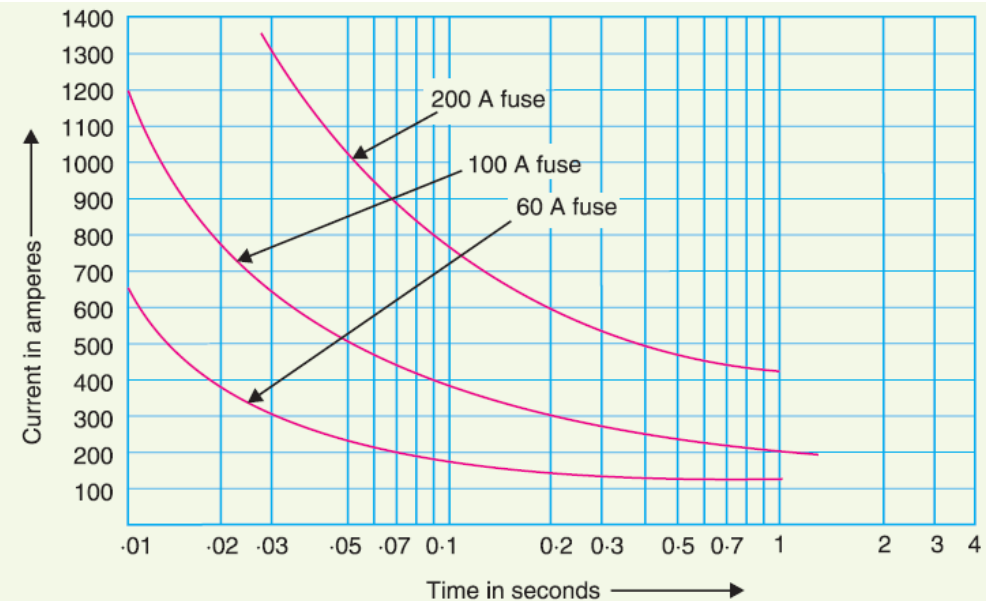
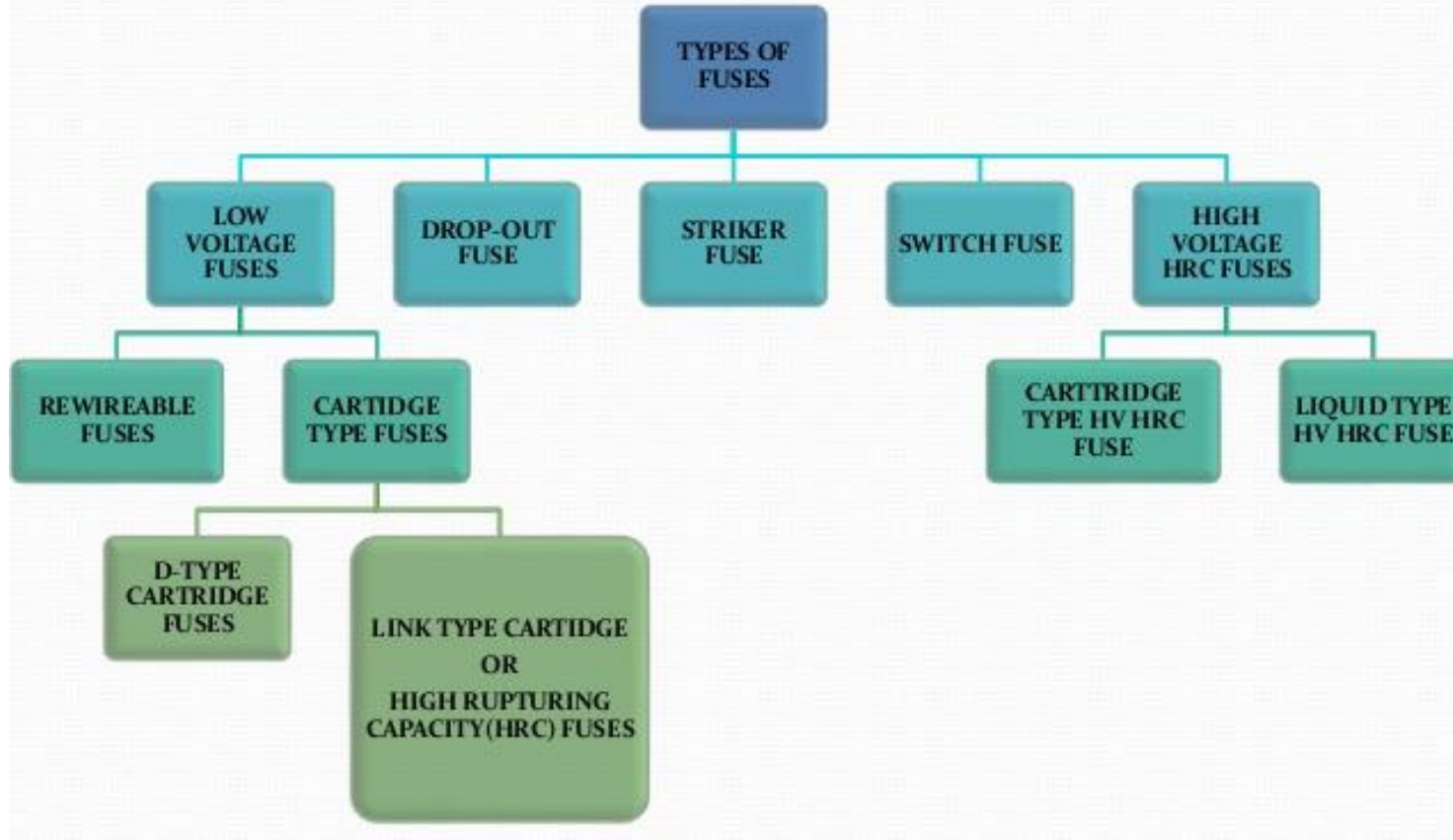


TYPES OF FUSES



Advantages of Fuses

- (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.

Advantages of Fuses

1. Operating time of the fuse is much smaller than that of the circuit breaker, for interrupting very large currents. The fuse operates in less than 5 milliseconds while interrupting large currents. Serious overheating and electromagnetic or electrodynamic forces in the system can thus be avoided.
2. The fuse does the function, viz detection and interruption of current unlike a circuit breaker which can only interrupt the fault current and requires elaborate equipment for detection of fault current(i.e., relays, current transformer, etc.). The low-voltage air circuit breakers and moulded-case circuit breakers are, however, fitted with thermal and electromagnetic releases.
3. The sealed cartridge fuses are silent in operation and do not emit flame.
4. Fuse is the cheapest form of protection.
5. Fuse requires no maintenance

Disadvantages of Fuses

- (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.
- (iv) Poor Protection against small over current

Discrimination between two fuses is said to occur if on the occurrence of a short-circuit or overcurrent fault, only the desired fuse operates

Disadvantages of Fuses

It takes longer time to replace a fuse than to reclose a circuit breaker. This drawback is often exaggerated, especially with modern cartridge fuses, some of which can be replaced quite quickly. It may, in practice, take longer to trace a blown fuse, if it is not fitted with an indicating device, than to replace it. Usually far more time is consumed in checking the faulty circuit; hence this disadvantage of more time in replacement loses its significance.

