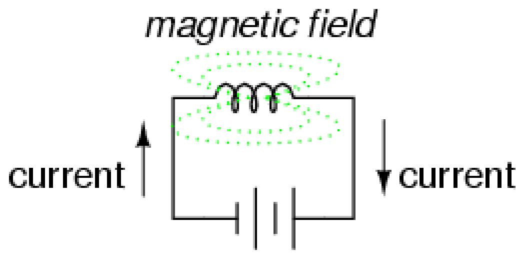
UNIT 1

PROTECTIVE RELAYS

PROTECTIVE RELAYING Requirement of Protective Relaying ϖ Zones of protection, primary and backup protection ϖ Essential qualities of Protective Relaying ϖ Classification of Protective Relays ϖ Introduction Protective Relaying is one of the several features of the power system design. Every part of the power system is protected. The factors affecting the choice of protection are type and rating of equipment, location of the equipment, types of funks, abnormal conditions and cost. The protective relaying is used to give an alarm or to cause prompt removal of any element of power system from service when that element behaves abnormally. The abnormal behavior of an element might cause damage or interference within effective operation of rest of the system. The protective relaying minimizes the damage to the equipment and interruptions to the service when electrical failure occurs. Along with some other equipment's the relays help to minimize damage and improve the service. The relays are compact and self contained devices which can sense the abnormal conditions. Whenever an abnormal condition exists the relay contacts get closed. This in tum closes the hip circuit of a circuit breaker. The circuit breakers are capable of disconnecting a fatty element, when they are called upon to do so by the relays. Thus entire process includes the operations like fault, operation of relay, opening of a circuit breaker and removal of faulty element. This entire process is automatic and fast, which is possible due to effective protector relaying scheme. The protective relaying scheme includes protective current transformers, voltage transformers, protective relays, time delay relays, auxiliary relays, secondary circuits, top circuits etc. Each component plays its own role, which is very important in the overall operation of the scheme the protective relaying is the team work of all these components. The protective relaying also provides the indication of location and type of the fault. www.vidyarthiplus.com www.vidyarthiplus.com Switch gear and Protection 10EE62 Page 61 Protective Zones in a protective relaying scheme, the circuit breakers are placed at the appropriate points such that any element of the entire power system can be disconnected for repairing work, usual operation and maintenance requirements and also under abnormal conditions like short circuits. Thus a protective covering is provided around rich element of the system. A protective zone is the separate zone which Es established around each system element. The significance of such a protective zone I B that any fault occurring within cause the tripping of relays which causes opening of all the circuit breakers within that zone. The various components which are provided with the protective zone are generators, transformers, transmission lines, bus bars, cables, capacitors etc. No part of the system is left unprotected The Fig. shows the various protective zones used in a system

Essential Qualities of Protective Relaying: Essential Qualities of Protective Relaying A protective relaying scheme should has certain important qualities Such an essential qualities of protective relaying are, 1. Reliability 2. Selectivity and Discrimination 3. Speed and Time 4. Sensitivity 5.

An electric current through a conductor will produce a magnetic field at right angles to the direction of electron flow. If that conductor is wrapped into a coil shape, the magnetic field produced will be oriented along the length of the coil. The greater the current, the greater the strength of the magnetic field, all other factors being equal:ability

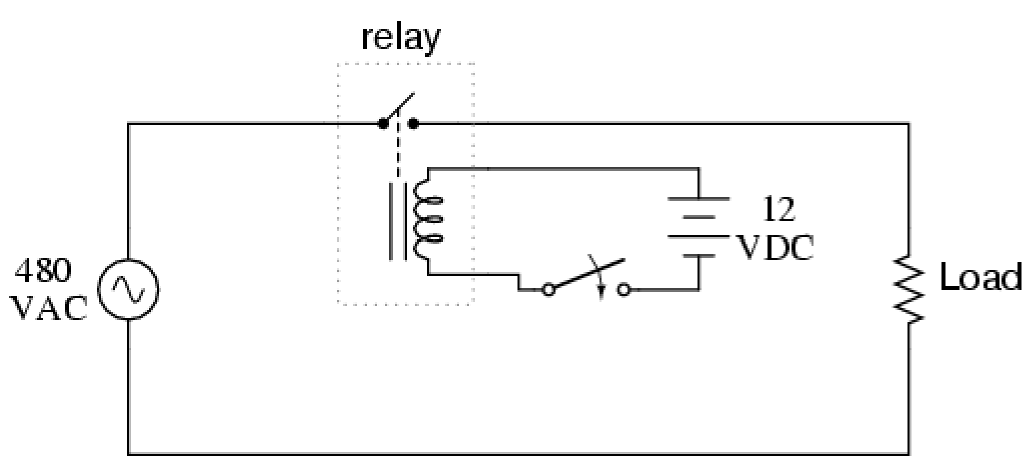


Inductors react against changes in current because of the energy stored in this magnetic field. When we construct a transformer from two inductor coils around a common iron core, we use this field to transfer energy from one coil to the other. However, there are simpler and more direct uses for electromagnetic fields than the applications we've seen with inductors and transformers. The magnetic field produced by a coil of current-carrying wire can be used to exert a mechanical force on any magnetic object, just as we can use a permanent magnet to attract magnetic objects, except that this magnet (formed by the coil) can be turned on or off by switching the current on or off through the coil.

If we place a magnetic object near such a coil for the purpose of making that object move when we energize the coil with electric current, we have what is called a *solenoid*. The movable magnetic object is called an *armature*, and most armatures can be moved with either direct current (DC) or alternating current (AC) energizing the coil. The polarity of the magnetic field is irrelevant for the purpose of attracting an iron armature. Solenoids can be used to electrically open door latches, open or shut valves, move robotic limbs, and even actuate electric switch mechanisms. However, if a solenoid is used to actuate a set of switch contacts, we have a device so useful it deserves its own name: the *relay*.

Relays are extremely useful when we have a need to control a large amount of current and/or voltage with a small electrical signal. The relay coil which produces the magnetic field may only consume fractions of a watt of power, while the contacts closed or opened by that magnetic field may be able to conduct hundreds of times that amount of power to a load. In effect, a relay acts as a binary (on or off) amplifier.

Just as with transistors, the relay's ability to control one electrical signal with another finds application in the construction of logic functions. This topic will be covered in greater detail in another lesson. For now, the relay's "amplifying" ability will be explored.



In the above schematic, the relay's coil is energized by the low-voltage (12 VDC) source, while the single-pole, single-throw (SPST) contact interrupts the high-voltage (480 VAC) circuit. It is quite likely that the current required to energize the relay coil will be hundreds of times less than the current rating of the contact. Typical relay coil currents are well below 1 amp, while typical contact ratings for industrial relays are at least 10 amps.

One relay coil/armature assembly may be used to actuate more than one set of contacts. Those contacts may be normally-open, normally-closed, or any combination of the two. As with switches, the "normal" state of a relay's contacts is that state when the coil is de-energized, just as you would find the relay sitting on a shelf, not connected to any circuit.

Relay contacts may be open-air pads of metal alloy, mercury tubes, or even magnetic reeds, just as with other types of switches. The choice of contacts in a relay depends on the same factors which dictate contact choice in other types of switches. Open-air contacts are the best for high-current applications, but their tendency to corrode and spark may cause problems in some industrial environments. Mercury and reed contacts are sparkless and won't corrode, but they tend to be limited in current-carrying capacity.

Shown here are three small relays (about two inches in height, each), installed on a panel as part of an electrical control system at a municipal water treatment plant:

The relay units shown here are called "octal-base," because they plug into matching sockets, the electrical connections secured via eight metal pins on the relay bottom. The screw terminal connections you see in the photograph where wires connect to the relays are actually part of the socket assembly, into which each relay is plugged. This type of construction facilitates easy removal and replacement of the relay(s) in the event of failure.

Aside from the ability to allow a relatively small electric signal to switch a relatively large electric signal, relays also offer electrical isolation between coil and contact circuits. This means that the coil circuit and contact circuit(s) are electrically insulated from one another.

One circuit may be DC and the other AC (such as in the example circuit shown earlier), and/or they may be at completely different voltage levels, across the connections or from connections to ground.

While relays are essentially binary devices, either being completely on or completely off, there are operating conditions where their state may be indeterminate, just as with semiconductor logic gates. In order for a relay to positively "pull in" the armature to actuate the contact(s), there must be a certain minimum amount of current through the coil. This minimum amount is called the *pull-in* current, and it is analogous to the minimum input voltage that a logic gate requires to guarantee a "high" state (typically 2 Volts for TTL, 3.5 Volts for CMOS). Once the armature is pulled closer to the coil's center, however, it takes less magnetic field flux (less coil current) to hold it there. Therefore, the coil current must drop below a value significantly lower than the pull-in current before the armature "drops out" to its spring-loaded position and the contacts resume their normal state. This current level is called the *drop-out* current, and it is analogous to the maximum input voltage that a logic gate input will allow to guarantee a "low" state (typically 0.8 Volts for TTL, 1.5 Volts for CMOS).

The hysteresis, or difference between pull-in and drop-out currents, results in operation that is similar to a Schmitt trigger logic gate. Pull-in and drop-out currents (and voltages) vary widely from relay to relay, and are specified by the manufacturer.

OVER CURRENT RELAY-2

Working Principle of Over Current Relay

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

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

Types of Over Current Relay

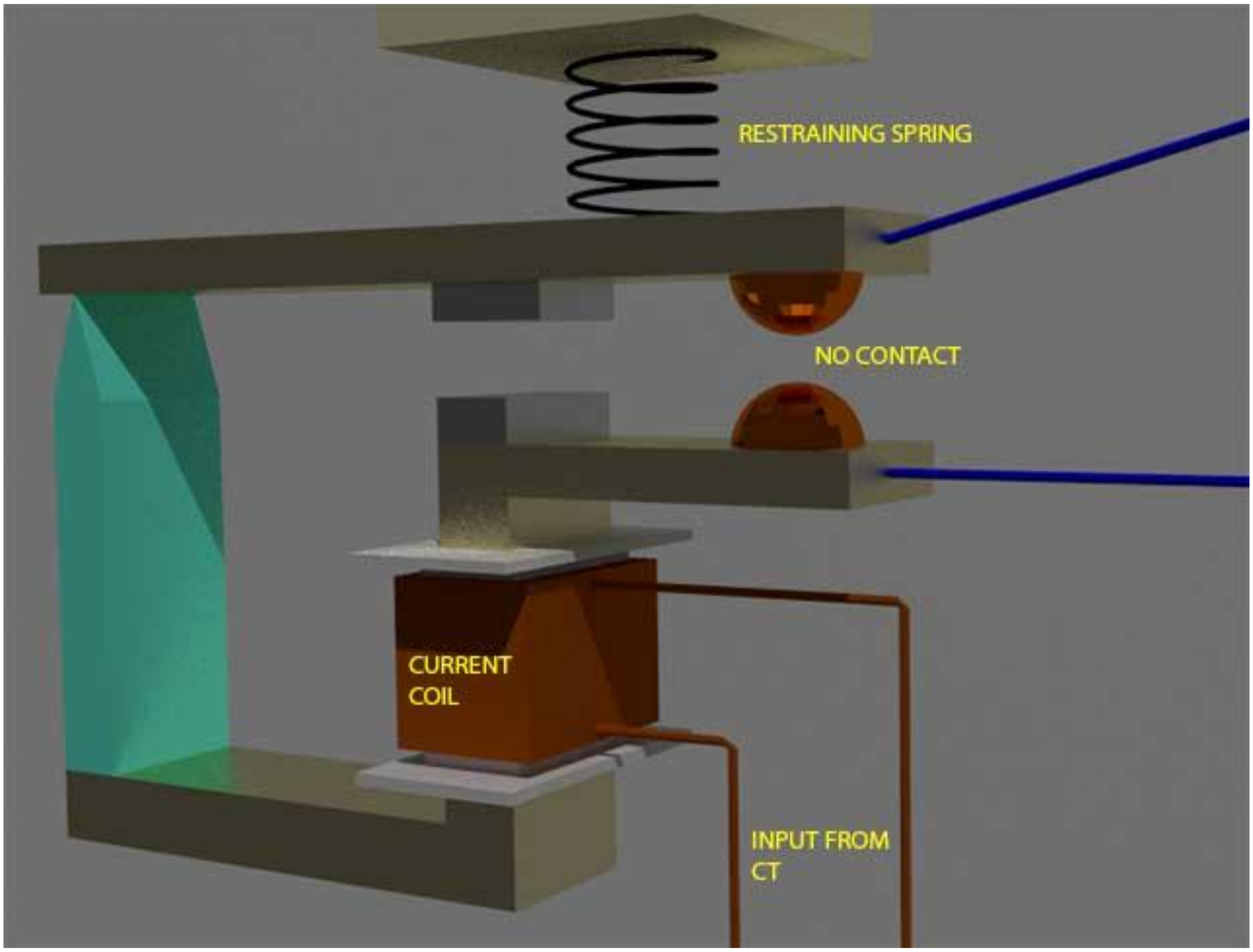
Depending upon time of operation, there are various **types of Over Current relays**, such as,

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

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

Instantaneous Over Current Relay

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



Here generally a magnetic core is wound by current coil. A piece of iron is so fitted by hinge support and restraining spring in the relay, that when there is not sufficient current in the coil, the NO contacts remain open. When current in the coil crosses a present value, the attractive force becomes sufficient to pull the iron piece towards the magnetic core and consequently the no contacts are closed.
The preset value of current in the relay coil is referred as pick up setting current. This relay is referred as instantaneous **over current relay**, as ideally, the relay operates as soon as the current in the coil gets higher than pick up setting current. There is no intentional time delay applied. But there is always an inherent time delay which can not be avoided practically. In practice the operating time of an instantaneous relay is of the order of a few milliseconds. Fig.

Definite Time Over Current Relay
This relay is created by applying intentional time delay after crossing pick up value of the current. A **definite time over current relay** can be adjusted to issue a trip output at definite amount of time after it picks up. Thus, it has a time setting adjustment and pick up adjustment.

Inverse Time Over Current Relay
Inverse time is a natural character of any induction type rotating device. This means the speed of rotation of rotating art of the device is faster if input current is increased. In other words, time of operation inversely varies with input current. This natural characteristic of electromechanical induction disc relay in very suitable for over current protection. This is because, in this relay, if fault is more severe, it would be cleared more faster. Although time inverse characteristic is inherent to electromechanical induction disc relay, but the same characteristic can be achieved in microprocessor based relay also by proper programming.

Inverse Definite Minimum Time Over Current Relay or IDMT O/C Relay

Ideal inverse time characteristics can not be achieved, in an over current relay. As the current in the system increases, the secondary current of the current transformer is increased proportionally. The secondary current is fed to the relay current coil. But when the CT becomes saturated, there would not be further proportional increase of CT secondary current with increased system current. From this phenomenon it is clear that from trick value to certain range of faulty level, an inverse time relay shows exact inverse characteristic. But after this level of fault, the CT becomes saturated and relay current does not increase further with increasing faulty level of the system. As the relay current is not increased further, there would not be any further reduction in time of operation in the relay. This time is referred as minimum time of operation. Hence, the characteristic is inverse in the initial part, which tends to a definite minimum operating time as the current becomes very high. That is why the relay is referred as **inverse definite minimum time over current relay** or simply **IDMT relay**.

*** Differential Relay**

The relays used in power system protection are of different types. Among them **differential relay** is very commonly used relay for protecting transformers and generators from localised faults.

Differential relays are very sensitive to the faults occurred within the zone of protection but they are least sensitive to the faults that occur outside the protected zone. Most of the relays operate when any quantity exceeds beyond a predetermined value for example over current relay operates when current through it exceeds predetermined value. But the principle of differential relay is somewhat different. It operates depending upon the difference between two or more similar electrical quantities.

Definition of Differential Relay

The differential relay is one that operates when there is a difference between two or more similar electrical quantities exceeds a predetermined value. In differential relay scheme circuit, there are two currents come from two parts of an electrical power circuit.

These two currents meet at a junction point where a relay coil is connected. According to Kirchhoff Current Law, the resultant current flowing through the relay coil is nothing but summation of two currents, coming from two different parts of the electrical power circuit. If the polarity and amplitude of both currents are so adjusted that the phasor sum of these two currents, is zero at normal operating condition. Thereby there will be no current flowing through the relay coil at normal operating conditions. But due to any abnormality in the power circuit, if this balance is broken, that means the phasor sum of these two currents no longer remains zero and there will be non-zero current flowing through the relay coil thereby relay being operated. In current differential scheme, there are two sets of current transformer each connected to either side of the equipment protected by **differential relay**. The ratio of the current transformers are so chosen, the secondary currents of both current transformers matches each other in magnitude. The polarity of current transformers are such that the secondary currents of these CTs opposes each other. From the circuit is clear that only if any nonzero difference is created between this to secondary currents, then only this differential current will flow through the operating coil of the relay. If this difference is more than the peak up value of the relay, it will operate to open the circuit breakers to isolate the protected equipment from the system. The relaying element used in differential relay is attracted armature type instantaneously relay since differential scheme is only adapted for clearing the fault inside the protected equipment in other words differential relay should clear only internal fault of the equipment hence the protected equipment should be isolated as soon as any fault occurred inside the equipment itself. They need not be any time delay for coordination with other relays in the system.

Types of Differential Relay

There are mainly two **types of differential relay** depending upon the principle of operation.

1. Current Balance Differential Relay
2. Voltage Balance Differential Relay

In **current differential relay** two current transformers are fitted on the either side of the equipment to be protected. The secondary circuits of CTs are connected in series in such a way that the carry secondary CT current in same direction. The operating coil of the relaying element is connected across the CT's secondary circuit. Under normal operating conditions, the protected equipment (either power transformer or alternator) carries normal current. In this situation, say the secondary current of CT_1 is I_1 and secondary current of CT_2 is I_2. It is also clear from the circuit that the current passing through the relay coil is nothing but I_1-I_2. As we said earlier, the current transformer's ratio and polarity are so chosen, $I_1 = I_2$, hence there will be no current flowing through the relay coil. Now if any fault occurs external to the zone covered by the CTs, faulty current passes through primary of the both current transformers and thereby secondary currents of both current transformers remain same as in the case of normal operating conditions. Therefore at that situation the relay will not be operated. But if any ground fault occurred inside the protected equipment as shown, two secondary currents will be no longer equal. At that case the differential relay is being operated to isolate the faulty equipment (transformer or alternator) from the system.

Principally this type of relay systems suffers from some disadvantages

1. There may be a probability of mismatching in cable impedance from CT secondary to the remote relay panel.
2. These pilot cables' capacitance causes incorrect operation of the relay when large through fault occurs external to the equipment.
3. Accurate matching of characteristics of current transformer cannot be achieved hence there may be spill current flowing through the relay in normal operating conditions.

