UNIT -I

OVER VOLTAGE IN ELECTRICAL POWER SYSTEM

Causes of over voltage in Power System:

Increase in voltage for the very short time in power system is called as the over voltage. it is also known as the voltage surge or voltage transients. The voltage stress caused by over voltage can damage the lines and equipment's connected to the system, There are two types of causes of over voltage in power system.

1. Over voltage due to external causes
2. Over voltage due to internal causes

Transient over voltages can be generated at high frequency (load switching and lightning), medium frequency (capacitor energizing), or low frequency.

Over voltage due to external causes: This cause of over voltage in power system is the lightning strokes in the cloud. Now, how lightning strokes are produced. So when electric charges get accumulated in clouds due to thunder Strom caused due to some bad atmosphere process.

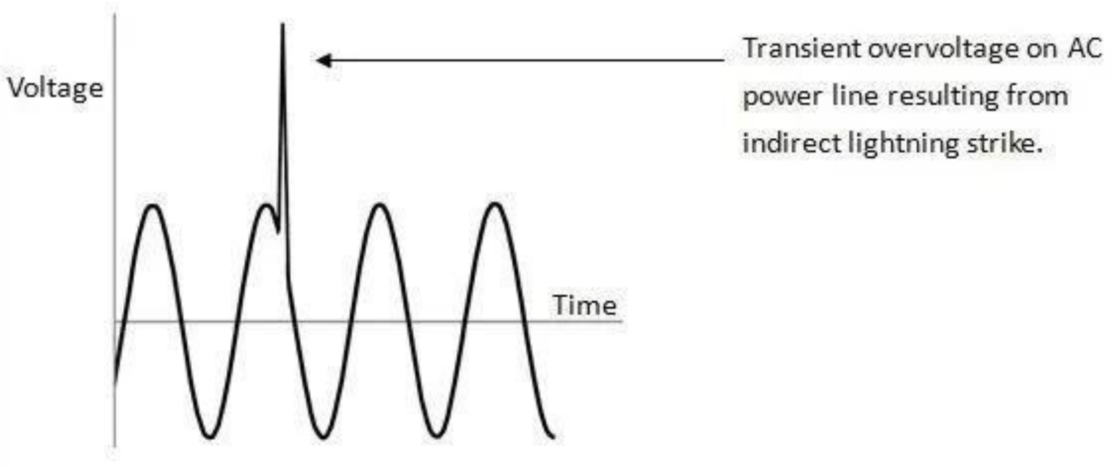
This type of over voltages originates from atmospheric disturbances, mainly due to lightning. This takes the form of a surge and has no direct relationship with the operating voltage of the line.

It may be due to any of the following causes:

1. Direct lightning stroke
2. Electromagnetically induced over voltages due to lightning discharge taking place near the line, called 'side stroke'.
3. Voltages induced due to atmospheric changes along the length of the line.
4. Electrostatic ally induced voltages due to presence of charged clouds nearby.
5. Electro statically induced over voltages due to the frictional effects of small particles like dust or dry snow in the atmosphere or due to change in the altitude of the line.
6. The potential between the clouds and earth breaks down and lightning flash takes place between the cloud and ground when this voltage becomes 5 to 20 million volts or when the potential gradient becomes 5000V to 10000V per cm.

There are two types of lightning strokes.

1. Direct lightning strokes
2. Indirect lightning strokes



LIGHTNING , SWITCHING AND TEMPORARY OVER VOLTAGE

Over-voltage-spike

Over voltages are caused on power systems due to external and internal influencing factors. The voltage stress caused by over voltage can damage the lines and equipment's connected to the system. Over voltages arising on a system can be generally classified into two main categories as below:

External Over voltages
This type of over voltages originates from atmospheric disturbances, mainly due to lightning. This takes the form of a surge and has no direct relationship with the operating voltage of the line. It may be due to any of the following causes:

i. Direct lightning stroke
ii. Electromagnetically induced over voltages due to lightning discharge taking place near the line, called 'side stroke'.
iii. Voltages induced due to atmospheric changes along the length of the line.
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v. Electro statically induced over voltages due to the frictional effects of small particles like dust or dry snow in the atmosphere or due to change in the altitude of the line.

Internal Over voltages:
These over voltages are caused by changes in the operating conditions of the power system. These can be divided into two groups as below:

Switching over voltages or Transient over operation voltages of high frequency:
This is caused when switching operation is carried out under normal conditions or when fault occurs in the network. When an unloaded long line is charged, due to Ferranti Effect the receiving end voltage is increased considerably resulting in over voltage in the system. Similarly when the primary side of the transformers or reactors is switched on, over voltage of transient nature occurs.

EFFECTS OF OVER VOLTAGES ON POWER SYSTEMS:
Over voltage tends to stress the insulation of the electrical equipment's and likely to cause damage to them when it frequently occurs. Over voltage caused by surges can result in spark over and flash over between phase and ground at the weakest point in the network, breakdown of gaseous/solid/ liquid insulation, failure of transformers and rotating machines.

Switching Impulse or Switching Surge:
When a no load transmission line is suddenly switched on, the voltage on the line becomes twice of normal system voltage. This voltage is transient in nature. When a loaded line is suddenly switched off or interrupted, voltage across the line also becomes high enough current chopping in the system mainly during opening operation of air blast circuit breaker, causes over voltage in the system. During insulation failure, a live conductor is suddenly earthed. This may also caused sudden over voltage in the system. If emf wave produced by alternator is distorted, the trouble of resonance may occur due to 5th or higher harmonics. Actually for frequencies of 5th or higher harmonics, a critical situation in the system so appears, that inductive reactance of the system becomes just equal to capacitive reactance of the system. As these both reactance cancel each other the system becomes purely resistive. This phenomenon is called resonance and at resonance the system voltage may be increased enough.
But all these above mentioned reasons create over voltages in the system which are not very high in magnitude.But over voltage surges appear in the system due to lightning impulses are very high in amplitude and highly destructive. The affect of lightning impulse hence must be avoided for over voltage protection of power system
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Voltage Surge:
The over voltage stresses applied upon the power system, are generally transient in nature. Transient voltage or voltage surge is defined as sudden sizing of voltage to a high peak in very short duration.The voltage surges are transient in nature, that means they exist for very short duration. The main causes of these voltage surges in power system are due to lightning impulses and switching impulses of the system. But over voltage in the power system may also be caused by, insulation failure, arcing ground and resonance etc.The voltage surges appear in the electrical power system due to switching surge, insulation

failure, arcing ground and resonance are not very large in magnitude. These over voltages hardly cross the twice of the normal voltage level. Generally, proper insulation to the different equipment of power system is sufficient to prevent any damage due to these over voltages. But over voltages occur in the power system due to lightning is very high. If over voltage protection is not provided to the power system, there may be high chance of severe damage. Hence all over voltage protection devices used in power system mainly due to lightning surges.

CORONA:

Definition: The phenomenon of ionisation of surrounding air around the conductor due to which luminous glow with hissing noise is rise is known as the corona effect .Corona Discharge **(**also known as the Corona Effect) is an electrical discharge caused by the ionization of a fluid such as air surrounding a conductor that is electrically charged. The corona effect will occur in high voltage systems unless sufficient care is taken to limit the strength of the surrounding electric field**.** Corona discharge can cause an audible hissing or cracking noise as it ionizes the air around the conductors. This is common in high voltage electric power transmission lines. The corona effect can also produce a violet glow, production of ozone gas around the conductor, radio interference, and electrical power loss .The corona effect occurs naturally due to the fact that air is not a perfect insulator – containing many free electrons and ions under normal conditions. When an electric field is established in the air between two conductors, the free ions and electrons in the air will experience a force. Due to this effect, the ions and free electrons get accelerated and moved in the opposite direction. The charged particles during their motion collide with one another and also with slow-moving uncharged molecules. Thus the number of charged particles increases rapidly. If the electric field is strong enough, a dielectric breakdown of air will occur and an arc will form between the conductors.

Two factors are important for corona discharge to occur:

i. Alternating electrical potential difference must be supplied across the line.
ii. The spacing of the conductors, must be large enough compared to the line diameter.

When an alternating current is made to flow across two conductors of a transmission line whose spacing is large compared to their diameters, the air surrounding the conductors (composed of ions) is subjected to dielectric stress.

At low values of the supply voltage, nothing occurs as the stress is too small to ionize the air outside. But when the potential difference increases beyond some threshold value (known as the critical disruptive voltage), the field strength becomes strong enough for the air surrounding the conductors to dissociated into ions – making it conductive. This critical disruptive voltage occurs at approximately 30 kV.

The ionized air results in electric discharge around the conductors (due to the flow of these ions). This gives rise to a faint luminescent glow, along with the hissing sound accompanied by the liberation of ozone.

This phenomenon of electric discharge occurring in high voltage transmission lines is known as the corona effect. If the voltage across the lines continues to increase, the glow and hissing noise becomes more and more intense – inducing a high power loss into the system.

Factors Affecting Corona Loss

The line voltage of the conductor is the main determining factor for corona discharge in transmission lines. At low values of voltage (lesser than the critical disruptive voltage) the stress on the air is not high enough to cause dielectric breakdown – and hence no electrical discharge occurs.

With increasing voltage, the corona effect in a transmission line occurs due to the ionization of atmospheric air surrounding the conductors – it is mainly affected by the conditions of the cable as well as the physical state of the atmosphere. The main factors affecting corona discharge are:

i. Atmospheric Conditions
ii. Condition of Conductors
iii. Spacing Between Conductors

Atmospheric Conditions:

We have proved that the voltage gradient for dielectric breakdown of air is directly proportional to the density of air. Hence in a stormy day, due to continuous air flow, the number of ions present surrounding the conductor is far more than normal, and hence it's more likely to have electrical discharge in transmission lines on such a day, compared to a day with the fairly clear weather. The system has to be designed considering those extreme situations.

Condition of Conductors:

This particular phenomenon depends highly on the conductors and its physical condition. It has an inverse proportionality relationship with the diameter of the conductors. i.e., with the increase in diameter, the effect of corona on power system reduces considerably. Also, the presence of dirt or roughness of the conductor reduces the critical breakdown voltage, making the conductors more prone to corona losses. Hence in most cities and industrial areas having high pollution, this factor is of reasonable importance to counter the ill effects it has on the system.

Spacing Between Conductors:

As already mentioned, for corona to occur in the spacing between the lines effectively should be much higher compared to its diameter, but if the length gets increased beyond a certain limit, the dielectric stress on the air reduces, and consequently, the effect of corona reduces as well. If the spacing is made too large, then corona for that region of the transmission line might not occur at all.

Reducing Corona Discharge:

Corona discharge always results in power loss. Energy is lost in the form of light, sound, heat, and chemical reactions. Although these losses are individually small, over time they can add up to significant power loss in high voltage networks.

Corona discharge can be reduced by:

i. Increasing the conductor size**:** A larger conductor diameter results in a decrease in the corona effect.
ii. Increasing the distance between conductors**:** Increasing conductor spacing decreases the corona effect.
iii. Using bundled conductors**:** Bundled conductors increase the effective diameter of the conductor – hence reducing the corona effect.
iv. Using corona rings: The electric field is stronger where there is a sharp conductor curvature. Because of this corona discharge occurs first at the sharp points, edges, and corners. Corona rings reduce the corona effect by 'rounding out' conductors (i.e. making them less sharp). They are used at the terminals of very high voltage equipment (such as at the bushings of high voltage transformers). A corona ring is electrically connected to the high voltage conductor, encircling the points where the corona effect is most likely to occur. This encircling significantly reduces the sharpness of the surface of the conductor – distributing the charge across a wider area. This in turn reduces corona discharge.

Disadvantages of corona discharge:

i) The undesirable effects of the corona are:
ii) The glow appear across the conductor which shows the power loss occur on it. .
iii) The vibration of conductor occurs because of corona effect.
iv) The corona effect generates the ozone because of which the conductor becomes corrosive.
v) The corona effect produces the non-sinusoidal signal thus the non-sinusoidal voltage drops occur in the line.
vi) The corona power loss reduces the efficiency of the line

Travelling Waves on Power Systems: The establishment of a potential difference between the conductors of an overhead transmission line is accompanied by the production of an electrostatic flux, whilst the flow of current along the conductor results in the creation of a magnetic field. The electrostatic fields are due, in effect, to a series of shunt capacitors whilst the inductances are in series with the line.

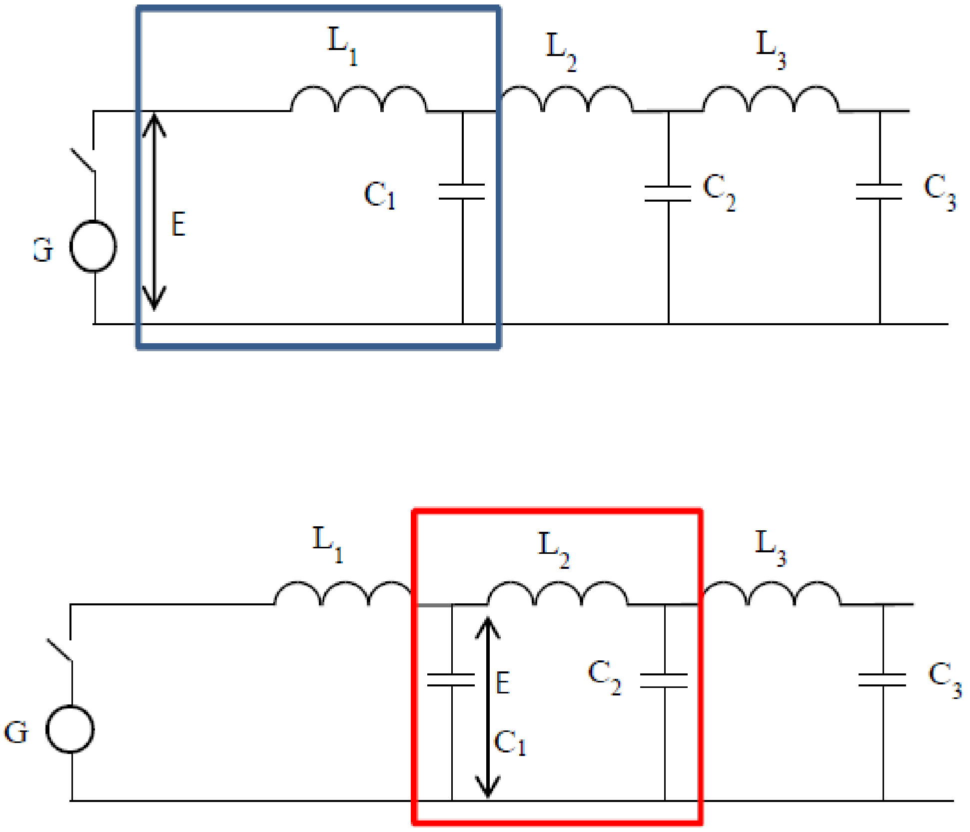


Figure 2.

Let the voltage E suddenly applied to the circuit by closing the switch. Under these conditions, the capacitanceC_1 takes a large initial charging current the whole of the voltage will at first be used in driving a charging current through the circuit consisting of L_1 and C_1 in series. As the charge on C1 builds up its voltage will increase and this voltage will begin to charge C2 by driving a current through the inductance L2 (Figure 2), and so on showing that the greater the distance from the generator, the greater will be the time elapsed from the closing the switch to the establishment of the full line voltage E. It is also clear that voltage and current are intimately associated and that any voltage phenomenon is associated with an attendant current phenomenon. The gradual establishment of the line voltage can be regarded as due to a voltage wave travelling from the generator towards the far end and the progressing charging of the line capacitances will account for the associated current wave.