The fuse gives comparatively poor protection against small overcurrents. A circuit breaker can be set to trip on as little as 5% overcurrent while the semi-enclosed fuse has a fusing factor (ratio of minimum fusing current to the rated current) of about 1.75.

A modern cartridge fuse can, however, be obtained with fusing factor as low as 1.25. The values lower than 1.25 are not recommended if unwanted blowing of fuse-element due to momentary system abnormalities is to be avoided.

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 Element Materials

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.

Important Terms

- (i) **Current rating of fuse element.** It is the current which the fuse element can normally carry without overheating or melting. It depends upon the temperature rise of the contacts of the fuse holder, fuse material and the surroundings of the fuse.
- (ii) **Fusing current.** It is the minimum current at which the fuse element melts and thus disconnects the circuit protected by it. Obviously, its value will be more than the current rating of the fuse element

For a round wire, the approximate relationship between fusing current I and diameter d of the wire is

$$I = k d^{3/2}$$

where k is a constant, called the **fuse constant**. Its value depends upon the metal of which the fuse element is made.

The value of k for different materials as given in the table below :

S. No.	Material	Value of k	
		d in cm	d in mm
1	Copper	2530	80
2	Aluminium	1873	59
3	Tin	405·5	12·8
4	Lead	340·6	10·8

The fusing current depends upon the various factors such as :

- (a) material of fuse element
- (b) length – the smaller the length, the greater the current because a short fuse can easily conduct away all the heat
- (c) diameter
- (d) size and location of terminals
- (e) type of enclosure used

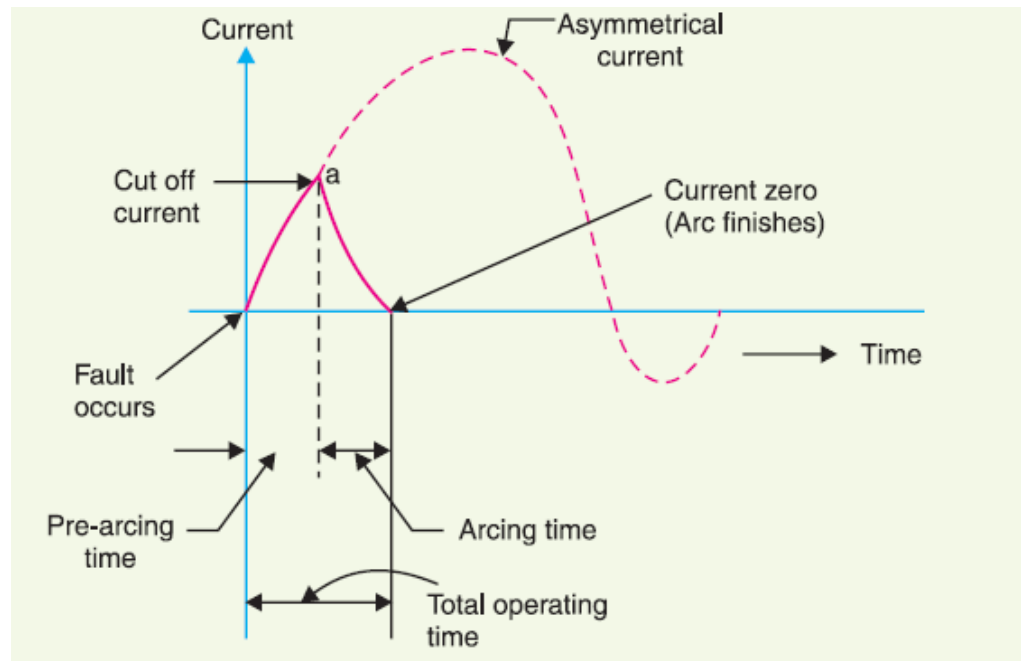
(iii) Fusing factor. It is the ratio of minimum fusing current to the current rating of the fuse element *i.e.*

Fusing factor = Minimum fusing current/Current rating of fuse

Its value is always more than one. The smaller the fusing factor, the greater is the difficulty in avoiding deterioration due to overheating and oxidation at rated carrying current

On the occurrence of a fault, the fault current has a very large first loop due to a fair degree of asymmetry. The heat generated is sufficient to melt the fuse element well before the peak of first loop is reached (point 'a' in Fig.). The current corresponding to point 'a' is the cut off current. The cut off value depends upon :

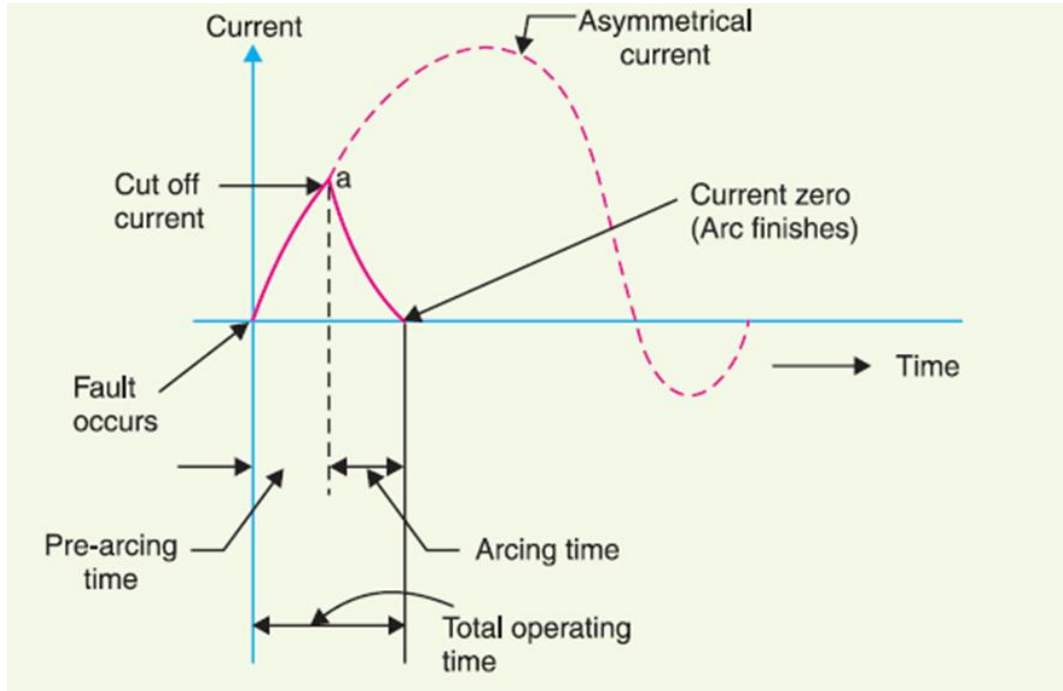
- (a) current rating of fuse
- (b) value of prospective current
- (c) asymmetry of short-circuit current



