UNIT - I

Over voltage in Electrical powersystems :-

Introduction :-

→ High voltages are used in Transmission Lines.

→ Also to measure the high voltage.

Application :

→ cathode ray tube
→ Spray painting
→ particle accelerator
→ Gas discharge Lamps.
→ Electrostatic precipitators.
→ Nuclear Research.

Over voltage :

It is an increase in RMS value of Ac Voltage greater than 110 percent at power frequency for Longer than 1 minute.

Causes of overvoltage (or) Types of over voltages.

1. External or Lightning overvoltage
2. Internal over voltage
   (i) Temporary overvoltage - power frequency oscillations (or) Harmonics
   (ii) Switching over voltage.

Lightning Over voltage :

→ It is a Natural phenomenon,

It is a peak discharge in which charges accumaled in the clouds, discharge into neighbouring cloud or to ground.

→ the magnitude of Lightning ... on Transmission Lines doesn't depend on line design & hence lightning performance tends to improve with insulation Level that is with system Voltage.

Sources of voltage:

(i) capacitor Switching

(ii) ferro Resonance

(iii) other Switching Transient.

Internal over voltage:

Switching over voltage:

→ originates in the system itself by connecting or disconnecting of circuit breaker or interruption of fault.

→ Its magnitude is proportional to operating Voltage. so the internal over voltage increases with the increasing voltage of the System.

→ Switching over voltage are highly damped for short duration.

→ Temporary over voltage with power frequency (or) its harmonic frequency are weakly damped.

→ Both Switching & power frequency over voltag have no common origin, they may occur together.

Lightning overvoltage

Lightning phenomenon:- It is a peak discharge in which charge accumulated in the clouds discharge into neighbouring clouds or to ground.

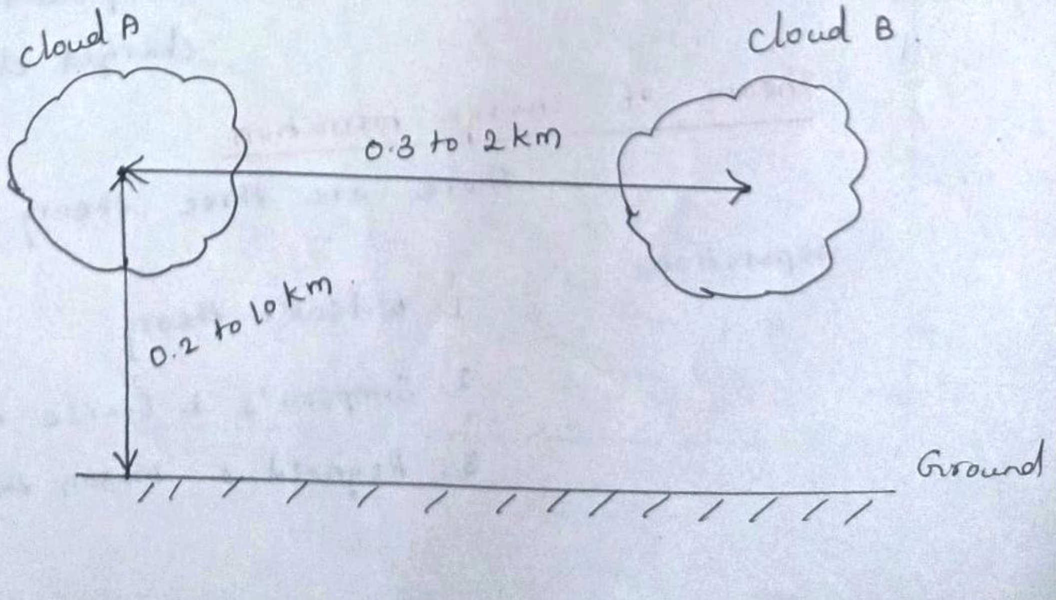
→ The electrode separation ie)
(i) cloud to cloud
(ii) cloud to ground is very Large (10km or more)

The mechanism of charge formation in the clouds are quite complicated & uncertain process.

charge formation in the cloud:

→ During thunder storms, positive & negative charges become separated by heavy air current with ice crystals in the upper parts & rain the lower parts.

→ This charge separation depends on the height of the clouds, which ranges from 0.2 to 10km with their charge centre probably at a distance about 0.3 to 2 km.

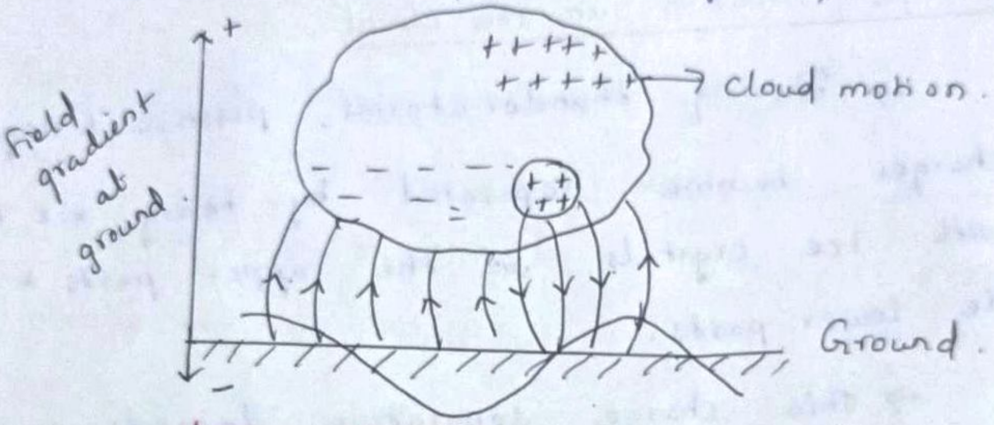


The charge inside the cloud → 1 - 100 C

potential of the cloud → $10^7 - 10^8$ V with field gradient ranging from 100 V/cm within the cloud to 10 kV/cm at initial discharge.

energy associated with the cloud → 250 kWhr.

→ The upper region of cloud → positive charge.
Lower region of cloud → negative charge except positive charge → Local region.



charge distribution in the cloud.

Fair weather condition : Max. gradient = 1 V/cm.

Bad weather condition : Max. gradient reached at the ground level due to charged cloud = 300 V/cm.

<u>Theory of charge formation</u>.

There are three theory for charge separation.

1. Wilson's theory
2. Simpson's & Scarse theory
3. Reynold & mason theory.

1. Wilson's theory

Assume,

→ Large No. of ions present in Atmosphere.

→ Ions attached with dust & water particles.

→ Electric field at Fair weather condition.

According to wilson's theory,

positive charge → upper position of cloud.

negative charge → Lower position of cloud.

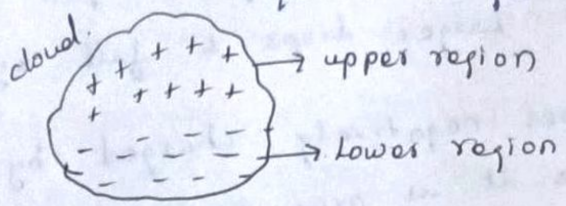
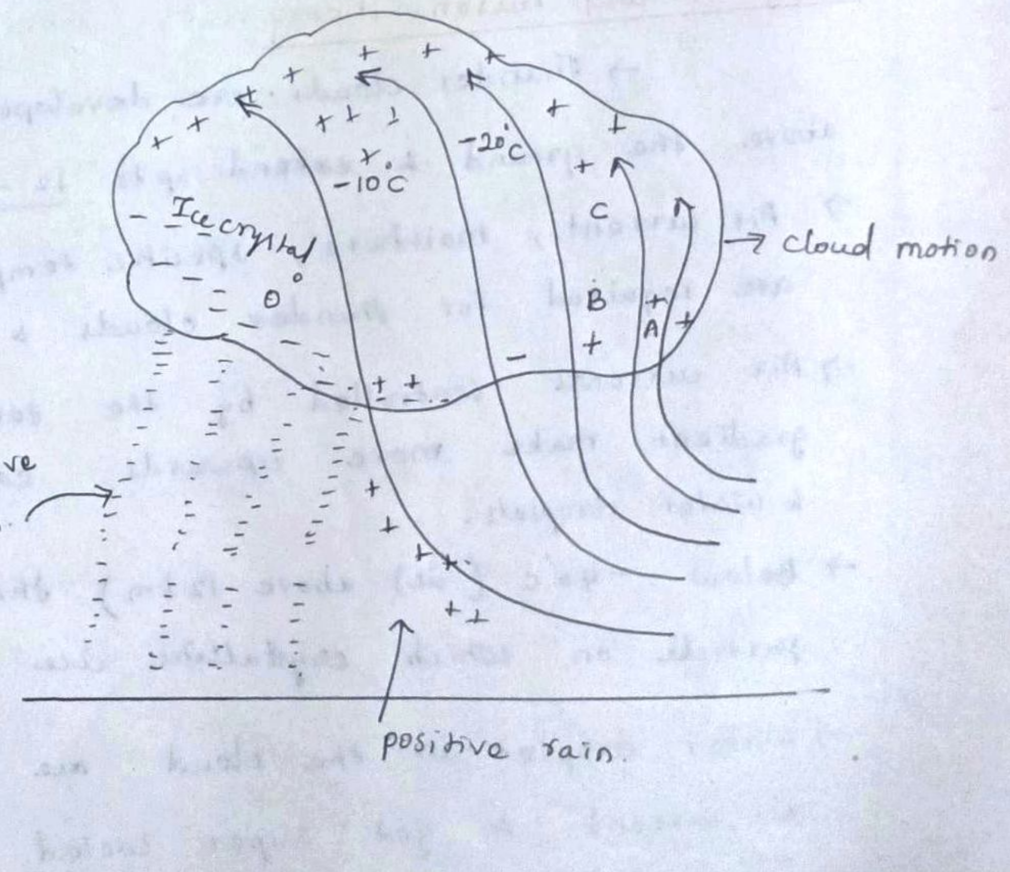


Fig: Charge Separation.

2. Simpson's & Scarse theory

Three region in the cloud is considered for charge formation.



Below region A :- → Air current velocity is Low.

→ Air current travels above 800 cm/sec.

→ No raindrop.

In Region A :-

→ Air velocity is high enough to break the raindrop causing positive charge spray in the cloud & charge in the air.

