

The electrical load handling capability of the contacts under specified conditions and for a prescribed number of operations.

Contact Release Time

Time from initial de-energization of the coil to the first opening of a closed contact, prior to contact bounce.

Contact Resistance

The electrical resistance of closed contacts.

Contact Weld

A contact failure due to fusing of the contacting surfaces to the extent that the contacts fail to separate when intended.

Continuous Current

The maximum current a relay may continuously carry without exceeding temperature limits.

DC Relays

A relay with coils designed for operation from a DC voltage source.

Dielectric Strength

The voltage which may be applied to two adjacent metal parts insulated from each other without causing electrical breakdown.

Drop Out (Release) Voltage
The voltage at which the relay returns safely to its un-operated position.
Duty Cycle
The ratio of operated time to the total cycle time expressed as a percentage.

OPERATIONAL PRINCIPLES & RELAY CONSTRUCTION

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

By their working principle, the electromagnetic relay is mainly classified into two types. These are

1. Electromagnetic Attraction Relay
2. Electromagnetic Induction Relay

1. 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

$$F_e = KI^2 = K(Imax\ sin\omega t)^2$$

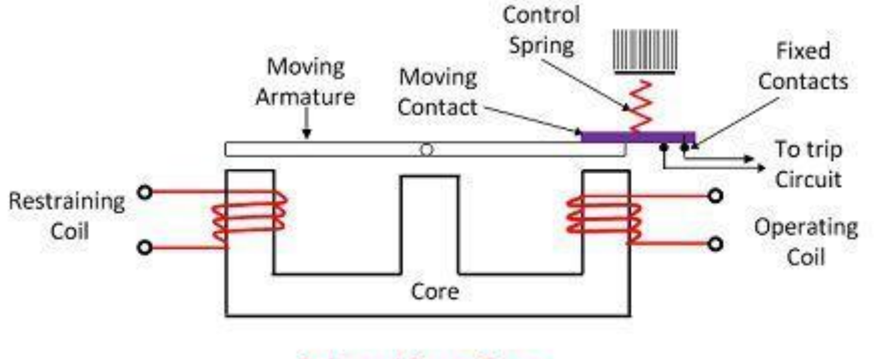
$$= \frac{1}{2}K[1^2_{max} - I^2_{max}cos2\omega t]$$

The above equation shows that the electromagnetic relay consists two components, one constant independent of time and another dependent upon time and pulsating at double supply frequency. 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.

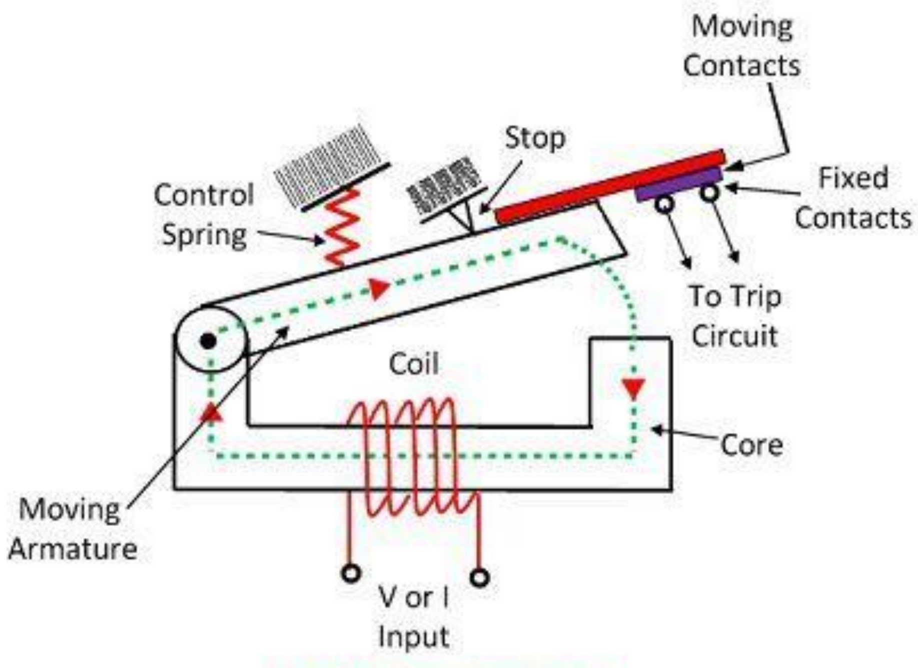
The electromagnetic attraction relay is the simplest type of relay which includes a plunger (or solenoid), hinged armature, rotating armature (or balanced) and moving iron polarised relay. All these relays are shown below.

a. 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.



Balanced Beam Type

b. 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.



Hinged Armature Type

2. Electromagnetic Induction Relay

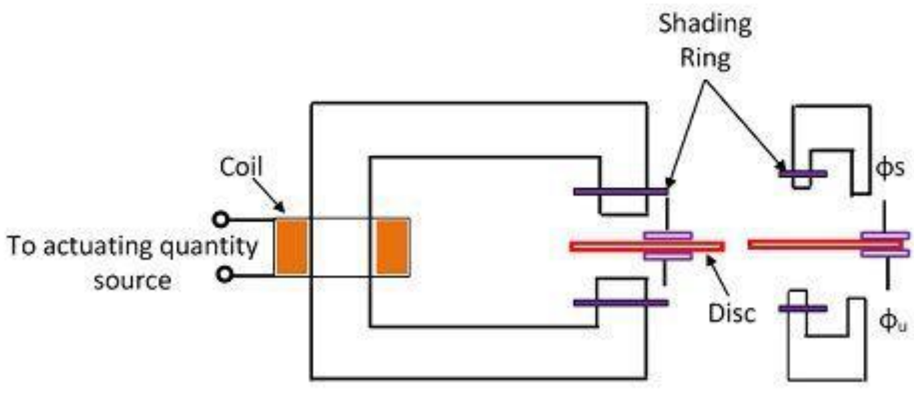
The electromagnetic relay operates on the principle of a split-phase induction motor. The initial force is developed on the moving element that may be disc or another form of the rotor of the non-magnetic moving element. The force is developed by the interaction of electromagnetic fluxes with eddy current, that is induced in the rotor by these fluxes.

The different type of structure has been used for obtaining the phase difference in the fluxes. These structures are

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

a. Shaded pole structure

This coil is usually energised 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.

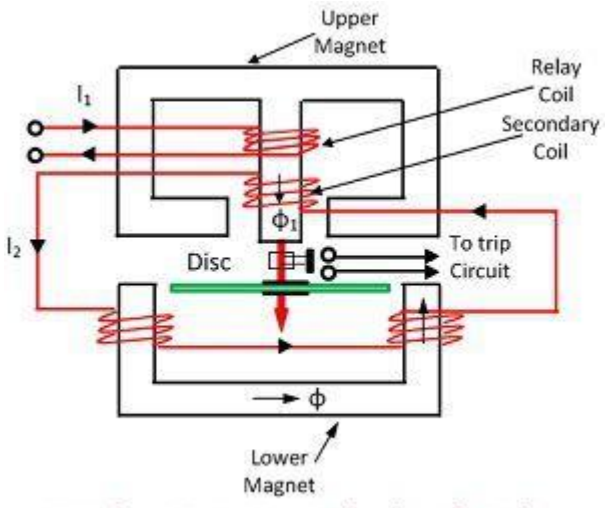


Shaded Pole Construction of Induction Disc Relay

The disc is made up of aluminium. The inertia of the aluminium disc is very less.. Hence they need less deflecting torque for its movement. The two rings have the current induced in them by the alternating flux of the electromagnetic. The magnetic field develops from the current 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 unshaded portion of the pole.

b. 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.



Watt-hour Meter Type Induction Disc Relay

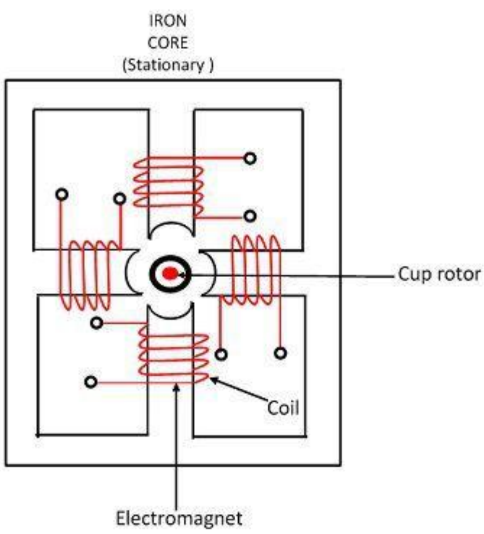
The E-shaped electromagnet carries the two windings the primary and the secondary. The primary current was carrying the relay current I_1 while the secondary winding is connected to the windings of the U-shaped electromagnet.

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 $\varphi_1\varphi \sin\theta$.

The most important feature of the relay is that opening can control their operation or close the secondary winding circuit. If the secondary winding is opened, then no torque will be developed, and thus relay can be made inoperative.

c. 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.



Induction Cup Relay

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 more torque is produced in the induction cup relay as compared to the shaded and watt meter type relay. The relay is fast in operation and their operating time is very less approximately 0.01 sec.

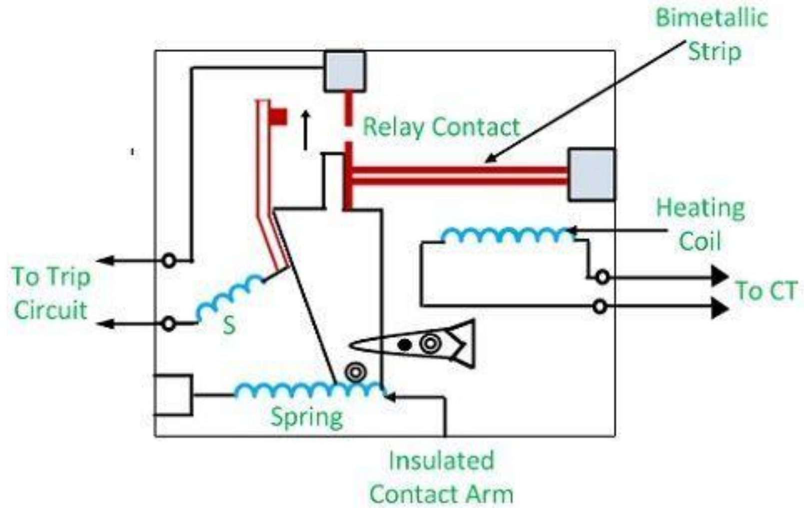
THERMAL RELAY:-

The coefficient of expansion is one of the basic properties of any material. Two different metals always have different degree of linear expansion. A bimetallic strip always bends when it heated up, due to this inequality of linear expansion of two different metals.

Working Principle of Thermal Relay

A thermal relay works depending upon the above mentioned property of metals. The basic working principle of thermal relay is that, when a bimetallic strip is heated up by a heating coil carrying over current of the system, it bends and makes normally open contacts.

Construction of Thermal Relay



Schematic Arrangement of Thermal Relay

The construction of thermal relay is quite simple. As shown in the figure above the bimetallic strip has two metals – metal A and metal B. Metal A has lower coefficient of expansion and metal B has higher coefficient of expansion.

When over current flows through the heating coil, it heats up the bimetallic strip. Due to the heat generated by the coil, both of the metals are expanded. But expansion of metal B is more than expansion of metal A. Due to this dissimilar expansion the bimetallic strip will bend towards metal A as shown in the figure below.

The strip bends, the NO contact is closed which ultimately energizes the trip coil of a circuit breaker.
The heating effect is not instantaneous. As per Joule's law of heating, the amount of heat generated is

$$H \propto I^2 Rt$$

Where, I is the over current flowing through the heating coil of thermal relay.
R is the electrical resistance of the heating coil, t is the time for which the current I flows through the heating coil. Hence from the above equation it is clear that, heat generator by the coil is directly proportional to the time during which the over current flows through the coil. Hence there is a prolonged time delay in the operation of thermal relay.

That is why this type of relay is generally used where over load is allowed to flow for a predetermined amount of time before it trips. If overload or over current falls down to normal value before this predetermined time, the relay will not be operated to trip the protected equipment.
A typical application of thermal relay is overload protection of electric motor.

STATIC RELAYS:-

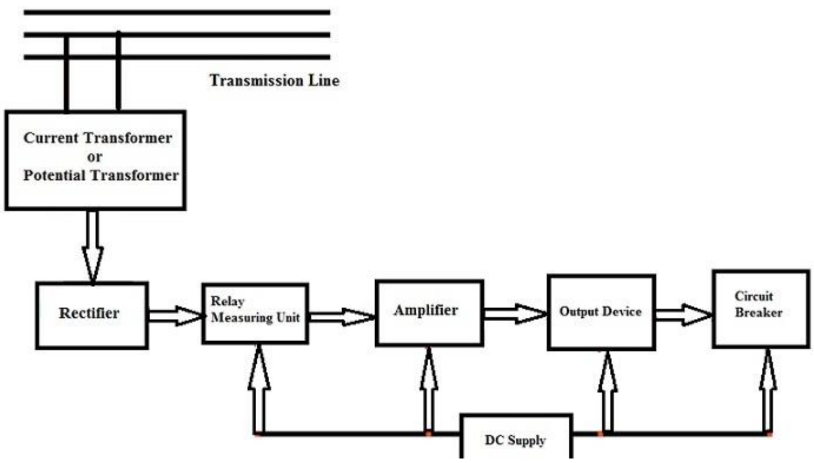
The solid-state relay or static relay was first launched in the year 1960. As the name suggests, the term static in the static relay implies that this relay has no moving parts in it. As compared to an electromechanical relay, the lifespan of this relay is longer and its response speed is faster. These relays were designed as semiconductor devices which include integrated circuits, transistors, small microprocessors, capacitors, etc. So these types of relays replace almost all the functions which were being accomplished earlier through an electromechanical relay.

An electrically operated switch that has no moving parts is known as a static relay. In this type of relay, the output is simply attained through the stationary components such as magnetic & electronic circuits. Static relays are compared with electromechanical type relays because these relays utilize moving parts to perform a switching action. But both relays are used to control electrical circuits using a switch that is open or closed based on an electrical input.

Static Relay

These types of relays are mainly designed to perform similar functions using electronic circuit control like an electromechanical relay performs by using elements or moving parts. A static relay mainly depends on the designs of microprocessors, analog solid-state circuits, or digital logic circuits.

The static relay block diagram is shown below. The static relay components in this block diagram mainly include a rectifier, amplifier, o/p unit & relay measuring circuit. Here, the measuring circuit of the relay includes the level detectors, logic gate & the comparators like amplitude & phase.



Static Relay Block Diagram

In the above block diagram, the transmission line is simply connected to the current transformer (CT) or potential transformer (PT) so that the transmission line provides the input to the CT/PT.
The output of the current transformer is given as an input to the rectifier which rectifies the input AC signal into the DC signal. This DC signal is given to the measuring unit of a relay.
The measuring unit relay performs the most significant action necessary within the static relay system by detecting the input signal level throughout the level detectors and evaluating the magnitude & phase of the signal throughout the comparators to perform the logic gate operations.

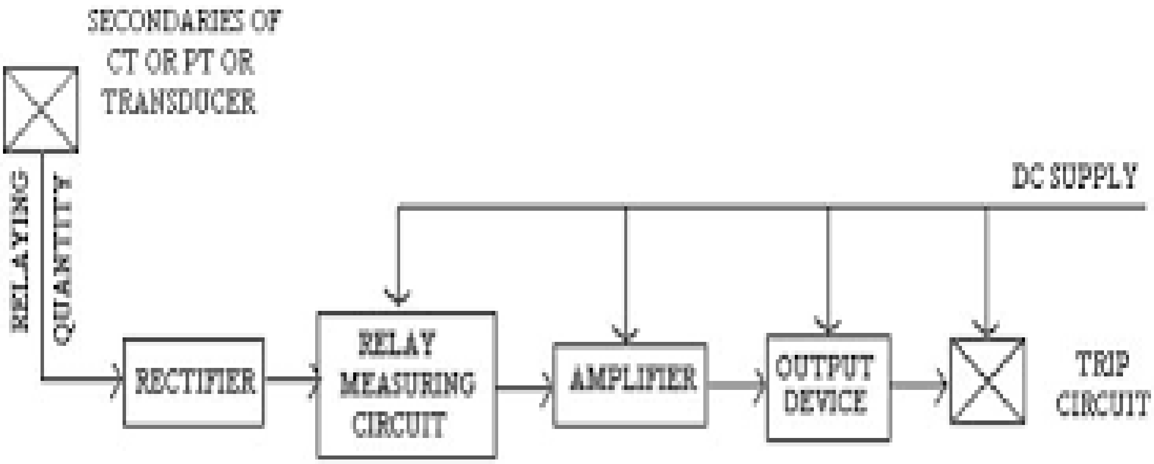
In this relay, two kinds of comparators are used amplitude and phase comparators. The main function of the amplitude comparator is to compare the input signal's magnitude whereas the phase comparator is used to compare the phase variation of the input quantity.