Percentage Differential Relay

This is designed to response to the differential current in the term of its fractional relation to the current flowing through the protected section. In this type of relay, there are restraining coils in addition to the operating coil of the relay. The restraining coils produce torque opposite to the operating torque. Under normal and through fault conditions, restraining torque is greater than operating torque. Thereby relay remains inactive. When internal fault occurs, the operating force exceeds the bias force and hence the relay is operated. This bias force can be adjusted by varying the number of turns on the restraining coils. As shown in the figure below, if I_1 is the secondary current of CT_1 and I_2 is the secondary current of CT_2then current through the operating coil is I_1 - I_2 and current through the restraining coil is $(I_1+ I_2)/2$. In normal and through fault condition, torque produced by restraining coils due to current $(I_1+ I_2)/2$ is greater than torque produced by operating coil due to current I_1- I_2 but in internal faulty condition these become opposite. And the bias setting is defined as the ratio of (I_1- I_2) to $(I_1+ I_2)/2$

$$Bias\ setting\ in\ percentage\ = \frac{I_1 - I_2}{(I_1 + I_2)/2} \times 100\%$$

It is clear from the above explanation, greater the current flowing through the restraining coils, higher the value of the current required for operating coil to be operated. The relay is called percentage relay because the operating current required to trip can be expressed as a percentage of through current.

CT Ratio and Connection for Differential Relay

This simple thumb rule is that the current transformers on any star winding should be connected in delta and the current transformers on any delta winding should be connected in star. This is so done to eliminate zero sequence current in the relay circuit.

If the CTs are connected in star, the CT ratio will be $I_n/1$ or 5 A CTs to be connected in delta, the CT ratio will be $I_n/0.5775$ or 5×0.5775 A

Voltage Balance Differential Relay

In this arrangement the current transformer are connected either side of the equipment in such a manner that EMF induced in the secondary of both current transformers will oppose each other. That means the secondary of the current transformers from both sides of the equipment are connected in series with opposite polarity. The differential relay coil is inserted somewhere in the loop created by series connection of secondary of current transformers as shown in the figure. In normal operating conditions and also in through fault conditions, the EMFs induced in both of the CT secondary are equal and opposite of each other and hence there would be no current flowing through the relay coil. But as soon as any internal fault occurs in the equipment under protection, these EMFs are no longer balanced hence current starts flowing through the relay coil thereby trips circuit breaker.

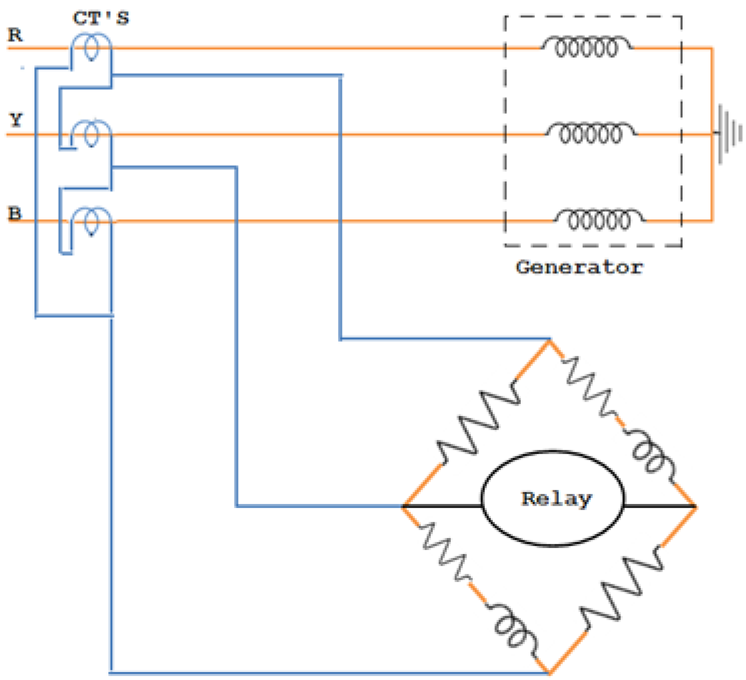
There are some disadvantages in the voltage balance differential relay such as A multy tap transformer construction is required to accurate balance between current transformer pairs. The system is suitable for protection of cables of relatively short length otherwise capacitance of pilot wires disturbs the performance. On long cables the charging current will be sufficient to operate the relay even if a perfect balance of current transformer achieved.

These disadvantages can be eliminated from the system by introducing translay system which is nothing but modified balance voltage differential relay system. Translay scheme is mainly applied for differential protection of feeders. Here, two sets of current transformers are connected either end of the feeder. Secondary of each current transformer is fitted with individual double winding induction type relay. The secondary of each current transformer feeds primary circuit of double winding induction type relay. The secondary circuit of each relay is connected in series to form a closed loop by means of pilot wires. The connection should be such that, the induced voltage in secondary coil of one relay will oppose same of other. The compensating device neutralises the effect of pilot wires capacitance currents and effect of inherent lack of balance between the two current transformers. Under normal conditions and through fault conditions, the current at two ends of the feeder is same thereby the current induced in the CT's secondary would also be equal. Due to these equal currents in the CT's secondary, the primary of each relay induce same EMF. Consequently, the EMF induced in the secondaries of the relays are also same but the coils are so connected, these EMFs are in opposite direction. As a result, no current will flow through the pilot loop and thereby no operating torque is produced either of the relays. But if any fault occurs in the feeder within the zone in between current transformers, the current leaving the feeder will be different from the current entering into the feeder. Consequently, there will be no equality between the currents in both CT secondaries. These unequal secondary CT currents will produce unbalanced secondary induced voltage in both of the relays. Therefore, current starts circulating in the pilot loop and hence torque is produced in both of the relays. As the direction of secondary current is opposite into relays, therefore, the torque in one relay will tend to close the trip contacts and at the same time torque produced in other relay will tend to hold the movement of the trip contacts in normal un-operated position. The operating torque depends upon the position and nature of faults in the protected zone of feeder. The faulty portion of the feeder is separated from healthy portion when at least one element of either relay operates.

This can be noted that in translay protection scheme, a closed copper ring is fitted with the Central limb of primary core of the relay. These rings are utilised to neutralise the effect of pilot capacity currents. Capacity currents lead the voltage impressed of the pilot by 90^o and when they flow in low inductive operating winding, produce flux that also leads the pilot voltage by 90^o. Since the pilot voltage is that induced in the secondary coils of the relay, it lags by a substantial angle behind the flux in the field magnetic air gap. The closed copper rings are so adjusted that the angle is approximately 90^o. In this way fluxes acting on the disk are in phase and hence no torque is exerted in the relay disc.

Negative Sequence Relay

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



The arrangement of negative sequence relay connection is shown in the figure. The relay is connected in parallel across the current transformer secondaries. Under normal conditions, as equal current flows in all the three phases, their algebraic sum is zero. Hence no current flows through the relay. But, if unbalancing occurs, the secondary currents will be different and the resultants current flows through the relay and the operation of the relaytrips the circuit breaker to disconnect the generator from the system.

UNIT 2

APPARATUS PROTECTION

GENERATOR PROTECTION APPLICATIONS PHASE FAULT PROTECTION

Phase faults in a generator stator winding can cause thermal damage to insulation, windings, and the core, and mechanical torsional shock to shafts and couplings. Trapped flux within the machine can cause fault current to flow for many seconds after the generator is tripped and the field is disconnected. Primary Protection Primary protection for generator phase-to-phase faults is best provided by a differential relay (function 87). Differential relaying will detect phase-to-phase faults, three-phase faults, and double-phase-to-ground faults. With low-impedance grounding of the generator, some singlephase-to-ground faults can also be detected. (Turn-to-turn faults in the same phase cannot be detected, since the current entering and leaving the winding will be the same.) Backup Protection Backup protection for phase-to-phase and three-phase faults in the generator, unit transformer, and connected system can be provided by a unit-connected differential relay (87U), or a phase distance relay (21). A definite time delay can provide coordination with all relays that the phase distance relay setting over-reaches. The protection zone depends on the relay reach, CT placement, and directional setting. When neutral-side CTs are used, the protection includes the generator, and protection will be available when the generator is both on- and off-line. When line-side CTs are used, the protected area depends on the relay offset: the relay can be set to look towards the generator, towards the system, or in both directions. When set to look towards the system, proper setting of the offset will provide some coverage for generator winding faults. The voltage restrained or controlled Inverse Time Overcurrent relay (51V) and Directional Overcurrent (67) functions can also be used as supplemental backup protection. The negative sequence overcurrent function (46) can also be used as backup for uncleared system phase-to phase faults; this function will also protect the generator and associated equipment from unbalanced conditions and faults. -

High-Impedance-Grounded Generator With high-impedance-grounded generators, the generator ground-fault current may not cause severe damage to the generator, but a subsequent ground fault on a different phase will result in a phase-to-phase fault which can cause serious damage. An overvoltage relay (device 59N) connected across the grounding impedance to sense zero-sequence voltage can detect faults to within 5%–10% of the stator neutral (90%–95% of the stator winding). In order to detect faults within the area not protected by this relay, an undervoltage relay sensitive to the decrease in the third-harmonic voltage at the neutral (device 27TN) can be used to protect the final 10%–30% of the neutral end of the stator. There are several additional schemes for 100% stator ground fault protection discussed in reference [1]. Low-Impedance-Grounded Generator For low-impedance-grounded generators, phase differential protection (87) may provide coverage for ground faults, depending on the fault level and differential relay sensitivity. A differential relay, responsive to zero sequence current, connected across the terminals of the generator and the neutral can provide higher sensitivity and fast operation. One of the requirements of zero sequence differential protection is that the line-side CTs and neutral CT have the same ratio; otherwise, an auxiliary CT with matching ratio must be used. When a zero sequence source is present on the system (several generators are bussed together and connected to the load through a single transformer), a ground directional differential relay (87GD) can be applied. The 87GD function can work with a wide range of CT mismatch and without requiring the use of an auxiliary CT. It operates on the product of the triple zero sequence current, the neutral current, and the cosine of the angle between the two. The relay is relatively insensitive to ratio errors and CT saturation.

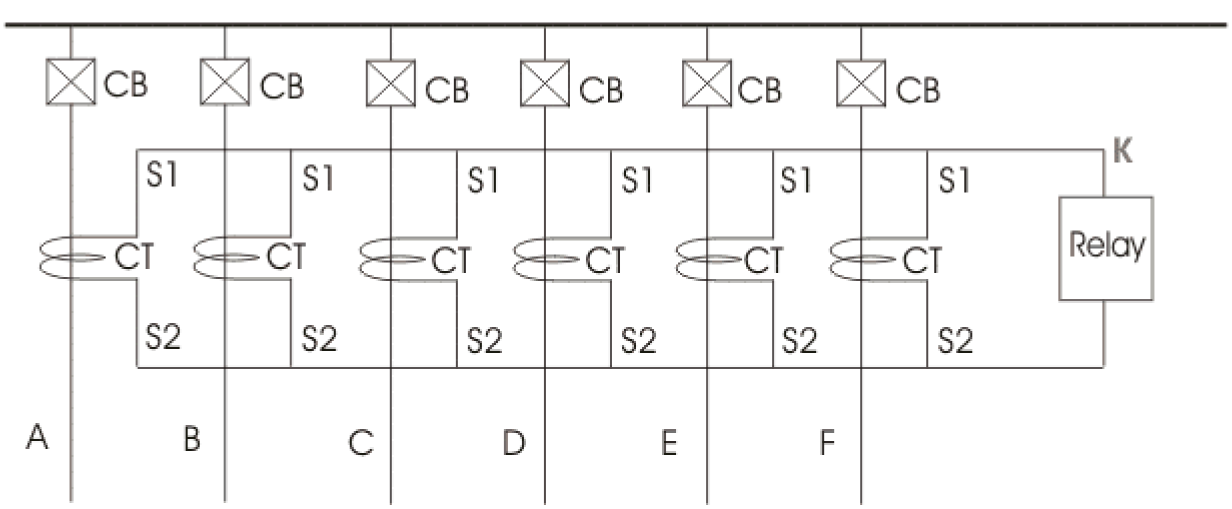
Busbar Protection | Busbar Differential Protection Scheme

In early days only conventional over current relays were used for **busbar protection**. But it is desired that fault in any feeder or transformer connected to the busbar should not disturb busbar system. In viewing of this time setting of busbar protection relays are made lengthy. So when faults occurs on busbar itself, it takes much time to isolate the bus from source which may came much damage in the bus system.
In recent days, the second zone distance protection relays on incoming feeder, with operating time of 0.3 to 0.5 seconds have been applied for **busbar protection**. But this scheme has also a main disadvantage. This scheme of protection can not discriminate the faulty section of the busbar.

Now days, electrical power system deals with huge amount of power. Hence any interruption in total bus system causes big loss to the company. So it becomes essential to isolate only faulty section of busbar during bus fault. Another drawback of second zone distance protection scheme is that, sometime the clearing time is not short enough to ensure the system stability. To overcome the above mentioned difficulties, differential busbar protection scheme with an operating time less than 0.1 sec., is commonly applied to many SHT bus systems.

Differential Busbar Protection

Current Differential Protection
The scheme of **busbar protection**, involves, Kirchoff's current law, which states that, total current entering an electrical node is exactly equal to total current leaving the node. Hence, total current entering into a bus section is equal to total current leaving the bus section. The principle of differential busbar protection is very simple. Here, secondaries of CTs are connected parallel. That means, S_1 terminals of all CTs connected together and forms a bus wire. Similarly S_2 terminals of all CTs connected together to form another bus wire. A tripping relay is connected across these two bus wires.



Here, in the figure above we assume that at normal condition feed, A, B, C, D, E and F carries current I_A, I_B, I_C, I_D, I_E and I_F. Now, according to Kirchoff's current law, $I_A + I_B + I_C + I_D + I_E + I_F = 0$ Essentially all the CTs used for differential busbar protection are of same current ratio. Hence, the summation of all secondary currents must also be equal to zero. Now, say current through the relay connected in parallel with all CT secondaries, is i_R, and i_A, i_B, i_C, i_D, i_E and i_F are secondary currents.

Now, let us apply KCL at node X. As per KCL at node X,

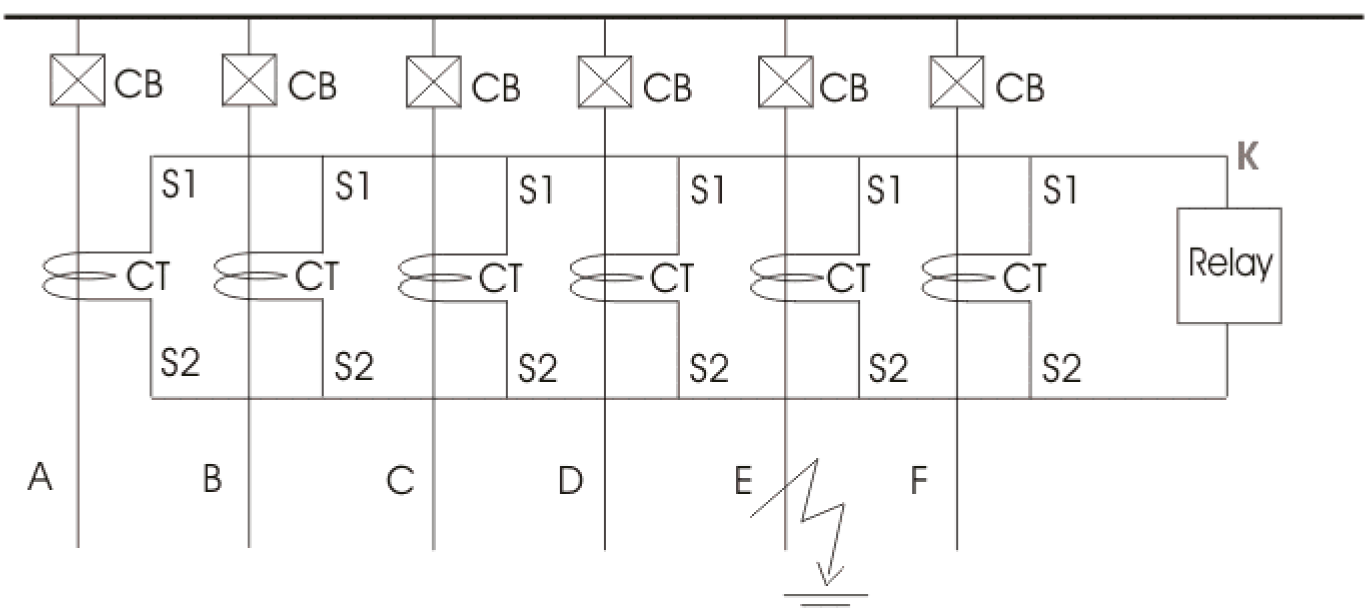
$$i_R + i_A + i_B + i_C + i_D + i_E + i_F = 0$$

$$\Rightarrow i_R + (i_A + i_B + i_C + i_D + i_E + i_F) = 0$$

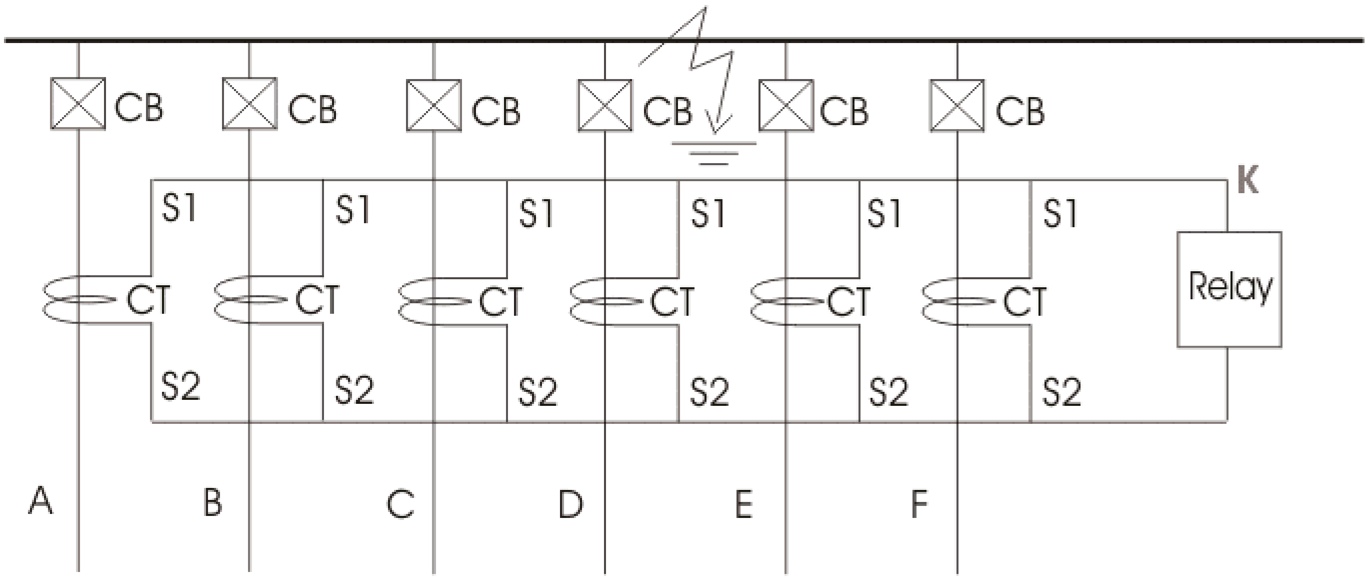
$$\Rightarrow i_R + (Sum\ of\ all\ secondary\ currents) = 0$$

$$\Rightarrow i_R + 0 = 0\ [As\ sum\ of\ all\ secondary\ currents\ is\ zero]$$

So, it is clear that under normal condition there is no current flows through the **busbar protection** tripping relay. This relay is generally referred as Relay 87. Now, say fault is occurred at any of the feeders, outside the protected zone. In that case, the faulty current will pass through primary of the CT of that feeder. This fault current is contributed by all other feeders connected to the bus. So, contributed part of fault current flows through the corresponding CT of respective feeder. Hence at that faulty condition, if we apply KCL at node K, we will still get, $i_R = 0$.