→ The spray is blown upwards but as velocity of air decreases, the positively charged water drops recombine with Larger drops & fall again.

Region B : It becomes negatively charged by air current. (because it is over region A).

Region C : The temperature is Low (below freezing point) and only Ice crystal exist. the impact of air on these crystal makes them negatively charged.

3. Reynold and mason Theory :

→ Thunder clouds are developed at a height 1-2km above the ground & extend up to 12-14km above ground.

→ Air current, moisture, specific temperature range are required for thunder clouds & charge formation.

→ Air currents controlled by the temperature gradient make move upwards carry moisture & water droplets.

→ Below -40°c (ie) above 12km) they freeze as solid particle on which crystalline ice pattern develop & grow.

→ Water droplet in the cloud are blown up by air current & get super cooled over a range of

In an ice slab with upper

Thus a thunder cloud consist of super cooled water droplets moving upwards and Large hailstones moving downwards.

→ When the upward moving supercooled water droplets act on Cooler hail stone, it freezes partially ie) the outer layer of the water droplets freezes forming a shell with water inside.

→ When the process of cooling extend to inside warmer water in the core, it expands, thereby splintering & spraying the frozen ice shell.

→ The splinters being fine in Size are moved up by the air currents and carry a net positive charge to the upper region of the cloud.

→ The hailstones that travels downwards carry an equivalent negative region charge to the Lower region of the cloud and thus negative charge builds up in the bottom side of the cloud.

<u>According to Mason,</u>

→ The ice Splinter should carry only positive charge upwards.

→ water being ionic in Nature has concentration of H^+ & OH^- ions. The ion density depends on temperature.

→ Thus in an ice slab with upper & Lower surfaces at temperature T_1 & T_2 ($T_1 < T_2$), there will be a higher concentration of ions in the Lower region.

→ H^+ ions are much lighter, they diffuse much faster all over the volume.

→ Therefore, Lower portion → warmer will have a net negative charge density

upper portion → cooler region will have a net positive charge density

→ hence, the outer shells of the frozen water droplets coming into contact with hailstones will be cooler & therefore a net positive charge acquire.

→ When the shell splinters, the charge carried by them in the upward direction is positive.

<u>According to Reynold's theory</u>,

→ It is based on experimental Results, the hail packets get negatively charged when impinged upon by warmer ice crystals. When the temperature conditions are reversed, the charing polarity reverse.

→ However, the extent of the charging & consequently the rate of charge generation was found to disagree with pratical observation relating to thunder clouds. This type of phenomenon also occur in thunder clouds.

Mechanism of Lightning

→ The cloud & the ground form two plates of capacitor & the dielectric medium is air.

Lower part of cloud → negatively charged.

Earth → positively charged, by induction.

→ Lightning discharge will require the puncture of air between the cloud & earth.

Breakdown of air → E = 30 kv/cm peak.

If moisture content in the air is Large
E → 10kv/cm

→ After a gradient of approximately 10 kv/cm is set up in the cloud, the air surrounding get ionised. At this streamer with plasma starts towards the ground with a velocity of about $\frac{1}{10}$ times that of Light (3×10^8 m/s) but may progre only about 50m or so before it comes to halt emitting a bright flash of Light.

→ The halt may be due to insufficient build up of electric charge at its head & not sufficient to maintain the necessary field gradient for further progress of the

Streamer.

→ But after short interval of about 100 μs, the streamer again starts out repeating its performance. This discharge is known as stepped leader.

→ from the tip of the discharge a pilot streamer starts with Low luminosity & current of a few amperes. (100 A)

Speed of the streamer - 0.16 m/μsec.

Which can't be detected with naked eye only a spot travelling is detected. This Streamer is called pilot streamer because this Leads to the Lightning phenomenon.

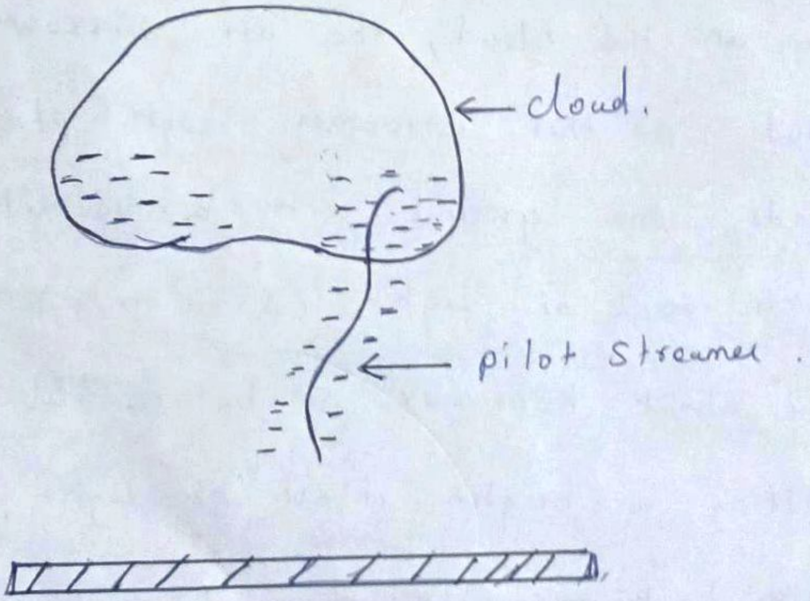


Fig: Pilot Streamer.

→ Depending upon the state of ionization of the air surrounding the streamer, it is branched to several paths & this is known as stepped Leader.

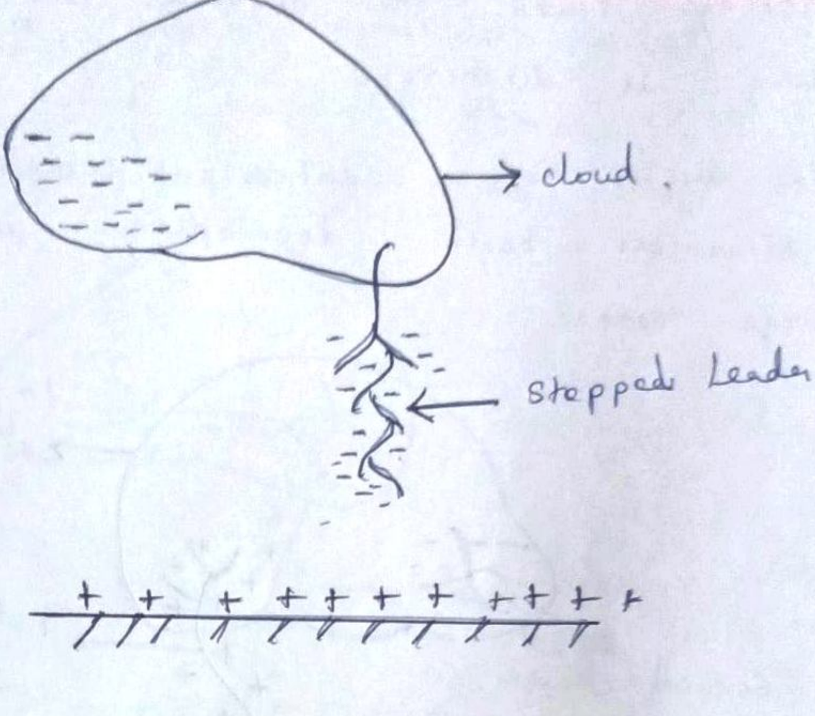


fig stepped leader.

→ The charge is brought from the cloud through the already ionized path. The air surrounding these paths is again ionized & the Leader in this way reaches the earth. once the stepped Leader has made contact with the earth, a power return stroke moves very fast up toward the cloud through the already ionized path by the Leader.

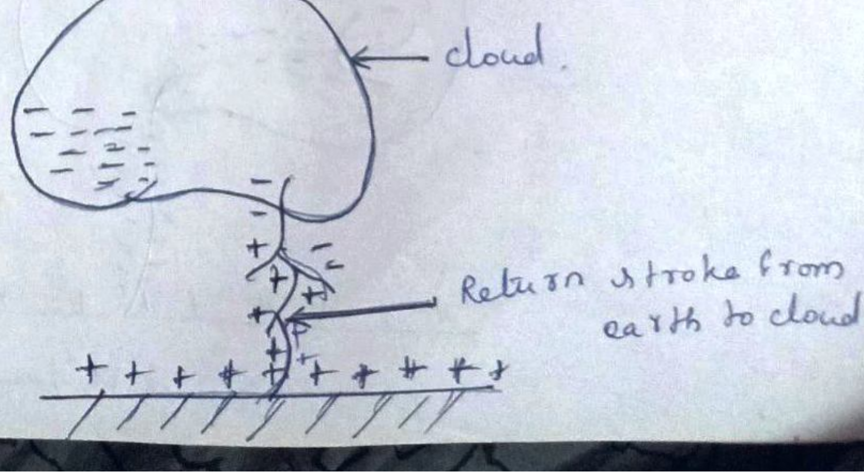


fig Return stroke.

→ The negative charge of the cloud is being neutralized by the positive induced charge on the earth. This instant gives rise to lighting flash. The negative charge of cloud being is discharged.

→ The first charge centre is completely discharged & streamers begin developing in the second charge centre.

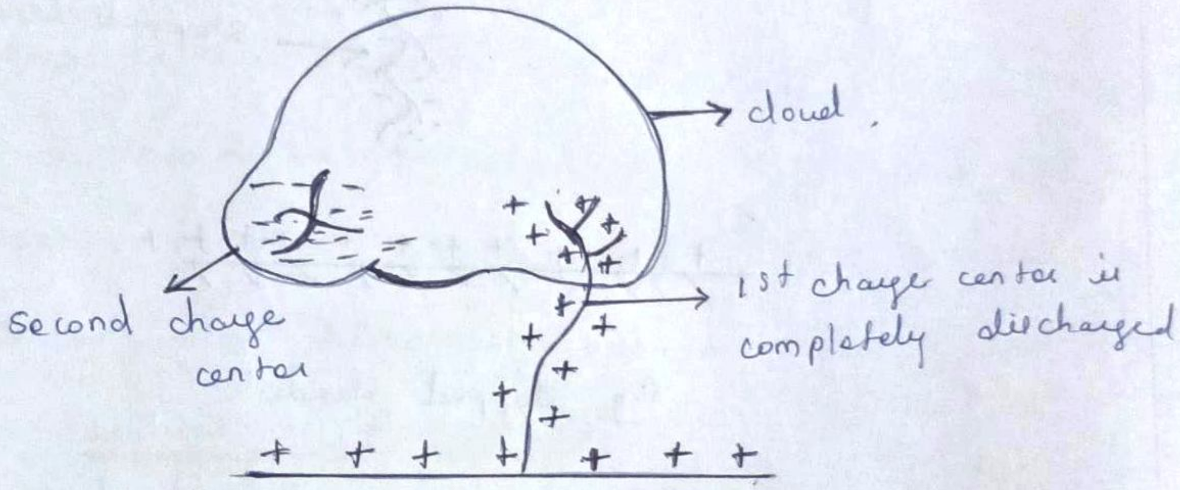


Fig: second charge center.

