KLR COLLEGE OF ENGINEERING & TECHNOLOGY

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BCM oncha-507115, Bhadradri Kothagudem(Dist.), Telangana.

LECTURE NOTES

ON

HIGH VOLTAGE ENGINEERING

2021 - 2022

III B. Tech I Semester

Estd.2008

ELECTRICAL AND ELECTRONICS ENGINEERING

BREAKDOWN IN GASES

IONIZATION PROCESSES AND DEIONIZATION PROCESSES

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

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

DEIONIZATION PROCESS :

Deionization results from the recombination of ions and electrons, their diffusion toward the boundaries of the volume occupied by the gas, and the extraction of the charged particles by an external electrical field applied to the gas.

Townsend's Theory:

Townsend"s has consider both primary and secondary process which leads breakdown in gas dielectricmedium 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 voltagep – primary ionization co-efficient

x – be the distance from cathoden_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 toprimary 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,

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 platesmust 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.

$e^{p.d}$ >>1therefore above condition can be written as ,

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

LIMITATION OF TOWNSEND'S THEORY

Townsend mechanism when applied to breakdown at atmospheric pressure was found to have certain drawbacks:

- The mechanism predicts time lags of the order of 10-5 ,while in actual practice voltage were found to depend on the gas pressure and the geometry of the gap.
- breakdown was observed to occur at very short times of the order of 10-8 s.
- Also , while the Townsend mechanism predicts a very diffused form of discharge, in actual practice, discharges were found to be filamentary and irregular

TYPES OF DISCHARGE :

The electrical discharges in gases are of two types;

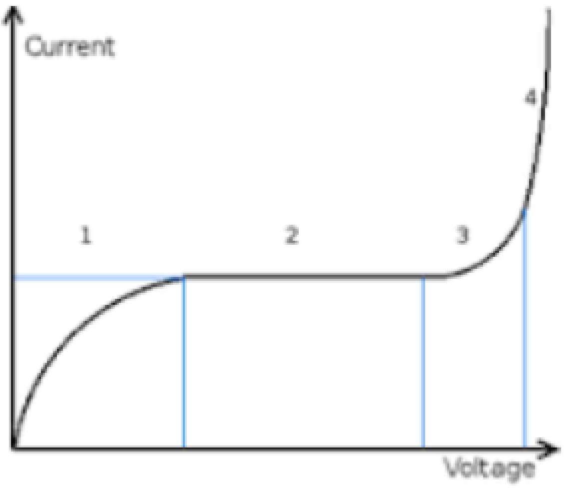
- non-sustaining discharges
- self-sustaining
- The breakdown in a gas (spark breakdown) is the transition of a non-sustaining discharges into a self-sustaining discharge.
- **non-sustaining discharges**
- This current being dependent on I0 does not represent self sustaining discharge.
- **self-sustaining**
- The breakdown in a gas (spark breakdown) is the transition of a non-sustaining discharges into a self-sustaining discharge.

GASES AS INSULATING MATERIALS :

The most common dielectrics are gases. Many electrical apparatus use air as the insulating medium, while in a few cases other gases such as N2, CO2, CCl2F2 (freon) and SF6 (hexafluoride) are used. Gases consist of neutral molecules, and are, therefore, good insulators.

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 FIELD

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.

NON UNIFORM GAPS:

In Breakdown in Non Uniform Fields, such as coaxial cylinders, point-plane and sphere-plane gaps, the applied field varies across the gap. Similarly, Townsend's first ionization coefficient (α) also varies with the gap. Hence αd in Townsend's criterion, Townsend's criterion for breakdown now becomes

$$\gamma\left\{\exp\left[\int_0^d \alpha\, dx\right]-1\right\}=1$$

Meek and Raether also discussed the non-uniform field breakdown process as applied to their Streamer theory, and the Meek's equation for the radial field at the head of an avalanche when it has crossed a distance x is modified as

$$E_r=\frac{5.27\times10^{-7}\ \alpha_x\ \exp\left(\int_0^x \alpha\, dx\right)}{(x/p)^{1/2}}\ \text{V/cm}$$

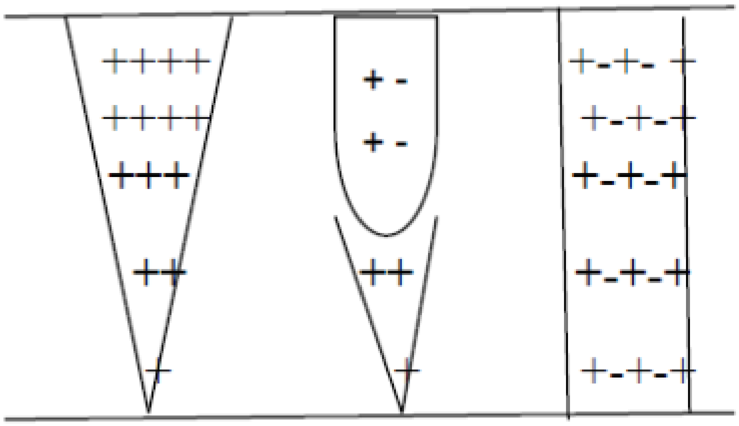
where α_x is the value of α at the head of the avalanche, and p is the gas pressure. The criterion for the formation of the streamer is reached when the space charge field E_r approaches a value equal to the applied field at the head of the avalanche.This equation has been successfully used for determining the corona onset voltages of many non-uniform geometries.

STREAMER MECHANISM:

STREAMER THEORY of breakdown mainly arises due to the added effect of the space- charge field of an avalanche and photo-electric ionization in the gas volume. But in practice, breakdown voltages were found to depend on the gas pressure and the geometry of the gap.

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 indicates how field of positive space charge ionizes the gas. Figure

indicates formation of avalanche between plates.

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

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, $g_2(E/b)[e^{g_1(E/b).d} – 1] = 1$

$g_2(V/d.b)[e^{g_1(V/d.b).d} – 1] = 1$

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

$V = g(d.b)$

CORONA DISCHARGE:

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 hissingor 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 aroundthe 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 airwill 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 isstrong 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 intoions – 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 atmosphericair 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 ofair. 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 ofcorona on power system reduces considerably. Also, the presence of dirt or roughness of the conductor reducesthe 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 forthat 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 inhigh 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 – hencereducing 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 veryhigh 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 mostlikely 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:

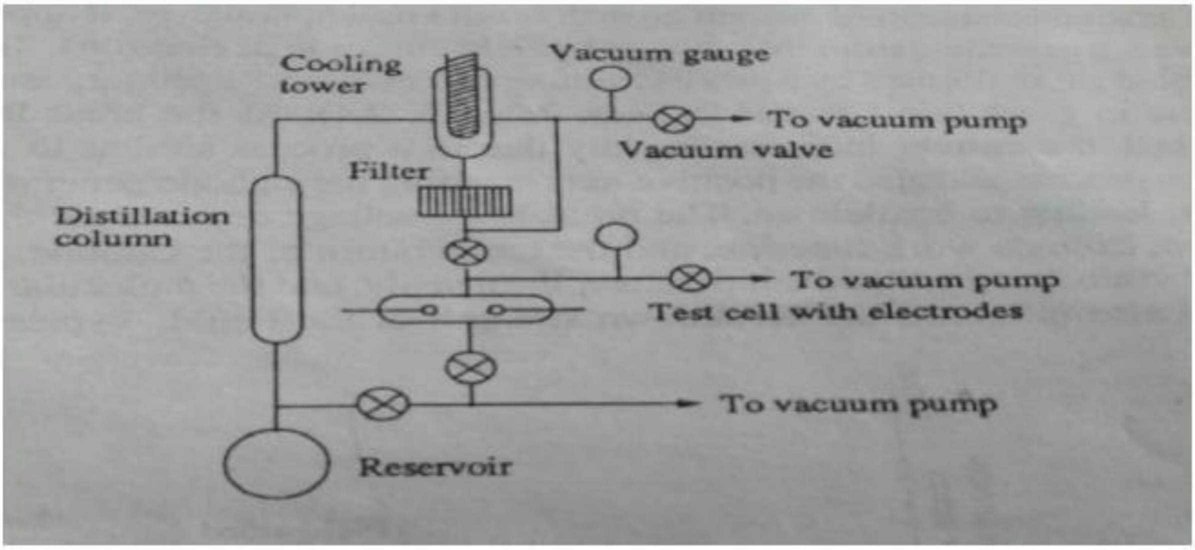
i) The undesirable effects of the corona are:

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 inthe line.
vi) The corona power loss reduces the efficiency of the line

BREAKDOWN IN LIQUID AND SOLID INSULATING MATERIALS:

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 onewhich 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 contentcan 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.

SOLID DIELECTRICS AND COMPOSITE DIELECTRIC:

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.

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BREAKDOWN INTRINSIC

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. Themaximum 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 participatein the conduction process. Based on this principle, two types of intrinsic breakdown mechanisms have beenproposed.

ii) 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 collisionsoccur. 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.

2.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.

ELECTROMECHANICAL BREAKDOWN AND THERMAL BREAKDOWN

Electro mechanical breakdown:

If high voltage is applied to solid insulation the electro static forces may experience

by high stress whichmay exceed mechanical stress of the specimen.

Let us consider d_0 – initial thickness of specimen.

Let us consider d0 – initial thickness of specimen.

d – compressed thickness due to static forces. E – applied voltage.

Under equilibrium

ε0 εr E2/2d2 = Y ln (d0 / d) E2 =(Y2d2 / ε0 εr) ln (d0 / d)

Where, Y – youngs modulus.

The mechanical breakdown may occurs if:

d / d0 = 0.6 d0 / d = 1.67

with above failure conditions the maximum field experienced by solid insulation is. Emax = 0.6(Y/ ε0 εr) ½

Thermal or Over heat breakdown:

When the DC high voltage is applied the heat experienced by solid insulation is : Wdc = E2 ζ.

When the AC high voltage is applied the heat experienced by solid insulation is : Wac = E2 fεr tan β / 1.8 * 1012

Where, f – frequency

β – power factor of insulation

E – RMS value of applied voltage. ζ – Dc conductivity.

The heat lost form the material is:

W = Cv dT/dt + ▼ (K grad T)

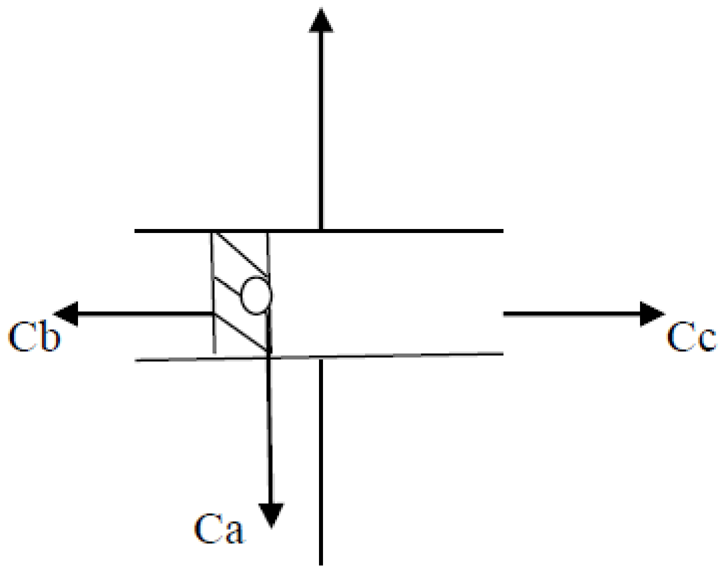
Where , Cv – material specific heat

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.