Prospective Current. Fig. shows how a.c. current is cut off by a fuse. The fault current would normally have a very large first loop, but it actually generates sufficient energy to melt the fuseable element well before the peak of this first loop is reached. The *r.m.s.* value of the first loop of fault current is known as prospective current. Therefore, prospective current can be defined as under:

It is the r.m.s. value of the first loop of the fault current obtained if the fuse is replaced by an ordinary conductor of negligible resistance.

(v) Cut-off current. It is the maximum value of fault current actually reached before the fuse melts.



(vi) Pre-arcing time. It is the time between the commencement of fault and the instant when cut off occurs. When a fault occurs, the fault current rises rapidly and generates heat in the fuse element. As the fault current reaches the cut off value, the fuse element melts and an arc is initiated. The time from the start of the fault to the instant the arc is initiated is known as pre-arcing time. The pre-arcing time is generally small : a typical value being 0.001second

(vii) Arcing time. This is the time between the end of pre-arcing time and the instant when the arc is extinguished.

(viii) Total operating time. It is the sum of pre-arcing and arcing times.

It may be noted that operating time of a fuse is generally quite low (say 0.002 sec.) as compared to a circuit breaker (say 0.2 sec or so). This is an added advantage of a fuse over a circuit breaker. A fuse in series with a circuit breaker of low-breaking capacity is a useful and economical arrangement to provide adequate short-circuit protection. It is because the fuse will blow under fault conditions before the circuit breaker has the time to operate.

Types of Fuses

Fuse is the simplest current interrupting device for protection against excessive currents. Since the invention of first fuse by Edison, several improvements have been made and now-a-days, a variety of fuses are available. Some fuses also incorporate means for extinguishing the arc that appears when the fuse element melts. In general, fuses may be classified into :

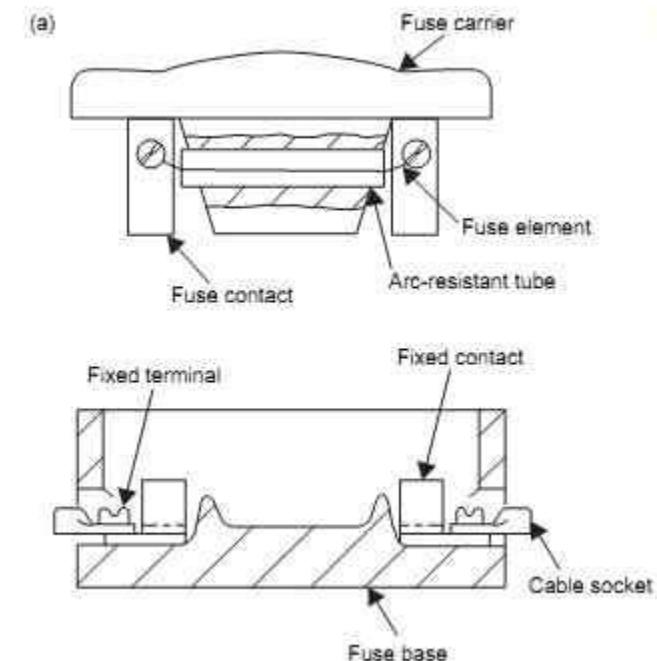
(i) Low voltages fuses (ii) High voltage fuses

Low Voltage Fuses

Low voltage fuses can be subdivided into two classes viz.,

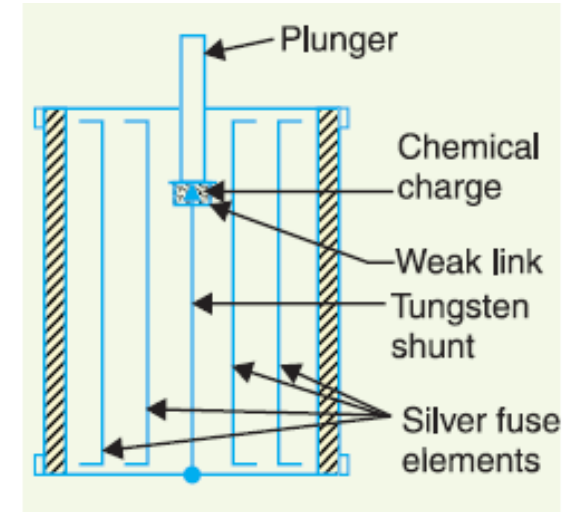
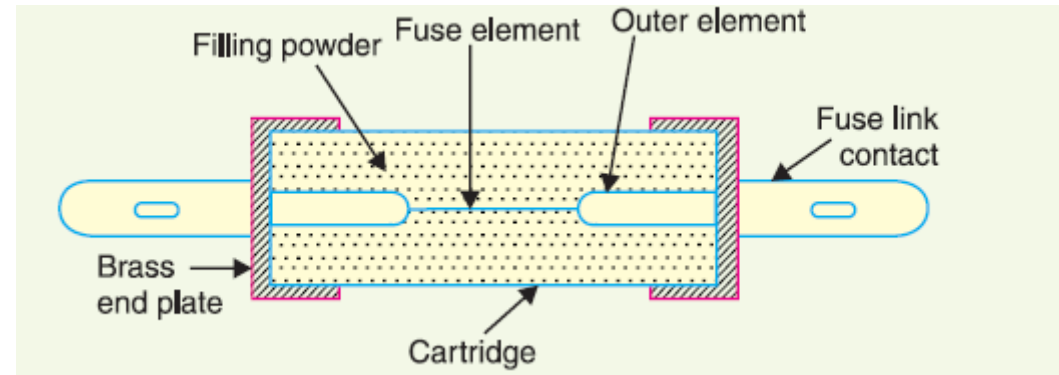
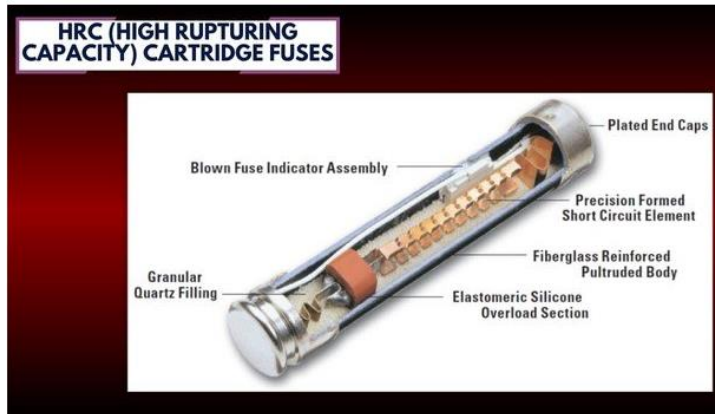
- (i) Semi-enclosed rewirable fuse
- (ii) High rupturing capacity (H.R.C.) cartridge fuse.

