VALVE TYPE ARRESTERS

Valve type arresters incorporate non-linear resistors and are extensively used on systems, operating at high voltages. Fig 12 (i) shows the various parts of a valve type arrester. It consists of two assemblies (i) series spark gaps and (ii) non-linear resistor discs in series. The non-linear elements are connected in series with the spark gaps. Both the assemblies are accommodated in tight porcelain container.

(i) **The spark gap** is a multiple assembly consisting of a number of identical spark gaps in series. Each gap consists of two electrodes with fixed gap spacing. The voltage distribution across the gap is linearised by means of additional resistance elements called grading resistors across the gap. The spacing of the series gaps is such that it will withstand the normal circuit voltage. However an over voltage will cause the gap to break down causing the surge current to ground via the non-linear resistors.

(ii) **The non-linear resistor discs** are made of inorganic compound such as thyrite or metrosil. These discs are connected in series. The non-linear resistors have the property of offering a high resistance to current flow when normal system voltage is applied, but a low resistance to the flow of high surge currents. In other words, the resistance of these non-linear elements decreases with the increase in current through them and vice-versa.
Working.

Under normal conditions, the normal system voltage is insufficient to cause the break down of air gap assembly. On the occurrence of an over voltage, the break down of the series spark gap takes place and the surge current is conducted to earth via the non-linear resistors. Since the magnitude of surge current is very large, the non-linear elements will offer a very low resistance to the passage of surge. The result is that the surge will rapidly go to earth instead of being sent back over the line. When the surge is over, the non-linear resistors assume high resistance to stop the flow of current

**EXPULSION TYPE ARRESTER**

This type of arrester is also called ‘protector tube’ and is commonly used on system operating at voltages up to 33kV. Fig 11(i) shows the essential parts of an expulsion type lightning arrester. It essentially consists of a rod gap AA’ in series with a second gap enclosed within the fiber tube. The gap in the fiber tube is formed by two electrodes. The upper electrode is connected to rod gap and the lower electrode to the earth. One expulsion arrester is placed under each line conductor. Fig11 (ii) shows the installation of expulsion arrester on an overhead line.

On the occurrence of an over voltage on the line, the series gap AA’ spanned and an arc is stuck between the electrodes in the tube. The heat of the arc vaporizes some of the fiber of tube walls resulting in the production of neutral gas. In an extremely short time, the gas builds up high pressure and is expelled through the lower electrode, which is hollow. As the gas leaves the tube violently it carries away ionized air around the arc. This de ionizing effect is generally so strong that the arc goes out at a current zero and will not be re-established.

**Advantages:**

(i) They are not very expensive.

(ii) They are improved form of rod gap arresters as they block the flow of power frequency follow currents

(iii) They can be easily installed.
Limitations:

(i) An expulsion type arrester can perform only limited number of operations as during each operation some of the fiber material is used up.

(iii) This type of arrester cannot be mounted on enclosed equipment due to discharge of gases during operation.

(i) Due to the poor volt/am characteristic of the arrester, it is not suitable for protection of expensive equipment.

ROD GAP ARRESTER

It is a very simple type of diverter and consists of two 1.5 cm rods, which are bent at right angles with a gap in between as shown in Fig 8. One rod is connected to the line circuit and the other rod is connected to earth. The distance between gap and insulator (i.e. distance \( P \)) must not be less than one third of the gap length so that the arc may not reach the insulator and damage it. Generally, the gap length is so adjusted that breakdown should occur at 80% of spark-voltage in order to avoid cascading of very steep wave fronts across the insulators. The string of insulators
for an overhead line on the bushing of transformer has frequently a rod gap across it. Fig 8 shows the rod gap across the bushing of a transformer. Under normal operating conditions, the gap remains non-conducting. On the occurrence of a high voltage surge on the line, the gap sparks over and the surge current is conducted to earth. In this way excess charge on the line due to the surge is harmlessly conducted to earth

Limitations:

(i) After the surge is over, the arc in the gap is maintained by the normal supply voltage, leading to short-circuit on the system.

(ii) The rods may melt or get damaged due to excessive heat produced by the arc.