→ The return stroke is followed by several strokes. The leader of second & the subsequent strokes is known as dart leader.

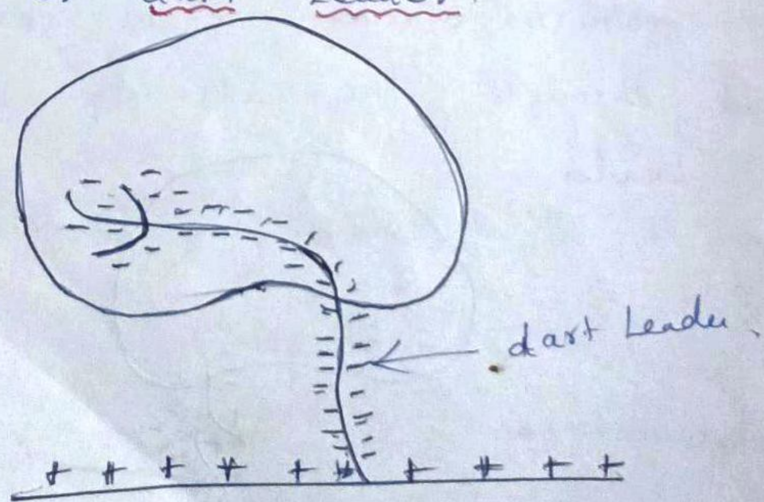


Fig: dart Leader

→ The second charge center is discharging to ground through dart Leader. positive streamer are going up from ground. This is called **heavy return strokes**, which begins to discharge negatively charge under the cloud & the second charge centre in the cloud.

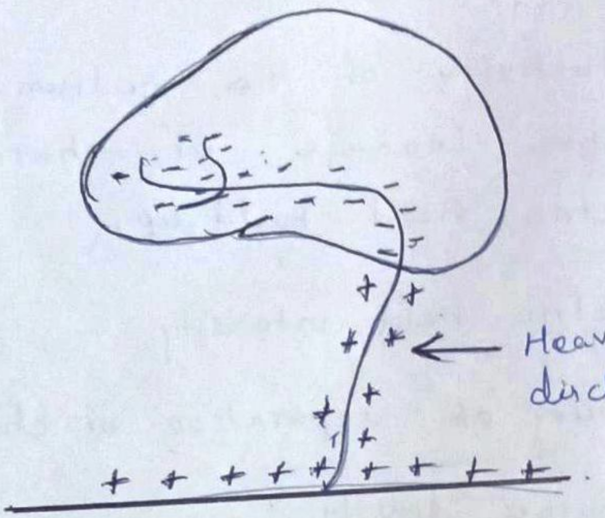


Fig Heavy return Stroke.

The discharge takes place between cloud is known as sheath Lightning.

Total time required for the stepped Leader to reach the ground = 20ms.

$I \Rightarrow 1000 - 250000\ A$

Velocity of the return or main stroke = 0.05 to 0.5 times the velocity of Light.

Rate of charging of thunder clouds.

According to Mason,

thunder clouds consist of mixture of positive and negative charges, due to hailstones & air current the charge separate vertically.

Let,

λ – conductivity of the medium there will be resistive Leakage of charge from electric field build up.

E – Electric field intensity

V – Velocity of separation of charge.

ρ – charge density.

$$\frac{dE}{dt} + \lambda E = \rho v$$

$$\frac{dE}{dt} + P(t)E = q(t)$$

where, $P(t) = \lambda$

$q(t) = \rho v$

from this

$$E = \frac{\int R(t) \cdot q(t)dt + c}{R(t)} \rightarrow (1)$$

$$R(t) = e^{\int P(t)\,dt} = e^{\int \lambda dt} = e^{\lambda t}$$

sub (1) $\Rightarrow$ $$E = \frac{\int e^{\lambda t} \cdot \rho v\,dt + c}{e^{\lambda t}}$$

$$= \frac{\frac{e^{\lambda t}}{\lambda} \rho v + c}{e^{\lambda t}}$$

$$E = \frac{\rho v}{\lambda} + c e^{-\lambda t} \longrightarrow (2)$$

To find c sub $E = 0$, $t = 0$

$$0 = \frac{\rho v}{\lambda} + c$$

$$c = -\frac{\rho v}{\lambda}$$

$$\therefore (2) \Rightarrow E = \frac{\rho v}{\lambda} - \frac{\rho v}{\lambda} e^{-\lambda t}$$

$$\boxed{E = \frac{\rho v}{\lambda}\left[1 - e^{-\lambda t}\right]}$$

Let

Q_s - separated charge A - cloud area

Q_g - generated charge. h - height of the charged region

$$\rho = \frac{\text{charge}}{\text{Area}} = \frac{Q_g}{Ah}$$

$\boxed{D = \varepsilon E}$

$$E = \frac{Q_s}{A \varepsilon_0}$$

ε_0 - permittivity of the medium.

$$Q_g = \rho A h = \rho \frac{Q_s}{\varepsilon_0 E} h$$

$$= \rho \frac{Q_s h}{\varepsilon \; \rho v (1 - e^{-\lambda t})} = \frac{Q_s h}{\ldots}$$

Mathematical model for Lightning

During charge formation process, the cloud may be consider as non conductor.

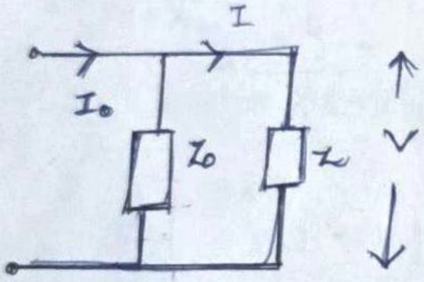
If charging process continued, gradient at the charged region exceeds the breakdown strength of air or moist air in the cloud. hence Local breakdown take place within the cloud.

Let

$I_0 \rightarrow$ current source (Lightning stroke current)

Z_0 - Source impedance discharging to earth.

Z - object impedance (surge impedance)



$$V = I Z$$

$$= I_0 \cdot \frac{Z_0 Z}{Z_0 + Z}$$

$\div Z_0$.

$$\boxed{V = I_0 \frac{Z}{1 + \frac{Z}{Z_0}}}$$

$Z_0 = 1000 - 3000\ \Omega$.

Z of Transmission Line $= \angle 500\ \Omega$.

Z of ground wire $= 100 - 150\ \Omega$.

Z of tower $= 10 - 50\ \Omega$.

Value of $\frac{z}{z_0} < 0.1$ may neglected.

$$V = I_0 z$$

→ High voltage during Lightning causes a flashover of the line conductor through insulator strings.

→ Suppose direct strokes occurs on the top of an unshielded line, then the current wave divide into two branches.

$$V = \frac{I_0}{2} \times z.$$

Which cause a flashover of line conductor through insulator strings.

→ The incidence of Lightning strikes on Transmission Lines & substations are related to the degree of thunderstorm activity. It is based on Thunderstorm day (TD).

Thunderstorm days (Isokeraunic Level)

It is defined as the No. of days in a year when thunder is recorded in a particular Location.

Number of ground flashovers

$$N_g = (0.1 \text{ to } 0.2)\ TD/\text{strokes}/km^2\text{-year},$$

Value of TD in India = 30 - 50

For power interruption $N_g = k_1 (TD)^b$

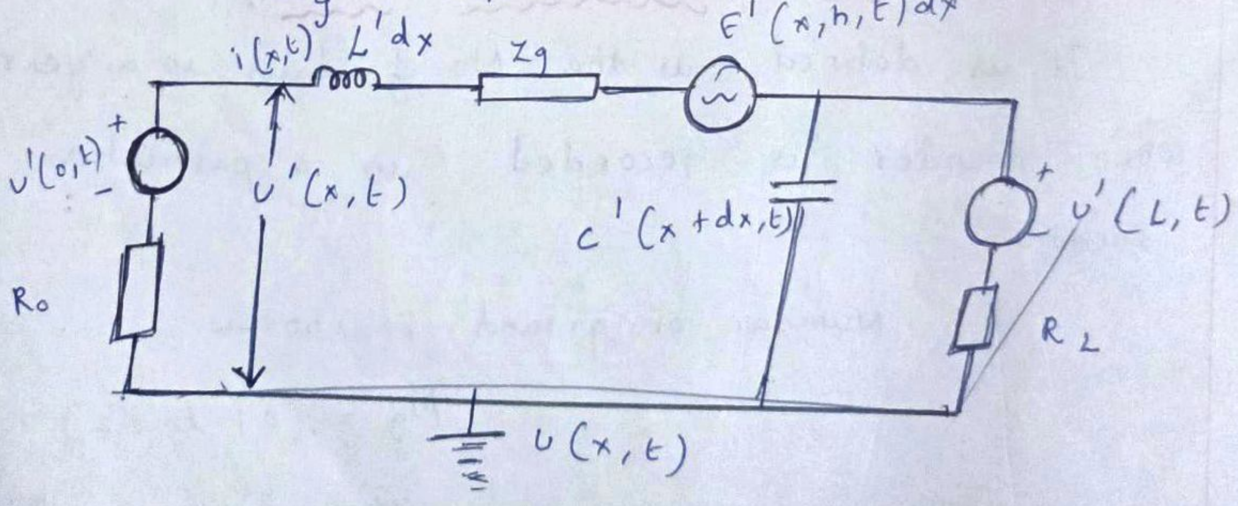
$k_1 = 0.04$, $b = 1.25$ (or)
$k_1 = 0.054$, $b = 1.1$

Model for Lightning.