The relay measuring unit o/p is given to the amplifier so that it amplifies the signal's magnitude & transmits it to the o/p device. So this device will strengthen the trip coil so that it trips the CB (circuit breaker).

Static Relay Working Principle

The working of the static relay is, first, the current transformer/potential transformer receives the input voltage/current signal from the transmission line & gives it to the rectifier. After that, this rectifier changes the AC signal into DC and this is given to the measuring unit of the relay.

Now, this measuring unit identifies the input signal level after that it comparators the magnitude & the phase of the signal with the available comparator in the measuring unit. This comparator compares the i/p signal to make sure whether the signal is defective or not. After that, this amplifier amplifies the signal's magnitude & transmits it to the o/p device to activate the trip coil to trip the circuit breaker.



Applications

The applications of static relay include the following.

- These relays are widely used in very high-speed-based protection systems of EHV-A.C transmission lines with distance protection.
- These are also used in earth fault & overcurrent protection systems.
- These are used in long & medium transmission protection.
- It is used to guard parallel feeders.
- It gives backup safety to the unit.
- These are used in interconnected & T-connected lines.

The advantages of static relay include the following.

- These relays consume very less power.
- This relay gives very quick response, high reliability, accuracy, and long life & it is shockproof.
- It doesn't include any thermal storage troubles
- This type of relay amplifies the i/p signal which enhances their sensitivity.
- The unwanted tripping chance is less.

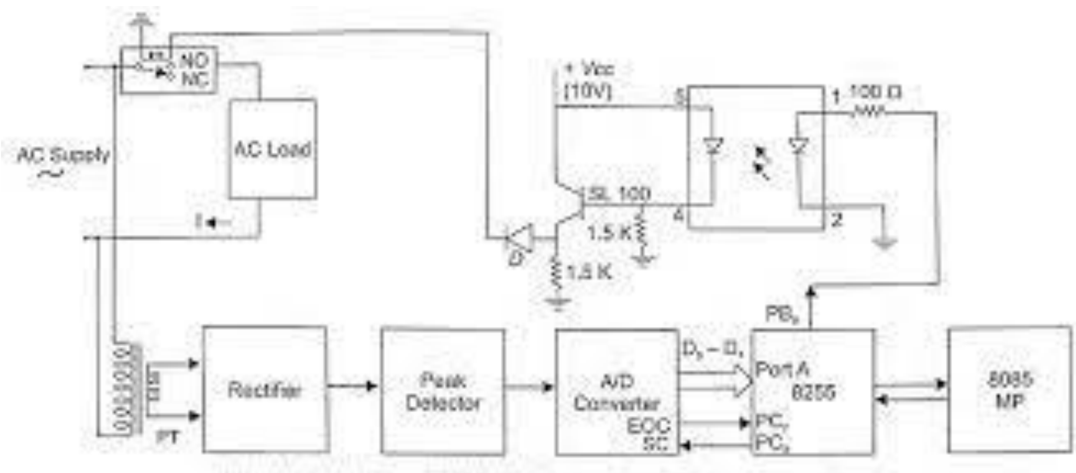
The **disadvantages of static relays** include the following.

- The components used in this relay are extremely responsive to the electrostatic discharges which mean unexpected electron flows between the charged objects. So, special maintenance is necessary to the components so that it does not affect the electrostatic discharges.

- This relay is affected easily by high voltage surges. So, precautions must be taken to avoid damage throughout voltage spikes.
- The relay working mainly depends on the used components in the circuit.
- This relay has less overloading capacity.

MICROPROCESSOR BASED PROTECTIVE RELAY:-

- An electrical power system consists of generators, transformers, transmission and distribution lines.
- Short circuit and other abnormal conditions often occur on a power system. The heavy current associated with short circuits is likely to cause damage to the equipment if suitable protective relays and circuit breakers are not provided for the protection of each section of the power system.
- A protective system includes circuit breakers, transducers (CTs and VTs), and protective relays to isolate the faulty section of the power system from the healthy sections.
- The function of a protective relay is to detect and locate a fault and issue a command to the circuit breaker to disconnect the faulty element. The conventional protective relays are either of electromechanical or static type.



- The electromechanical relays suffer from several drawbacks such as high burden on instrument transformer, high operating time, contact problem etc.
- The static relays also suffer from a number of disadvantages such as inflexibility, inadaptability to changing system conditions and complexity.
- The functions of electromechanical protection systems are now being replaced by microprocessor-based digital protective relays, sometimes called "numeric relays".

- The increased growth of power system both in size and complexity has brought about the need for fast and reliable relays to protect major equipment and to maintain system stability.
- The concept of digital protection employing computers which shows much promise in providing improved performance has evolved during the past two decades. Digital computer can easily fulfil the protection requirements of modern power system without difficulties.
- With the development of economical, powerful and sophisticated microprocessor, there is a growing interest in developing microprocessor-based protective relays which are more flexible because of being programmable and are superior to conventional relays.
- The objective of this paper is to give a comparative review of microprocessor-based protective relays.

UNIT – II

OVER-CURRENT PROTECTION

TIME- CURRENT CHARACTERISTICS:-

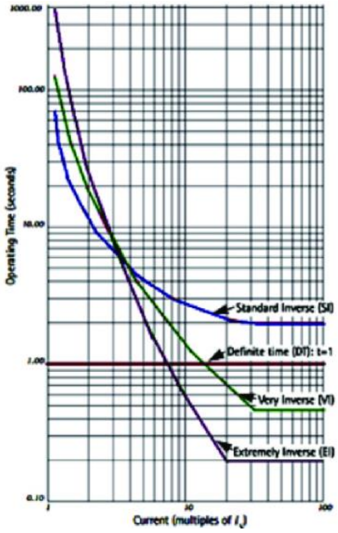
A time-current characteristic curve, for any specified fuse, is displayed as a continuous line representing the average melting time in seconds for a range of overcurrent conditions. The melting time is considered nominal unless noted otherwise. Several curves are traditionally shown on one sheet to represent a family of fuses.

Information can be accessed from these curves in several ways:

• If a fuse has been selected, the designer can use the curve for that fuse to check its opening time versus a given overcurrent. Example: Using the 30 ampere fuse curve, what is the fuse opening time in seconds at a current of 160 amperes? At the bottom of the sheet (Current in Amperes) find 160 amperes (Pt. A) and follow that line straight up to the point where it intersects the 30A curve (Pt. B). Then follow that line to the left edge (Time in Seconds) and read 10 seconds. (Pt. C). This tells us that the AJT30 will open in 10 seconds on a current of 160 amperes.

• Likewise, for the same fuse we might want to know what current will open the fuse in 0.1 second. On the vertical axis (Time in Seconds) find 0.1 second (Pt. D) and follow that line to the right until it intersects the 30A curve (Pt. E). Then follow that line straight down to the horizontal axis (Current in Amperes) and read 320 amperes (Pt. F). This shows that the AJT30 requires an overcurrent of 320 amperes to open in 0.1 second.

• The curves can be used in other ways by the designer. For example, if a family has been chosen (i.e. Time Delay Class J AJT) and an opening time of approximately 1 second is required at 3000 amperes, what fuse in the family best meets this need? Find the 3000 ampere line on the horizontal axis (Pt. G) and follow it up to the 1 second line (Pt. H). The nearest curve to the right is the AJT400. If the point is not near a curve shown, other intermediate curves are available from the factory. Sometimes the fuse family or type has not been chosen, so a design requirement can be presented to several family characteristic curves. One fuse type will emerge as a good choice. Voltage rating, interrupting rating, physical size, time delay, etc. are all considerations in the final choice.



CURRENT SETTING:-

The minimum pick up the value of the deflecting force of an electrical relay is constant. Again the deflecting force of the coil is proportional to its number of turns and the current flowing through the coil.
Now, if we can change the number of active turns of any coil, the required current to reach at minimum pick value of the deflecting force, in the coil also changes. That means if active turns of the relay coil are reduced, then proportionately more current is required to produce desired relay actuating force. Similarly, if active turns of the relay coil are increased, then proportionately reduced current is required to produce same desired deflecting force.

Practically same model relays may be used in different systems. As per these system requirements, the pickup current of the relay is adjusted. This is known as the current setting of the relay. This is achieved by providing the required number of tapping in the coil. These taps are brought out to a plug bridge. The number of active turns in the coil can be changed by inserting a plug in different points in the bridge.
The current setting of relay is expressed in percentage ratio of relay pick up current to the rated secondary current of CT.
That means,

$$Current\ setting = \frac{Pick\ up\ current}{Rated\ secondary\ current\ of\ CT} \times 100\%$$

For example, suppose, you want that, an over current relay should operate when the system current just crosses 125% of rated current. If the relay is rated with 1 A, the normal pick up current of the relay is 1 A and it should be equal to secondary rated current of current transformer connected to the relay.
Then, the relay will be operated when the current of CT secondary becomes more than or equal to 1.25 A.
As per definition,

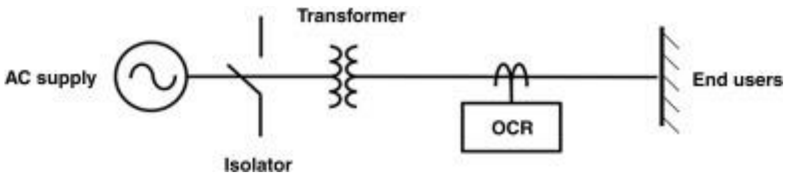
$$Current\ setting = \frac{1.25}{1} \times 100\% = 125\%$$

The current setting is sometimes referred as current plug setting.
The current setting of overcurrent relay is generally ranged from 50 % to 200 %, in steps of 25 %. For earth fault relay it is from 10% to 70% in steps of 10%.

OVER CURRENT PROTECTIVE SCHEMES:-

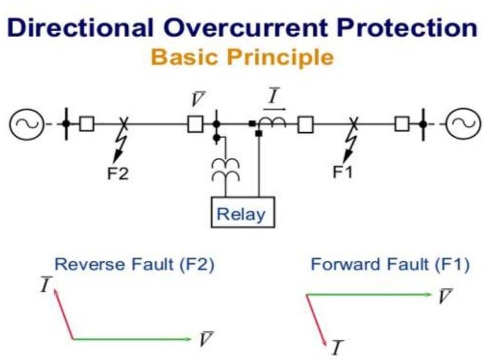
- The overcurrent protection scheme is used to protect the distribution lines of electric grids integrated with DER. This protection scheme is further classified into two categories, the phase overcurrent protection and the ground overcurrent protection.
- The relays used in such schemes could be directional (operating for in-front events) and non-directional (will operate for all) depending upon the mode of distribution. The nondirectional relays are mostly used for radial distribution systems.
- In all the cases, the feeder protection starts at the electric grid with feeder control mechanism (a breaker or recloser).
- Reclosers are usually prepared with the inverse time overcurrent device that senses the faults and sends signal to the breaker, and then after a predetermined setback, it operates by reclosing the breaker.
- All the protective devices should be in sound coordination with the upstream and downstream links.
- The upstream link is the high voltage transformers, and the downstream are the protective equipments.

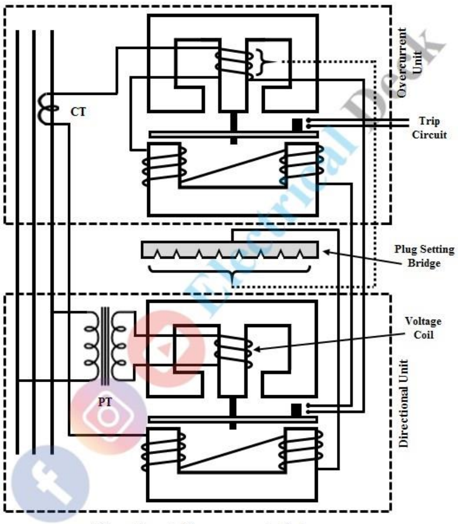
The schematic arrangement for overcurrent protection of DER with coordinated protection. The generation is fed to the transformer via isolator switch, and the output power from transformer passing the OCR is supplied to end-users.



DIRECTIONAL RELAY:-

The directional relays permit tripping only for a certain direction of current flow, and the other relays determine (1) if it is a short circuit that is causing the current to flow, and (2) if the short circuit is near enough so that the relays should trip their circuit breaker.

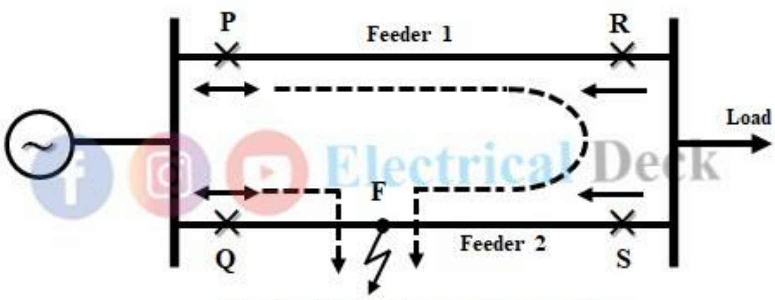




Directional Overcurrent Relay

PROTECTION OF PARALLEL FEEDER:-

To increase the transmission capacity and where continuity of supply is particularly necessary, two feeders are connected in parallel. So that in case of a fault on any of the feeders only that feeder is isolated and continuity of the supply can be maintained through another feeder. The below figure shows the protective scheme of parallel-connected feeders fed from one end.



Protection of Parallel Feeders

In this scheme both the feeders have non-directional overcurrent relays at the source end (at P and Q), the symbol ↔ indicates the non-directional relay, and the relays near the load end (at R and S) are directional relays (reverse power relays).

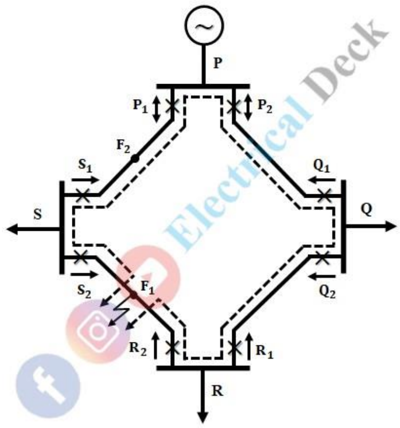
In case the directional relays near the load side are not provided in conjunction with overcurrent relays, then the required region will not be protected and both the feeders will be tripped out for any fault on any feeder. This is not desired as the healthy feeder is also tripped. Thus the relays at R and S must be directional overcurrent relays.

If a fault F occurs on feeder 2, the power is fed into the fault through two paths PRSF and QF. Here we can see that the power flow at relay R is in the normal direction, but the power flow at relay S is reversed. Thus the relay at S operates instantaneously.

Also due to excess fault current, the overload relay at Q operates. Thus the circuit breaker trips and isolates feeder 2, whereas feeder 1 maintains the continuity of supply.

PROTECTION OF RING MAIN FEEDER :-

The below shows the overcurrent schemes for the protection of a ring feeder. There are four substations P, Q, R, and S, which are interconnected by alternate routes and fed through one source, thus forming a closed ring.



The substation P is connected to a generating station and supplies power to substations Q, R, and S. There are six-time graded directional relays at both ends of the substations Q, R, and S having their tripping direction when an overload flows away from the substation. The relays at substation P are non-directional time lag overload relays. Since at substation P the power flow will be only in one direction i.e., away from the bus bars.

