Over Voltages and Insulation requirement - I

Requirements

- Generation of Overvoltages:
    - Lightning and
    - Switching Surges
- Protection against Overvoltage
- Insulation Coordination
- Propagation of Surges
- Voltages produced by travelling surges.

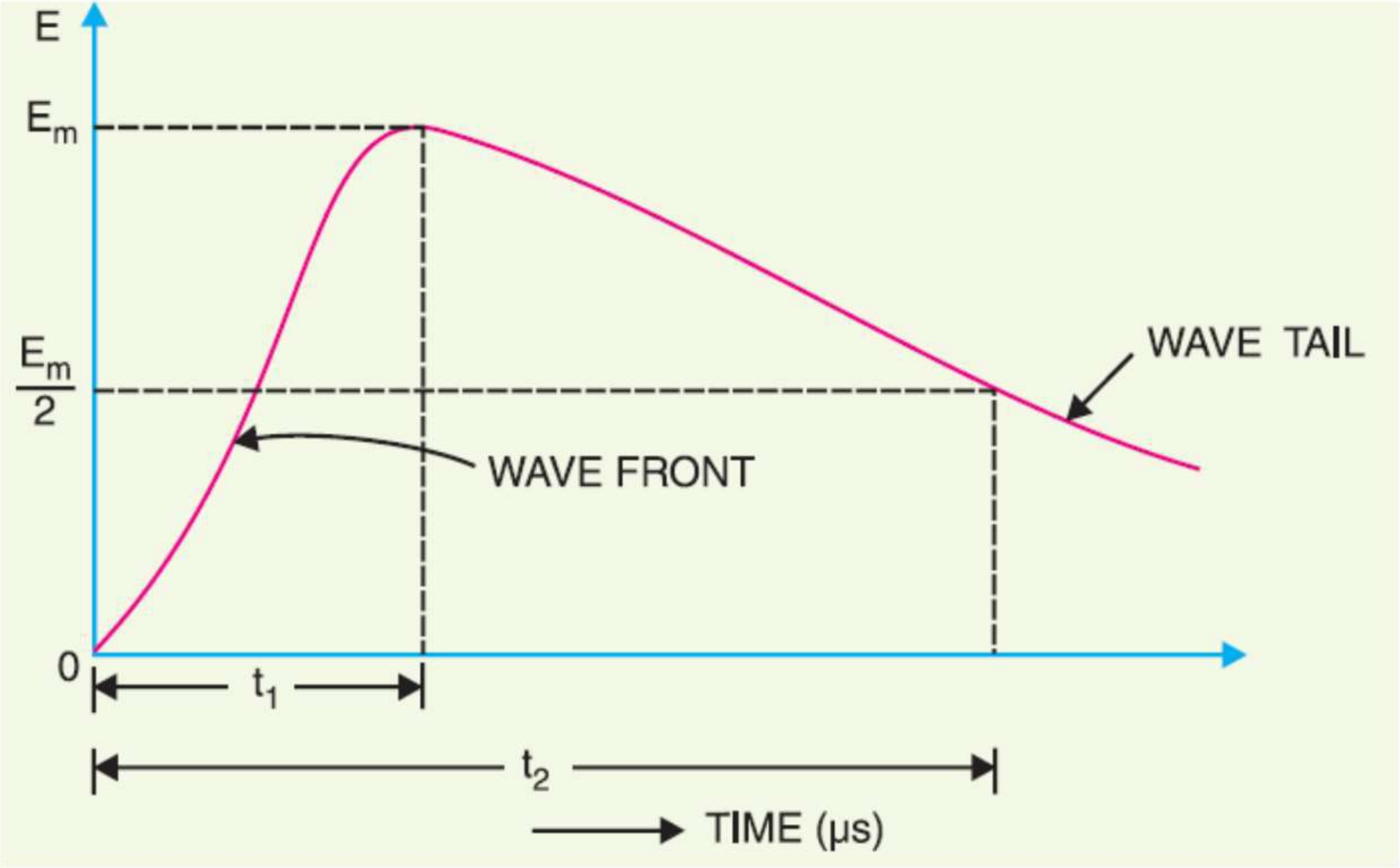
Voltage Surge

- A sudden rise in voltage for a very short duration on the power system is known as a voltage surge or transient voltage.
- Transients or surges are of temporary nature and exist for a very short duration (a few hundred μs) but they cause overvoltages on the power system.

Voltage Surge

- They originate from switching and lightning striking a transmission line.
- Surges may cause the line insulators to flash over
- They may also damage the nearby transformers, generators or other equipment connected to the line if the equipment is not suitably protected.

Wave-form of a typical lightning surge



Wave-form of a typical lightning surge

- Lightning introduces a steep-fronted wave.
- The steeper the wave front, the more rapid is the build-up of voltage at any point in the network.
- Voltage surges are generally specified in terms of *rise time t_1 and the time t_2 to decay to half of the peak value.
- Ex: a 1/50 μs surge is one which reaches its maximum value in 1μs and decays to half of its peak value is 50 μs.