Semi-enclosed rewirable fuses are made upto 500 A rated current, but their breaking capacity is low *e.g.*, on 400 V service, the breaking capacity is about 4000 A. Therefore, the use of this type of fuses is limited to domestic and lighting loads.



High-Rupturing capacity (H.R.C.) cartridge fuse.

Low voltage H.R.C. fuses may be built with a breaking capacity of 16,000 A to 30,000 A at 440V. They are extensively used on low-voltage distribution system against over-load and short circuit conditions



H.R.C. fuse with tripping device

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 provide reliable discrimination.
- (v) They require no maintenance.
- (vi) They are cheaper than other circuit interrupting devices of equal breaking capacity.
- (vii) 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

Cartridge type.

High voltage cartridge fuses are used upto 33 kV with breaking capacity of about 8700 A at that voltage. Rating of the order of 200 A at 6.6kV and 11 kV and 50 A at 33 kV are also available.

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.

High voltage cartridge fuses are used upto 33 kV with breaking capacity of about 8700 A at that voltage. Rating of the order of 200 A at 6.6 kV and 11 kV and 50 A at 33 kV are also available

RT16 Series filled and enclosed cartridge knifecontactor fuse-link



RT12 / RT15 Connecting Bolt Type Fuse-Link

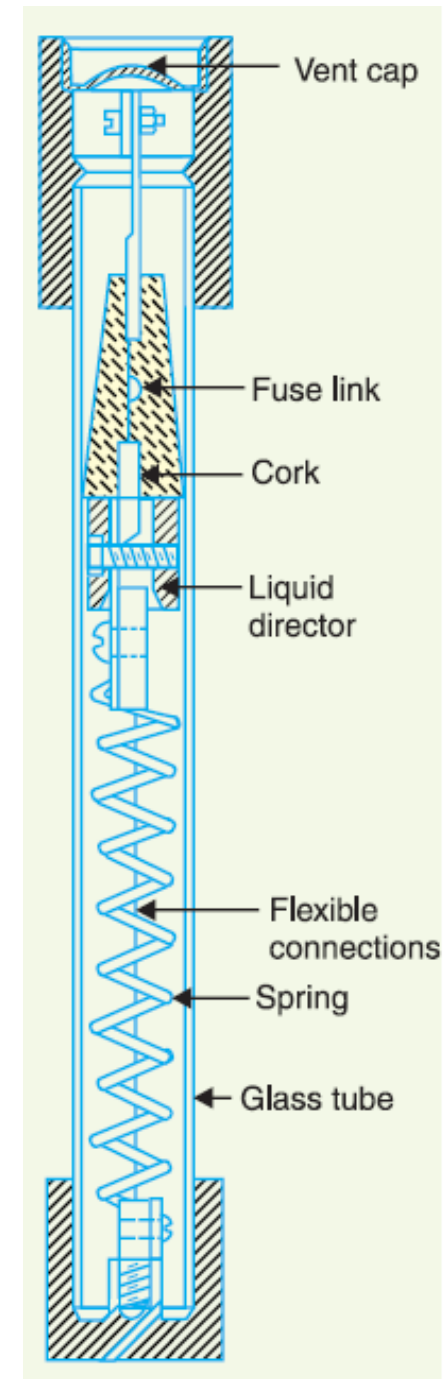


Liquid type

These fuses are filled with carbon tetrachloride and have the widest range of application to H.V. systems.

They may be used for circuits upto about 100 A rated current on systems upto 132 kV and may have breaking capacities of the order of 6100 A.

Fig. shows the essential parts of the liquid fuse. It consists of a glass tube filled with carbon tetrachloride solution and sealed at both ends with brass caps. The fuse wire is sealed at one end of the tube and the other end of the wire is held by a strong phosphor bronze spiral spring fixed at the other end of the glass tube. When the current exceeds the prescribed limit, the fuse wire is blown out. As the fuse melts, the spring retracts part of it through a baffle (or liquid director) and draws it well into the liquid. The small quantity of gas generated at the point of fusion forces some part of liquid into the passage through baffle and there it effectively extinguishes the arc



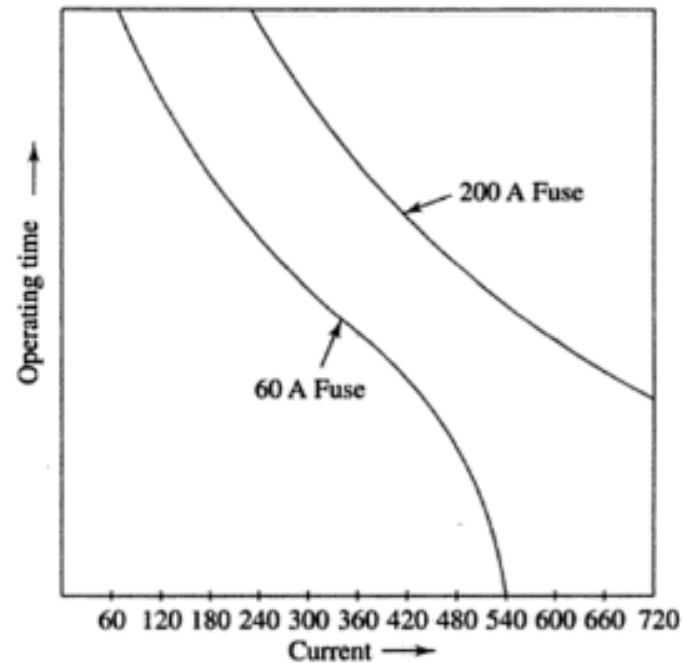
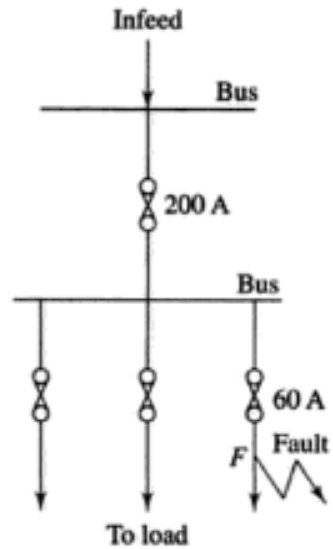
Difference Between a Fuse and Circuit Breaker

It is worthwhile to indicate the salient differences between a fuse and a circuit breaker in the tabular form.