A fault in any section causes to trip circuit breaker only associated with that section and power flows from the alternate path. If a fault occurs at F1, then the relays at S1 and R2 will trip to isolate the faulty feeder. The relay at R1 will not trip since the fault current is not flowing in its tripping direction, though its operating time is the same as that of R2. Similarly, if a fault at F2 occurs then the relays at S2 and P1 will trip.

PHASE FAULT AND EARTH PROTECTION:-

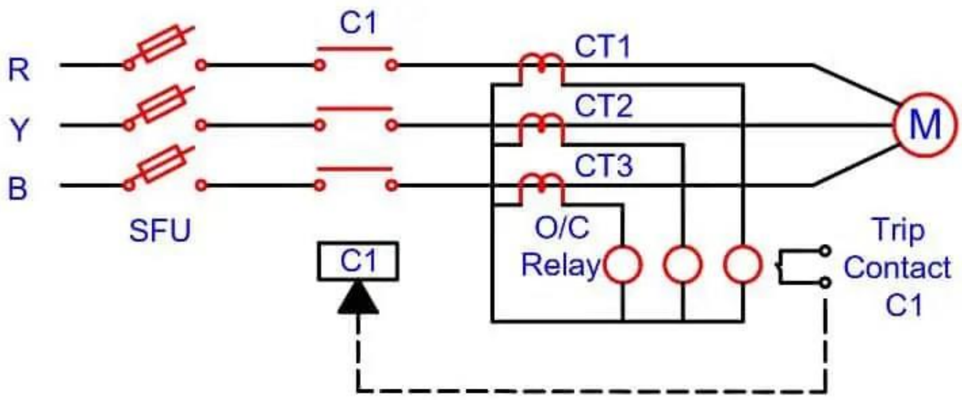
PHASE FAULT:

Phase fault protection is used for protection of induction motor. The protection relay trips the motor in the case of fault. We can call the protection as short circuit protection. In this post, we will discuss in more detail about protection scheme.

Thus, the **net torque** of the motor reduces, and motor tends to draw even more current. This heavy current cause overheating of motor winding and causes insulation failure. Therefore, it is must to protect the motor from phase fault protection.

At the time of fault, the motor draws abnormally high current, about 5-10 times of full load current. If the motor keep running in this condition, the motor apt to fail. Therefore, the motor needs to stop immediately by phase fault protection system.

Phase Fault Protection Scheme



Phase Fault Protection

The SFU, contactor and relay forms the protection system. CT1,CT2, and CT3 senses the current of each phase. When there is no fault, the relay does not trip and motor keep on running.

EARTH FAULT PROTECTION:

Earth Fault is an inadvertent fault between the live conductor and the earth. When earth fault occurs, the electrical system gets short-circuited and the short-circuited current flows through the system. The fault current returns through the earth or any electrical equipment, which damages the equipment. It also interrupts the continuity of the supply and may shock the user. To protect the equipment and for the safety of people, fault protection devices are used in the installation.

Earth Fault Protection Devices

The devices give the tripping command to break the circuit when earth fault occurs. The fault current is restricted and the fault is dispersed by the Restricted Earth Fault Protection (REFP) scheme. Normally earth fault relay, earth leakage circuit breaker and ground fault circuit interrupter, etc. are used to restrict the fault current.

Earth Fault Relay (EFR)

It is a safety device used in electrical installations with high earth impedance. It detects small stray voltages on the metal enclosures of electrical equipment. The result is to interrupt the circuit if a dangerous voltage is detected. The EFR is protected against tripping from transients and prevents shock.

The following figure shows the Earth Fault Relay −

DIRECTIONAL EARTH FAULT RELAY:-

Two-stage directional earth-fault relay for distribution networks

• Directional low-set earth-fault stage with definite time characteristic

• Directional high-set earth-fault stage with instantaneous operation or definite time characteristic

• Operation direction of the high-set earthfault stage either the same as that of the low-set stage, or the opposite

• Output relay functions to be freely configured by the user

• Flexible adaptation of the relay to different applications

• Manual selection or remote control of the operation characteristic I0sinϕ or I0cosϕ

• Digital display of settings, measured quantities, recorded fault values, etc.

• Extensive two-way data communication via fibre-optic serial bus

• Continuous self-supervision of hardware and software including auto-diagnosis

• Powerful software support for parameterization and supervision of the relay.

Application

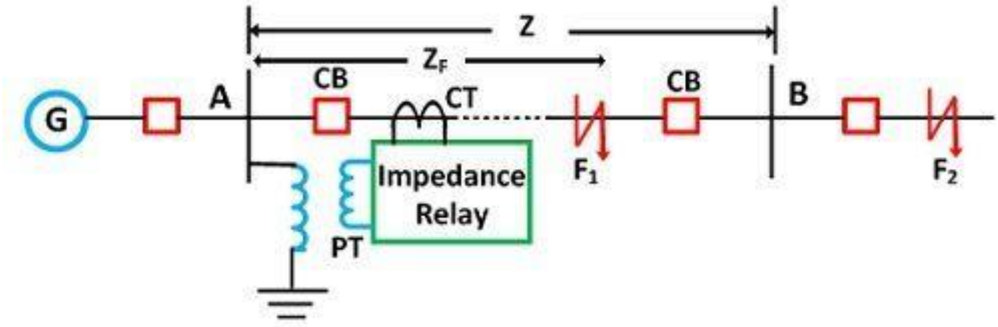
The directional earth-fault relay SPAS 120 C is designed to be used for selective feeder earth-fault protection in isolated neutral and impedance earthed networks. The relay is especially useful in networks, where the operation characteristic of the earth-fault relay must be remotely controllable. The directional earth-fault relay can also be used for the earth-fault protection of power generators and large motors.

DISTANCE PROTECTION

INPUT QUANTITIES FOR VARIOUS TYPES OF DISTANCE RELAYS:-

IMPEDANCE RELAY:

The relays whose operation is governed by the ratio of the applied voltage to current in the protected circuit is known as impedance relay. It is a distance relay that measures the distance by equating the fault current with voltage (which equates to impedance) across the fault loop and thus trips only for the faults on the line within the specified distance.



Principle of operation of an Impedance Relay

OPERATION:

The voltage coil of the relay is connected to the line to be protected through a potential transformer. While current coil of the relay is excited by the current transformer connected in series with the line to be protected.

The current element of the relay produces the operating torque (positive torque) proportional to the operating current of the line. While the voltage element of the relay produces the restraining torque (negative torque) which is in opposition to the operating torque and proportional to the line voltage i.e., an impedance relay is a voltage restrained overcurrent relay.

The impedance of the line when there is no fault i.e., under normal operating conditions. The relay is designed such that it operates when the ratio V/I falls below the preset value i.e., the impedance of the section to be protected falls below the preset value ZL.

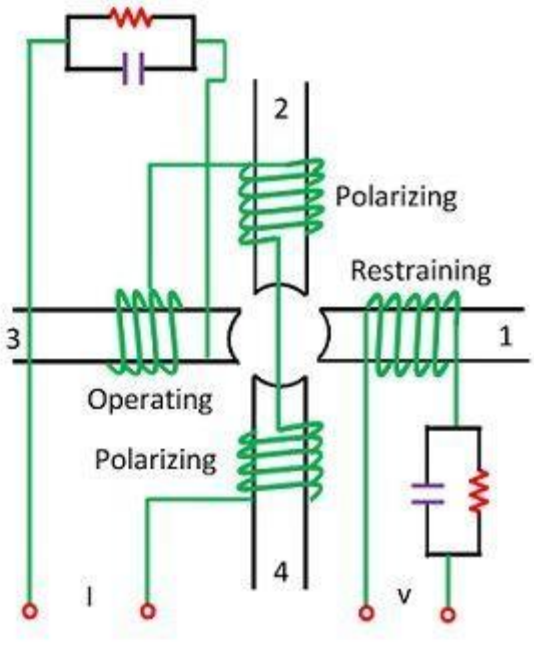
REACTANCE RELAY:

The reactance relay is a high-speed relay. This relay consists of two elements an overcurrent element and a current-voltage directional element. The current element developed positive torque and a current-voltage developed directional element which opposes the current element depending on the phase angle between current and voltage.

Reactance relay is an overcurrent relay with directional limitation. The directional element is arranged to develop maximum negative torque when its current lag behinds its voltage by 90°. The induction cup or double induction loop structures are best suited for actuating reactance type distance relays.

Construction of Reactance Relay

A typical reactance relay using the induction cup structure is shown in the figure below. It has a four-pole structure carrying operating, polarizing, and restraining coils, as shown in the figure below. The operating torque is developed by the interaction of fluxes due to current carrying coils, i.e., the interaction of fluxes of 2, 3 and 4 and the restraining torque is produced by the interaction of fluxes due to poles 1, 2 and 4.



Reactance Type Distance Relay

The operating torque will be proportional to the square of the current while the restraining torque will be proportional to VI cos (Θ – 90°). The desired maximum torque angle is obtained with the help of resistance-capacitance circuits, as illustrated in the figure. If the control effect is indicated by –k3, the torque equation becomes

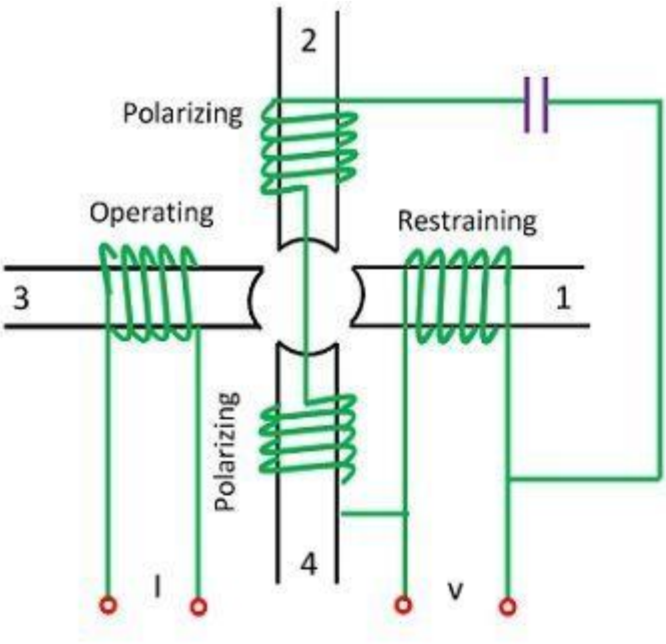
$$T = K_1 I^2 - K_2 VIcos(\theta - 90^{\circ}) - K_3$$

$$T = K_1 I^2 - K_2 sin\theta - K_3$$

MHO RELAY:-

A mho Relay is a high-speed relay and is also known as the admittance relay. In this relay operating torque is obtained by the volt-amperes element and the controlling element is developed due to the voltage element. It means a mho relay is a voltage controlled directional relay.

A mho relay using the induction cup structure is shown in the figure below. The operating torque is developed by the interaction of fluxes due to pole 2, 3, and 4 and the controlling torque is developed due to poles 1, 2 and 4.



Schematic Diagram of Mho Relay

Circuit Globe

If the spring controlling effect is indicated by –K3, the torque equation becomes,

$$T = K_1 VIcos(\theta - 90°) - K_3$$

Where Θ and τ are defined as positive when I lag behind V. At balance point, the net torque is zero, and hence the equation becomes

$$K_1 VIcos(\theta - \tau) - K_2 V^2 - K_3 = 0$$

$$\frac{K_1}{K_2} \text{Cos}(\theta - \tau) - \frac{K_3}{K_2 VI} = \frac{V}{I} = Z$$

$$Z = \frac{K_1}{K_2} \text{Cos}\,(\theta - \tau)$$

EFFECT OF ARC RESISTANCE:-

The high energy of arcing will result in the formation of corrosion products such as oxides, chlorides, sulfides, nitrides, and carbon on the surface of the contacts. This will cause the electrical resistance of the contact interface to increase over time.

Concern about the accuracy, it will help to find the accurate value of studies in fault analysis method. The previous literature was not include the arc resistance value in their analysis of fault, so it will give unaccurate results.

By considering the arc resistance value in computing fault current, it will induce the path of fault impedance and decrease fault current in the point of fault location happen. Since the arc resistance is directly propotional to the fault current, the typical values for arc resistance are based on the type and location of fault.

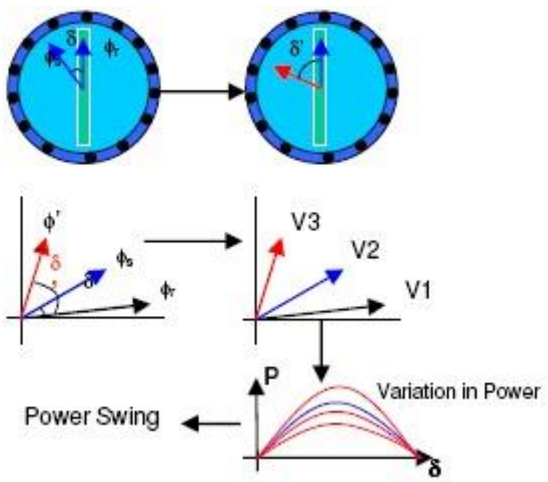
In the other word, the arc resistance is important thing to be concerned in analyzing the fault current in overall system indeed.

EFFECT OF POWER SWINGS:-

Power swings can cause the load impedance which under steady state conditions, whereas within the relay's operating characteristic, to induce unwanted relay operations at different network locations.

Power swings can cause the load impedance, which under steady state conditions is not within the relay’s operating char-acteristic, to enter into the relay’s operating characteristic, Operation of these relays during a power swing may cause undesired tripping of transmission lines or other power system elements, thereby weakening the system and possibly leading to cascading outages and the shutdown.

A Power Swing Block (PSB) function is available in modern relays to prevent unwanted distance relay element op-eration during power swings. The main purpose of the PSB function is to differentiate between faults and power swings and block distance or other relay elements from operating during a power swing. However, faults that occur during a power swing must be detected and cleared with a high degree of selectivity and dependability.



EFFECT OF LINE LENGTH & SOURCE IMPEDANCE ON THE PERFORMANCE OF DISTANCE RELAY:

- In normal operating condition, restoring torque is more than deflecting torque. Hence relay will not operate.

- But in faulty condition, the current becomes quite large whereas voltage becomes less. Consequently, deflecting torque becomes more than restoring torque and dynamic parts of the relay starts moving which ultimately close the No contact of relay.

- Hence clearly operation or working principle of distance relay depends upon the ratio of system voltage and current.

- As the ratio of voltage to current is nothing but impedance so a distance relay is also known as impedance relay.
  The operation of such relay depends upon the predetermined value of voltage to current ratio.

- This ratio is nothing but impedance. The relay will only operate when this voltage to current ratio becomes less than its predetermined value. Hence, it can be said that the relay will only operate when the impedance of the line becomes less than predetermined impedance (voltage/current).

- As the impedance of a transmission line is directly proportional to its length, it can easily be concluded that a distance relay can only operate if fault is occurred within a predetermined distance or length of line.

SELECTION OF DISTANCE RELAYS:-

The factors to be considered for the Selection of Distance Relay scheme can be enumerated as follows:

1. Speed of Operation:

Operating time is of great importance on systems which are liable to become unstable if the fault persists for more than 5 cycles or so. Zone 1 operation in non-switched schemes where separate measuring units for different phases are used is in the region of 2-3 cycles; but about 40% of the protected section viewed from both ends is covered in zone.

2. Measuring Relay Characteristics:

The field of application of various Selection of Distance Relay overlap to a large extent and as such a hard line cannot be drawn for their respective fields. The length of the line to be protected and the voltage of transmission play a very important role in the choice of these Reactance relays are preferred for short line sections because of being insensitive to fault resistances which may be large compared with the line impedance. Since power swings affect reactance relays to a large degree than the other factors these relays are unsuited to long line protection.

3. Fault Coverage:

Where a system is not effectively earthed or earthed through an arc suppression coil it is only necessary to apply phase-fault schemes of protection; while on effectively earthed systems fault coverage for both phase and earth faults is provided.

4. Economic Considerations:

The foregoing discussion makes it amply clear that there are a number of alternatives to achieve the objective of feeder protection. Maybe time graded overcurrent protection is sufficient under particular circumstances. As far as earth-fault protection is concerned overcurrent earth-fault protection works quite satisfactorily and is normally provided with phase protection as one of the Selection of Distance Relay schemes. The occasional slower clearing time with overcurrent relays is unimportant because single phase of earth-faults have negligible effect on system stability.