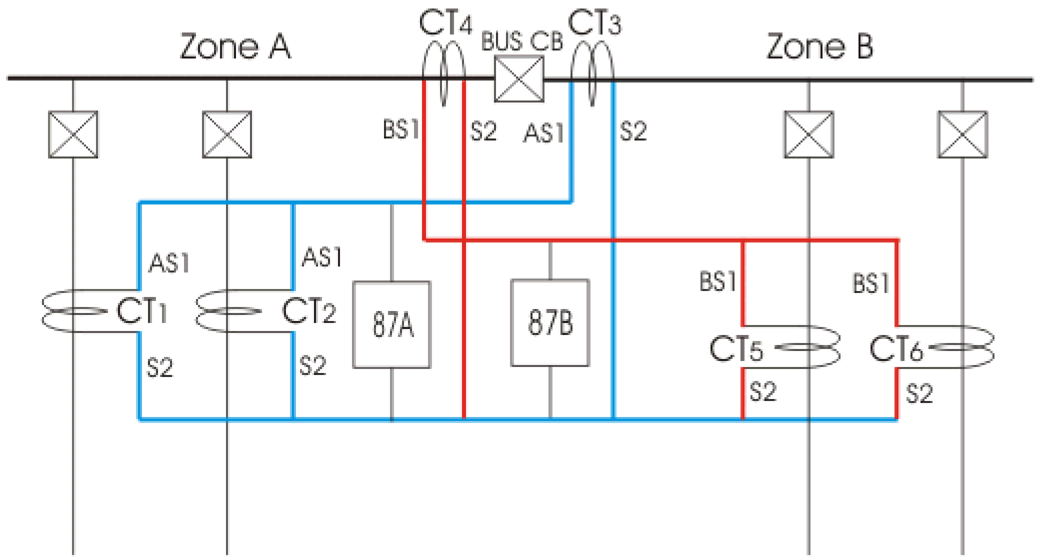
That means, at external faulty condition, there is no current flows through relay 87. Now consider a situation when fault is occurred on the bus itself. At this condition, also the faulty current is contributed by all feeders connected to the bus. Hence, at this condition, sum of all contributed fault current is equal to total faulty current. Now, at faulty path there is no CT. (in external fault, both fault current and contributed current to the fault by different feeder get CT in their path of flowing).



The sum of all secondary currents is no longer zero. It is equal to secondary equivalent of faulty current.
Now, if we apply KCL at the nodes, we will get a non zero value of i_R. So at this condition current starts flowing through 87 relay and it makes trip the circuit breaker corresponding to all the feeders connected to this section of the busbar. As all the incoming and outgoing feeders, connected to this section of bus are tripped, the bus becomes dead.
This differential busbar protection scheme is also referred as current differential protection of busbar.

Differential Protection of Sectionalized Bus

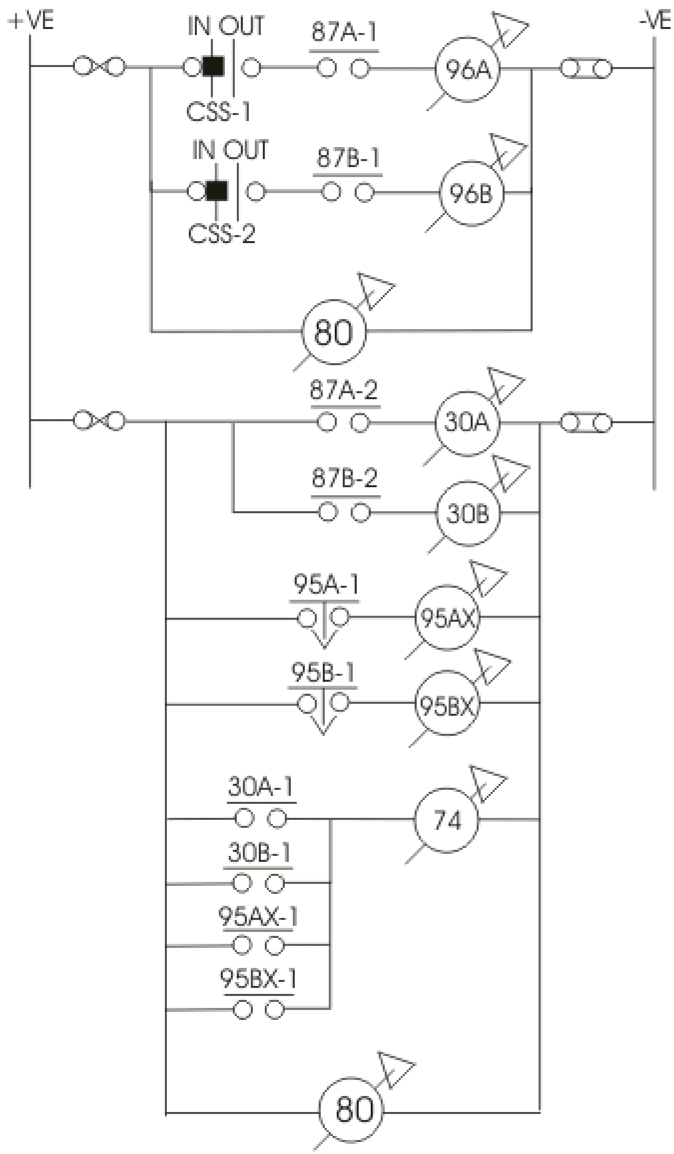
During explaining working principle of current differential protection of busbar, we have shown a simple non sectionalized busbar. But in moderate high voltage system electrical bus sectionalized in than one sections to increase stability of the system. It is done because, fault in one section of bus should not disturb other section of the system. Hence during bus fault, total bus would be interrupted. Let us draw and discuss about protection of busbar with two sections.



Here, bus section A or zone A is bounded by CT_1, CT_2 and CT_3 where CT_1 and CT_2 are feeder CTs and CT_3 is bus CT. Similarly bus section B or zone B is bounded by CT_4, CT_5 and CT_6 where CT_4 is bus CT, $CT_5$and CT_6 are feeder CT. Therefore, zone A and B are overlapped to ensure that, there is no zone left behind this **busbar protection** scheme.
ASI terminals of CT_1, 2 and 3 are connected together to form secondary bus ASI;
BSI terminals of CT_4, 5 and 6 are connected together to form secondary bus BSI.
S_2 terminals of all CTs are connected together to form a common bus S_2.
Now, busbar protection relay 87A for zone A is connected across bus ASI and S_2.
Relay 87B for zone B is connected across bus BSI and S_2.
This section **busbar differential protection scheme** operates in some manner simple current differential protection of busbar.
That is, any fault in zone A, with trip only CB_1, CB_2 and bus C_B.
Any fault in zone B, will trip only CB_5, CB_6 and bus CB.
Hence, fault in any section of bus will isolate only that portion from live system.
In current differential protection of busbar, if CT secondary circuits, or bus wires is open the relay may be operated to isolate the bus from live system. But this is not desirable.

DC Circuit of Differential Busbar Protection

A typical DC circuit for **busbar differential protection scheme** is given below.



Here, CSSA and CSSB are two selector switch which are used to put into service, the **busbar protection** system for zone A and zone B respectively. If CSSA is in "IN" position, protection scheme for zone A is in service. f CSSB is in "IN" position, protection for zone B is in service. Generally both of the switches are in "IN' position in normal operating condition. Here, relay coil of 96A and 96B are in series with differential busbar protection relay contact 87A-1 and 87B-1 respectively.

96A relay is multi contacts relay. Each circuit breaker in zone A is connected with individual contact of 96A.

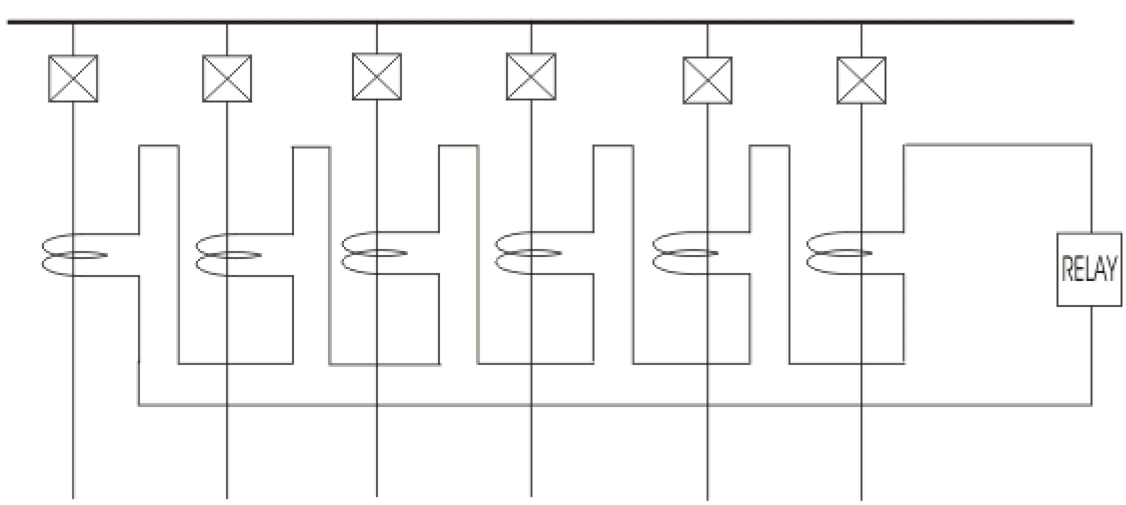
Similarly, 96B is multi contacts relay and each circuit breaker in zone-B is connected with individual contacts of 96B.

Although here we use only one tripping relay per protected zone, but this is better to use one individual tripping relay per feeder. In this scheme one protective relay is provided per feeder circuit breaker, whereas two tripping relays one for zone A and other for zone B are provided to bus section or bus coupler circuit breaker. On an interval fault in zone A or bus section A, the respective bus protection relay 87A, be energized whereas during internal fault in zone B, the respective relay 87B will be energized. As soon as relay coil of 87A or 87B is energized respective no. contact 87A-1 or 87B-1 is closed.Hence, the tripping relay 96 will trip the breakers connected to the faulty zone. To indicate whether zone A or B busbar protection operated, relay 30 is used. For example, if relay 87A is operated, corresponding “No” contact 87A-2 is closed which energized relay 30A. Then the No contact 30A-1 of relay 30A is closed to energized alarm relay 74. Supervision relay 95 of respective zone is also energized during internal fault, but it has a time delay of 3 second. So, it reset as soon as the fault is cleared and therefore does not pick up zone bus wire shorting relay 95x which in turn shorts out the bus wires. An alarm contact is also given to this auxiliary 95x relay to indicate which CT is open circuited. No volt relay 80 is provided in both trip and non-trip section of the DC circuit of differential busbar protection system to indicate any discontinuity of D. C. supply.

Voltage Differential Protection of Busbar

The current differential scheme is sensitive only when the CTs do not get saturated and maintain same current ratio, phase angle error under maximum faulty condition. This is usually not 80, particularly, in the case of an external fault on one of the feeders. The CT on the faulty feeder may be saturated by total current and consequently it will have very large errors. Due to this large error, the summation of secondary current of all CTs in a particular zone may not be zero. So there may be a high chance of tripping of all circuit breakers associated with this protection zone even in the case of an external large fault. To prevent this maloperation of current differential **busbar protection**, the 87 relays are provided with high pick up current and enough time delay.

The greatest troublesome cause of current transformer saturation is the transient dc component of the short circuit current. This difficulties can be overcome by using air core CTs. This current transformer is also called linear coupler. As the core of the CT does not use iron the secondary characteristic of these CTs, is straight line. In voltage differential busbar protection the CTs of all incoming and outgoing feeders are connected in series instead of connecting them in parallel.



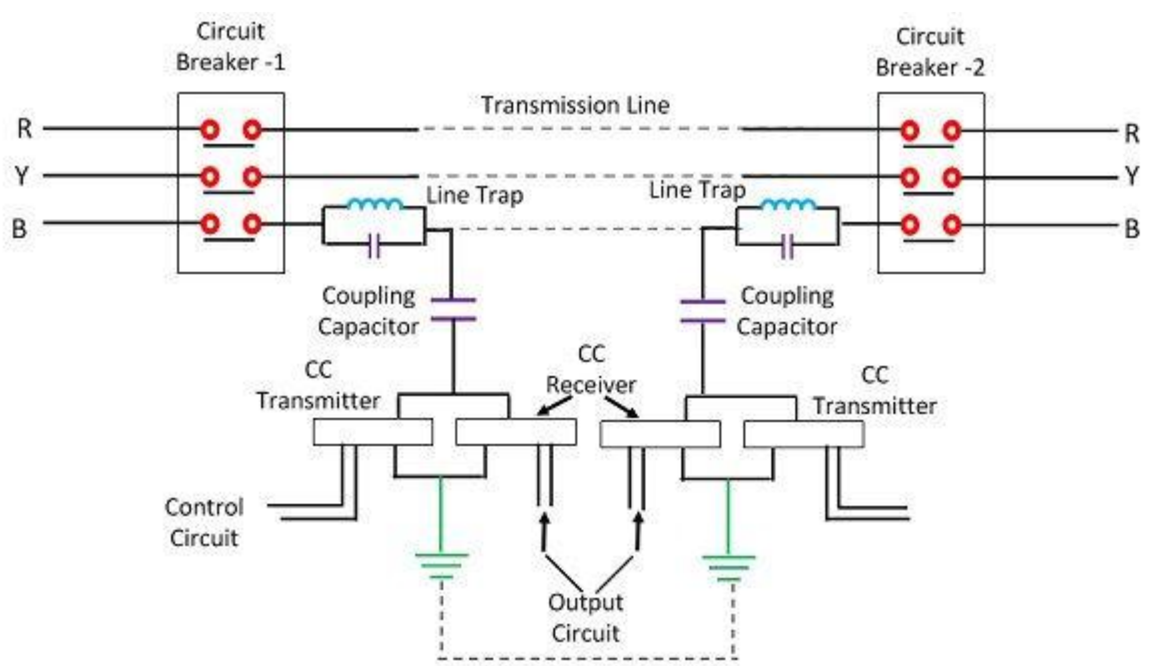
The secondaries of all CTs and differential relay form a closed loop. If polarity of all CTs are properly matched, the sum of voltage across all CT secondaries is zero. Hence there would be no resultant voltage appears across the differential relay. When a buss fault occurs, sum of the all CT secondary voltage is no longer zero. Hence, there would be current circulate in the loop due to the resultant voltage. As this loop current also flows through the differential relay, the relay is operated to trip all the circuit beaker associated with protected bus zone. Except when ground fault current is severally limited by neutral impedance there is usually no selectivity problem when such a problem exists, it is solved by use of an additional more sensitive relaying equipment including a supervising protective relay

Carrier Current Protection of Transmission Lines

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 transmission

the carrier current receiver receives the carrier current from the transmitter at the distant end of the line. The receiver converts the received carrier current into a DC voltage that can be used in a relay or other circuit that performs any desired function. The voltage is zero when the carrier current, is not being received.

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.

Methods of Carrier Current Protection

The different methods of current carrier protection and the basic form of the carrier current protection are

1. Directional Comparison protection
2. Phase Comparison Protection

Circuit GlobeSwitchgear and ProtectionCarrier Current Protection of Transmission Lines

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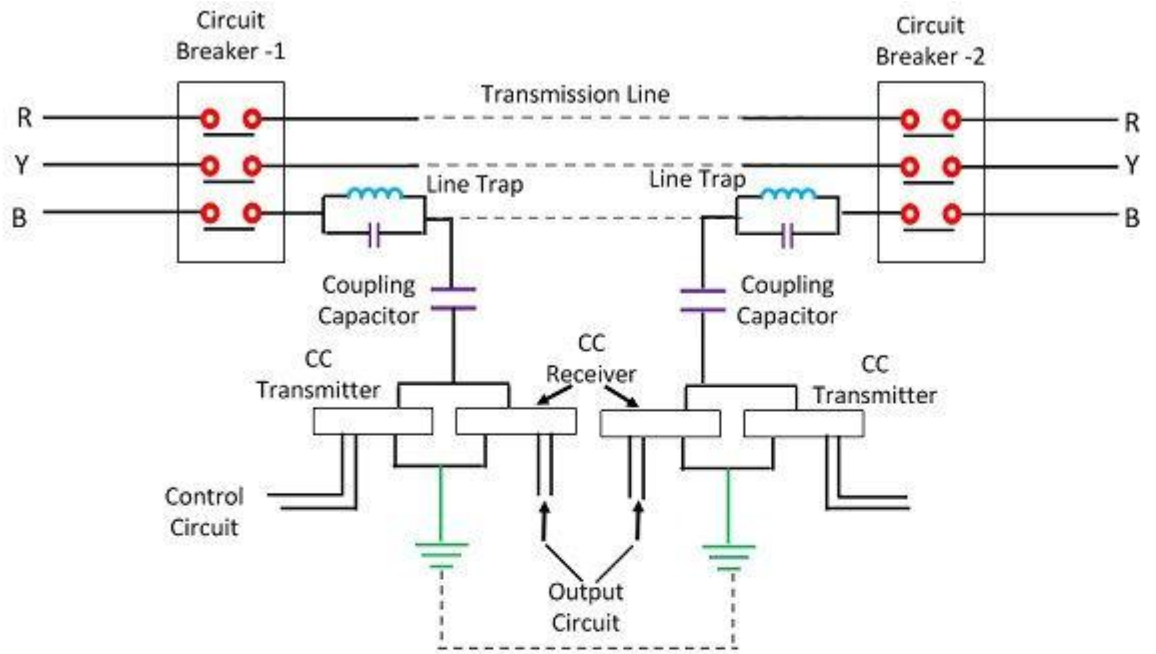

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Methods of Carrier Current Protection

The different methods of current carrier protection and the basic form of the carrier current protection are

1. Directional Comparison protection
2. Phase Comparison Protection

These types are explained below in details

1. Directional Comparison Protection

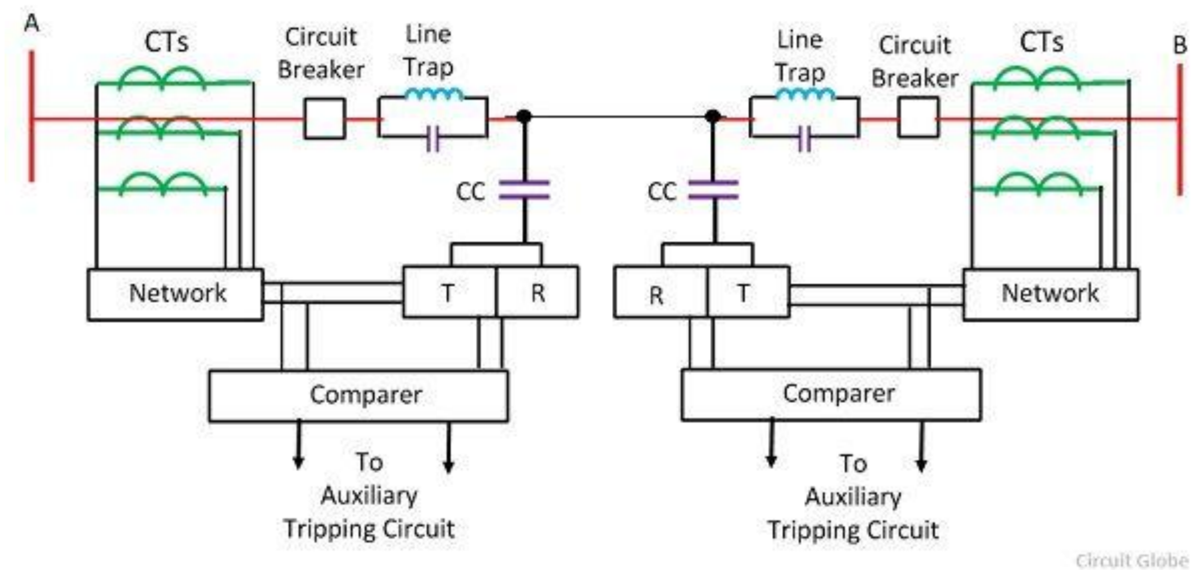
In this protection schemes, the protection can be done by the comparison of a fault of the power flow direction at the two ends of the line. The operation takes place only when the power at both the end of the line is on the bus to a line direction. After the direction comparison, the carrier pilot relay informs the equipment how a directional relay behaves at the other end to a short circuit.

