# HARYANA STATE BOARD OF TECHNICAL EDUCATION

## ELECTRICAL POWER-II

**6th Semester**

**Branch: Electrical Engineering**

## What is relay or protective Relays?

*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.*

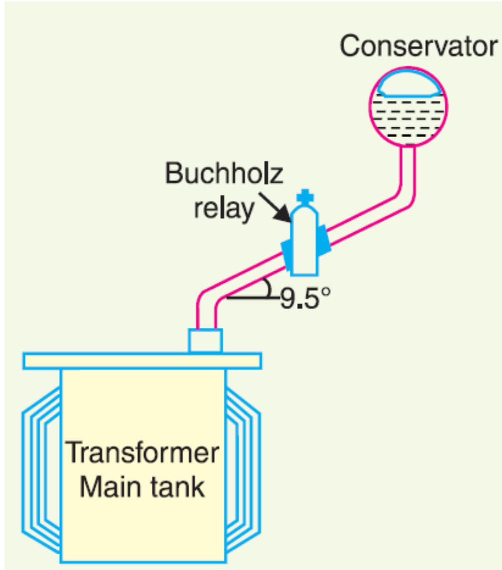
Most of the relays in service on electric power system today are of electro-mechanical type. They work on the following two main operating principles:

**(*i*)** Electromagnetic attraction

**(*ii*)** Electromagnetic induction

## What is Buchholz Relay? Or Explain which relay is used for Transformer Protection?

Buchholz relay is a gas-actuated relay installed in oil immersed transformers for protection against all kinds of faults. Named after its inventor, Buchholz, it is used to give an alarm in case of incipient (*i.e.* slow-developing) faults in the transformer and to disconnect the transformer from the supply in the event of severe internal faults. It is usually installed in the pipe connecting the conservator to the main tank as shown in the figure. It is a universal practice to use Buchholz relays on all such oil immersed transformers having ratings in excess of 750 kVA.




**Construction:** Figure shows the constructional details of a Buchholz relay. It takes the form of a domed vessel placed in the connecting pipe between the main tank and the conservator. The device has two elements. The upper element consists of a mercury type switch attached to a float. The lower element contains a mercury switch mounted on a hinged type flap located in the direct path of the flow of oil from the transformer to the conservator. The upper element closes an alarm circuit during incipient faults whereas the lower element is arranged to trip the circuit breaker in case of severe internal faults.

**Operation.** The operation of Buchholz relay is as follows :

**(*i*)** In case of incipient faults within the transformer, the heat due to fault causes the decomposition of some transformer oil in the main tank. The products of decomposition contain more than 70% of hydrogen gas. The hydrogen gas being light tries to go into the conservator and in the process gets entrapped in the upper part of relay chamber. When a predetermined amount of gas gets accumulated, it exerts sufficient pressure on the float to cause it to tilt and close the contacts of mercury switch attached to it. This completes the alarm circuit to sound an alarm.

**(*ii*)** If a serious fault occurs in the transformer, an enormous amount of gas is generated in the main tank. The oil in the main tank rushes towards the conservator *via* the Buchholz relay and in doing so tilts the flap to close the contacts of mercury switch. This completes the trip circuit to open the circuit breaker controlling the transformer.

***Advantages***

**(*i*)** It is the simplest form of transformer protection.

**(*ii*)** It detects the incipient faults at a stage much earlier than is possible with other forms of protection.

***Disadvantages***

**(*i*)** It can only be used with oil immersed transformers equipped with conservator tanks.

**(*ii*)** The device can detect only faults below oil level in the transformer. Therefore, separate protection is needed for connecting cables.

## What is Circuit Breakers and its operating principle?

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

**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 energised 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.

## Write down about the Arc Phenomenon inn Circuit breaker?

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 potential difference 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.

## What is the 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.

## Explain the methods of Arc Extinction?

There are two methods of extinguishing the arc in circuit breakers *viz.*

**1.** High resistance method.

**2.** Low resistance or current zero method

**1. 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. The principal disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in d.c. circuit breakers and low-capacity a.c. circuit breakers.

The resistance of the arc may be increased by:

**(*i*)** ***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.

**(*ii*)** ***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.

**(*iii*)** ***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 contacts.

**(*iv*)** ***Splitting the arc:*** The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthening and cooling. The arc may be split by introducing some conducting plates between the contacts.

**2. Low resistance or Current zero method:** This method is employed for arc extinction in a.c. circuits only. In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally and is prevented from restriking inspite of the rising voltage across the contacts. All modern high power a.c. circuit breakers employ this method for arc extinction.

