Fundamental of protection in power system

The purpose of an Electric Power System is to generate and supply electrical energy to consumers. The power system should be designed and managed to deliver this energy to the utilization points with both reliability and economically .The capital investment involved in power system for the generation, transmission and distribution is so great that the proper precautions must be taken to ensure that the equipment not only operates as nearly as possible to peak efficiency, but also must be protected from accidents .The normal path of the electric current is from the power source through copper (or aluminum) conductors in generators, transformers and transmission lines to the load and it is confined to this path by insulation. The insulation, however, may break down, either by the effect of temperature and age or by a physical accident, so that the current then follows an abnormal path generally known as Short Circuit or Fault. Any abnormal operating state of a power system is known as FAULT. Faults in general consist of short circuits as well as open circuits. Open circuit faults are less frequent than short circuit faults, and often they are transformed in to short circuits by subsequent event

Basic idea of relay protection

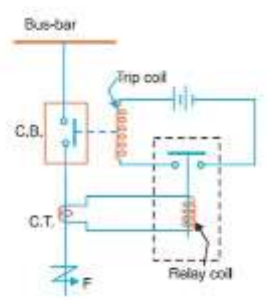
A good electric power system should ensure the availability of electrical power without any interruption to every load connected to it. Generally power is transmitted through high voltage transmission line and lines are exposed, there may be chances of their breakdown due to storms, falling of external objects, and damage to the insulators etc. These can result not only mechanical damage but also in an electrical fault. Protective relays and relaying systems detect abnormal conditions like faults in electrical circuits and automatically operate the switchgear to isolate faulty equipment from the system as quick as possible. This limits the damage at the fault location and prevents the effects of the fault spreading into the system. The switch gear must be capable of interrupting both normal currents as well as fault current. The protective relay on the other hand must be able to recognize an abnormal condition in the power system and take suitable steps so that there will be least possible disturbance to normal operation. Relay does not prevent the appearance of faults. It can take action only after the fault has occurred. However, there are some devices which can anticipate and prevent major faults. For example, Buchholz relay is capable of detecting the gas accumulation produced by an incipient fault in a transformer.

Needs of protection

The objective of power system protection is to isolate a faulty section of electrical power system from rest of the live system so that the rest portion can function satisfactorily without any severe damage due to fault current.

Circuit breaker isolates the faulty system from rest of the healthy system and these circuit breakers automatically open during fault condition due to its trip signal which comes from protection relay. The main philosophy about protection is that no protection of power system can prevent the flow of fault current through the system, it only can prevent the continuation of flowing of fault current by quickly disconnect the short circuit path from the system

Basic protection circuit:



In the picture the basic connection of protection relay has been shown. It is quite simple. The secondary of current transformer is connected to the current coil of relay and secondary of voltage transformer is connected to the voltage coil of the relay. Whenever any fault occurs in the feeder circuit, proportionate secondary current of the CT will flow through the current coil of the relay due to which mmf of that coil is increased. This increased mmf is sufficient to mechanically close the normally open contact of the relay. This relay contact actually closes and completes the DC trip coil circuit and hence the trip coil is energized. The mmf of the trip coil initiates the mechanical movement of the tripping mechanism of the circuit breaker and ultimately the circuit breaker is tripped to isolate the fault.

Nature and causes of faults

The nature of a fault simply implies any abnormal condition which causes a reduction in the basic insulation strength between phase conductors, or between phase conductors and earth, or any earthed screens surrounding the conductors. Actually the reduction of the insulation is not considered as a fault until it produces some effect on the system that is until it results either in an excess current or in the reduction of the impedance between conductors or between conductors and earth to a value below that of the lowest load impedance normal to the circuit.

Cause of fault

There is a number of causes for the occurrence of a fault in the power system. Some of the possible causes of faults are,

- Overvoltage due to switching surges
- Severe lightning strokes
- Aging of conductor
- Heavy wind, rains, and snowfall
- Falling trees on the transmission line
- Excessive internal and external stresses on the conductors
- High changes in atmospheric temperatures

- ➢ Accident of vehicle with towers or poles of transmission line
- ➢ Perching of birds on the lines
- ➢ Accidental short circuit due to string, snakes
- ➢ Chemical