When a transmission Line is nearer to the Stroke channel, there will be a coupling between Line & stroke channel.

The voltage at any length $x = L$

- L - Length of Line
- R_0 - Soure resistance
- R_L - Load resistance
- L' - Impedance Inductance of Line / unit Length
- c' - capacitance of line / unit Length
- $u'(x,t)$ - voltage developed at any distance x
- $i'(x,t)$ - current through the Line at any distance x.
- $E'(x,t)$ - Electric field in x direction at a height h
- z_g - Equivalent ground impedance.



Factors influencing the Lightning induced voltages on Transmission Lines.

→ The ground conductivity

→ the Leader stroke current

→ corona.

1.3 Switching surges.

→ For transmission voltages (400kV & above), the overvoltages generated due to switching is same as that of the magnitude of Lightning over voltage.

→ These overvoltage exist for Long time, so it is dangerous to the System.

→ Switching over voltage increases as the system voltage increases.

→ In extra high voltage Line, switching over voltage determines the insulation Level of the Lines & their dimension & cost.

Sources (or) origin of switching Surges.

→ Opening & closing of switchgear [abnormal over voltage in L, C]

→ In circuit breaker operation, Switching surges with high rate of rise of voltage may cause repeated restriking of the arc between the contacts of the C.B.

→ High natural frequencies of the system

→ damped normal frequency voltage components

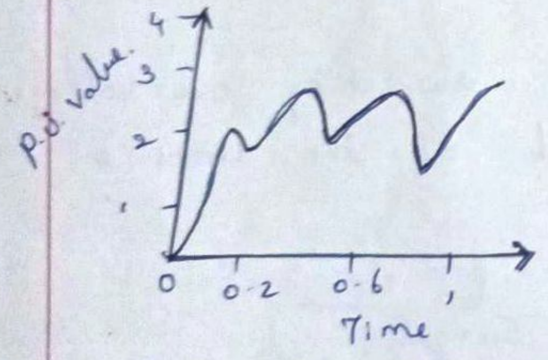
→ Restriking & recovery voltage with successive reflected waves from terminations.

characteristics of switching surges

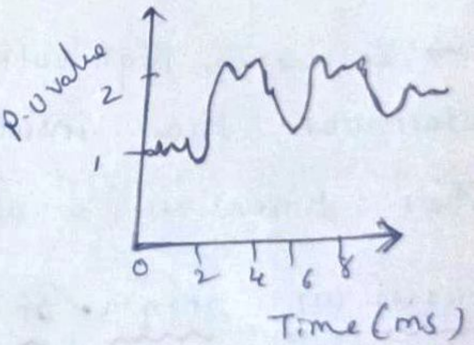
Switching surges arise from any one of the following sources.

- → De energizing of line, cable, shunt capacitor banks etc
- → disconnection of unloaded transformers, reactor etc
- → opening & closing of protective devices connected to line & reactive loads.
- → Switch off the loads suddenly
- → Short circuits & fault clearances.
- → Resonance phenomenon like ferro - resonance, arcing ground etc.

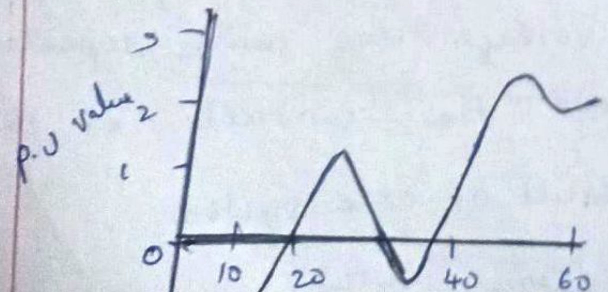
Shapes of switching surges



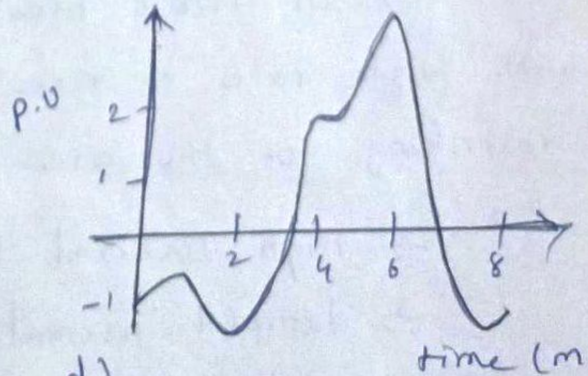
a) Recovery voltage after fault clearing.



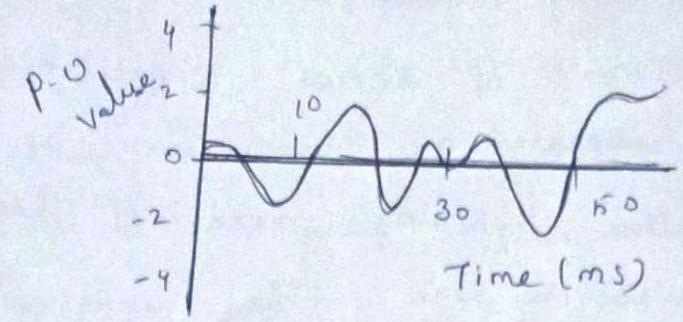
b) fault initiation.



c) over voltage at the line and after fault clearing.



d) Energization of Long Transmission Line



e) overvoltage at Line end during (d).

The shape of switching surges are

→ irregular

→ powerfrequency with harmonics.

Magnitude of overvoltage — 2.4 pu (transformer)

— 1.4 to 2.0 p.u (switching Transmission Lines)

Switching overvoltages in EHV & UHV systems.

Switching overvoltage in EHV & UHV systems are generated when sudden release of internal energy stored due to electrostatic or electromagnetic form. This may happen due to.

→ Interruption of Low inductive currents by high speed circuit breakers.

→ Interruption of small capacitive current by switching off the unloaded Lines.

→ ferro resonance condition

→ Energization of Long EHV or UHV Lines

→ Interruption of fault current when fault is cleared

→ Single pole closing of C.B.

→ Resistance Switching used in C.B

→ Switching operation of series capacitor connected to Line for compensation.

→ Sparking of the Lightning arrester Located at receiving end of the Line.

Measures to control overvoltage due to switching and power frequency.

In EHV or UHV Lines, we should control the switching voltages Less than 2.5 P.U. The following measures are taken to reduce overvoltages:

→ one or multi step energization of Lines by inserting resistors

→ phase controlled closing of C.B with proper sensors.

→ Drain the trapped charges before reclosing of the Lines.

→ using shunt reactors

→ By using Lightning arrester or surge diverters.

1. one or multistep energization of Lines by inserting resistor.

During switching of circuit breakers, inserting a series resistance in series with C.B contacts & short circuiting this resistance after a few cycles. By using inserting resistance, the transient due to switching reduces.

→ If the resistance is inserted for a Long time, the successive reflection take place and the overvoltage reaches high value.

→ Therefore preinsertion of resistance limits the overvoltage.

2. phase controlled closing of circuit breaker.

→ Life of the C.B depends on the No. of operation of the C.B.

→ overvoltage can be avoided by closing 3 φ exactly at the same instant by using phase controlled techniques.

3. Drain the trapped charges before reclosing of the Lines.

→ If the Transmission Lines are suddenly switched off, electric charges are stored on capacitor & Line conductors.

→ These charges are drained by Line insulator or through potential transformers.

→ But the effective method is connecting tempory inserting resistor to ground before reclosure & removing before closure of switch or C.B.

4. Shunt Reactors

→ Shunt Reactors are used to Limit voltage rise due to ferranti effect in EHV lines.

→ Reduce surges due to sudden switching

→ But will give oscillations with the capacitance of the system.

→ To suppress these oscillations and to limit the overvoltages, resistor are connected in series with these reactor.

5. By using Lightning arrestors or surge diverters.

→ Lightning arrestor are provided at power station, substation, big industries, tallest building ect.

→ To protect the equipment from Lightning.

1.4 power frequency over voltages in power system

→ The power frequency overvoltages occur in Large power systems and they are of much concern in EHV system ie) System of 400kV & above.

→ overvoltages of power frequency harmonics & voltages with frequencies nearer to the operating frequency are caused during tap changing operations & by resonating overvoltages due to series capacitor with shunt reactors or transformer.

→ The duration of these voltages may be from one to two cycles to a few seconds depending on the overvoltage protection employed.

The main causes for power frequency & its harmonic over voltages are

a) Sudden Loss of Loads

b) disconnection of inductive Loads or connection of capacitive Loads.

c) ferranti effect, unsymmetrical faults &

d) saturation in Transformers etc.

a) Sudden Load Rejection.

→ Sudden load rejection on Large power system causes the speeding up of generator prime movers. The speed governors & automatic voltage regulators will intervene to restore normal conditions.

→ But initially both the frequency & voltage increase

The approximate voltage rise is given by

$$V = \frac{f}{f_0} E' \left[\left(1 - \frac{f}{f_0}\right) \frac{x_s}{x_c} \right]$$

X_s - reactance of the generator

X_c - capacitive reactance

E' - Voltage generated before over speeding & Load rejection.

f - increased frequency

f_0 - normal frequency

b) Ferranti effect

→ In Long Transmission Lines & cables, receiving end voltage is greater than sending end voltage during Light Load or no Load operation.

→ under no Load or Light Load, the capacitance associated with the Line, generate more reactive power than the reactive power which is absorbed hence

$$V_R > V_S .$$

This effect is called Ferranti effect

→ Due to ferranti effect, the power frequency over voltages may occur.

→ shunt reactor are used to Limit voltage rise due to ferranti effect in EHV Lines. (1.2 to 1.4 pu)

→ for improving voltage in the transmission Line Inductive Loads are disconnected or Capacitive Loads are added.

→ Due to this power frequency over voltage may occur.

c) Ground Fault & their Effect:

Single L-G fault cause rise in voltage in other healthy phase single line to ground fault occurs at phase a.

$V_a = 0$

Voltage at healthy phase 'b' & 'c', increases for solidly grounded system,

$$\frac{X_0}{X_1} \leq 3 \quad \& \quad \frac{R_0}{X_1} \leq 1$$

Where,

X_0 - zero sequence reactance.