Causes of Overvoltages

Internal causes

- Switching surges
- Insulation failure
- Arcing ground
- Resonance

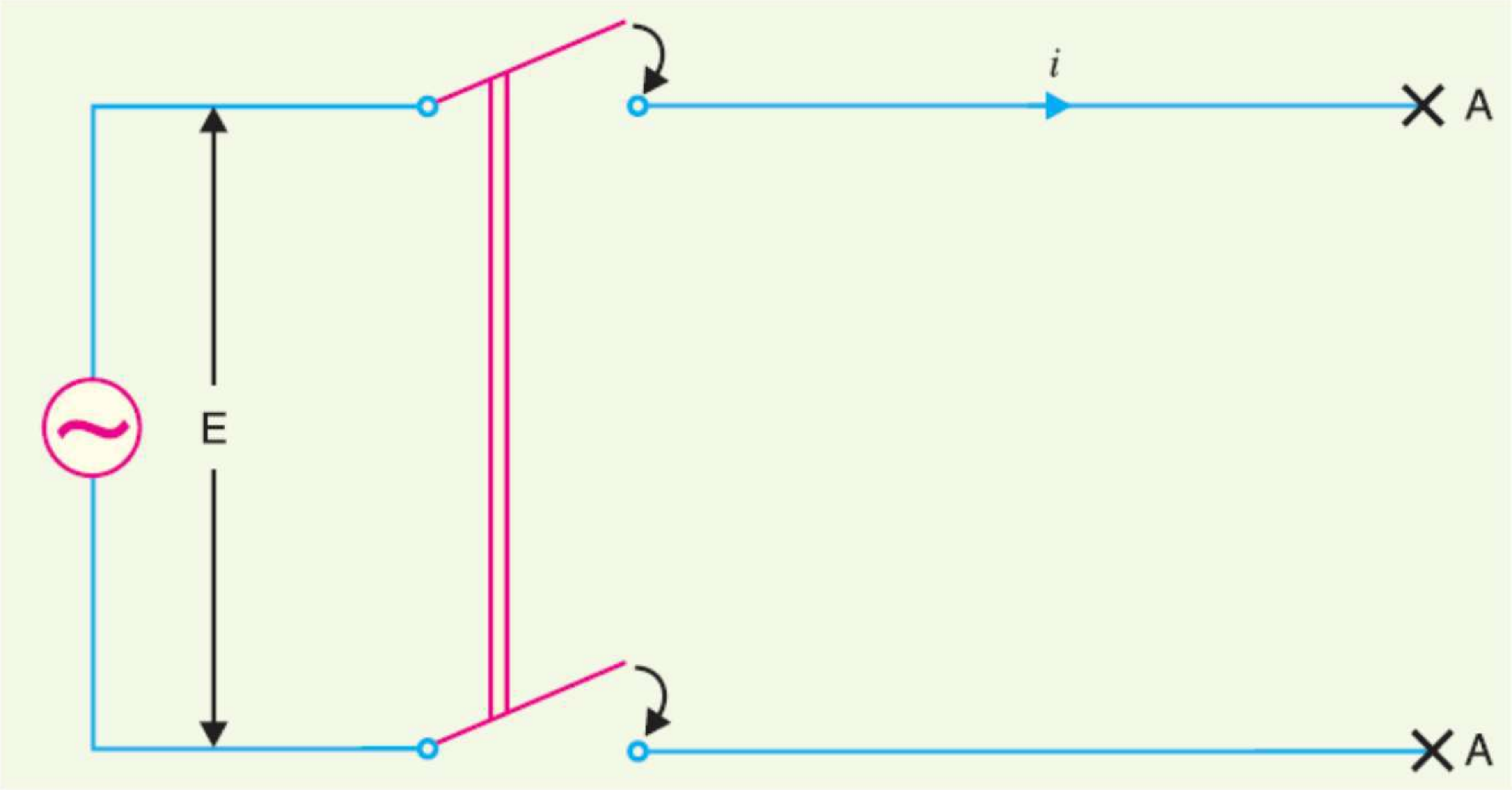
External causes

- Lightning

Switching Surges

- The overvoltages produced on the power system due to switching operations are known as switching surges.

Case of an open line.



Case of an open line.

- During switching operations of an unloaded line, travelling waves are set up which produce overvoltages on the line.
- 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.

Case of an open line.

- If $E_{r.m.s.}$ is the supply voltage, then instantaneous voltage which the line will have to withstand will be $2\sqrt{2}\,E$.
- This overvoltage 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 of $2\sqrt{2}\,E$ for a moment before settling down to the normal value.

Case of a loaded line

- Suppose a loaded line is suddenly interrupted. This will set up a voltage of 2 Zn i across the break (i.e. switch)

  where

  i is the instantaneous value of current at the time of opening of line and

  Zn is the natural impedance of the line.

Case of a loaded line

Example:

- suppose the line having Zn = 1000 Ω carries a current of 100 A (r.m.s.) and the break occurs at the moment when current is maximum.
- The voltage across the breaker (i.e. switch) = 2 2 × 100 × 1000/1000 = 282·8 kV.
- If Vm is the peak value of voltage in kV, the maximum voltage to which the line may be subjected is = (Vm + 282·8) kV.

Over Voltages and Insulation requirement - II

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.

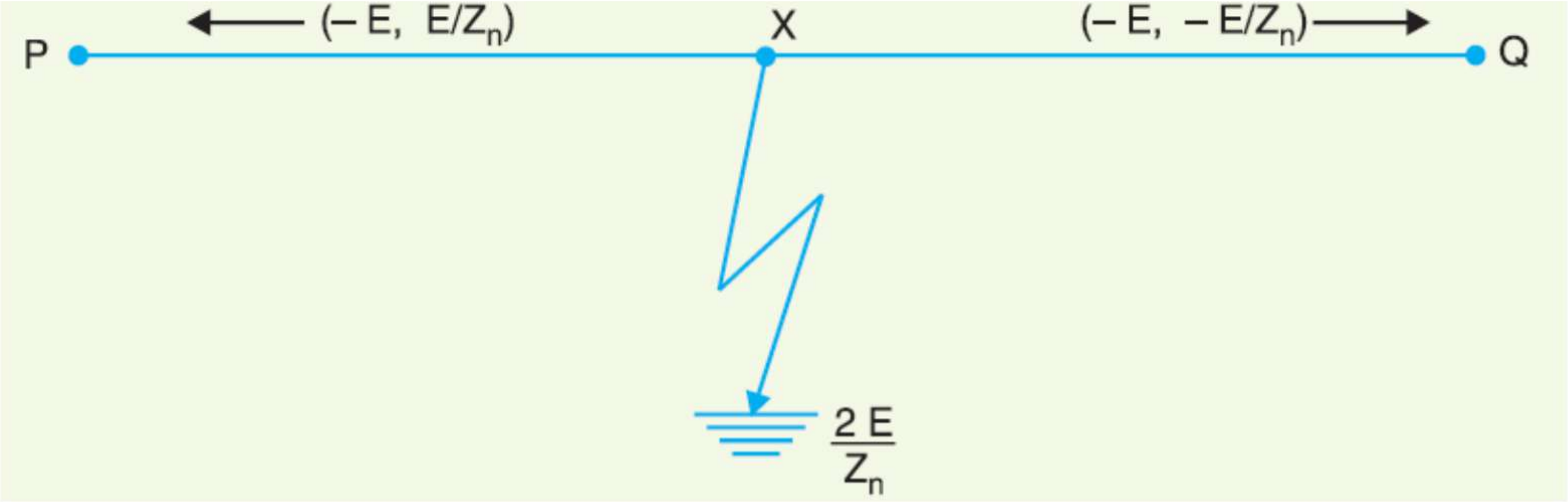
Current chopping

- When breaking low currents (e.g. transformer magnetising 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 the breaker contacts.
- Overvoltages due to current chopping are prevented by resistance switching

Insulation failure

- The most common case of insulation failure in a power system is the **grounding of conductor** (i.e. insulation failure between line and earth) which may cause overvoltages in the system.
- 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.
- Bot these currents pass through X to earth so that current to earth is 2 E/Zn

Insulation failure



- Bot these currents pass through X to earth so that current to earth is 2 E/Zn

Arcing ground

- In the early days of transmission, the neutral of three phase lines was not earthed to gain two advantages.
- Firstly, in case of line-to-ground fault, the line is not put out of action.
- Secondly, the zero sequence currents are eliminated, resulting in the decrease of interference with communication lines.