The relay at both the end removes the fault from the bus. If the fault is in protection section the power flows in the protective direction and for the external fault power will flow in the opposite direction. During the fault, a simple signal through carrier pilot is transmitted from one end to the other. The pilot protection relaying schemes used for the protection of transmission are mainly classified into two types. They are

- **Carrier Blocking Protection Scheme** – The carrier blocking protection scheme restricts the operation of the relay. It blocks the fault before entering into the protected section of the system. It is one of the most reliable protecting schemes because it protects the system equipment from damage.
- **Carrier Permitting Blocking Scheme** – The carrier, protective schemes allows the fault current to enter into the protected section of the system.

2. Phase Comparison Carrier Protection

This system compares the phase relation between the current enter into the pilot zone and the current leaving the protected zone. The current magnitudes are not compared. It provided only main or primary protection and backup protection must be provided also. The circuit diagram of the phase comparison carrier protection scheme is shown in the figure below.



The transmission line CTs feeds a network that transforms the CTs output current into a single phase sinusoidal output voltage. This voltage is applied to the carrier current transmitter and the comparer. The output of the carrier current receiver is also applied to the comparer. The comparer regulates the working of an auxiliary relay for tripping the transmission line circuit breaker.

Advantage of Carrier Current Protection

The following are the advantage of the carrier current protection schemes. These advantages are

1. It has a fast and simultaneous operation of circuit breakers at both the ends.
2. It has a fast, clearing process and prevents shock to the system.
3. No separate wires are required for signalling because the power line themselves carry the power as well as communication signalling.
4. It's simultaneously tripping of circuit breakers at both the end of the line in one to three cycles.
5. This system is best suited for fast relaying also with modern fast circuit breakers.

RELAY COORDINATION IN THE PROTECTION OF RADIALLY-CONNECTED POWER SYSTEM NETWORK

1. Introduction When a feeder fault causes the supply-side relay to trip, not only are the customers on the faulted feeder inconvenienced with an outage, but all the customers that are being served by the other feeders from the same supply-side relay and breaker also experience an outage. Therefore necessary discrimination must be enabled during fault conditions. This can be achieved in the foll

As soon as the fault takes place it is sensed by both prima-ry and backup protection. The primary protection is thefirst to operate as its operating time being less that that of the backup relay.A simple radial feeder with two sections is shown in figure 1. For fault at point F, relay R B is first to operate. Letthe operating time of R B is set to 0.1 s. The relay R A shouldwait for 0.1 s plus, a time equal to the operating time of circuit breaker (CB) at bus B, plus the overshoot time of re-lay A [1]. This is necessary for maintaining the selectivityof relays at A and B.Fig. 1 A radial feederA ring main feeder system is shown in figure 2. It allowssupply to be maintained to all the loads in spite of fault onany section. Relays 1, and 8 are non directional whereasall other relays (2, 3, 4, 5, 6, and 7) are directional OC re-lays. All directional relays have their tripping directionaway from the concerned bus

UNIT III

THEORY OF ARC QUENCHING

The Arc Phenomena, Arc Extinction & Method of Arc Extinction

When a short-circuit occurs, a heavy current flows through the contacts of the circuit breaker before they are opened by the protective system. At the instant when the contacts begin to separate, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature. The heat produced in the medium between contacts (usually the medium is oil or air) is sufficient to ionise the air or vapourise and ionise the oil. The ionised air or vapour acts as conductor and an arc is struck between the contacts. The p.d. between the contacts is quite small and is just sufficient to maintain the arc. The arc provides a low resistance path and consequently the current in the circuit remains uninterrupted so long as the arc persists.

During the arcing period, the current flowing between the contacts depends upon the arc resistance. The greater the arc resistance, the smaller the current that flows between the contacts.

The arc resistance depends upon the following factors :

1. Degree of ionization— the arc resistance increases with the decrease in the number of ionized particles between the contacts.
2. Length of the arc— the arc resistance increases with the length of the arc i.e., separation of contacts.
3. Cross-section of arc— the arc resistance increases with the decrease in area of X-section of the arc.

Factors responsible for maintaining ARC.

P.D.. between the contacts

When the contacts have a small separation, the p.d. between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that p.d. becomes inadequate to maintain the arc. However, this method is impracticable in high voltage system where a separation of many meters may be required.

Ionized particles between contacts

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

Methods of ARC extinction.
Basically 2 methods:

1) High Resistance method.

2) Low resistance method or zero current method.

High Resistance Method

In this method, arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc. Consequently, the current is interrupted or the arc is extinguished. It is employed only in d.c. circuit breakers and low-capacity a.c. circuit breakers. Why?? Of course cause heat dissipation is very large that's why.

Methods of increasing arc resistance.

1. Lengthening of arc.
2. Cooling of arc.
3. Reducing cross section area of arc.
4. Splitting the arc.

Lengthening the arc.

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

Cooling the arc.

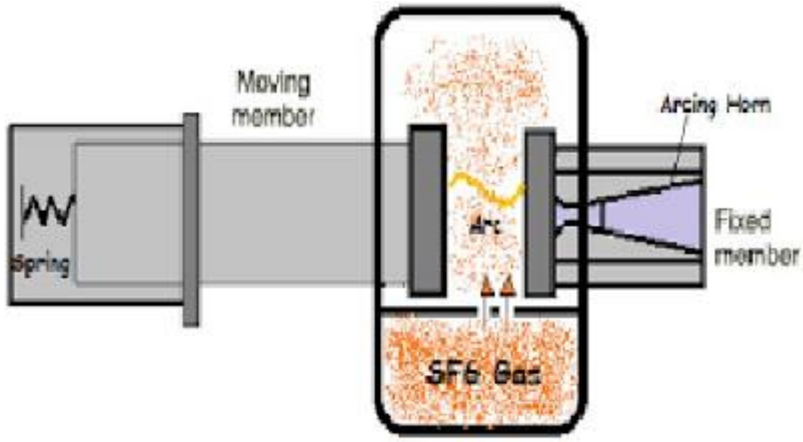
Cooling helps in the deionisation of the medium between the contacts. This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

Reducing X-section of the arc.

If the area of X-section of the arc is reduced, the voltage necessary to maintain the arc is increased. In other words, the resistance of the arc path is increased. The cross-section of the arc can be reduced by letting the arc pass through a narrow opening or by having smaller area of contact

Phenomenon in Circuit Breaker:

When a short circuit occurs, heavy current flows through the contacts of circuit breaker before they are opened by the protective system. At the instant when the contacts begin to open after getting trip command from the Relay, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature. The heat produced in the medium in between the contacts is sufficient enough to ionize the medium. This ionized medium acts as a conductor and arc is stuck in between the contacts of the circuit breaker. It shall be noted here that the potential difference between the fixed and moving contacts is quite small and just enough to maintain the arc. This arc provides a low resistance path to the current and thus due to arcing the current in the circuit remain uninterrupted as long as arcing persists.



During the arcing period the current flowing through the contacts of circuit breaker deepens upon the arc resistance. The greater the arc resistance the smaller will be the current flowing through the contacts of CB. The arcing resistance depends upon the following factors:

Degree of Ionization:
The more the ionization of medium between the contacts, the less will be the arcing resistance.

Length of Arc:
The arc resistance increases as the length of arc increases i.e. as the separation between the contacts of Breaker increases the arcing resistance also increases.

Cross Section of the Arc:
The arcing resistance increases with decrease in the cross sectional area of the arc.

Arcing phenomena
Principle of Arc Extinction:

As we discussed earlier in this post, ionization of medium in between the contacts and potential difference across the contacts are responsible for the production and maintenance of arc. Thus for arc extinction, we can increase the separation between the contacts to such an extent that potential difference across the contacts is not sufficient enough to maintain the arc. But this philosophy is impractical as in EHV (Like 220 kV, 400 kV, 765 kV etc.) system; the separation between the contacts to extinguish the arc will be many meters which is not practically achievable.

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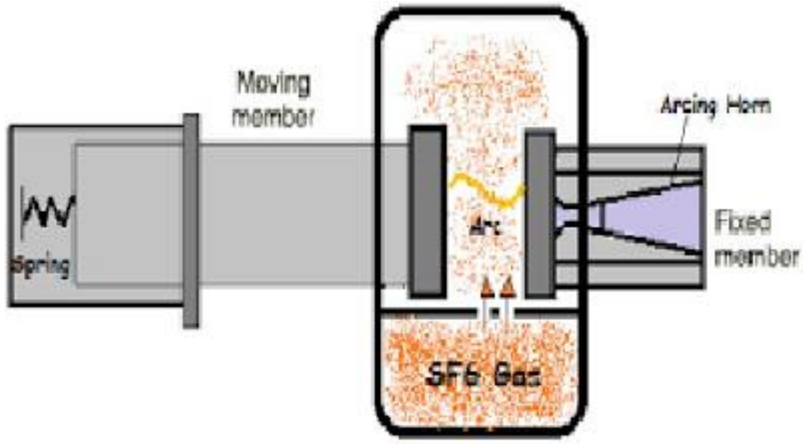

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Resistance switching

Modeling of resistive switching

An early attempt to model the RS effect in bipolar TMOs was made by Rozenberg et al. in 2004 [25]. Though phenomenological and solely based on the scarce data available at that time, the model remarkably captured some key experimental observations and predicted several features that were eventually confirmed. For instance, the active role of interfaces containing inhomogeneous regions of nanometer scale, where field induced migration of electronic species control the resistive switching. Eventually, the model evolved to incorporate several key physical features that have been revealed in the extensive experimental research reported in recent years [18]. The model remains phenomenological, as it aims to apply to a large variety of systems that range from band-insulator STO, to doped Mott-insulators that are strongly correlated metals, such as manganites and cuprates. The key features that the model incorporates are the presence of inhomogeneous conductive paths, active regions near the electrode/dielectric interface with large resistivity due to the presence of Shottky barriers, oxygen vacancy (V*O*) migration along a network of nanometer sized domains, which may be extended defects (*cf* STO) or grains and grain boundaries, etc. The local resistivities along the conduction path is assumed to be determined by the V*O* concentration. In fact, a universal feature of TMOs is that their resistivity is most strongly influenced by oxygen stochiometry. This is because oxygen vacancies play a double role by providing electron dopants, but also introducing disorder in the conduction bands by disrupting the TM-O-TM bonds.

Thus, the model basically consists on a resistor network, where the links have a resistivity that is determined by their local V*O* concentration. The high resistivity of the Shottky barriers is simply modeled by and enhanced resistivity of the few outermost links at either end.

A last feature of the model is the assumption that migration of the V*O* ions from domain to domain is enhanced by electric field. Thus the model behavior is simulated through the following steps: initially, a uniform profile of V*O* concentration is assumed along the conductive domain path. This determines the resistive profile of the links of the network. An external voltage is applied, the current and the local potential drops are computed. The V*O* migration from domain to domain is simulated using the following expression for the probability to transfer ions among neighboring domains

$$pab \propto \delta a(1-\delta b)e(-EA+\Delta Va)/VB$$

where δa is the concentration of vacancies at domain "a", ΔVa is the potential drop at domain "a", VB is potential associated to the migration barrier height, and EA is an energy associated to the intrinsic vacancy drift constant at the given temperature when no external potential is applied.

After the migration transfers are computed and updated in a simulation step, the new values of the resistors of the network are recalculated. At the following time step the external voltage is updated, then the new voltage drops along the networks are obtained, and so on.

As shown in Fig.8, the predictions of this simple model reproduce the "table with legs" *R-V* characteristics that were experimentally measured in two different symmetric devices, one with a PLCMO dielectric and another with YBCO. Moreover, introducing asymmetry in the model through a single parameter, it can also account for the RS behavior in asymmetric devices, remarkably well [18]. This study provided strong support to the mechanism of electric-field-enhanced migration of oxygen vacancies at the nanoscale for bipolar type resistive switching. However, it also clarified the necessity of having "poorly" conductive interfaces (Shottky barriers).

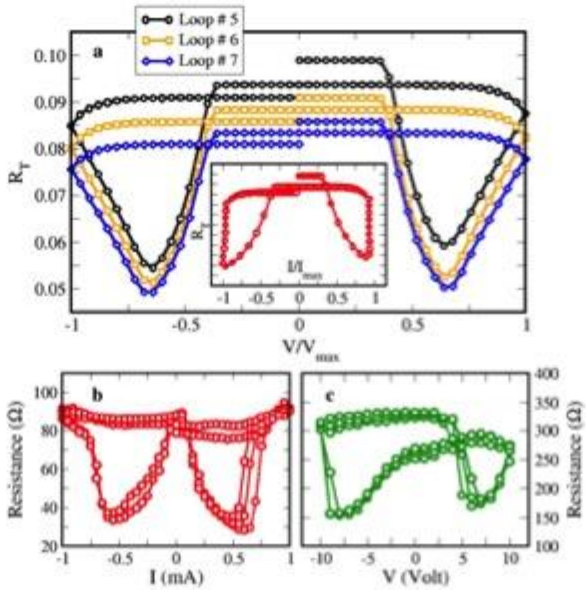


Figure 8: Top panel: model prediction for the "table-with-legs" *R-V* characteristics of a bipolar symmetric device. Lower panels: Experimental *R-V*data for a PCMO (left) and a YBCO (right) samples (figure from [18]).

Another feature that was elucidated by the study is that in perfectly symmetric bipolar devices a cancellation of the resistance occurs for the extreme values of the applied voltage (positive and negative). In contrast, this cancellation does not take place in asymmetric devices. Therefore, the magnitude of RS should be larger in asymmetric devices. This is an example of how simple theoretical modeling may assist in providing useful experimental guidance.

Other theoretical modeling attempts focused on unipolar binary oxide systems [26,27,28,29]. A generic model for unipolar switching has been proposed by Chae et al. [26], based on a random circuit breaker network. The model consisted on a resistor network where the resistance of each link may undergo a resistive switching, depending on the its values of current and voltage. The model is simple and appealing as the simulations reproduce well the qualitative features of experimental data. However, one of its main limitations is the *ad-hoc* assumption made on the I-V characteristics of each network unit. A different model has been proposed by Ielmini et al. [27] that focused on the NiO compound. They argue that the SET transition is driven by threshold switching into a high conductive state, which leads to a structural change where stable conductive filaments are created. The RESET is, more simply, due to the dissolution of the filaments due to Joule heating.

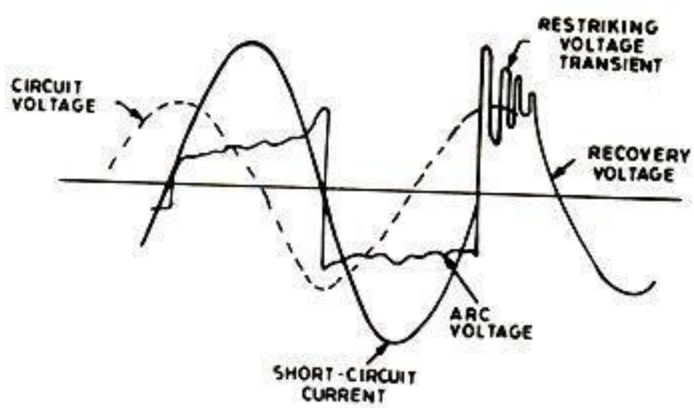
A binary system that received particular attention is TiO2 . Devices made with this compound may exhibit either, unipolar or bipolar RS, depending on fabrication details. In fact, bipolar switching has been observed only in relatively small systems, where electrode separation is less than 50 nm. Unipolar switching of this compound is not surprising, as it also observed in many other binary oxides. However, bipolar switching in this insulator is rather surprising, as it is structurally very different from the other bipolar systems, which are complex oxides.

A simple phenomenological model for the bipolar RS effect in TiO_2 has been proposed by the group of Williams [28]. They assumed a spatially inhomogeneous system, where the initial forming step induces a high concentration of oxygen vacancies on a portion of the dielectric closest to the negative electrode. The vacancies are donors of electron carriers, thus decrease the resistivity of that region. The ensuing model is that of two series resistors where one corresponds to high resistivity stoichiometric TiO_2, while the other corresponds to low resistivity TiO_{2-x}, where x is the oxygen vacancy concentration. As external voltage is applied to the electrodes, the boundary of the oxygen vacancy reach region moves due to ionic migration, thus changing the total resistance of the system.

Another model for bipolar switching in TiO_2 has been introduced by Jeong et al. [29]. Their model is based on electrochemical redox reactions involving oxygen vacancies near the electrodes. They argue that the reactions modulate the height of the Schottky barriers formed at the interfaces. Their model seems to account for experimental RS data, however, it relies on a relatively large number of parameters.

Current chopping

While interrupting highly inductive current, like no-load current of transformer, the rapid deionization of contact space and blast effect may cause current interruption before its natural zero. Such an'interruption of current before its natural zero is termed as “**current chopping**”.This phenomenon is more pronounced in case of air-blast circuit breakers which exerts the same deionizing force for all currents within its short-circuit capacity. Even though, the instantaneous value of current being interrupted may be less than the normal current rating of the breaker, it is quite dangerous from the point of view of overvoltages which may result in the system.



Let,
L = Inductance of the system
C = Capacitance of the system
i =Instantaneous value of arc current

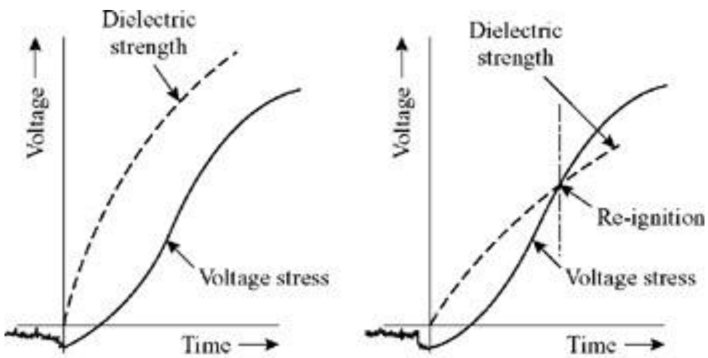
V = Instantaneous value of capacitor voltage (which appears across the breaker when it opens)

The electromagnetic energy stored in the system at the instant before interruption is $1/2(Li^2)$ As soon as the current is interrupted the value of i becomes zero. But, the electromagnetic energy stored in the system $[1/2(Li^2)]$ cannot become zero instantaneously and so it is converted into electrostatic energy $[1/2(CV^2)]$ as the system has some capacitance.