Effect of the 60 Hz Alternating Voltage:

In the above treatment, the voltage E has been assumed constant and in practice such an assumption is usually adequate owing to the very high velocity of propagation. So far as most lines are concerned, the impulse would have completely traversed the whole length before sufficient time had elapsed for an appreciable change in the 60 Hz voltage to occur. Assuming that v is equal 3×10^8 m/sec in an actual case, the first impulse will have travelled a distance of $(3 \times 10^8)/60$ i.e. 5×10^6 meters by the end of the first cycle which means that the line would have to be 5000 km long to carry the whole of the voltage distribution corresponding to one cycle. A line of such a length is impossible.

The Open-Circuited Line:

Let a source of constant voltage E be switched suddenly on a line open-circuited at the far end. Then neglecting the effect of line resistance and possible conductance to earth, a rectangular voltage wave of amplitude E and its associated current wave of amplitude $I = E/Z_c$ will travel with velocity v towards the open end. Figure 3.a shows the conditions at the instant when the waves have reached the open end, the whole line being at the voltage E and carrying a current I

Figure 3.a

At the open end, the current must of necessity fall to zero, and consequently the energy stored in the magnetic field must be dissipated in some way. In the case under consideration, since resistance and conductance have been neglected, this energy can only be used in the production of an equal amount of electrostatic field. If this is done, the voltage at the point will be increased by an amount e such that the energy lost by the electromagnetic field ($0.5\ LI^2$) is equal to the energy gained by the electrostatic field ($0.5Cv^2$), or:

$$\frac{1}{2}LI^2 = \frac{1}{2}Cv^2$$

Whence,

$$e = \sqrt{\frac{L}{C}}I = Z_cI = E$$

Hence, the total voltage at the open end becomes 2E. The open end of the line can thus be regarded as the origin of a second voltage wave of amplitude E, this second wave travelling back to the source with the same velocity v. At some time subsequent to arrival of the initial wave at the open end, i.e. the condition shown in Figure 3.a, the state affairs on the line will be as in Figure 3.b in which the incoming and reflected voltage waves are superposed, resulting in a step in the voltage wave which will travel back towards the source with a velocity v. The doubling of the voltage at the open end must be associated with the disappearance of the current since none can flow beyond the open circuit. This is equivalent to the establishment of a reflected current wave of negative sign as shown in Figure 3.b.

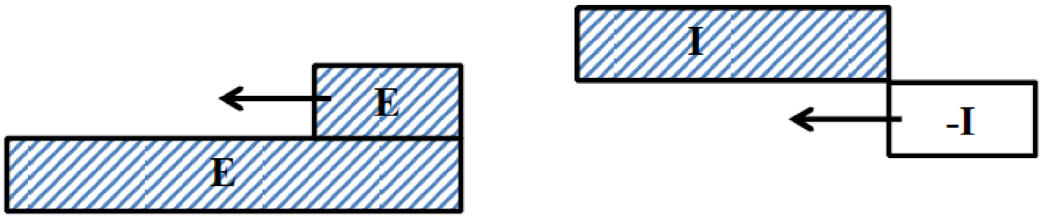


Figure 3.b

At the instant the reflected waves reach the end G, the distribution along the whole line will be a voltage of 2E and a current of zero as in Figure 3.c.

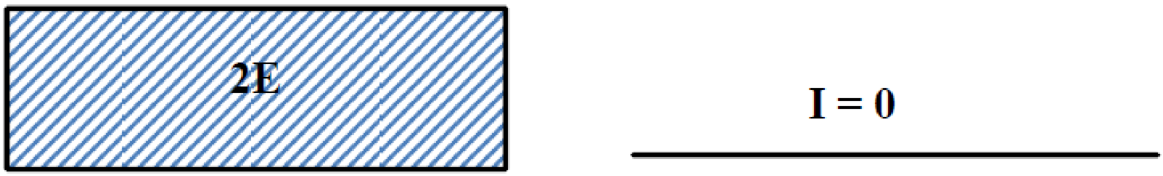


Figure 3.c

At G, the voltage is held by the source to the value E, it follows that there must be a reflected voltage of –E and associated with it there will be a current wave of –I. After these have travelled a little way along the line, the conditions will be as shown in Figure 3.d.

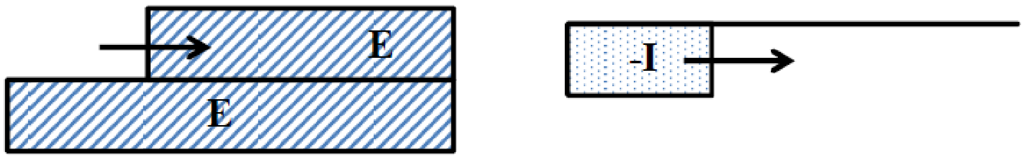
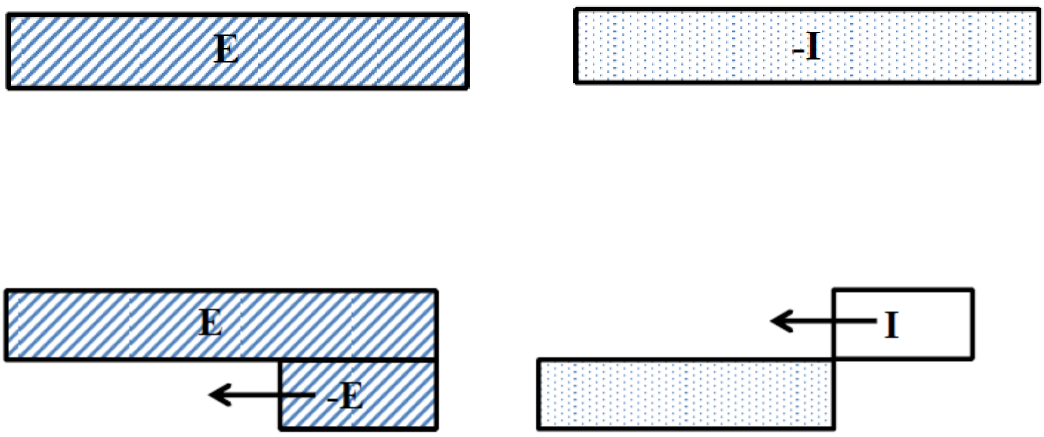


Figure 3.d

When these reach the open end the conditions along the line will be voltage E and current –I. The reflected waves due to these will be –E and +I and when these have travelled to the end G they will have wiped out both voltage and current distributions, leaving the line for an instant in its original state. The above cycle is then repeated.



The Short-Circuited Line*:*

In this case, the voltage at the far end of the line must of necessity be zero, so that as each element of the voltage wave arrives at the end there is a conversion of electrostatic energy into electromagnetic energy. Hence, the voltage is reflected with reversal sign while the current is reflected without any change of sign: thus on the first reflection, the current builds up to 2I. Successive stages of the phenomenon are represented in Figure 4.

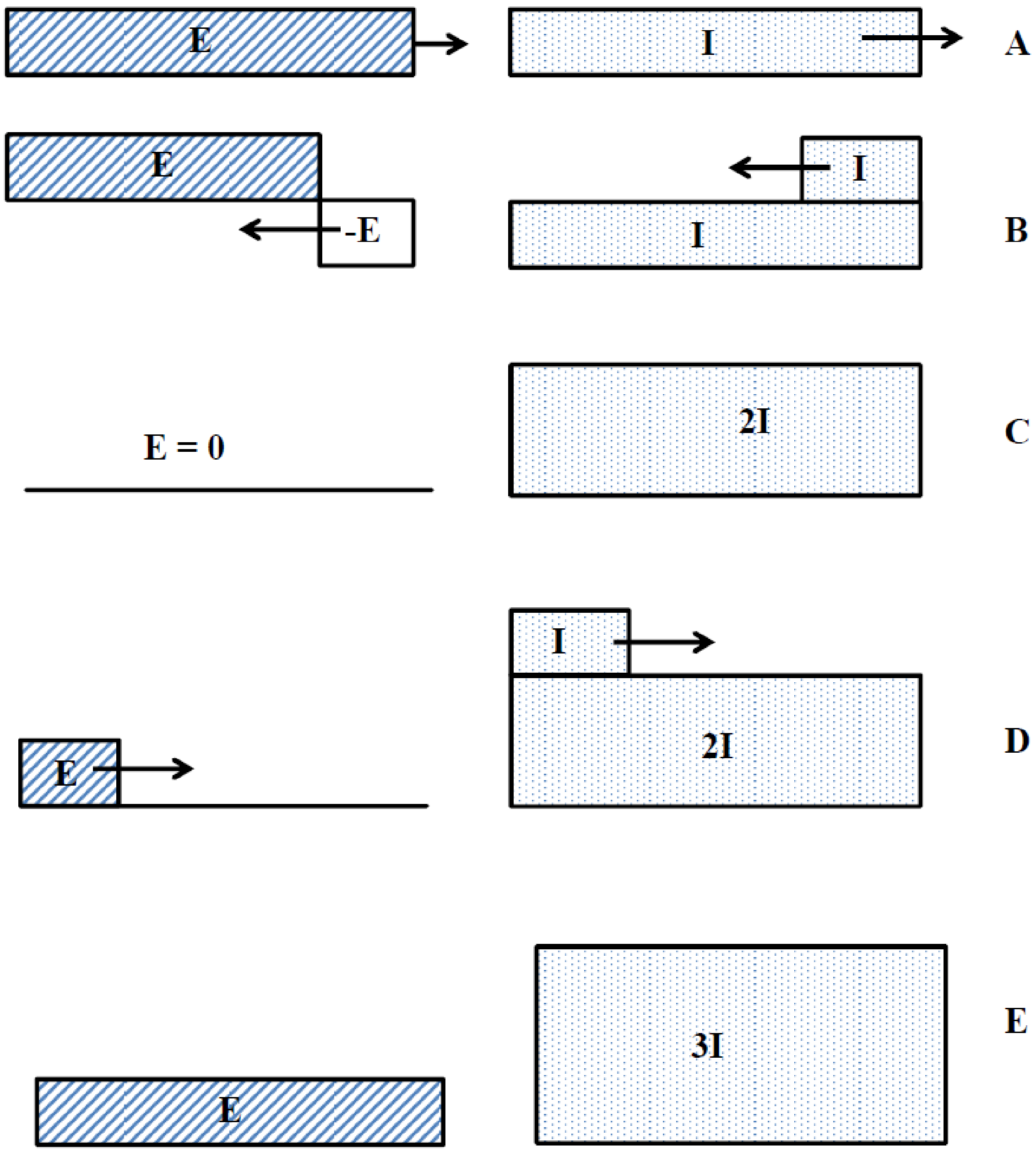


Figure 4

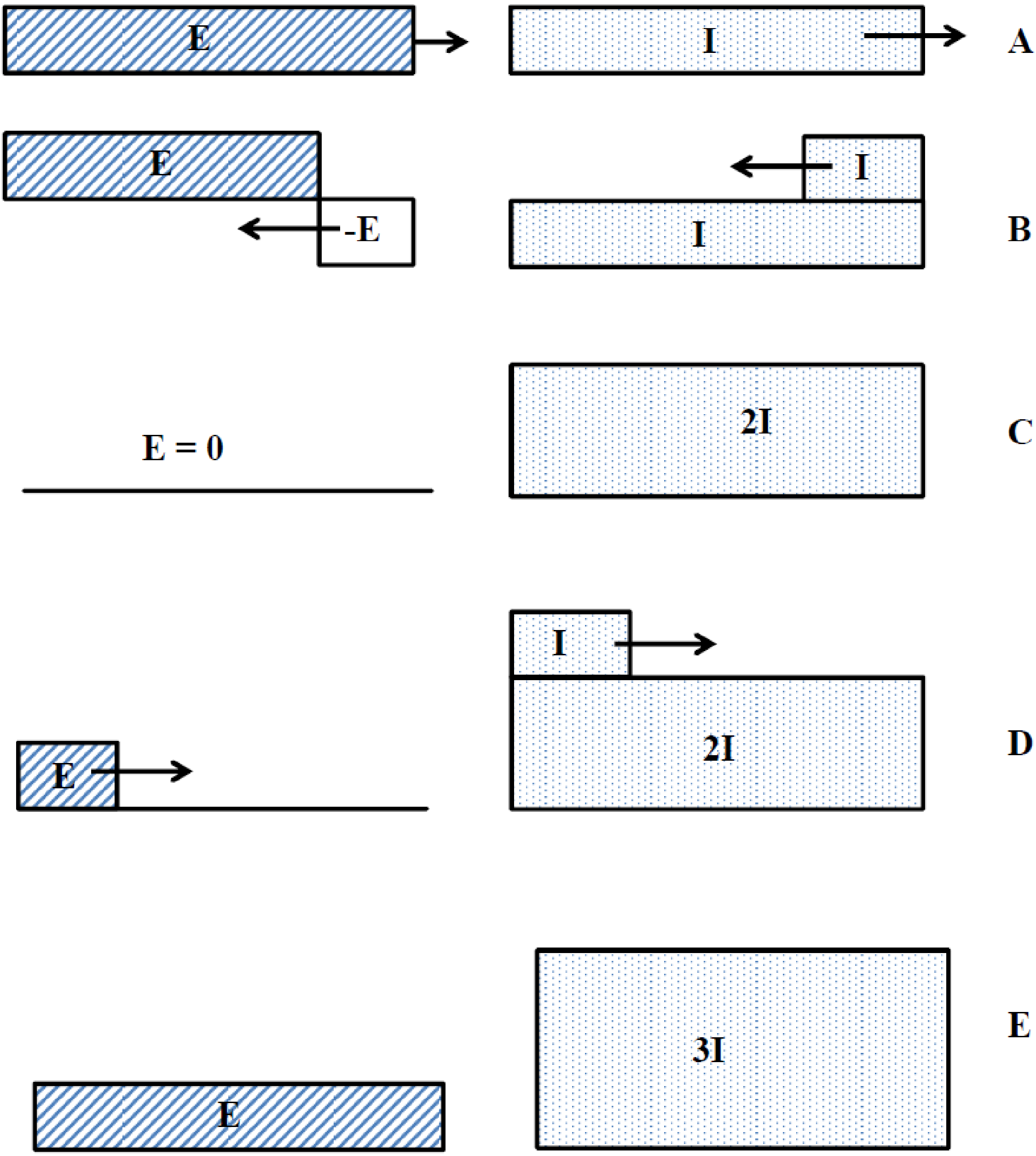


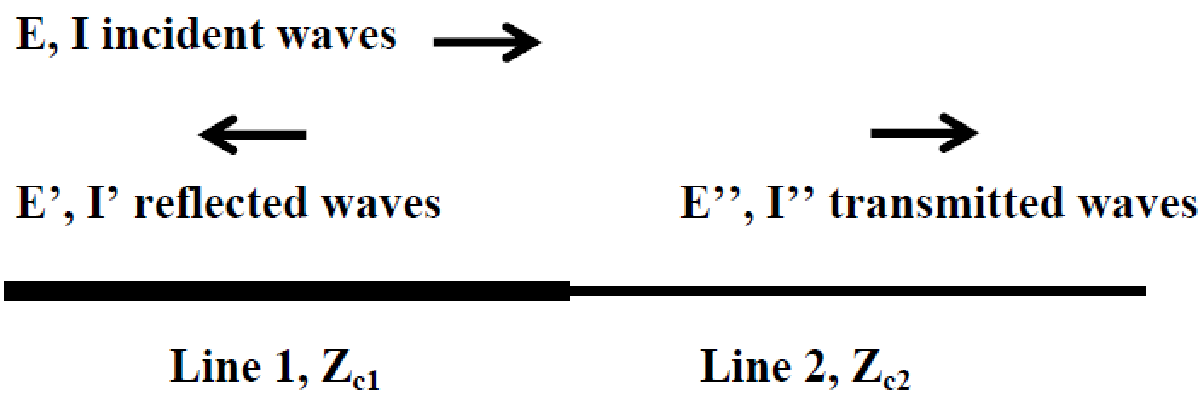
Figure 4

A. Original current and voltage waves just prior to the first reflection.
B. Distributions just after the first reflection.
C. Distributions at the instant the first reflection waves have reached the generator. Note that the whole of the line is at zero voltage.
D. Distributions after the first reflection at the generator end.
E. Distributions at the instant the first reflected waves from the generator reach the far end.