Arcing ground

- Insulated neutrals give no problem with short lines and comparatively low voltages.
- However, when the lines are long and operate at high voltages, serious problem called arcing ground is often witnessed.
- The arcing ground produces severe oscillations of three to four times the normal voltage.

Arcing ground

- The phenomenon of intermittent arc taking place in line-to-ground fault of a 3φ system with consequent production of 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 can be prevented by earthing the neutral.

Resonance

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

Resonance

- In the usual transmission lines, the capacitance is very small so that resonance rarely occurs at the fundamental supply frequency.
- However, if generator e.m.f. wave is distorted, the trouble of resonance may occur due to 5th or higher harmonics and in case of underground cables too.

Lightning

How the clouds acquire charge?

- During the uprush of warm moist air from earth, the friction between the air and the tiny particles of water causes the building up of charges.
- When drops of water are formed, the larger drops become positively charged and the smaller drops become negatively charged.

Lightning

How the clouds acquire charge?

- When the drops of water accumulate, they form clouds, and hence cloud may possess either a positive or a negative charge, depending upon the charge of drops of water they contain.
- The charge on a cloud may become so great that it may discharge to another cloud or to earth and we call this discharge as lightning.

Lightning

How the clouds acquire charge?

- The thunder which accompanies lightning is due to the fact that lightning suddenly heats up the air, thereby causing it to expand.
- The surrounding air pushes the expanded air back and forth causing the wave motion of air which we recognise as thunder.

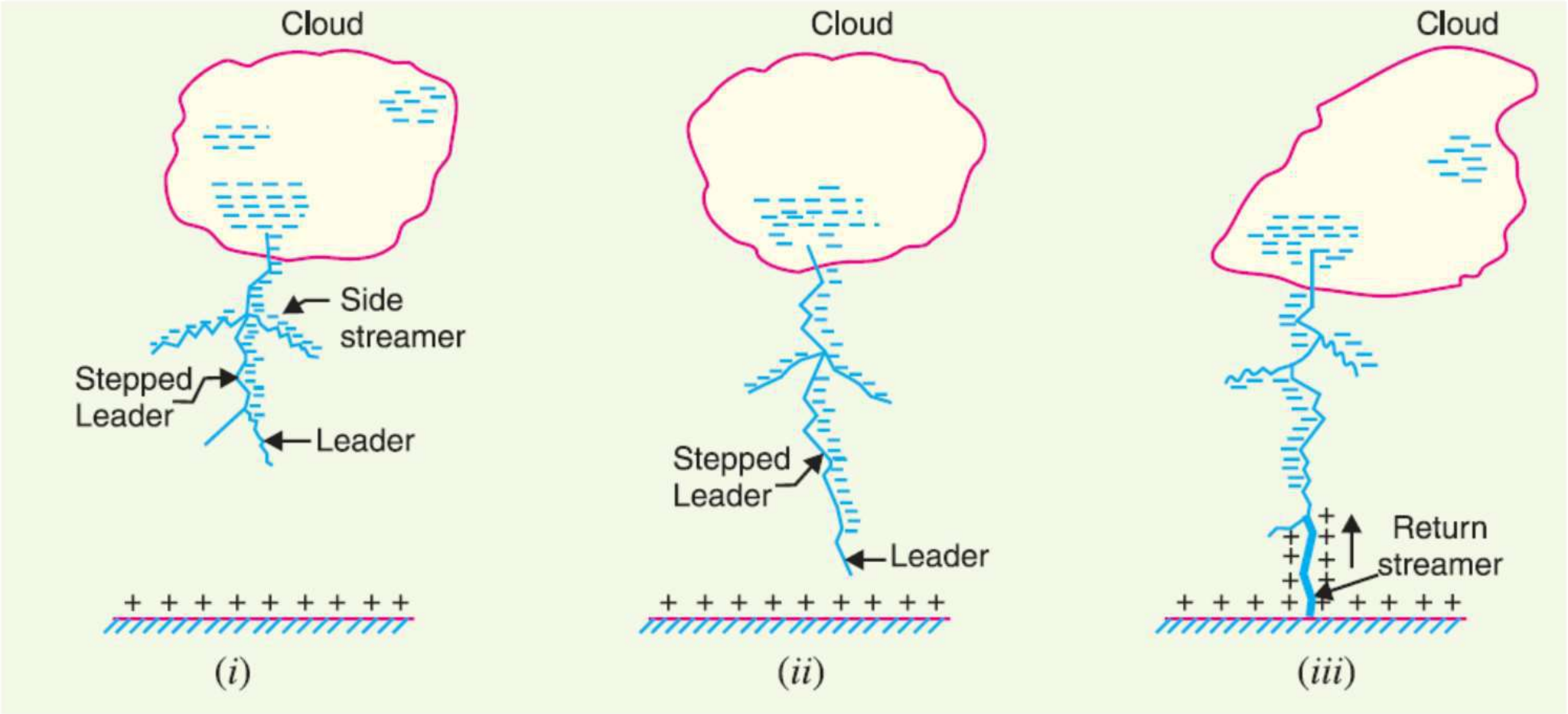
Lightning

- An electric discharge between cloud and earth, between clouds or between the charge centres of the same cloud is known as lightning.
- Lightning is a huge spark and takes place when clouds are charged to such a high potential (+ve or –ve) with respect to earth or a neighbouring cloud that the dielectric strength of neighbouring medium (air) is destroyed.

Mechanism of Lightning Discharge

- When a charged cloud passes over the earth, it induces equal and opposite charge on the earth below.
- As the charge acquired by the cloud increases, the potential between cloud and earth increases and, therefore, **gradient in the air increases**.
- When the potential gradient is sufficient (5 kV/cm to 10 kV/cm) to break down the surrounding air, the lightning stroke starts.

Mechanism of Lightning Discharge



Mechanism of Lightning Discharge

- As soon as the air near the cloud breaks down, a streamer called **leader streamer** or **pilot streamer** starts from the cloud towards the earth and carries charge with it.
- The leader streamer will continue its journey towards earth as long as the cloud, from which it originates feeds enough charge to it to maintain gradient at the tip of leader streamer above the strength of air.