Effects

- ➢ **A great reduction of the line voltage over a major part of the power this will lead to the breakdown of the electrical supply to the consumer and may produce wastage in production.**
- ➢ **Damage caused to the elements of the system by the electrical arc which almost always accompanies a short circuit.**
- ➢ **Damage to other apparatus in the system due to overheating and due to abnormal mechanical forces setup.**
- ➢ **Disturbances to the stability of the electrical system and this may even lead to a complete shutdown of the power system.**
- ➢ **A marked reduction in the voltage which may sometimes be so great that Protection Relay having pressure coils tend to fail.**
- ➢ **Considerable reduction in the voltage on healthy feeders connected to the system having fault. This may cause either an abnormally high current being drawn by the motors or the operation of no-voltage coils of the motors. In the latter case considerable loss of industrial production may result as the motors will have to be restarted.**

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<u>Classification of fault</u>

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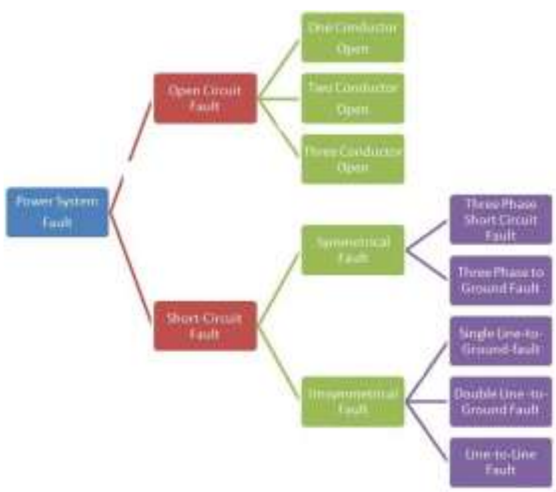


Open Circuit Fault

The open circuit fault mainly occurs because of the failure of one or two conductors. The open circuit fault takes place in series with the line, and because of this, it is also called the series fault. Such types of faults affect the reliability of the system. The open circuit fault is categorised as

- ➢ Open Conductor Fault
- ➢ Two conductors Open Fault
- ➢ Three conductors Open Fault.

Short-Circuit Fault

In this type of fault, the conductors of the different phases come into contact with each other with a power line, power transformer or any other circuit element due to which the large current flow in one or two phases of the system. The short-circuit fault is divided into the symmetrical and unsymmetrical fault.

Symmetrical Fault

The faults which involve all the three phases is known as the symmetrical fault. Such types of fault remain balanced even after the fault. The symmetrical faults mainly occur at the terminal of the generators. The fault on the system may arise on account of the resistance of the arc between the conductors or due to the lower footing resistance. The symmetrical fault is sub-categorized into line-to-line-to-line fault and three-phase line-to-ground-fault

Unsymmetrical Fault

The fault gives rise to unsymmetrical current, i.e., current differing in magnitude and phases in the three phases of the power system are known as the unsymmetrical fault. It is also defined as the fault which involves the one or two phases such as L- G, L – L, L – L – G fault. The unsymmetrical makes the system unbalanced. It is mainly classified into three types. They are

- ➢ Single Line-to-ground (L – G) Fault
- ➢ Line-to-Line Fault (L – L)
- ➢ Double Line-to-ground (L – L – G) Fault

Single Phase to Ground Fault – It is also called a line-to-ground fault. It mainly occurs due to insulation breakdown between one of the phase and earth. Single-line-to-fault is most frequently occurs in the power system. Their chances of appearance in the power system are 70%.**Line-to-line Fault –** Such type of fault rarely occurred on the power system. It is also called Line-to-line fault. It occurs when two conductors are short circuited. Their chance of appearance is hardly 15 % in the power system.

Double line to Ground Fault – In this type of fault breakdowns of insulation between two phases and earth occur. It is the most severe type of fault but rarely occurs in the power system. It is also called Line-to-line-to-ground fault (L-L-G). Their chance of occurrence is hardly 10 %.
Phase to phase and Third Phase to Ground Fault – It is the combination of phase to phase and phase to phase to ground fault. Such types of fault occur due to the breakdown of insulation between two phases and simultaneous breakdown of insulation between the third phase and earth. The chance of such type of fault is hardly 2 % to 3 %.

The below table shows the percentage occurrence of different types of faults.

Sr. No.	Type of Fault	% occurrence
1	Line to Ground (L-G)	85
2	Double Line to Ground (L-L-G)	5
3	Line to Line (L-L)	8
4	L-L-L or L-L-L-G	>2

According to nature, the faults are classified as,

- Transient Fault
- Permanent Fault.

Transient Fault

Most of the faults are transient in nature. These faults remain for a short duration of time.
For example, if a twig falls across a line and across the arm and burns itself or falls down, then the fault is transient. It will vanish after a few cycles.