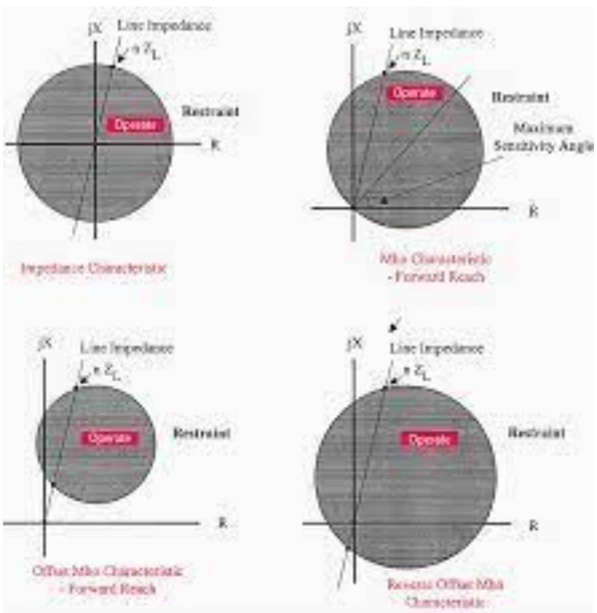
MHO RELAY WITH BLINDERS:-

The characteristics of a conventional load blinder. The blinder restrains the operation of the distance element for load impedance that appears to the right of the blinder.

If the impedance seen by the relay is within the Mho characteristic and to the left of the blinder, it is allowed to operate and trip the breaker. some areas of zones 2 and 3 will be lost. The NERC recommendation is used to set this conventional blinder.

As per NERC Task Force requirements, phase distance settings and other applicable phase and ground distance zone settings must permit loading of the line, without trip, up to 150% of emergency line ampere rating and 115% of short duration (15 min) emergency line ampere rating, with 0.85 per unit bus voltage and a load angle of 30.

Considering the above guidelines, the load blinder element is set to prevent the tripping of the distance protection element on load.



REDUCTION OF MEASURING UNITS:-

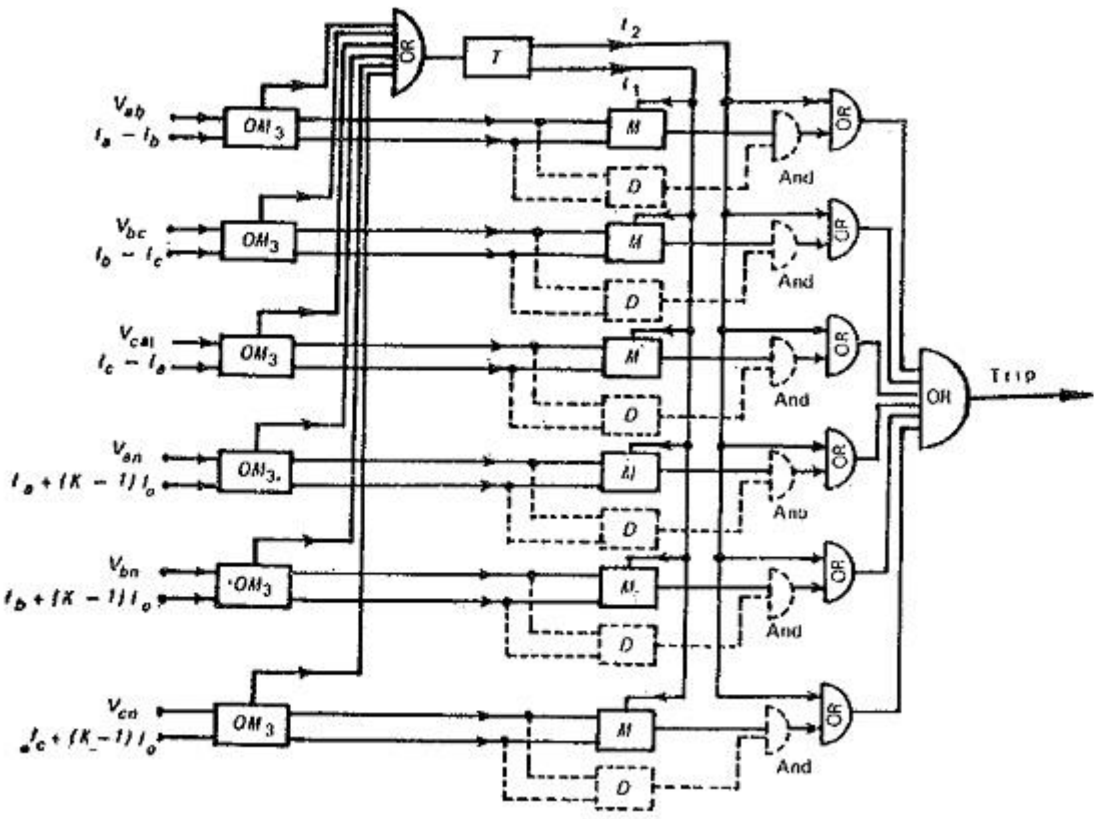
Unit measure reduction, the type of vessel representing the greatest risk to the platform needs to be analyzed. For the passing vessel collision, the risk reduction measures are:

Improving the information distribution for the platform's site—this measure can increase the probability of the platform being located, and subsequently ships may preplan their voyage to avoid collision.

Warning to the incoming ships as early as possible if they come along a collision course—calling the vessel on VHF/radio and actively using a standby vessel to intercept the incoming vessel are also effective risk reduction measures. Collision consequence reduction measures include the use of rubber fenders and protection nets on the platform, which are standard design practice.

SWITCHING DISTANCE SCHEME:-

One set of relays is used and can be switched to any one of the six measuring conditions. This phase selection is normally accomplished by overcurrent and residual current relays, but may be supplemented by undervoltage relays. This is commonly known as switched distance protection scheme. Such schemes are economical and are common with static.



AUTO-RECLOSING:-

Auto reclosing is a phenomenon in which the breaker tries to reconnect the line between two points with the delay or without delay at the time of the fault.

Auto recloser is a device which can open at the time of fault and reclose after a delay or without delay, but engineer needs to define that how many reclosing options are allowed, let suppose 3 reclosers are allowed, then after 3 O-C (open and close) operations, auto reclosers programmed (manually or remotely) blocked further operation and remain in the open position.

During the opening phase of the recloser's operation, the arc is opted to deionize. Let suppose our auto recloser is programmed for 2 successful reclosers, and after 2 reclosers fault persists in a system, then the fault will be characterized as semi transient or permanent, and auto recloser performed blocking of line.

UNIT-III

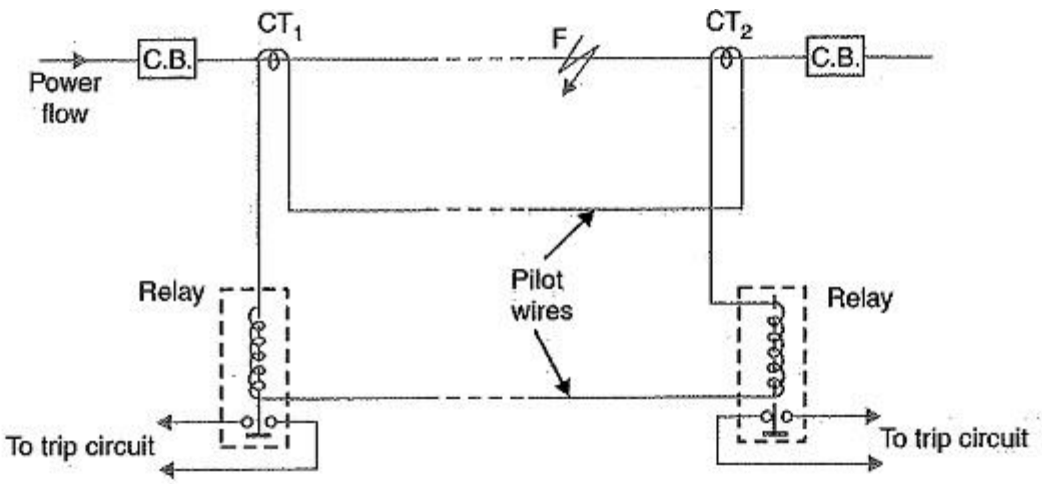
PILOT RELAYING SCHEMES

WIRE PILOT PROTECTION:-

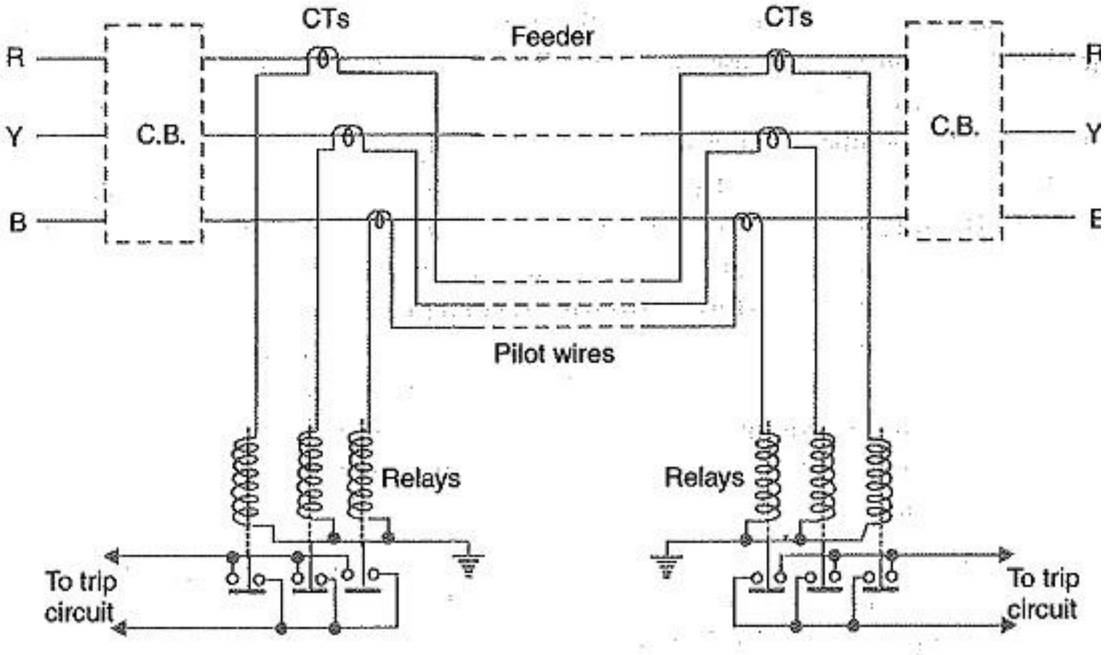
The Differential Pilot Wire Protection is based on the principle that under normal conditions, the current entering one end of a line is equal to that leaving the other end. As soon as a fault occurs between the two ends, this condition no longer holds and the difference of incoming and outgoing currents is arranged to flow through a relay which operates the circuit breaker to isolate the faulty line. There are several Differential Pilot Wire Protection schemes in use for the lines.

1. Merz-Price voltage balance system
2. Translay scheme

1. **Men-Price voltage balance system:** Fig. 23.8 shows the single line diagram of MerzPrice voltage balance system for the protection of a 3-phase line. Identical current transformers are placed in each phase at both ends of the line. The pair of CTs in each line is connected in series with a relay in such a way that under, normal conditions, their secondary voltages are equal and in opposition i.e. they balance each other.

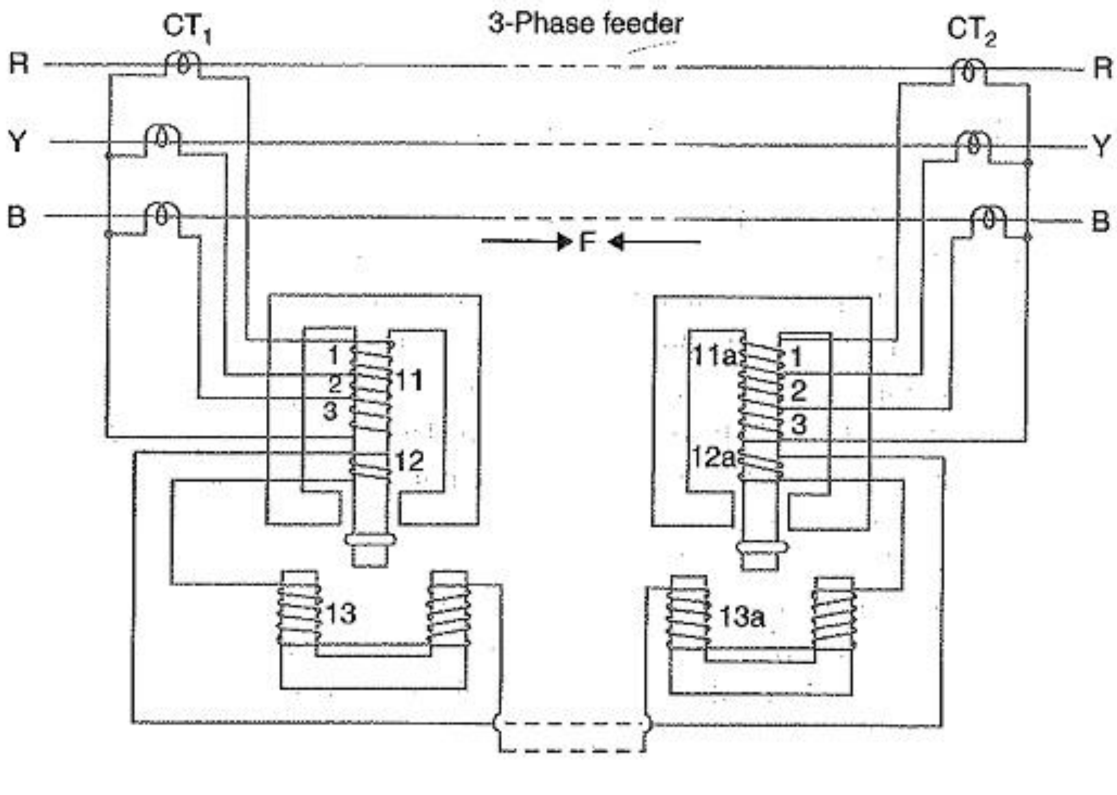


Under healthy conditions, current entering the line at one-end is equal to that leaving it at the other end. Therefore, equal and opposite voltages are induced in the secondaries of the CTs at the two ends of the line. The result is that no current flows through the relays. Suppose a fault occurs at point F on the line as shown in Fig. 23.8. This will cause a greater current to flow through CT1 than through CT2. Consequently, their secondary voltages become unequal and circulating current flows through the pilot wires and relays. The circuit breakers at both ends of the line will trip out and the faulty line will be isolated.



2. **Translay scheme:**

This system is similar to voltage balance system except that here balance or opposition is between the voltages induced in the secondary windings wound on the relay magnets and not between the secondary voltages of the line current transformers. This permits to use current transformers of normal design and eliminates one of the most serious limitations of original voltage balance system, namely ; its limitation to the system operating at voltages not exceeding 33 kV.