X_1 - positive sequence reactance.

R_0 - zero sequence resistance.

d) Saturation effects

→ When voltages above the rated value are applied to transformers, their magnetizing current increases rapidly and may be about the full rated current for 50% over voltage.

→ These magnetizing current are not sinusoidal in nature but are of a peaky waveform.

→ The 3rd, 5th, 7th harmonic content may be 65%, 35%, 25% of the exciting current of the fundamental frequency corresponding to an over voltage of 1.2 pu.

→ For higher harmonics in series resonance between the transformer inductance & the line capacitance can occur which may produce even higher voltages.

protection against over voltages.

Types of fault that may occur in power Lines

→ Symmetrical – 3φ fault (LLLG)

→ unsymmetrical fault < L-G fault, L-L fault, L-L-G fault.

protection of equipment in the power system from overvoltage due to Lightning can be done by

→ using ground wires.

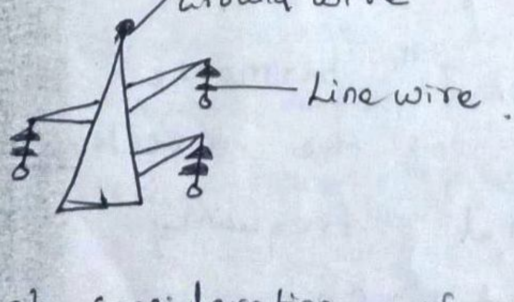
→ using ground rods

→ using counter poise wires.

→ using protective devices Like rod gap, expulsion type & value type surge arrestor etc

Ground wires.

→ Ground wire is a conductor run parallel to the main conductor of the transmission Line, supported on the same tower & earthed at every equally & regularly spaced tower.



Important consideration of groundwires are

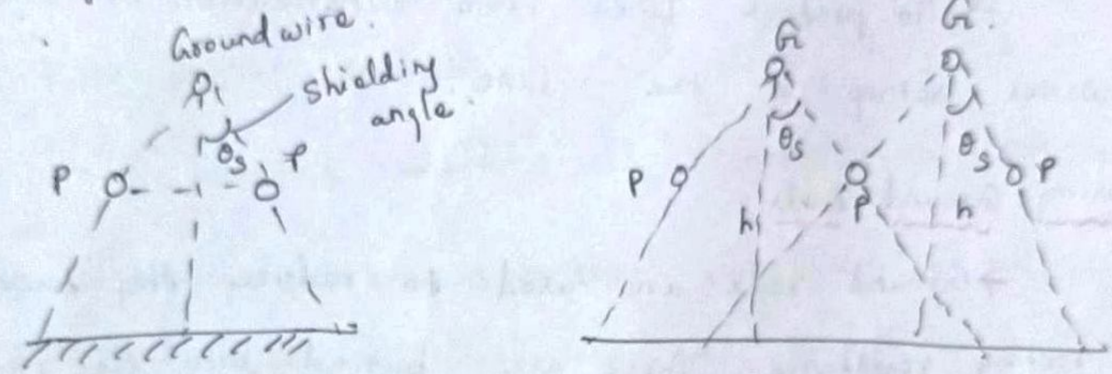
→ Ground wire should be based on Mechanical consideration rather than electrical consideration.

→ It should have high strength & non corrosive.

→ Ground resistance, insulation & clearance between the ground wire & the lines are important in the design.

Shielding angle or protection Angle θ_s.

The angle between the vertical line drawn through the vertical of tower & a line through the ground wire & the shielded conductor.



protection of Line using Groundwire

Assume,

→ positively charged cloud is present above the line, it induces a negative charge near the line conductor & ground wire.

→ Ground wire is earthed at regular interval so that the negative charges drained to the earth.

→ As the ground wire is nearer to the line conductor, the induced charge on it will be much less & the potential rise is small.

A single ground wire reduces the induced voltage to one half of that without ground wire.

effective protection depends on

→ h (height.

→ θ_s (shielding angle) ≈ 30

material used: Galvanized stranded steel conductor.

uses

→ It is used for direct stroke protection of Lines for voltage of 110kV & above.

→ To protect Lines from attenuation of travelling waves setup in the Line.

using Ground Rods.

→ Ground rods are used to reduce the tower footing resistance. These are buried into the ground surrounding the tower structure.

→ Ground rods are a No. of rod about 15 mm diameter & 3m Long driven into the ground.

→ The tower footing resistance can be varied by

→ varying the spacing of the rod

→ varying the number of rod.

→ varying the depth to which they are driven.

Material used:- Galvanized iron or copper bearing steel.

using counter-poise wires

→ counter poise wires are buried in the ground at a depth of 0.5 to 1m, running parallel to the transmission line conductors & connected to the tower legs.

→ wire length may be 50 to 100 m long.

→ When the lightning stroke, incident on the tower, discharges first through the tower to ground & discharges through the counter-poise.

→ for proper operation,

Leakage resistance of counter poise < Surge impedance

→ If lightning strikes a tower, current is injected & potential rises & flash over of insulator disc take place which result in a L-G fault. So, the tower footing resistance value should be low.

Material used: Galvanized steel wire.

using protective devices.

→ To protect the power system component against the travelling waves caused by lightning.

Basic Requirement of a Lightning arrestor or Surge Arrestor Diverter.

The basic requirement of a lightning arresters are

→ It should not pass any current to the system component which is to be protected at abnormal conditions.

→ It should breakdown as quickly as possible when abnormal condition occurs.

→ It should discharge the surge current without damaging it.

→ It should interrupt the power frequency follow current after the surge is discharged to ground.

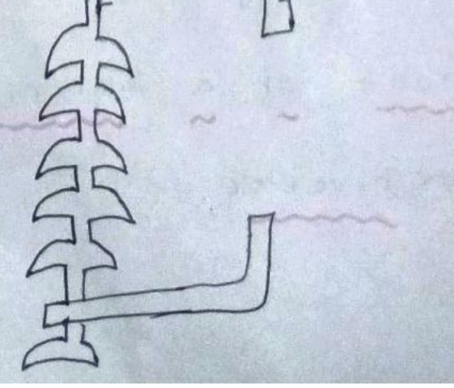
Shunt Protected devices.

Rod gap :-

→ Rod gap is used to protect the system from lightning or thunderstorm activity is less

→ A plain air gap usually between 1 inch square rod cuts at right angle at the ends, connected between line & earth.

→ The rod gap arrangement is



→ When magnitude of an incoming waves exceeds the gap setting of the rod gap, a spark over occurs and the surge is diverted.

distance between the gap & the insulator ≮ $\frac{1}{3}$ gap Length

Advantage

→ Simple in construction
→ cheap
→ Rugged construction.

Reflection & Refraction of Travelling waves.

→ Over voltage propogating as a travelling wave to the end of the Line.

→ High frequency, reflected, transmitted, attenuated distorted during propagating.

Characteristic equation

$$\frac{dv}{dx} = R + L\left(\frac{di}{dt}\right)$$

$$\frac{di}{dx} = G + C\left(\frac{dv}{dt}\right)$$

x - distance, t - time, i - current, v - Voltage, R - Resistance, L - Inductance, G - conductance, C - capacitance.

solution of C.E is

$$V = e^{\gamma x} f_1(t) + e^{-\gamma x} f_2(t)$$

$$i = \sqrt{y/z}\left[e^{\gamma x} f_1(t) - e^{-\gamma x} f_2(t)\right]$$

Where,

$\gamma = \sqrt{(R+Ls)(G+Cs)} = \sqrt{zy}$

$y(s)$ = surge admittance = $\sqrt{y/z}$

$Z(s)$ - surge impedance = $\sqrt{z/y}$

Classification of Transmission Lines

1) ideal Lines : $R = G = 0$

2) distortionless Lines : $R/L = G/C = \alpha$

3) Lines with small Losses : R/L, G/C = small

4) Lines with finite & infinite Length

1) Ideal Lines $R = G = 0$

$$V = f_1(t + x/v) + f_2(t - x/v)$$

$$i = -y\left(f_2(t - x/v) - f_1(t + x/v)\right)$$

Where,

v = propogation Velocity = $1/\sqrt{LC}$

y - Surge admittance = $\sqrt{C/L}$

z - Surge impedance = $\sqrt{1/y}$

2) Distortion Less Line $R/L = G/C = \alpha$.

$$V = e^{-\alpha t}\left[f_3(t + x/v) + f_4(t - x/v)\right]$$

$$i = -\frac{e^{-\alpha t}}{z}\left[f_4(t - x/v) - f_3(t + x/v)\right]$$

Where,

v - propogation velocity = $1/\sqrt{LC}$

$\alpha = R/L = G/C$

Z = surge impedance = $\sqrt{L/C}$

3) Line with small Losses

$$v = e^{\alpha x/v} f_1 (t + x/v) + e^{-\alpha x/v} f_2 (t - x/v))$$

$$i = -y(s) \left[e^{-\alpha x/v} f_2 (t - x/v) - e^{\alpha x/v} f_1 (t + x/v) \right]$$

$$+ v\beta \left(e^{\alpha x/v} \int_{-x/v}^{t} (t + x/v)\, dt - e^{-\alpha x/v} \int_{x/v}^{t} f_2 (t - x/v) . dt \right)$$

Where,

v = propogation velocity = $1/\sqrt{LC}$

$\alpha = \frac{1}{2} * \left(R/L + G/C \right)$ — attenuator constant.

$\beta = \frac{1}{2} * \left(R/L - G/C \right)$ — wavelength constant.

$$y(s) = \sqrt{C/L \left(1 - \beta/s \right)}$$

4) exact solution for Lines of finite & infinite Length.

→ It is quite complex & normally of Little pratical importance.

Inference

→ ct & voltage are dissimilar

→ Attenuation & distortion due to small Line resistance & Leakage conductance are of Little consequence.

→ surge impedance is a complex function & is not uniquely defined.

Attenuation & distortion

decrease in Magnitude - Attenuation

elongation / change of wave shape - distortion

Attenuation caused by energy Loss

distortion caused by inductance & capacitance.

energy Loss

→ Resistance as modified by skin effect

→ change in R_g

→ Leakage Resistance & non uniform ground Resistance etc.