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

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

APPLICATIONS OF INSULATING MATERIALS:
The applications of insulating material are
2 Cable and transmission lines
3 Electronic systems
4 Power systems
5 Domestic portable appliances
6 Electrical cable insulating tape
7 Personal protective equipment
8 Electrical rubber mats

UNIT II

GENERATION OF HIGH VOLTAGES

Introduction:

Once the study of insulation technology is completed , next important part of high voltage engineering isgeneration 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

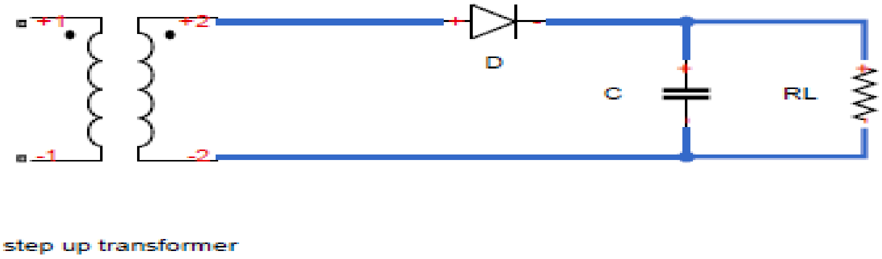
.

Generation of High DC Voltage:

Generally hig DC voltage got applications research labs, medical equipment, electronic precipitator etc. highDC 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

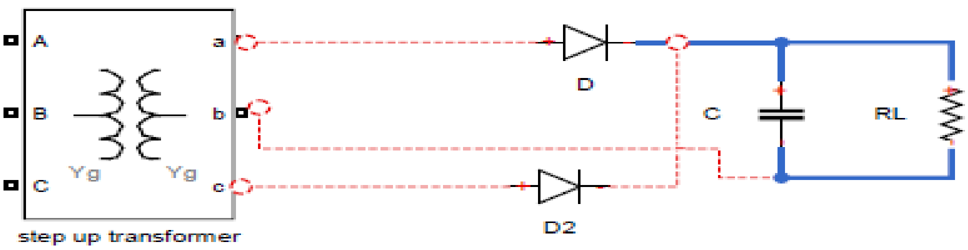


Here secondary of transformer has high AC voltage, during positive cycle of that voltage diode conducts and capacitor is charge V_{max} (secondary winding voltage). During negative half cycle voltage across capacitor is discharged through the load resistor R_L. during the negative half cycle voltage 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 inversevoltage . the arrange for full wave rectification is shown below

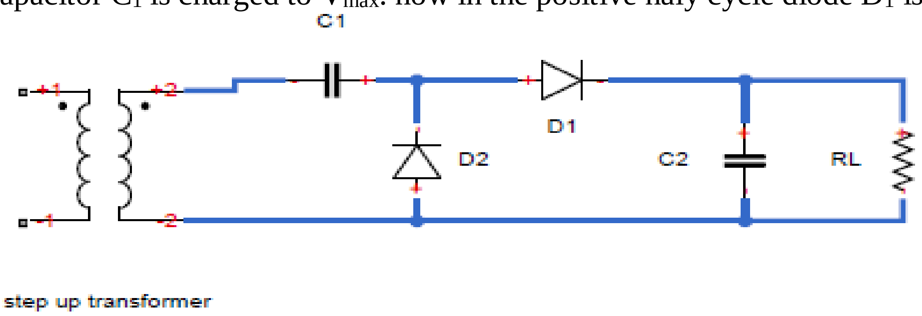
Here secondary of transformer has high AC voltage, during positive cycle of that voltage diode 1 conducts and capacitor is charge V_{max} (secondary winding voltage). During negative half cycle diode 2 conducts and capacitor is charge V_{max} . Here the output of circuit is an continuous high voltage 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-

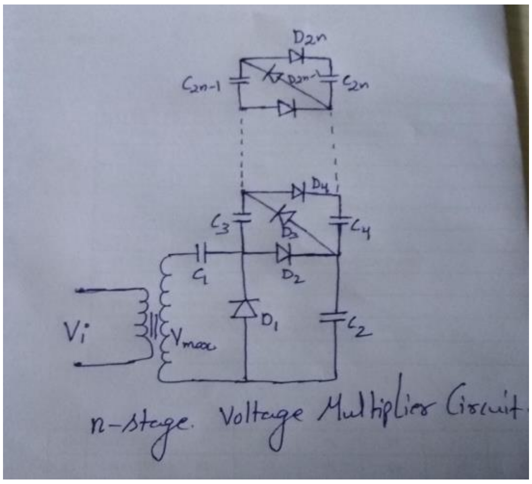
Here first let us consider negative half cycle for which diode D_2 is conducted and capacitor C_1 is charged to V_{max}. now in the positive haly cycle diode D_1 is conducted



, here voltage across C_1 and supply voltage addedup 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

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,

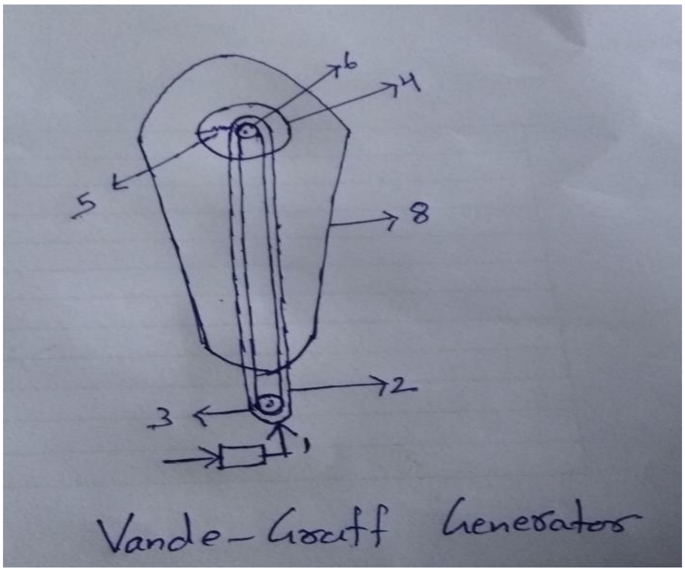
$\delta V = I/f\,C + 2I/f\,C + 3I/f\,C + \text{--------------------} nI/f\,C.$
$= I/f\,C\,[\,1+2+3 \text{--} n]$
$= In(n+1)/2f\,C$
Voltage regulation from voltage multiplier circuit The voltage drop at last stage will be,
$\blacktriangle V_{2n} = I(2n-n)/f\,C$
The voltage drop at last but one stage ,
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,
$n_{opt} = \text{sqrt}(\ V_{max}.fC/I)$
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 earthb- width of the belt
r- 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.

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

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

I = s.b.dx /dt

I = s.b.v

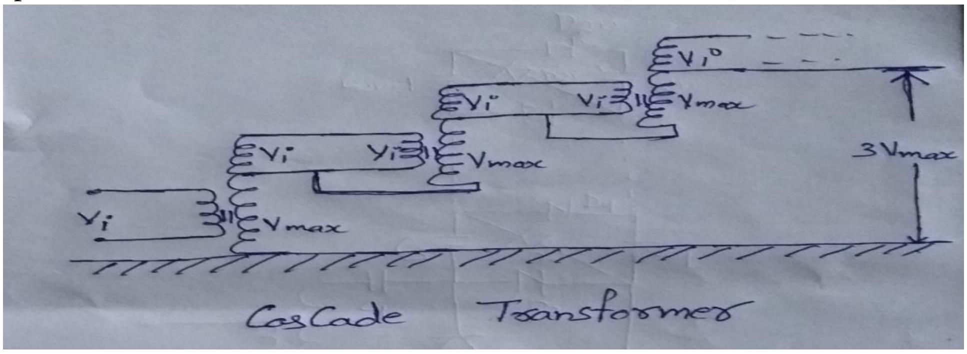
The voltage between the electrodes is , $V = \int E\, dx$

Generation Of High AC Voltage:

Some of the arrangements for generation of high Ac voltage are cascade transformer, resonanttransformer, 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 transformeris shown below-

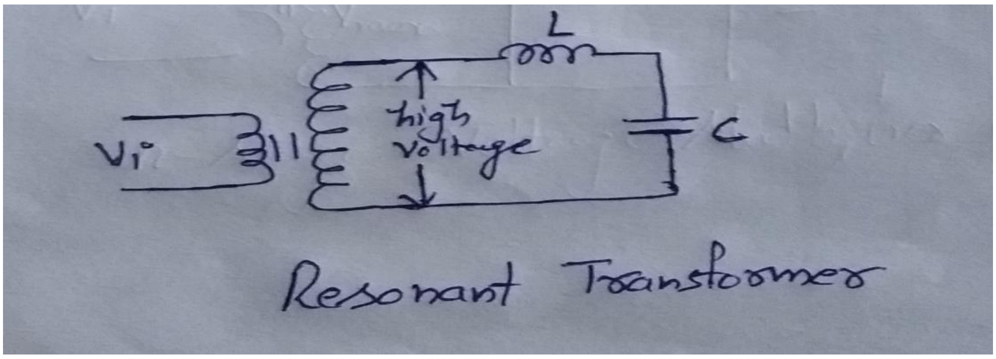


Operation:

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 stagetransformer 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 ofelectrical 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

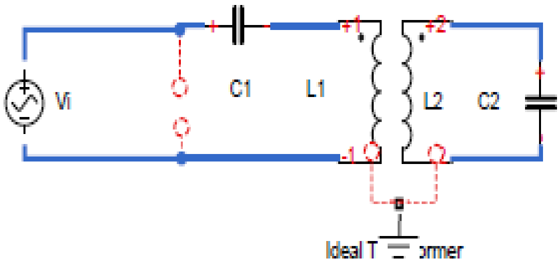
L – magnetizing reactance cause.
C- shunt capacitance due to bushings and also test object.
If the arrangement is under resonant condition then large current flows through it, this happens when ($L_1 + L_2$) = (1/wC). Then the voltage across test ojbject is
Vc = (V.Xc / R)
Vc = (V /wC R)
Where R is the total resistance series connection of secondary. The factor Xc / R in series connection is Qfactor 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.

Generation high ac voltage with high frequency:

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

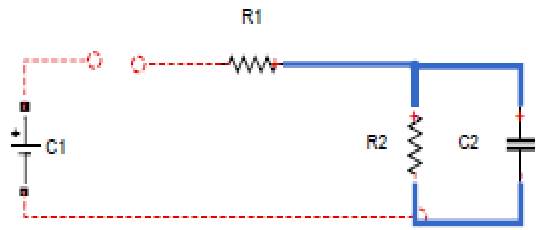


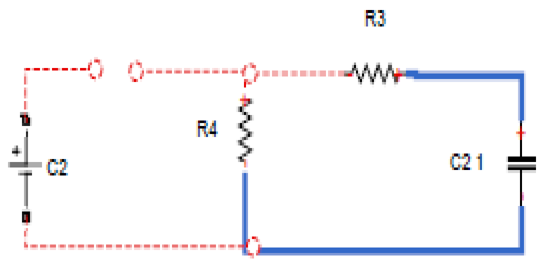
Operation:

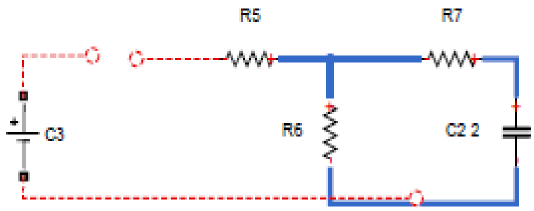
The primary is rated for 10KV and secondary is rated 1000KV. The primary is fed with DC or AC voltage through the capacitor C_1. Here spark gap is arranged such that at its required voltage it induces high self excitation in the secondary winding. This transformer in wounded on the air core. The transformer 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.