According to the principle of energy conversion we have,
$1/2(Li^2)=1/2(CV^2)$
$V=i\sqrt{(L/C)}$

This theoretical value of V is called as "**prospective Voltage or Arc Voltage**". If this voltage is very high when compared with the gap withstanding voltage, then the gap breakdowns and so "the arc restrikes. Again the current is chopped (interrupted) because of high quenching force and so, restriking occurs. This process repeats until the current is suppressed finally without any restrike and this occurs near current zero as shown in the figure.

In actual proactive the voltage across the breaker does not reach dangerously high prospective values of voltage. It is due to the fact that as soon as the breaker voltage increases beyond the gap withstanding voltage, it breaks down and the arc restrikes due to which the voltage across breaker falls to a very low value of arc voltage which can also be seen in the figure. Hence, it can be said that the arc is not an undesirable phenomenon and instead it protects the power system from severe stress on insulation due to overvoltages.



(a) Interruption maintained (b) Initial interruption followed by dielectric failure

In order to reduce the **phenomenon of current chopping**, the overvoltages are to be reduced. This is possible by connecting voltage— grading (or non—linear) resistors across the circuit breaker contacts during arc interruption. In medium voltage systems, an RC surge absorber is connected across line and ground in between the inductive load and the circuit breaker. As a result, the RC combination absorbs the overvoltages

Electrical Fuse HRC Fuse High Rupturing Capacity

Electrical Fuse

In normal working condition of electrical network, the current flows through the network is within the rated limit. If fault occurs in the network mainly phase to phase short circuit fault or phase to ground fault, the network current crosses the rated limits. This high current may have very high thermal effect which will cause a permanent damage to the valuable equipments connected in the electrical network.
So this high fault current should be interrupted as fast as possible. This is what an **electrical fuse** does. A fuse is a part of the circuit which consists of conductor which melts easily and breaks the connection when current exceeds the predetermined value. An electrical fuse is a weakest part of an electrical circuit which breaks when more than predetermined current flows through it.

Fuse Wire

The function of **fuse wire** is to carry the normal current without excessive heating but more than normal current when pass through fuse wire, it rapidly heats up and melts.

Materials used for Fuse Wires

The **materials used for fuse wires** are mainly tin, lead, zinc, silver, antimony, copper, aluminum etc.

Fuse Wire Rating

The melting point and specific resistance of different metals used for fuse wire

Metal	Melting point	Specific Resistance
Aluminium	240°F	2.86 μ Ω - cm
Copper	2000°F	1.72 μ Ω - cm
Lead	624°F	21.0 μ Ω - cm
Silver	1830°F	1.64 μ Ω - cm
Tin	463°F	11.3 μ Ω - cm
Zinc	787°F	6.1 μ Ω - cm

Some Important Terms need for Fuse

1. Fuse it is already defined earlier.
2. Fuse wire, it is also defined earlier.
3. **Minimum Fusing Current:** It is minimum value of current due to which fuse melts.
4. **Current Rating of Fuse:** It is maximum value of current due to which fuse does not get melt.
5. **Fusing Factor:** This is the ratio of minimum fusing current and current rating of fuse. Therefore, fusing factor = Minimum fusing current or current rating of fuse. The value of fusing factor is always more than 1.
6. **Prospective Current in Fuse:** Before melting, the fuse element has to carry the short circuit current through it.The prospective current is defined as the value of current which would flow through the fuse immediately after a short circuit occurs in the network.

7. **Melting Time of Fuse or Pre-arcing Time of Fuse:** This is the time taken by an fuse wire to be broken by melting. It is counted from the instant, the over current starts to flow through fuse, to the instant when fuse wire is just broken by melting.
8. **Arcing Time of Fuse:** After breaking of fuse wire there will be an arcing between both melted tips of the wire which will be extinguished at the current zero. The time accounted from the instant of arc initiated to the instant of arc being extinguished is known as arcing time of fuse.
9. **Operating Time of Fuse:** When ever over rated current starts to flow through a fuse wire, it takes a time to be melted and disconnected, and just after that the arcing stars between the melted tips of the fuse wire, which is finally extinguished. The operating time of fuse is the time gap between the instant when the over rated current just starts to flow through the fuse and the instant when the arc in fuse finally extinguished. That means operating time of fuse = melting time + arcing time of fuse.

Current Carrying Capacity of Fuse Wire

Current carrying capacity of a fuse wire depends upon numbers of factors like, what material used for it, what are the dimension of it, i.e. diameter and length, size and shape of terminals used to connect it, and the surrounding.

Fuse Law

Fuse law determines the current carrying capacity of a fuse wire. The law can be established in the following way. At steady state condition that is when fuse carry normal current without increasing its temperature to the melting limit. That means at this steady state condition, heat generated due to current through fuse wire is equal to heat dissipated from it. Heat generated = I^2R.

Where, R is the resistance of the fuse wire. $I^2.\rho.\frac{l}{a}$ Where, ρ is the resistivity, l is the length and a is the cross sectional area of fuse wire. $I^2.\rho.\frac{l}{\pi d^2/4}$ Where, d is the diameter of fuse wire. $I^2.K_1.\frac{l}{d^2}$ ....(i) Where, K_1 is a constant.

Heat lost ∝ surface area of fuse wire ∝ πd.l. Therefore, heat lost = $K_2.d.l$ ....(ii) Where, K_2 is a constant.

Now, equating (i) and (ii), we get, $I^2.K_1.\frac{l}{d^2} = K_2.d.l$ $\Rightarrow I^2 = K.d^3$

Where $K = \frac{K_2}{K_1}$ is another costant

$$\Rightarrow I = K.d^{3/2}$$
$$\Rightarrow I = K.d^{1.5}$$

This is known as **fuse law**

Metal	value of K when d is measured in mm
Aluminium	59
Copper	80
Iron	24.6
Lead	10.8

Rewirable or Kit Kat Fuse Unit

This is most commonly used fuse in our day to day life. This fuse has mainly two parts. The unit in which the incoming and outgoing line or phase wire connected permanently is known as fuse base. The removable parts which hold a the fuse wire and fits into the base, is known as fuse carrier. The fuse carrier is also known as **cutout**.

Cartridge Fuse

In **cartridge fuse** the fuse wire is enclosed in a transparent glass tube or bulb, the whole unit is sealed off. In case the fuse blows, it is to be replaced by new one as the **cartridge fuse** can not be rewired due to its sealing.

Lead – tin Alloy Fuse Wire or Eutectic Alloy Fuse Wire

For small value of current interruption lead – tin alloy fuse wire has been used in past. The most preferred lead – tin alloy for fuse wire containing 37% lead and 63% tin. This alloy fuse wire is also known as known as Eutectic Alloy Fuse Wire. This type of alloy has some specific characteristics due to which this is preferred as fuse wire.

1. It has the high brinnel hardness and has less tendency to spread over.
2. The alloy metal is quite homogeneous.
3. If the fusing characteristics of eutectic alloy and other composition of alloys is studied there is only one arrest point in eutectic alloy as compared to two other types of alloys.

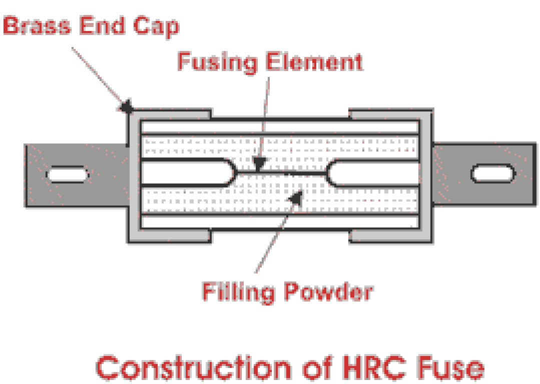
Approximate fusing currents of lead – tin alloy fuse wire in air

Diameter of wire in inch	Fusing Current in A	Maximum safe Current in A
0.02	3	2
0.022	3.5	2.3

0.024	4	2.6
0.028	5	3.3
0.032	6	4.1
0.036	7	4.8
0.048	10	7
0.064	16	11

NB : - The minimum length of the fuse wire used must be 2.5 to 3.5 inches. The values in the above table are true only when the fuse wire does not touches the fuse grip body because when the fuse wire comes in contact with porcelain or other the value of fusing current increases as the heat dissipation rate from the current carrying fuse wire, is increased. Hence precaution should always be taken during rewiring a fuse wire on a fuse grip so that it should not touch the fuse grip body.

HRC Fuse or High Rupturing Capacity Fuse



HRC fuse or **high rupturing capacity fuse**- In that type of fuse, the fuse wire or element can carry short circuit heavy current for a known time period. During this time if the fault is removed, then it does not blow off otherwise it blows off or melts. The enclosure of **HRC fuse** is either of glass or some other chemical compound. This enclosure is fully air tight to avoid the effect of atmosphere on the fuse materials. The ceramic enclosure having metal end cap at both heads, to which fusible silver wire is welded. The space within the enclosure, surrounding the fuse wire or fuse element is completely packed with a filling powder. This type of fuse is reliable and has inverse time characteristic, that means if the fault current is high then rupture time is less and if fault current is not so high then rupture time is long.

Operation of HRC Fuse

When the over rated current flows through the fuse element of **high rupturing capacity fuse** the element is melted and vapourized. The filling powder is of such a quantity that the chemical reaction between the silver vapour and the filling powder forms a high electrical resistance substance which very much help in quenching the arc

Recovery voltage

It is the normal frequency (50 Hz) r.m.s. voltage that appears across the contacts of the circuit breaker after final arc extinction. It is approximately equal to the system voltage.
When contacts of circuit breaker are opened, current drops to zero after every half cycle. At some current zero, the contacts are separated sufficiently apart and dielectric strength of the medium between the contacts attains a high value due to the removal of ionised particles. At such an instant, the medium between the contacts is strong enough to prevent the breakdown by the restriking voltage.

Consequently, the final arc extinction takes place and circuit current is interrupted. Immediately after final current interruption, the voltage that appears across the contacts has a transient part. However, these transient oscillations subside rapidly due to the damping effect of system resistance and normal circuit voltage appears across the contacts. The voltage across the contacts is of normal frequency and is known as recovery voltage.

UNIT IV

CIRCUIT BREAKERS

Introduction

Circuit breakers have been classified into a number of types, based on different categories they have been subdivided into.

It should be noted here that there is no specific criteria of classifying the circuit breakers, but instead there are a number of ways in which we can categorize them for our easier understanding and knowledge of the operating conditions of the device.

These different categorizes can be according to the medium in which the **circuit breaker** operates, the actuating signal on which its works, the different types of constructing and working principles etc.

Firstly I am going to give you a brief overview of all the different types, mentioning their names and how they have been classified into that category. Further ahead, we will be discussing some of the widely used types now-a-days.

Typology of circuit breakers

Firstly we classify the circuit breakers according to the voltage levels they can operate on. So there are three most used types of circuit breakers in this category. These are:

1. Low **Voltage Circuit** Breakers
2. Medium Voltage Circuit Breakers
3. High Voltage Circuit Breakers

There is another category which is based on the mechanism used to actuate the circuit breaker, which specifies the mechanism of operation of the breaker, there are three further types:

1. Hydraulic Circuit Breakers
2. Pneumatic Circuit Breakers
3. Spring actuated Circuit Breakers

Another very important category is where to use the circuit breaker. This may seem a bit weird at first, but when installing a breaker, you must have to take care if it will be used inside your home or any other building or it has to be installed somewhere outdoors. This is because the outer mechanical body of the breaker has to be designed accordingly for it to be tough and protective to prevent the internal circuitry from damaging. So two more types can be:

1. Outdoor Circuit Breakers
2. Indoor Circuit Breakers

Now considering the medium in which a circuit breaker can operate. Most of us would have the concept that circuit breakers can only be installed in the circuits present in our homes so that the medium surrounding them is air. But now here is something for you to ponder over. Not Only air, but circuit breakers can also be installed in water or other mediums. Here are the basic types according to the medium of installation:

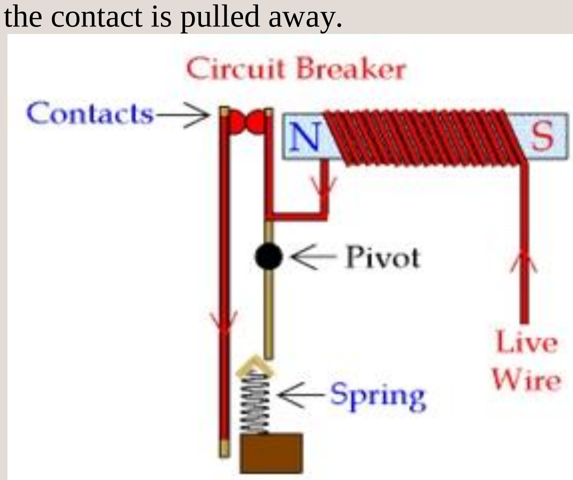
1. Vacuum Circuit Breakers
2. SF6 Circuit Breakers
3. Oil Circuit Breakers
4. Air Circuit Breakers

Top 3 of the most used circuit breakers

Now we come to the three most common types of circuit breakers used:

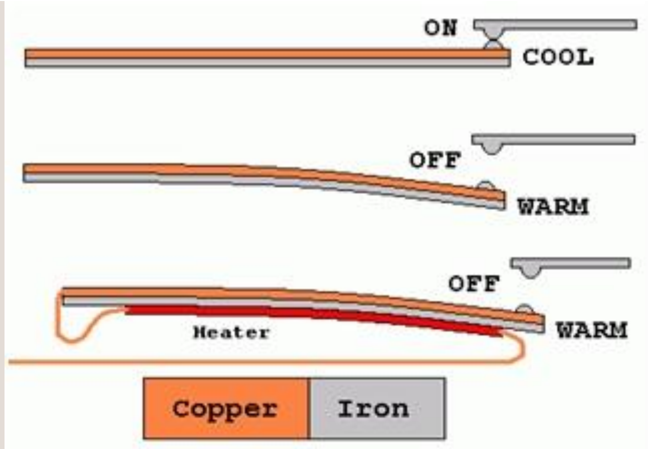
1. <u>Magnetic Type Circuit Breakers</u>:

   These circuit breakers use the principle of electromagnetism to break the circuit. So when the current passing through the circuit increases, the electromagnetic force increases and the contact is pulled away.

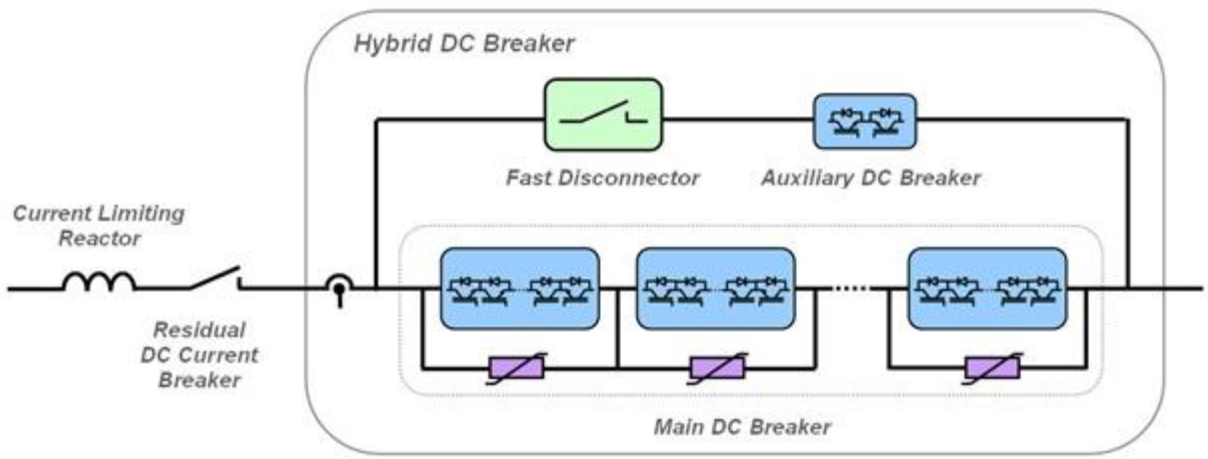


2. <u>Thermal Type Circuit Breakers:</u>

   As evident from the name, the circuit is interrupted by the heat produced from the excessively large current passing through the circuit.



3. <u>Hybrid Type Circuit Breakers</u>:
   Clearly visible from the name, they are a combination of the above two. They use heat as well as magnetism to break the circuit. One of these types is shown in the figure below:



There are three other widely used types as well, based on the operating voltage as mentioned above. They will be discussed in detail in the upcoming tutorials.

Circuit breaker / switchgear testing

With central elements such as busbars, disconnectors and circuit breakers, switchgears represent the hubs of electrical energy grids. Gas-insulated switchgear (GIS) is a space-saving alternative to classic outdoor switchgear. The compressed gas (typically SF_6) boasts significantly greater insulation strength than air and the distances to ground can be drastically smaller.

Circuit breakers are particularly important and maintenance-intensive components, since they comprise many moving parts. In many cases they remain standing still for several years, but in the event of a malfunction they have to reliably disconnect fault currents of many kiloamps within just a few milliseconds. Junction and transfer points of busbars and disconnectors are prone to error and therefore should be tested regularly.

The high voltage in switchgear creates stress for the materials being used in the equipment. Therefore, insulation tests are recommended. In principle, GIS systems require exactly the same tests as other systems. However, they are often difficult to access and this is why they require special solutions.

- Vacuum circuit breaker-SF_6, circuit breaker

Vacuum Circuit Breaker

Evolis MV Circuit Breaker

In a Vacuum circuit breaker, vacuum interrupters are used for breaking and making load and fault currents. When the contacts in vacuum interrupter separate, the current to be interrupted initiates a metal vapour arc discharge and flows through the plasma until the next current zero. The arc is then extinguished and the conductive metal vapour condenses on the metal surfaces within a matter of micro seconds. As a result the dielectric strength in the breaker builds up very rapidly.

SF6 Gas Circuit Breaker

SF6 circuit breakers

In an SF6 circuit-breaker, the current continues to flow after contact separation through the arc whose plasma consists of ionized SF6 gas. For, as long as it is burning, the arc is subjected to a constant flow of gas which extracts heat from it. The arc is extinguished at a current zero, when the heat is extracted by the falling current. The continuing flow of gas finally de-ionises the contact gap and establishes the dielectric strength required to prevent a re-strike.

The direction of the gas flow, i.e., whether it is parallel to or across the axis of the arc, has a decisive influence on the efficiency of the arc interruption process. Research has shown that an axial flow of gas creates a turbulence which causes an intensive and continuous interaction between the gas and the plasma as the current approaches zero. Cross-gas-flow cooling of the arc is generally achieved in practice by making the arc move in the stationary gas. This interruption process can however, lead to arc instability and resulting great fluctuations in the interrupting capability of the circuit breaker.