Mechanism of Lightning Discharge

- If this gradient is not maintained, the leader streamer stops and the charge is dissipated without the formation of a complete stroke.
- In many cases, the leader streamer **continues its journey** towards earth until it makes contact with earth or some object on the earth.
- As the leader streamer moves towards earth, it is accompanied by points of luminescence which travel in jumps giving rise to stepped leaders.

Mechanism of Lightning Discharge

- The velocity of stepped leader exceeds **one-sixth of that of light** and distance travelled in one step is about **50 m**.
- Stepped leaders have sufficient luminosity and give rise to **first visual phenomenon of discharge**
- As the leader streamer reaches near the earth, a **return streamer** shoots up from the earth to the cloud, following the same path as the main channel of the downward leader.

Mechanism of Lightning Discharge

- The action can be compared with the closing of a switch between the positive and negative terminals; the downward leader having negative charge and return streamer the positive charge.
- This phenomenon causes a sudden spark which we call **lightning**.
- With the resulting **neutralisation** of much of the negative charge on the cloud, any further discharge from the cloud may have to originate from some other portion of it.

Points to be noted: Lightning Discharge

- The interval between strokes varies from 0·0005 to 0·5 second.
- Each separate stroke starts as a downward leader from the cloud.
- 87% of all lightning strokes result from negatively charged clouds and only 13% originate from positively charged clouds.
- There occur about 100 lightning strokes/ second.
- Lightning discharge may have currents in the range of 10 kA to 90 kA.

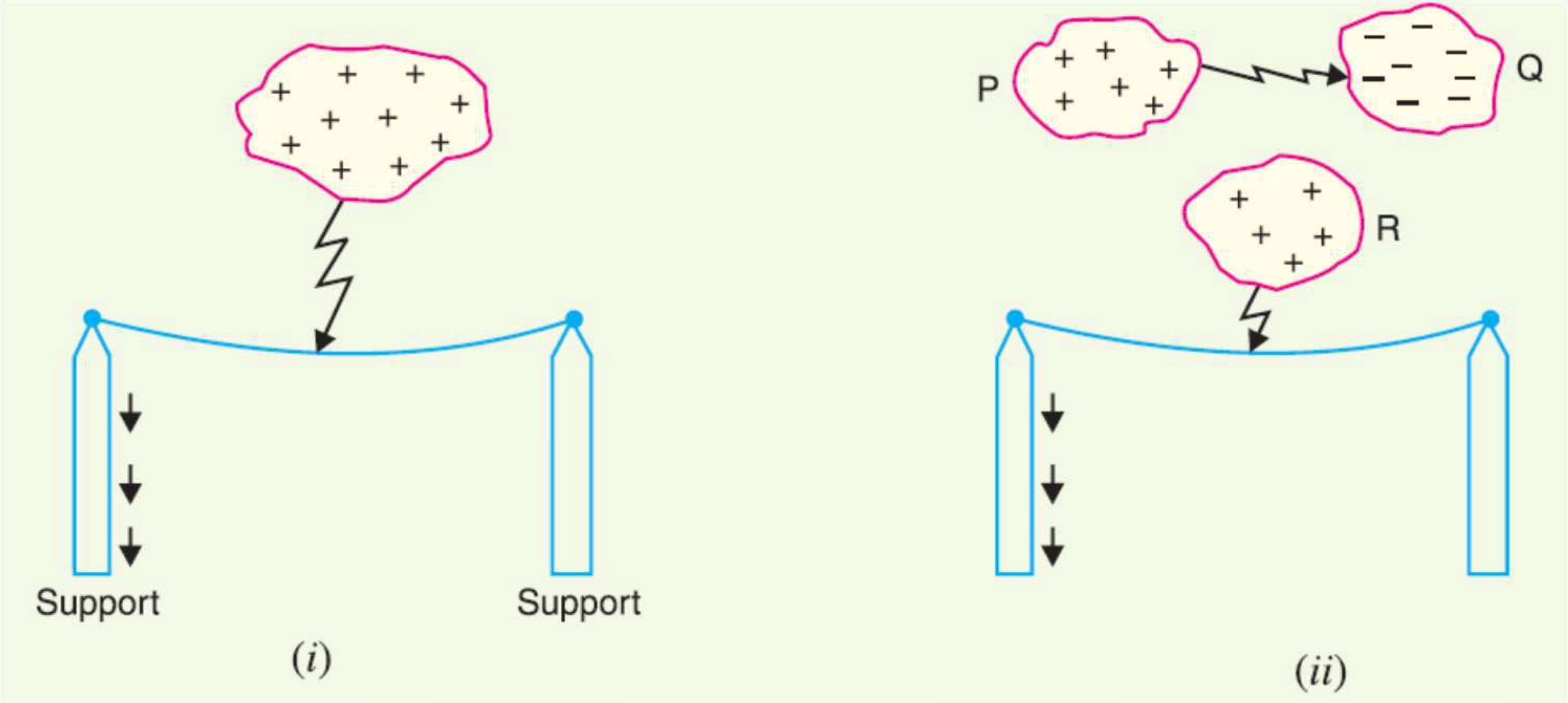
Types of Lightning Strokes

- **Direct stroke**
- **Indirect stroke**

Direct stroke

- Lightning discharge is directly from the cloud to the subject equipment e.g. an overhead line.
- From the line, the current path may be over the insulators down the pole to the ground.
- The overvoltages set up due to the stroke may be large enough to flashover this path directly to the ground.
- The direct strokes can be of two types viz.
  (i) Stroke A and (ii) stroke B.

Direct stroke



Direct stroke: Stroke A

- Lightning discharge is from the cloud to the subject equipment i.e. an overhead line in this case as shown in Fig. (i).
- The cloud will induce a charge of opposite sign on the tall object.
- When the potential between the cloud and line exceeds the breakdown value of air, the lightning discharge occurs between the cloud and the line.

Direct stroke: Stroke B

- There are three clouds P, Q and R having positive, negative and positive charges respectively.
- The charge on cloud Q is bound by the cloud R.
- If the cloud P shifts too near the cloud Q, then lightning discharge will occur between them and charges on both these clouds disappear quickly.
- The result is that charge on cloud R suddenly becomes free and it then discharges rapidly to earth, ignoring tall objects.