(iii) The climatic conditions (e.g. rain, humidity, temperature etc.) affect the performance of rod gap arrester.

(iv) The polarity of the surge also affects the performance of this arrester.

Due to the above limitations, the rod gap arrester is only used as a back-up protection in case of main arresters.
LIGHTNING ARRESTERS

The earthing screen and ground wires can well protect the electrical system against direct lightning strokes but they fail to provide protection against travelling waves, which may reach the terminal apparatus. The lightning arresters or surge diverters provide protection against such surges. A lightning arrester or a surge diverter is a protective device, which conducts the high voltage surges on the power system to the ground

Fig 7(i) shows the basic form of a surge diverter. It consists of a spark gap in series with a non-linear resistor. One end of the diverter is connected to the terminal of the equipment to be protected and the other end is effectively grounded. The length of the gap is so set that normal voltage is not enough to cause an arc but a dangerously high voltage will break down the air insulation and form an arc. The property of the non-linear resistance is that its resistance increases as the voltage (or current) increases and vice-versa. This is clear from the volt/amp characteristic of the resistor shown in Fig 7 (ii).

The action of the lightning arrester or surge diverter is as under:

(i) Under normal operation, the lightning arrester is off the line i.e. it conducts no current to earth or the gap is non-conducting

(ii) On the occurrence of over voltage, the air insulation across the gap breaks down and an arc is formed providing a low resistance path for the surge to the ground. In this way, the excess charge on the
line due to the surge is harmlessly conducted through the arrester to the ground instead of being sent back over the line.

(iii) It is worthwhile to mention the function of non-linear resistor in the operation of arrester. As the gap sparks over due to over voltage, the arc would be a short-circuit on the power system and may cause power-follow current in the arrester. Since the characteristic of the resistor is to offer low resistance to high voltage (or current), it gives the effect of short-circuit. After the surge is over, the resistor offers high resistance to make the gap non-conducting.

**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. Following are the different types of lightning relays:

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

**GROUND WIRES**

The most effective method of providing protection to transmission lines against direct lightning strokes is by use of overhead ground wires as shown in Fig 6. For simplicity, one ground wire and one line conductor are shown. The ground wires are placed above the line conductors at such positions that practically all lightning strokes are intercepted by them (i.e. ground wires). The ground wires are grounded at each tower or pole through a low resistance as possible. Due to their proper location, the ground wires will take up all the lightning strokes instead of allowing them to line conductors. The degree of protection provided by the ground wires depends upon the footing resistance of the tower.
CAUSES OF OVERVOLTAGES

The over voltages on a power system may be broadly divided into two main categories:

1. Internal causes

   (i) Switching surges  (ii) Insulation failure

   (iii) Arcing ground  (iv) Resonance

2. External causes i.e. lightning

Internal causes do not produce surges of large magnitude. Experience shows that surges due to internal causes hardly increase the system voltage twice the normal value. Generally, surges due to internal causes are taken care of by providing proper insulation to the equipment in the power system. But surges due to lightning are very severe and may increase the system voltage to several the normal value. If the equipment in the power system is not protected against lightning surges, these surges may cause considerable damage.
INTERNAL CAUSES OF OVERVOLTAGES

Internal causes of over voltages on the power system are primarily due to oscillations set up by the sudden changes in the circuit conditions. This circuit change may be abnormal switching operation such as opening of a circuit breaker, or it may be the fault condition such as grounding of a line conductor.

1. Switching Surges – The over voltage, produced on the power system due to switching operations are known as switching surges. A few cases will be discussed by way of illustration:

(i) Case of open line – During switching operations of an unloaded line, traveling waves are set up to produce over voltages on the line. As an illustration consider an unloaded line being connected to a voltage source as shown in Fig 2.