In an a.c. system, current drops to zero after every half-cycle. At every current zero, the arc extinguishes for a brief moment. Now the medium between the contacts contains ions and electrons so that it has small dielectric strength and can be easily broken down by the rising contact voltage known as *restriking voltage.* If such a breakdown does occur, the arc will persist for another half-cycle. If immediately after current zero, the dielectric strength of the medium between contacts is built up more rapidly than the voltage across the contacts, the arc fails to restrike and the current will be interrupted. The rapid increase of dielectric strength of the medium near current zero can be achieved by :

**(*a*)** causing the ionised particles in the space between contacts to recombine into neutral molecules.

**(*b*)** sweeping the ionised particles away and replacing them by un-ionised particles

Therefore, the real problem in a.c. arc interruption is to rapidly deionise the medium between contacts as soon as the current becomes zero so that the rising contact voltage or restriking voltage cannot breakdown the space between contacts. The de-ionisation of the medium can be achieved by:

**(*i*)** ***lengthening of the gap:*** The dielectric strength of the medium is proportional to the length of the gap between contacts. Therefore, by opening the contacts rapidly, higher dielectric strength of the medium can be achieved.

**(*ii*)** ***high pressure:*** If the pressure in the vicinity of the arc is increased, the density of the particles constituting the discharge also increases. The increased density of particles causes higher rate of de-ionisation and consequently the dielectric strength of the medium between contacts is increased.

**(*iii*)** ***cooling:*** Natural combination of ionised particles takes place more rapidly if they are allowed to cool. Therefore, dielectric strength of the medium between the contacts can be increased by cooling the arc.

(*iv*) ***blast effect:*** If the ionised particles between the contacts are swept away and replaced by un-ionised particles, the dielectric strength of the medium can be increased considerably. This may be achieved by a gas blast directed along the discharge or by forcing oil into the contact space.

## Classify circuit breakers?

**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 ($SF_6$) 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.

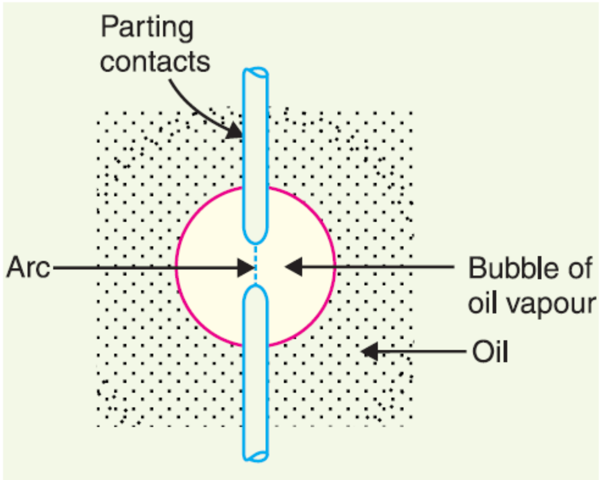
(*iii*) ***Sulphur hexafluroide circuit breakers*** in which sulphur hexafluoride ($SF_6$) gas is used for arc extinction.

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

Each type of circuit breaker has its own advantages and disadvantages. In the following sections, we shall discuss the construction and working of these circuit breakers with special emphasis on the way the arc extinction is facilitated.

## Explain Oil Circuit Breakers, its advantages, disadvantages, types and arc control?

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 (See Figure). 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.




**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.

**Types of Oil Circuit Breakers**

The oil circuit breakers find extensive use in the power system. These can be classified into the following types:

**(*i*)** ***Bulk oil circuit breakers*** which use a large quantity of oil. The oil has to serve two purposes. Firstly, it extinguishes the arc during opening of contacts and secondly, it insulates the current

conducting parts from one another and from the earthed tank. Such circuit breakers may be classified into :
**(*a*)** Plain break oil circuit breakers **(*b*)** Arc control oil circuit breakers.

In the former type, no special means is available for controlling the arc and the contacts are directly exposed to the whole of the oil in the tank. However, in the latter type, special arc control devices are employed to get the beneficial action of the arc as efficiently as possible.

**(*ii*)** ***Low oil circuit breakers*** which use minimum amount of oil. In such circuit breakers, oil is used *only* for arc extinction; the current conducting parts are insulated by air or porcelain or organic insulating material.

**Arc Control Oil Circuit Breakers**
It is necessary and desirable that final arc extinction should occur while the contact gap is still short. For this purpose, some arc control is incorporated and the breakers are then called arc control circuit breakers. There are two types of such breakers, namely :
**(*i*)** *Self-blast oil circuit breakers*— in which arc control is provided by internal means *i.e.* the arc itself is employed for its own extinction efficiently.
**(*ii*)** *Forced-blast oil circuit breakers*— in which arc control is provided by mechanical means external to the circuit breaker.