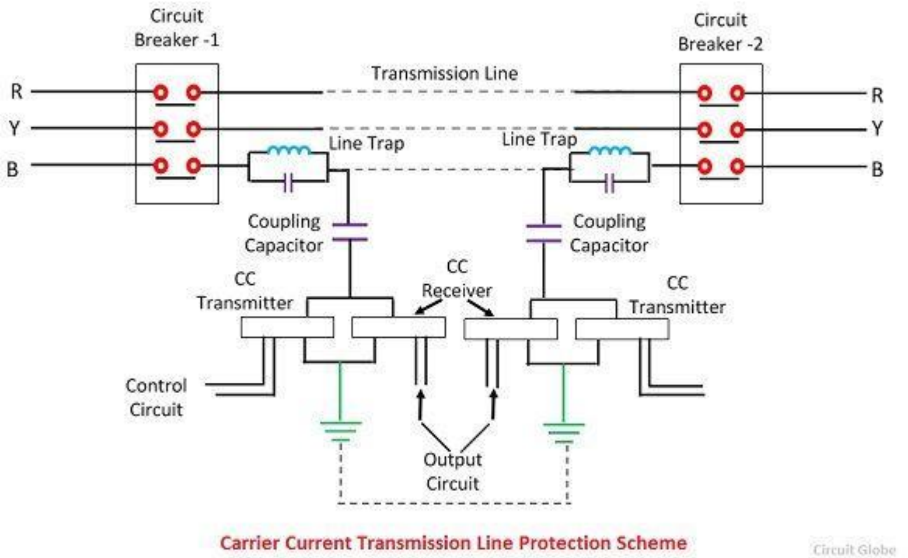
OPERATION:

When the feeder is sound, the currents at its two ends are equal so that the secondary currents in both sets of CTs are equal. Consequently, the currents flowing in the relay primary winding 11 and 11 a will be equal and they will induce equal voltages in the secondary windings 12 and 12a. Since these windings are connected in opposition, no current flows in them or in the operating windings 13 and 13a. In the event of a fault on the protected line, the line current at one end must carry a greater current than that at the other end. The result is that voltages induced in the secondary windings 12 and 12 a will be different and the current will flow through the operating coils 13, 13a and the pilot circuit. Under these conditions, both upper and lower elements of each relay are energised and a forward torque acts on the each relay disc. The operation of the relays will open the circuit breakers at both ends of the line.

CARRIER CURRENT PROTECTION:-

Carrier current protection scheme is mainly used for the protection of the long transmission line. In the carrier, current protection schemes, the phase angle of the current at the two phases of the line are compared instead of the actual current. And then the phase angle of the line decides whether the fault is internal and external. The main elements of the carrier channel are a transmitter, receiver, coupling equipment, and line trap.

Line trap is inserted between the bus-bar and connection of coupling capacitor to the line. It is a parallel LC network tuned to resonance at the high frequency. The traps restrict the carrier current to the unprotected section so as to avoid interference from the with or the other adjacent carrier current channels. It also avoids the loss of the carrier current signal to the adjoining power circuit.



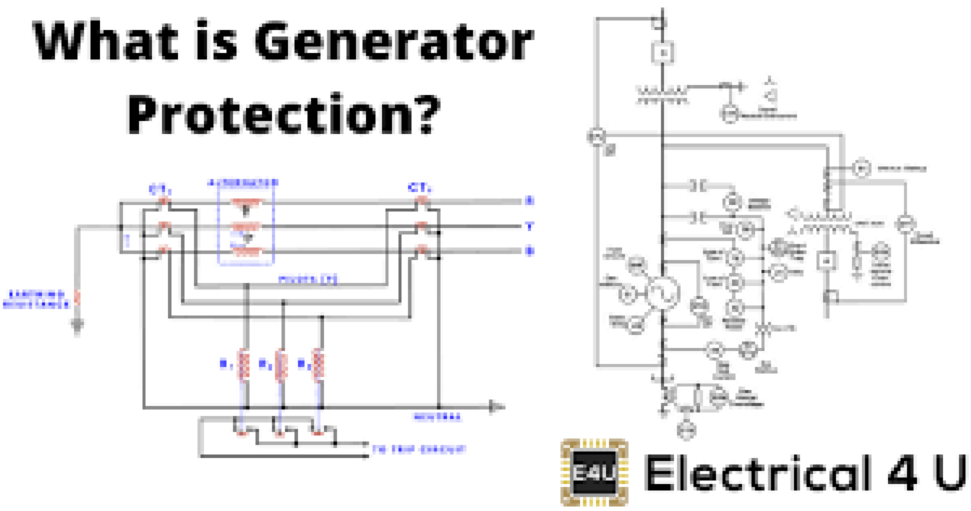
Carrier Current Transmission Line Protection Scheme

The coupling capacitor connects the high-frequency equipment to one of the line conductors and simultaneously separate the power equipment from the high power line voltage. The normal current will be able to flow only through the line conductor, while the high current carrier current will circulate over the line conductor fitted with the high-frequency traps, through the trap capacitor and the ground.

AC MACHINES AND BUS ZONE PROTECTION:-

PROTECTION OF GENERATOR:

A generator is subjected to electrical stresses imposed on the insulation of the machine, mechanical forces acting on the various parts of the machine, and temperature rise. These are the main factors which make protection necessary for the generator or alternator. Even when properly used, a machine in its perfect running condition does not only maintain its specified rated performance for many years, but it does also repeatedly withstand certain excess of overload.



Preventive measures must be taken against overloads and abnormal conditions of the machine so that it can serve safely. Even ensuring an efficient design, construction, operation, and preventive means of protection – the risk of a fault cannot be completely eliminated from any machine. The devices used in generator protection, ensure that when a fault arises, it is eliminated as quickly as possible.

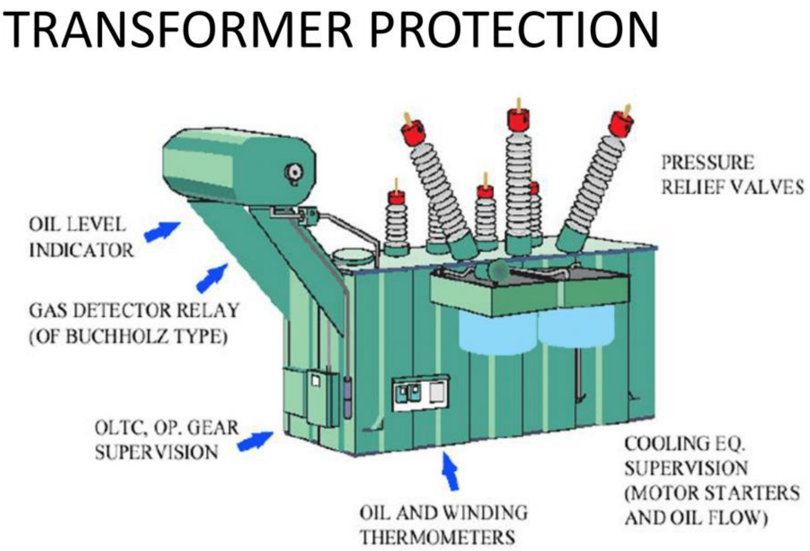
PROTECTION OF TRANSFORMER:

Two types of over voltages may stress and even destroy a transformer:

• The lightning over voltages due to lightning stroke falling on or near an overhead line supplying the installation where the transformer is installed
• The switching over voltages generated by the opening of a circuit breaker or a load break switch for instance.

Depending of the application, protection against these two types of voltage surges may be necessary and are often ensured by means of ZnO surge arrestors preferably connected on the MV bushing of the transformer.

A transformer overload is always due to an increase of the apparent power demand (kVA) of the installation. This increase of the demand can be the consequence of either a progressive adjunction of loads or an extension of the installation itself. The effect of any overload is an increase of the temperature of oil and windings of the transformer with a reduction of its life time.



The protection of a transformer against the overloads is performed by a dedicated protection usually called thermal overload relay. This type of protection simulates the temperature of the transformer's windings.

The simulation is based on the measure of the current and on the thermal time constant of the transformer. Some relays are able to take into account the effect of harmonics of the current due to non-linear loads such as rectifiers, computers, variable speed drives etc. This type of relay is also able to evaluate the remaining time before the emission of the tripping order and the time delay before re-energizing the transformer.

In addition, oil-filled transformers are equipped with thermostats controlling the temperature of the oil.

Dry-type transformers use heat sensors embedded in the hottest part of the windings insulation.

Each of these devices (thermal relay, thermostat, heat sensors) generally provides two levels of detection:

- A low level used to generate an alarm to advise the maintenance staff,
- A high level to de-energize the transformer.

BUS ZONE PROTECTION:

Bus Zone Protection includes, besides the bus itself the apparatus such as circuit breakers, disconnecting switches, instrument transformers and bus sectionalizing reactors, etc. Although bus zone faults are rare, experience shows that bus zone protection is highly desirable in large and important stations. Bus zone is more vulnerable to the effects of faults once it occurs for the following reasons:

- Concentration of fault MVA increases risk of considerable damage.
- Loss of bus zone would result in widespread supply interruption.

It is of utmost importance therefore that bus zone protection should be fast, stable and most reliable.

Periodic testing is necessary to check the pickup of the relay on internal faults.

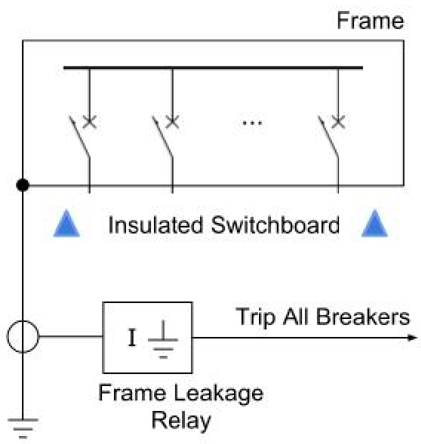
It is the opinion of some experts that local bus protection should not be provided and the bus faults cleared by the backup relays at the neighbouring stations, as the provision of local bus protection would certainly increase the risk of inadvertent tripping.

Where local bus protection is provided care is taken by providing two independent protective circuits, both of which must be satisfied before tripping can occur.

FRAME LEAKAGE PROTECTION:-

Frame leakage protection is one of the most simple forms of bus-bar protection available, suitably designed to withstand the earth faults occurring within the indoor installations. This type of protection is applicable to metal-clad switchgear of small size. All the metal frameworks are attached together and insulated from the ground.

It is essential to isolate the switchgear framework from lead cable sheaths, such that when a leakage to the framework occurs then the leakage current will pass through the primary of the current transformer provided in the earth connection. The current transformer secondary is connected to an earth leakage relay.



- The metal-clad switchgear is grounded through a current transformer, the secondary of which is connected to an overcurrent relay.
- Under normal working conditions, the overcurrent relay remains inoperative but when a fault takes place, the leakage current will pass through the faulted section to the ground causing the relay to operate resulting in tripping of the circuit breaker connecting equipment to the bus.
- Supply is provided to the station busbars having earthed star-connected secondary also to which a current transformer is connected which energizes the operating coil of the check relay connected to its secondary.
- When an earth fault occurs within the protected area, the contacts of both the leakage and check relay are closed energizing the tripping relay and enabling the operation of the circuit breaker.

UNIT-IV

STATIC RELAYS

AMPLITUDE AND PHASE COMPARATORS:-

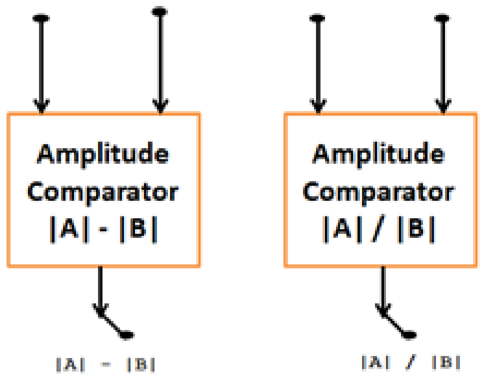
AMPLITUDE COMPARATOR:-

Amplitude comparator compares the amplitudes of two (or more) input quantities. The phase angle between the quantities under comparison (inputs) is not recognized or noticed by the amplitude comparator.

If the two input signals are S1 and S2 (say S1 the operating and S2 restraining), the amplitude comparator gives positive output only if –

$S2/S1 < K$.

The function is represented by a circle in the complex plane with its centre at the origin. This defines the boundary of the marginal operation.



PHASE COMPARATOR:-

Phase comparison technique is the most widely used technique for all practical directional, distance, differential and carrier relays.

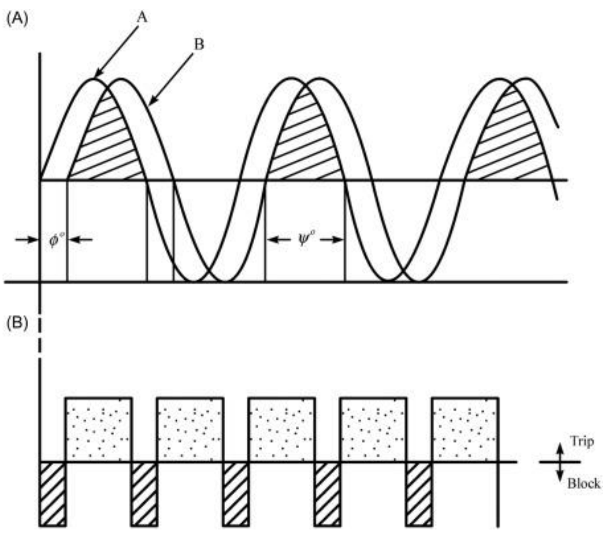
In a phase comparator, the operation of the relay takes place when the phase relation between two inputs S1 and S2 varies within certain specified limits.

Both inputs must exist for an output to occur; ideally, operation is independent of their amplitudes, and depends only on their phase relationship.

The function, as defined by the boundary of marginal operation, is represented by two straight lines from the origin of the complex plane.

Mathematically, the condition of operation is given as –

$-\alpha 1 \leq \theta \leq \alpha 2$



DUALITY BETWEEN AC & PC:-

The general operating characteristics of the relays using the amplitude and phase comparators respectively. These are Comparator Equation in Power System Protection of a circle on complex planes and indicate that an operating characteristic equation can be obtained either by a phase comparator or by an amplitude comparator through proper selection of the four constants K1 through K4. This further suggests the possibility of a simple relation between the two comparators and it can be proved that an inherent amplitude comparator becomes a phase comparator and vice versa, if the input quantities are changed to the sum and difference of the original two input quantities.

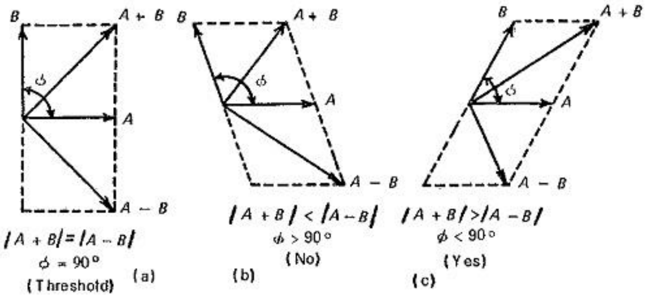
Consider the operation of an amplitude comparator with input signals A and B. It operates, say, when

$$|A| > |B|$$

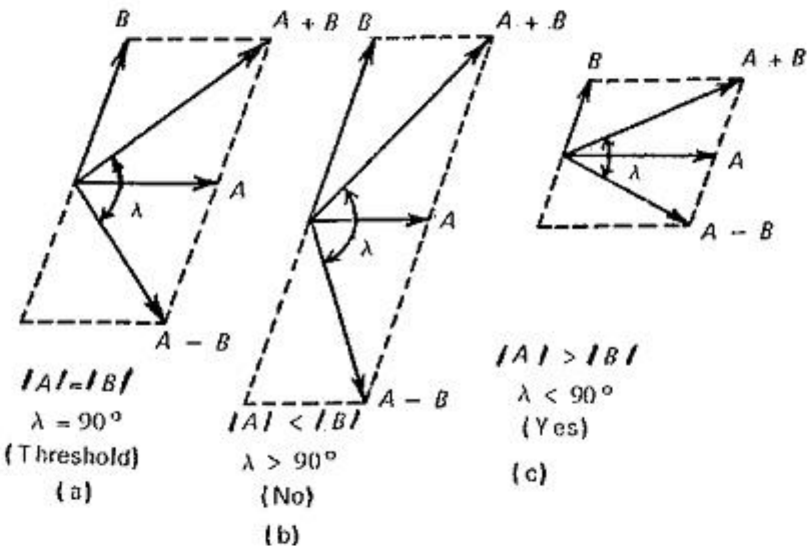
If the inputs are changed to (A + B) and (A — B) so that it operates when

$$|A+B|>|A-B|$$

It has now become an inherent phase comparator vector diagram, i.e. if the inputs are changed to (A + B) and (A—B) the original amplitude comparator would compare phases of A and B.