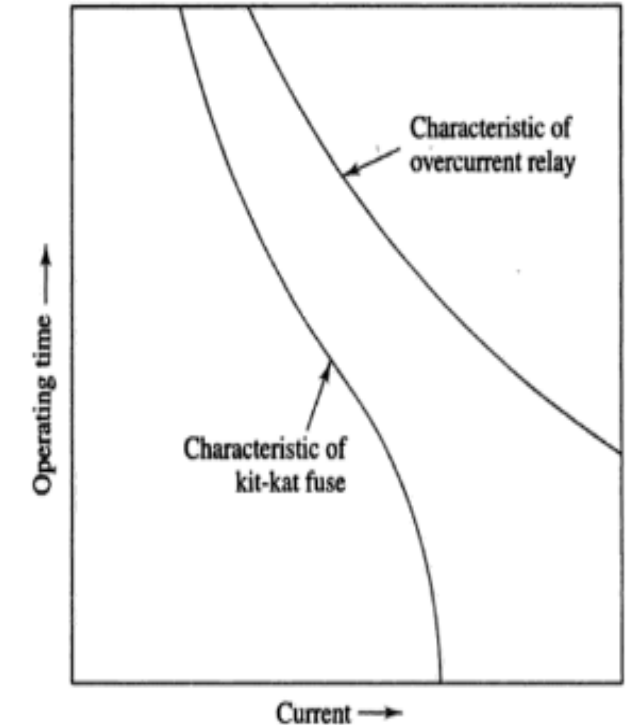
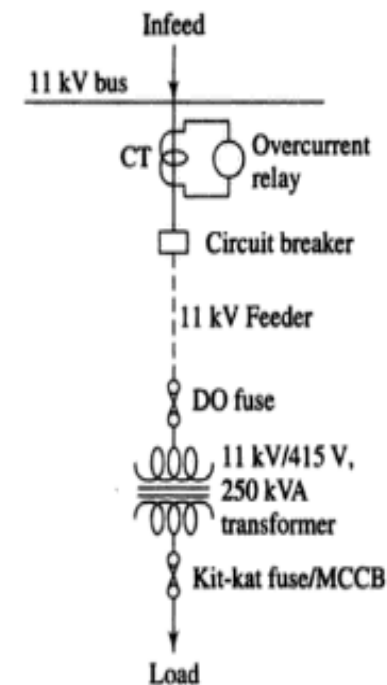
S. No.	Particular	Fuse	Circuit breaker
1.	<i>Function</i>	It performs both detection and interruption functions.	It performs interruption function only. The detection of fault is made by relay system.
2.	<i>Operation</i>	Inherently completely automatic.	Requires elaborate equipment (<i>i.e.</i> relays) for automatic action.
3.	<i>Breaking capacity</i>	Small	Very large
4.	<i>Operating time</i>	Very small (0.002 sec or so)	Comparatively large (0.1 to 0.2 sec)
5.	<i>Replacement</i>	Requires replacement after every operation.	No replacement after operation.

Discrimination:- Discrimination between two fuses is said to occur if on the occurrence of a short-circuit or overcurrent fault, only the desired fuse operates

Discrimination between Two Fuses



Discrimination between a fuse and over current relay



Protection of Overhead Transmission Lines from Direct Lightning Strokes by Ground Wires

The two methods of protecting overhead transmission lines against lightning strokes are:

(i) Overhead ground wires and (ii) Expulsion protector tubes.

(i) Protection of Overhead Transmission Lines from Direct Lightning Strokes by Ground Wires:

A ground wire is a form of lightning protection employing a conductor or conductors, well-grounded at regular intervals, preferably at each support (pole or tower), and attached from support to support above the transmission line conductors.

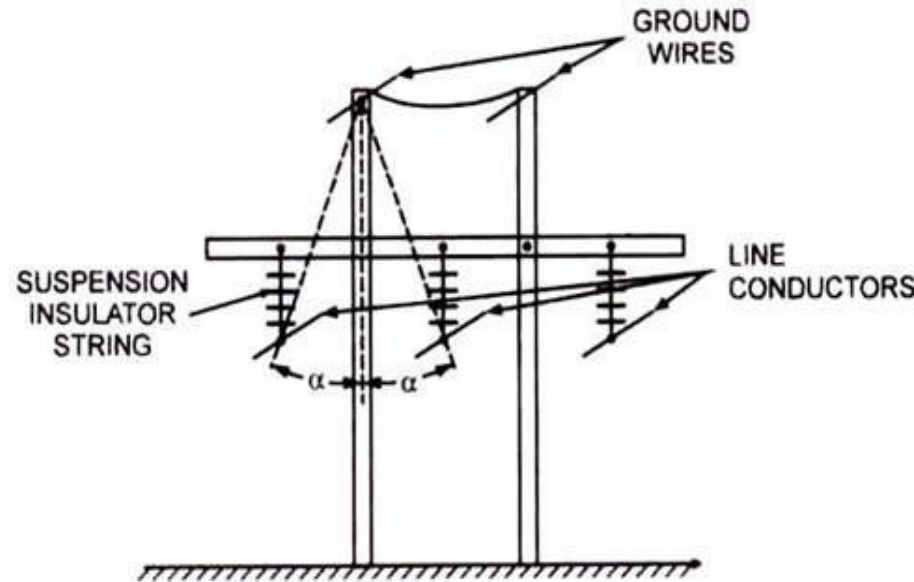


Fig. Arrangement of Ground Wires on a Transmission Line For Direct Stroke Lightning Protection

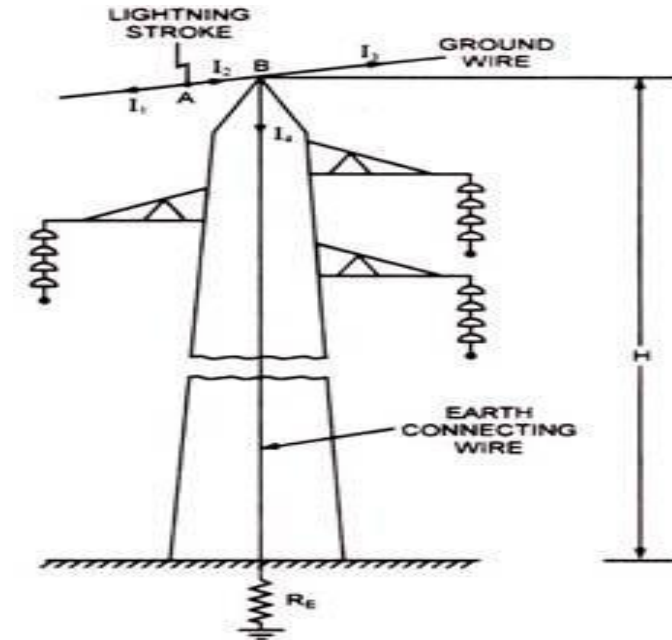


Fig. 9.12. Arrangement of Conductors and Earth Representing Lightning Current

(ii) Expulsion protector tubes.