![Fig 2](image)

When the unloaded line is connected to the voltage source, a voltage wave is set up which travels along the line. On reaching the terminal point A, it is reflected back to the supply end without change of sign. This causes voltage doubling i.e. voltage on the line becomes twice the normal value. If E rms is the supply voltage, then the instantaneous voltage that the lines have to withstand will be $2\sqrt{2}E$. This over voltage is of temporary nature. It is because the line losses attenuate the wave and in a very short time, the line settles down to its normal supply voltage E. Similarly if an unloaded line is switched off, the line will attain a voltage $2\sqrt{2}E$ for a moment before settling down to the normal value.
(ii) **Case of a loaded line** - Over voltages will also be produced during switching operations of a loaded line. Suppose a loaded line is suddenly interrupted. This will set up a voltage of $2ZnI$ across the break. (i.e. switch) where $I$ is the instantaneous value of current at the time of opening of line and $Z$ is the natural impedance of the line.

(iii) **Current chopping** – Current chopping results in the production of high voltage transients across the contacts of the air blast circuit breaker. Unlike oil circuit breakers, which are independent for the effectiveness on the magnitude of the current being interrupted, air-blast circuit breakers retain the same extinguishing power irrespective of the magnitude of this current. When breaking low currents (e.g. transformer magnetizing current) with air-blast breaker, the powerful de-ionising effect of air-blast causes the current to fall abruptly to zero well before the natural current zero is reached. This phenomenon is called current chopping and produces high transient voltage across breaker contacts. Over voltages due to current chopping are prevented by resistance switching.

2. **Insulation failure** - The most common case of insulation failure in a power system is grounding of conductor (i.e. insulation failure between line and earth) which may cause over voltages in the system. This is illustrated in Fig 3.

Suppose a line at potential $E$ is earthed at point $X$. The earthing of the line causes two equal voltages of $-E$ to travel along $XQ$ and $XP$ containing currents $-E/Zn$ and $+E/Zn$ respectively. Both these current pass through $X$ to earth, so that current to earth is $2E/Zn$. 

![Diagram](image-url)
3. Arcing ground – The phenomenon of intermittent arc taking place in line-to-ground fault of a 3 phase system with consequent production transients is known as arcing ground. The transients produced due to arcing ground are cumulative and may cause serious damage to the equipment in the power system by causing breakdown of insulation, Arcing-ground be prevented by earthing the neutral.

4. Resonance – Resonance in an electrical system occurs when inductive reactance of the circuit becomes equal to the capacitive reactance. Under resonance, the impedance of the circuit is equal to inductance of the circuit and the p.f. is unity. Resonance causes high voltages in the electrical system.

**Vacuum Circuit Breakers (VCB)**

In this breaker, vacuum is being used as the arc quenching medium. Vacuum offers highest insulating strength, it has far superior arc quenching properties than any other medium. 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 that obtained with other circuit breakers.

**Principle:** When the contacts of the breaker are opened in vacuum (10^-7 to 10^-5 torr), an arc is produced between the contacts by the ionization of metal vapours of contacts. The arc is quickly extinguished because the metallic vapours, electrons, and ions produced during arc condense quickly on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength. 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:** Fig 16 shows the parts of a typical vacuum circuit breaker. 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 contacts separates from the fixed contacts and an arc is struck between the contacts. The production of arc is due to the ionization 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 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.

**Advantages:**

a. They are compact, reliable and have longer life.

b. There are no fire hazards

c. There is no generation of gas during and after operation

d. 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.

e. They require little maintenance and are quiet in operation

f. Can withstand lightning surges

g. Low arc energy

h. Low inertia and hence require smaller power for control mechanism.

**Applications:** For outdoor applications ranging from 22 kV to 66 kV. Suitable for majority of applications in rural area.

**Sulpher Hexa Flouride (SF6) Circuit Breakers**

In this circuit breaker, sulphur hexaflouride (SF$_6$) gas is used as the arc quenching medium. The SF$_6$ gas 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 are very effective for high power and high voltage service.

**Construction:** Fig 15 shows the parts of a typical SF$_6$ circuit breaker. 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 reservoir. 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, its reconditioned and reclaimed by a suitable auxiliary system after each operation of the breaker.
Working: In the closed position of the breaker the contacts remained surrounded by \( \text{SF}_6 \) 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 synchronized with the opening of a valve which permits \( \text{SF}_6 \) gas at 14 kg/cm\(^2\) pressure from the reservoir to the arc interruption chamber. The high pressure flow of \( \text{SF}_6 \) 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 the valve is closed by the action of a set of springs.