After the transient state is over, a steady-state is reached. The RMS value of short-circuit current remains constant during the steady-state. The circuit breaker operates during a transient state.

Permanent Fault

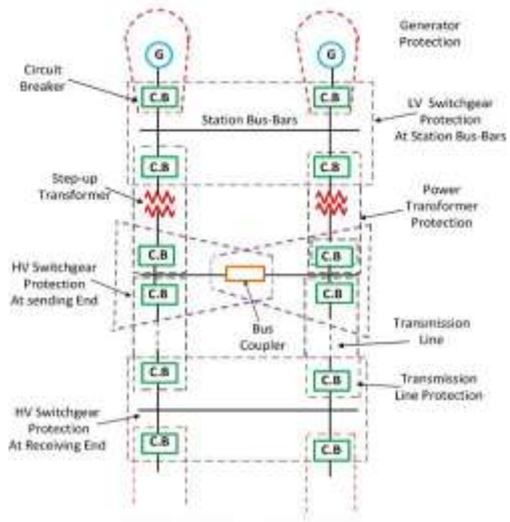
In this type of fault, the fault is permanent. For example, the insulation of two conductors are failed and due to this short-circuit occurs in the system.
These faults will not vanish itself. This fault needs to do some maintenance and required more time to solve the fault. This type of fault occurs rarely.

Zones of protection

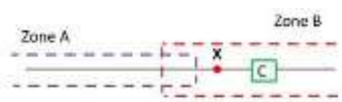
Protection zone is defined as the part of the power system which is protected by a certain protective scheme. It is established around each power system equipment. When the fault occurs on any of the protection zones then only the circuit breakers within that zone will be opened. Thus, only the faulty element will be isolated without disturbing the rest of the system.
The protection zone covers the entire power system, and no part of the equipment is left unprotected. It usually consists one or more element of the power system. The protection zone of the power system mainly depends upon the rating of the machine, its location, the probability of faults and abnormal condition of the equipment.

Overlapping Zone of Power System

If there were no overlapping in the protective zone, then the failure occurs in the equipment will not lie in any one of the zones and hence no circuit breaker would be tripped. The fault occurs in the unprotective system will damage the equipment and hence disturb the continuity of the supply.
The probability of failure in the overlap region is very small. But the overlap region will cause the tripping of the more circuit breaker than the minimum necessary for the disconnection of the faults region. Because when the fault occurs in any one of the two overlapping regions than the breaker of both the region will be opened, and the systems are isolated.



Consider the two protective zone A and B which will overlap each other. The X is the fault occurs in the zone B, and due to this fault, the circuit breakers of zone B tripped along with the C (circuit breaker). The relay of the zone B will also trip the circuit breaker of zone A for other faults in the zone B which occurs to the right of the C (circuit breaker). Hence the unnecessary tripping of the breaker can be tolerated only in the particular region.



Primary and Backup protection in a Power System

There is always some possibility of a circuit breaker failure. For this reason, it is usual to supplement primary protection with other systems to 'back-up' the operation of the main system and ensure that nothing can prevent the clearance of a fault from the system.
The protection provided by the protective relaying equipment can be categorized into two types as :
1. Primary protection
2. Backup protection.

Primary protection

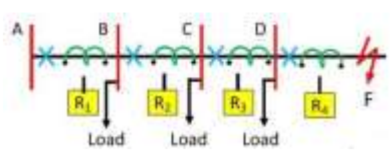
The main protection or primary protection is the first line protection which provides quick-acting and selective clearing of a fault within the boundary of the circuit section or element it protects. The primary protection is the first line of defense and is responsible to protect all the power system elements from all the types of faults. The backup protection comes into play only when the primary protection fails.
The backup protection is provided as the main protection can fail due to many reasons like,

- Failure in circuit breaker
- Failure of CTs or PTs operation
- Failure in protective relay
- Failure in tripping circuit
- Failure of DC supply to the tripping Circuit
- Loss of voltage or current supply to the relay

Backup protection

The backup protection provides the back up to the main protection whenever it fails in operation or its cut out for repairs. The backup protection is essential for the proper working of the electrical system. The backup protection is the second line of defence which isolates the faulty section of the system in case the main protection fail to function properly
The backup protection may be provided either on the same circuit breaker which would be normally opened by the main protection or in the different circuit breaker. The backup protection is mainly used where the main protection of the adjacent circuit is unable to backup the main protection of the given circuit. Sometimes for simplification, the backup protection has a low sensitivity and operated over a limited backup zone.