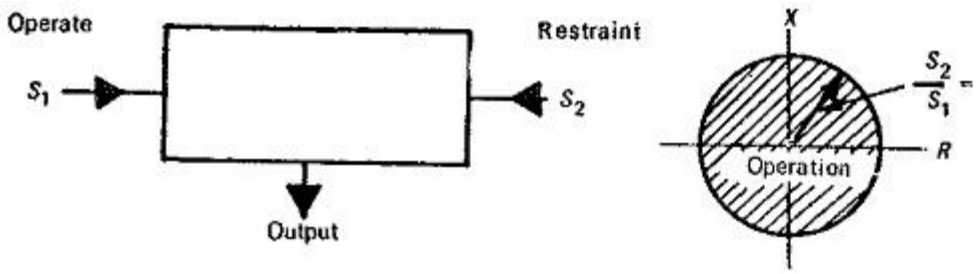
Similarly, a phase comparator working with inputs A and B, operates when A and B have same directional sense. If now the inputs are changed to (A + B) and (A—B) it would operate when (A + B) and (A—B) have the same directional sense, i.e. |A| > |B| Such comparators are known as converted comparators.



Though a given relay characteristic can be obtained using either of the two comparators, consideration of the constants calculated for required characteristics would indicate which type of comparator is preferable. In general an inherent comparator is better than the converted type, because if one quantity is very large compared with the other, a small error in the large quantity may cause an incorrect comparison when their sum and difference are supplied as inputs to the relay.

STATIC AMPLITUDE COMPARATOR:-

If the two input signals are S1 and S2 the amplitude comparator gives positive (yes) output only if S2/S1 ≤ K S1 is the operating quantity and S2 is the restraining quantity. Ideally, the comparison of the two input signals is independent of their level and their phase relationship. The function is represented by a circle in the complex plane, with its centre at the origin: this defines the boundary of the marginal operation. Static Amplitude Comparator may be of the following types:



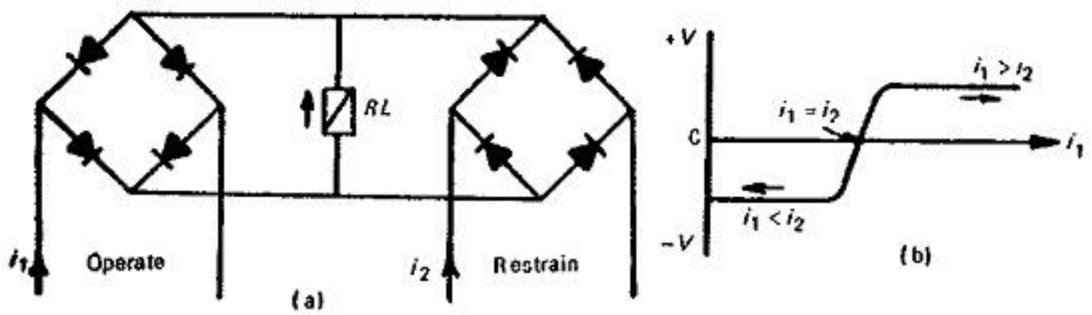
1. Integrating comparators,

2. Instantaneous comparators, and

3. Sampling comparators.

Integrating Comparators:

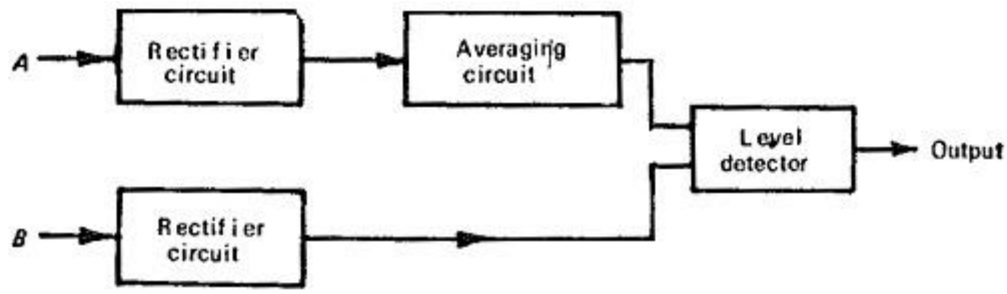
It is possible to arrange rectifier bridge networks as amplitude comparators. Rectifier bridge comparator can either be of circulating current type or opposed voltage type.



Basic circuit for the circulating current type of Static Amplitude Comparator. The polarized relay operates when S1>S2, where S1=K1i1 and S2=K2i2. This arrangement provides a sensitive relay whose voltage may be ideally The relay voltage will never exceed twice the forward voltage drop of the rectifiers, and typically will be of the order of 1 volt.

Instantaneous Comparators:

Instantaneous or direct amplitude comparators can be of two types: averaging type and phase splitting type.



In the averaging type instantaneous amplitude comparator the restraining signal is rectified and smoothed completely in order to provide a level of restraint. This is then compared with the peak value of the operating signal, which may or may not be rectified, but is not smoothed. The tripping signal is provided if the operating signal exceeds the level of restraint.

Sampling Comparators:

Sometimes it is convenient to get the required characteristics by comparing the magnitude of one input signal at a certain point on its wave against the rectified and smoothed value of the second signal. Reactance characteristic is one such case where the instantaneous value of the voltage at the moment of current zero is compared against the rectified and smoothed value of current. If current I lags behind voltage V by an angle Φ then the value of voltage at current zero is Vm sin Φ.

The reactance relay operates for X < K, i.e.

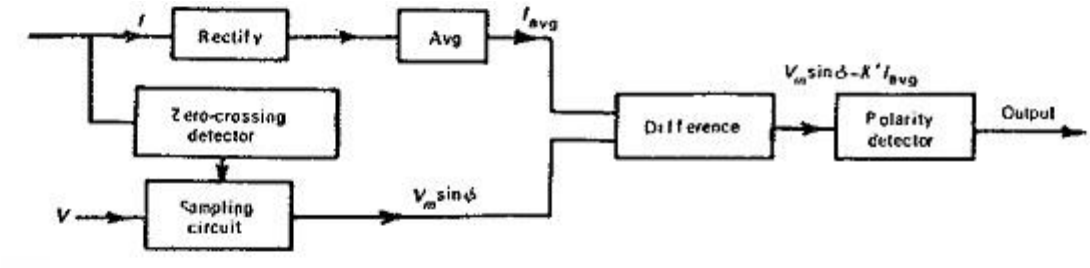
$$Z \sin \phi < K$$

$$\frac{V}{I} \sin \phi < K$$

$$\frac{V_m}{\sqrt{2}} \sin \phi < K I_{avg} \times 1.11$$

$$V_m \sin \phi < K' I_{avg}$$

The block schematic diagram is shown in Fig.



INTEGRATING AND INSTANTANEOUS COMPARATOR:-

INTEGRATING COMPARATOR:

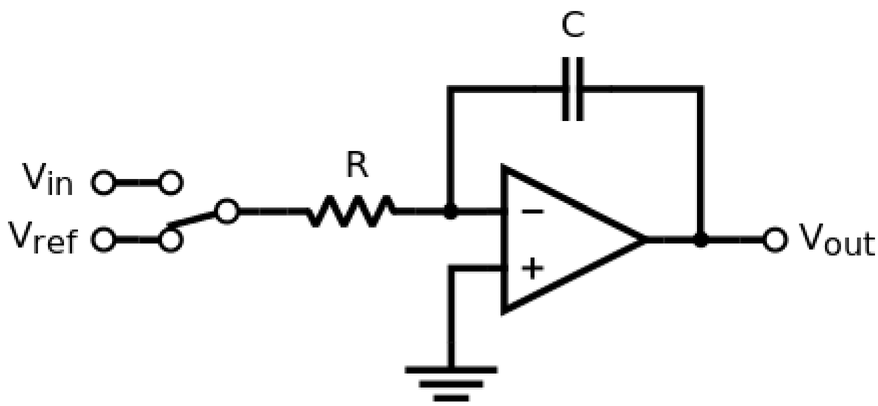
An integrating phase comparator, designed to indicate the phase angle difference between any two sine wave signals of nearly the same frequency over a fixed period of time is described.

The input signal from the first generator is split in three signals differing in phase by 120° and then each one of these signals is individually modulated with the signal from the second generator.

The resultant outputs are fed to drive a three-phase synchronous motor coupled to a gear operated counter mechanism.

The total frequency difference, integrated over a fixed period of time, is obtained from the counter readings.

The instrument is transistorized for continuous operation at low power consumption.



INSTANTANEOUS COMPARATOR:-

Instantaneous or direct amplitude comparators can be of two types:

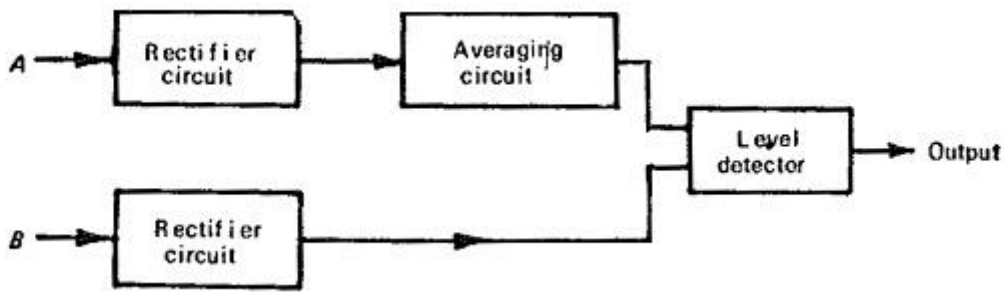
1. Averaging type

2. Phase splitting type.

In the averaging type instantaneous amplitude comparator the restraining signal is rectified and smoothed completely in order to provide a level of restraint.

This is then compared with the peak value of the operating signal, which may or may not be rectified, but is not smoothed.

The tripping signal is provided if the operating signal exceeds the level of restraint.



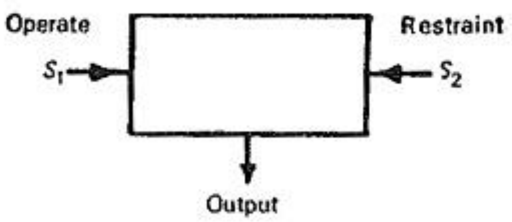
STATIC PHASE COMPARATORS:-

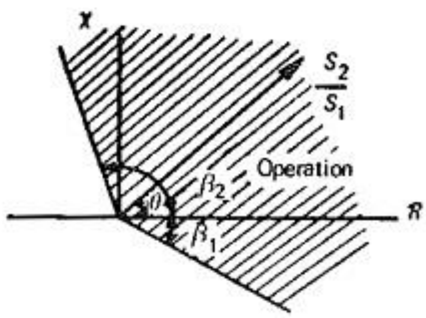
• Period of coincidence of +ve polarity of 2 signals are compared with a reference angle. (usually 90 degree)

•If the 2 signals have a phase difference of ϕ, then the angle of coincidence ψ = 180 - ϕ.

•If ϕ < 900, then ψ > 900. The phase comparator may be designed to trip the C.B, when ψ > 900.

• The period of coincidence is measured by different technique



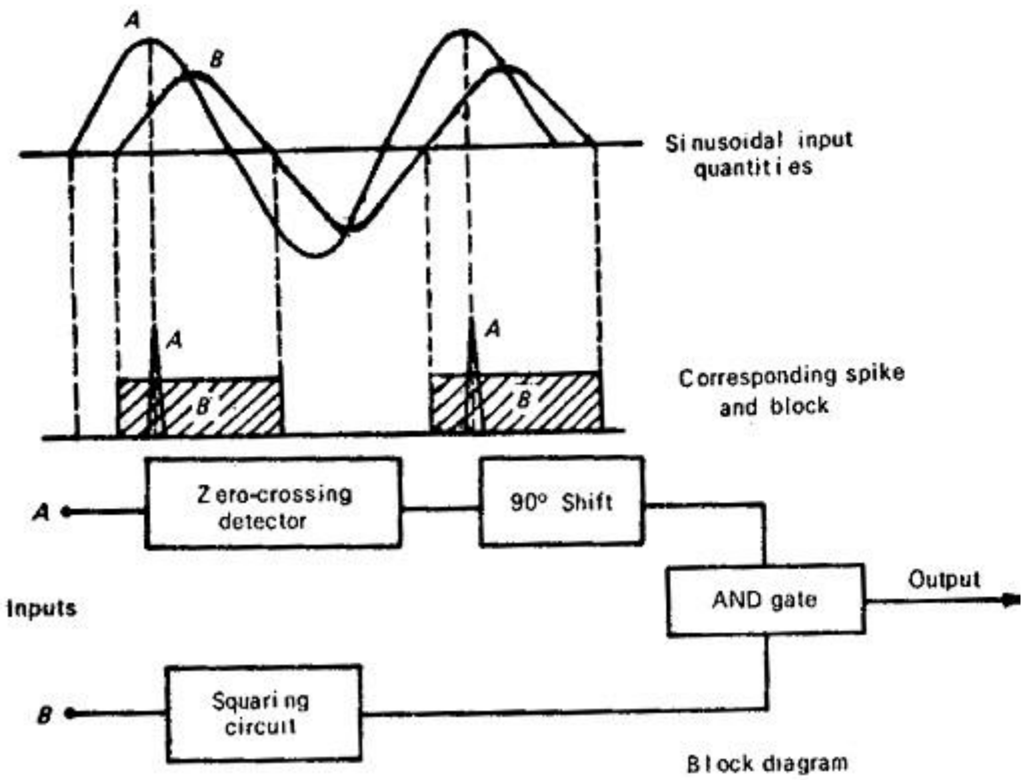


COINCIDENT TYPE OF PHASE COMPARATOR:-

It can be seen that the period of coincidence is equal to the period of noncoincidence for a phase difference of ±90°,the period of coincidence is less than the period of no coincidence and vice versa when the phase difference is less than ±90°.

Depending upon the phase relation of the input signals it is possible to design the circuit to give an output a Yes or a No, by measuring the period of Coincidence Type Phase Comparator.

The period of coincidence of two signals with a phase difference of θ is ψ=180-θ. Different techniques can be employed to measure the period of coincidence.



STATIC OVER CURRENT RELAYS:-

The overcurrent relays, even though simplest of all types of electromechanical relays, are the most difficult static relays. This is because the induction disc characteristics of the overcurrent relays (inverse characteristics) are not amenable to simple mathematical analysis. The first static relays developed were the high speed differential relays and the distance relays.

Fault current level detectors are termed overcurrent relays. They are more complicated in static form as compared to their electromagnetic counterparts.

However, static overcurrent relays offer several advantages over the electromagnetic form:

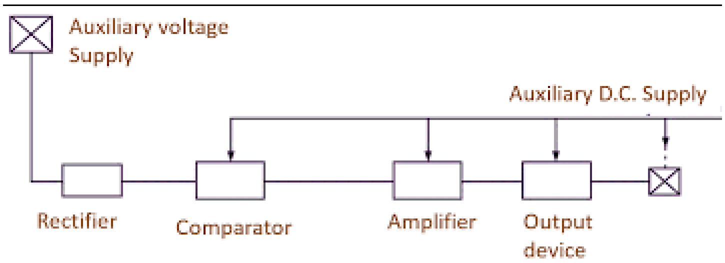
1. Low CT burden – The VA consumption of static overcurrent relays is quite low (7 mVA to 100 mVA) as compared with that of electromagnetic relays (1VA to 3VA) so that smaller CTs are required. The performance of CT under short-circuit condition is also improved.

2. Compact in size – The size of a single three-phase overcurrent relay may be about one-fourth of three electromagnetic relays. Hence less panel space is required in case of static overcurrent relays.

3. Possibility of Instantaneous Reset-In case of static overcurrent relays instantaneous reset is possible. This is due to the absence of moving parts, which facilitates the application of automatic reclosing of breakers.