Direct strokes

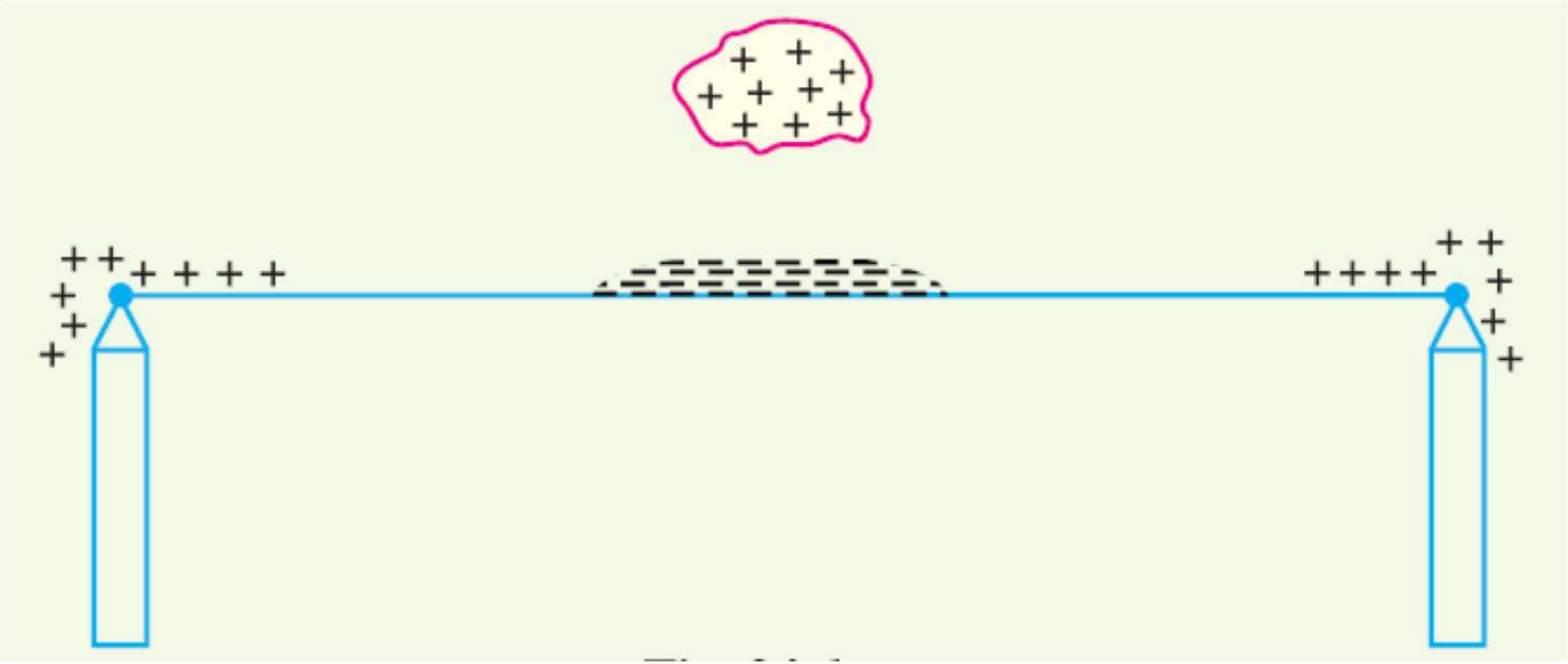
Points worth noting:

- Direct strokes on the power system are very rare.
- Stroke A will always occur on tall objects and hence protection can be provided against it.
- Stroke B completely ignores the height of the object and can even strike the ground. Therefore, it is not possible to provide protection against stroke B.

Indirect stroke

- Indirect strokes result from the electrostatically induced charges on the conductors due to the presence of charged clouds.
- A positively charged cloud is above the line and induces a negative charge on the line by electrostatic induction.
- This negative charge, however, will be only on that portion of the line right under the cloud and the portions of the line away from it will be positively charged.

Indirect stroke



Indirect stroke

- The induced positive charge leaks slowly to earth via the insulators.
- When the cloud discharges to earth or to another cloud, the negative charge on the wire is isolated as it cannot flow quickly to earth over the insulators.
- The result is that negative charge rushes along the line is both directions in the form of travelling waves.
- Majority of the surges in a transmission line are caused by indirect lightning strokes.

Harmful Effects of Lightning

- The travelling waves produced due to lightning surges will shatter the insulators and may even wreck poles.
- If the travelling waves produced due to lightning hit the windings of a transformer or generator, it may cause considerable damage.
- If the arc is initiated in any part of the power system by the lightning stroke, this arc will set up very disturbing oscillations in the line. This may damage other equipment connected to the line.

Protection Against Lightning

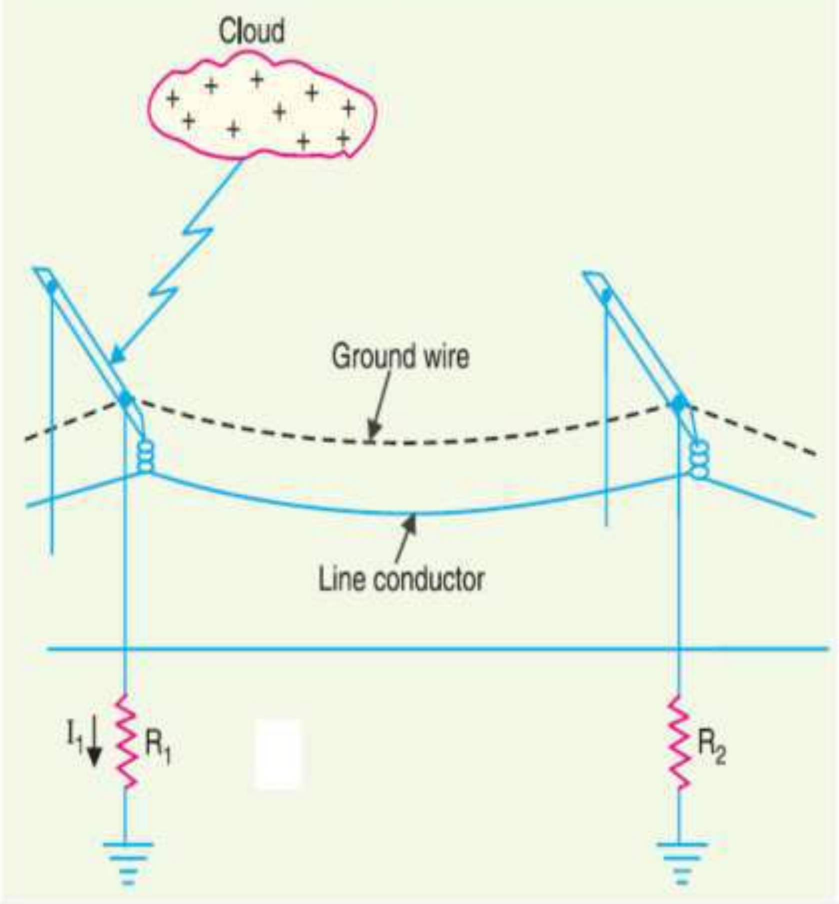
- Earthing screen
- Overhead ground wires
- Lightning arresters or surge diverters

The Earthing Screen

- It consists of a network of copper conductors mounted all over the electrical equipment in the sub-station or power station.
- The shield is properly connected to earth on atleast two points through a low impedance.
- On the occurrence of direct stroke on the station, screen provides a low resistance path by which lightning surges are conducted to ground.
- Limitation:it does not provide protection against the travelling waves which may reach the equipment in the station.