Example: Consider the remote backup protection is provided by a small time graded relay, as shown in the figure below. Let F be the fault occur on relay R_4. The relay R_4 operates the circuit breaker at D and isolate the faulty section. Now if the circuit breaker D fails to operate, the faulty section would be isolated by the operation of the relay R_3 at C.



Components of Protection System:

Some of the more commonly used Components of Protection System are

1. Relays
2. Circuit Breakers
3. Tripping and Other Auxiliary Supplies
4. Current Transformer (CT)
5. Voltage Transformers (VT)

Relays:

The main function of a protective relay is to isolate a faulty section with the least interruption to service by controlling the circuit breaker, when abnormal conditions develop. Thus the relays may be designed to detect and to measure abnormal conditions and close the contacts in the tripping circuit.

The following two categories of relays are most commonly used in protective relaying:

- **Secondary indirect-acting relays:** a group including practically all kinds of relays, e.g. current, voltage, power, impedance, reactance and frequency, whether minimum or maximum.
- **Secondary direct-acting relays:** a group of over current and under-voltage relays designed to operate instantaneously or with time lag. These are primarily relays of the electromagnetic type which are built into circuit breaker operating mechanisms.

Circuit Breakers:

Circuit breakers may be operated either manually or automatically. Circuit breakers of various types are installed in all power circuits to Open and close them under normal load conditions. The time of operation of circuit breaker actually depends on its design and usually lies between 0.05 and 0.25s. This must be accounted for while calculating final fault clearance time.

Tripping and Other Auxiliary Supplies

Protective relay and automatic control schemes, in power system practice use two kinds of auxiliary supply: d.c. or a.c. D.C. auxiliary power supply is provided from storage batteries maintained continuously charged by some type of supply set or a charger. The advantages of storage batteries are their high reliability and independence of a.c. power circuit conditions and of the existence of faults. Usually the voltage of the auxiliary supply is maintained at 110 V

A.C. auxiliary supply for the protective relay scheme is mainly derived from the CTs. Under fault conditions, the current passing through the secondary of properly selected CTs, will always be sufficient to reliably trip the associated circuit breaker.

Current Transformer (CT):

The primary circuit currents which are of high-magnitudes are to be reduced to values suitable for relay operation with the help of current transformers (CTs). Thus the CTs essentially insulate the secondary (relay) circuits from the primary (power) circuits and, provide currents in the secondary which are proportional to those in the primary. The primary winding of the CT is connected in series with the load and carries the actual power system currents (normal or fault). The secondary is connected to the measuring circuit or the relay,

It is common practice to use IA secondary rating CTs. There is a practical limit to the number of turns which can be wound on the bar primary CT which is usually about 1500 secondary turns. When rated primary currents much in excess of 1500 A are encountered then the main bar primary CT with rated secondary current of 5A or 10A along with auxiliary CTs of 5/1 or 10/1 A respectively, are used.

Voltage Transformers (VT):

It is not possible to connect the voltage coils of the protective devices directly to the system in case of high voltage systems. It is therefore necessary to step down the voltage and also to insulate the protective equipment from the primary (power) circuit. This is achieved by using a voltage transformer (VT) also known as a potential transformer (PT) which is similar to a power transformer. The voltage transformer is rated in terms of the maximum burden (VA output) it delivers without exceeding specified limits of error, whereas the power transformer is rated by the secondary output it delivers without exceeding a specified temperature rise. The output of VTs is usually limited to a few hundred volt amperes and the secondary voltage is usually 110 V between phases.

Functional Requirements of Protection Relay

Reliability

The most important requisite of protective relay is reliability. They remain inoperative for a long time before a fault occurs; but if a fault occurs, the relays must respond instantly and correctly.

Selectivity

There may be some typical condition during fault for which some relays should not be operated or operated after some definite time delay hence protection relay must be sufficiently capable to select appropriate condition for which it would be operated.

Sensitivity

The relaying equipment must be sufficiently sensitive so that it can be operated reliably when level of fault condition just crosses the predefined limit

Speed

The protective relays must operate at the required speed. There must be a correct coordination provided in various power system protection relays in such a way that for fault at one portion of the system should not disturb other healthy portion. Fault current may flow through a part of healthy portion since they are electrically connected but relays associated with that healthy portion should not be operated faster than the relays of faulty portion otherwise undesired interruption of healthy system may occur.