4. No over-reaching tendencies and more accurate time-current characteristic.

5. Less maintenance, long life and not affected by shock and vibration.

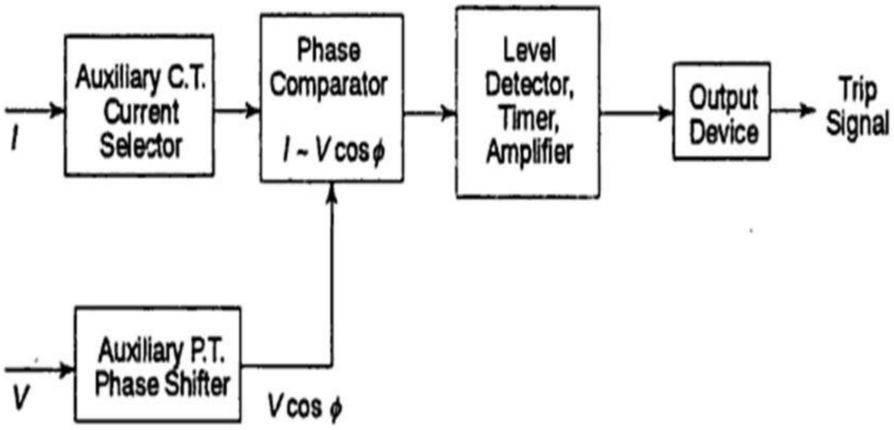


The technique of overcurrent relaying is still widely used as a means of fault detection on distribution system and on transmission lines supplied from one end. In the case of transmission lines supplied from both ends, it is employed with directional relays. Overcurrent relays are also employed in conjunction with distance relays to provide backup protection.

STATIC DIRECTIONAL RELAY:-

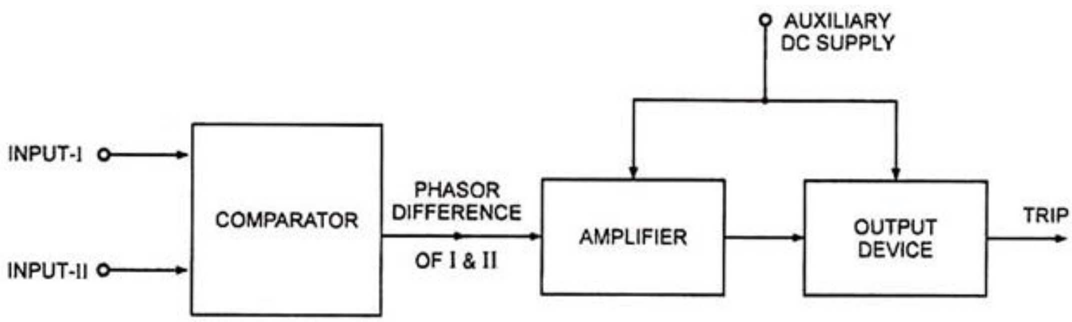
- Static directional relay or Directional overcurrent static relay:
- The static directional relay with two inputs (V and I). The inputs are supplied to the phase comparator.
  - A phase shifter is included in the voltage input circuit, whose output is fed to the phase comparator.
  - Technique of overcurrent relaying is still widely used as a means of fault detection on distribution system and on transmission lines supplied from one end. In the case of transmission lines supplied.

Static Directional Over current relay



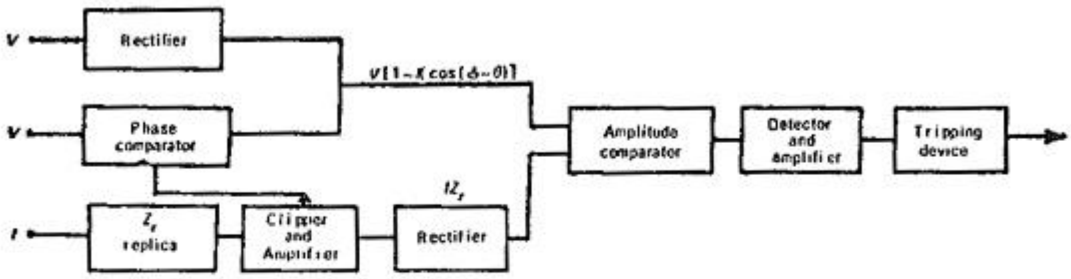
STATIC DIFFERENTIAL RELAY:-

The differential relay measures the phasor difference between two similar electrical quantities (voltage-voltage or current-current). The rectifier bridge amplitude comparator is the most common static form for applications as a differential relay element.



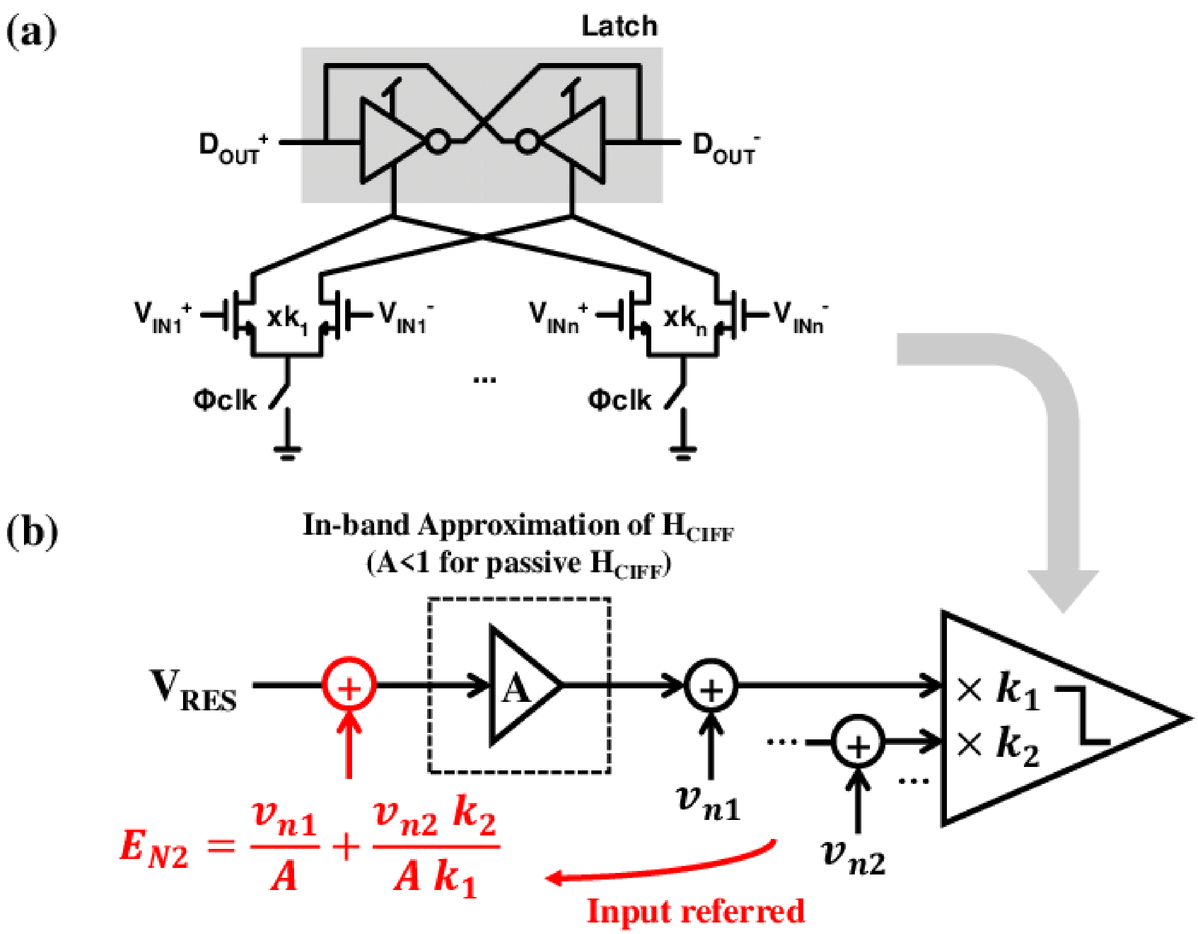
STATIC DISTANCE RELAY:-

Static Distance Protection Relay are characterized by having two input quantities respectively proportional to the voltage and current at a particular point in the power system, referred to as the relaying point. The ideal forms of such relays have characteristics which are not dependent on the actual values of voltage and current, but only on their ratio and the phase angle between them. The basic measurement of impedance is done in comparators of the type already discussed which pass on the signal to tripping circuit through suitable timing unit.



MULTI INPUT COMPARATORS:-

A multi-input comparator determines a minimum or maximum signal value in a given set of signal values. In an illustrative embodiment, a multi-input comparator includes a number of interconnected inversion circuits, with each of the inversion circuits having an input node associated therewith. The input node of each of the inversion circuits is coupled to an output of at least one of the other inversion circuits. As a result, after activation of the inversion circuits, the voltages at the input nodes are indicative of the relative magnitude of the signal values previously applied thereto. The inversion circuits may be constructed using, for example, single-inverter or multiple-inverter building blocks. Additional inputs can be provided by replicating the corresponding single-inverter or multiple-inverter blocks.



CONCEPT OF QUADRILATERAL RELAY CHARACTERISTICS:-

The quadrilateral distance relay characteristic consists of four straight lines .The positive torque region is the region covered by all the four lines i.e. quadrilateral ABCDA. If the impedance seen by the relay is inside the operating region, then relay trips.

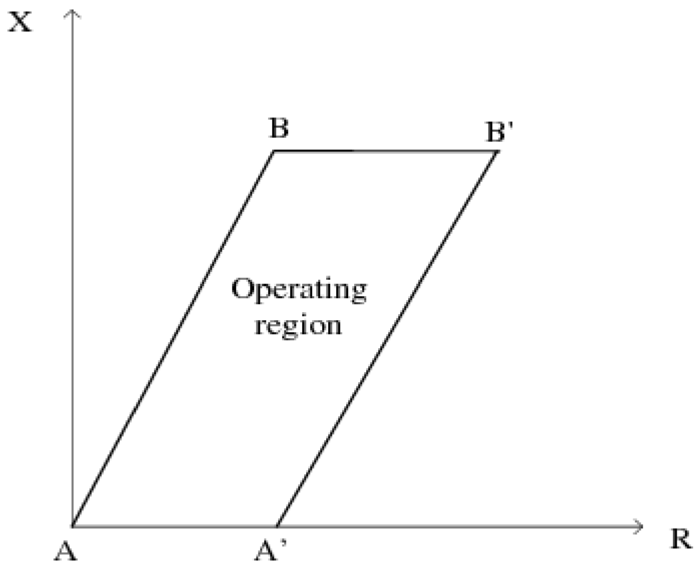
Each of these lines can be defined by an equation given by; Line AB: X = m1*R

(1) Line BC: X = constant (k)

(2) Line CD: X = m2*R+C

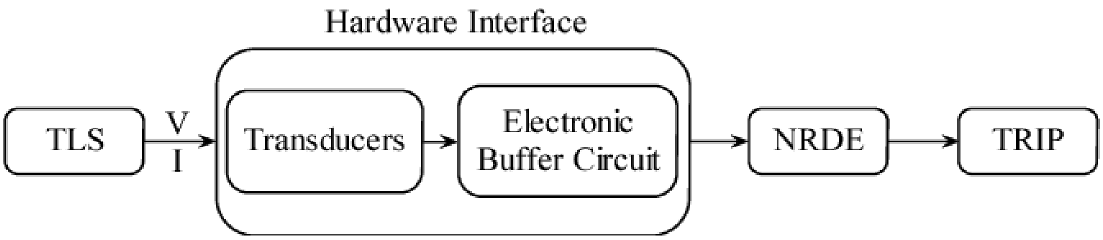
(3) Line DA: X = 0

(4) Where, m1 is the slope of the line AD; m2 is the slope of the line BC and C is the constant. Hence, during fault if reactance and resistance (X and R) up to the fault point are known, the trip condition can be decided. In this paper, simple algebraic equations as given below are used for calculating the impedance, resistance and reactance of the line which is required for the development of relay characteristic.



CONCEPT OF ELLIPTICAL RELAY CHARACTERISTICS:-

An elliptical relay is a non-conventional directional relay. It is a subset of conic section relay. The R-X characteristics of elliptical relay is shown in Figure 1. Figure 1: R-X characteristics of elliptical relay.



MICROPROCESSOR BASED RELAYS

ADVANTAGES OF OVER CURRENT:-

- Overcurrent relay has selectable operating characteristic.
- The operating characteristic of fuse is similar to Extremely Inverse characteristic (IEC) available in relay.
- In addition, overcurrent relay comes with options - Standard and Very Inverse characteristics too. There are IEEE etc. characteristic options too available.
- Thus, overcurrent relay provides choice of operating characteristic that can be selected depending on the operating time required and also to coordinate with downstream feeder protection in an optimum way.

ADVANTAGES OF DIRETIONAL RELAY:-

- Directional overcurrent relays are able to detect the direction of the current flow and will only operate when the current is flowing in a certain direction.
- This helps prevent unnecessary trips or circuit breaker operations in systems with several current paths or power sources.

ADVANTAGES OF DISTANCE RELAYS:-

- It replaces the protection of overcurrent transmission lines.
- Provides protection very fastly.
- Coordination and application is very simple.
- Available with permanent settings and there is no need to readjust the settings.
- Effect of a generation of fault levels, fault current magnitude is less.

UNIT-V

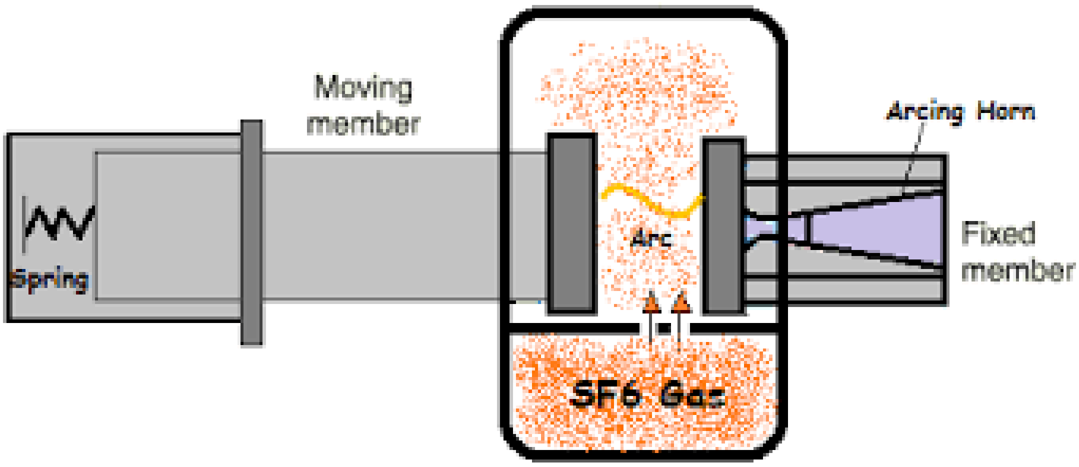
CIRCUIT BREAKERS

INTRODUCTION:-

- A circuit breaker is an electrical safety device designed to protect an electrical circuit from damage caused by overcurrent.
- Its basic function is to interrupt current flow to protect equipment and to prevent the risk of fire.
- Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation.
- Circuit breakers are made in varying sizes, from small devices that protect low-current circuits or individual household appliances, to large switchgear designed to protect high voltage circuits feeding an entire city.
- The generic function of a circuit breaker, or fuse, as an automatic means of removing power from a faulty system, is often abbreviated as OCPD (Over Current Protection Device).

ARCING IN CIRCUIT BREAKERS:-

- Arcing usually occurs when a circuit becomes overloaded and overheats.
- The overheating causes damage not only to the circuit breaker but also to its connection to the bus.
- Once damaged, a circuit breaker can malfunction and continue to let electricity flow between its connection instead of tripping.
- Arc flashes can happen anywhere there is electrical current flowing. Thirty-six percent of arc flashes occur in electrical panels and enclosures.
- . Electrical panels contain many different circuits, buses, and connections.



ARC INTERRUPTION THEORIES:-

Methods of Arc Interruption There are two methods of Arc Interruption or Extinction are

i) High resistance interruption.
ii) Current zero interruption High resistance interruption.

The arc resistance can be increased by cooling, lengthening, reducing x-section and splitting the arc.

Methods of Arc Interruption

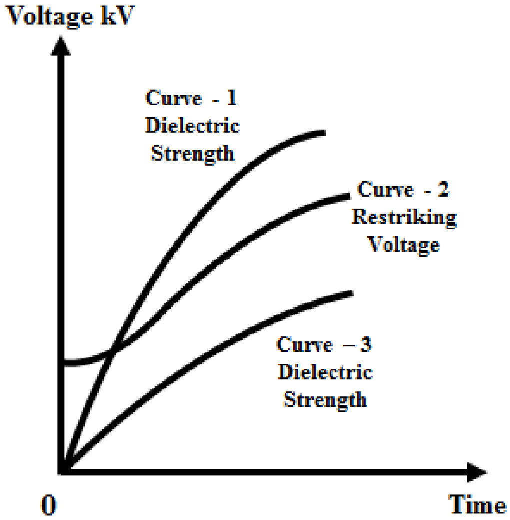
It is employed for low power AC and DC circuit breakers.
Current zero interruption.