Over Voltages and Insulation requirement - III

Overhead Ground Wires



Overhead Ground Wires

- The ground wires are placed above the line conductors at such positions that practically all lightning strokes are intercepted by them.
- The ground wires are grounded at each tower or pole through as low resistance as possible.
- The heavy lightning current (10 kA to 50 kA) from the ground wire flows to the ground, thus protecting the line from the harmful effects of lightning.

Overhead Ground Wires

- Degree of protection provided by the ground wires depends upon the footing resistance of the tower.
- Ex: If Tower-footing resistance is R_1 ohms and that the lightning current from tower to ground is I_1 amperes.
- Then the tower rises to a potential V_t given by ;
  $V_t = I_1 R_1$

Overhead Ground Wires

- Since Vt (= I_1R_1) is the approximate voltage between tower and line conductor, this will appear across the string of insulators.
- If the value of Vt is less than that required to cause insulator flashover, no trouble results.
- On the other hand, if Vt is excessive, the insulator flashover may occur.
- Since Vt depends upon tower-footing resistance R_1, it should be kept as low as possible to avoid insulator flashover.

Overhead Ground Wires

Advantages

- Provides protection against direct lightning strokes.
- A grounding wire provides damping effect on any disturbance travelling along the line as it acts as a short-circuited secondary.
- It provides a certain amount of electrostatic shielding against external fields.
- Thus it reduces the voltages induced in the line conductors due to the discharge of a neighbouring cloud.

Overhead Ground Wires

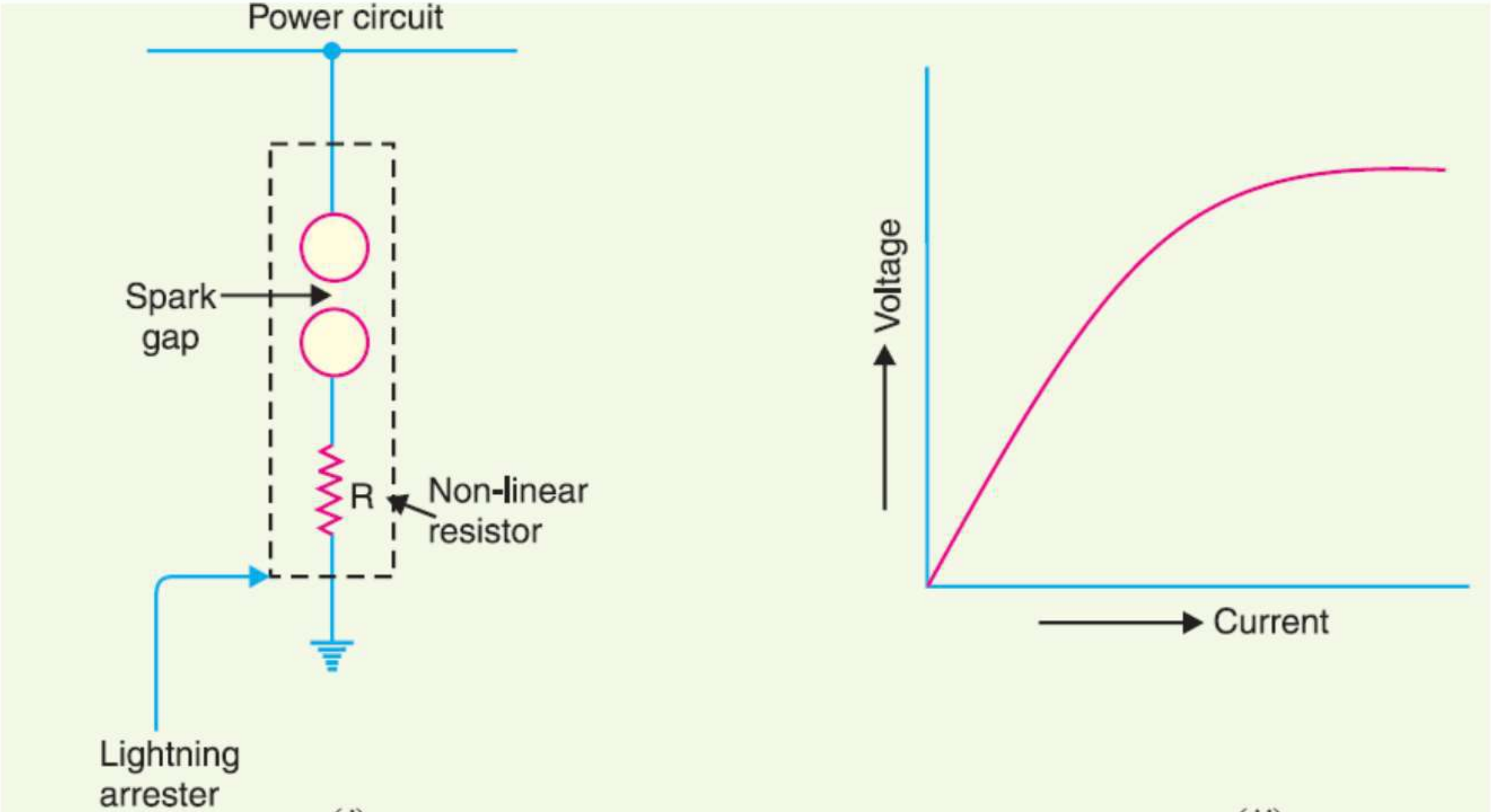
Disadvantages

- It requires additional cost.
- There is a possibility of its breaking and falling across the line conductors, thereby causing a short-circuit fault.
- This objection has been greatly eliminated by using galvanised stranded steel conductors as ground wires. This provides sufficient strength to the ground wires.

Lightning Arresters

- The earthing screen and ground wires fail to provide protection against travelling waves which may reach the terminal apparatus.
- A **lightning arrester** or **a surge diverter** is a protective device which conducts the high voltage surges on the power system to the ground.