**(*i*) Self-blast oil circuit breakers.** In this type of circuit breaker, the gases produced during arcing are confined to a small volume by the use of an insulating rigid pressure chamber or pot surrounding the contacts. Since the space available for the arc gases is restricted by the chamber, a very high pressure is developed to force the oil and gas through or around the arc to extinguish it. The magnitude of pressure developed depends upon the value of fault current to be interrupted. As the pressure is generated by the arc itself, therefore, such breakers are sometimes called self-generated pressure oil circuit breakers.

The pressure chamber is relatively cheap to make and gives reduced final arc extinction gap length and arcing time as against the plain-break oil circuit breaker.

## Expain Air-Blast Circuit Breakers, its advantages, disadvantages & types?

These breakers employ a high pressure air-blast as an arc quenching medium. The contacts are opened in a flow of air-blast established by the opening of blast valve. The air-blast cools the arc and sweeps away the arcing products to the atmosphere. This rapidly increases the dielectric strength of the medium between contacts and prevents from re-establishing the arc. Consequently, the arc is extinguished and flow of current is interrupted.

**Advantages:**

An air-blast circuit breaker has the following advantages over an oil circuit breaker:

**(*i*)** The risk of fire is eliminated.

**(*ii*)** The arcing products are completely removed by the blast whereas the oil deteriorates with successive operations; the expense of regular oil replacement is avoided.

**(*iii*)** The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small. This reduces the size of the device.

**(*iv*)** The arcing time is very small due to the rapid build up of dielectric strength between contacts. Therefore, the arc energy is only a fraction of that in oil circuit breakers, thus resulting in less burning of contacts.

**(*v*)** Due to lesser arc energy, air-blast circuit breakers are very suitable for conditions where frequent operation is required.

**(*vi*)** The energy supplied for arc extinction is obtained from high pressure air and is independent of the current to be interrupted.

**Disadvantages:**

The use of air as the arc quenching medium offers the following disadvantages :

**(*i*)** The air has relatively inferior arc extinguishing properties.

**(*ii*)** The air-blast circuit breakers are very sensitive to the variations in the rate of rise of restriking voltage.

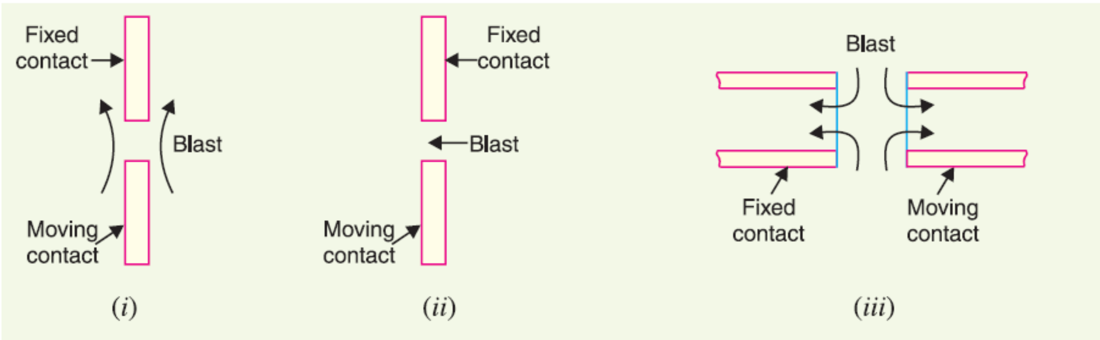
**(*iii*)** Considerable maintenance is required for the compressor plant which supplies the air-blast.

The air blast circuit breakers are finding wide applications in high voltage installations. Majority of the circuit breakers for voltages beyond 110 kV are of this type.

**Types of Air-Blast Circuit Breakers**

Depending upon the direction of air-blast in relation to the arc, air-blast circuit breakers are classified into:

**(*i*)** *Axial-blast type* in which the air-blast is directed along the arc path as shown in Figure (*i*).




**(*ii*)** *Cross-blast type* in which the air-blast is directed at right angles to the arc path as shown in Fig (*ii*).

**(*iii*)** *Radial-blast type* in which the air-blast is directed radially as shown in Figure (*iii*).

**Explain Sulphur Hexaflouride ($SF_6$) Circuit Breakers, its construction, working and advantages?**

In such circuit breakers, sulphur hexaflouride ($SF_6$) gas is used as the arc quenching medium. The $SF_6$ is an electro-negative gas and has a strong tendency to absorb free electrons. The contacts of the breaker are opened in a high pressure flow of $SF_6$ gas and an arc is struck between them. The conducting free electrons in the arc are rapidly captured by the gas to form relatively immobile negative ions. This loss of conducting electrons in the arc quickly builds up enough insulation strength to extinguish the arc. The $SF_6$ circuit breakers have been found to be very effective for high power and high voltage service.