There are two theories to explain the zero current interruption of the arc.

i) Recovery rate theory (Slepain'sTheory)
ii) Energy balance theory (Cassie's Theory) .

Recovery rate theory (Slepain'sTheory)

The arc is interrupted if ions are removed from the gap recovers its dielectric strength is compared with the rate at which the restriking voltage (transient voltage) across the gap rises.



Build-up of Dielectric Strength and Restriking Voltage

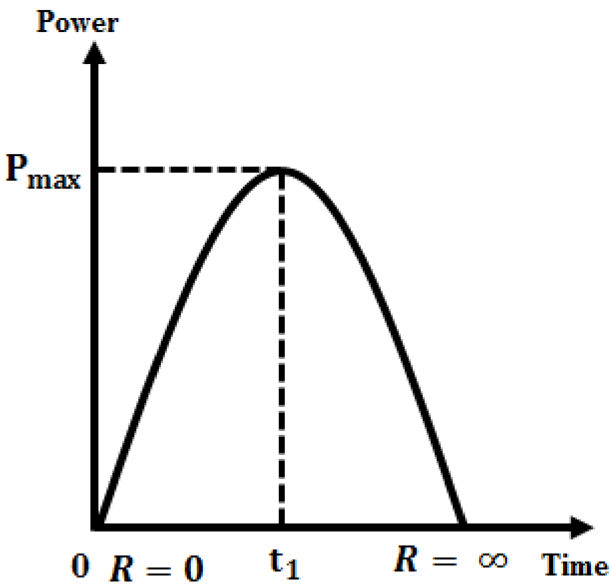
Energy balance theory (Cassie's Theory)

- This theory is also known as Cassie's theory. The following assumptions are made in the theory,

- The arc is composed of a cylindrical column, which has a constant temperature at its cross-section.
- There is a uniform distribution of energy in this column.
- There will be no change in temperature.

- In order to accommodate the arc current, the cross-section of the arc adjust itself.
- The power dissipation and the cross-sectional area of the arc column are proportional to each other.

This theory explains, how the arc is extinguished or restrict i.e. when the rate of heat removal between the contacts is lower than the rate at which the heat is generated, then the arc will restrike. When the rate of generation of heat between the contacts is lower than the rate of removal of heat, then the arc will be extinguished.



Variation of Power

RE-STRIKING AND RECOVERY VOLTAGE:-

RESTRIKING VOLTAGE:

Whenever arc interruption occurs at zero current instant, the voltage across the circuit breaker gap will suddenly rise from zero to a very high value. This high voltage will be transient in nature.
The transient voltage that appears across the circuit breaker contacts immediately after the arc extinction or at current zero during the arcing period is called Restriking Voltage.

This voltage is so named because the arc can restrike only during the existence period of this transient voltage. If the arc does not restrike during this transient period, it will not restrike later. This restriking voltage is also known as Transient Recovery Voltage.

RECOVERY VOLTAGE:

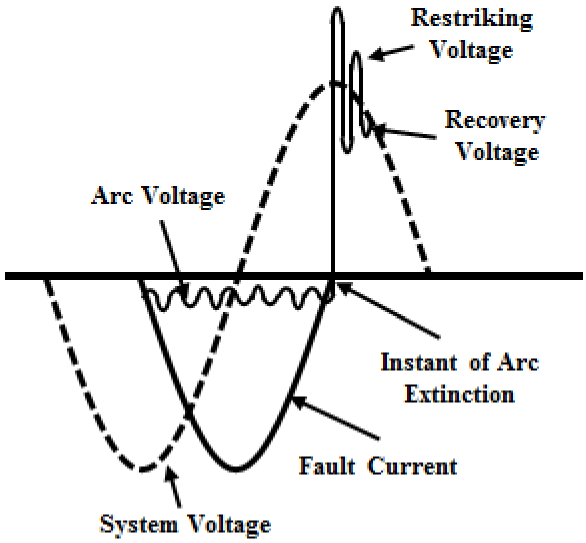
It is defined as the voltage appearing across the circuit breaker contacts after the final arc extinction and after all the transients die out (or disappears).

The frequency of recovery voltage is the same as the supply frequency.

Consider a circuit breaker whose contacts are opened, then the fault current drops to zero.

At zero current instant, no ions are present in the gap between the contacts. At this condition, the dielectric strength of the medium (air or oil) between the contacts will be high, which is strong enough to avoid the breakdown by the restriking voltage. As a result the final arc extinction takes place and circuit current is interrupted.

As soon as the current is interrupted after the final arc extinction, the voltage appears across the circuit breaker contacts, which has a transient part. Therefore, the voltage appearing across the circuit breaker contacts after all transient oscillations die out or disappear is known as recovery voltage. This voltage is of normal frequency RMS voltage which is approximately equal to the system voltage.



Recovery Voltage, Restriking Voltage and Arc Voltage

RESISTANCE SWITCHING:

Resistive switching refers to the physical phenomena where a dielectric suddenly changes its (two terminal) resistance under the action of a strong electric field or current. The change of resistance is non-volatile and reversible.

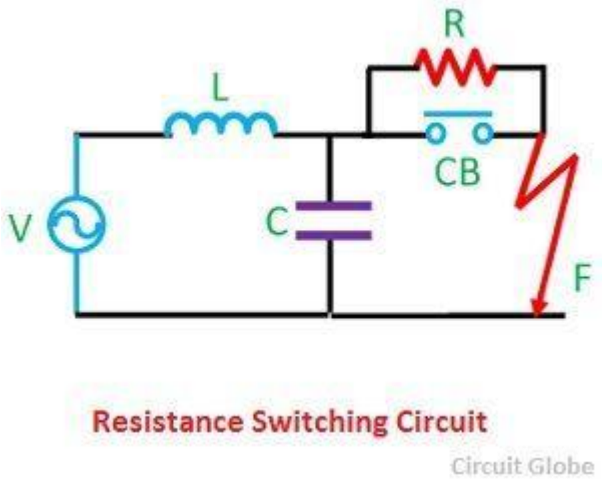
Typical resistive switching systems are capacitor like devices, where the electrode is an ordinary metal and the dielectric a transition metal oxide.

Resistive switching is the physical phenomenon that consists on the sudden and non-volatile change of the resistance due to the application of electric stress, typically voltage or current pulsing.

This effect may allow the fabrication of future novel electronic memory concepts, such as non-volatile random access memories (RAM), hence, it is also termed resistive RAM, RRAM, or ReRAM.

While non-volatile memory effects have been reported in a huge variety of systems, here we shall be concerned with those based on Transition Metal Oxides (TMO). Typical systems have a capacitor-like two-terminal configuration, metal-electrode/TMO/metal-electrode, where the TMO is the dielectric.

In fact, TMOs usually exhibit high dielectric constants, which is considered a desirable feature towards dense electronic integration.



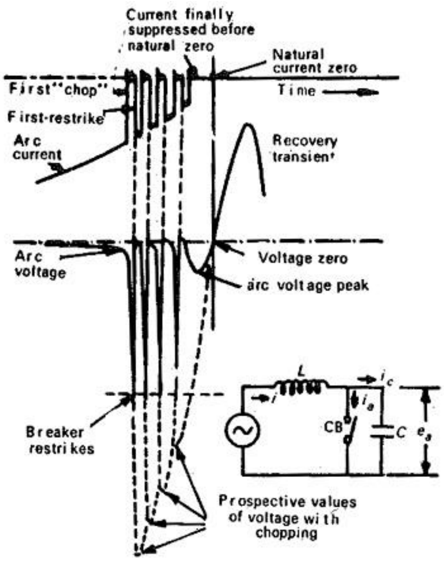
Resistance Switching Circuit

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 current (e.g., transformer magnetising current) with such breakers, the powerful de-ionising effect of air blast cases the current to fall abruptly to zero will before the natural current zero is reached.

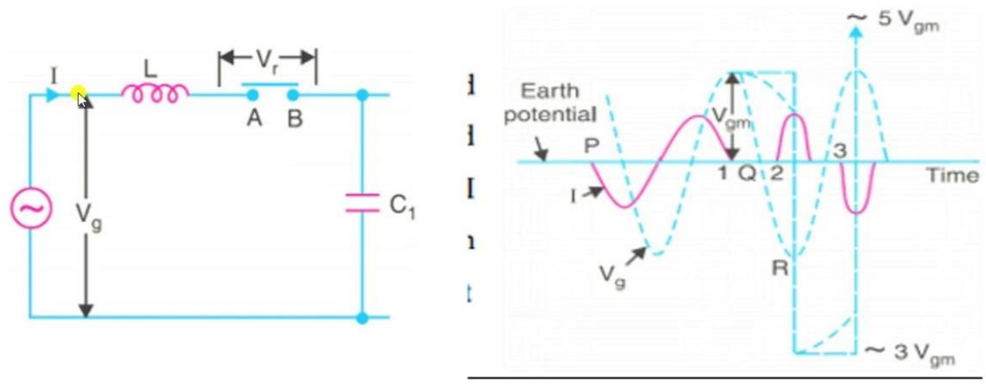
This phenomenon is known as current chopping and results in the production of high voltage transient across the contacts of the circuit breaker.



INTERRPUTION OF CAPACITIVE CURRENT:-

The interruption of capacitive current produces high voltage transients across the gap of the circuit breaker.

This occurs when an unloaded long transmission line or a capacitor bank is switched off.

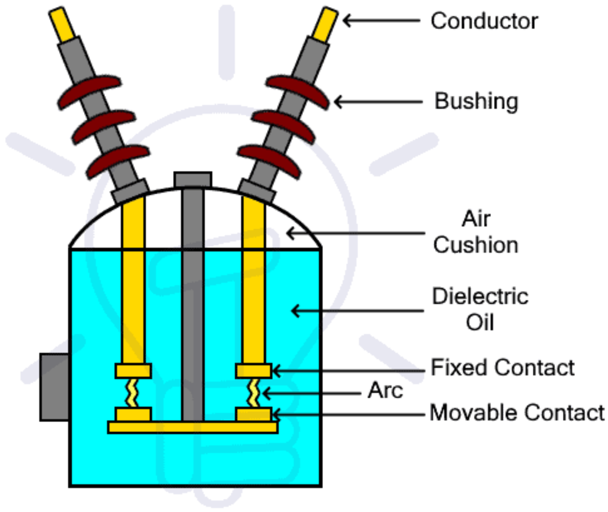


The capacitive current, caused by physics, is an unwanted side effect.

The cause of this current is ions accumulating in front of the electrode.

OIL CIRCUIT BREAKER:-

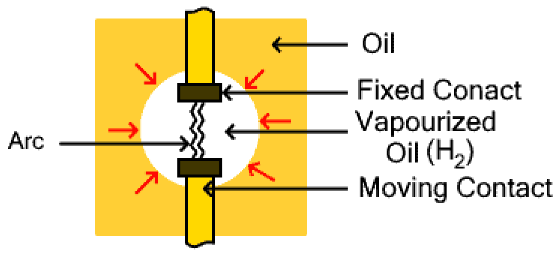
An Oil circuit breaker aka OCB is a type of circuit breaker that uses insulating oil as a dielectric medium to quench the arc and break the circuit safely. The oil used is insulating oil used usually transformer oil that has better dielectric strength than air. The heat produced by the arc vaporizes the oil, producing a hydrogen gas bubble surrounding the arc. The pressure of the oil compresses the gas bubble increasing its dielectric strength which extinguishes the arc during the zero-crossing.



Oil Circuit Breaker

Working Principle of OCB

When a fault condition occurs, the current-carrying contacts are separated inside the insulating oil. As the contacts separate, the high voltage difference between the contacts ionizes the medium surrounding it and an arc is struck. The immense heat generated by arc vaporizes the oil surrounding the contacts. The oil is decomposed into mostly hydrogen gas including a small amount of methane, ethylene, and acetylene. The decomposed gases form a gas bubble surrounding the contacts.



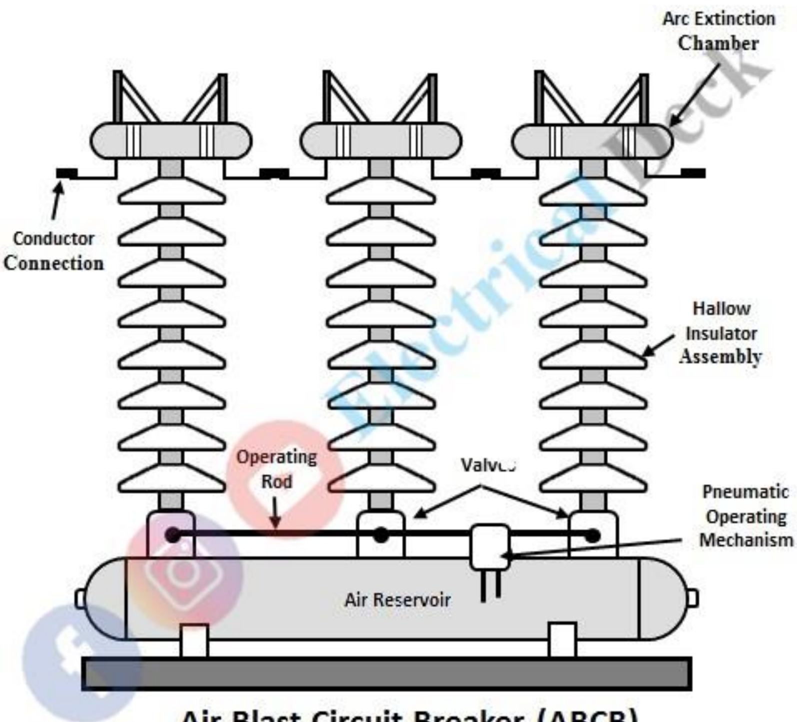
The hydrogen gas breaks into atomic form releasing immense heat that increases the temperature of the arc. Consequently, the oil vaporization increases. The volume of the gas produced is 1000 times larger than the oil decomposed. Due to high temperatures, the volume of the gas bubble rapidly increases. The surrounding oil inside an enclosed container puts a lot of pressure on the gas bubble. Due to compression, the ionized medium surrounding the contacts starts to de-ionize. As the pressure keeps increasing due to the heat of arc, the medium rapidly de-ionizes that increases the dielectric strength of the medium. The arc is quenched at the next current zero-crossing.
Besides that, the cooling effect of the oil and the gas bubbles also helps in arc quenching.

AIR BLAST:-

Air blast circuit breaker used compressed air or gas as the arc interrupting medium. In the air blast, circuit breaker compressed air is stored in a tank and released through a nozzle to produce a high-velocity jet; this is used to extinguish the arc. Air blast circuit breakers are used for indoor services in the medium high voltage field and medium rupturing capacity. Generally up to voltages of 15 KV and rupturing capacities of 2500 MVA. The air blast circuit breaker is now employed in high voltage circuits in the outdoors switch yard for 220 KV lines.

Though gasses such as carbon dioxide, nitrogen, Freon or hydrogen are used as the arc interrupting medium, compressed air is the accepted circuit breaking medium for gas blast circuit breakers. The reasons are given below.

The circuit breaking capacities of nitrogen are similar to compressed air and hence no advantage of using it. Carbon dioxide has the drawback of its being difficult to control owing to freezing at valves and other restricted passages. Feron has high dielectric strength and good arc extinguishing properties, but it is expensive, and it is disintegrated by the arc into acid-forming elements.



Air Blast Circuit Breaker (ABCB)

Principle of Arc Extinction in Circuit Breaker

The air blast needs an additional compressed air system which supplies air to the air receiver. When opening air is required, compressed air is admitted to the arc extinction chamber. It pushes away the moving contacts. In doing so, the contacts are pulled apart, and the air blast moves away the ionized gas along with it and assists arc extinction.

Air blast extinguishes the arc within one or more cycles, and the arc chamber is filled with high-pressure air, which prevents restrikes. The air blast circuit breakers fall under the category of external extinguishing energy type. The energy supplied for arc quenching is achieved from the high-pressure air, and it is free from the current to be interrupted.