It will be seen that the line voltage is periodically reduced to zero, but that at each reflection at either end the current is built up by the additional amount $I = E/Z_C$. Thus, theoretically, the current will eventually become infinite as is to be expected in the case of a lossless line. In practice, the resistance of the line produces attenuation so that the amplitude of each wave-front gradually diminishes as it travels along the line and the ultimate effect of an infinite number of reflections is to give the steady Ohm's law of current E/R.

Junction of Lines of Different Characteristic Impedance: If a second line is connected to the termination of the first, the voltage of the reflected wave *at the junction* will depend on the magnitude of Z_{c1} and Z_{c2}.

With $Z_{c2} = \infty$, we have the case of the open-circuited line. With $Z_{c2} = 0$, the case of the short- circuit line. If $Z_{c2} = Z_{c1}$, the second line can be regarded as a natural continuation of the first and the current and voltage waves pass into Z_{c2} without any change. For any value of Z_{c2} different from the above special cases, there will be partial reflection of the current and voltage waves.



Since the reflection is accompanied by a change in sign of either voltage or current but not both.

Reflection and Refraction at a Bifurcation:

Let a line of natural impedance Z_1 bifurcate into two branches of natural impedances Z_2 and Z_3, then, as far as the voltage wave is concerned, the transmitted wave will be the same for both branches, since they are in parallel. On the other hand, the transmitted currents will be different in the general case of $Z_3 \neq Z_2$. A short time after reflection the condition will be as shown in Figure B-1 in which it is assumed that the voltage is reflected with reversal of sign.

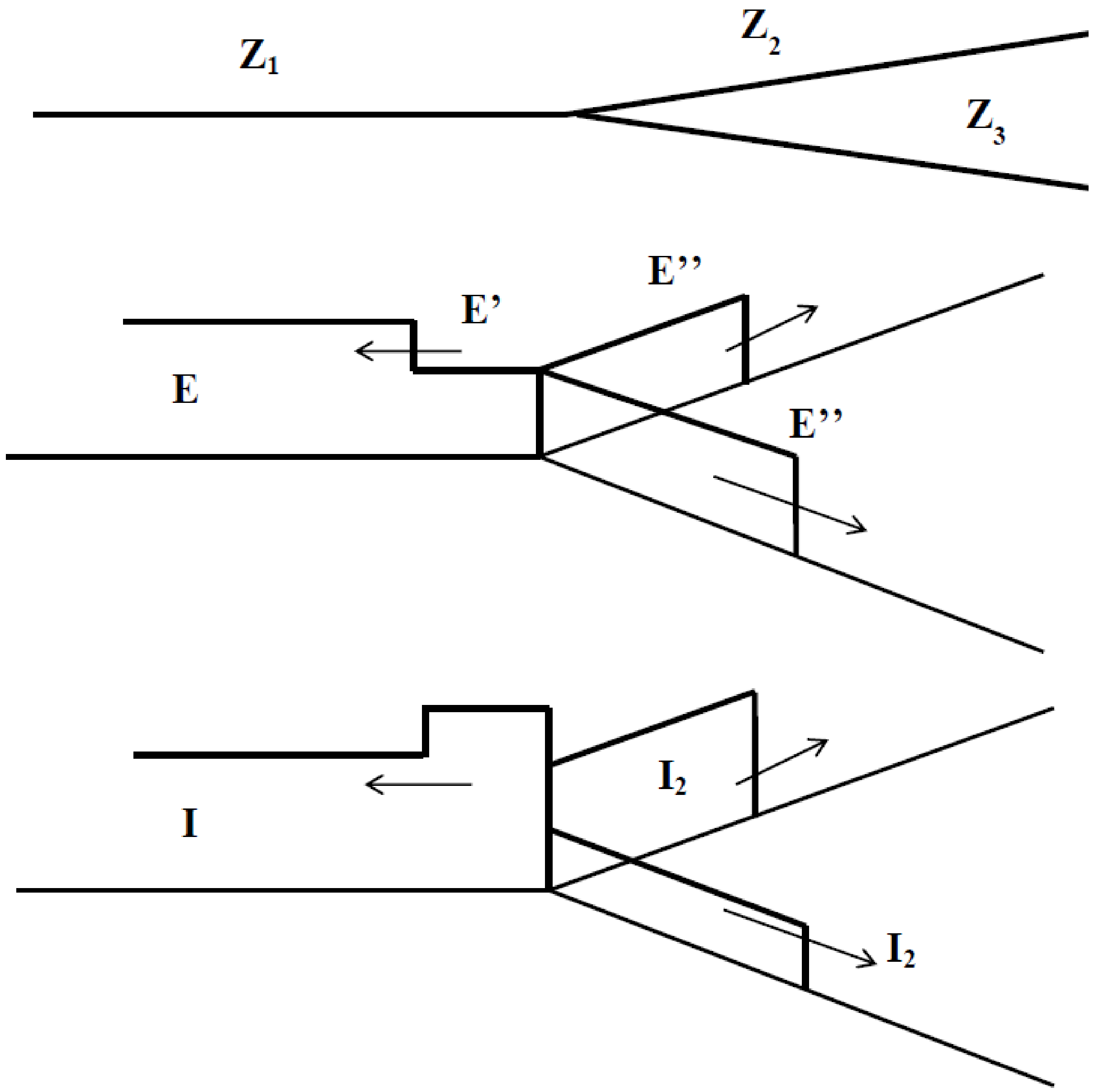


Figure B.1: Effect of a bifurcation on the travelling waves.

Let E_1, I_1 be the incident voltage and current E', I' be the reflected voltage and current
E'', I_2 be the transmitted voltage and current along Z_2
E'', I_3 be the transmitted voltage and current along Z_3

—

Then $I_2 = \frac{E''}{Z_2}$ and $I_3 = \frac{E''}{Z_3}$

Also $\frac{E_1}{Z_1} - \left(\frac{E''-E_1}{Z_1}\right) = \frac{E''}{Z_2} + \frac{E''}{Z_3}$

The solution of which is

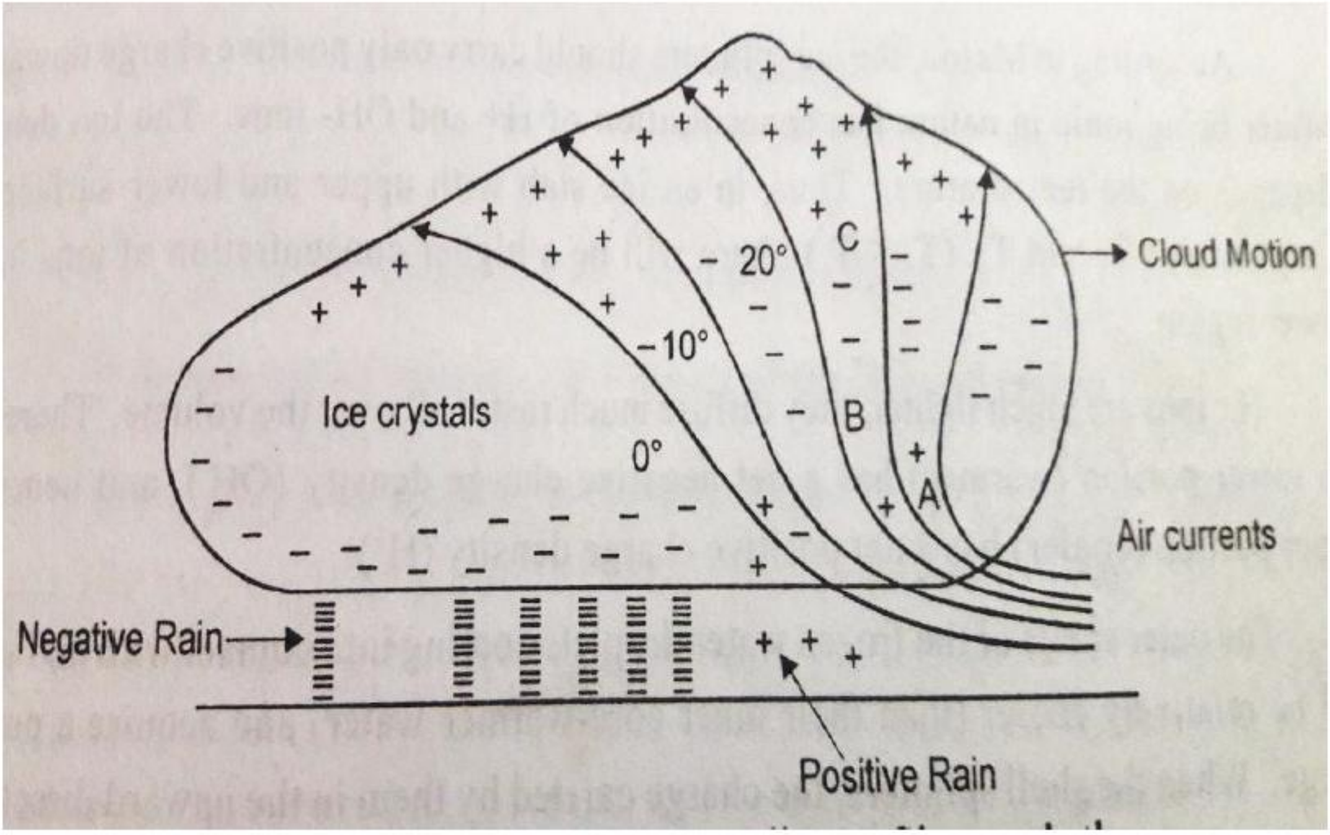
$$E'' = \frac{\frac{2E_1}{Z_1}}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}}$$

Knowing E_1, all the other quantities can be calculated. If we put $Z_3 = \infty$ in the above expression, we have

$$E'' = \frac{2E_1 Z_2}{Z_1 + Z_2}$$

Charge formation theories:

The impact of air on these crystals makes them –vely charged ,thus the distribution of charge within the cloud is as shown.



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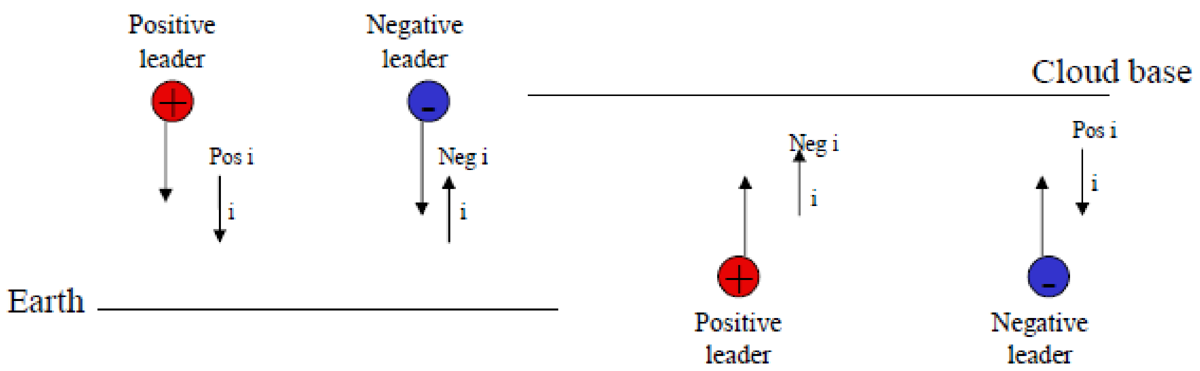
REYNOLD AND MASON'STHEORY:

i. According to this theory, thunder clouds are developed at heights 1 to 2km above ground level& they go up to 14km.
ii. The temperature is 0^oC at 4km & may reach -50^oC at 12km.
iii. Water droplets do not freeze at 0^oC & freeze only when temperature is below -40^oC & form solid particles on which crystalline ice patterns develop & grow.
iv. Thundercloud consisting super cooled water droplets moving upwards and large hail stones moving downwards.
v. The ice splinters should carry only +ve charge upwards.
vi. Water has H+&OH-ions, the ion density depends on temperature.
vii. Lower portion has a net –ve charge density(OH-)&upper portion has a net +ve charge density(H+).

Stepped Leader:

The lightning stroke begins when the electric fields exceed breakdown voltage. At the ground the maximum fields get to ~10 kV/m. Initially streams of electrons surge from the cloud base toward the ground in steps of 50 to 100 m. • Start and stop steps as the stepped leader progresses toward ground.

Leader
- Downward (cloud → earth)
- Upward (earth → cloud)



The polarity of a leader is defined by the polarity of its charge and not by its current.

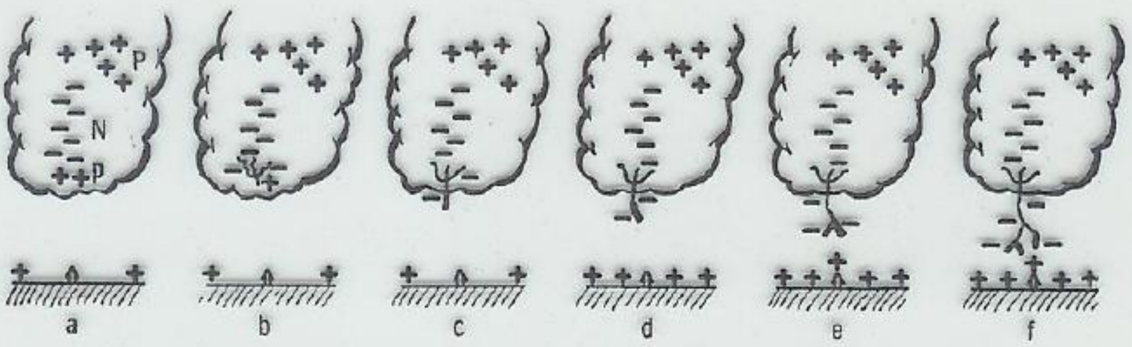


Fig. 9.1. Stepped leader initiation and propagation. (a) Cloud charge distribution just prior to p-N discharge. (b) p-N discharge. (c)-(f) Stepped leader moving toward ground in 50-yard steps. Time between steps is about 50 millionths of a second. Scale of drawing is distorted for illustrative purposes.