In order to achieve a flow of gas axially to the arc a pressure differential must be created along the arc. The first generation of the SF6 circuit breakers used the two-pressure principle of the air-blast circuit-breaker. Here a certain quantity of gas was kept stored at a high pressure and released into the arcing chamber. At the moment high pressure gas and the associated compressor was eliminated by the second generation design. Here the pressure differential was created by a piston attached to the moving contacts which compresses the gas in a small cylinder as the contact opens. A disadvantage is that this puffer system requires a relatively powerful operating mechanism.

Neither of the two types of circuit breakers described was able to compete with the oil circuit breakers price wise. A major cost component of the puffer circuit-breaker is the operating mechanism; consequently developments followed which were aimed at reducing or eliminating this additional cost factor. These developments concentrated on employing the arc energy itself to create directly the pressure-differential needed. This research led to the development of the self-pressuring circuit-breaker in which the over – pressure is created by using the arc energy to heat the gas under controlled conditions. During the initial stages of development, an auxiliary piston was included in the interrupting mechanism, in order to ensure the satisfactory breaking of small currents. Subsequent improvements in this technology have eliminated this requirement and in the latest designs the operating mechanism must only provide the energy needed to move the contacts.

Parallel to the development of the self-pressuring design, other work resulted in the rotating – arc SF6 gas circuit breaker. In this design the arc is caused to move through, in effect the stationery gas. The relative movement between the arc and the gas is no longer axial but radial, i.e., it is a cross-flow mechanism. The operating energy required by circuit breakers of this design is also minimal.

Oil Circuit Breaker Bulk and Minimum Oil Circuit Breaker

Mineral oil has better insulating property than air. In **oil circuit breaker** the fixed contact and moving contact are immerged inside the insulating oil. Whenever there is a separation ofcurrent carrying contacts in the oil, the arc in circuit breaker is initialized at the moment of separation of contacts, and due to this arc the oil is vaporized and decomposed in mostly hydrogen gas and ultimately creates a hydrogen bubble around the arc. This highly compressed gas bubble around the arc prevents re-striking of the arc after current reaches zero crossing of the cycle. The **oil circuit breaker** is the one of the oldest type of circuit breakers.

peration of Oil Circuit Breaker

The **operation of oil circuit breaker** is quite simple let's have a discussion. When the current carrying contacts in the oil are separated an arc is established in between the separated contacts. Actually, when separation of contacts has just started, distance between the current contacts is small as a result the voltage gradient between contacts becomes high. This high voltagegradient between the contacts ionized the oil and consequently initiates arcing between the contacts. This arc will produce a large amount of heat in surrounding oil and vaporizes the oil and decomposes the oil in mostly hydrogen and a small amount of methane, ethylene and acetylene. The hydrogen gas cannot remain in molecular form and its is broken into its atomic form releasing lot of heat.

The arc temperature may reach up to $5000^{o}K$. Due to this high temperature the gas is liberated surround the arc very rapidly and forms an excessively fast growing gas bubble around the arc. It is found that the mixture of gases occupies a volume about one thousand times that of the oil decomposed. From this figure we can assume how fast the gas bubble around the arc will grow in size. If this growing gas bubble around the arc is compressed by any means then rate of de – ionization process of ionized gaseous media in between the contacts will accelerate which rapidly increase the dielectric strength between the contacts and consequently the arc will be quenched at zero crossing of the current cycle. This is the basic **operation of oil circuit breaker**. In addition to that cooling effect of hydrogen gas surround the arc path also helps, the quick arc quenching in oil circuit breaker.

Types of Oil Circuit Breakers

There are mainly two **types of oil circuit breakers** available-

Bulk Oil Circuit Breaker or BOCB

Bulk oil circuit breaker or **BOCB** is such **types of circuit breakers** where oil is used as arc quenching media as well as insulating media between current carrying contacts and earthed parts of the breaker. The oil used here is same as transformer insulating oil.

Minimum Oil Circuit Breaker or MOCB

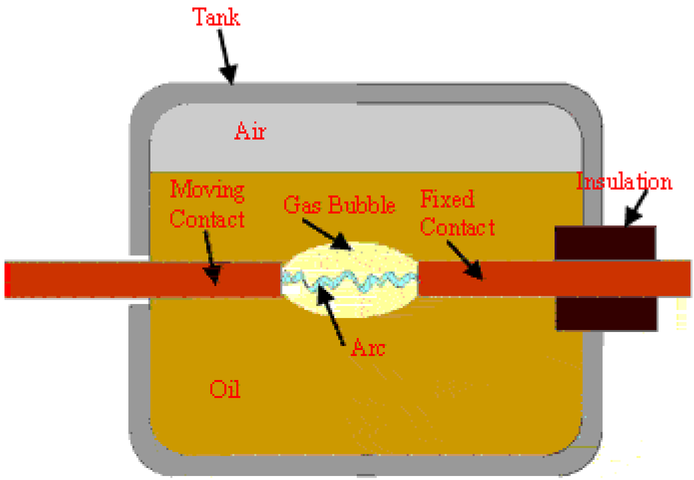
These types of circuit breakers utilize oil as the interrupting media. However, unlike **bulk oil circuit breaker**, a **minimum oil circuit breaker** places the interrupting unit in insulating chamber at live potential. The insulating oil is available only in interrupting chamber. The features of designing **MOCB** are to reduce requirement of oil, and hence these breaker are called **minimum oil circuit breaker**.

Bulk Oil Circuit Breaker

Construction of Bulk Oil Circuit Breaker

The basic construction of bulk oil circuit breaker is quite simple. Here all moving contacts and fixed contacts are immerged in oil inside closed iron vessel or iron tank. Whenever the current carrying contacts are being open within the oil the arc is produced in between the separated contacts. The large energy will be dissipated from the arc in oil which vaporizes the oil as well as decomposes it. Because of that a large gaseous pressure is developed inside the oil which tries to displace the liquid oil from surrounding of the contacts. The inner wall of the oil tank has to withstand this large pressure of the displaced oil. Thus the oil tank of bulk oil circuit breaker has to be sufficiently strong in construction. An air cushion is necessary between the oil surface and tank roof to accommodate the displaced oil when gas forms around the arc. That is why the oil tank is not totally filled up with oil it is filled up to certain level above which the air is tight in the tank. The breaker tank top cover should be securely bolted on the tank body and total breaker must be properly locked with foundation otherwise it may jump out during interruption of high fault current. In these type of equipment where expansible oil is enclosed in an air tight vessel (oil tank) there must be a gas vent fitted on the tank cover. Naturally some form of gas vent always is provided on the cover of bulk oil circuit breaker tank. This is very basic features for construction of bulk oil circuit breaker.

Arc Quenching in Bulk Oil Circuit Breaker

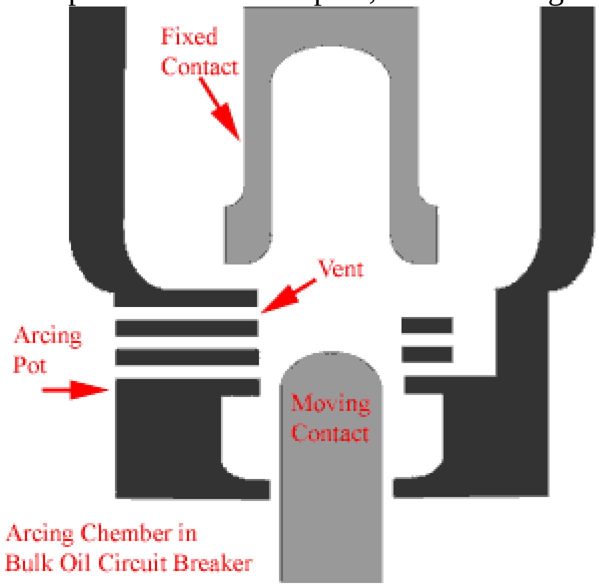


Conceptual view of Bulk Oil Circuit Breaker

When the current carrying contacts in the oil are separated an arc is established in between the separated contacts. This arc will produce rapidly growing gas bubble around the arc. As the moving contact move away from fixed contact the length of arc is increased as a result the resistance of the arc increases. The increased resistance causes lowering the temperature and hence reducing the formation of gasses surround the arc. The arc quenching in bulk oil circuit breaker takes place when current passes through zero crossing. If we go through the arc quenching phenomenon more thoroughly we will find many other factors effects the arc quenching in **bulk oil circuit breaker**. As the gas bubble is enclosed by the oil inside the totally air tight vessel, the oil surround it will apply high pressure on the bubble, which results highly compressed gas around the arc. As the pressure is increased the de – ionization of gas increases which helps the arc quenching. The cooling effect of hydrogen gas also helps in arc quenching in oil circuit breaker.

Single Break Bulk Oil Circuit Breaker

In single break bulk oil circuit breaker there is one pair of current carrying contacts for each phase of power circuit. The each pair of current carrying contacts in this bulk oil circuit breaker consists of one fixed contact and one moving contact. Fixed contact is stationary contact and moving contact moves away from fixed contact during opening of the circuit breaker. As the moving contact is being moved away from fixed contact the arc is produced in between the contacts and it is extinguished during zero crossing of the fault current, due to the reasons as explain in previous chapter. As the days go on further research works have been done to improve better arc control in single break bulk oil circuit breaker. The main aim of development of bulk oil circuit breaker is to increase the pressure developed by the vaporization and dissociation of oil. Since in large gas pressure, the mean free paths of electrons and ions are reduced which results in effective deionization. So if the pressure can be increased, the rate of deionization is increased which helps to quick arc extinction. It has been found that if the opening of fixed and moving contacts is done inside a semi closed insulated chamber then the gas bubble created around the arc will get less space of expansion, hence it becomes highly compressed. These semi closed insulated arcing chamber in bulk oil circuit breaker is known as side vented explosion pot or cross jet pot. The principle of operation of cross jet pot is quite simple let's have a discussion. The pressure developed by the vaporization and dissociation of the oil is retained in the side vented explosive pot by withdrawing the moving contact through a stack of insulating plates having a minimum radial clearance around the contact. Thus there is practically no release of pressure until the moving contact uncovers one of the side vents. The compressed hydrogen gas can then escape across the arc path, thus exerting a powerful cooling action on the ionized column.

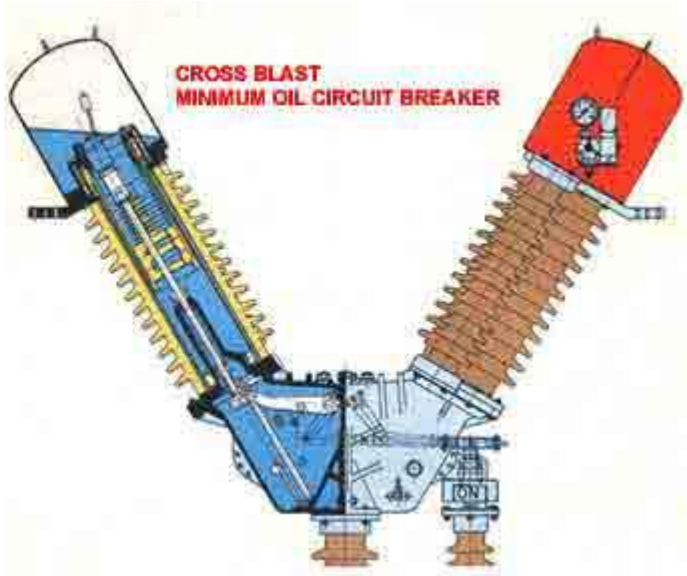


When the current zero is reached, the post arc resistance increased rapidly due this cooling action. At higher breaking currents larger will be the pressure generated and a bulk oil circuit breaker gives its best performance at the highest current within its rating. This single break bulk oil circuit breaker may have problem during clearing low currents such as load current of the breaker. Various improvements in the design of pressure chamber or side vented explosive chamber have been suggested to overcome the problem of low current interruption. One solution of this is providing a supplementary oil chamber below the side vents. This supplementary oil chamber is known as compensating chamber which provides fresh source of oil to be vaporized in order to feed more clean gas back across the arc path during clearing low current.

Double Break Bulk Oil Circuit Breaker

Various improvements in the design of bulk oil circuit breaker have been suggested to satisfactory and safe arc interruption especially at currents below the rated maximum. One solution to this problem is to use an intermediate contact between tow current carrying contacts. The arc is here split into two parts in series. The aim here is to extinguish the second arc quickly by using the gas pressure and oil momentum due to the first arc. In double break bulk oil circuit breaker, there are two fixed contact and are bridged by one moving contact. The moving contact is fitted with driving mechanism of the oil circuit breaker by means of an insulated rod. As the moving contact bridge moves downwards the contact gaps are created with fixed contacts at both end of the intermediate moving contact bridge. Hence arcs are produced at both contacts gap.

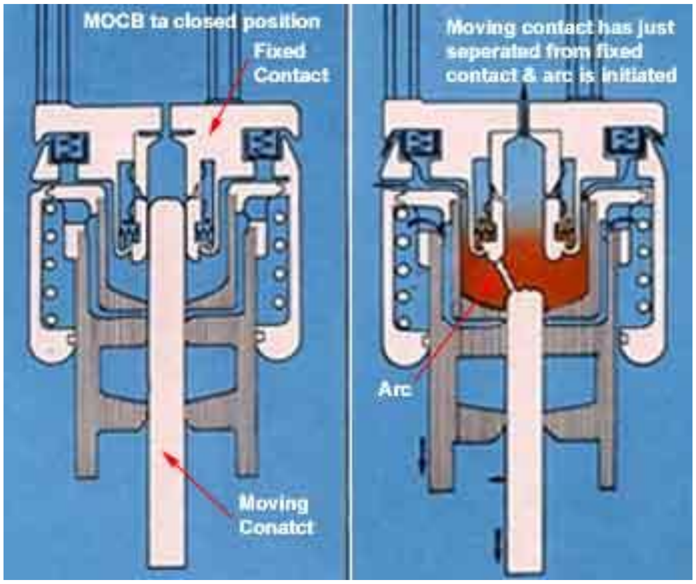
Minimum Oil Circuit Breaker

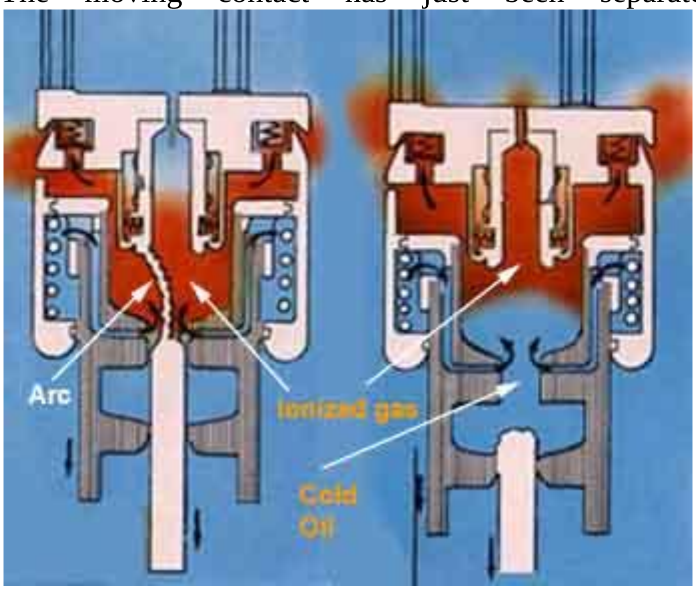


As the volume of the oil in bulk oil circuit breaker is huge, the chances of fire hazard in bulk oil system are more. For avoiding unwanted fire hazard in the system, one important development in the design of oil circuit breaker has been introduced where use of oil in the circuit breaker is much less than that of bulk oil circuit breaker. It has been decided that the oil in the circuit breaker should be used only as arc quenching media not as an insulating media. Then the concept of **minimum oil circuit breaker** comes. In this type of circuit breaker the arc interrupting device is enclosed in a tank of insulating material which as a whole is at live potential of system. This chamber is called arcing chamber or interrupting pot. The gas pressure developed in the arcing chamber depends upon the current to be interrupted. Higher the current to be interrupted causes larger the gas pressure developed inside the chamber, hence better the arc quenching. But this put a limit on the design of the arc chamber for mechanical stresses. With use of better insulating materials for the arcing chambers such as glass fiber, reinforced synthetic resin etc, the **minimum oil circuit breaker** are able to meet easily the increased fault levels of the system.

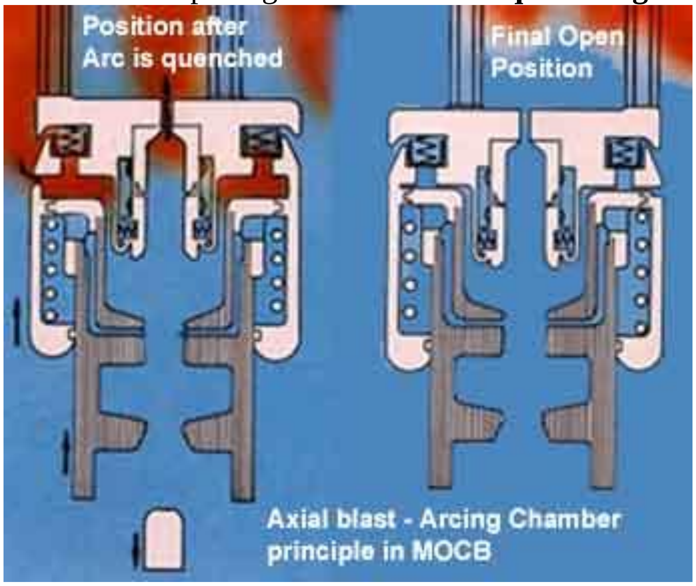
Working Principle or Arc Quenching in Minimum Oil Circuit Breaker

Working Principle of minimum oil circuit breaker or **arc quenching in minimum oil circuit breaker** is described below. In a **minimum oil circuit breaker**, the arc drawn across the current carrying contacts is contained inside the arcing chamber. Hence, the hydrogen bubble formed by the vaporized oil is trapped inside the chamber. As the contacts continue to move, after its certain travel an exit vent becomes available for exhausting the trapped hydrogen gas. There are two different types of arcing chamber is available in terms of venting are provided in the arcing chambers. One is axial venting and other is radial venting. In axial venting, gases (mostly Hydrogen), produced due to vaporization of oil and decomposition of oil during arc, will sweep the arc in axial or longitudinal direction. Let's have a look on **working principle Minimum Oil Circuit Breaker** with axial venting arc chamber.

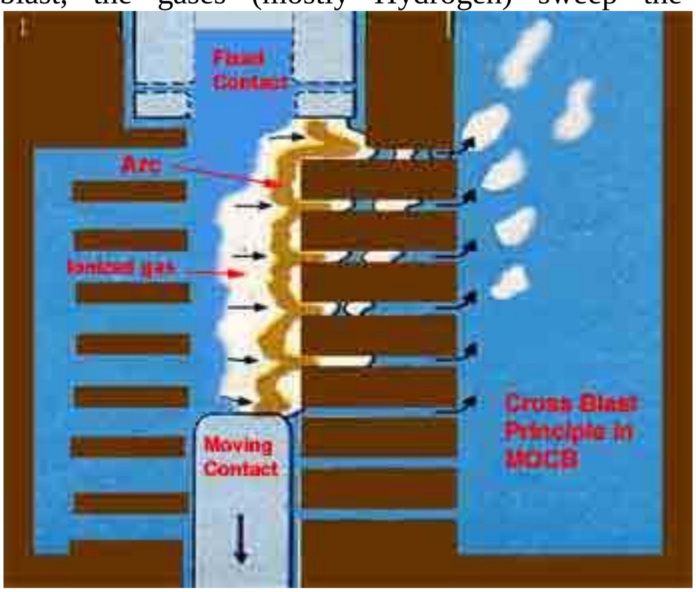


The moving contact has just been separated and arc is initiated in **MOCB**.


