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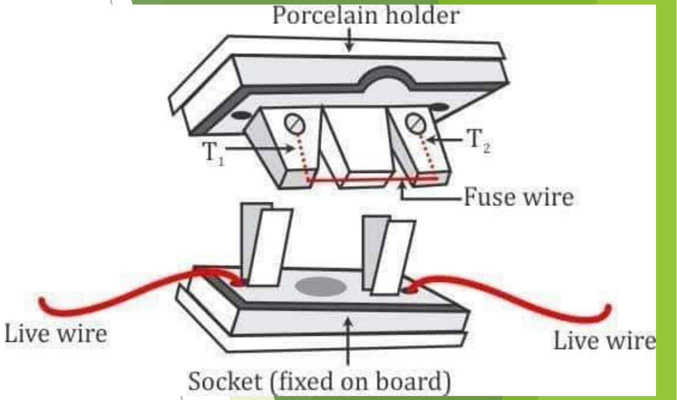
Electrical Protection and Control

All electrical circuits and equipment need to be protected from damages due to abnormal currents and voltage fluctuations. Protection devices ensure that the current does not exceed the withstanding current limit of your equipment

The electrical power system is one of the most crucial systems running across the globe. Every country has its own power manufacturing unit, which then distributes power across the country through various power lines. With such heavy power running through these lines, it is important that the entire system is kept safe, protected, and under control. This is why there is a power protection system that deals with protecting the electrical system that is done through the isolation of faulted parts in the electrical network.

Fuse



Fuse interrupts the circuit automatically on the occurrence of a short-circuit fault.

- It has lesser reliability and efficiency.
- Invented in 1890 by Edison.
- Cheapest form of protection against excessive currents.

A **fuse** is a short piece of metal, inserted in the circuit, which melts when excessive current flows through it and thus breaks the circuit.

The fuse element is generally made of materials having low melting point, high conductivity and least deterioration due to oxidation *e.g.*, silver, copper etc. It is inserted in series with the circuit to be protected. Under normal operating conditions, the fuse element is at a temperature below its melting point. Therefore, it carries the normal current without overheating. However, when a short-circuit or overload occurs, the current through the fuse increases beyond its rated value. This raises the temperature and fuse element melts (or blows out), disconnecting the circuit protected by it. In this way, a fuse protects the machines and equipment from damage due to excessive currents.

Fuse

The time required to blow out the fuse depends upon the magnitude of excessive current. The greater the current, the smaller is the time taken by the fuse to blow out.

Advantages

(*i*) It is the cheapest form of protection available.
(*ii*) It requires no maintenance.
(*iii*) Its operation is inherently completely automatic unlike a circuit breaker which requires an elaborate equipment for automatic action.
(*iv*) It can break heavy short-circuit currents without noise or smoke.
(*v*) The smaller sizes of fuse element impose a current limiting effect under short-circuit conditions.
(*vi*) The inverse time-current characteristic of a fuse makes it suitable for overcurrent protection.
(*vii*) The minimum time of operation can be made much shorter than with the circuit breakers.

Disadvantages

(*i*) Considerable time is lost in rewiring or replacing a fuse after operation.
(*ii*) On heavy short-circuits, *discrimination between fuses in series cannot be obtained unless there is sufficient difference in the sizes of the fuses concerned.
(*iii*) The current-time characteristic of a fuse cannot always be co-related with that of the protected apparatus.

Fuse

Desirable Characteristics of Fuse Element

The function of a fuse is to carry the normal current without overheating but when the current exceeds its normal value, it rapidly heats up to melting point and disconnects the circuit protected by it. In order that it may perform this function satisfactorily, the fuse element should have the following desirable characteristics :

(*i*) low melting point *e.g.*, tin, lead.

(*ii*) high conductivity *e.g.*, silver, copper.

(*iii*) free from deterioration due to oxidation *e.g.*, silver.

(*iv*) low cost *e.g.*, lead, tin, copper.

The above discussion reveals that no material possesses all the characteristics. For instance, lead has low melting point but it has high specific resistance and is liable to oxidation. Similarly, copper has high conductivity and low cost but oxidises rapidly. Therefore, a compromise is made in the selection of material for a fuse.

Fuse

The most commonly used materials for fuse element are lead, tin, copper, zinc and silver. **For small currents upto 10 A**, **tin** or an **alloy of lead and tin (lead 37%, tin 63%)** is used for making the fuse element. For **larger currents**, **copper** or **silver** is employed. It is a usual practice to tin the copper to protect it from oxidation. Zinc (in strip form only) is good if a fuse with considerable time-lag is required *i.e.*, one which does not melt very quickly with a small overload.

The present trend is to use silver despite its high cost due to the following reasons :

(i) It is comparatively free from oxidation.