Protection of Overhead Transmission Lines from Direct Lightning Strokes by Protector Tube:

Even after reduction in the induced voltage by using a ground wire, there still exist over-voltages in the system which must be removed by using additional protective devices such as lightning arrester that bypasses the surges to the ground. Another device that is quite common in use is the protector tube

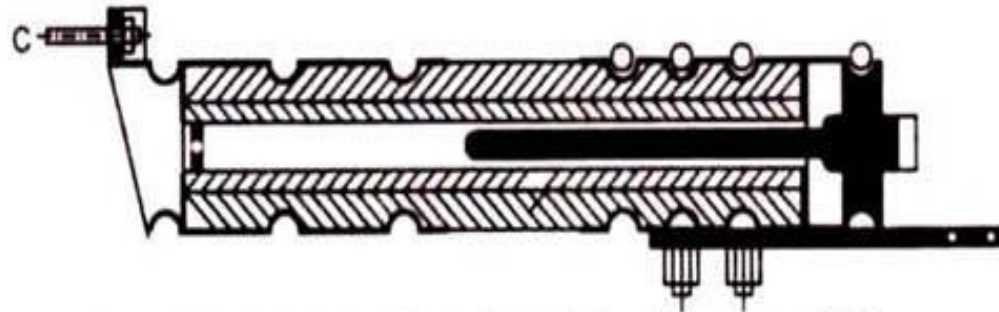
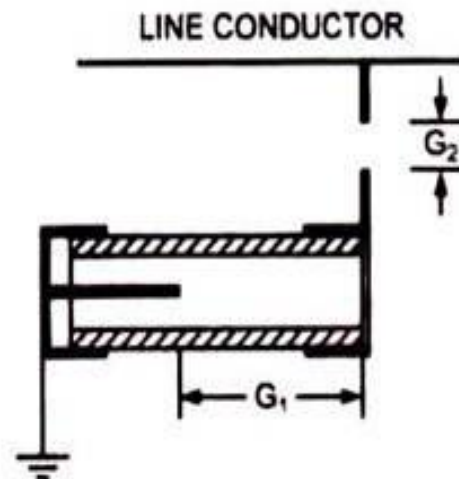
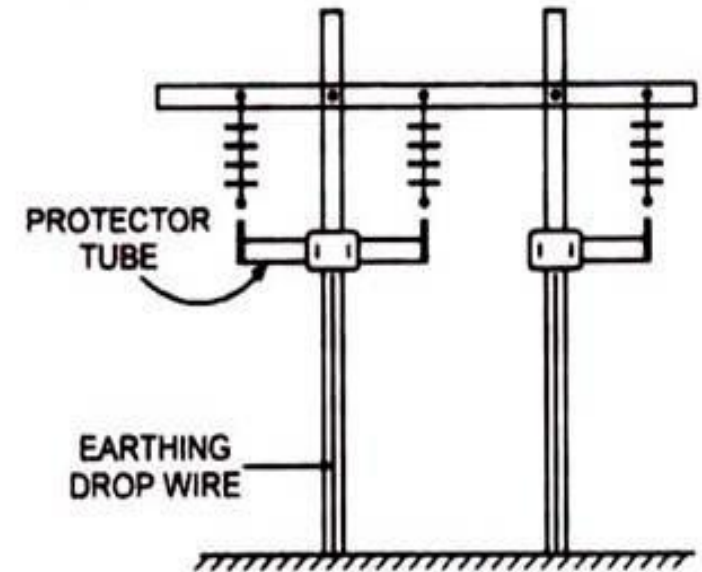


Fig. 9.15. Power Line Expulsion Protector Tube



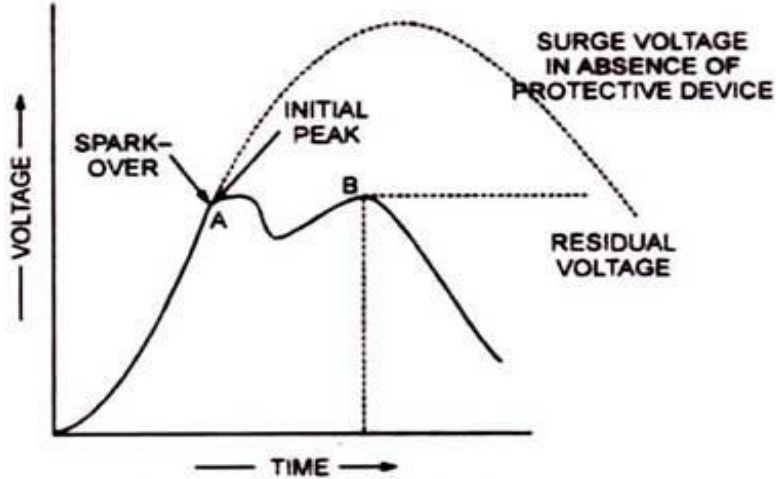
(a) Schematic Diagram of Protector Tube Connections



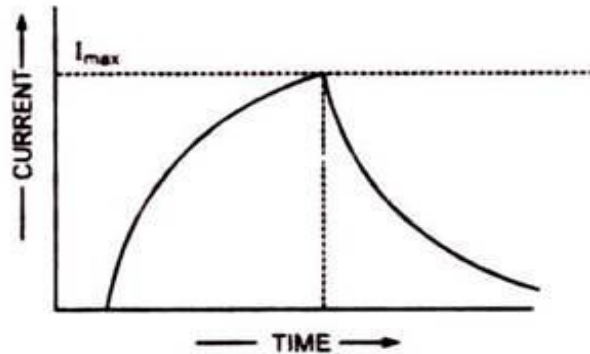
(b) Protector Tube Mounted on 110 kV Wooden Pole

Fig. 9.16. Expulsion Protector Tube

Protection of Electrical Equipment from Travelling Waves



(a) Voltage Characteristic



(b) Current Characteristic
Voltage and Current Characteristics of
Surge Diverters

Fig. 9.17

it is absolutely necessary to provide some protective device at the power stations or substations to prevent transformers and other equipment from being subjected to travelling surges reaching there. The most common devices used for protection of equipment at the substations against travelling waves are lightning arresters or surge diverters.