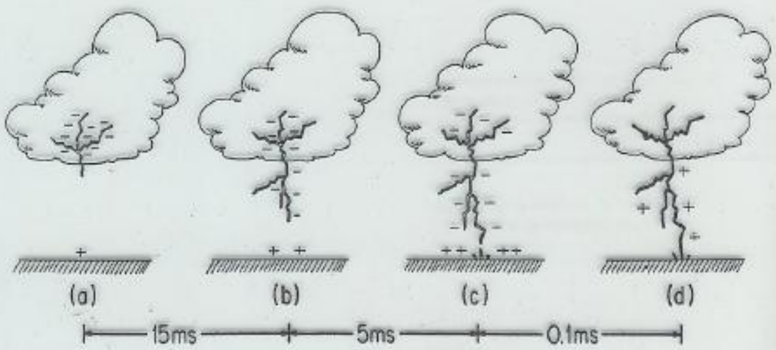
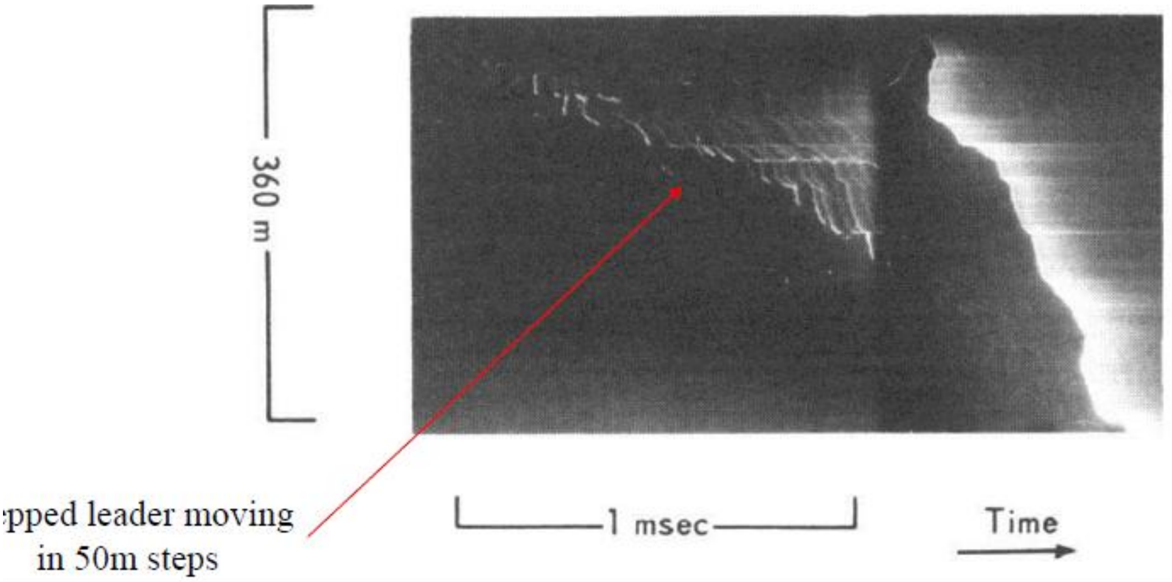


Figure 6.2. Sketch of the time development of a lightning stepped leader and the ensuing return strokes.

The stepped leader is:
Very Faint. Essentially invisible to the humaneye. Produces an ionized channel that will allow for the flow of charge during the remainder of the lightning stroke.



The AttachmentProcess:
When the stepped leader gets near the ground (~100 m or so) Positive charge moves from the ground up toward the stepped leader -- these are called streamers.
The streamers may come from almost any pointed object on the ground:

i. Trees
ii. Antennas
iii. Flagpoles
iv. Telephone Poles
v. People

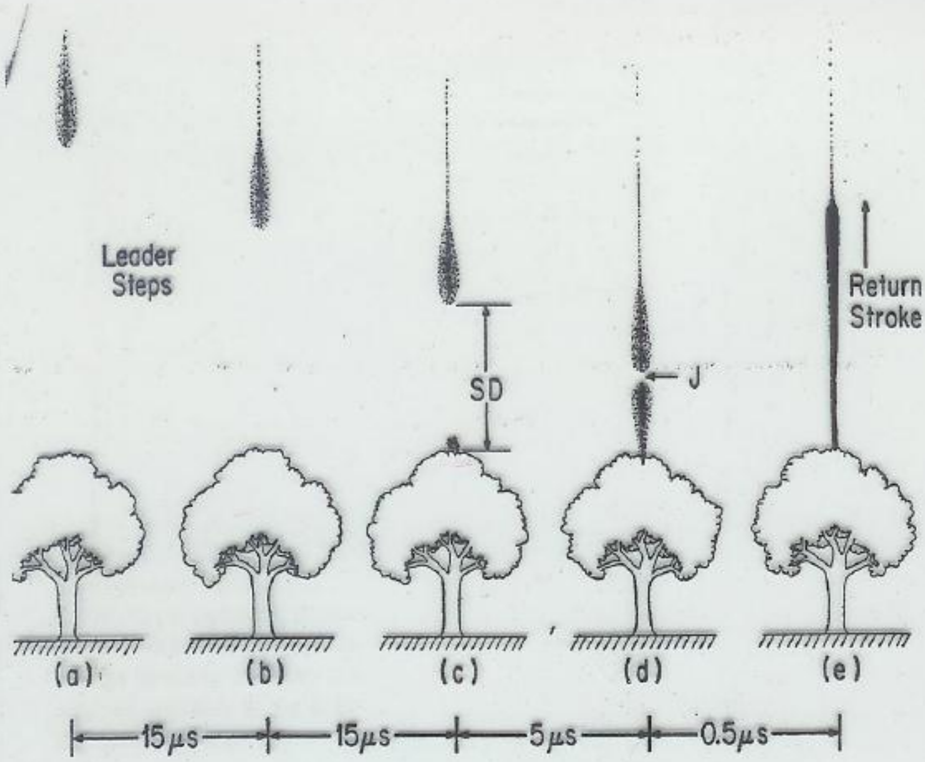
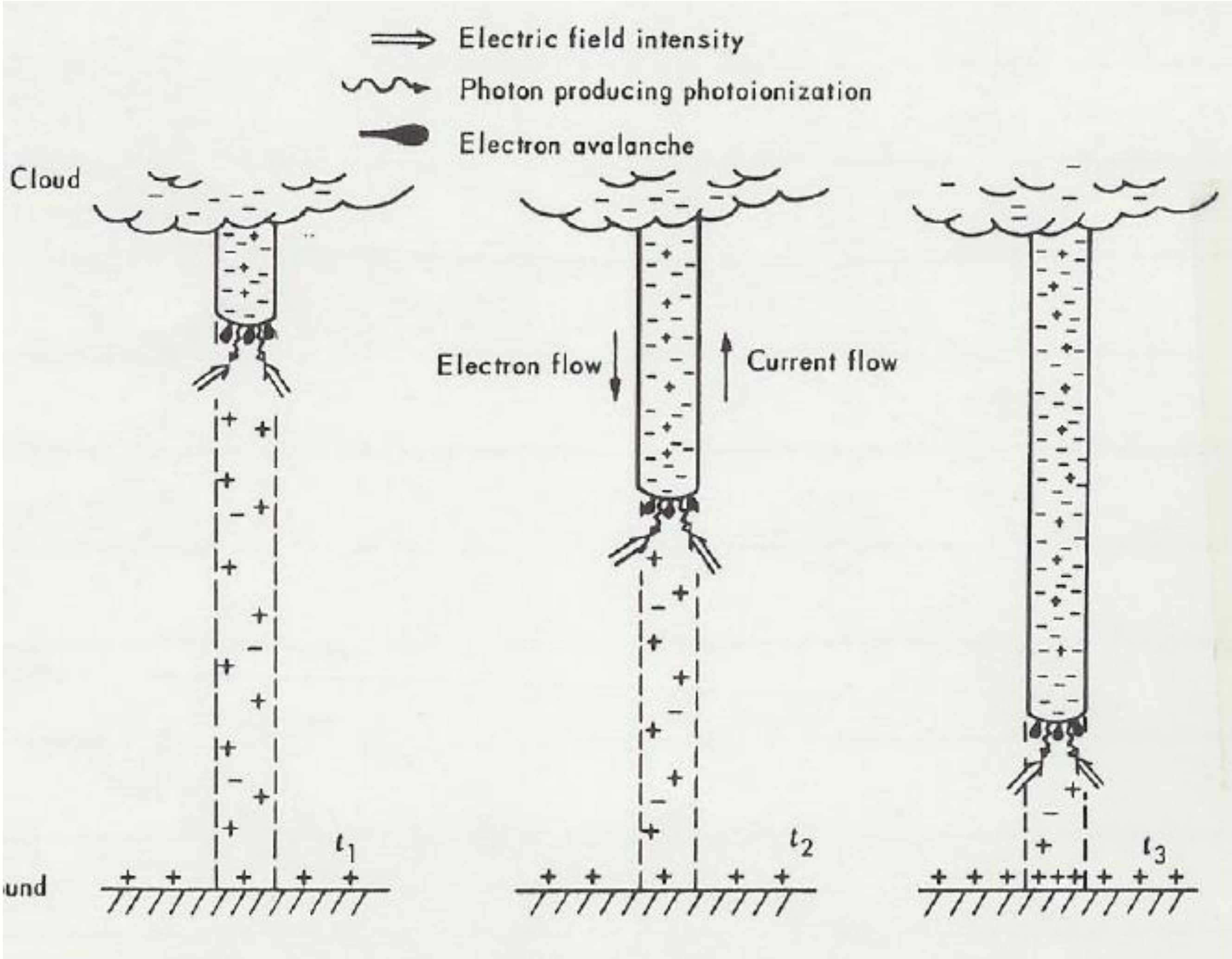


Figure 6.3. Sketch of the luminous processes that occur during a lightning strike. An upward-connecting discharge forms in (c) when the stepped leader is at the striking distance, SD.

Dart Leader:

- **i.** Approximately 0.04 sec after the return stroke the dart leader travels down the ionized channel without “steps “followed by another return stroke after ~1 msec.
- **ii.** Another dart leader can occur 0.04 sec after the next return stroke, and so on….May get several sets of dart leader/return stroke pairs. Appears as if the lightning “flashes.”



. 7.1*b* *Diagram showing general features of streamer mechanism as applied to dart leader. The times* $t_3 > t_2 > t_1$.

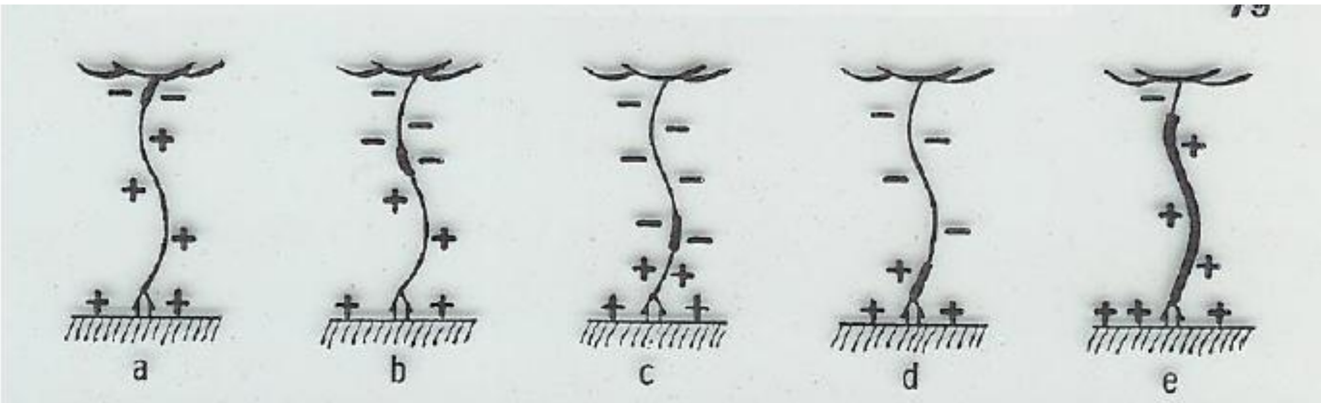
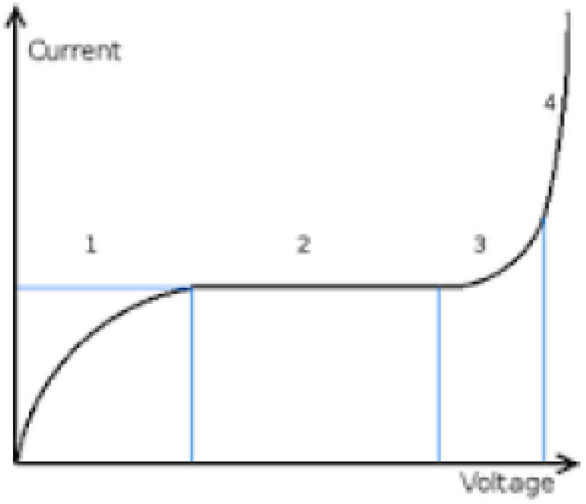


Fig. 9.4. Dart leader and subsequent return stroke. (a)-(c) Dart leader deposits negative charge on defunct first-stroke channel during its thousandth-of-a-second trip to ground. (d)-(e) Subsequent return stroke propagates from ground to cloud in about 100 millionths of a second. Scale of drawing is distorted.

UNIT -II
DIELECTRIC BREAKDOWN

GASEOUS BREAKDOWN IN UNIFORM AND NON UNIFORM FIELDS:

Gases Electrical breakdown occurs within a gas when the dielectric strength of the gas is exceeded. The voltage that leads to electrical breakdown of a gas is approximated by Paschen's Law. Partial discharge in air causes the "fresh air" smell of ozone during thunderstorms or around high-voltage equipment.



UNIFORM AND NON UNIFORM FIELDS:

Electric fields are represented by drawing field lines that represent the direction of the field, as well as the strength of the field. More field lines represent higher field strength. In a non-uniform electric field, the field lines tend to be curved and are more concentrated near the charges. In a uniform electric field, since the field strength does not vary, the field lines are parallel to each other and equally spaced. Uniform fields are created by setting up a potential difference between two conducting plates placed at a certain distance from one another. The field is considered to be uniform at the center of the plates, but varies close to the edge of the plates. The strength of the field depends on the potential difference applied to the plates and the distance by which they are separated. A higher potential difference or voltage results in a stronger electric field. The greater the distance between the plates, the weaker the field becomes. The electric field is therefore calculated as a ratio of the voltage between the plates to the distance they are separated by them.

CORONA DISCHARGE:

A corona discharge is an electrical discharge brought on by the ionization of a fluid such as air surrounding a conductor that is electrically charged. Spontaneous corona discharges occur naturally in high-voltage systems unless care is taken to limit the electric field strength. A corona will occur when the strength (potential gradient) of the electric field around a conductor is high enough to form a conductive region, but not high enough to cause electrical breakdown or arcing to nearby objects. It is often seen as a bluish (or other color) glow in the air adjacent to pointed metal conductors carrying high voltages, and emits light by the same property as a gas discharge lamp. In many high voltage applications corona is an unwanted side effect. Corona discharge from high voltage electric power transmission lines constitutes an economically significant waste of energy for utilities. In high voltage equipment like televisions, radio transmitters, X-ray machines and particle accelerators the current leakage caused by coronas can constitute an unwanted load on the circuit. In air, coronas generate gases such as ozone (O_3) and nitric oxide (NO), and in turn nitrogen dioxide (NO_2), and thus nitric acid (HNO_3) if water vapor is present. These gases are corrosive and can degrade and embrittle nearby materials, and are also toxic to people. Corona discharges can often be suppressed by improved insulation, corona rings, and making high voltage electrodes in smooth rounded shapes. However, controlled corona discharges are used in a variety of processes such as air filtration, photocopiers and ozone generators.

VACCUM BREAKDOWN:

Experiments have been performed in order to get information about the phenomena preceding the electrical breakdown in small vacuum gaps. Most experiments have been made with impulse voltages of different rise times; some complementary results obtained with alternating voltage are also presented. The effect of surface layers on the breakdown voltage and on the pre-breakdown current is discussed. It has been found that the rise time of the voltage affects both the breakdown voltage and the pre-breakdown current. The experiments seem to indicate that breakdown in the underlying circumstances is the result of a discharge in metal vapour, originating from the anode. The vapour is thought to be generated by the heating of the anode by a bombardment of field-emission electrons. The transition of the pre-breakdown current to a sudden discharge may occur when the vapour density passes a critical value.