**Construction:**

It consists of fixed and moving contacts enclosed in a chamber (called arc interruption chamber) containing $SF_6$ gas. This chamber is connected to $SF_6$ gas reservior. When the contacts of breaker are opened, the valve mechanism permits a high pressure $SF_6$ gas from the reservoir to flow towards the arc interruption chamber. The fixed contact is a hollow cylindrical current carrying contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides to permit the $SF_6$ gas to let out through these holes after flowing along and across the arc. The tips of fixed contact, moving contact and arcing horn are coated with copper-tungsten arc resistant material. Since $SF_6$ gas is costly, it is reconditioned and reclaimed by suitable auxiliary system after each operation of the breaker.

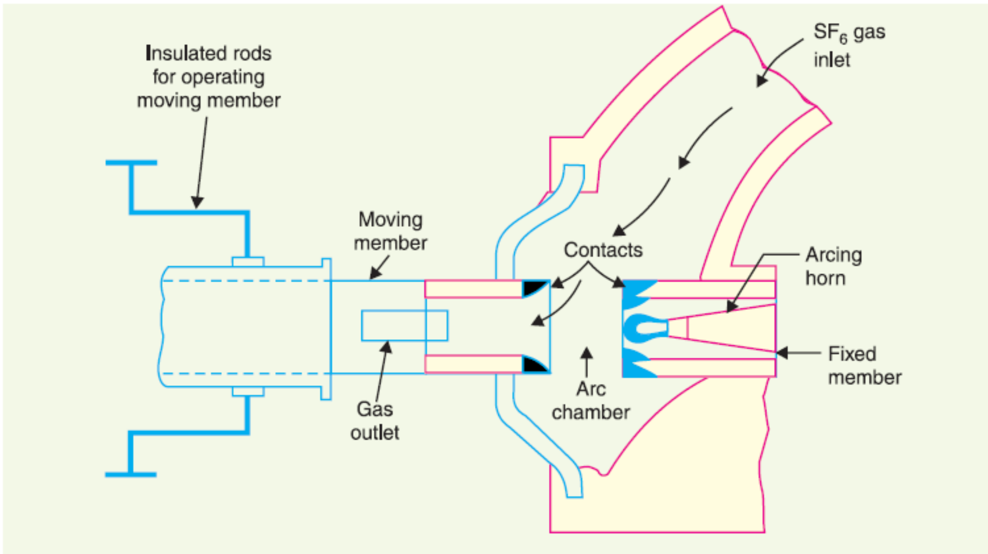



Figure: Shows the parts of a typical $SF_6$ circuit breaker

**Working:** In the closed position of the breaker, the contacts remain surrounded by $SF_6$ gas at a pressure of about 2·8 kg/cm$^2$. When the breaker operates, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronised with the opening of a valve which permits $SF_6$ gas at 14 kg/cm$^2$ pressure from the reservoir to the arc interruption chamber. The high pressure flow of $SF_6$ rapidly absorbs the free electrons in the arc path to form immobile negative ions which are ineffective as charge carriers. The result is that the medium between the contacts quickly builds up high dielectric strength and causes the extinction of the arc. After the breaker operation (*i.e.*, after arc extinction), the valve is closed by the action of a set of springs.

**Advantages:**

Due to the superior arc quenching properties of $SF_6$ gas, the $SF_6$ circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below :

***(i)*** Due to the superior arc quenching property of $SF_6$, such circuit breakers have very short arcing time.

***(ii)*** Since the dielectric strength of $SF_6$ gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.

***(iii)*** The $SF_6$ circuit breaker gives noiselss operation due to its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker.

***(iv)*** The closed gas enclosure keeps the interior dry so that there is no moisture problem.

***(v)*** There is no risk of fire in such breakers because $SF_6$ gas is non-inflammable.

***(vi)*** There are no carbon deposits so that tracking and insulation problems are eliminated.

***(vii)*** The $SF_6$ breakers have low maintenance cost, light foundation requirements and minimum auxiliary equipment.

***(viii)*** Since $SF_6$ breakers are totally enclosed and sealed from atmosphere, they are particularly suitable where explosion hazard exists *e.g.,* coal mines.