A surge diverter is a device that is connected between line and earth, i.e., in parallel with the equipment to be protected at the substation.

An ideal surge diverter should have the following characteristics:

- 1) It should not draw any current during normal operating conditions, i.e., its spark over voltage must be above the normal or abnormal power frequency that may occur in the system.
- 2) Any abnormal transient voltage above the breakdown value must cause it to breakdown as quickly as possible so that it may provide a conducting path to ground.
- 3) When the breakdown have taken place, it should be capable of carrying the resulting discharge current without getting damaged itself and without the voltage across it exceeding the breakdown value.
- 4) The power frequency current following the breakdown must be interrupted as soon as the transient voltage has fallen below the breakdown value.

There are many types of surge diverters which are used to protect the power system.

The choice of lightning arrester depends upon the following factors:

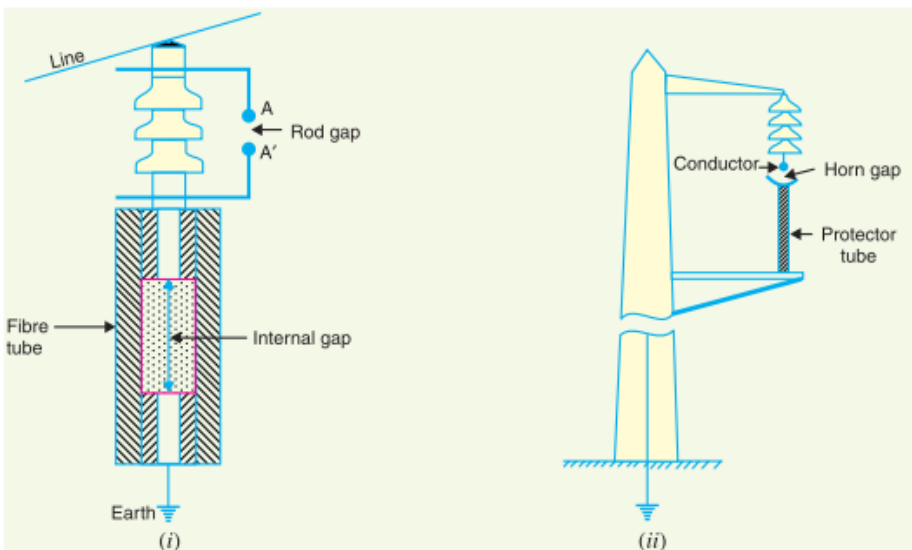
- (i) Voltage of the line.
- (ii) Frequency of the lightning.
- (iii) Cost.
- (iv) Weather conditions.
- (v) Reliability

Types of Lightning Arresters

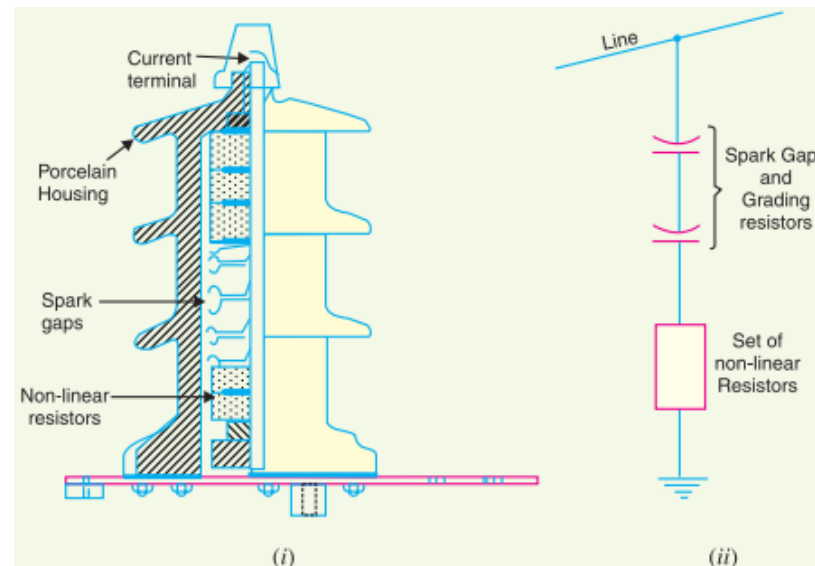
There are several types of lightning arresters in general use. They differ only in constructional details but operate on the same principle *viz.* providing low resistance path for the surges to the ground. We shall discuss the following types of lightning arresters :

1. Rod gap arrester
2. Horn gap arrester
3. Multigap arrester
4. Expulsion type lightning arrester
5. Valve type lightning arrester

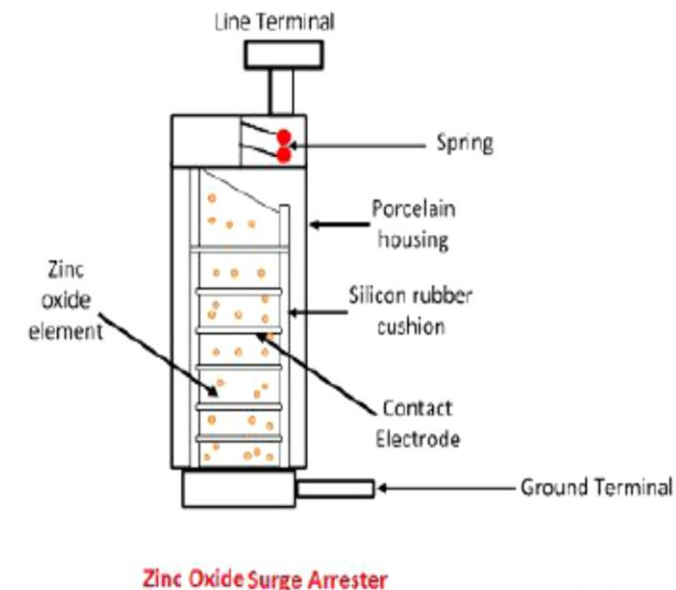
Expulsion type arrester



Valve type arrester



Metal Oxide Lightning Arrester



Insulation Coordination

Insulation Coordination is the process of determining the proper insulation levels of various components in a power system as well as their arrangements. It is the selection of an insulation structure that will withstand voltage stresses to which the system, or equipment will be subjected to, together with the proper surge arrester. The process is determined from the known characteristics of voltage surges and the characteristics of surge arresters.

Some common terms that must be known when performing an Insulation Coordination Study.

1. Basic Impulse Insulation Level (BIL)

This is the reference insulation level expressed as an impulse crest (or peak) voltage with a standard wave not longer than a **1.2 x 50 microsecond** wave.

A **1.2 x 50 microsecond** wave means that the impulse takes 1.2 microseconds to reach the peak and then decays to 50% of the peak in 50 microseconds.