Induction changes

→ Skin effect

→ proximity effect

→ non uniform distribution effect of current & nearness to steel Structures (tower)

capacitance changes

→ In insulation near to ground

corona is the another factor affect Attenuation & distortion.

For distortionless Lines,

Attenuation is approximated by Loss function

$$\varphi(v) = -C \frac{dv^2}{dt}$$

i) For Lines having four parameters R, L, G & C

$$\varphi(v) = \left[RC + LG) / LC \right] v^2 \quad \& \quad \frac{dv}{dt} = -\alpha v$$

where, $\alpha = \frac{1}{2} \left[\left(\frac{R}{L} \right) + \left(\frac{G}{C} \right) \right]$

2) Skilling Form

$$V = V_0 e^{-(\alpha t)}$$

2) Skilling formula

$\varphi(v)$ is assumed to be equal to

$\beta (V - V_c)$ where, V_c - Critical corona Voltage.

$$\frac{dv}{dt} = \frac{-\beta}{2C \left(\frac{V - V_c}{V} \right)}$$

$$\left(\frac{\beta}{2C} \right) t = (V_0 - V) + V_0 \ln \left[(V_0 - V_c) / (V - V_c) \right]$$

3) Quadratic formula.

$\varphi(v)$ is assumed to be vary $(V - V_c)^2$ then.

$$\frac{dv}{dt} = \left(-\frac{\gamma}{2C} \right) \left[\frac{V_0 - V_c}{(V - V_c)} \right]^2$$

Integrating the equation.

$$\left[(v_0 - v) \cdot v_c / (v_0 - v_c)(v - v_c) \right] + \ln \left[(v_0 - v_c) / (v - v_c) \right] = \gamma t / 2c$$

4) Foust & Manger formula.

$\varphi(v)$ is assumed to be equal to λv^3.

$$\frac{dv}{dt} = \left(\frac{-\lambda}{2c} \right) v^2$$

where, $v = v_0 / (1 + k v_0 t)$

$$k = \lambda / 2c.$$

Reflection & Transmission of waves

For Lossless Lines

$\frac{e_1}{i_1} = z_1 \rightarrow$ incident wave.

$\frac{e_1'}{i_1'} = -z_1 \rightarrow$ Reflected wave.

$\frac{e_1''}{i_1''} = z_1'' \rightarrow$ transmitted waves.

$$i_0 = i_1 + i_1'$$

$$e_0 = e_1 + e_1' = z_0(s) \cdot i_0.$$

$$e_1' = \left[\frac{z_0(s) - z_1)}{z_0(s) + z_1)} \right] e_1$$

$$i_1' = \left[\frac{z_0(s) - z_1)}{z_0(s) + z_1)} \right] i_1$$

Junction voltage & current is given by

$$e_0 = \left[\frac{2Z_0(s)}{(Z_0(s)+Z_1)}\right] e_1$$

$$i_0 = \left[\frac{2e_1}{Z_0(s)+Z_1}\right]$$

Successive Reflection & Lattice diagram

1. All waves travel downhill, ie) into positive time

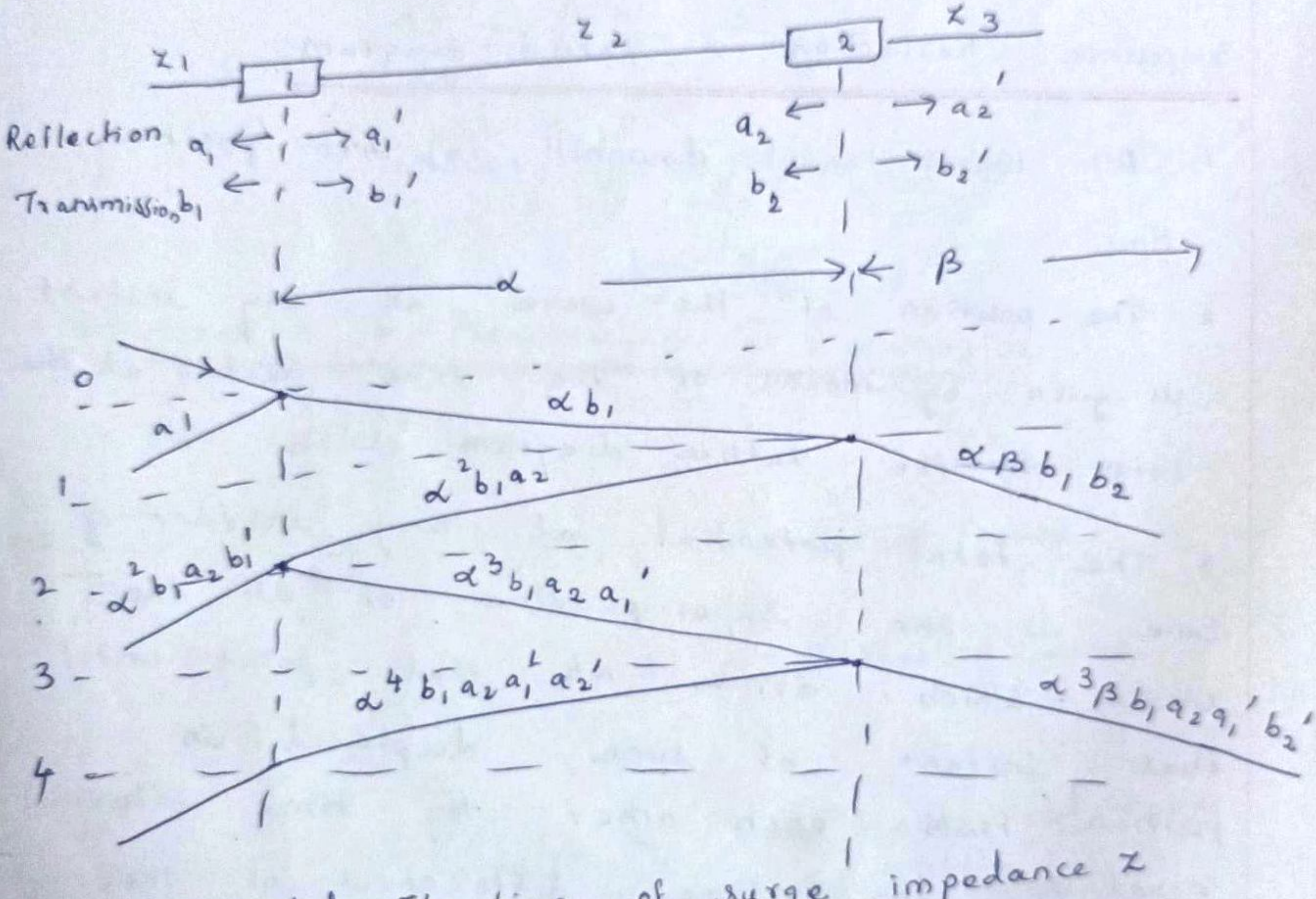
2. The position of the wave at any instant is given by means of the time scale at the left of the lattice diagram.

3. The total potential at any instant of time is the superposition of all the waves which arrive at that point until that instant of time, displaced in position from each other by time interval equal to the time differences of their arrival.

4. Attenuation is included so that amount by which a wave is reduced is taken care of

5. The previous history of the wave, if desired can be easily traced. If the

computation is to be carried out at a point where the operations cannot be directly placed on the Lattice diagram, the arms can be numbered & the quantity can be tabulated & computed.



open ended T/m Line of surge impedance Z

$$e = E\,u(t)$$

$$Z_1 = Z, \quad Z_2 = \infty.$$

coefficient of reflection $\Gamma = \frac{(Z_2 - Z_1)}{(Z_2 + Z_1)} = \frac{(1 - Z_1/Z_2)}{(1 + Z_1/Z_2)}$

sub the value

$$\Gamma = \frac{(\infty - Z)}{(\infty + Z)} = 1$$

$$\Gamma = 1$$

Reflected wave $e' = \Gamma e = E\,u(t)$

Transmitted wave $e'' = (1+\Gamma) e = 2E\,u(t)$

The voltage at the open end rises to double its value.

Short circuit Line

$e = E\,u(t)$, $z_1 = z$, & $z_2 = 0$

coefficient of reflection $\Gamma = -1$

Reflected wave $e' = \Gamma e = -E\,u(t)$

Transmitted wave $e'' = (1+\Gamma) e = 0$

Reflected current wave $= \left| \dfrac{-E\,u(t)}{z} \right|$

$= \dfrac{E\,u(t)}{z}$

Total current $i_0 = (i + I') = 2i$

Current at junction point rises to double the value.

Line terminated with Resistance equal to the Surge impedance of the Line.

$z_1 = z$, $z_2 = R = z$.

coefficient of reflection $\Gamma = 0$

Reflected wave $e' = \Gamma e = 0$

Transmitted wave $e'' = (1+\Gamma) e = e$

∴ No Reflected wave.

Line terminated with a capacitor

$Z_1 = Z$ & $Z_2 = 1/SC$

coefficient of reflection $\Gamma = \frac{(1 - CZ_s)}{(1 + CZ_s)}$

Reflected wave $e' = [1 - 2\exp(-t/CZ)]Eu(t)$

Transmitted wave $e'' = 2[1 - \exp(-t/CZ)] Eu(t)$.

Line terminated with a Inductor

$Z_1 = Z$ & $Z_2 = LS$

coefficient of reflection $\Gamma = \frac{(LS - Z)}{(LS + Z)}$

Reflected wave $e' = -[1 - 2e^{(-Zt/L)}] Eu(t)$.

Transmitted wave $e'' = 2e^{(-Zt/L)} Eu(t)$.