**Disadvantages**

***(i)*** $SF_6$ breakers are costly due to the high cost of $SF_6$.

***(ii)*** Since $SF_6$ gas has to be reconditioned after every operation of the breaker, additional equipment is requried for this purpose.

**Applications:**

A typical $SF_6$ circuit breaker consists of interrupter units each capable of dealing with currents upto 60 kA and voltages in the range of 50—80 kV. A number of units are connected in series according to the system voltage. SF6 circuit breakers have been developed for voltages 115 kV to 230 kV, power ratings 10 MVA to 20 MVA and interrupting time less than 3 cycles.

**Explain Vacuum Circuit Breakers (VCB), its construction, working and also write its advantages?**

In such breakers, vacuum is used as the arc quenching medium. Since vacuum offers the highest insulating strength, it has far superior arc quenching properties than any other medium. For example, when contacts of a breaker are opened in vacuum, the interruption occurs at first current zero with dielectric strength between the contacts building up at a rate thousands of times higher than that obtained with other circuit breakers.

**Principle:** The production of arc in a vacuum circuit breaker and its extinction can be explained as follows : When the contacts of the breaker are opened in vacuum, an arc is produced between the contacts by the ionisation of metal vapours of contacts. However, the arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc rapidly condense on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength. The reader may note the salient feature of vacuum as an arc quenching medium. As soon as the arc is produced in vacuum, it is quickly extinguished due to the fast rate of recovery of dielectric strength in vacuum.

**Construction:** It consists of fixed contact, moving contact and arc shield mounted inside a vacuum chamber. The movable member is connected to the control mechanism by stainless steel bellows. This enables the permanent sealing of the vacuum chamber so as to eliminate the possibility of leak. A glass vessel or ceramic vessel is used as the outer insulating body. The arc shield prevents the deterioration of the internal dielectric strength by preventing metallic vapours falling on the inside surface of the outer insulating cover.

**Working:** When the breaker operates, the moving contact separates from the fixed contact and an arc is struck between the contacts. The production of arc is due to the ionisation of metal ions and depends very much upon the material of contacts. The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in a short time and seized by the surfaces of moving and fixed members and shields. Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker occurs with a short contact separation (say 0·625 cm).

**Advantages**

Vacuum circuit breakers have the following advantages :

**(*i*)** They are compact, reliable and have longer life.

**(*ii*)** There are no fire hazards.

**(*iii*)** There is no generation of gas during and after operation.

**(*iv*)** They can interrupt any fault current. The outstanding feature of a VCB is that it can break any heavy fault current perfectly just before the contacts reach the definite open position.

**(*v*)** They require little maintenance and are quiet in operation.

**(*vi*)** They can successfully withstand lightning surges.

**(*vii*)** They have low arc energy.

**(*viii*)** They have low inertia and hence require smaller power for control mechanism.

**Applications**

For a country like India, where distances are quite large and accessibility to remote areas difficult, the installation of such outdoor, maintenance free circuit breakers should prove a definite advantage. Vacuum circuit breakers are being employed for outdoor applications ranging from 22 kV to 66 kV. Even with limited rating of say 60 to 100 MVA, they are suitable for a majority of applications in rural areas.

## What is breaking capacity?

**Breaking capacity:** *It is current (r.m.s.) that a circuit breaker is capable of breaking at given recovery voltage and under specified conditions (e.g., power factor, rate of rise of restriking voltage).*

## What is making capacity?

**Making capacity:** *The peak value of current (including d.c. component) during the first cycle of current wave after the closure of circuit breaker is known as* **making capacity.**

## What is Tariff?

*The rate at which electrical energy is supplied to a consumer is known as* **tariff**.

Although tariff should include the total cost of producing and supplying electrical energy plus the profit, yet it cannot be the same for all types of consumers. It is because the cost of producing electrical energy depends to a considerable extent upon the magnitude of electrical energy consumed by the user and his load conditions. Therefore, in all fairness, due consideration has to be given to different types of consumers (*e.g.*, industrial, domestic and commercial) while fixing the tariff. This makes the problem of suitable rate making highly complicated.

## ***What are the Objectives of tariff?***

Like other commodities, electrical energy is also sold at such a rate so that it not only returns the cost but also earns reasonable profit. Therefore, a tariff should include the following items :

**(*i*)** Recovery of cost of producing electrical energy at the power station.

**(*ii*)** Recovery of cost on the capital investment in transmission and distribution systems.

**(*iii*)** Recovery of cost of operation and maintenance of supply of electrical energy *e.g.*, metering equipment, billing etc.