1. Introduction.

The mechanism of the electrical break down in vacuum has been the subject of many investigations. Generally, field emission of electrons is accepted as the first step in the process. Different explanations have to be given for the breakdown of small gaps (< 1 mm) and for the high-voltage breakdown of large gaps, since it has been found that the breakdown field strength decreases considerably with increasing gap length. The pre-breakdown current introducing the discharge should therefore be much smaller in large gaps than in small ones. A few hypotheses with regard to the development of the discharge will be briefly mentioned here. Except for assumption e), breakdown is thought to occur as a result of some multiplication process in metallic vapour produced at one of the electrodes: a) Evaporation of the anode surface is caused by a bombardment by field-emission electrons breakdown mechanisms in solid and composite dielectrics Solid dielectric materials are used in all kinds of electrical circuits and devices to insulate one current carrying part from another when they operate at different voltages. A good dielectric should have low dielectric loss, high mechanical strength, should be free from gaseous inclusion, and moisture, and be resistant to thermal and chemical deterioration. Solid dielectrics have higher breakdown strength compared to liquids and gases. Studied of the breakdown of solid dielectrics are of extreme importance in insulation studies. When breakdown occurs, solids get permanently damaged while gases fully and liquids partly recover their dielectric strength after the applied electric field removed. The mechanism of breakdown is a complex phenomenon in the case of solids, and varies depending on the time of application of voltage.

The various breakdown mechanisms can be classified INTRINSIC BREAKDOWN

When voltages are applied only for short durations of the order of 8 10 s the dielectric strength of a solid dielectric increases very rapidly to an upper limit called the intrinsic electric strength. Experimentally, this highest dielectric strength can be obtained only under the best experimental conditions when all extraneous influences have been isolated and the value depends only on the structure of the material and the temperature. The maximum electrical strength recorder is 15 MV/cm for polyvinyl-alcohol at -1960 C. The maximum strength usually obtainable ranges from 5 MV/cm. Intrinsic breakdown depends upon the presence of free electrons which are capable of migration through the lattice of the dielectric. Usually, a small number of conduction electrons are present in solid dielectrics, along with some structural imperfections and small amounts of impurities. The impurity atoms, or molecules or both act as traps for the conduction electrons up to certain ranges of electric fields and temperatures. When these ranges are exceeded, additional electrons in addition to trapped electrons are released, and these electrons participate in the conduction process. Based on this principle, two types of intrinsic breakdown mechanisms have been proposed.

i) Electronic Breakdown

Intrinsic breakdown occurs in time of the order of 10-8 s and therefore is assumed to be electronic in nature. The initial density of conduction (free) electrons is also assumed to be large, and electron-electron collisions occur. When an electric field is applied, electrons gain energy from the electric field and cross the forbidden energy gap from the valence band to the conduction band. When this process is repeated, more and more electrons become available in the conduction band, eventually leading to breakdown.

Avalanche or Streamer Breakdown

This is similar to breakdown in gases due to cumulative ionization. Conduction electrons gain sufficient energy above a certain critical electric field and cause liberation of electrons from the lattice atoms by collision. Under uniform field conditions, if the electrodes are embedded in the specimen, breakdown will occur when an electron avalanche bridges the electrode gap. An electron within the dielectric, starting from the cathode will drift towards the anode and during this motion gains energy from the field and loses it during collisions. When the energy gained by an electron exceeds the lattice ionization potential, an additional electron will be liberated due to collision of the first electron.

Ionization Process : Ionization process are of two phenomenon that occurs in gas insulation, they are primary and secondary ionization process. First let us see primary ionization process.

i. Primary ionization process.
ii. Ionization by collision.

Townsend's Theory:

Townsend's has consider both primary and secondary process which leads breakdown in gas dielectric medium and proved that increase of electrons in gas medium is not linear but exponential.

Let us assume, n_o – electrons liberated from cathode due to applied voltage
p – primary ionization co-efficient
x – be the distance from cathode
n_x – total electron at distance x
dx- small distance from x

then total electrons in dx is $p.n_x.dx$

at, $x = 0,\ n_x = n_o$

$$(dn_x / dx) = p.n_x$$

$$(dn_x / n_x) = p.\ dx$$

Integrating on both sides,

$$\ln(n_x) = p.x$$

or $$n_x = e^{p.x}$$

now for a total distance of d and initial electrons of n_o , total electrons liberated in gas medium due to primary ionization process is,

$$n_d = n_o .e^{p.d}$$

and in terms of current between electrodes it is given as,

$$I_d = I_o .e^{p.d}$$

Considering now both criteria-

Let us consider, s- secondary ionization co-efficient considering all secondary Ionization process.
n_s – number of secondary electrons liberated due to secondary process
n_c – total electrons released form cathode

there fore, $n_c = n_o + n_s$

the total number of electrons reaching anode are,

$$n = n_c\ .\ e^{p.d}$$

$$n = (n_o + n_s)\ .\ e^{p.d}$$

$$n_s = s(\ n-(\ n_o + n_s))$$

by eliminating n_s,

$$n = n_o. e^{p.d} / 1-s[e^{p.d} – 1]$$

in terms of current between the plates,

$$I = I_o. e^{p.d} / 1-s[e^{p.d} – 1]$$

Townsend's condition of breakdown:

To say that great avalanche is formed between the plates , the denominator of current through the plates must be zero.

$$1-s[e^{p.d} – 1] = 0$$
$$s[e^{p.d} – 1] = 1$$

this is called as Townsend's condition of breakdown in gas insulation medium.

$$e^{p.d} >>1$$

therefore above condition can be written as ,

$$s.e^{p.d} = 1$$

2.2.3 Time Lag In Breakdown Of Gas:

Time lag of the breakdown in gas insulation is divided into two parts 1) statistical time 2) formative time.

Statistical time- it is the time elapse between application of voltage to initiation of electron in the gas medium.

Formative time- it is the time elapse between initiation of electron to formation of avalanche between electrode causing breakdown.

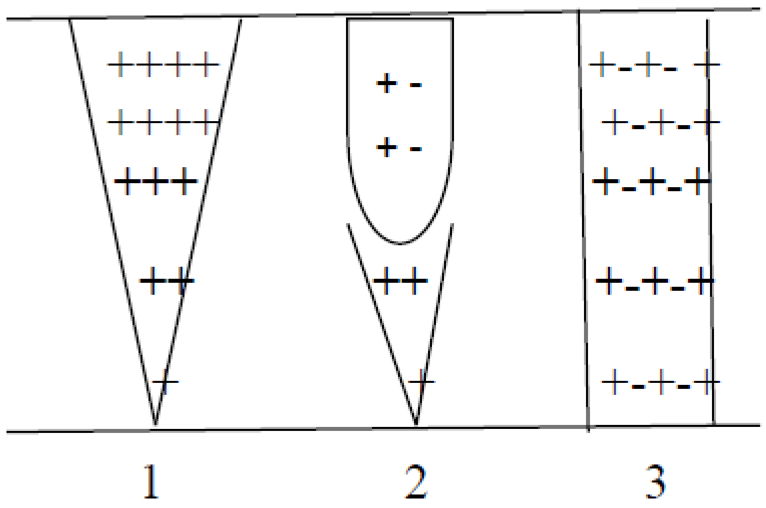
2.2.4 Streamer's Theory:

Townsend's theory has drawback that it has consider only ionization process as cause of breakdown in gas insulation, but dint consider atmospheric and shape of the medium between the electrodes.

i.Townsend's criteria says that time lag is approximately 10^{-5} seconds but which actually as small as estimated is 10^{-8} seconds. Townsend's criteria says that discharge has regular shape but practically discharge

ii. May be irregular and thin path type spark.

Streamer theory says that positive space charges due to ionization process enhances electric field and tends to cathode very rapidly which is called as streamer. This forms an second avalanche between the plates.



In the above diagram figure 1 indicate formation positive space charge tending towards cathode. Figure 2 indicates how field of positive space charge ionizes the gas. Figure 3 indicates formation of avalanche between plates.

Field developed by space charge is , $E = \frac{5.27 \times 10^{-7} \times p \times e^{p.x}}{(x/b)^{1/2}}$

Where, E- electric field due to space charge

b- gas pressure.

Above equation can further simplified as , $Pd + \ln(p/b) = 14.5 + \ln(E/b) + 0.5\ln(d/b)$

Paschen's Law: From the breakdown criteria of Townsend's,

$$1 - s[e^{p.d} - 1] = 0$$

$$s[e^{p.d} - 1] = 1$$

where the co-efficient p and s are functions of E/b i.e

$$p/b = g_1(E/b)$$

$$s = g_2(E/b)$$

$$E = V/d$$

Substituting above equations in townsend's criteria,

$$g_2(E/b)[e^{g1(E/b).d} - 1] = 1$$

$$g_2(V/d.b)[e^{g1(V/d.b).d} - 1] = 1$$

hence from above equation we can say that applied voltage is the function of produce of pressure and distance.

V = g(d.b).

Liquid As Dielectric And Its Breakdown:

Liquid dielectrics provide two purposes in power system as protection and coolant. The power system equipment like transformer, circuit breakers etc use liquid dielectrics. Liquid dielectric is self healing. Dielectric strength of liquid insulation is somewhat greater than gas medium. The breakdown voltage of liquid dielectric is in the ranges of 10MV/cm to 100MV/cm.

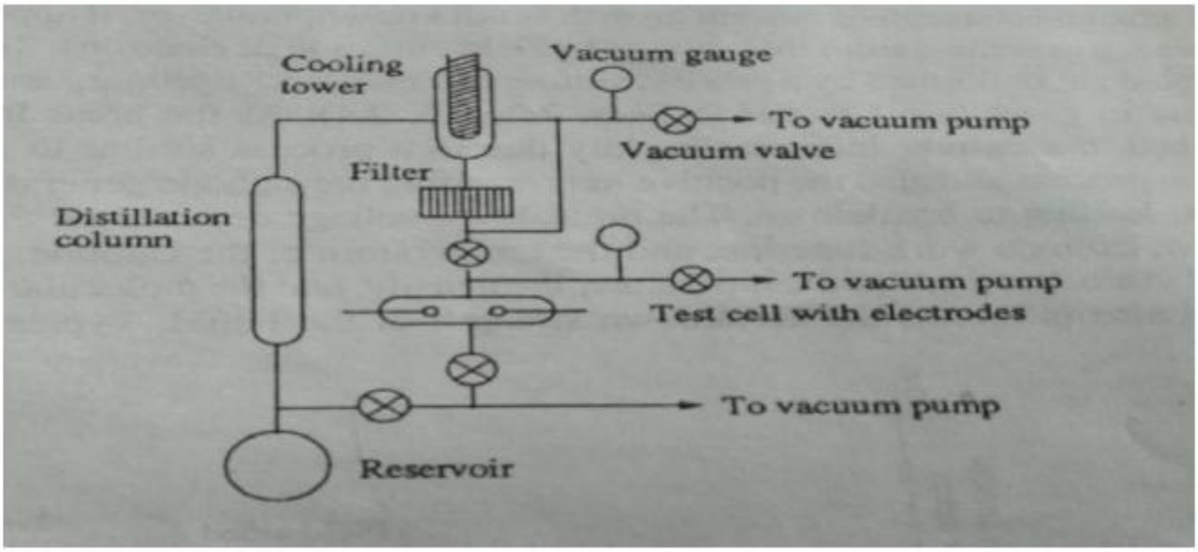
Some of the electrical properties which are necessary to estimate its dielectric strength are-

i. Capacitance per unit volume.
ii. Resistivity of liquid
iii. Power factor of the liquid
iv. High electric field stress

v. Permittivity of medium.

Pure And Commercial Liquid:

Pure liquids are the one which has no contaminants in the traces of 1 in 10^9 . commercial liquids are the one which contains impurities like sand particles, gas pockets, air bubbles, dust etc. before taking any liquid insulation into service once purification process is recommendable.



The general impurities in liquid dielectrics are dust particles which cane removed by the process of filtration, gas bubbles and moisture are other impurities which can be eliminated by distillation and degassing, ionic impurities leads increase in conductivity of liquid. Water content can be removed by drying agents. Sometimes liquids are shaked with some chemicals agents to purify the liquid dielectric.

The above figure indicates the process of purification of the commercial liquids.

i. Firstly liquid insulation stored in the reservoir.
ii. Liquid dielectric first undergo distillation process where gas bubbles, moisture content can be removed.
iii. Then it undergoes drying agents where unwanted water contents can be eliminated.
iv. Then undergoes filtration where dust particles are removed.
v. Then an sample of liquid is sent into test cell where it is tested for withstand voltage.

Process Of Breakdown In Liquid Dielectric:

The various process which leads to breakdown in the commercial liquid are –

1) Suspended particle theory.
2) Cavitations and bubble mechanism
3) Stressed volume theory.

Suspended particle theory-

Here main impurity is dust or sand particles. Let us consider an arrangement of liquid dielectric between two electrodes containing dust particle. To such an arrangement a voltage of E is applied. Then these dust particles gets energized and forming an local electric field. If there are number of dust particles the excited dust particles forms an avalanche between the electrodes which may cause breakdown of liquid insulation if surrounding dust particles filed is very high.

Let ϵ_1 – permittivity of liquid dielectric

ϵ_2 – permittivity of dust particle r- radius of the dust particles

E- applied voltage

The force experience by the dust particle to form avalanche between plates is ,

$$F = (1/2r^3) [(\epsilon_2 - \epsilon_1)/ (\epsilon_2 + \epsilon_1)]. gradE^2$$

Cavitations and the bubble theory-

Here main impurity is gas bubbles or air particles. Let us consider an arrangement of liquid dielectric between two electrodes containing gas pockets. To such an arrangement a voltage of E is applied. Then these bubbles get energized and elongated. Here there are two methods which lead to avalanche between electrodes.

i. When bubbles get energized and elongated forms the bridge between the electrodes which may lead to breakdown of liquid insulation.
ii. When bubble gets energized there may be local breakdown which liberates more bubble and these bubbles forms bridge between electrode causing breakdown.

Field which leads to breakdown,

$$E_o = (1/ \epsilon_1 - \epsilon_2)*[2*\Pi*\delta(2\epsilon_1 + \epsilon_2)/r* (\Pi/4)sqrt\{ (Vb/2rE_o)-1\}]^{1/2}$$

Let ϵ_1 – permittivity of liquid dielectric

ϵ_2 – permittivity of bubbles

r- Radius of the bubbles

E_o – electric field at breakdown

δ – surface tension

Vb – voltage across bubble

Stressed oil volume theory-

Here main impurity is weak region containing some impurities. Let us consider an arrangement of oil liquid dielectric between two electrodes containing some weak regions. To such an arrangement a voltage of E is applied. The volume of the region which consists of considerable contaminants experiences high stress and leads to local breakdown. As number of stressed oil volumes increases the breakdown strength decreases. Hence we can say that breakdown strength and volumes of high stress are inversely proportional.

Applied voltage α 1/(stressed oil volume)

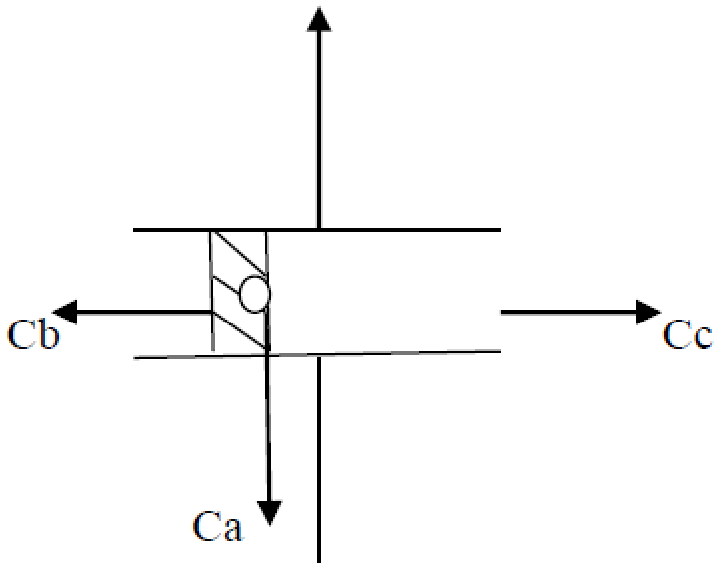
2.4 Breakdown in solid insulations :

Solid insulation is one of the strong medium of dielectric, whose dielectric strength is very much greater than gas and liquid insulations. Unlike gas and liquid insulations if the breakdown occurs in solid insulation leads to the permanent damage. The breakdown in solid insulation may occur due to corona, internal voids, treeing and tracking, mechanical stresses etc..