Lightning Arresters



(i) (ii)

Lightning Arresters

- 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 line voltage is not enough to cause an arc across the gap but a dangerously high voltage will break down the air insulation and form an arc.

Lightning Arresters

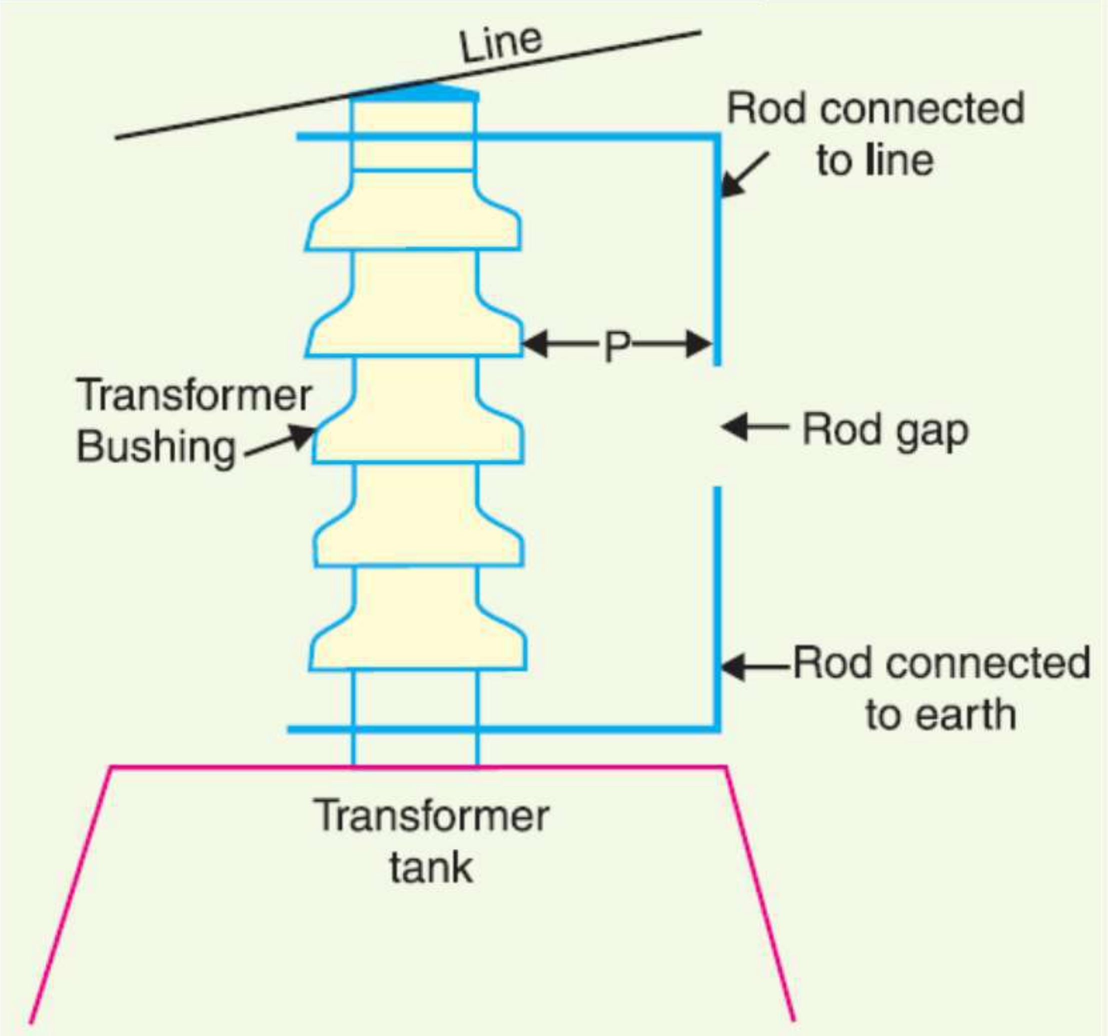
- The property of the non-linear resistance is that its resistance decreases as the voltage (or current) increases and vice-versa.
- This is clear from the *volt/amp characteristic of the resistor

Types of Lightning Arresters

- Rod gap arrester
- Horn gap arrester
- Multigap arrester
- Expulsion type lightning arrester
- Valve type lightning arrester

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.
- One rod is connected to the line circuit and the other rod is connected to earth.



Rod Gap Arrester

- The distance between gap and insulator must not be less than one-third of the gap length so that the arc may not damage the insulator.
- Gap length is so adjusted that breakdown should occur at 80% of spark- over 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.

Rod Gap Arrester

Limitations

- After the surge is over, the arc in the gap is maintained by the normal supply voltage, leading to a short-circuit on the system.
- The rods may melt or get damaged due to excessive heat produced by the arc.
- The climatic conditions (e.g. rain, humidity, temperature etc.) affect the performance of rod gap arrester.