**(*iv*)** A suitable profit on the capital investment.

## **What are the desirable Characteristics of a Tariff**

A tariff must have the following desirable characteristics:

**(*i*)** *Proper return*: The tariff should be such that it ensures the proper return from each consumer. In other words, the total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit. This will enable the electric supply company to ensure continuous and reliable service to the consumers.

**(*ii*)** *Fairness*: The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy. Thus a big consumer should be charged at a lower rate than a small consumer. It is because increased energy consumption spreads the fixed charges over a greater number of units, thus reducing the overall cost of producing electrical energy. Similarly, a consumer whose load conditions do not deviate much from the ideal (*i.e.*, non-variable) should be charged at a lower* rate than the one whose load conditions change appreciably from the ideal.

**(*iii*)** *Simplicity*: The tariff should be simple so that an ordinary consumer can easily understand it. A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.

**(*iv*)** *Reasonable profit*: The profit element in the tariff should be reasonable. An electric supply company is a public utility company and generally enjoys the benefits of monopoly. Therefore, the investment is relatively safe due to non-competition in the market. This calls for the profit to be restricted to 8% or so per annum.

**(*v*)** *Attractive*: The tariff should be attractive so that a large number of consumers are encouraged to use electrical energy. Efforts should be made to fix the tariff in such a way so that consumers can pay easily.

## Explain the different types of Tariff and their advantages and disadvantages?

There are several types of tariff. However, the following are the commonly used types of tariff :

**1. Simple tariff.** *When there is a fixed rate per unit of energy consumed, it is called a* **simple tariff** *or* **uniform rate tariff.**

In this type of tariff, the price charged per unit is constant *i.e.*, it does not vary with increase or decrease in number of units consumed. The consumption of electrical energy at the consumer's terminals is recorded by means of an energy meter. This is the simplest of all tariffs and is readily understood by the consumers.

**Disadvantages**

(*i*) There is no discrimination between different types of consumers since every consumer has to pay equitably for the fixed charges.

(*ii*) The cost per unit delivered is high.

(*iii*) It does not encourage the use of electricity.

**2. Flat rate tariff.** *When different types of consumers are charged at different uniform per unit rates, it is called a* **flat rate tariff**.

In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate. For instance, the flat rate per kWh for lighting load may be 60 paise, whereas it may be slightly less (say 55 paise per kWh) for power load. The different classes of consumers are made taking into account their diversity and load factors. The advantage of such a tariff is that it is more fair to different types of consumers and is quite simple in calculations.

**Disadvantages**

(*i*) Since the flat rate tariff varies according to the way the supply is used, separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.

(*ii*) A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

**3. Block rate tariff.** *When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a* **block rate tariff**.

In block rate tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block. The price per unit in the first block is the highest and it is progressively reduced for the succeeding blocks of energy. For example, the first 30 units may be charged at the rate of 60 paise per unit; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.

The advantage of such a tariff is that the consumer gets an incentive to consume more electrical energy. This increases the load factor of the system and hence the cost of generation is reduced. However, its principal defect is that it lacks a measure of the consumer's demand. This type of tariff is being used for majority of residential and small commercial consumers.

**4. Two-part tariff.** *When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a* **two-part tariff**.

In two-part tariff, the total charge to be made from the consumer is split into two components *viz*., fixed charges and running charges. The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer. Thus, the consumer is charged at a certain amount per kW of maximum†† demand plus a certain amount per kWh of energy consumed *i.e.*, Total charges = Rs ($b \times$ kW + $c \times$ kWh)

where, $b$ = charge per kW of maximum demand

$c$ = charge per kWh of energy consumed

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

**Advantages**

**(*i*)** It is easily understood by the consumers.

**(*ii*)** It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

**Disadvantages**

**(*i*)** The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.

**(*ii*)** There is always error in assessing the maximum demand of the consumer.

**5. Maximum demand tariff:** It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer. This type of tariff is mostly applied to big consumers. However, it is not suitable for a small consumer (*e.g.*, residential consumer) as a separate maximum demand meter is required.

**6. Three-part tariff.** *When the total charge to be made from the consumer is split into three parts viz., fixed charge, semi-fixed charge and running charge, it is known as a* **three-part tariff**. *i.e.*,

Total charge = Rs ($a + b \times$ kW + $c \times$ kWh)

where $a$ = fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution and labour cost of collecting revenues,

$b$ = charge per kW of maximum demand,

$c$ = charge per kWh of energy consumed.