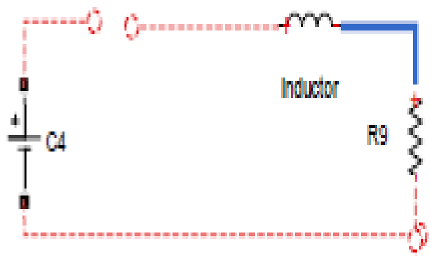
Generation of high impulse voltages.

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 areshown below.



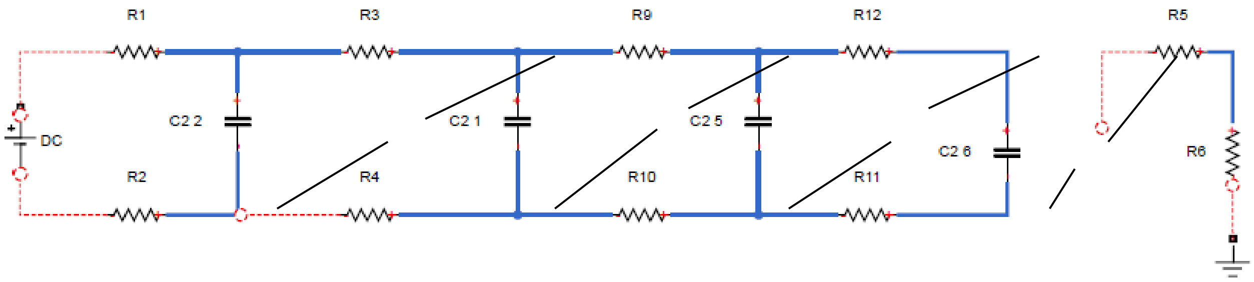






Impulse generator with multiple stages (Marx circuits)

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

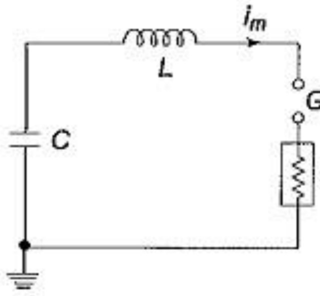
T – test object

R1 R2 – used for wave shape control.

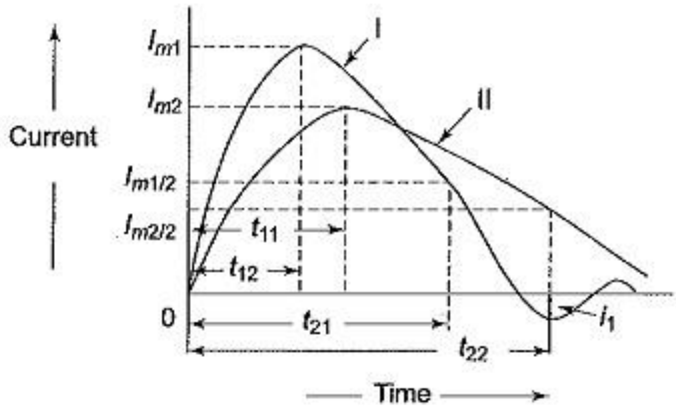
An DC voltage is applied to above arrangement which charges first capacitor through limiting resistor R.The breakdown voltage of spark gap is greater than charging voltage of capacitor.
When the breakdown occur in the spark gap the first capacitor discharges through the second and this continued till 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.

GENERATION OF IMPULSE CURRENTS:

The impulse current generator comprises many capacitors that are also charged in parallel by a high-voltage, low-current, direct-current source, but it is discharged in parallel through resistances, inductances, and a test object by a spark gap.



(a) Basic circuit of an impulse current generator



t_1 and t_{12} = time-to-front of waves I and II
t_{21} and t_{22} = time-to-tail of waves I and II

I — damped oscillatory wave
II — overdamped wave
i_1 — overshoot

(b) Types of impulse current waveforms

Generation of Impulse Current Generator Output Waveform:

Lightning discharges involve both high voltage impulses and high current impulses on transmission lines. Protective gear like surge diverters have to discharge the lightning currents without damage. Therefore, Generation of Impulse Current Generator Output Waveform of high magnitude (≈ 100 kA peak) find application in test work as well as in basic research on non-linear resistors.

Generation of High Impulse Currents:

For producing large values of impulse currents, a number of capacitors are charged in parallel and discharged in parallel into the circuit. The arrangement of capacitors is shown in Fig. 6.20c. In order to minimize the effective inductance, the capacitors are subdivided into smaller units. If there are n_1 groups of capacitors, each consisting of n_2 units and if L_0 is the inductance of the common discharge path, L_1 is that of each group and L_2 is that of each unit, then the effective inductance L is given by

$$L = L_0 + \frac{L_1}{n_1} + \frac{L_2}{n_1 n_2}$$

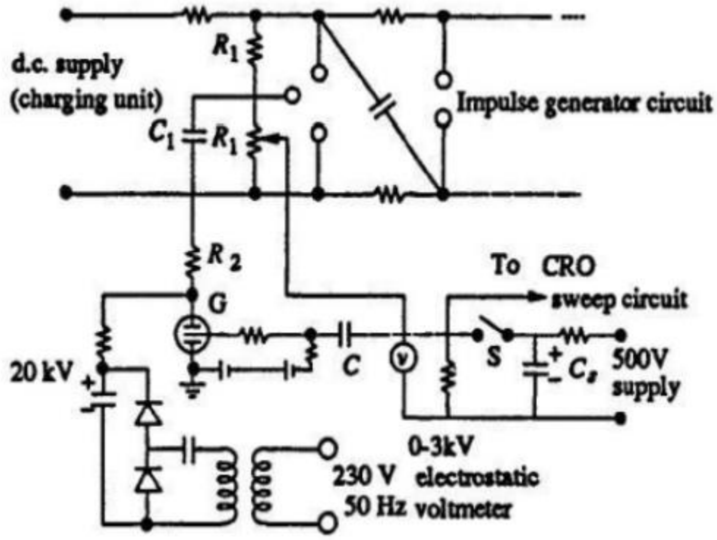
Also, the arrangement of capacitors into a horse-shoe shaped layout minimizes the effective load inductance (Plate 4). The essential parts of an Impulse Current Generator Output Waveform are:

- a d.c. charging unit giving a variable voltage to the capacitor bank
- capacitors of high value (0.5 to 5 μF) each with very low self-inductance, capable of giving high short circuit currents,
- an additional air cored inductor of high current value,
- proper shunts and oscillograph for measurement purposes, and
- a triggering unit and spark gap for the initiation of the current.

TRIPPING AND CONTROL OF IMPULSE GENERATORS

In large impulse generators, the spark gaps are generally sphere gaps or gaps formed by hemispherical electrodes. The gaps are arranged such that sparking of one gap results in automatic sparking of other gaps as overvoltage is impressed on the other. In order to have consistency in sparking, irradiation from an ultra-violet lamp is provided from the bottom to all the gaps. To trip the generator at a predetermined time, the spark gaps may be mounted one movable frame, and the gap distance is reduced by moving the movable electrodes closer.

This method is difficult and does not assure consistent and controlled tripping. A simple method of controlled tripping consists of making the first gap a three electrode gap and firing it from a controlled source. Figure 3.25 gives the schematic arrangement of a three electrode gap The first stage of the impulse generator is fitted with a three electrode gap, and the central electrode is maintained at a potential in-between that of the top and the bottom electrodes with the resistors R\ and RL. The tripping is initiated by applying a pulse to the thyratron G by closing the switch S. The capacitor C produces an exponentially decaying pulse of positive polarity the pulse goes and initiates the oscillograph time base. The thyratron conducts on receiving thepulse from the switch S and produces a negative pulse through the capacitance Ci at the central electrode of the three electrode gap.
Hence, the voltage between the central electrode and the top electrode of the three electrode gap goes above its sparking potential and thus the gap conducts. The time lag required for the thyratron firing andbreakdown of the three electrode gap ensures that the sweep circuit of the oscillographbegins before the start of the impulse generator voltage. The resistance R^ ensures decoupling of voltage oscillations produced at the spark gap entering the oscilloscopethrough the common trip circuit. The three electrode gap requires larger space and an elaborate construction.Now-a-days a trigatron gap shown in Fig.3.26 is used, and this requires much smaller voltage for operation compared to the three electrode gap



UNIT III

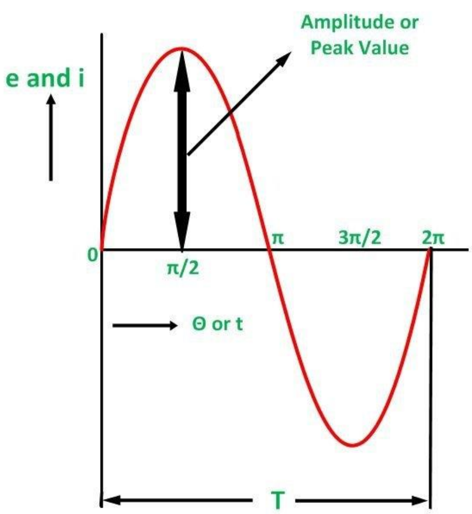
MEASUREMENTS OF HIGH VOLTAGES AND CURRENTS

PEAK VOLTAGE:

Peak voltage is the highest point or highest value of voltage for any voltage waveform. It is a power quality issue that occurs when devices that use Pulse Width Modulation, such as a variable frequency drive, is added to a power system.

Peak voltage of source VS,p=√2. Vrms=√(2×340)=26.076 Volts.

The maximum value attained by an alternating quantity during one cycle is called its Peak value. It is also known as the maximum value or amplitude or crest value. The sinusoidal alternating quantity obtains its peak value at 90 degrees as shown in



the figure below. The peak values of alternating voltage and current is represented by Em and Im respectively

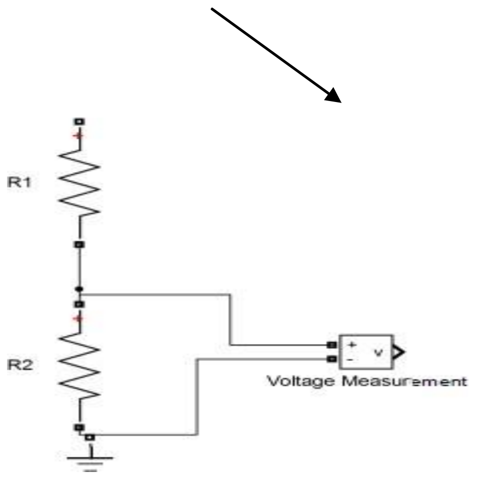
IMPULSE VOLTAGE AND HIGH DIRECT CURRENT MEASUREMENT METHOD:

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.