(ii) It does not deteriorate when used in dry air.

(iii) The coefficient of expansion of silver is so small that no critical fatigue occurs. Therefore, the fuse element can carry the rated current continuously for a long time.

(iv) The conductivity of silver is very high. Therefore, for a given rating of fuse element, the mass of silver metal required is smaller than that of other materials. This minimises the problem of clearing the mass of vapourised material set free on fusion and thus permits fast operating speed.

(v) Due to comparatively low specific heat, silver fusible elements can be raised from normal temperature to vapourisation quicker than other fusible elements. Moreover, the resistance of silver increases abruptly as the melting temperature is reached, thus making the transition from melting to vapourisation almost instantaneous. Consequently, operation becomes very much faster at higher currents.

(vi) Silver vapourises at a temperature much lower than the one at which its vapour will readily ionise. Therefore, when an arc is formed through the vapourised portion of the element, the arc path has high resistance. As a result, short-circuit current is quickly interrupted.

Circuit Breaker

During the operation of power system, it is often desirable and necessary to switch on or off the various circuits (*e.g.*, transmission lines, distributors, generating plants etc.) under both normal and abnormal conditions. In earlier days, this function used to be performed by a switch and a fuse placed in series with the circuit.

However, such a means of control presents two disadvantages.
Firstly, when a fuse blows out, it takes quite sometime to replace it and restore supply to the customers.
Secondly, a fuse cannot successfully interrupt heavy fault currents that result from faults on modern high-voltage and large capacity circuits.

Due to these disadvantages, the use of switches and fuses is limited to low-voltage and small capacity circuits where frequent operations are not expected *e.g.*, for switching and protection of distribution transformers, lighting circuits, branch circuits of distribution lines etc.

Circuit Breaker

With the advancement of power system, the lines and other equipment operate at very high voltages and carry large currents. The arrangement of switches along with fuses cannot serve the desired function of swithgear in such high capacity circuits. This necessitates to employ a more dependable means of control such as is obtained by the use of *circuit breakers.*

A circuit breaker is a piece of equipment which can
(*i*) make or break a circuit either manually or by remote control under normal conditions
(*ii*) break a circuit *automatically* under fault conditions
(*iii*) make a circuit either manually or by remote control under fault conditions
Thus a circuit breaker incorporates manual (or remote control) as well as automatic control for switching functions.

Circuit Breaker

Operating principle. A circuit breaker essentially consists of fixed and moving contacts, called electrodes. Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty. Of course, the contacts can be opened manually or by remote control whenever desired. When a fault occurs on any part of the system, the trip coils of the circuit breaker get energized and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them. The current is thus able to continue until the discharge ceases. The production of arc not only delays the current interruption process but it also generates enormous heat which may cause damage to the system or to the circuit breaker itself. Therefore, the main problem in a circuit breaker is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

Circuit Breaker

Arc Phenomenon

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 :

(i) Degree of ionisation— the arc resistance increases with the decrease in the number of ionized particles between the contacts.

(ii) Length of the arc— the arc resistance increases with the length of the arc *i.e.*, separation of contacts.

(iii) Cross-section of arc— the arc resistance increases with the decrease in area of X-section of the arc.

Circuit Breaker

Principles of Arc Extinction

Before discussing the methods of arc extinction, it is necessary to examine the factors responsible for the maintenance of arc between the contacts. These are :

(i) p.d. between the contacts
(ii) ionised particles between contacts

Taking these in turn,

(i) 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 metres may be required.

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

Circuit Breaker

Classification of Circuit Breakers

There are several ways of classifying the circuit breakers. However, the most general way of classification is on the basis of medium used for arc extinction. The medium used for arc extinction is usually oil, air, sulphur hexafluoride (SF6) or vacuum. Accordingly, circuit breakers may be classified into :

(i) Oil circuit breakers which employ some insulating oil (*e.g.*, transformer oil) for arc extinction.

(ii) Air-blast circuit breakers in which high pressure air-blast is used for extinguishing the arc.

(iii) Sulphur hexafluroide circuit breakers in which sulphur hexafluoride (SF6) gas is used for arc extinction.