It may be seen that by adding fixed charge or consumer's charge (*i.e.*, *a*) to two-part tariff, it becomes three-part tariff. The principal objection of this type of tariff is that the charges are split into three components. This type of tariff is generally applied to big consumers.

## What is Electrical Fuse?

In normal working condition of electrical network, the current flows through the network is within the rated limit. If a 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 a very high thermal effect which will cause permanent damage to the valuable pieces of equipment connected to 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 a conductor which melts easily and breaks the connection when current exceeds the predetermined value. An electrical fuse is the weakest part of an electrical circuit which breaks when more than predetermined current flows through it.

## What is Fuse Wire?

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

## Which materials are used for Fuse Wires?

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

## Define the following terms:

1. **Minimum Fusing Current**
2. **Current Rating of Fuse**
3. **Fusing Factor**
4. **Prospective Current in Fuse**
5. **Melting Time of Fuse or Pre-arcing Time of Fuse**
6. **Arcing Time of Fuse**

## 7. Operating Time of Fuse

### 1. Minimum Fusing Current

It is minimum value of current due to which fuse melts.

### 2. Current Rating of Fuse

It is the maximum value of current which the fuse element can normally carry without overheating or melting.

### 3. Fusing Factor

This is the ratio of minimum fusing current and current rating of fuse.

Therefore, fusing factor = Minimum fusing current/ current rating of the fuse.

The value of fusing factor is always more than 1.

### 4. 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.

### 5. Melting Time of Fuse or Pre-arcing Time of Fuse

This is the time taken by a fuse wire to get broken by melting. It gets counted from the instant; the overcurrent starts flowing through the fuse, to the instant when fuse wire gets just broken by melting.

### 6. 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 the arc gets extinguished is known as arcing time of fuse.

### 7. Operating Time of Fuse

Whenever overrated current starts to flow through a fuse wire, it takes time to be melted and disconnected, and just after that the arcing stars between the melted tips of the fuse wire, which finally gets extinguished. The operating time of fuse is the time gap between the instant when the overrated current starts to flow through the fuse and the instant when the arc in fuse finally gets extinguished. That means operating time of fuse = melting time + arcing time.

## What is the current Carrying Capacity of Fuse Wire? Or Expalin the Fuse Law?

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. We can establish the law in the following way. At steady state condition that is when fuse carries normal current without increasing its temperature to the melting limit. That means at this steady state condition, heat generated due to the 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, $\rho$ 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.

$$I^2.K_1.\frac{l}{d^2} \text{.............(i)}$$

Where, $K_1$ is a constant.

Heat lost $\propto$ surface area of fuse wire $\propto$ $\pi$d.l.

Therefore, heat lost = $K_2$.d.l .............(ii)

Where, $K_2$ is a constant.

Now, equating (i) and (ii), we get,

$$I^2.K_1.\frac{l}{d^2} = K_2.d.l$$

$$\Rightarrow I^2 = K.d^3$$

$I^2$ = constant × $d^3$

or $I^2 \propto d^3$ ...(i)

Expression (i) is known as ordinary fuse law

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**

## Explain the different types of Fuses and their advantages and disadvantages?

Fuse is the simplest current interrupting device for protection against excessive currents. In general, fuses may be classified into:

**(*i*)** Low voltages fuses

**(*ii*)** High voltage fuses

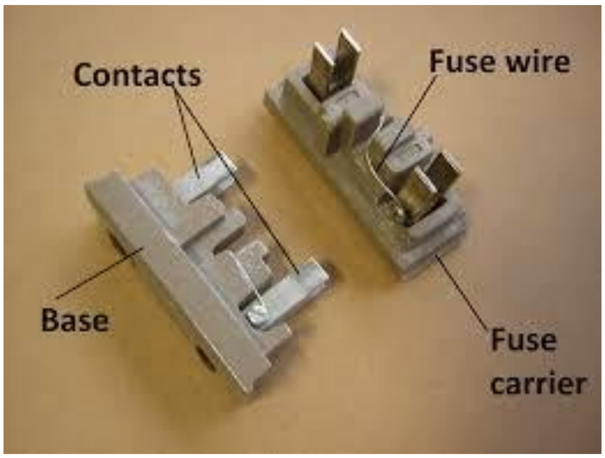
It is a usual practice to provide isolating switches in series with fuses where it is necessary to permit fuses to be replaced or rewired with safety. If such means of isolation are not available, the fuses must be so shielded as to protect the user against accidental contact with the live metal when the fuse carrier is being inserted or removed.

### Low Voltage Fuses

Low voltage fuses can be subdivided into two classes *viz*., (*i*) semi-enclosed rewireable fuse (*ii*) high rupturing capacity (H.R.C.) cartridge fuse.