The various phenomenon which causes failure of liquid insulations are listed below:

i. Intrinsic or Ionic breakdown.
ii. Breakdown due to treeing and tracking.
iii. Electro chemical breakdown.
iv. Over heat breakdown.
v. Partial discharge.
vi. Breakdown due to mechanical stress.

Partial discharge:



This type of discharge mainly occurs due to presence of internal voice or cavities. If solid insulation consist of voids which may be considered as gas pockets, when the high voltage is applied to such a insulation ionization process occurs in the gas pockets which may leads to internal discharge. This internal discharge may be treated as partial discharge. If the structure of solid insulation consists of multiple voids then possible multiple partial discharge may occur.

These partial discharges decrease the dielectric strength of solid insulation.

If the applied voltage to the insulation is V, the voltage across the void which leads to breakdown is

$V_1= Vd_1 / d_1+(\varepsilon_0 / \varepsilon_1) d_2$.

Where d_1: thickness of void.

d_2: thickness of insulation.

We know that d1 is very much less than d2. Then voltage across void can be written as:

$V_1 = V\varepsilon_r (d_1/d_2)$.

Intrinsic breakdown:

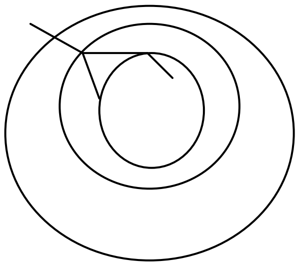
The intrinsic breakdown may occur when high voltage is applied to the solid insulation for small duration of 10^{-8} seconds. The intrinsic breakdown is caused due to the presence of free electrons in the structure of insulation which may migrate throughout the structure. This free electrons are present because of impurities of solid insulations which may increase conductivity of the material. The ionic breakdown may occur in two ways.

Electronic breakdown:

Due to the presence of free electrons in the structure of solid insulation, when the high voltage is applied these free electrons participates in the process of ionization. This may increase more free electrons there by increasing the conductivity of the insulation and decreasing its which stand capability.

Treeing and tracking:

We know that one of the major phenomena which leads to breakdown of solid insulation surface. If further high voltage is applied continuously the responds on the surface of solid insulation is formed like a treeing. Tracking is the other effect where conductivity of solid insulation is spread into the layers of materials in the form of tracking channels following the weakest regions.



Thermal or Over heat breakdown:

When the DC high voltage is applied the heat experienced by solid insulation is :

$W_{dc} = E^2 \sigma$.

When the AC high voltage is applied the heat experienced by solid insulation is :

$W_{ac} = E^2 f\varepsilon_r \tan\beta / 1.8 * 10^{12}$

Where, f – frequency

β – power factor of insulation

E – RMS value of applied voltage.

σ – Dc conductivity.

The heat lost form the material is:

W = Cv dT/dt + ▼ (K grad T)

Where , Cv – material specific heat

T – temperature of specimen.

K – thermal conductivity of the material.

t – time taken to leave the heat.

Under normal working condition heat generated must be equal to heat lost. Otherwise over heat of specimen may takes place thereby causing breakdown of insulation.

Electro mechanical breakdown:

If high voltage is applied to solid insulation the electro static forces may experience by high stress which may exceed mechanical stress of the specimen.

Let us consider d_0 – initial thickness of specimen.

d – compressed thickness due to static forces.

E – applied voltage.

Under equilibrium

$\varepsilon_0 \varepsilon_r E^2/2d^2 = Y \ln (d_0 / d)$

$E^2 =(Y2d^2 / \varepsilon_0 \varepsilon_r) \ln (d_0 / d)$

Where, Y – youngs modulus.

The mechanical breakdown may occurs if:

$d / d_0 = 0.6$

$d_0 / d = 1.67$

with above failure conditions the maximum field experienced by solid insulation is.

$E_{max} = 0.6(Y/ \varepsilon_0 \varepsilon_r)^{½}$

UNIT-III
GENERATION OF HIGH VOLTAGES & CURRENTS

1 Introduction:

Once the study of insulation technology is completed , next important part of high voltage engineering is generation of high voltages and high currents. The generation of several voltages and currents, they are

i. High DC voltage
ii. High AC voltage
iii. High direct current
iv. High alternating current
v. High impulse voltage
vi. High impulse currents.

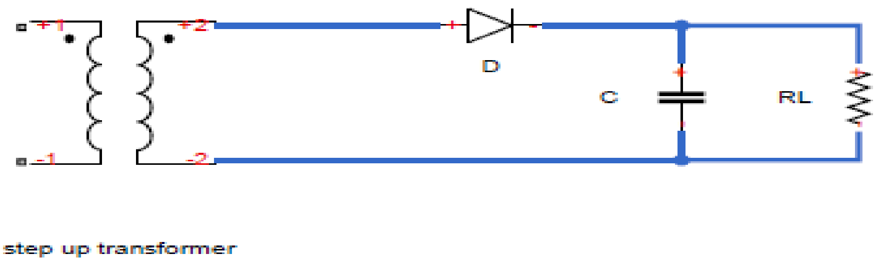
In this unit we are going to study different arrangements to generate high voltage currents.

Generation of High DC Voltage:

Generally hig DC voltage got applications research labs, medical equipment, electronic precipitator etc. high DC voltage generation is as high as 100KV to 200KV. Upto 100KV rectifier circuits can be used with current of 100mA.

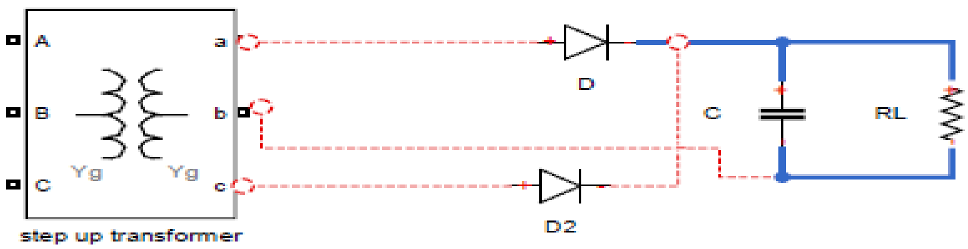
Half wave rectifier circuit:

Half wave circuit consists of only one diode which is of high peak inverse voltage . the arrange for half wave rectification is shown below



Here secondary of transformer has high AC voltage, during positive cycle of that voltage diode conducts and capacitor is charge V_{max} (secondary winding voltage). During negative half cycle voltage across capacitor is discharged through the load resistor R_L. during the negative half cycle voltage across diode will be $2.V_{max}$, hence choose the diode with peak inverse voltage of $2.V_{max}$.The time constant with which capacitor discharges is CR_L.

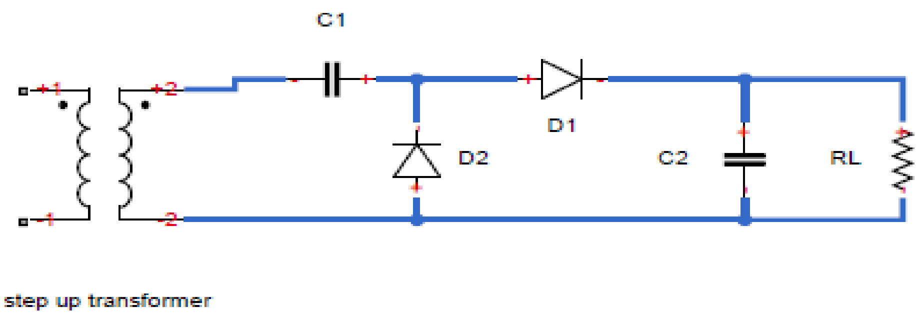
Full wave rectifier circuit: Full wave circuit consists of only two diode which is of high peak inverse voltage . the arrange for full wave rectification is shown below



Here secondary of transformer has high AC voltage, during positive cycle of that voltage diode 1 conducts and capacitor is charge V_{max} (secondary winding voltage). During negative half cycle diode 2 conducts and capacitor is charge V_{max} . Here the output of circuit is an continuous high voltage V_{max} . but this voltage may consist of ripples , hence to eliminate these ripples and to get constant high DC voltage filter are used. The time constant with which capacitor discharges is CR_L.

Voltage Doublers Circuit:

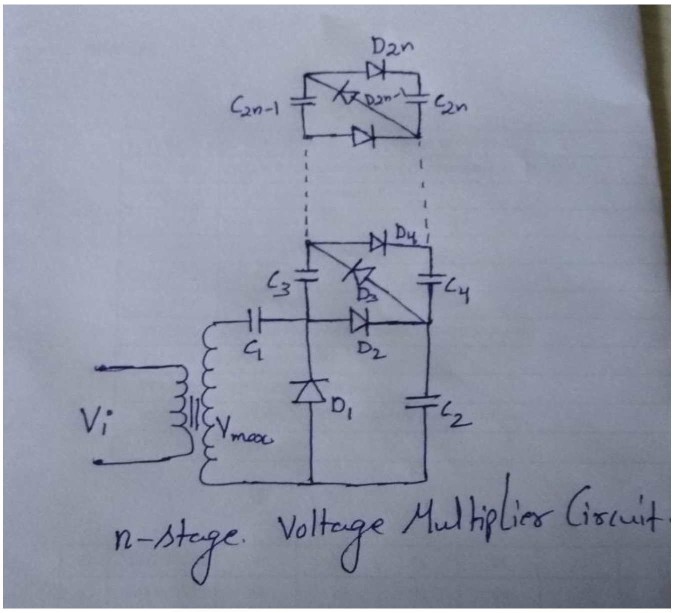
The circuit diagram of voltage doubler is shown below-



Here first let us consider negative half cycle for which diode D_2 is conducted and capacitor C_1 is charged to V_{max}. now in the positive haly cycle diode D_1 is conducted , here voltage across C_1 and supply voltage added up and capacitor C_2 is charges to same voltage i.e $2.V_{max}$. this could be safety is all the devices are rated for $2.V_{max}$. The time constant with which capacitor discharges is C_2R_L.

Voltage Multiplier Circuit Or Cockcroft Walton Circuit:

Cockcroft Walton circuit is similar to voltage doubler circuit but here more such stages are cascaded to increase high DC voltage. In the operation voltage multiplier circuit is same as voltage doubler circuit. The Cockcroft Walton circuit is shown below.



Operation:

First stage of voltage multiplier circuit is same as voltage doubler circuit. Here first let us consider negative half cycle for which diode D_1 is conducted and capacitor C_1 is charged to V_{max}. now in the positive haly cycle diode D_2 is conducted , here voltage across C_1 and supply voltage added up and capacitor C_2 is charges to same voltage i.e $2.V_{max}$. in the next stage during negative half cycle D_3 will conduct and C_3 will be charged to equivalent voltage Vmax, during positive half cycle D_4 conducts and now equivalent voltage is $2.V_{max}$ where C4 is charged to this voltage.cin this process second capacitor of every stage is charged to $2.V_{max}$. if the multiplier circuit consists of n stages then total voltage which discharged through R_L is 2.n. V_{max} with small current in mA. The output of this also consists of ripples.

Calculation of ripples voltage multiplier circuit:

Let , f – supply frequency

I – load current from rectifier

q- charge transfered in each cycle

t_1- conduction interval of rectifier

t_2- non-conduction interval of rectifier

δV – ripple voltage.

In the first stage during non conduction period discharge current is ,

$I = q/t_2$

charge transferred is , $q = C_2. \delta V$

$t_2 = 1/f$

$It_2 = C_2. \delta V$

$I/f = C_2. \delta V$

$I/f\ C_2 = \delta V$

Let us consider every stage second capacitor has came value C,

The ripple voltage at different stages is given as I/f C , 2I/f C , 3I/f C ------------ nI/f C.

Hence total ripple voltage voltage in n stages is,

$\delta V = I/f\ C + 2I/f\ C + 3I/f\ C +$ ------------ nI/f C.

$= I/f\ C\,[\ 1+2+3$------------------$n]$

$= In(n+1)/2f\ C$

Voltage regulation from voltage multiplier circuit

The voltage drop at last stage will be,

$\blacktriangle V_{2n} = I(2n-n)/f\ C$

The voltage drop at last but one stage ,

$\blacktriangle V_{2n} = I(2n+2(n-1)-(n-1))/f\ C$

In this fashion drop is continued till first stage, therefore total voltage drop is,

$\blacktriangle V = (I/fC)\ \text{summation}(\blacktriangle V_{2r})_1^n$

$\blacktriangle V = (I/fC)\ .\ (\sum n(2n) - \sum n)$

$\blacktriangle V = (I/fC)\ .\ (\sum n(2n-1))$

$\blacktriangle V = (I/fC)\ [\ (2/3)n^3 + n^2/2 + n/6]$

For highest stages >> 5 $n^2/2$, n/6 small compare to $(2/3)n^3$, then voltage drop is

$\blacktriangle V = (I/fC)\ (2/3)n^3$

Hence total output voltage from cockcroft walton circuit of n stages is ,

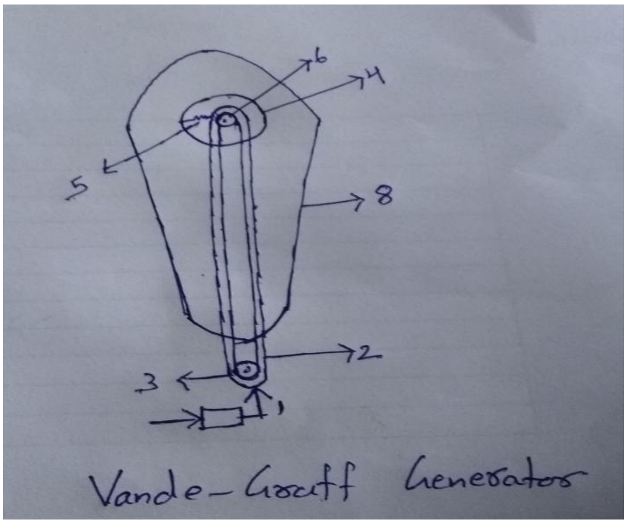
$V_0 = 2nV_{max} - (I/fC)\ (2/3)n^3$

The optimum number of stages with minimum voltage drop is given as,

$$n_{opt} = sqrt(V_{max}.fC/I)$$

Vande-Graff Generator Or Electrostatic Generator:

Vande –graff is the name of scientist who invented an generator of high DC voltage based on the principle of electro-static. This generator is used build up to voltage of 10KV to 100KV. The figure of vande-graff generator is shown below



The construction of vande-graff generator consists of

i. Lower spray point.
ii. Insulated belt.
iii. Driven pulley lower one
iv. High voltage material.
v. Collector
vi. Pully at top to drive belt
vii. Upper spray point .
viii. Shield.

Operation :

From the lower spray poni charge are injected on to the insulated belt at bottom, then belt is driven by lower pulley toward top, where at the top collector collects the charge on ijects on to high voltage material which gets excited with such high charge, their by causing high voltage between high voltage material to earth.