Advantages over oil and air circuit breakers:

a. Due to superior arc quenching property of \( \text{SF}_6 \), such breakers have very short arcing time

b. Dielectric strength of \( \text{SF}_6 \) gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.

c. Gives noiseless operation due to its closed gas circuit

d. Closed gas enclosure keeps the interior dry so that there is no moisture problem

e. There is no risk of fire as \( \text{SF}_6 \) is non inflammable

f. There are no carbon deposits
g. Low maintenance cost, light foundation requirements and minimum auxiliary equipment

h. SF₆ breakers are totally enclosed and sealed from atmosphere, they are particularly suitable where explosion hazard exists

**Disadvantages:**

A. SF₆ breakers are costly due to high cost of SF₆
B. SF₆ gas has to be reconditioned after every operation of the breaker, additional equipment is required for this purpose

**Applications:** SF₆ breakers have been used for voltages 115kV to 230 kV, power ratings 10 MVA to 20 MVA and interrupting time less than 3 cycles.

**Air Blast Circuit Breaker**

These type of breakers employ ‘air blast’ as the quenching medium. The contacts are opened by air blast produced 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 the flow of current is interrupted.

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 air-blast is directed along the arc path as shown in figure below.

(ii) **Cross-blast type** in which air blast is directed at right angles to the arc path as shown in figure below.
(iii) Radial-blast type in which the air blast is directed radially as shown in figure below

(i) Axial-blast air circuit breaker

The figure below shows the essential components of a typical axial blast circuit breaker. The fixed and moving contacts are held in closed position by spring pressure under normal conditions. The air reservoir is connected to the arcing chamber through an air valve. This valve remains closed under normal conditions but opens automatically by tripping impulse when a fault occurs on the system.
When a fault occurs, the tripping impulse causes the opening of the air valve which connects the circuit breaker reservoir to the arcing chamber. The high pressure air entering the arcing chamber pushes away the moving contact against spring pressure. The moving contact is separated and an arc is struck. At the same time, high pressure air blast flows along the arc and takes away the ionised gases along with it. Consequently, the arc is extinguished and current flow is interrupted.

It may be noted that in such circuit breakers, the contact separation required for interruption is generally small about 1.75 cm. Such a small gap may constitute inadequate clearance for the normal service voltage. Therefore, an isolating switch is incorporated as part of this type of circuit breaker. This switch opens immediately after fault interruption to provide necessary clearance for insulation.

(ii) Cross Blast air breaker

In this type of circuit breaker, an air blast is directed at right angles to the arc. The cross-blast lengthens and forces the arc into a suitable chute for arc extinction. Figure below shows the parts of a typical cross-blast air circuit breaker.

![Cross Blast Air Circuit Breaker Diagram](image)

When the moving contact is withdrawn, an arc is struck between the fixed and moving contacts, the high pressure cross-blast forces into a chute consisting of an arc splitters and baffles. The splitters serve to increase the length of the arc and baffles give improved cooling. The result is that arc is extinguished and flow of current is interrupted. Since the blast pressure is same for all currents, the inefficiency at low currents is eliminated. The final gap for interruption is great enough to give normal insulation clearance so that series isolating switch is not necessary.

Advantages

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

1. The risk of fire is eliminated
2. The arcing products are completely removed by the blast whereas the oil deteriorates with successive operations; the expense of regular oil is replacement is avoided
3. The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small. This reduces the size of device.
4. 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 that in oil circuit breakers, thus resulting in less burning of contacts.
5. Due to lesser arc energy, air blast circuit breakers are very suitable for conditions where frequent operation is required.
6. The energy supplied for arc extinction is obtained from high pressure air and is independent of the current to be interrupted.

**Disadvantages:**

1. Air has relatively inferior arc extinguishing properties.
2. Air blast circuit breakers are very sensitive to the variations in the rate of restriking voltage.
3. Considerable maintenance is required for the compressor plant which supplies the air blast.