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:

V = V*R2 / (R1 + R2)

From above expression the applied high voltage is measured as:

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

CATHODE RAY OSCILLOGRAPHS FOR IMPULSE VOLTAGE AND CURRENT MEASUREMENT:

The coupling impedance Zm is a parallel combination of R, L and C whose quality factor is low. The complex impedance Zm is given as

$$\frac{1}{Z_m} = \frac{1}{R} + \frac{1}{j\omega L} + j\omega C$$

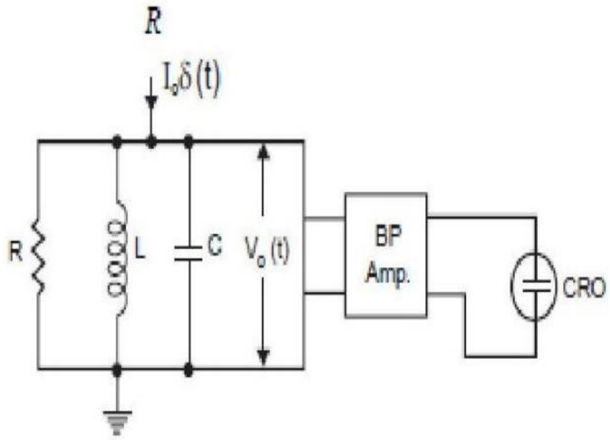


Figure: 4.9 CRO for impulse voltage and current measurement

The measuring impedance Zm is the impedance of a band pass filter which suppresses harmonic currents depending upon the selected circuit quality factor Q, below and above the resonance frequency f0 i.e., Zm will suppress all frequency currents below and above its resonance frequency. The alternate is– 20 dB per decade if Q = 1 and can be greatly increased.

Also, the measuring circuit Zm performs integration of the PD pulse currents i (t) = I0 δ (t).The above equation shows a damped oscillatory output voltage where amplitude is proportional to the charge q. The charge due to the pulse i(t) is actually stored by the capacitor C instantaneously but due to the presence of inductance and resistance, Oscillations are produced. If these oscillations are not damped, the resolution time of the filter will be large and proper integration will not take place especiallyof the subsequent current pulses. There is a possibility of over lapping and the results obtainedwill be erroneous. The resolution time as is said earlier should be smaller than the time constant τ of thecurrent pulse [*i* (*t*) *I*0*e*-*t/*τ].The resolution time or decay time depends upon the *Q*-factor and resonancefrequency *f*0 of the measuring impedance *Zm*. Let *Q* = 1 = *R*/ *LC* . The voltage *v*0(*t*) as shown in Fig. 6.28 can be obtained by writing nodal equation.

$$\frac{V_0(s)}{R}+\frac{V_0(s)}{sL}+V_0(s)\,Cs=I_0$$

$$V_0(s)=\frac{RsLI_0}{RLCs^2+sL+R}=\frac{I_0 s/C}{s^2+\frac{s}{RC}+\frac{1}{LC}}$$

$$=\frac{I_0 s/C}{\left(s+\frac{1}{2RC}\right)^2+\frac{1}{LC}-\frac{1}{(4R^2C^2)}}=\frac{I_0 s/C}{(s+\alpha)^2+\beta^2}$$

where $\alpha=\frac{1}{2RC}$ and $\beta=\sqrt{\frac{1}{LC}-\alpha^2}$

Therefore, $V_0(s)=\frac{q}{C}\cdot\left[\frac{s}{(s+\alpha)^2+\beta^2}\right]$

$$V_0(s)=\frac{q}{C}\frac{s}{(s+\alpha)^2+\beta^2}=\frac{q}{C}\left[\frac{s+\alpha}{(s+\alpha)^2+\beta^2}-\frac{\alpha}{(s+\alpha)^2+\beta^2}\right]$$

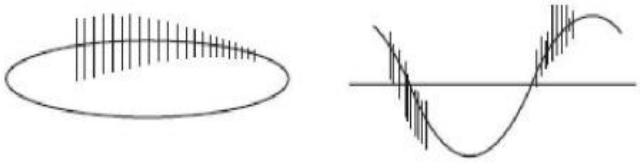
$$=\frac{q}{C}\left[\frac{s+\alpha}{(s+\alpha)^2+\beta^2}-\frac{\alpha}{\beta}\cdot\frac{\beta}{(s+\alpha)^2+\beta^2}\right]$$

$$=\frac{q}{C}\left[e^{-\alpha t}\cos\beta t-\frac{\alpha}{\beta}e^{-\alpha t}\sin\beta t\right]$$

$$=\frac{q}{C}e^{-\alpha t}\left[\cos\beta t-\frac{\alpha}{\beta}\sin\beta t\right]$$

The resolution time is about 10 μ sec and for higher values of *Q*, *T* will be still larger. The resonance frequency is also affected by the coupling capacitance *Ck* and the capacitance *Ct* of the test specimen as these contribute to the formation of *C*. Therefore, the *R L C* circuit should be chosen or selected according to the test specimen so that a desired resonance frequency is obtained. The desired central frequency f_0 or a band width around *f*0 is decided by the band pass amplifier connected to this resonant circuit
These amplifiers are designed for typically lower and upper cut off frequencies (–3 *dB*) between 150 kHz and 100 kHz. This band of frequency is chosen as it is much higher than thepower supply frequency and also the frequency which are not used by broadcasting stations.

The magnitude of the individual discharge is quantified by comparing the pulse crest value with the one obtained from the calibration circuit as shown in Fig. 6.30. The calibration circuit consists of a voltage step generator V0 and a series capacitor C0. The charge q is simulated with no normal voltage applied to the PD testing circuit. It is possible to suggest the location of the partial discharges in an insulating material by looking at the display on the CRO screen.



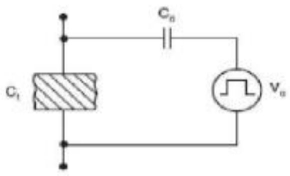
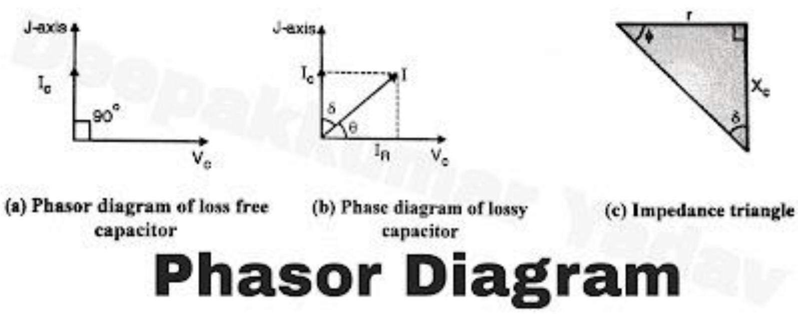


Figure:4.10 Circuit for calibration of the oscilloscope

MEASUREMENT OF DIELECTRIC CONSTANT AND LOSS FACTOR:

Introduction to Dielectric Loss:
Dielectric constant is also called relative permittivity of the insulating material.
Many of the insulating materials have dielectric constant more than unity.
These materials show dielectric loss when subjected to AC voltages.
Dielectric constant as well as dielectric loss depends on
1.Magnitude of voltage stress
2.Frequency of the applied voltage.

i. Dielectric is generally used in 'capacitors' or cables. Variation of dielectric constant dielectric low with frequency is very important in such equipments.
ii. Generally variation of these two quantities w.r.t. frequency is combined together to be known as complex quantity or complex permittivity.
iii. The value of this is to be determined at different values of frequencies. In the ideal case current IC leads the voltage VC by exactly 90°.
iv. But in the actual case (capacitance with lossy dielectric) the angle of lead falls by some angle δ.
v. This angle θ is called as loss angle. The current leads the voltage by less than 90° i.e.
vi. θ = (90-δ)o
vii. This relation is shown in below figures.



Two components of currents are :

$$I \rightarrow I_C,\ I_R$$

Where I_R is the loss component current I

I_R = charging current

$$\text{Loss component } I_R = \frac{\text{Voltage}}{\text{Resistance of dielectric}} = \frac{V}{R}$$

Loss Component I_R = Voltage / Resistance of dielectric = V / R

Two components of currents are :

$$I \rightarrow I_C,\ I_R$$

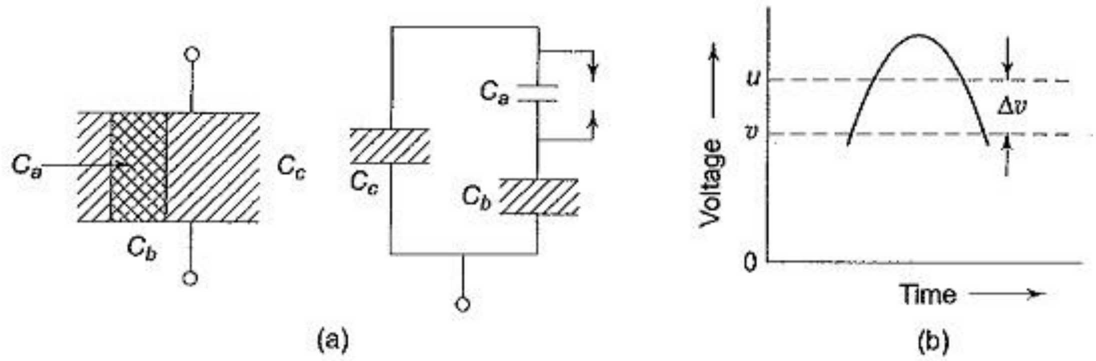
Where I_R is the loss component current I

I_R = charging current

$$\text{Loss component } I_R = \frac{\text{Voltage}}{\text{Resistance of dielectric}} = \frac{V}{R}$$

PARTIAL DISCHARGE MEASUREMENTS:

Earlier the testing of insulators and other equipment was based on the insulation resistance measurements, dissipation factor measurements and breakdown tests. It was observed that the dissipation factor (tan δ) was voltage dependent and hence became a criterion for the monitoring of the high voltage insulation. In further investigations it was found that weak points in an insulation like voids, cracks, and other imperfections lead to internal or intermittent discharges in the insulation. These imperfections being small were not revealed in capacitance measurements but were revealed as power loss components in contributing for an increase in the dissipation factor. In modern terminology these are designated as "Partial Discharge Measurements" which in course of time reduce the strength of insulation leading to a total or partial failure or breakdown of the insulation.



C_a – Capacitance of the void acting as a spark gap

C_b – Capacitance of the remaining series insulation with the void

C_c – Remaining part of the discharge free insulation of the test object

If the sites of Partial Discharge Measurements can be located inside an equipment, like in a power cable or a transformer, it gives valuable information to the insulation engineer about the regions of greater stress and imperfections in the fabrication.

Electrical insulation with imperfections or voids leading to Partial Discharge Measurements can be represented by an electrical equivalent circuit shown in Fig. 9.20. Consider a capacitor with a void inside the insulation (C_a). The capacitance of the void is represented by a capacitor in series with the rest of the insulation capacitance (C_b). The remaining void-free material is represented by the capacitance C_c. When the voltage across the capacitor is raised, a critical value is reached across the capacitor C_a and a discharge occurs through the capacitor, i.e. it becomes short circuited. This is represented by the closure of the switch.