**1. Semi-enclosed rewireable fuse:** Rewireable fuse (also known as kit-kat type) is used where low values of fault current are to be interrupted. It consists of (*i*) a base and (*ii*) a fuse carrier. The base is of porcelain and carries the fixed contacts to which the incoming and outgoing phase wires are connected. The fuse carrier is also of porcelain and holds the fuse element (tinned copper wire) between its terminals. The fuse carrier can be inserted in or taken out of the base when desired.

When a fault occurs, the fuse element is blown out and the circuit is interrupted. The fuse carrier is taken out and the blown out fuse element is replaced by the new one. The fuse carrier is then reinserted in the base to restore the supply. This type of fuse has two advantages. Firstly, the detachable fuse carrier permits the replacement of fuse element without any danger of coming in contact with live parts. Secondly, the cost of replacement is negligible.




**Disadvantages**

**(*i*)** There is a possibility of renewal by the fuse wire of wrong size or by improper material.

**(*ii*)** This type of fuse has a low-breaking capacity and hence cannot be used in circuits of high fault level.

**(*iii*)** The fuse element is subjected to deterioration due to oxidation through the continuous heating up of the element. Therefore, after some time, the current rating of the fuse is decreased *i.e.*, the fuse operates at a lower current than originally rated.

**(*iv*)** The protective capacity of such a fuse is uncertain as it is affected by the ambient conditions.

**2. High-Rupturing capacity (H.R.C.) cartridge fuse:** The primary objection of low and uncertain breaking capacity of semi-enclosed rewireable fuses is overcome in H.R.C. cartridge fuse. H.R.C. cartridge fuse consists of a heat resisting ceramic body having metal end-caps to which is welded silver current-carrying element. The space within the body surrounding the element is completely packed with a filling powder. The filling material may be chalk, plaster of paris, quartz or marble dust and acts as an arc quenching and cooling medium.

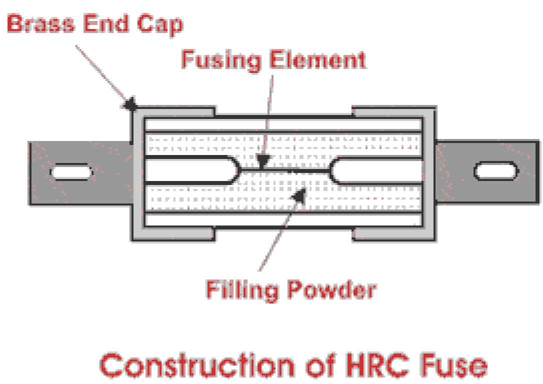



Figure: Shows the essential parts of a typical H.R.C. cartridge fuse

Under normal load conditions, the fuse element is at a temperature below its melting point. Therefore, it carries the normal current without overheating. When a fault occurs, the current increases and the fuse element melts before the fault current reaches its first peak. The heat produced in the process vapourises the melted silver element. The chemical reaction between the silver vapour and the filling powder results in the formation of a high resistance substance which helps in quenching the arc.

### Advantages

**(*i*)** They are capable of clearing high as well as low fault currents.
**(*ii*)** They do not deteriorate with age.
**(*iii*)** They have high speed of operation.
**(*iv*)** They require no maintenance.
**(*v*)** They are cheaper than other circuit interrupting devices of equal breaking capacity.
**(*vi*)** They permit consistent performance.

### Disadvantages

**(*i*)** They have to be replaced after each operation.

**(*ii*)** Heat produced by the arc may affect the associated switches.

## High Voltage Fuses

The low-voltage fuses discussed so far have low normal current rating and breaking capacity. Therefore, they cannot be successfully used on modern high voltage circuits. Intensive research by the manufacturers and supply engineers has led to the development of high voltage fuses. Some of the high voltage fuses are:

**(*i*) Cartridge type:** This is similar in general construction to the low voltage cartridge type except that special design features are incorporated. Some designs employ fuse elements wound in the form of a helix so as to avoid corona effects at higher voltages. On some designs, there are two fuse elements in parallel; one of low resistance (silver wire) and the other of high resistance (tungsten wire). Under normal load conditions, the low resistance element carries the normal current. When a fault occurs, the low-resistance element is blown out and the high resistance element reduces the short-circuit current and finally breaks the circuit.

**(*ii*) Metal clad fuses.** Metal clad oil-immersed fuses have been developed with the object of providing a substitute for the oil circuit breaker. Such fuses can be used for very high voltage circuits and operate most satisfactorily under short-circuit conditions approaching their rated capacity.

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