The ionized gas around the arc sweep away through upper vent and cold oil enters into the arcing chamber through the lower vent in axial direction as soon as the moving contact tip crosses the lower vent opening and final **arc quenching in minimum oil circuit breaker**occurs.



The cold oil occupies the gap between fixed contact and moving contact and the **minimum oil circuit breaker** finally comes into open position. Where as in case of radial venting or cross blast, the gases (mostly Hydrogen) sweep the arc in radial or transverse direction.



The axial venting generates high gas pressure and hence has high dielectric strength, so it is mainly used for interrupting low current at high voltage. On the other hand radial venting produces relatively low gas pressure and hence low dielectric strength so it can be used for low voltage and high current interruption. Many times the combination of both is used in **minimum oil circuit breaker** so that the chamber is equally efficient to interrupt low current as well as high current. These types of circuit breaker are available up to 8000 MVA at 245 KV.

UNIT V

OVER VOLTAGE PROTECTION

Causes of Over voltage in Power System

Increase in voltage for the very short time in power system is called as the **over voltage**. it is also known as the **voltage surge** or **voltage transients**. The voltage stress caused by over voltage can damage the lines and equipment's connected to the system, There are two types of causes of over voltage in power system.

1. Over voltage due to external causes
2. Over voltage due to internal causes

Transient over voltages can be generated at high frequency (load switching and lightning), medium frequency (capacitor energizing), or low frequency.

- **Over voltage due to external causes:**

This cause of over voltage in power system is the lightning strokes in the cloud. Now, how lightning strokes are produced. So when electric charges get accumulated in clouds due to thunder Strom caused due to some bad atmosphere process.

This type of over voltages originates from atmospheric disturbances, mainly due to lightning. This takes the form of a surge and has no direct relationship with the operating voltage of the line.

It may be due to any of the following causes:

A) Direct lightning stroke
B) Electromagnetically induced over voltages due to lightning discharge taking place near the line, called 'side stroke'.
C) Voltages induced due to atmospheric changes along the length of the line.
D) Electrostatically induced voltages due to presence of charged clouds nearby.
E) Electrostatically induced over voltages due to the frictional effects of small particles like dust or dry snow in the atmosphere or due to change in the altitude of the line.

The potential between the clouds and earth breaks down and lightning flash takes place between the cloud and ground when this voltage becomes 5 to 20 million volts or when the potential gradient becomes 5000V to 10000V per cm.

There are two **types of lightning strokes**.
1. Direct lightning strokes
2. Indirect lightning strokes

If any query or suggestion about **causes of over voltage** please comment below or Email on sohal@electricalidea.com.

Related Posts

Over voltage due to internal causes

Over voltage due to Internal causes. When there is sudden change in circuit conditions of the power system, oscillation are produced due to the capacitance and inductance of the circuit and

there is increase in voltage. this voltage is may be double the system voltage. There are different Types of…
December 5, 2016
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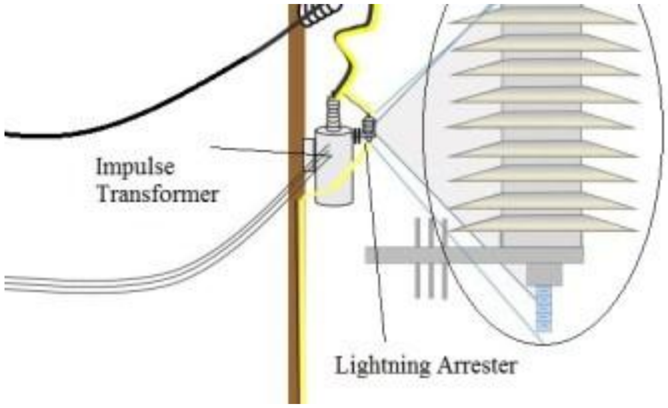

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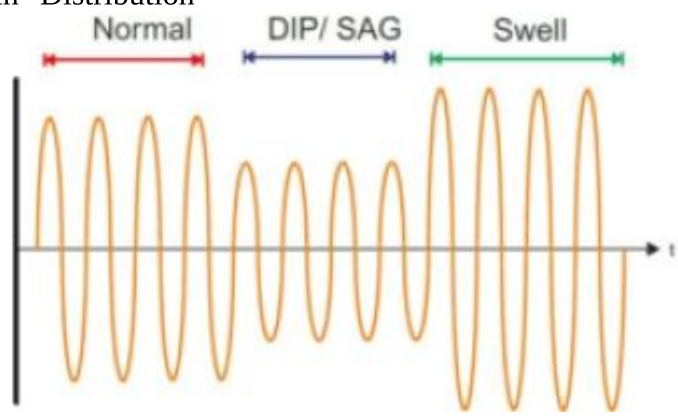
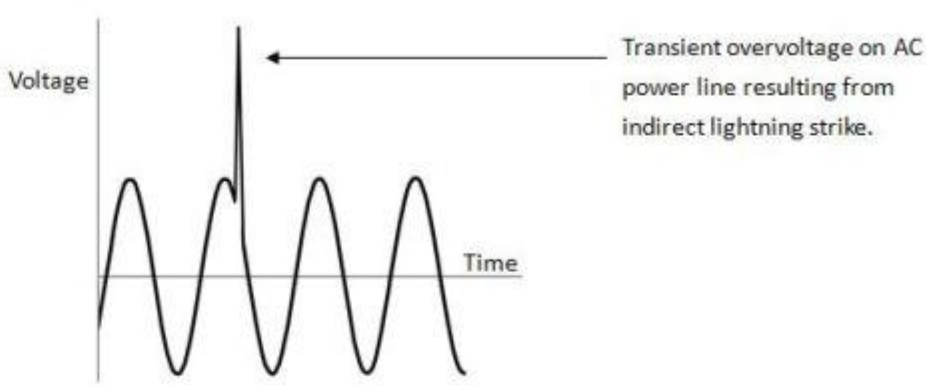
December 23, 2016
In "Distribution"



Power Quality Issues
December 24, 2016
In "Power System



EARTHING SYSTEM

Introduction:

- In the early power systems were mainly Neutral ungrounded due to the fact that the first ground fault did not require the tripping of the system. An unscheduled shutdown on the first ground fault was particularly undesirable for continuous process industries. These power systems required ground detection systems, but locating the fault often proved difficult. Although achieving the initial goal, the ungrounded system provided no control of transient over-voltages.
- A capacitive coupling exists between the system conductors and ground in a typical distribution system. As a result, this series resonant L-C circuit can create over-voltages well in excess of line-to-line voltage when subjected to repetitive re-strikes of one phase to ground. This in turn, reduces insulation life resulting in possible equipment failure.
- Neutral grounding systems are similar to fuses in that they do nothing until something in the system goes wrong. Then, like fuses, they protect personnel and equipment from damage. Damage comes from two factors, how long the fault lasts and how large the fault current is. Ground relays trip breakers and limit how long a fault lasts and Neutral grounding resistors limit how large the fault current is.

Importance of Neutral Grounding:

- There are many neutral grounding options available for both Low and Medium voltage power systems. The neutral points of transformers, generators and rotating machinery to the earth ground network provides a reference point of zero volts. This protective measure offers many advantages over an ungrounded system, like,

1. Reduced magnitude of transient over voltages
2. Simplified ground fault location
3. Improved system and equipment fault protection
4. Reduced maintenance time and expense
5. Greater safety for personnel
6. Improved lightning protection
7. Reduction in frequency of faults.

Method of Neutral Earthing:

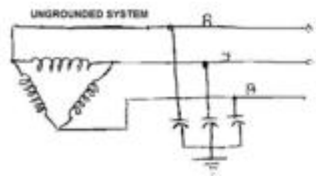
- There are five methods for Neutral earthing.

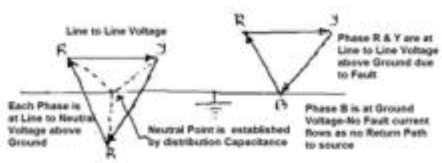
1. Unearthed Neutral System
2. Solid Neutral Earthed System.
3. Resistance Neutral Earthing System.Resonant Neutral Earthing System.
   1. Low Resistance Earthing.
   2. High Resistance Earthing.
4. Resonant Earthing System.
5. Earthing Transformer Earthing.

(1) Ungrounded Neutral Systems:

- In ungrounded system there is no internal connection between the conductors and earth. However, as system, a capacitive coupling exists between the system conductors and the adjacent grounded surfaces. Consequently, the “ungrounded system” is, in reality, a “capacitive grounded system” by virtue of the distributed capacitance.

- Under normal operating conditions, this distributed capacitance causes no problems. In fact, it is beneficial because it establishes, in effect, a neutral point for the system; As a result, the phase conductors are stressed at only line-to-neutral voltage above ground.
- But problems can rise in ground fault conditions. A ground fault on one line results in full line-to-line voltage appearing throughout the system. Thus, a voltage 1.73 times the normal voltage is present on all insulation in the system. This situation can often cause failures in older motors and transformers, due to insulation breakdown.





- **Advantage:**

1. After the first ground fault, assuming it remains as a single fault, the circuit may continue in operation, permitting continued production until a convenient shut down for maintenance can be scheduled.

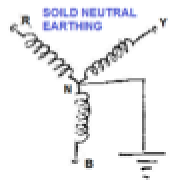
- **Disadvantages:**

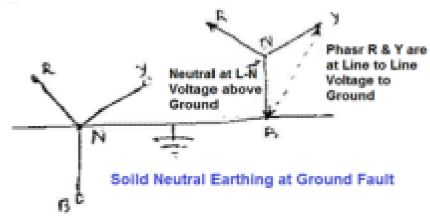
1. The interaction between the faulted system and its distributed capacitance may cause transient over-voltages (several times normal) to appear from line to ground during normal switching of a circuit having a line-to ground fault (short). These over voltages may cause insulation failures at points other than the original fault.
2. A second fault on another phase may occur before the first fault can be cleared. This can result in very high line-to-line fault currents, equipment damage and disruption of both circuits.
3. The cost of equipment damage.
4. Complicate for locating fault(s), involving a tedious process of trial and error: first isolating the correct feeder, then the branch, and finally, the equipment at fault. The result is unnecessarily lengthy and expensive down downtime.

(2) Solidly Neutral Grounded Systems:

- Solidly grounded systems are usually used in low voltage applications at 600 volts or less.
- In solidly grounded system, the neutral point is connected to earth.
- Solidly Neutral Grounding slightly reduces the problem of transient over voltages found on the ungrounded system and provided path for the ground fault current is in the range of ***25 to 100% of the system three phase fault current.*** However, if the reactance of the generator or transformer is too great, the problem of transient over voltages will not be solved.
- While solidly grounded systems are an improvement over ungrounded systems, and speed up the location of faults, they lack the current limiting ability of resistance grounding and the extra protection this provides.
- To maintain systems health and safe, Transformer neutral is grounded and grounding conductor must be extend from the source to the furthest point of the system within the same raceway or conduit. Its purpose is to maintain very low impedance to ground faults so that a relatively high fault current will flow thus insuring that circuit breakers or fuses will clear the

fault quickly and therefore minimize damage. It also greatly reduces the shock hazard to





personnel

- If the system is not solidly grounded, the neutral point of the system would “float” with respect to ground as a function of load subjecting the line-to-neutral loads to voltage unbalances and instability.
- The single-phase earth fault current in a solidly earthed system may exceed the three phase fault current. The magnitude of the current depends on the fault location and the fault resistance. One way to reduce the earth fault current is to leave some of the transformer neutrals unearthed.
- **Advantage:**

1. The main advantage of solidly earthed systems is low over voltages, which makes the earthing design common at high voltage levels (HV).

- **Disadvantage:**

1. This system involves all the drawbacks and hazards of high earth fault current: maximum damage and disturbances.
2. There is no service continuity on the faulty feeder.
3. The danger for personnel is high during the fault since the touch voltages created are high.

- **Applications:**

1. Distributed neutral conductor.
2. 3-phase + neutral distribution.
3. Use of the neutral conductor as a protective conductor with systematic earthing at each transmission pole.
4. Used when the short-circuit power of the source is low.

(3) Resistance earthed systems:

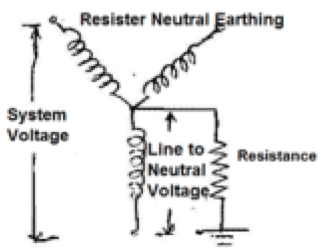
- Resistance grounding has been used in three-phase industrial applications for many years and it resolves many of the problems associated with solidly grounded and ungrounded systems.
- Resistance Grounding Systems limits the phase-to-ground fault currents. The reasons for limiting the Phase to ground Fault current by resistance grounding are:

1. To reduce burning and melting effects in faulted electrical equipment like switchgear, transformers, cables, and rotating machines.
2. To reduce mechanical stresses in circuits/Equipments carrying fault currents.
3. To reduce electrical-shock hazards to personnel caused by stray ground fault.
4. To reduce the arc blast or flash hazard.
5. To reduce the momentary line-voltage dip.
6. To secure control of the transient over-voltages while at the same time.
7. To improve the detection of the earth fault in a power system.

- Grounding Resistors are generally connected between ground and neutral of transformers, generators and grounding transformers ***to limit maximum fault current as per Ohms Law to a value which will not damage the equipment*** in the power system and allow sufficient flow of fault current to detect and operate Earth protective relays to clear the fault. Although it is possible to limit fault currents with high resistance Neutral grounding Resistors, earth short circuit currents can be extremely reduced. As a result of this fact, protection devices may not sense the fault.
- Therefore, it is the most common application to limit single phase fault currents with low resistance Neutral Grounding Resistors to approximately rated current of transformer and / or generator.
- In addition, limiting fault currents to predetermined maximum values permits the designer to selectively coordinate the operation of protective devices, which minimizes system disruption and allows for quick location of the fault.
- There are two categories of resistance grounding:

(1) Low resistance Grounding.
(2) High resistance Grounding.

- Ground fault current flowing through either type of resistor when a single phase faults to ground will increase the phase-to-ground voltage of the remaining two phases. As a result, ***conductor insulation and surge arrestor ratings must be based on line-to-line voltage***. This temporary increase in phase-to-ground voltage should also be considered when selecting two and three pole breakers installed on resistance grounded low voltage systems.
- The increase in phase-to-ground voltage associated with ground fault currents also precludes the connection of line-to-neutral loads directly to the system. If line-to neutral loads (such as 277V lighting) are present, they must be served by a solidly grounded system. This can be achieved with an isolation transformer that has a three-phase delta primary and a three-phase,



four-wire, wye secondary

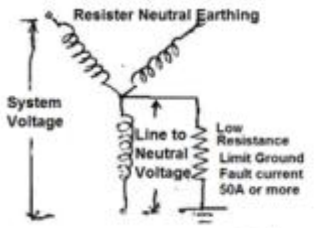
- Neither of these grounding systems (low or high resistance) reduces arc-flash hazards associated with phase-to-phase faults, but both systems significantly reduce or essentially eliminate the arc-flash hazards associated with phase-to-ground faults. Both types of grounding systems limit mechanical stresses and reduce thermal damage to electrical equipment, circuits, and apparatus carrying faulted current.
- The difference between Low Resistance Grounding and High Resistance Grounding is a matter of perception and, therefore, is not well defined. ***Generally speaking high-resistance grounding refers to a system in which the NGR let-through current is less than 50 to 100 A. Low resistance grounding indicates that NGR current would be above 100 A.***
- A better distinction between the two levels might be alarm only and tripping. An alarm-only system continues to operate with a single ground fault on the system for an unspecified amount of time. In a tripping system a ground fault is automatically removed by protective relaying and circuit interrupting devices. Alarm-only systems usually limit NGR current to 10 A or less.
- **Rating of The Neutral grounding resistor:**

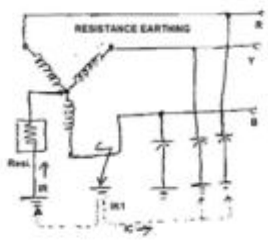
1. **1.** Voltage: Line-to-neutral voltage of the system to which it is connected.

2. **2.** Initial Current: The initial current which will flow through the resistor with rated voltage applied.
3. **3.** Time: The “on time” for which the resistor can operate without exceeding the allowable temperature rise.

(A).Low Resistance Grounded:

- Low Resistance Grounding is used for large electrical systems where there is a high investment in capital equipment or prolonged loss of service of equipment has a significant economic impact and it is not commonly used in low voltage systems because the limited ground fault current is too low to reliably operate breaker trip units or fuses. This makes system selectivity hard to achieve. Moreover, low resistance grounded systems are not suitable for 4-wire loads and hence have not been used in commercial market applications
- A resistor is connected from the system neutral point to ground and generally sized to permit only ***200A to 1200 amps*** of ground fault current to flow. Enough current must flow such that protective devices can detect the faulted circuit and trip it off-line but not so much current as to create major damage at the fault point.





- Since the grounding impedance is in the form of resistance, any transient over voltages are quickly damped out and the whole transient overvoltage phenomena is no longer applicable. Although theoretically possible to be applied in low voltage systems (e.g. 480V),significant amount of the system voltage dropped across the grounding resistor, there is not enough voltage across the arc forcing current to flow, for the fault to be reliably detected. For this reason**, low resistance grounding is not used for low voltage systems** (under 1000 volts line to-line).
- **Advantages:**

1. Limits phase-to-ground currents to 200-400A.
2. Reduces arcing current and, to some extent, limits arc-flash hazards associated with phase-to-ground arcing current conditions only.
3. May limit the mechanical damage and thermal damage to shorted transformer and rotating machinery windings.

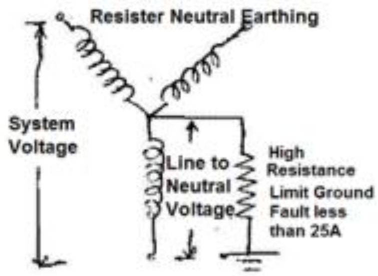
- **Disadvantages:**

1. Does not prevent operation of over current devices.
2. Does not require a ground fault detection system.
3. May be utilized on medium or high voltage systems.
4. Conductor insulation and surge arrestors must be rated based on the line to-line voltage. Phase-to-neutral loads must be served through an isolation transformer.

- **Used:** Up to 400 amps for 10 sec are commonly found on medium voltage systems.