Air blast circuit breakers are finding wide applications in high voltage installations. Majority of circuit breakers for voltages beyond 110 kV are of this type.
**Oil circuit breakers**

In oil circuit breakers insulating oil is used as an arc quenching medium. The contacts are opened under oil and an arc is struck between them, heat of the arc evaporates the surrounding oil and produce hydrogen at high pressure. The oil is pushed away from the arc region and the gas bubble occupies adjacent portions of the contact. The arc extinction is facilitated mainly by two processes. Firstly the hydrogen gas has high heat conductivity and cools the arc, thus aiding the deionisation 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 resulting in arc extinction and interruption of current.

The advantages of using oil as an arc quenching medium are:

1. It absorbs the arc energy to decompose the oil into gases, which have excellent cooling properties.

2. It acts as an insulator and permits smaller clearance between live conductors and earthed components.

The disadvantages of oil as an arc quenching medium are:

1. Its inflammable and there is risk of fire

2. It may form an explosive mixture with air.
3. The arcing products remain in the oil and it reduces the quality of oil after several operations. This necessitates periodic checking and replacement of oil.

Oil circuit breakers can be classified into following types:

**1) Bulk oil circuit breakers**, which use a large quantity of oil. In this circuit breaker the oil serves 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 are classified into:

a) Plain oil circuit breakers
b) Arc control circuit breakers

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

**2) 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 Interruption Method**

**High resistance method** – In this method arc resistance is made to increase with time so that current becomes insufficient to maintain the arc. Disadvantage of this method is enormous energy is dissipated in the arc. Hence it can be used only in dc circuit breakers and low capacity ac circuit breakers.

Arc resistance can be increased by:

1. **Lengthening the arc** – Arc resistance is directly proportional to length of arc so to increase resistance separation between the contacts are increased

2. **Cooling the arc** – Cooling helps in deionisation of medium thus increasing arc resistance

3. **Reducing cross section of the arc** – When area of arc reduced, voltage necessary to maintain arc increased i.e. resistance is increased. Allowing the arc to pass through narrow opening can reduce cross section area.
4. Splitting the arc – The resistance can be increased by splitting the arc into number of smaller arcs in series. Each arcs experiences the effect of lengthening and cooling. Arc may be split by introducing some conducting plates between the contacts.

- **Low resistance method** – This method is employed for arc extinction in ac circuits only. In this method the arc resistance is maintained low till current zero during which arc extinguishes naturally and is prevented from restriking inspite of rising voltage across the contacts.

In ac system current drops to zero after every half cycle, during which the arc extinguishes for a brief moment. The medium still contains ions and electrons so has small dielectric strength which can be easily broken down by the rising voltage between the contacts known as restriking voltage. So if break down occur arc will persist for another half cycle. If at current zero the dielectric strength is built up more rapidly than the voltage across the contacts the arc will fail to restrike and current will be interrupted.

**Dielectric strength can be increased by:**

- Recombination of ionized particles into neutral molecules
- Replacing ionised particles by unionised particles

**Deionisation can be achieved by:**

1. **Lengthening of the gap** – Dielectric strength is directly proportional to length of gap between contacts. So by opening contacts rapidly dielectric strength can be achieved.

2. **High pressure** – When pressure increases, density of particles increases, which causes high rate of deionisation and hence increases dielectric strength of medium.

3. **Cooling** – Natural combination of ions occur rapidly when they are cooled. Therefore cooling the arc can increase dielectric strength.

4. **Blast effect** – If ionized particles are swept away and replaced by unionized particles dielectric strength can be increased. It can be achieved by gas blast directed along the discharge or by forcing oil into the contact space.
16.1 VOLT-TIME CURVE

The breakdown voltage for a particular insulation or flashover voltage for a gap is a function of both the magnitude of voltage and the time of application of the voltage. The volt-time curve is a graph showing the relation between the crest flashover voltages and the time to flashover for a series of impulse applications of a given wave shape. For the construction of volt-time curve the following procedure is adopted. Waves of the same shape but of different peak values are applied to the insulation whose volt-time curve is required. If flashover occurs on the front of the wave, the flashover point gives one point on the volt-time curve. The other possibility is that the flashover occurs just at the peak value of the wave; this gives another point on the V-T curve. The third possibility is that the flashover occurs on the tail side of the wave. In this case to find the point on the V-T curve, draw a horizontal line from the peak value of this wave and also draw a vertical line passing through the point where the flashover takes place. The intersection of the horizontal and vertical lines gives the point on the V-T curve. This procedure is nicely shown in Fig. 16.2.