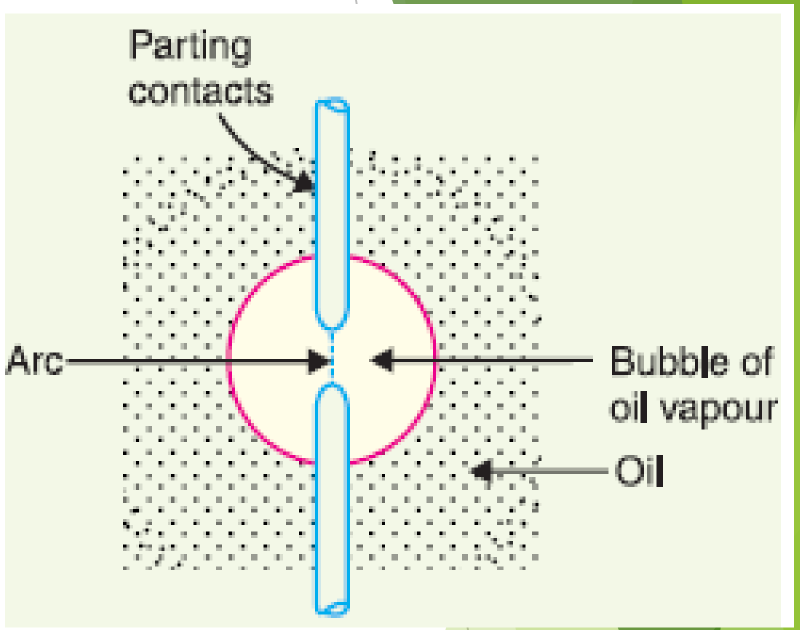
(iv) Vacuum circuit breakers in which vacuum is used for arc extinction.

Each type of circuit breaker has its own advantages and disadvantages.

Circuit Breaker

Oil Circuit Breakers

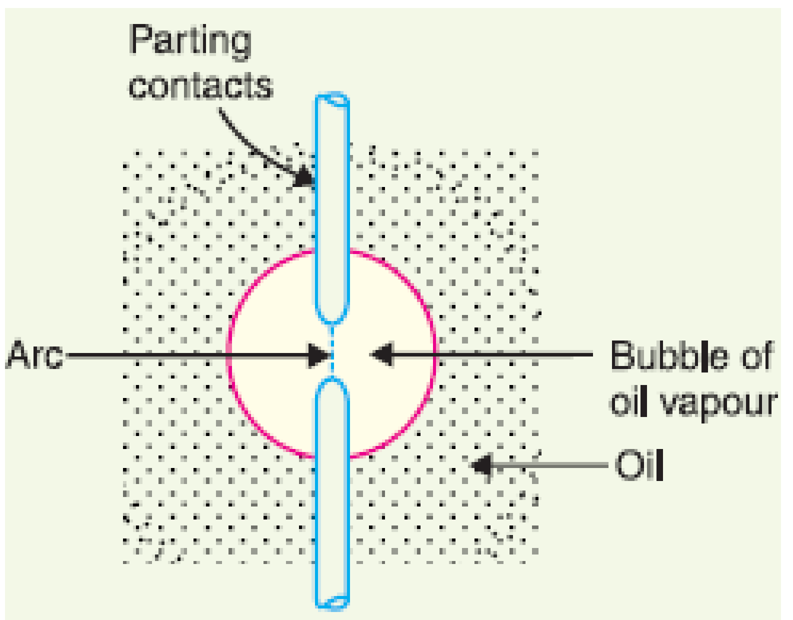
In such circuit breakers, some insulating oil (*e.g.*, transformer oil) is used as an arc quenching medium. The contacts are opened under oil and an arc is struck between them. The heat of the arc evaporates the surrounding oil and dissociates it into a substantial volume of gaseous hydrogen at high pressure. The hydrogen gas occupies a volume about one thousand times that of the oil decomposed. The oil is, therefore, pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region and adjacent portions of the contacts. The arc extinction is facilitated mainly by two processes. Firstly, the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionisation of the medium between the contacts. Secondly, the gas sets up turbulence in the oil and forces it into the space between contacts, thus eliminating the arcing products from the arc path. The result is that arc is extinguished and circuit current interrupted.



Circuit Breaker

Advantages. The advantages of oil as an arc quenching medium are :
(i) It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.
(*ii*) It acts as an insulator and permits smaller clearance between live conductors and earthed components.
(*iii*) The surrounding oil presents cooling surface in close proximity to the arc.

Disadvantages. The disadvantages of oil as an arc quenching medium are :
(*i*) It is inflammable and there is a risk of a fire.
(*ii*) It may form an explosive mixture with air
(*iii*) The arcing products (*e.g.*, carbon) remain in the oil and its quality deteriorates with successive operations. This necessitates periodic checking and replacement of oil.



Difference between Fuse and Circuit breaker

S. No.	Particular	Fuse	Circuit breaker
1.	*Function*	It performs both detection and interruption functions.	It performs interruption function only. The detection of fault is made by relay system.
2.	*Operation*	Inherently completely automatic.	Requires elaborate equipment (*i.e.* relays) for automatic action.
3.	*Breaking capacity*	Small	Very large
4.	*Operating time*	Very small (0·002 sec or so)	Comparatively large (0·1 to 0·2 sec)
5.	*Replacement*	Requires replacement after every operation.	No replacement after operation.