Principle of electro-static generator

Let E – field between material and earth
b- width of the belt
s- charge density
d – separation between plates.

On the belt at a distance of dx the charge is , dq = s.b.dx

The force on the belt is, $F = \int E\, dq.$

$$F = \int E\, s.b.dx$$

Let v be the velocity of belt, hence mechanical power with which it is moving is,

. $P = F.v$

$$P = v . \int E\, s.b.dx.$$

The current generated can be given as, $I = dq/dt$

$I = s.b.dx /dt$

$I = s.b.v$

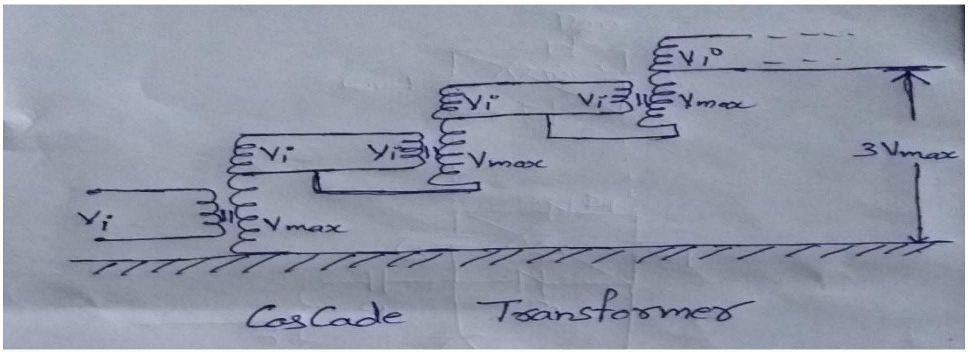
The voltage between the electrodes is , $V = \int E\, dx$

3.3 Generation Of High AC Voltage:

Some of the arrangements for generation of high Ac voltage are cascade transformer, resonant transformer, rogowski coil etc.

Cascade transformer;

Cascade transformer is an very easy arrangement using which high AC voltage can be generated. This generated voltage helps in testing the insulation of power system equipment. The circuit of cascade transformer is shown below-

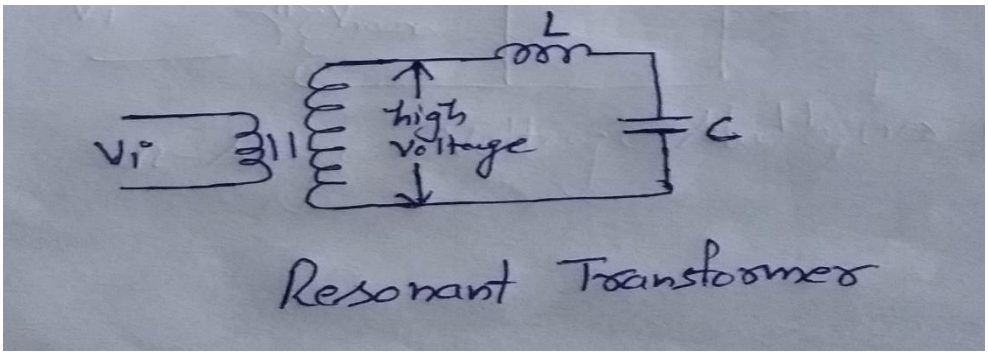


Operation:

In the construction cascade transformer it consists of primary, secondary and tertiary winding. Primary winding and tertiary winding has same number of turns, where secondary winding has more turns when compare to both. Their by we can call transformer as step up transformer. When the input low voltage is given to the primary winding by the principle of mutual induction voltage will be induced on both secondary and tertiary winding. Secondary winding voltage let be V_{max} and tertiary winding voltage same as primary winding voltage. Now in the second stage tertiary winding voltage is fed to primary winding of second stage transformer primary, secondary windings of both first stage and second are connected in series their by total voltage generated between them is $2V_{max}$. like this we can increase number of stages to generate high AC voltage , but as stages increases the insulation technology required also increases which is not economical. Here every stage transformer shielded properly and grounded. This type of arrangement is generally suggestible for generation of up to 300KV.

Resonant transformer:

Resonant transformer is the arrangement which is used to generate high AC voltage using the principle of electrical resonance**.** We know that if electrical circuit tin under resonance maximum response will occur. Below diagram is the arrangement of resonant transformer.



Operation:

Here, L_1, L_2- leads to reactance each winding respectively.

r_1,r_2 – winding resistances respectively

L – magnetizing reactance cause.

C- shunt capacitance due to bushings and also test object.

If the arrangement is under resonant condition then large current flows through it, this happens when (L_1 + L_2) = (1/wC). Then the voltage across test ojbject is

Vc = (V.Xc / R)

Vc = (V /wC R)

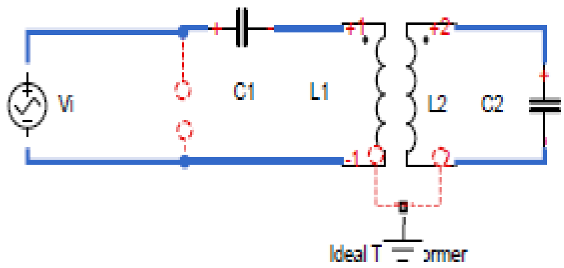
Where R is the total resistance series connection of secondary. The factor Xc / R in series connection is Q factor of capacitor , which is the multiplication factor to supply voltage to increase voltage across test object. This arrangement has capacity to generate as high as 3000KV AC voltage.

Advantages:

i. Set up this type generation is easy.
ii. Voltage generated is pure sine form.
iii. Cascading of units is easy.
iv. Power requirements are less.

3.4 Generation high ac voltage with high frequency:

This type of arrangement is required to generator high AC voltage of high frequency, which is helpful in generating high DC voltage rectifier circuit. Below is the figure for generation high AC voltage.

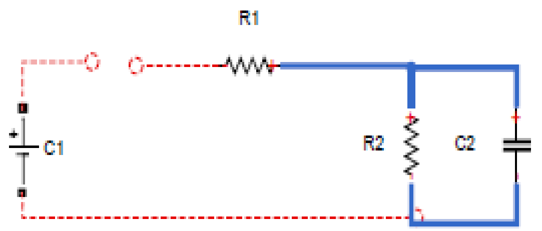


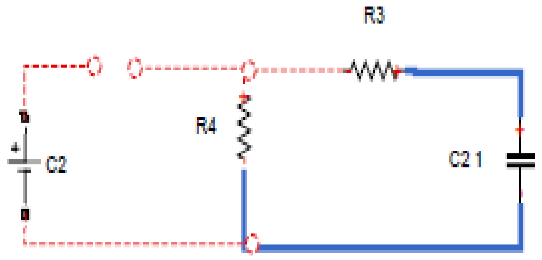
Operation:

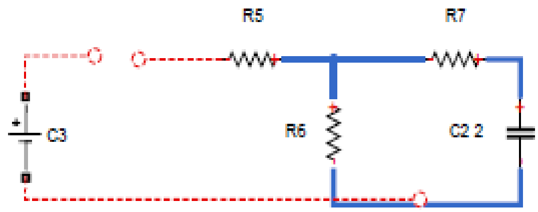
The primary is rated for 10KV and secondary is rated 1000KV. The primary is fed with DC or AC voltage through the capacitor C_1. Here spark gap is arranged such that at its required voltage it induces high self excitation in the secondary winding. This transformer in wounded on the air core. The transformer is also named as double tuned transformer. The tuning of primary depends on L_1 and C_1, secondary L_2 and C_2. Because of double we can generate high damped voltage whose frequency also more. The output voltage depends on C_1,C_2,L_1,L_2.

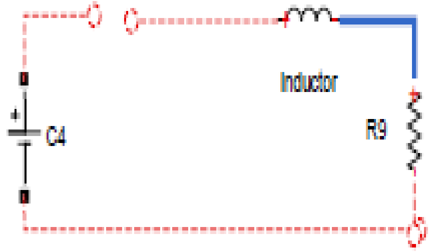
Generation of high impulse voltages.

The regular faults which occurs on the power system equipment are lightening surges and switching surges. These surges remains for very short duration of time hence to test the power system apparatus impulse voltage are the best suitable. The impulse wave form is featured with rise time and decade time. Generally decade time is 50% of decade time. some of the arrangements for the generation of high impulse voltage are shown below.



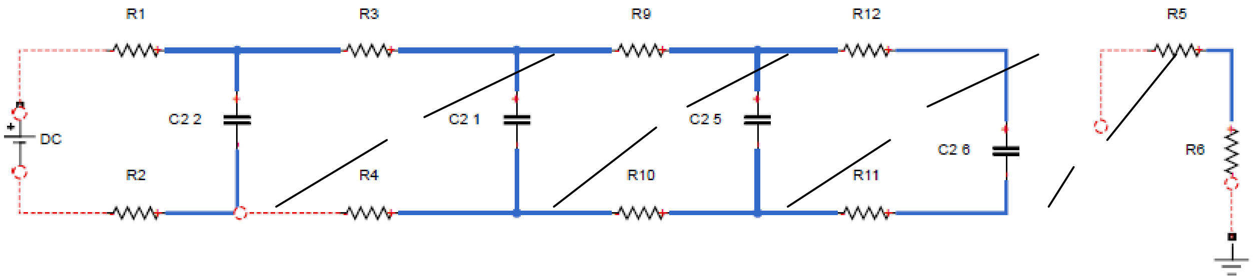






Impulse generator with multiple stages (Marx circuits)

The arrangement for the generation for high impulse voltage is shown below.



Operation

Let R – charging resister also current limiter.

C – capacitance of the generator

G – spark gap

T – test object

R1 R2 – used for wave shape control.

An DC voltage is applied to above arrangement which charges first capacitor through limiting resistor R.

The breakdown voltage of spark gap is greater than charging voltage of capacitor.

When the breakdown occur in the spark gap the first capacitor discharges through the second and this continued till all the capacitors are charged where these capacitors falls in series with each other there by the total voltage is discharged through R1 R2. The charging time constant of each stage is CR and the discharging time constant is CR1 / n. where n is the number of stages.

UNIT – IV
MEASUREMENT OF HIGH VOLTAGES AND HIGH CURRENTS

Various methods to measure the generated voltages and currents are:

DC voltages:

i. Series resistance micro ammeter.
ii. Resistance potential divider.
iii. Generation volt meter.

AC voltages:

i. Series impedance ammeter
ii. Potential divider.
iii. Potential transformer.
iv. Spear gaps.

High frequency AC voltage.

i. Peak volt meter
ii. Sphere gap.

Methods to measure the high currents.
Direct currents.

i. Resistive shunt.
ii. Magnetic links.
iii. Hall effect.

Alternating currents

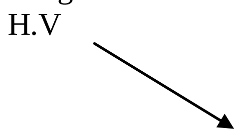
i. Resistive shunts.
ii. Electro magnetic transformers

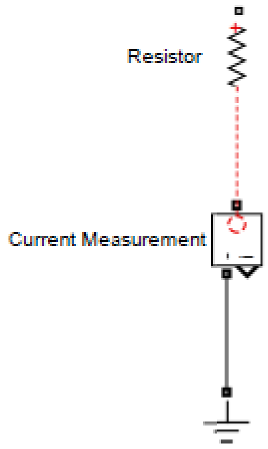
High frequency alternating current

i. Resistive shunts.
ii. Magnetic links.
iii. hall effect.

Micro ammeter with series resistance

The arrangement for measuring high dc voltage is shown below.



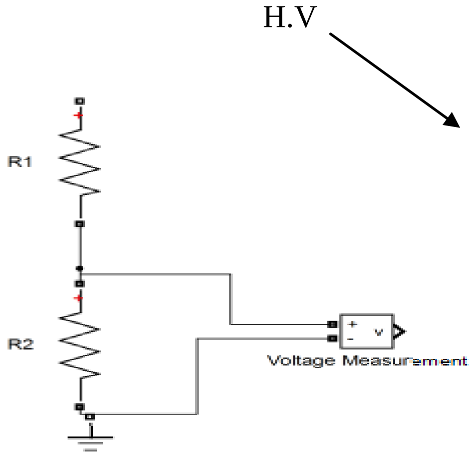


The series resistance with micro ammeter is ranged as high as in mega ohms. In the above arrangement the voltage to be measured is applied which allows a small current to the series resistance R. the current through the series resistance is measured by micro ammeter. The voltage drop across micro ammeter is negligible. These arrangement is used to measure DC voltage as high as 500KV. The voltage measure is given as:

V = IR

Potential divider to measure high DC voltage.

The arrangement to measure high DC voltage is shown in below diagram:



Here an electro static volt meter connected across R2, which is given as:

V2 = V*R2 / (R1 + R2)

From above expression the applied high voltage is measured as:

V = V2* (R1 + R2) / R2.

Series capacitance volt meter to measure high AC voltage.

To measure high AC voltage the arrangement is shown below:

The voltage to be measured is applied to the above arrangement such that current flowing through capacitor C is:

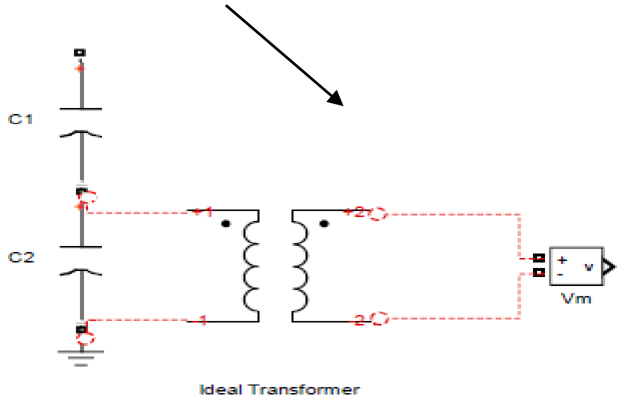
$I_c = J*\omega*C*V$

Where C – capacitance of the series capacitance

V – voltage to be measured.

ω – angular frequency.
Using this arrangement we can measure AC voltage up to 1000KV.