Line having a series Inductor

$Z_1 = Z + LS$ & $Z_2 = Z$

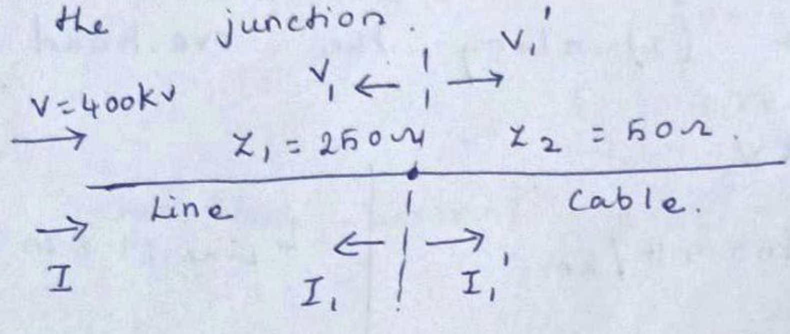
coefficient of reflection $\Gamma = \frac{LS}{LS + 2Z}$

Reflected wave $e' = -e^{(-2Zt/L)} Eu(t)$

Transmitted wave $e'' = [1 - e^{(-2Zt/L)}] Eu(t)$

problem

1. A transmission Line of surge impedance 250 Ω & is connected to a cable of surge impedance 50 Ω at the other end, if a surge of 400 kV travel along the Line to the junction point, find the voltage build at the junction.



$$V_1 = V \cdot \frac{Z_2 - Z_1}{Z_1 + Z_2} = 400\left[\frac{50 - 250}{50 + 250}\right]$$

$$= 400\left[-\frac{200}{300}\right]$$

$$= -266.67 \text{ kv}.$$

Voltage at the junction $= V + V_1$

$$V_1' = 400 + (+266.67)$$

$$= 666.67 \text{ kv}.$$

2) An underground cable of inductance 0.150 mH/km and of capacitance 0.2 μF/km is connected to an overhead line having an inductance of 1.2 mH/km & capacitance of 0.006 μF/km. Calculate the transmitted & reflected voltage & current waves at the junction, if a surge of 200 kV travels to the junction (1) along the cable & (2) along the overhead line.

Soln

$V = 200\,kV$

$L_{cable} = 0.150\,mH/km$

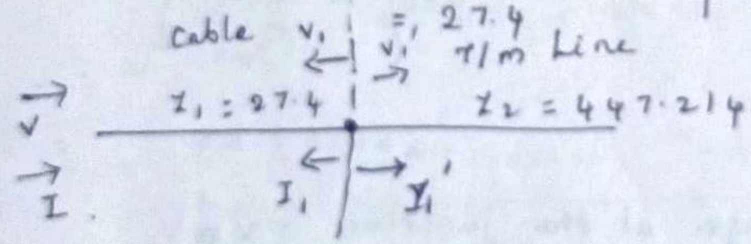
$C_{cable} = 0.2\,\mu F/km$

$Z_1 = \sqrt{L/C} = \sqrt{\dfrac{0.150 \times 10^{-3}}{0.2 \times 10^{-6}}} = 27.4$

$L_{Line} = 1.2\,mH/km$

$C_{Line} = 0.006\,\mu F/km$

$Z_2 = \sqrt{L/C} = \sqrt{\dfrac{1.2 \times 10^{-3}}{0.006 \times 10^{-6}}} = 447.214$



1) Along the cable.

$V_1' = V + V_1, \quad I_1' = I - I_1$

Reflected voltage $V_1 = \left(\dfrac{Z_2 - Z_1}{Z_1 + Z_2}\right) \cdot V$

$= \left(\dfrac{447.214 - 27.4}{447.214 + 27.4}\right) \times 200\,kV$

$= 176.91\,kV$.

Reflected current $I_1 = \frac{V_1}{Z_1}$

$= \frac{176.91}{27.4}$

$= 6.45 \text{ kA}$.

Transmitted voltage $V_1' = V + V_1$

$= 200 + 176.91$

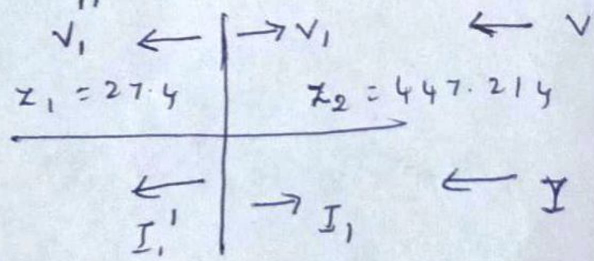
$= 376.91 \text{ kV}$.

Transmitted current $I_1' = \frac{2Z_1}{Z_1 + Z_2} * \frac{V}{Z_1}$

$= \frac{2 * 27.4}{27.4 + 447.214} * \frac{200}{27.4}$

$= 0.84 \text{ kA}$.

Case 2: Along the Line.



$V_1' = V + V_1$, $I_1' = I - I_1$

Reflected voltage $V_1 = \frac{Z_1 - Z_2}{Z_1 + Z_2} \cdot V$.

$= \frac{27.4 - 447.214}{27.4 + 447.214} \times 200$

$= -176.91\ kV$

Reflected current $I_1 = \frac{V_1}{Z_2}$

$= \frac{-176.91}{447.214}$

$= -0.395\ kA$

Transmitted voltage $V_1' = \frac{2Z_1}{Z_1 + Z_2} \cdot V$

$= \frac{2 \times 27.4}{27.4 + 447.214} \times 200$

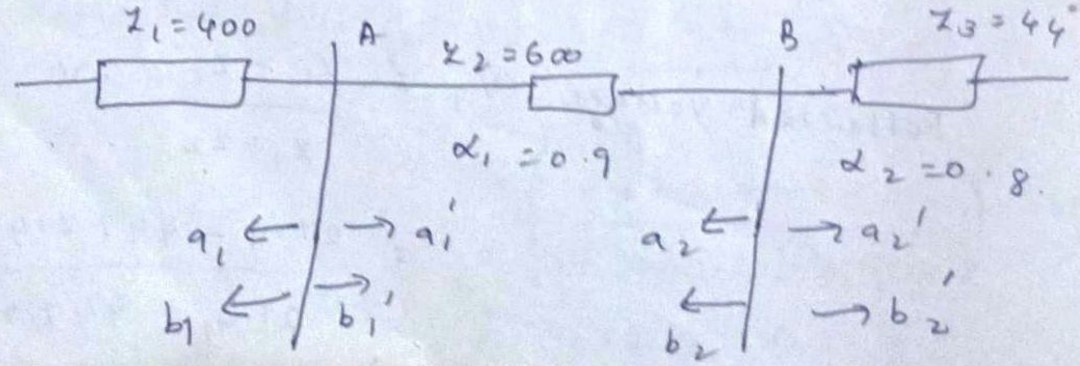
$= 23.09\ kV$

Transmitted current $I_1' = \frac{V_1'}{Z_2}$

$= \frac{23.09}{447.214}$

$= 0.05163\ kA$

3) Two substation A, B are shown in figure. The attenuation factor is taken as 0.9 & 0.8 draw Bewley lattice diagram.



UNIT - 2

Dielectric Breakdown

2 . Gaseous Breakdown

Gaseous dielectrics are

- → air
- → Nitrogen (N_2)
- → carbon di oxide (CO_2)
- → freon (CCl_2F_2)
- → Sulphur hexa fluoride (SF_6) are

used in electrical apparatus.

Gaseous breakdown

For High voltages, current increases between the electrode in dielectric then breakdown occurs.

Breakdown voltage - Maximum voltage applied to the insulation at the moment of breakdown.

Types

- → Self sustaining discharge
- → Non sustaining discharge

Theories

- → Townsend theory
- → Streamer theory

Ionization : Townsend's theory

The process of Liberating an electron from a gas molecules with the simultaneous protection of an positive ion is called ionization.

→ By collision

→ photo ionization

→ secondary ionization

→ Electron Attachment process.

Ionization by collision

* A free electron collides with a neutral gas molecules and give rise to a new electron & a positive ion.

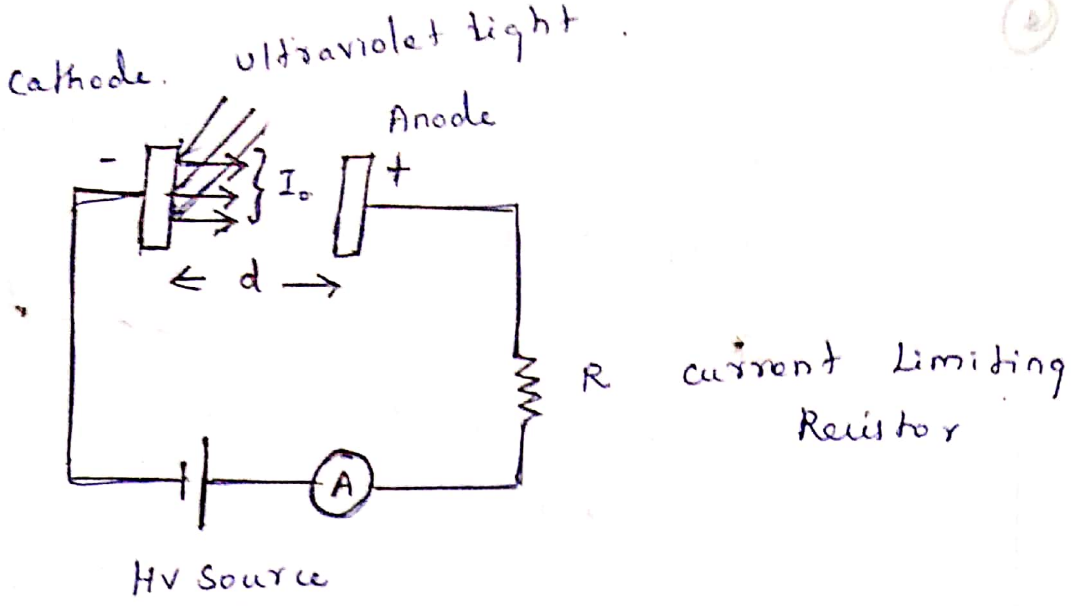
* If the energy gained during this travel between collisions exceeds ionisation potential, which is the energy required to dislodge an electron from its atomic shell then ionization take place.

$$e^- + A \rightarrow e^- + A^+ + e^-$$

e^- → electron

A → Atom

A^+ → positive ion



* Electrons produced at the cathode by UV Light falling on the cathode, ionize neutral gas particles producing positive ions & additional electrons.

* The additional electrons then themselves makes ionizing collisions & the process repeats itself.

* No. of. electron reaching the anode per time is greater than those Liberated from cathode.

<u>photo ionization</u>

→ Involves radiation of matter

→ Occurs when the radiation energy absorbed by atom exceed ionization potential.

process :

1. excitation of the atom to a higher energy rate.