![Volt-time curve (construction)](image)

The overvoltages against which coordination is required could be caused on the system due to system faults, switching operation or lightning surges. For lower voltages, normally up to about 345 kV, overvoltages caused by system faults or switching operations do not cause damage to equipment insulation although they may be detrimental to protective devices. Overvoltages caused by lightning are of sufficient magnitude to affect the equipment insulation whereas for voltages above 345 kV it is these switching surges which are more dangerous for the equipments than the lightning surges.

The problem of coordinating the insulation of the protective equipment involves not only guarding the equipment insulation but also it is desired that the protecting equipment should not be damaged.

To assist in the process of insulation coordination, standard insulation levels have been recommended. These insulation levels are defined as follows:

Basic impulse insulation levels (BIL) are reference levels expressed in impulse crest voltage with a standard wave not longer than 1.2/50 μsec wave. Apparatus insulation as demonstrated by suitable tests shall be equal to or greater than the basic insulation level.
Phenomenon Of Arc Formation

The separation of the C.B. contacts which are carrying current gives rise to an arc without changing much the current wave form. Initially when the contacts just begin to separate the magnitude of current is very large but the contact resistance being very small, a small voltage appears across them. But the distance of separation being very very small, a large voltage gradient is set up which is good enough to cause ionization of the particles between the contacts. Also it is known that with the copper contacts which are generally used for the circuit breakers very little thermal ionization can occur at temperature below the melting point. For effective field emission the voltage gradient required is $10^6$ V/cm. From this it is clear that the arc is initiated by the field emission rather than the thermal ionization. This high voltage gradient exists only for a fraction of a micro-second. But in this short period a large number of electrons would have been liberated from the cathode and these electrons while reaching anode, on their way would have collided with the atoms and molecules of the gases. Thus each emitted electron tends to create others and these in turn derive energy from the field and multiply. In short, the work done by the initially emitted electrons enables the discharge to be maintained. Finally, if the current is high, the discharge attains the form of an arc having a temperature high enough for thermal ionization, which results in lower voltage gradient. Thus an arc is initiated due to field effect and then maintained due to thermal ionization.

Neutral Earthing:

- The process of connecting the neutral point of a supply system on the non-current carrying parts of electrical apparatus to the general mass of earth in such a manner that at all times an immediate discharge of electrical energy takes place without danger is called earthing.

  Or

Earthing means connecting earth-terminals to electrodes installed solidly in the mass of earth.

  Or

A wire coming from the ground 2.5 to 3 metres deep from an electrode (plate or so) is called earthing.

- The earth's potential is always taken as zero for all practical purposes. The electrical appliances or machines when connected with earth attain zero potential and are said to be earthed.

- Good earthing is that earthing which gives very low resistance to the flow of heavy current (short-circuit current) of a circuit.

- Double earth is used to give minimum resistance to the flow of whole current of the apparatus in case short-circuit to leakage or any other such fault occurs. Second reason is, if one earth is out of order, second will do the work.

- The earth resistance for copper wire is 1 Ω and for G.I. wire it should not be more than 3 Ω.

- The earth resistance should be kept as low as possible.
Earthing is carried out to achieve the following objectives:

1. To save human life from danger or shock or death by blowing fuse of any apparatus which becomes leaky.
2. To protect all machines fed from overhead lines from lightning.
3. To protect large buildings from atmospheric lightning.
4. To maintain the line voltage constant (since neutral of every alternator, transformer is earthed).

*Earthing of neutrals of all industrial power systems is always preferable.* Earthing is necessary as it offers many *advantages* given below:

1. Persistent arcing grounds is eliminated.
2. Overvoltage due to restriking is minimized.
3. The ground faults can be located and isolated fastly.
4. Steady state voltage stress to earth is reduced.
5. Sensitive protective apparatus can be used.
6. The maintenance expenditure is reduced.
7. Better safety is ensured.
8. Service reliability is improved.
9. Earthing provides improved lightning protection.