Generally $C_a << C_b << C_c$. A charge Ag_a which was present in the capacitor C_a flows through C_b and C_c giving rise to a voltage pulse across the capacitor C_c. A measure of the voltage pulse across the capacitor gives the amount of discharge quality. But this measurement is difficult in practice, and an apparent charge measurement across a detecting impedance is usually made.

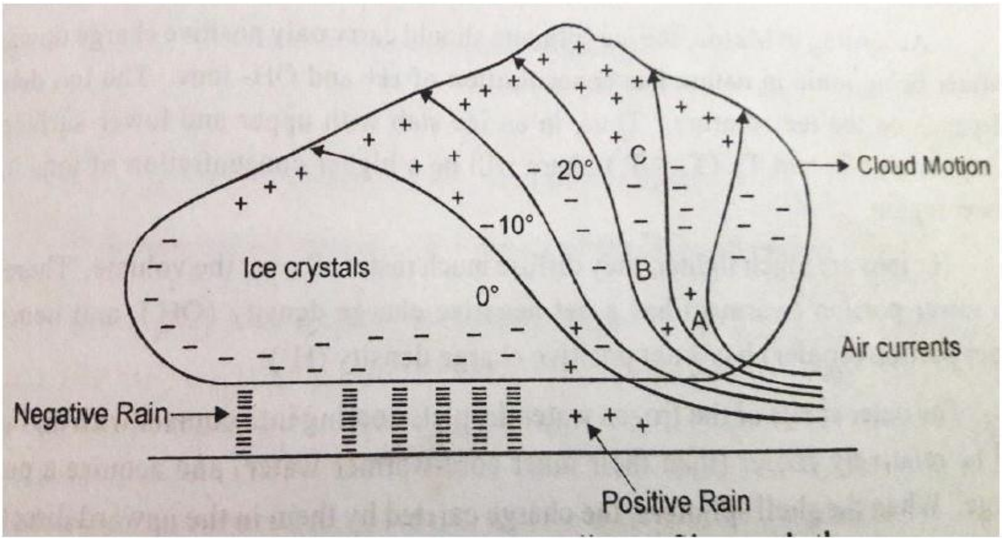
UNIT IV

LIGHTNING AND SWITCHING OVER – VOLTAGES

CHARGE FORMATION IN CLOUDS:

Charge formation theories:

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



REYNOLD AND MASON'STHEORY

i. According to this theory, thunder clouds are developed at heights 1 to 2km above groundlevel& they go up to 14km.

ii. The temperature is 0°C at 4km & may reach -50°C at 12km.

iii. Water droplets do not freeze at 0°C & freeze only when temperature is below -40°C & form solidparticles on which crystalline ice patterns develop & grow.

iv. Thundercloud consisting super cooled water droplets moving upwards and large hail stonesmoving downwards.

v. The ice splinters should carry only +ve charge upwards.

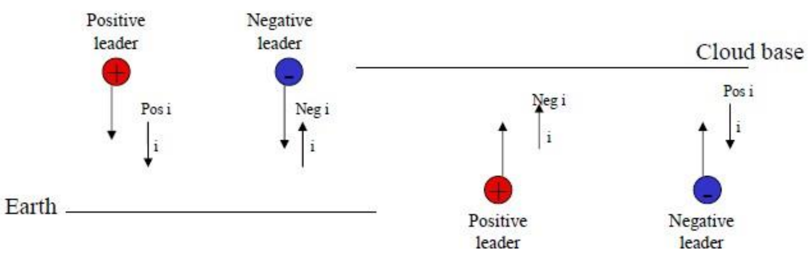
vi. Water has H+&OH-ions, the ion density depends on temperature.

vii. Lower portion has a net –ve charge density(OH-)&upper portion has a net +ve chargedensity(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

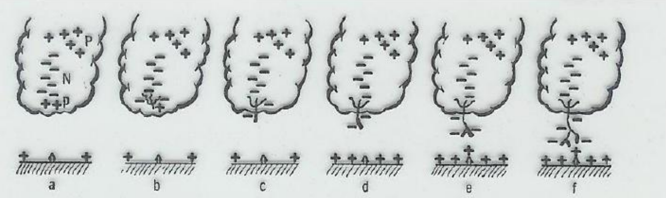


Fig. 9.1. Stepped leader initiation and propagation. (a) Cloud charge distribution just prior to p-N discharge. (b) p-N discharge. (c)-(f) Stepped leader moving toward ground in 50-yard steps. Time between steps is about 50 millionths of a second. Scale of drawing is distorted for illustrative purposes.

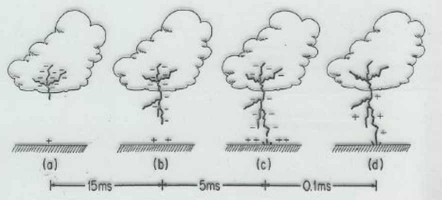
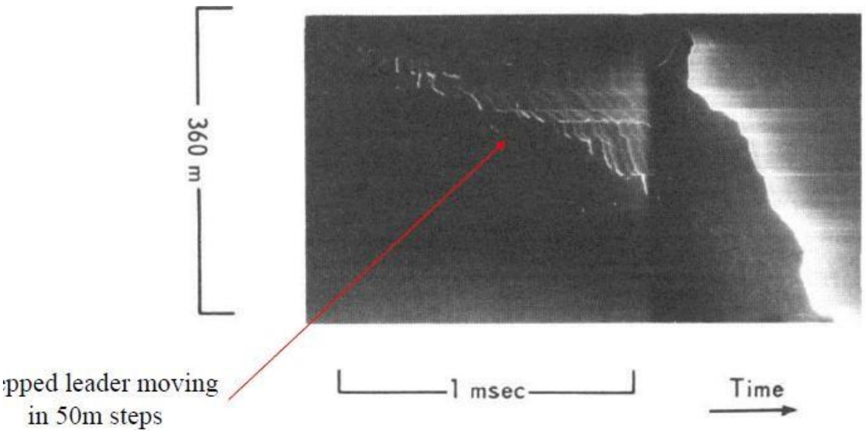


Figure 6.2. Sketch of the time development of a lightning stepped leader and the ensuing return strokes.

The stepped leader is:

Very Faint. Essentially invisible to the humaneye. Produces an ionized channel that will allow for the flowof 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 uptoward 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

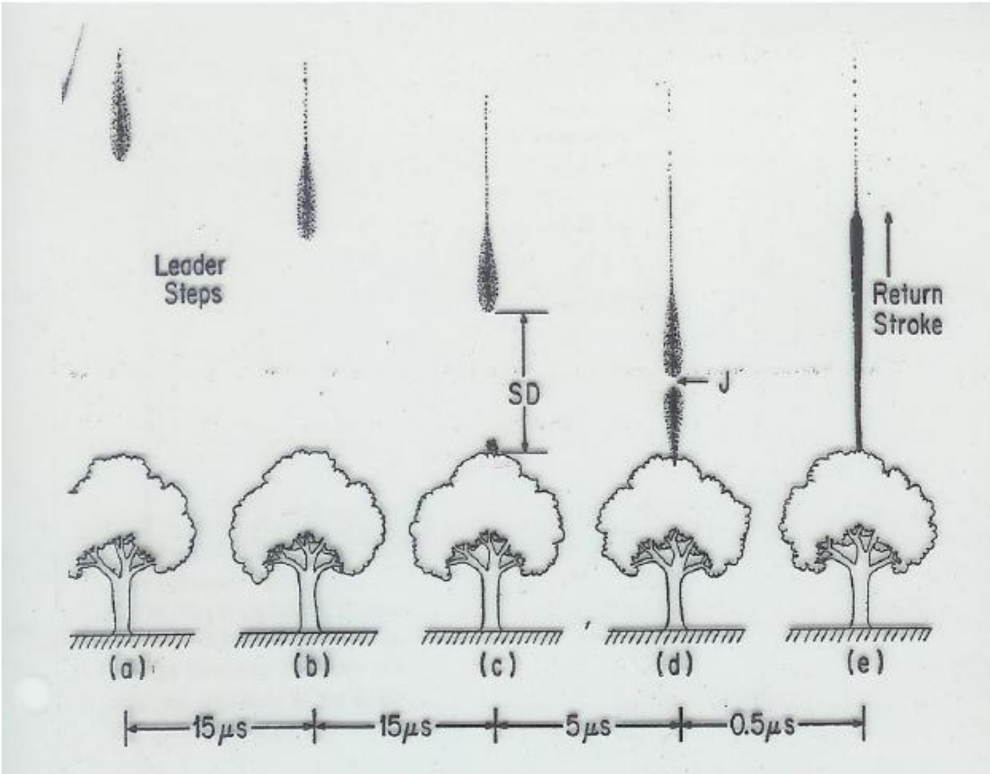
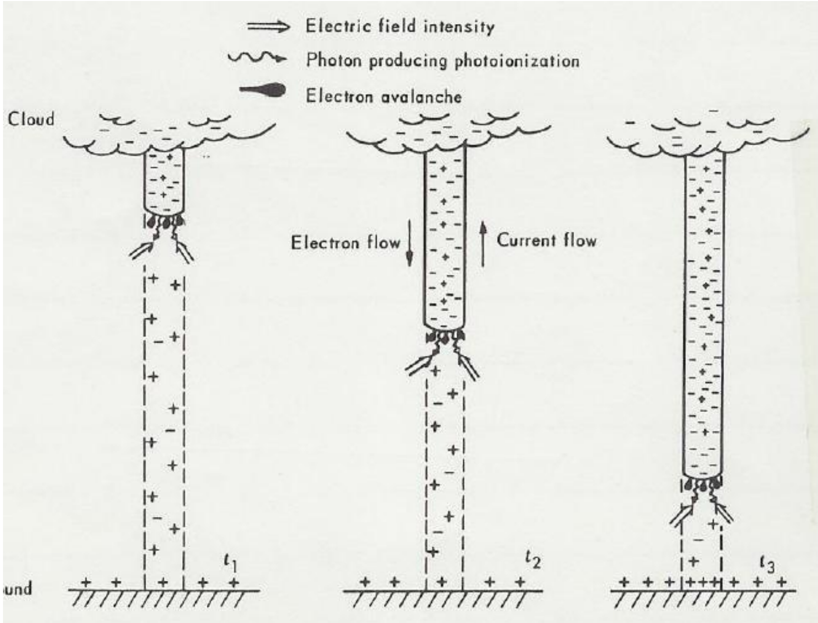


Figure 6.3. Sketch of the luminous processes that occur during a lightning strike. An upward-connecting discharge forms in (c) when the stepped leader is at the striking distance, SD.

Dart Leader:

i. Approximately 0.04 sec after the return stroke the dart leader travels down the ionized channelwithout “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 severalsets of dart leader/return stroke pairs. Appears as if the lightning “flashes.”