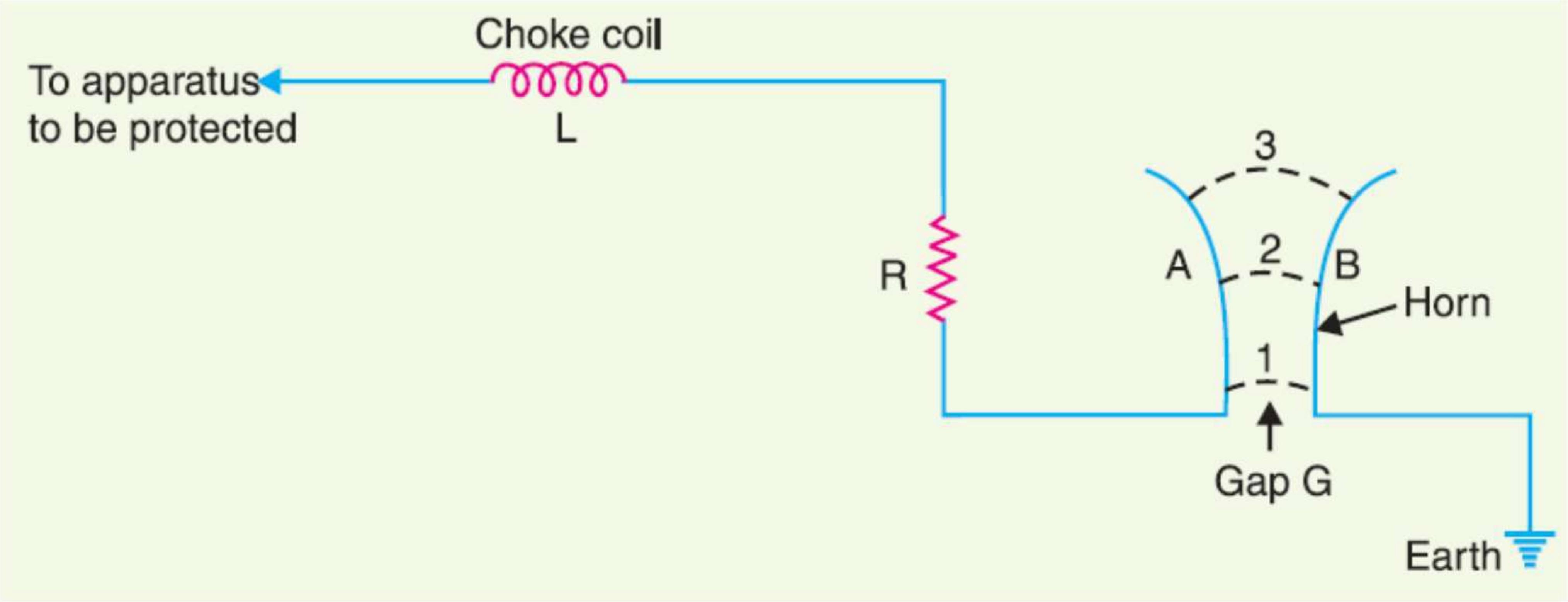
Rod Gap Arrester

Limitations

- The polarity of the surge also affects the performance of this arrester.

Hence, the rod gap arrester is only used as a '**back-up**' protection in case of main arresters.

Horn Gap Arrester



Horn Gap Arrester

- It consists of two horn shaped metal rods A and B separated by a small air gap.
- The horns are so constructed that distance between them gradually increases towards the top as shown.
- The horns are mounted on porcelain insulators.
- One end of horn is connected to the line through a resistance R and choke coil L while the other end is effectively grounded.

Horn Gap Arrester

- The resistance R helps in limiting the follow current to a small value.
- The choke coil is so designed that it offers small reactance at normal power frequency but a very high reactance at transient frequency.
- Thus the choke does not allow the transients to enter the apparatus to be protected.
- The gap between the horns is so adjusted that normal supply voltage is not enough to cause an arc across the gap.

Horn Gap Arrester

- On the occurrence of an overvoltage, spark-over takes place across the small gap G.
- The heated air around the arc and the magnetic effect of the arc cause the arc to travel up the gap.
- The arc moves progressively upwards and at some position of the arc, the distance may be too great for the voltage to maintain the arc.
- Consequently, the arc is extinguished.
- The excess charge on the line is thus conducted through the arrester to the ground.

Horn Gap Arrester

Advantages

- The arc is self-clearing. Therefore, this type of arrester does not cause short-circuiting of the system after the surge is over as in the case of rod gap.
- Series resistance helps in limiting the follow current to a small value.

Horn Gap Arrester

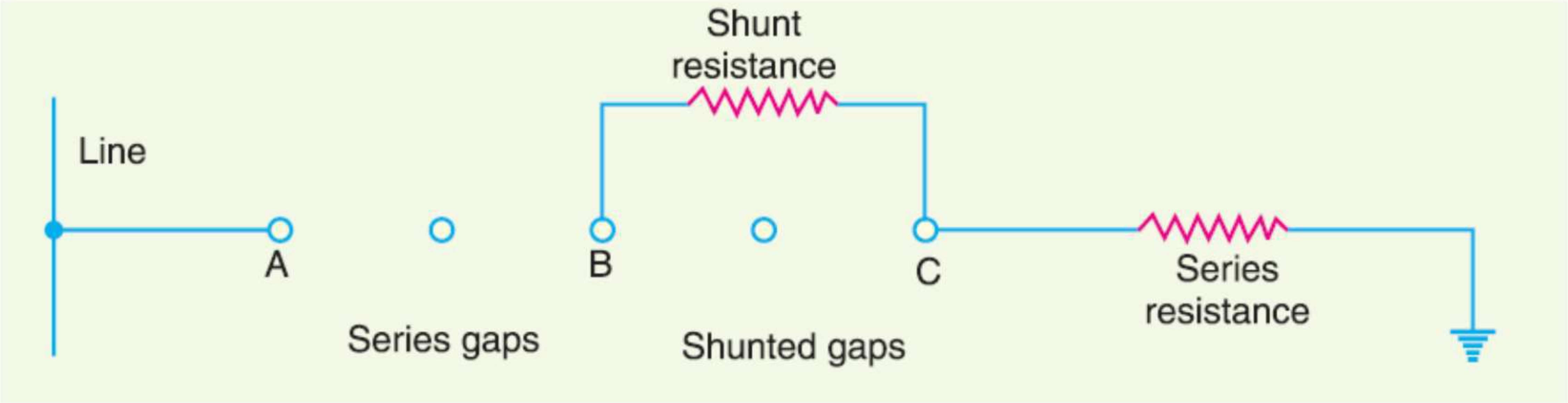
Limitations

- The bridging of gap by some external agency (e.g. birds) can render the device useless.
- The setting of horn gap is likely to change due to corrosion or pitting. This adversely affects the performance of the arrester.
- The time of operation is comparatively long, say about 3 seconds. In view of the very short operating time of modern protective gear for feeders, this time is far long.

Horn Gap Arrester

Due to the above limitations, this type of arrester is not reliable and can only be used as a second line of defence like the rod gap arrester.

Multigap arrester



Multigap arrester

- It consists of a series of metallic (generally alloy of zinc) cylinders insulated from one another and separated by small intervals of air gaps.
- The first cylinder (i.e. A) in the series is connected to the line and the other to the ground through a series resistance.
- The series resistance limits the power arc.
- **By the inclusion of series resistance, the degree of protection against travelling waves is reduced**.

Multigap arrester

- In order to overcome this difficulty, some of the gaps (B to C) are shunted by a resistance.
- Under normal conditions, the point B is at earth potential and the normal supply voltage is unable to break down the series gaps.
- On the occurrence of an overvoltage, the breakdown of series gaps A to B occurs.

Multigap arrester

- The heavy current after breakdown will choose the straight - through path to earth via the shunted gaps B and C, instead of the alternative path through the shunt resistance.
- When the surge is over, the arcs B to C go out and any power current following the surge is limited by the two resistances (shunt resistance and series resistance) which are now in series.

Multigap arrester

- The current is too small to maintain the arcs in the gaps A to B and normal conditions are restored.
- Such arresters can be employed where system voltage does not exceed 33 kV.