(B).High Resistance Grounded:

- High resistance grounding is almost identical to low resistance groundingexcept that the ground fault current magnitude is typically limited to ***10 amperes or less***. High resistance grounding accomplishes two things.
- The first is that the ***ground fault current magnitude is sufficiently low enough such*** that no appreciable damage is done at the fault point. This means that the faulted circuit need not be tripped off-line when the fault first occurs. Means that once a fault does occur, we do not know where the fault is located. In this respect, it performs just like an ungrounded system.
- The second point is it can ***control the transient overvoltage phenomenon*** present on ungrounded systems if engineered properly.
- Under earth fault conditions, the resistance must dominate over the system charging capacitance but not to the point of permitting excessive current to flow and thereby excluding



continuous operation
- High Resistance Grounding (HRG) systems limit the fault current when one phase of the system shorts or arcs to ground, but at lower levels than low resistance systems.
- In the event that a ground fault condition exists, the HRG typically limits the current to 5-10A.
- HRG's are continuous current rated, so the description of a particular unit does not include a time rating. Unlike NGR's, ground fault current flowing through a HRG is usually not of significant magnitude to result in the operation of an over current device. Since the ground fault current is not interrupted, a ground fault detection system must be installed.
- These systems include a bypass contactor tapped across a portion of the resistor that pulses (periodically opens and closes). When the contactor is open, ground fault current flows through the entire resistor. When the contactor is closed a portion of the resistor is bypassed resulting in slightly lower resistance and slightly higher ground fault current.
- **To avoid transient over-voltages, an HRG resistor must be sized so that the amount of ground fault current**the unit will allow to flow exceeds the electrical system's charging current. As a rule of thumb, charging current is estimated at 1A per 2000KVA of system capacity for low voltage systems and 2A per 2000KVA of system capacity at 4.16kV.
- These estimated charging currents increase if surge suppressors are present. Each set of suppressors installed on a low voltage system results in approximately 0.5A of additional charging current and each set of suppressors installed on a 4.16kV system adds 1.5A of additional charging current.
- A system with 3000KVA of capacity at 480 volts would have an estimated charging current of 1.5A.Add one set of surge suppressors and the total charging current increases by 0.5A to 2.0A. A standard 5A resistor could be used on this system. Most resistor manufacturers publish detailed estimation tables that can be used to more closely estimate an electrical system's charging current.
- **Advantages:**

1. Enables high impedance fault detection in systems with weak capacitive connection to earth
2. Some phase-to-earth faults are self-cleared.

3. The neutral point resistance can be chosen to limit the possible over voltage transients to 2.5 times the fundamental frequency maximum voltage.
4. Limits phase-to-ground currents to 5-10A.
5. Reduces arcing current and essentially eliminates arc-flash hazards associated with phase-to-ground arcing current conditions only.
6. Will eliminate the mechanical damage and may limit thermal damage to shorted transformer and rotating machinery windings.
7. Prevents operation of over current devices until the fault can be located (when only one phase faults to ground).
8. May be utilized on low voltage systems or medium voltage systems up to 5kV. IEEE Standard 141-1993 states that “high resistance grounding should be restricted to 5kV class or lower systems with charging currents of about 5.5A or less and should not be attempted on 15kV systems, unless proper grounding relaying is employed”.
9. Conductor insulation and surge arrestors must be rated based on the line to-line voltage. Phase-to-neutral loads must be served through an isolation transformer.

- **Disadvantages:**

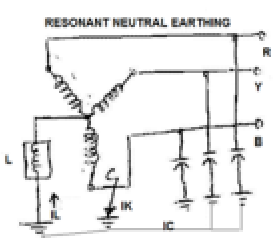
1. Generates extensive earth fault currents when combined with strong or moderate capacitive connection to earth Cost involved.
2. Requires a ground fault detection system to notify the facility engineer that a ground fault condition has occurred.

(4) Resonant earthed system:

- Adding inductive reactance from the system neutral point to ground is an easy method of limiting the available ground fault from something near the maximum 3 phase short circuit capacity (thousands of amperes) to a relatively low value (200 to 800 amperes).
- To limit the reactive part of the earth fault current in a power system a neutral point reactor can be connected between the transformer neutral and the station earthing system.
- A system in which at least one of the neutrals is connected to earth through an

1. Inductive reactance.
2. Petersen coil / Arc Suppression Coil / Earth Fault Neutralizer.

- The current generated by the reactance during an earth fault approximately compensates the capacitive component of the single phase earth fault current, is called a resonant earthed system.
- The system is hardly ever exactly tuned, i.e. the reactive current does not exactly equal the capacitive earth fault current of the system.
- A system in which the inductive current is slightly larger than the capacitive earth fault current is over compensated. A system in which the induced earth fault current is slightly smaller than the capacitive earth fault current is under compensated



- However, experience indicated that this inductive reactance to ground resonates with the system shunt capacitance to ground under arcing ground fault conditions and creates very high transient over voltages on the system.

- To control the transient over voltages, the design must permit at least 60% of the 3 phase short circuit current to flow underground fault conditions.
- Example. A 6000 amp grounding reactor for a system having 10,000 amps 3 phase short circuit capacity available. Due to the high magnitude of ground fault current required to control transient over voltages, inductance grounding is ***rarely used within industry.***
- **Petersen Coils:**

- A Petersen Coil is connected between the neutral point of the system and earth, and is rated so that the capacitive current in the ***earth fault is compensated by an inductive current passed by the Petersen Coil***. A small residual current will remain, but this is so small that any arc between the faulted phase and earth will not be maintained and the fault will extinguish. Minor earth faults such as a broken pin insulator, could be held on the system without the supply being interrupted. Transient faults would not result in supply interruptions.
- Although the standard 'Peterson coil' does not compensate the entire earth fault current in a network due to the presence of resistive losses in the lines and coil, it is now possible to apply 'residual current compensation' by injecting an additional 180° out of phase current into the neutral via the Peterson coil. The fault current is thereby reduced to practically zero. Such systems are known as 'Resonant earthing with residual compensation', and can be considered as a special case of reactive earthing.
- Resonant earthing can reduce EPR to a safe level. This is because the Petersen coil can often effectively act as a high impedance NER, which will substantially reduce any earth fault currents, and hence also any corresponding EPR hazards (e.g. touch voltages, step voltages and transferred voltages, including any EPR hazards impressed onto nearby telecommunication networks).
- **Advantages:**

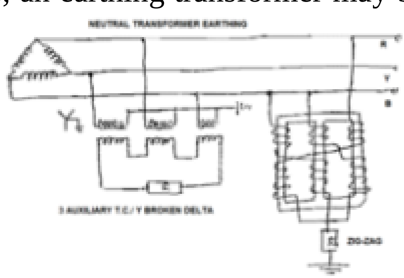
1. Small reactive earth fault current independent of the phase to earth capacitance of the system.
2. Enables high impedance fault detection.

- **Disadvantages:**

1. Risk of extensive active earth fault losses.
2. High costs associated.

(5) Earthing Transformers:

- For cases where there is no neutral point available for Neutral Earthing (e.g. for a delta winding), an earthing transformer may be used to provide a return path for single phase fault



currents
- In such cases the impedance of the earthing transformer may be sufficient to act as effective earthing impedance. Additional impedance can be added in series if required. A special 'zig-zag' transformer is sometimes used for earthing delta windings to provide a low zero-sequence impedance and high positive and negative sequence impedance to fault currents.

GROUND WIRES

Neutral

The neutral wire is at a voltage close to or equal to ground. Current which flows to an appliance via the hot wire returns via the neutral core in a cable. (See note below)

Ground

This is a protective conductor, included to prevent shock and/or fire. Ground is also known as "earth" in some countries.

The supply from the transformer feeding your home is split phase and in the U.S., 2 hots in addition to a neutral are provided. Lower power appliances are connected between either of the hots and neutral and this gives a 120 volt supply. The voltage between the two hots is 240 volt for supplying higher power appliances.

Note: The electricity supply in our homes is AC. So while we tend to think of current flowing out through the hot wire to an appliance and returning via the neutral wire, current actually flows both ways. So for one half of an AC cycle, current flows out through hot and returns via the neutral wire. During the second half cycle, the process is reversed and current flows to the appliance via neutral and returns via hot.

Ground - The Protective Conductor

The flex or fixed wiring supplying metal cased appliances includes a ground conductor (colored green in US or green/yellow in EU) in addition to hot and neutral. Inside the appliance, the ground core of the cable is connected to the outer casing of the appliance. The connection may be made either using a screw terminal or a ring crimp and self tapping screw/bolt. Ground acts as a "bypass" for currents in the event of a fault. Fixed (e.g. storage heater, kitchen range) and portable i.e corded appliances with extraneous metal which can be touched in normal use must be grounded

The fault could be due to:

- Conductors (e.g. wires, terminals, components) at hot or near full mains potential breaking, bending or detaching and touching the casing of the appliance
- Breakdown of insulation. For instance insulation on cores of the power flex could become damaged inside an appliance or insulating spacers could become dislodged. Also metal parts such as screws or nuts which have come undone could bridge the gap between hot and the metal casing
- Making contact with a power cable when drilling through a wall

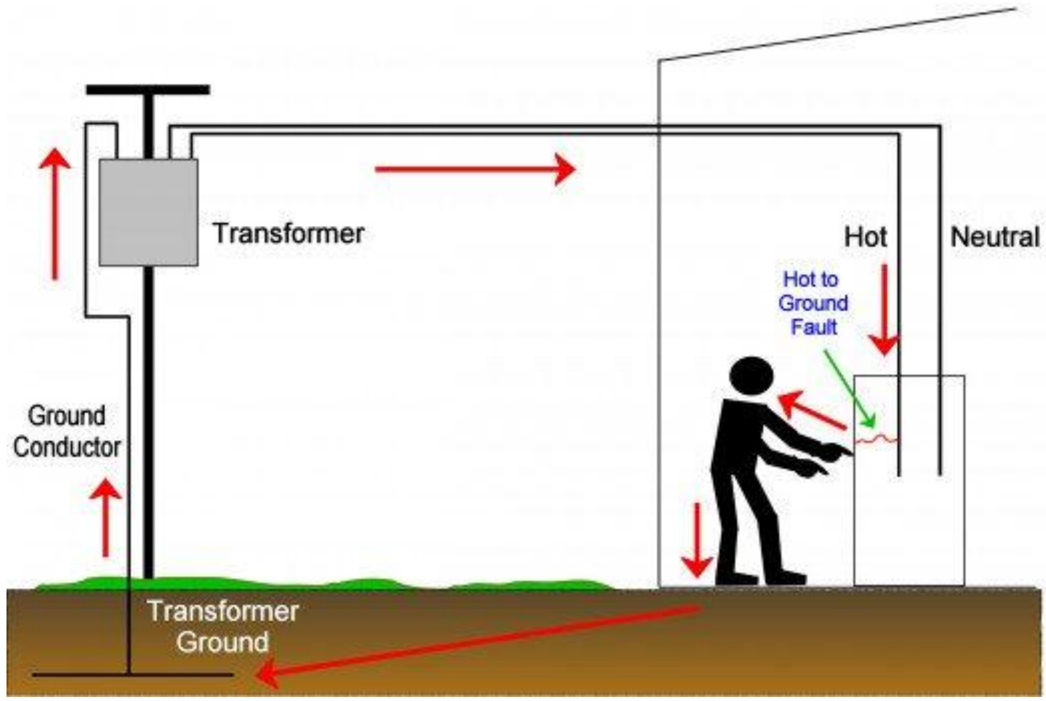
Inside a microwave oven, the ground core of the power flex is connected to the casing using a ring crimp and screw. Note the symbol for ground | Source

What Happens During a Fault if an Appliance isn't Grounded?

If a fault occurs, the external metal of an appliance will become live and the voltage with respect to earth will be anything up to 120 volts, depending on which part of the internal circuit touches the casing. If the metal isn't grounded and someone touches the appliance, current will travel through their body to ground. If they are lucky and have rubber soled shoes and are standing on a dry floor, they may just experience a tingling sensation. However if conditions are damp, they have wet hands and standing outdoors, they are more likely to experience a severe shock. If one hand touches the appliance and the other touches a grounded object, e.g pipework, poles, radiators or whatever, current will travel across their heart, a more dangerous scenario. If the person is unlucky or has a heart condition, this can kill.

Why Does Current Flow to Ground?

The reason why current flows to ground is because the neutral point in the supply transformer is connected via a ground conductor to a ground electrode. This raises the potential of the hot conductor to about 120 volts with respect to the ground surface. During a fault, or if someone touches a live conductor, current flows through the ground back to the transformer. Isolating safety transformers, which are sometimes used for powering tools on construction sites, isolate the neutral from ground so that current cannot flow (or at least very little) if a fault occurs. These transformers are also used convert voltage to 110 volts in countries where 230 volts is the standard supply voltage. This reduces the current to a safer level if someone experiences a shock. Grounding the neutral of the supply transformer is a safety measure taken to eliminate dangerous rises in potential (greater than the hot voltage) on the hot or neutral conductors entering a home. This could occur for instance if a very high voltage power line (possibly hundreds of kilovolts) breaks and lands on a "low" voltage (120 volt) line. Another scenario is the insulation between the primary and secondary of the transformer being breached. This could allow the primary voltage (>10kv) to appear on the secondary. Yet another possibility is a lightning strike on the lines. Basically grounding the neutral pulls down the voltage of the line so that neutral is close to 0 volts and the voltage on either of the hot lines doesn't greatly exceed 120 volts.

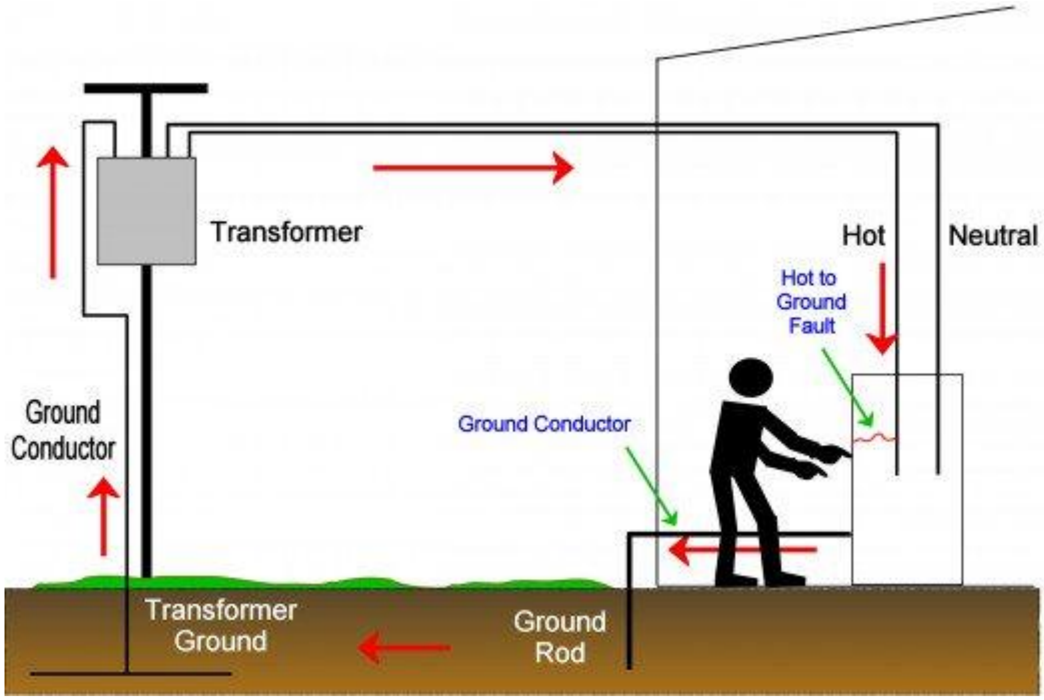


The path of fault current when someone touches a non-grounded faulty appliance (2nd hot in U.S. wiring systems not shown)

How Does Grounding Solve the Problem?

Grounding provides a bypass, shunt or shortcut through which electricity can flow, instead of passing to earth through the person who touches the appliance. Wires called grounding conductors are run from the electrical panel(sometimes called a breaker box), through the fixed wiring to all socket outlets, fixed appliances such as ranges or water heaters, light switches and ceiling roses in your home. In the case of a portable appliance, this grounding path continues from the pin in the plug through the flex, to the metal body of the appliance. At the electrical panel, a conductor runs outside the premises to a grounding rod (earth rod), embedded in the soil.

When a fault occurs, current flows via the grounding conductor back to the electrical panel. If a TNC or TNCS earthing system is in use, all neutrals are joined to ground at the panel (or the neutral and ground may be joined at the output of the supply meter s*ee earthing systems schematic below*), and so the hot to ground fault at the appliance effectively becomes a hot to neutral fault. A large over-current flows, and this trips the MCB (miniature circuit breaker) and possibly also the GFCI (whichever acts first) for the circuit, cutting power and making everything safe.
Grounding however, also has another important function. Even if current is insufficient to trip a breaker or the neutral conductor breaks outside the home, it reduces the touch voltage between the casing of the appliance and the area on the ground on which the person is standing to a safe level.



The low impedance ground conductor shunts current away from the person touching the appliance, reducing the touch voltage to a safe level. (In reality the conductor passes via the plug and flex of the appliance and electrical panel to the ground rod)

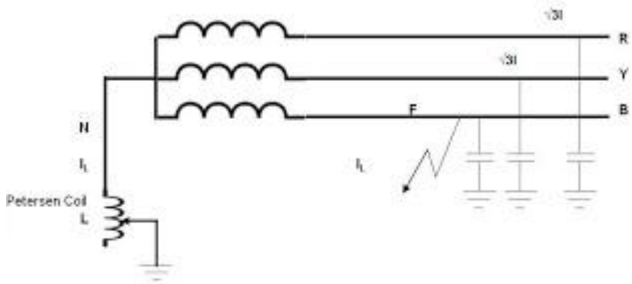
Double Insulated and Non Grounded Appliances

Appliances such as hair driers, TVs, hand held kitchen appliances, etc. generally have plastic casings. If a fault occurs inside the appliance, e.g. a wire or component touches the inside of the casing, there is no danger since the plastic body is an insulator. These appliances don't have a ground wire in the flex. Some appliances such as power tools are not grounded and instead are "doubly insulated". This means that although the external casing of the tool or appliance may be metal, sufficient separation and isolation of the external metal from internal high voltages is effected to prevent electric shock. These devices don't have a ground wire in the cord either. Double insulated appliances can be extremely dangerous if they get wet. This is because the casing is not grounded and can become live if water breaches the separation between live parts and casing. Also the MCB is unlikely to trip and the GFI may not operate either.

Petersen Coils - Principle and Application

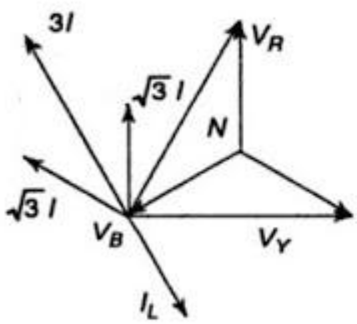
Application:

When a phase to earth fault occurs in ungrounded 3 phase systems, the phase voltage of the faulty phase is reduced to the ground potential. This causes the phase voltage in the other two phases to rise by √3 times. This increase in voltage causes a charging current, Ic between the phase-to-earth capacitances. The current Ic,



which increases to three times the normal capacitive charging current, needs to complete its circuit. This causes a series of restrikes at the fault locations known as arcing grounds. This can also lead to overvoltages in the system.

A Petersen coil consists of an iron-cored reactor connected at the star point of a three phase system. In the event of a fault, the capacitive charging current is neutralized by the current across the reactor which is equal in magnitude but 180 degrees out of phase. This compensates for the leading current drawn by the line capacitances.



The power factor of the fault moves closer to unity. This facilitates the easy extinguishing of the arc as both the voltage and current have a similar zero-crossing