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

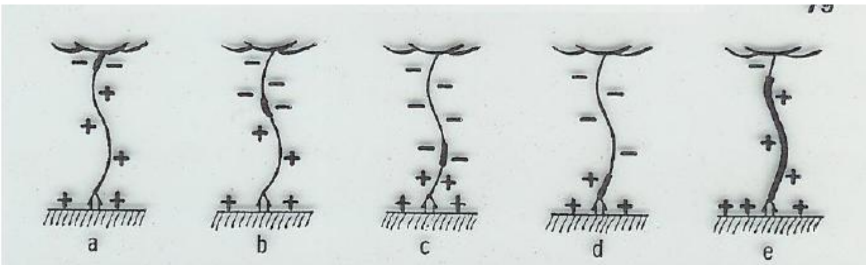


Fig. 9.4. Dart leader and subsequent return stroke. (a)-(c) Dart leader deposits negative charge on defunct first-stroke channel during its thousandth-of-a-second trip to ground. (d)-(e) Subsequent return stroke propagates from ground to cloud in about 100 millionths of a second. Scale of drawing is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

LIGHTNING SURGES:

Lightning surges are the surges that have high transient voltage, surge currents due to lightning, sparks, arcs of isolation, etc. These devices defends the power systems by diverting the high voltage surges directly to the ground.

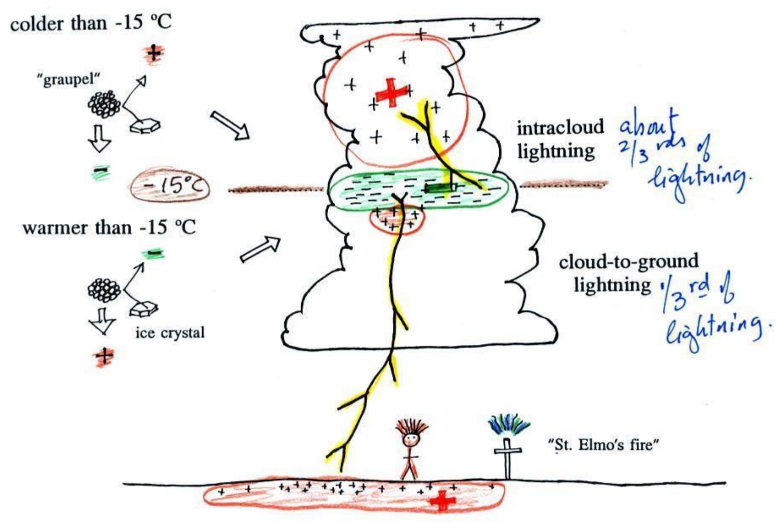
Types of Lightning Strikes

There are several different types of lightning strikes:

1.Cloud to ground — Negatively charged particles are drawn toward the positive particles on the ground.

2.Ground to cloud — The same as cloud-to-ground lightning, except the strike is initiated by a usually a tall, earth-bound object rather than the cloud.

3.Cloud to cloud — Similar mechanics to ground-to-cloud lightning, except the strike travels from one cloud to another



Origin of Switching Surges :

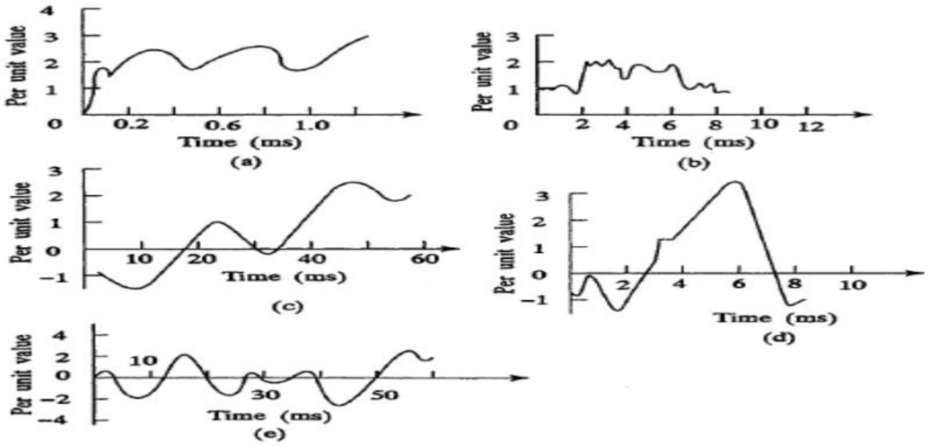
The making and breaking of electric circuits with switchgear may result in abnormal overvoltages in power systems having large inductances and capacitances. The overvoltages may go as high as six times the normal power frequency voltage. In circuit breaking operation, switching surges with a high rate of rise of voltage may cause repeated restriking of the arc between the contacts of a circuit breaker, thereby causing destruction of the circuit breaker contacts. The switching surges may include high natural frequencies of the system, a damped normal frequency voltage component, or the restriking and recovery voltage of the system with successive reflected waves form terminations.

Characteristics of Switching Surges

The wave shapes of switching surges are quite different and may have origin from any of the following sources. De-energizing of transmission lines, cables, shunt capacitor, banks, etc.

- Disconnection of unloaded transformers, reactors, etc
- Energization or reclosing of lines and reactive loads.
- Sudden switching off of loads.
- Short circuits and fault clearances.
- Resonance phenomenon like ferro-resonance, arcing grounds, etc

Typical wave shapes of the switching surges are given in Figs. a to (e).



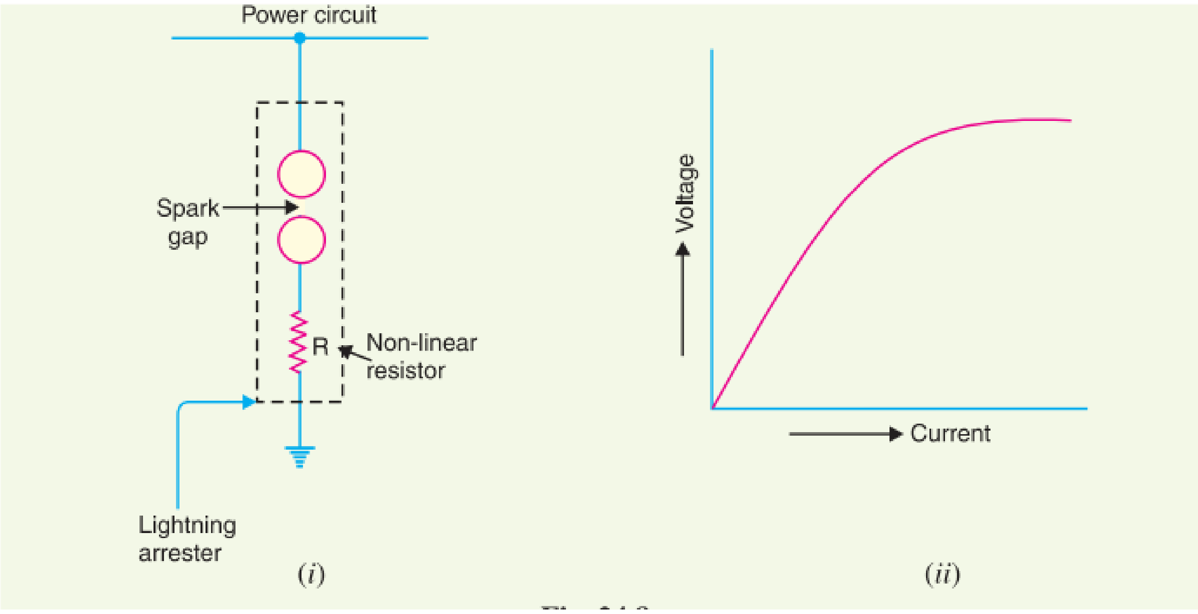
(a) Recovery voltage after fault clearing
(b) Fault initiation
(c) Overvottage at the line end after fault clearing
(d) Energization of long transmission line
(e) Overvoltage at line end during (d)

From the figures of the switching surges it is clear that the overvoltages are irregular (oscillatory or unipolar) and can be of high frequency or power frequency with its harmonics. The relative magnitudes of the overvoltages may be about 2.4 p.u. in the case of transformer energizing and 1.4 to 2.0 p.u. in switching transmission lines.

PROTECTION AGAINST OVERVOLTAGES:

Lightning Arresters:

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



the basic form of a surge diverter. It consists of a spark gap in series with a non-linear resistor. One end of the diverter is connected to the terminal of the equipment to be protected and the other end is effectively grounded. The length of the gap is so set that normal 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. 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 shown.

- Under normal operation, the lightning arrester is off the line i.e. it conducts **no current to earth or the gap is non-conducting.
- On the occurrence of overvoltage, the air insulation across the gap breaks down and an arc is formed, providing a low resistance path for the surge to the ground. In this way, the excess charge on the line due to the surge is harmlessly conducted through the arrester to the ground instead of being sent back over the line.
- It is worthwhile to mention the function of non-linear resistor in the operation of arrester.

As the gap sparks over due to overvoltage, the arc would be a short-circuit on the power system and may cause power-follow current in the arrester. Since the characteristic of the resistor is to offer high resistance to high voltage (or current), it prevents the effect of a short-circuit. After the surge is over, the resistor offers high resistance to make the gap non-conducting. Two things must be taken care of in the design of a lightning arrester. Firstly, when the surge is over, the arc in gap should cease. If the arc does not go out, the current would continue to flow through the resistor and both resistor and gap may be destroyed. Secondly, I R drop (where I is the surge current) across the arrester when carrying surge current should not exceed the breakdown strength of the insulation of the equipment to be protected.

the following types of lightning arresters :
1. Rod gap arrester
2. Horn gap arrester
3. Multigap arrester
4. Expulsion type lightning arrester
5. Valve type lightning arrester

1. Rod Gap Arrester:

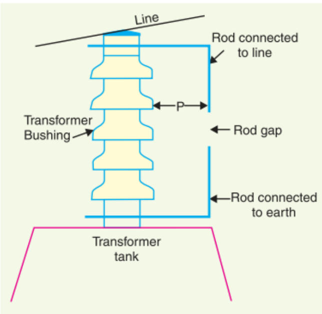
It is a very simple type of diverter and consists of two 1·5 cm rods which are bent at right angles with a gap inbetween as shown in Fig. One rod is connected to the line circuit and the other rod is connected to earth. The distance between gap and insulator (i.e. distance P) must not be less than one-third of the gap length so that the arc may not reach the insulator and damage it. Generally, the gap length is so adjusted that breakdown should occur at 80% of spark- 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. Fig. shows the rod gap across the bushing of a transformer. Under normal operating conditions, the gap remains non-conducting. On the occurrence of a high voltage surge on the line, the gap sparks over and the surge current is conducted to earth. In this way, excess charge on the line due to the surge is harmlessly conducted to earth

Limitations :

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

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

(iii) The climatic conditions (e.g. rain, humidity, temperature etc.) affect the

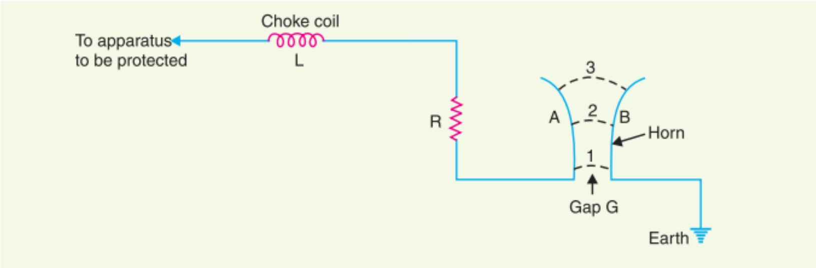


performance of rod gap arrester.