The earthing of systems should be done at the neutral of the supply transformers and generators. If the supply transformers and generators are delta connected, separate earthing transformers may be used.

(a) Solid-earthing (already mentioned) in which the only impedance between the neutral and earth is that represented by the earthing conductor itself and the resistance between the earth-plate (or rods) and earth. An internationally accepted definition of a solidly earthed system is ‘an effectively-earthed’ system which is defined as one ‘in which, during a phase-to-earth fault, the voltage-to-earth of any sound phase does not exceed 80 per cent of the voltage between phases of the system.’

(b) Resistance-earthing, in which a resistor is interposed between the star-point and earth. This is also known as ‘non-effective’ earthing, the converse of effective earthing.

(c) Reactance-earthing (also non-effective), in which a reactor is used instead of a resistor. The reactance (like the resistance of the resistor) is chosen to suit the requirements of the protection, or to control inductive interference, which is the predominant requirement.
(d) Arc-suppression (Petersen) coil earthing, in which a reactor is used but its reactance is adjusted to match, more or less exactly, the value of the capacitance to earth of two phases with the third phase connected solidly to earth. In this way the reactive component of the capacitive current flowing in the connection to earth formed by the fault is neutralized by the coil current, which flows in the same path but is displaced in phase by 180° from the capacitive current (see Fig. 1.3.1B). The coil reactance is adjustable in relatively coarse steps, to allow for variations in system zero-sequence capacitance resulting from the switching out of circuits.

(e) Earthing through a combination of arc suppression coil and resistor, in which a persistent earth-fault on one phase is ‘suppressed’ by the coil. As it is not desired that the fault should remain indefinitely on the system, after a delay, adjustable up to 30 s, the coil is automatically shunted by a resistor of low value which permits adequate earth-fault current to flow to operate orthodox discriminative protection. The resistor and its associated circuit-breaker are seen in Fig. 1.3.1B.
Basic Impulse Insulation Level (BIL)

The insulation strength of equipment like transformers, circuit breakers, etc. should be higher than that of the lightning arresters and other surge protective devices. In order to protect the equipment of the power system from overvoltages of excessive magnitude, it is necessary to fix an insulation level for the system to see that any insulation in the system does not breakdown or flashover below this level and to apply protective devices that will give the apparatus effective protection.

Several methods of providing coordination between insulation levels in the station and on the line leading to the station have been offered. The best method is to establish a definite common level for all the insulation in the station and bring all insulation to or above this level. This limits the problem to three fundamental requirements, namely, the selection of a suitable insulation level, the assurance that the breakdown or flashover strength of all insulation in the station will equal or exceed the selected level, and the application of protective devices that will give the apparatus as good protection as can be justified economically.

The common insulation level for all the insulation in the station is known as Basic Impulse Insulation Level (B.I.L) which have been established in terms of withstanding voltages of apparatus and lines.

Basic impulse insulation level can be defined as reference level expressed in impulse crest voltage with a standard wave not longer than a 1.2/50 microsecond wave, according to Indian standards (1.5/40 μs in USA and 1/50 μs in UK). Apparatus insulation as demonstrated by suitable tests should be equal to or greater than the B.I.L.

The basic impulse insulation level for a system is selected such that the system could be protected with a suitable lightning protective device, e.g. a lightning arrester. The margin between the B.I.L. and the lightning arrester should be fixed such that it is economical and it also ensures protection to the system. The B.I.L. chosen must be higher than the maximum expected surge voltage across the selected arrester.
Surge Diverter

They are connected between the line and ground at the substation and always act in shunt (parallel) with the equipment to be protected, and perform their protective function by providing a low-impedance path for the surge currents so that the surge arrester’s protective level is less than the surge voltage withstanding capacity of the insulation of equipment being protected. A lightning arrester’s protective level is the voltage appearing across the terminals of the arrester at sparkover or during the flow of current through the arrester after sparkover. The main purpose of lightning arresters is to divert or discharge the surge to the ground.