Protective Relay

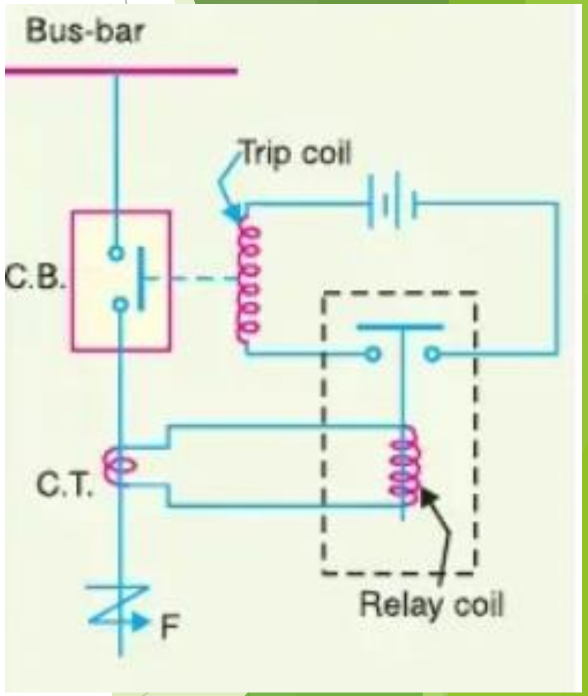
A **Protective relay** is a device that detects the fault and initiates the operation of the circuit breaker to ioslate the defective element from the rest of the system.

The relays detect the abnormal conditions in the electrical circuits by constantly measuring the electrical quantities which are different under normal and fault conditions. The electrical quantities which may change under fault conditions are voltage, current, frequency and phase angle. Through the changes in one or more of these quantities, the faults signal indicates their presence, type and location to the protective relays. Having detected the fault, the relay operates to close the trip circuit of the breaker. This results in the opening of the breaker and disconnection of the faulty circuit.

Protective Relay

The relay circuit connections can be divided into three parts

(i) First part is the primary winding of a current transformer(C.T.) which is connected in series with the line to be protected.
(ii)Second part consists of secondary winding of C.T. and the relay operating coil.
(iii)Third part is the tripping circuit which may be either a.c. or d.c. It consists of a source of supply, the trip coil of the circuit breaker and the relay stationary contacts. When a short circuit occurs at point *F* on the transmission line, the current flowing in the line increases to an enormous value. This results in a heavy current flow through the relay coil, causing the relay to operate by closing its contacts. This in turn closes the trip circuit of the breaker, making the circuit breaker open and isolating the faulty section from the rest of the system. In this way, the relay ensures the safety of the circuit equipment from damage and normal working of the healthy portion of the system



Protective Relay

Fundamental Requirements of Protective Relaying

The principal function of protective relaying is to cause the prompt removal from service of any element of the power system when it starts to operate in an abnormal manner or interfere with the effective operation of the rest of the system. In order that protective relay system may perform this function satisfactorily, it should have the following qualities :

(*i*) Selectivity **(*ii*)** speed **(*iii*)** sensitivity **(*iv*)** reliability **(*v*)** simplicity **(*vi*)** economy

(i) **Selectivity.** *It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system.*

(*ii*) Speed. The relay system should disconnect the faulty section as fast as possible for the following reasons :

(*a*) Electrical apparatus may be damaged if they are made to carry the fault currents for a long time.

(*b*) A failure on the system leads to a great reduction in the system voltage. If the faulty section is not disconnected quickly, then the low voltage created by the fault may shut down consumers' motors and the generators on the system may become unstable.

(*c*) The high speed relay system decreases the possibility of development of one type of fault into the other more severe type.

(*iii*) Sensitivity. *It is the ability of the relay system to operate with low value of actuating quantity.*

Protective Relay

Fundamental Requirements of Protective Relaying (Contd.)

(*iv*) Reliability. It is the ability of the relay system to operate under the pre-determined conditions. Without reliability, the protection would be rendered largely ineffective and could even become a liability.

(*v*) Simplicity. The relaying system should be simple so that it can be easily maintained. Reliability is closely related to simplicity. The simpler the protection scheme, the greater will be its reliability.

(*vi*) Economy. The most important factor in the choice of a particular protection scheme is the economic aspect. Sometimes it is economically unjustified to use an ideal scheme of protection and a compromise method has to be adopted. As a rule, the protective gear should not cost more than 5% of total cost. However, when the apparatus to be protected is of utmost importance (*e.g.* generator, main transmission line etc.), economic considerations are often subordinated to reliability.

Thank You