(iv) The polarity of the surge also affects the performance of this arrester. Due to the above limitations, the rod gap arrester is only used as a 'back-up' protection in case of main arresters.

2**. Horn Gap Arrester**:

Fig.shows the 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. 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. Under normal conditions, the gap is non-conducting i.e. normal supply voltage is insufficient to initiate the arc between the gap. 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 into positions 1, 2 and 3. At some position of the arc (perhaps position 3), 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.



Advantages

✓ The very short operating time of modern protective gear for feeders, this time is far long. 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. 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.

Limitations

✓ The bridging of gap by some external agency (e.g. birds) can render the device useless.

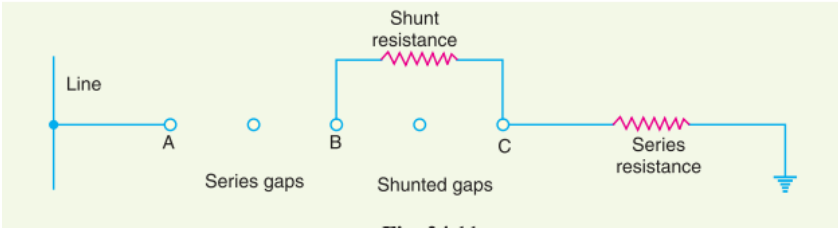
✓ The setting of horn gap is likely to change due to corrosion or pitting. This adversely affects the performance of the arrester.

✓ The time of operation is comparatively long, say about 3 seconds. In view of of the very short operating time of modern protective gear for feeders, this time is far long. 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.

✓

3. Multigap arrester:

Fig. shows the 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. In order to overcome this difficulty, some of the gaps (B to C in Fig) 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. 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. 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.

4. Expulsion type arrester:

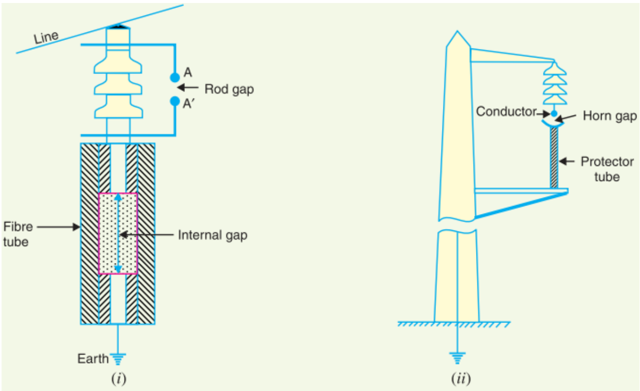
This type of arrester is also called 'protector tube' and is commonly used on system operating at voltages upto 33 kV.

(i) The essential parts of an expulsion type lightning arrester. It essentially consists of a rod gap A A′ in series with a second gap enclosed within the fibre tube. The gap in the fibre tube is formed by two electrodes. The upper electrode is connected to rod gap and the lower electrode to the earth. One expulsion arrester is placed under each line conductor.

(ii) The installation of expulsion arrester on an overhead line. On the occurrence of an overvoltage on the line, the series gap A A′ is spanned and an arc is struck between the electrodes in the tube. The heat of the arc vaporises some of the fibre of tube walls, resulting in the production of a neutral gas*. In an extremely short time, the gas builds up high pressure and is expelled through the lower electrode which is hollow. As the gas leaves the tube violently, it carries away ionised air around the arc. This de-ionising effect is generally so strong that arc goes out at a current zero and will not be re-establishe

Advantages

(i) They are not very expensive.



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

(iii) They can be easily installed.

Limitations

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

(ii) This type of arrester cannot be mounted in an enclosed equipment due to the discharge of gases during operation.

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

5. Valve type arrester:

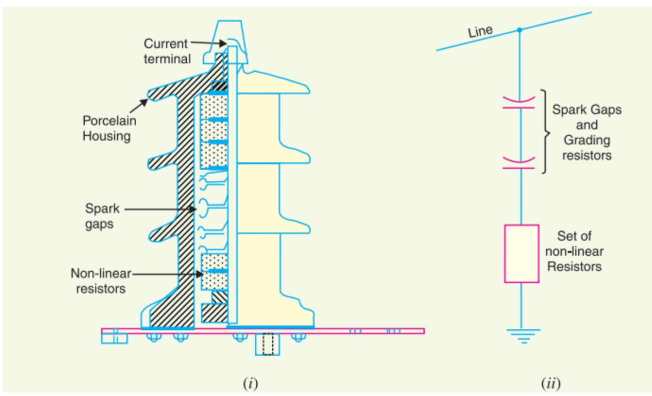
Valve type arresters incorporate non-linear resistors and are extensively used on systems operating at high voltages.

✓ accommodated in tight porcelain container. the various parts of a valve type arrester. It consists of assemblies series spark gaps and

✓ non-linear resistor discs (made of material such as thyrite or metrosil) in series. The non-linear elements are connected in series with the spark gaps. Both the assemblies are

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

(ii) The non-linear resistor discs are made of an inorganic compound such as Thyrite or Metrosil. These discs are connected in series. The non-linear resistors have the property of offering a high resistance to current flow when normal system voltage



is applied, but a low resistance to the flow of high-surge currents. In other words, the resistance of these non-linear elements decreases with the increase in current through them and vice-versa.

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

Advantages

- ✓ They provide very effective protection (especially for transformers and cables) against surges.
- ✓ They operate very rapidly taking less than a second.
- ✓ The *impulse ratio is practically unity.

Limitations

(i) They may fail to check the surges of very steep wave front from reaching the terminal apparatus. This calls for additional steps to check steep-fronted waves.

(ii) Their performance is adversely affected by the entry of moisture into the enclosure. This necessitates effective sealing of the enclosure at all times.

Applications

According to their application, the valve type arresters are classified as

- ✓ station type and line type.
- ✓ The station type arresters are generally used for the protection of important equipment in power stations operating on voltages upto 220 kV or higher
- ✓ The line type arresters are also used for stations handling voltages upto 66 kV.

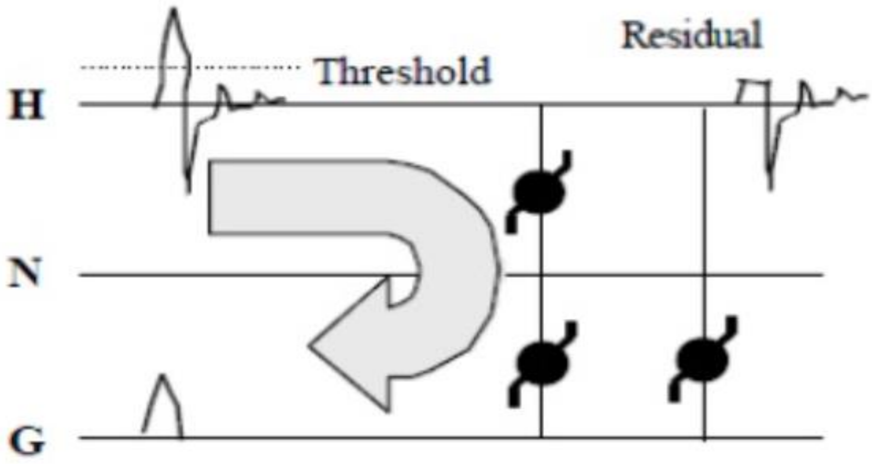
SURGE DIVERTERS:

A surge arrester is a device to protect electrical equipment from over-voltage transients caused by external (lightning) or internal (switching) events. Also called a surge protection device (SPD) ortransient voltage surge suppressor (TVSS), this class of device is used to protect equipment in power transmission and distribution systems. (For consumer equipment protection, different products called surge protectors are used.)

To protect a unit of equipment from transients occurring on an attached conductor, a surge arrester is connected to the conductor just before it enters the equipment. The surge arrester is also connected toground and functions by routing energy from an over-voltage transient to ground if one occurs, while isolating the conductor from ground at normal operating voltages. This is usually achieved through use of a varistor, which has substantially different resistances at different voltages.

Surge Diverters operation:

The event we commonly call a surge is more accurately defined as a high voltage transient or impulse. Surge diverters are designed to divert the impulse away from the sensitive electronic system. That’s why the term diverter is more appropriate – it better describes the function of this device. Surge diverter products commonly use



one or more of several electronic components. These include metal oxide varistors (MOVs), silicon avalanche diodes (SADs), and gas tubes. There are differences in how each functions but the intent is the same divert a part of the harmful impulse energy away from the computer or system being protected.

All surge diverters have a voltage threshold, called a “clamping voltage”, at which they began to conduct. Above that threshold, impulses are shunted across the diverter to another pathway. When the impulse voltage once again falls below the threshold, the diverter stops conducting. Surge diverters also have a “clamping response” time or the time required for the device to respond to an impulse. The amount of energy each is capable of handling without being destroyed is also a consideration. Due to these factors, each type of component used in surge diverters has unique advantages and disadvantages. MOVs have a high clamping voltage (300 to 500 volts) and a slow response time.

This means that in best case scenarios, voltage impulses of less than 500 volts usually enter the computer system unimpeded. In addition, higher voltage events with very fast rise times may pass by the MOV before it is able to respond. And while MOVs can handle a significant amount of energy, they are physically degraded each time they clamp. This characteristic alters their future performance and ultimately leads to physical failure.

SURGE MODIFIER:

Surge modifiers which are surge capacitor, a surge reactor and surge absorber: A surge modifier is nothing but a small shunt capacitor connected between the line and earth, or a series air-cored inductor.

Types of Lightning Absorbers or Surge Absorbers :

The most commonly used surge or lightning absorbers are,

- ✓ Condenser or capacitor surge absorber.
- ✓ Inductor and resistance combination surge absorber.
- ✓ Ferranti surge absorber.

Surge Absorption Using Capacitor or Condenser :

In this type of surge absorption, a capacitor is connected between the line and the earth . This arrangement acts as a surge absorber. When connected across transformer winding, it prevents the transformer from damage

.

Surge Absorption Using Parallel Combination of Inductor and Resistance :

Surge absorption using a parallel combination of choke and resistance in series with the line . Here, the choke is nothing but the inductor.
When the surge passes through the resistor, they are dissipated as heat owing to the property of the resistor. Under normal operating conditions, if the frequency is less, then XL is also less and acts as a short circuit to the line currents, and the current flows to the power line.

Ferranti Surge Absorber :

In this type of absorber, an inductor is connected in series with the line . The inductor is air-cored and insulated with a metallic sheet that is grounded. This insulated metal sheet acts as a dissipater. This type of setup is equivalent to the transformer whose secondary is earthed i.e., short-circuited. Its primary winding is formed by the inductor and secondary winding is formed by the dissipater.
We know that a huge amount of energy is generated during surge formation and the energy is utilized for the transformer action. Even during the surge formation, the energy obtained is utilized efficiently and prevents the winding from damage.

UNIT V

HIGH VOLTAGE TESTING OF ELECTRICAL APPARATUS AND HIGH VOLTAGE LABORATORIES

HV TESTING OF ELECTRICAL APPARATUS:

- Transformer
- Circuit breaker
- Insulator
- Cable

High Voltage Test on Transformer:

High Voltage Test on Transformer are very important and costly apparatus in power systems. Great care has to be exercised to see that the transformers are not damaged due to transient overvoltages of either lightning or power frequency. Hence, overvoltage tests become very important in the testing of transformers. Here, only the overvoltage tests are discussed, and other routine tests like the temperature rise tests, short circuit tests, etc. are not included and can be found in the relevant specifications.