The action of the surge diverter can be studied with the help of Fig. 11.15. When the travelling surge reaches the diverter, it sparks over at a certain prefixed voltage as shown by point P and provides a relatively low-impedance path to ground for the surge current. The current flowing to ground through the surge impedance of the line limits the amplitude of the overvoltage across the line and ground known as ‘residual voltage’ (as shown by point Q in Fig. 11.15) to such a value which will protect the insulation of the equipment being protected.

![Voltage characteristic of surge diverter](image)

**FIGURE 11.15 Voltage characteristic of surge diverter**

It is however, essential that the low-impedance path to ground must not exist before the overvoltage appears and it must cease to exist immediately after the voltage returns back to its normal value.

An ideal lightning arrester or surge diverter should possess the following characteristics.

(i) It should not draw any current at normal power frequency voltage, i.e. during the normal operation.

(ii) It should breakdown very quickly when the abnormal transient voltage above its breakdown value appears, so that a low-impedance path to ground can be provided.

(iii) The discharge current after breakdown should not be so excessive so as to damage the surge diverter itself.
**Arcing Ground**

3. **Arcing ground.** The phenomenon of intermittent arc taking place in line-ground fault of a 3-phase system with consequent production of transients is known as **arc ing ground.**

The transients produced due to arcing ground are cumulative and may cause serious damage to the equipment in the power system by causing insulation breakdown.

Arcing ground can be prevented by **earthing the neutral.**

**DC Current Breaking**

It is easy to interrupt a.c. currents because of their natural zeros. Since d.c. is a steady unidirectional current it does not have a natural zero and therefore it is difficult to interrupt large d.c. currents at high voltages.

The d.c. transmission projects till this date are two terminal projects and it is not difficult to interrupt the fault currents. The faults on the d.c. line or in the converters are cleared by using the control grids of the converter valves to stop the direct current temporarily.

The a.c. transmission lines also were radial initially. But later on with the increase in demand the requirement of low cost energy and of higher reliability, these transmission lines turned into complex networks. The lack of d.c. breakers has inhibited the networking of d.c. lines. The transient faults can be cleared using grid control, but permanent faults can be cleared using a combination of grid control, fault locators and isolating switches. Reasonable proposals have been made for clearing faults on such lines by running the whole system to zero using grid control, opening switches to isolate the faulty section and then raising the voltage back to normal. The time taken for this sequence of operation is approximately equal to the rapid reclosure of a.c. circuit breakers.

The requirement for d.c. circuit breaking is not to break the actual short circuit current but to interrupt load currents in circuits at high potential with respect to ground because the short circuit currents can be limited to normal load currents using the grid control. If such switches could be developed, lines could be switched into or out of an unfaulted network without running the voltage down. Some such switches have been suggested wherein an artificial zero of current is created through the contacts of the switch by the oscillatory discharge of a capacitor. The crest value of the oscillatory currents should be greater than the direct current to be interrupted.

A schematic diagram of such a switch is shown in Fig. 5.24.

A is a normally open contact whereas M and B are normally closed contacts. As a result the capacitor C is charged to line voltage through the high resistance R. When it is desired to interrupt the current I₀, the operating mechanism opens contact B and closes A, thus initiating the oscillations in the circuit consisting of M, A, C and L and immediately afterwards the contact M opens which interrupt the current at a current zero such as P as shown in Fig. 5.24 (b). After this, contact A is opened and B closed.
Fig. 5.24  (a) Schematic diagram of a d.c. switch (oscillatory discharge),
(b) Current waveform through $M$.

Another switch proposed is as shown in Fig. 5.25.

Fig. 5.25 Schematic diagram of a d.c. switch (Nonlinear resistor).

Here $M$ is the main contact which is normally closed and $C$ is a capacitor which is normally uncharged. When it is desired to interrupt current $I_d$, the contacts $M$ open, thereby a part of the current is diverted to the capacitor and as a result the current to be interrupted by the contact $M$ is small. The rate of rise of recovery voltage across $M$ is $\frac{dV_c}{dt} = \frac{I_d}{C}$. The nonlinear resistor $R$ absorbs energy without greatly adding to the voltage across $M$. 