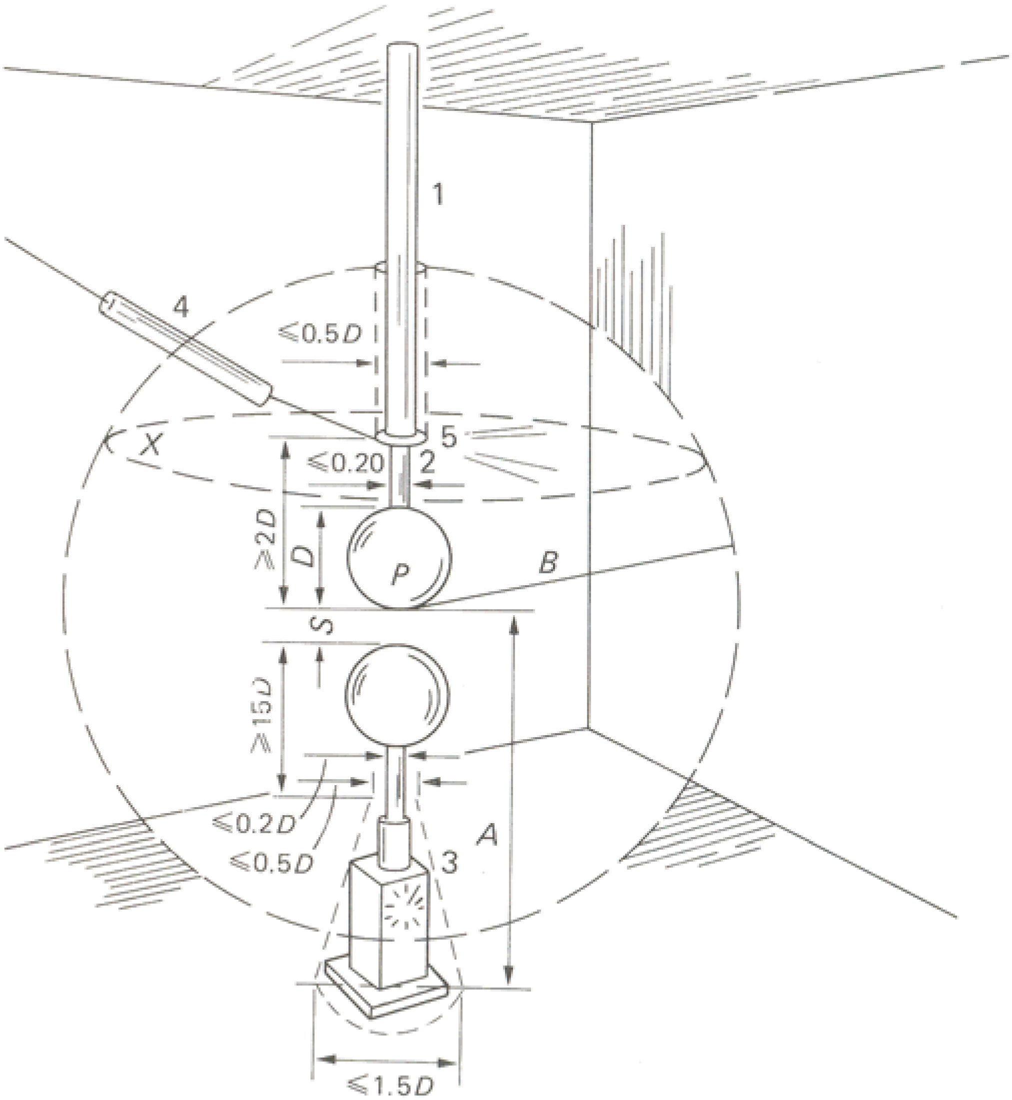
Capacitance voltage transformer to measure high AC voltage.
The arrangement for measurement of high AC voltage is shown below:



In the above diagram capacitors are connected in series where the bottom layer arrangement indicates principle of resonant transformer. The voltage across C2 is measured by the meter connected to one of the winding of the transformer. Once the voltage across C2 is determined the applied voltage are voltage to be measured can be given in terms of C2 meter reading and rest of the capacitors in series. This arrangement is simple and has advantage of measuring meter isolation.

Magnetic links:
Magnetic links are the metallic strips which are arranged on the drum which is parallel to the current carrying conductor. The remnant magnetism due to current carrying conductor has the influence on magnetic strips. The magnetism experienced by magnetic links can be approximated in terms of current thereby total current can be measure.

SPHERE GAP:



31.2 Sphere gap in a HV Laboratory

UNIT - V

HIGH VOLTAGE TESTING AND INSULATION COORDINATION

Insulation co-ordination:

It is the process of getting understand of power system equipment with insulation technology for their safe and secure operation. Here insulation co-ordination with power system equipment is required to know the withstand capability of specimens and to avoid chances of failure.

Basic impulse level (BIL):

The electrical strength of the insulation what it can withstand without puncture and is the threshold value of lightning surge.

Basic switching impulse level (BSL)

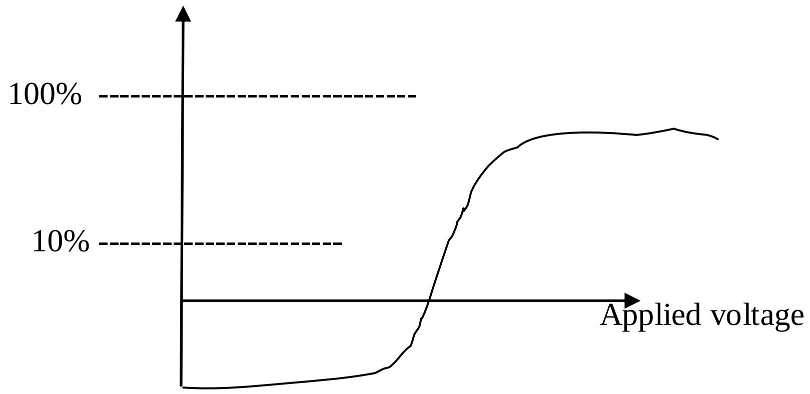
The electrical strength of the insulation what it can withstand without puncture and is the threshold value of switch surge.

Factor of Earthing:

It is the ratio of highest RMS value of working frequency phase to earth voltage during during an earth fault to the RMS value of normal frequency phase to phase voltage at the required location without fault . This ratio helps in identifying the earthing constraints as view from the fault location.

Effective Earthing System:

An power system is said to be effectively earthed if the factor of earthing does not exceed 80% and if it exceeds is not effective. It is the maximum value of the switching and impulse testing voltages according to specifications which has 90 percent to withstand without flashover.In reality there is no withstand voltage which has 100 percent probability of flashover, hence 90 percent probability of withstand voltage is taken.



Statistical impulse voltage:

It is the lightning surge and switch surge overvoltage applied to the power system equipment the maximum value of which has a 2% probability of surplus.

Secure level of protective devices:

This is the highest level of lightning surge and switch surge overvoltage at the terminals of the specimen which should not be exceeded for the normal working condition.

Need of insulation co-ordination:

- **i)** To increase long life and continuity in service.
- **ii)** To reduce the number of flashovers due to surges.
- **iii)** For economical installation and operation.

Necessity of protective devices:

- **i)** Protects power system apparatus from high surges.
- **ii)** The V-I characteristics of any power system equipment must lie below the withstand voltage level.
- **iii)** Helps in discharges high currents and retain normal condition fastly.
- **iv)** The breakdown voltage of any apparatus is the function applied withstand voltage and time of application.
- **v)** The V-t plot indicates relation between applied voltage and time of application which leads to breakdown

<u>How Volt-Time Curve plotted:</u>

Function of same shape but with different maximum values are applied to the specimen whose V-I characteristics are required.

Generally the flashover on specimen can be observed at the front of the function can be observes in V-I plot.

Otherwise the flashover on specimen can be observed at the maximum value of the function can be observes in V-I plot.

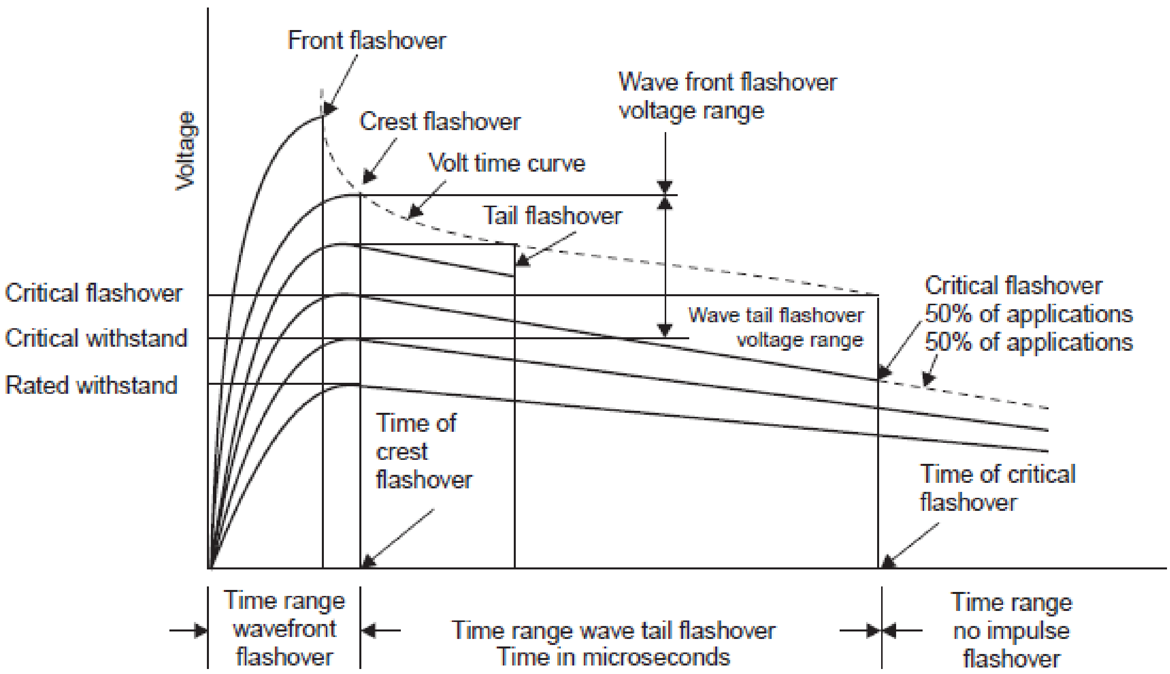
Another possibility is that flashover may occur at tail end of the function

Surge arresters :

Present surge arrester are the gapless ZnO , earlier silicon carbide arrester are used. This zinc oxide surge arrester has exceeded the characteristics of other has it has non-linear resistance behavior. Therefore it is possible to eliminate the series gaps between the individual ZnO block making up the arrester.

Procedure to select surge arrester-

- **i)** estimate the arrester voltage regularly which in general rated voltage.
- **ii)** Choose the rated voltage of the surge arrester
- **iii)** Calculate the normal lightning discharge current.
- **iv)** Find the long duration required discharged capability
- **v)** Determine the required long duration discharge capability.



5 Destructive Testing:

Here power systems equipment are tested for their withstand capability under different atmospheric, mechanical, electrical conditions. These are mainly classified into two types – type test, routine test.

Type test: This test is meant to check the design features of the specimen.
Routine test: This test is meant to check the quality of individual specimen.

Nomenclature related testing of insulators:

i) **Discharge disruptive voltage-** This is the voltage which leads to breakdown of insulation making voltage zero and allowing through insulation.

ii) **Withstand voltage-** the voltage applied to the specimen under given specifications and insulation withstand for this voltage without discharge.

iii) **Fifty percent flash over voltage-** this is the voltage which has 50% chances to cause the breakdown of insulation.

iv) **Hundred percent flash over voltage-** this is the voltage which has 100% chances to cause the breakdown of insulation.

v) **Creepage distance:** it is the shortest distance between the two metal fittings on the surface of insulation.

vi) **AC test voltage:** it is the Ac voltage with frequency between 40 to 60Hz used to test insulation withstand.

vii) **Impulse voltage-** these are the voltage which remain for very short duration of time used to check the withstand capability of dielectric medium under fault conditions.

Reference atmospheric conditions-

viii) **Indian standards-** temperature -27°C

i) Pressure- 1013mbars

ii) Absolute humidity-17gm/m3

ix) **British standards-** temperature -20°C

i. Pressure- 1013mbars

ii. Absolute humidity-11gm/m3

In general flashover voltage of test specimen is given as,

$$V = v*(h/l)$$

Where, V- flashover voltage

v- voltage under reference atmospheric conditions

h-humidity correction factor

l- air density correction factor

5.5.1 Testing Of Insulator:

The testing are again classified as

1) power frequency tests
2) impulse test.

Let us test the insulator under power frequency mode

.

Power frequency tests:

Dry and wet flashover test- in this test insulator is tested with AC power frequency voltage where the voltage applied continuously increased at rate of 2 percent per second till 75 percent rated voltage is reached. If this test is conducted dry atmospheric conditions it Is named as dry flashover test otherwise wet flashover test. Is the flashover occurs then the insulator fails to operate otherwise pass

.

Wet and dry with stand test-in this test the specified voltage is applied for one minute both in dry and wet condition and to say that test is passed the insulator must withstand that voltage without flashover.

Impulse test:

Impulse withstand test-in this the specified impulse voltage is applied to insulator under dry conditions with both positive and negative voltages. If the insulator with stand for five consecutive attempts then test is passed , but at least for two attempts flashover occurs then test is said to be failed

Impulse flashover test- here the specified impulse voltage is applied till the flashover occurs. But it is difficult to identify exact voltage of impulse as its duration is very small. Hence the test is conducted by applying 20% to 80% voltages .

Pollution test- as insulators are exposed to air they may effected by different pollutants, some of them are sand particles, dust particles, bird excreta, moisture, snow, industrial waste etc.

To test this the surroundings of insulators is injected with salt fog and then rated normal voltage is applied to test withstand of the equipment. This test conducted by slowly increasing the salinity of fog and testing withstand voltage.

5.5.2 Testing Of Bushings:

Power frequency test:

Power factor and voltage test- here the specimen is immersed in oil and then set up in Schering bridge The voltage applied is continuously changes and then capacitance, power factor or loss factor of bushing is calculated. Their by a plot between applied voltage and loss factor is drawn.

Internal discharge: in this test an bushing is tested for its internal discharge due to cavities in it. The voltage is continuously applied and discharge is observed. the plot between voltage and discharge is drawn to understand the withstand capability of equipment.

Momentary withstand test- the Indian standard voltage of bushing is applied to it and has withstand without any flashover for 30 seconds.

One minute withstand test- in this test the specimen is tested with rated voltage both in dry and wet conditions for one minute. The equipment has to withstand without flashover for one minute then test is said to be passed

Impulse Test:

Full wave withstand test-in this the specified impulse voltage is applied to insulator under dry conditions with both positive and negative voltages. If the insulator with stand for five consecutive attempts then test is passed , but at least for two attempts flashover occurs then again 10 attempts are done on the bushing.

Chopped wave withstand test- this is similar to above test but conducted for high rated bushings.

5.5.2 Testing Of isolators and circuit breakers:

The different tests that can be conducted are –

- **i)** Overvoltage tests
- **ii)** Temperature rise test
- **iii)** Mechanical test
- **iv)** Short circuit test.

Short circuit test again classified as ,

- i. Direct test
- ii. Synthetic test

Synthetic test again classified as,

- i. Direct testing the networks or in the field.
- ii. Direct testing the short circuit test lab
- iii. Synthetic testing of circuit breaker
- iv. Composite testing
- v. Unit testing
- vi. Asymmetrical test.

5.5.3 Testing Of cables: The different test classified on cables are ,

- i. Mechanical test
- ii. Thermal duty test
- iii. Dielectric power factor test
- iv. Withstand voltage test at power frequency

v. Withstand test impulse voltage
vi. Internal discharge test
vii. Life expectancy.

Power factor and voltage test- here the specimen is immersed in oil and then set up in schering bridge . the voltage applied is continuously changes as 0.5 , 1, 1.66 and 2 times of rated voltage and then capacitance , power factor or loss factor of bushing is calculated. Their by a plot between applied voltage and loss factor is drawn.

Internal discharge: in this test an cable is tested for its internal discharge due to cavities in it. The voltage is continuously applied and discharge is observed. the plot between voltage and discharge is drawn to understand the withstand capability of equipment.

Life test- this test in meant check the long life of the cable with good normal operating conditions.
The life index of cable is given as,

$$E = K.t^{-(1/n)}$$

Where, E- electric field stress(maximum)
K-constant
n- life index.

5.5.4 Testing Of Transformers:
The most common equipment which is effected by lightning surges in power system is power transformer.

The test on power transformer are-
Induced over voltage test- the transformer secondary is tested by inducing over voltages for their withstand. The frequency of over voltage can be as high as 100 to 400Hz.

Partial discharge test- in this test an transformer winding is tested for its internal discharge due to cavities in it. The voltage is continuously applied and discharge is observed. the plot between voltage and discharge is drawn to understand the withstand capability of equipment

Impulse test- the procedure to conduct impulse test is –
a) Applying basic impulse voltage of 75%.
b) One full wave of basic impulse voltage.
c) Two chopped waves of rated basic impulse voltage.
d) One full wave of basic impulse voltage.
e) Applying basic impulse voltage of 75%.

Radio interference also plays important role to test power system equipment like transformer, transmission cable, rotating machines etc.