(a) Induced Overvoltage Test:

High Voltage Test on Transformer by exciting the secondary of the transformer from a high frequency a.c. source (100 to 400 Hz) to about twice the rated voltage. This reduces the core saturation and also limits the charging current necessary in large power transformers. The insulation withstand strength can also be checked

.

(b) Partial Discharge Tests:

Partial discharge tests on the windings are done to assess the discharge magnitudes and the radio interference levels. The High Voltage Test on Transformer is connected in a manner similar to any other equipment and the discharge measurements are made The location of the fault or void is sometimes done by using the travelling wave technique similar to that for cables. So far, no method has been standardized as to where the discharge is to be measured. Multi-terminal partial discharge measurements are recommended. Under the application of power frequency voltage, the discharge magnitudes greater than 10^4 pico coulomb are considered to be severe, and the transformer insulation should be such that the discharge magnitude will be far below this value.

High Voltage Test on Circuit Breaker and Isolators:

High Voltage Test on Circuit Breaker and Isolators is covered, giving common characteristics for both. While these characteristics are directly relevant to the testing of circuit breakers, they are not much relevant as far as the testing of isolators are concerned since isolators are not used for interrupting high currents. At best, they interrupt small currents of the order of 0.5 A (for rated voltages of 420 kV and below) which may be the capacitive currents of bushings, busbars etc.
An isolator or a disconnector is a mechanical switching device, which provides in the open position, an isolating distance in accordance with special requirements. An isolator is capable of opening and closing a circuit when either negligible current is broken or made or when no significant change in the voltage across the terminals of each of the poles of the isolator occurs. It is also capable or carrying currents under normal circuit conditions, and carrying for a specified time, currents under abnormal conditions such as those of a short circuit.
Thus, most of the discussion here refers to the High Voltage Test on Circuit Breaker and Isolators.
High Voltage Test on Circuit Breaker and Isolators is intended to evaluate
(a) the constructional and operational characteristics, and
(b) the electrical characteristics of the circuit Which the switch or the breaker has to interrupt or make
.
The different characteristics of High Voltage Test on Circuit Breaker and Isolators or a switch may be summarized as per the following groups.
The electrical characteristics which determine the arcing voltage, the current chopping characteristics, the residual current, the rate of decrease of conductance of the arc space and the plasma, and the shunting effects in interruption.
Other physical characteristics including the media in which the arc is extinguished, the pressure developed or impressed at the point of interruption, the speed of the contact travel, the number of breaks, the size of the arcing chamber, and the materials and configuration of the circuit interruption.
The characteristics of the circuit include the degree of electrical loading, the normally generated or applied voltage, the type of fault in the system which the breaker has to clear, the time of interruption, the time constant, the natural frequency and the power factor of the circuit, the rate of rise of recovery voltage, the re striking voltage, the decrease in the a.c. component of the short circuit current, and the degree of asymmetry and the d.c. component of the short circuit current.

TESTING OF CABLES:
High voltage power cables have proved quite useful especially in case of HV d.c. transmission. Underground distribution using cables not only adds to the aesthetic looks of a metropolitan city but it provides better environments and more reliable supply to the consumers.

Preparation of Cable Sample The cable sample has to be carefully prepared for performing various tests especially electrical tests. This is essential to avoid any excessive leakage or end flash over‘s which otherwise may occur during testing and hence may give wrong information regarding the quality of cables. The length of the sample cable varies between 50cms to 10 m. The terminations are usually made by shielding the ends of the cable with stress shields so as to relieve the ends from excessive high electrical stresses. A cable is subjected to following tests:

(i) Bending tests

It is to be noted that a voltage test should be made before and after a bending test. The cable is bent round a cylinder of specified diameter to make one complete turn. It is then unwound and rewound in the opposite direction. The cycle is to be repeated three times.

(**ii) Loading cycle test**

A test loop, consisting of cable and its accessories is subjected to 20 load cycles with a Minimum conductor temperature 5°C in excess of the design value and the cable is energized to1.5 times the working voltage. The cable should not show any sign of damage.

(iii) Thermal stability test

After test as at (ii), the cable is energized with a voltage 1.5 times the working voltage for a cable of 132 kV rating (the multiplying factor decreases with increases in operating voltage) and the loading current is so adjusted that the temperature of the core of the cable is 5°C higher than its specified permissible temperature. The current should be maintained at this value for six hours.

(**iv) Dielectric thermal resistance test**

The ratio of the temperature difference between the core and sheath of the cable and the Heat flow from the cable gives the thermal resistance of the sample of the cable. It should be within the limits specified in the specifications.

(v) Life expectancy test

In order to estimate life of a cable, an accelerated life test is carried out by subjecting the Cable to a voltage stress higher than the normal working stress. It has been observed that the relation between the expected life of the cable in hours and the voltage stress is given by gKn t=where K is a constant which depends on material and n is the life index depending again on the material.

TESTING OF INSULATORS AND BUSHINGS

TESTING OF BUSHINGS

Bushings are an integral component of high voltage machines. A bushing is used to bring high voltage conductors through the grounded tank or body of the electrical equipment without excessive potential gradients between the conductor and the edge of the hole in the body. The bushing extends into the surface of the oil at one end and the other end is carried above the tank to a height sufficient to prevent breakdown due to surface leakage.

Following tests are carried out on bushings:

- Power Factor Test The bushing is installed as in service or immersed in oil. The high voltage terminal of the bushing is connected to high voltage terminal of the Schering Bridge and the tank or earth portion of the bushing is connected to the detector of the bridge. The capacitance and p.f. of the bushing is measured at different voltages as specified in the relevant specification and the capacitance and p.f. should be within the range specified.

- Impulse Withstand Test The bushing is subjected to impulse waves of either polarity or magnitude as specified in the standard specification. Five consecutive full waves of standard wave form (1/50 μ sec.) are applied and if two of them cause flash over, the bushing is said to be defective. If only one flash

- Chopped Wave and Switching Surge Test Chopped wave and switching surge of appropriate duration tests are carried out on high voltage bushings. The procedure is identical to the one given in (ii) above.

- Partial Discharge Test In order to determine whether there is deterioration or not of the insulation used in the bushing, this test is carried out. The shape of the discharge is an indication of nature and severity of the defect in the bushing. This is considered to be a routine test for High voltage bushings.

- Visible Discharge Test at Power Frequency The test is carried out to ascertain whether the given bushing will give rise to ratio interference or not during operation. The test is carried out in a dark room. The voltage as

specified is applied to the bushing (IS 2099). No discharge other than that from the grading rings or arcing horns should be visible.

(vi) Power Frequency Flash Over or Puncture Test (Under Oil): The bushing is either immersed fully in oil or is installed as in service condition. This test is carried out to ascertain that the internal breakdown strength of the bushing is 15% more than the power frequency momentary dry withstand test value.

HIGH VOLTAGE LABORATORY LAYOUT

Classification of High Voltage Laboratories :

Classification of High Voltage Laboratories depending on the purpose for which they are intended and the resources (finances) available, can be classified into four types. Small laboratories Medium size laboratories Large general purpose laboratories UHV laboratories Some salient features of these various types of laboratories are discussed below. 1.Small Laboratories: A small laboratory is one that contains d.c. or power frequency test equipment of less than 10 kW/10 kVA rating and impulse equipment of energy rating of about 10 KJ or less.

Grounding of Impulse Testing Laboratories :

An earth or ground system means an established stable .reference potential normally taken to be zero. There are three types of Grounding of Impulse Testing Laboratories are: the ideal ground, single point ground (Fig. 11.4a), and the bus ground (Fig. 11.4b). Of all these, the best ground is the ideal ground which cannot be realized in practice. The next preferred ground is the single point ground, and the bus ground is least satisfactory.

High Voltage Laboratory Equipments :

A High Voltage Laboratory Equipments is expected to carry out withstand and/or flashover tests at high voltages on the following transmission system equipment: Transformers Lightning arresters Isolators and circuit breakers Different types of insulators Cables Capacitors Line hardware and accessories Other equipment like reactors, etc. Different tests conducted on the above equipment are: Power frequency withstand tests—wet and dry Impulse tests c. withstand tests Switching surge tests Tests underpolluted atmospheric conditions Partial discharge and RIV measurements High current tests. In addition to the above facilities, the laboratories should also have facilities for conducting research.

High Voltage Laboratory Rating :

The High Voltage Laboratory Rating and size of test equipment chosen in the h.v. laboratories depends on the test facilities to be provided. Normally, the design of the laboratories for 230 kV system voltage and below does not pose any problems, but laboratories intended for system voltages of 400 kV and above require special attention. In Tables 11.1 and 11.2 various test voltages for different transmission system voltages are given. For research and development work, the voltage levels needed.

Operation of UHV Laboratory :

Operation of UHV Laboratory are designed as indoor laboratories or outdoor laboratories depending on the specific requirements. An indoor laboratory is preferred when most of the equipment testing and associated research work is carried out indoors, whereas outdoor laboratories are preferred when the electrical and mechanical parameters of the UHV transmission lines are to be experimentally determined so that the design of future lines can be based on this data.

TESTING FACILITY REQUIREMENTS:

Types of test:

- Lightning impulse withstand test (full and chopped wave)
- Lightning impulse flashover test (standard and steep front)
- Switching impulse wet and dry withstand test.
- Switching impulse wet and dry flashover test.
- Special non-standard impulse flashover test and withstand test.
- Steep front (<200 nS) impulse test.

SAFETY PRECAUTIONS IN H.V LABS:

It is critical to carefully follow the following safety precautions.

- Always connect a ground wire. ...
- Do not touch high voltage areas. ...
- Cover high voltage areas. ...
- Share an awareness of danger. ...

- Perform operations with your right hand. ...
- Turn off the power before touching equipment. ...
- Pay attention to electric charge in cables.

INDOOR AND OUTDOOR LABORATORIES:

- Medium Size Laboratory High voltage laboratories may be either (a) indoor type or (b) outdoor type. The indoor type has the advantage of protection of testing equipment against variable weather conditions, simplicity in design and control of the test equipment, and provision of observation facilities during testing.

- But outdoor laboratories have the advantage of less cost due to the absence of building cost and the planned facility layout cost But outdoor test areas have limitations such as O absence of lifting and supporting facilities, (if) climatic conditions which may restrict or impede testing, (1/0 reproducibility of results not being guaranteed due to uncontrolled atmospheric conditions, and (iv) artificial and wet test studies which are difficult due to wind variation, etc.

- When high voltage laboratories are planned as indoor laboratories, the following figures fix the dimensions of the laboratories :

POWER TRANSFORMERS AND SOME HIGH VOLTAGE EQUIPMENTS:

High voltage equipment typically include power transformer, switchgears, control equipment, communicating devices, insulators, and so on.

power transformers :

Power Voltage Transformers also known as Substation Service Voltage Transformers (SSVT) are used to supply Low Voltage power directly from a High Voltage line up to 550 kV They offer all the benefits of a potential transformer with the applications of a distribution transformer.