2. Withstand Voltage

This is the BIL level that can repeatedly be applied to an equipment without flashover, disruptive charge or other electrical failure under test conditions.

Insulation Coordination

3. Chopped Wave Insulation Level

This is determined by using impulse waves that are of the same shape as that of the BIL waveform, with the exception that the wave is chopped after 3 microseconds. Generally, it is assumed that the Chopped Wave Level is 1.15 times the BIL level for oil filled equipment such as transformers. However, for dry type equipment, it is assumed that the the Chopped Wave Level is equal to the BIL level.

4. Critical Flashover Voltage

This is the peak voltage for a 50% probability of flashover or disruptive charge.

5. Impulses Ratio

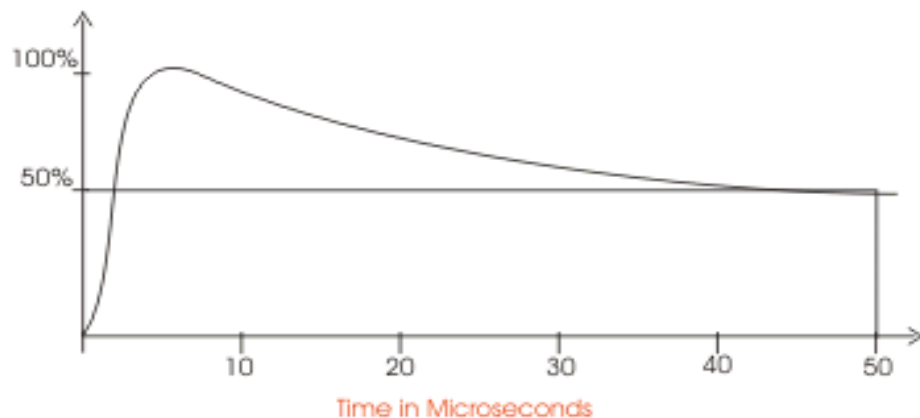
This is normally used for Flashover or puncture of insulation. It is the ratio of the impulse peak voltage to the value of the 60 Hz voltage that causes flashover or puncture. Or, it is the ratio of breakdown voltage at surge frequency to breakdown voltage at normal system frequency (60 Hz).

Basic Insulation Level

When lightning impulse over voltage appears in the system, it is discharged through surge protecting devices before the equipments of the system gets damaged. Hence, the insulation of such equipment must be designed to withstand a certain minimum voltage before the lightning impulse over voltage gets discharged through surge protecting devices. Therefore, operating voltage level of surge protecting devices must be lower than the said minimum voltage withstanding level of the equipment. This minimum voltage rating is defined as BIL or basic insulation level of electrical equipment

Impulse Voltage

As per American Standard the impulse wave shape is 1.5/40 microsecond. As per Indian Standard this is 1.2/50 microsecond. This representation of the wave has a special significance. Such as 1.2/50 microsecond impulse wave represents a unidirectional wave which rises to its peak value from zero in 1.2 microseconds and then falls to 50% of peak value in 50 microseconds. The represented wave shape is shown below,



Basic Insulation Level Table

Nominal System Voltage	Indian Standards BIL	British Standards BIL
11 KV	75 KV	-
33 KV	170 KV	200 KV
66 KV	325 KV	450 KV
132 KV	550/650 KV	650/750 KV
220 KV	900/1050 KV	900/1050 KV

GAS INSULATED SUBSTATIONS

SF₆ gas insulated high voltage switchgear has been in commercial operation for more than 30 years. Continuous technological and design improvements of all the components during the course of the time are characterized by appreciable savings in area and volume occupied by the substation. Gas insulated substations are in service up to the highest voltage of 800 kV, meeting almost all the requirements in urban, industrial as well as rural areas. In the initial stages, the new SF₆ gas insulated substations were almost exclusively used where space limitations, site restrictions or exponential ambient conditions made it difficult to use conventional air insulated substations. However, over the last 30 years, GIS at voltage up to 800 kV in various station configurations and with various performance requirements, have been installed in increasing numbers worldwide. The modular of design of GIS offers a high degree of flexibility to meet layout requirements of both substations, as well as power station switchgear, making efficient use of available space. GIS technology has reached a stage of application and a wide range of GIS equipment up to highest voltage of 800 kV is available with many unique features.

They are:

1. Wide spread application of aluminum enclosure materials for standardized component models for all voltage ranges
2. The light weight enclosures have good conductivity, low eddy-current losses and a high resistance to corrosion
3. Easy handling, as well as reduced stresses on foundation and support structure are additional features
4. Standard arrangements can be easily modified and extended with good co-ordination between the manufacturer and the user.
5. A gas- tight barrier insulator in switchgear serve for the separation of gas compartments and prevents neighbouring switchgear parts from being affected during maintenance

The Gas insulated substation comprises the following components:

- 1 Circuit breaker
- 2 Disconnect switch
- 3 Earthing switch
- 4 Current transformer
- 5 Voltage transformer
- 6 Bus bar & connectors
- 7 Power transformer
- 8 Surge arrester
- 9 Cable termination
- 10 SF6 / air or SF6 / oil bushing

Advantages of GIS over the conventional open air substation

The application of GIS during the last fifteen years has been very rapid. The rapid growth in GIS application is due to the following special advantages:

1. Area and volume saving in construction for over or underground applications. Therefore they offer saving in land area and construction costs.
2. Insensitivity to external influences because of grounded metal enclosures.
3. Greatly improved safety and reliability due to earthed metal housing of all high voltage parts and much higher intrinsic strength of SF₆ gas as insulation.
4. Short on site erection times, based on large factory assembled and tested shipping units
5. Fulfillment of aesthetic requirements with indoor applications
6. High service reliability due to non-exposure of the use of high voltage parts to atmosphere influences
7. Reduction in radio interference with the use of earthed metal enclosures
8. Use as mobile substations for transportation to load centers on standard tracks. These substations can be located closer to load centers thereby reducing transmission losses and expenditure in the distribution network.
9. More optimal life cycle costs because of lesser maintenance, down time and repair costs.
10. It is not necessary that high voltage or extra high voltage switchgear has to be installed out doors

Disadvantages of GIS

Although GIS has been in operation for several years, a lot of problems encountered in practice need fuller understanding. Some of the problems being studied are:

1. Switching operation generate Very Fast Transients Over Voltages (VFTOS).
2. VFTOS may cause secondary breakdown inside a GIS and Transient Enclosure Voltages (TEV) outside the GIS.
3. Field non-uniformities reduce withstanding levels of a GIS.
4. Prolonged arcing may produce corrosive/toxic by-products.
5. Support spacers can be weak points when arc by-products and metallic particles are present