2. continuous absorption by direct excitation of an atom or dissociation of diatomic molecules or direct ionization etc.

$$h\nu + A \rightleftharpoons A^*.$$

Ionization occurs when

$$\lambda = \frac{c \cdot h}{V_i}$$

$$\lambda = 1.27 \times 10^{-6} / V_i \text{ cm}$$

Where, h - planck's constant

λ - wavelength of incident radiation

c - velocity of Light.

V_i → electron volts.

photo ionisation occurs with a radiation of 1250 A°.

Secondary ionization

It is a process by which secondary electrons are produced are one which sustains a discharge after it is established due to

Collision & photo ionization.

1) Electron emission due to positive ion impact
2) Electron emission due to photons
3) Electron emission due to metastable & neutral atoms.

1. positive ion impact

→ positive ion can cause emission of electrons from the cathode by giving up its kinetic energy on impact.

→ If the Total energy (Ionization energy + kinetic energy) is greater than twice the work function, than one electron will be ejected and a secondary electron will neutralise the ion.

→ The probability of this process is measured as γ_i

γ_i → Townsend's secondary ionization coefficient due to positive ions.

(Net yield of electron per incident positive ion).

$\gamma_i \uparrow$ → ion velocity.

depends on
→ gas kind.
→ electrode material.

2. electron emission due to photons.

energy (in the form of photons) by UV Light cause electron to escape from a metal.

It occurs $h.\nu \leq \varphi$

where, φ - work function

ν - threshold frequency.

Clean nickel surface,

$\varphi - 4.5 eV$

threshold frequency correspond wavelength

$\lambda = 2755 A^{\circ}$.

3) Electron emission due to metastable & neutral atoms.

→ Metastable excited particle whose Lifetime $(10^{-3}s)$ is Large compared to that of an ordinary one $(10^{-8}s)$

→ Electron can be ejected from the metal surface by the impact of excited metastable atoms, provided that their total work energy is sufficient to overcome the work function.

→ yields can be large (nearly 100%) for interactions of excited He atom with molybdenum, nikkel or Magnesium.

→ neutral atoms in the ground state also give rise to secondary electrons if K.E is high (1000 ev).

At low energy the yield is less.

Electron attachement process

→ The type of collision in which electron may become attached to atoms or molecules to form negative ions are called attachement collision process depends on

→ Energy of the electron

→ Nature of gas

Electrically insulating gases such as

- O_2
- CO_2
- Cl_2
- F_2
- C_2F_6
- C_3F_8
- C_4F_{10}
- CCl_2F_2 &
- SF_6. exhibit this property.

$$\text{Atom} + e^- + K \longrightarrow A^- + E_a + K.$$

where, A – Atom

A^- – negative atomic ion

K – kinetic energy, E_a – electron affinity

→ It removes free electrons from an ionised gas when arc interruption occurs in gas insulated switchgear.

Townsend's current growth equation

Let us assume,

n_o – No. of electron emitted from cathode.

When one electrode collides with neutral particle, a positive ion & an electron are formed → ionizing collision.

α - Average No. of ionizing collision made by an electron per cm Level travel in the direction of field.

α - depends on gas pressure p & E/p.

It is called as Townsend's 1st ionization coefficient.

At any distance x from the cathode,

Let n_x → No. of electrons.

When there n_x electron travel a further distance of dx they give rise to $\alpha n_x \cdot dx$ electron.

At, $x = 0$, $n_x = n_o$.

$$\frac{dn_x}{dx} = \alpha n_x$$

$$dn_x = \alpha n_x dx.$$

$$\int \frac{dn_x}{n_x} = \int \alpha \, dx$$

$$\ln n_x = \alpha x + k \quad \rightarrow (1)$$

To find the value of k.

$x = 0, \quad n_x = n_0$.

$$\boxed{k = \ln n_0} \quad \rightarrow (2)$$

Sub (2) in (1)

$$\ln n_x = \alpha x + \ln n_0$$

$$\ln n_x - \ln n_0 = \alpha x$$

$$\ln \left[\frac{n_x}{n_0} \right] = \alpha x.$$

$$\frac{n_x}{n_0} = e^{\alpha x}$$

$$\boxed{n_x = n_0 e^{\alpha x}} \quad \rightarrow (3)$$

Then the number of electron reaching anode $(x = d)$ will be.

$$\boxed{n_d = n_0 e^{\alpha d}}.$$

No. of. new electron created, on the average, by each electron is $\frac{n_d - n_0}{n_0} = e^{\alpha d} - 1$

∴ The average current in the gap, which is equal to the No. of electron travelling per second will be

$$I = I_0 e^{\alpha d}$$

Current growth in the presence of secondary process

Mechanism for producing Additional electrons to create Avalanche.

The Mechanism are

1) The positive ions liberated may have sufficient energy to cause the Liberation of electrons from the cathode when they impinge on it.

2) The excited atoms or molecules in the avalanche may emit photons, & this will Lead to the emission of electron due to photo emission.

3) Meta stable particles may diffuse back causing electron emission.

The electron produced by these processes are called secondary electrons.

The secondary ionization coefficient γ is defined in the same way as α

→ The net no. of secondary electron produced per incident positive ion, photon, excited particle, or metastable particle.

→ The total value of γ is the sum of the individual coefficient due to three different processes. ie) $\gamma = \gamma_1 + \gamma_2 + \gamma_3$.

Where γ – Townsend's secondary ionization coefficient. & is a function of gas pressure p & E/p.

Let us assume,

n_0' – No. of. secondary electrons.

n_0'' – total No. of. electrons leaving the cathode.

$$n_0'' = n_0' + n_0 \quad \rightarrow (1)$$

n – total No. of electron reaching the anode.

$$n = n_0'' e^{\alpha d} \quad \rightarrow (2)$$

$$n = (n_0' + n_0) e^{\alpha d} \quad \& \quad \rightarrow (3)$$

$$n_0' = \gamma \left[n - (n_0 + n_0') \right] \quad \rightarrow (4)$$

From (3)

$$n_0' e^{\alpha d} + n_0 e^{\alpha d} = n$$

$$n_0' = \frac{n - n_0 e^{\alpha d}}{e^{\alpha d}} \quad \rightarrow (5)$$

Sub eq (5) in (4)

$$\frac{n - n_0 e^{\alpha d}}{e^{\alpha d}} = \gamma \left[n - \left(n_0 + \frac{n - n_0 e^{\alpha d}}{e^{\alpha d}} \right] \right.$$

$$\frac{n}{e^{\alpha d}} - n_0 = \gamma \left[n - \left(\cancel{n_0} + \frac{n}{e^{\alpha d}} - \cancel{n_0} \right] \right.$$

$$\frac{n}{e^{\alpha d}} - n_0 = \gamma \left[n - \frac{n}{e^{\alpha d}} \right]$$

$$\frac{n - n_0 e^{\alpha d}}{\cancel{e^{\alpha d}}} = \frac{\gamma \left[n e^{\alpha d} - n \right]}{\cancel{e^{\alpha d}}}$$

$$n - n_0 e^{\alpha d} = \gamma \left[n e^{\alpha d} - n \right]$$

$$n - \gamma \left[n e^{\alpha d} - n \right] = n_0 e^{\alpha d}.$$

$$n \left[1 - \gamma \left[e^{\alpha d} - 1 \right] \right. = n_0 e^{\alpha d}.$$

$$\boxed{n = \frac{n_0 e^{\alpha d}}{1 - \gamma \left[e^{\alpha d} - 1 \right]}}$$

$\therefore$ Average current in the gap before breakdow

$$\boxed{I = \frac{I_0 e^{\alpha d}}{1 - \gamma \left(e^{\alpha d} - 1 \right)}}$$

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Townsend's criterion for Breakdown

As the distance b/w the electrode d increased the denominator of the equation tends to zero.

at critical distance $d = d_s$

$$1 - \gamma (e^{\alpha d} - 1) = 0.$$

for, $d < d_s$, $I \simeq I_0$.

External source for supply I_0 is removed.

$$I = 0.$$

If $d = d_s$, $I \to \infty$.

→ The current will be Limited only by the resistance of the power supply & external circuits.

→ This condition is called Townsend's breakdown criterion.

$$\gamma [e^{\alpha d_s} - 1] = 1$$

normally $e^{\alpha d_s}$ is Large

$$\boxed{\gamma e^{\alpha d_s} = 1}$$

Voltage gives the value of γ, the breakdown α - satisfying above equation, the breakdown voltage. Voltage is called spark breakdown distance → sparking distance. Corresponding

Breakdown in Electronegative gases.

→ Collision in which electrons attached to atom to form negative ions.

→ electrically insulating gases, O_2, CO_2, Cl_2, F_2, C_2F_6, C_3F_8, C_4F_{10}, CCl_2F_2 & SF_6 exhibit this property

$$A + e^- + k \rightarrow A^- + E_a + k.$$

Where,

A - atom, E_a - electron affinity, A^- - Negative Atomic ion.

e^- - electron, k - kinetic energy

process

1) Direct Attachment
electron directly attaches to form a negative ion.

$$AB + e^- \rightarrow AB^-$$

2) Dissociative attachment :-
In which the molecules split into their constituent atoms and the electronegative atom forms a negative ion.

$$AB + e \rightarrow A + B^-$$

Where,

A - Sulphur or Carbon atom

B — oxygen / Halogen atom / molecules.

$$I = I_0 \frac{\left\{ \left[\frac{\alpha}{\alpha - \eta} e^{(\alpha - \eta)d} \right] - \left[\frac{\eta}{\alpha - \eta} \right] \right\}}{1 - \left[\gamma \frac{\alpha}{\alpha - \eta} e^{(\alpha - \eta)d} - 1 \right]}$$

Where,

η - attachment coefficient = No. of attaching collision made by one electron drifting one cm in the direction of the field.

Townsend breakdown criterion,

$$1 - \left[\gamma \left(\frac{\alpha}{\alpha - \eta} \right) e^{(\alpha - \eta)d} - 1 \right] = 0$$

$$\gamma \left(\frac{\alpha}{\alpha - \eta} \right) e^{(\alpha - \eta)d} - 1 = 1$$

if $\alpha < \eta$, then

$$\gamma \left(\frac{\alpha}{\alpha - \eta} \right) = 1 \quad \text{or} \quad \alpha = \frac{\eta}{(1 - \gamma)}$$

Normally, γ is small, so $\alpha = \eta$

This condition puts a Limit called critical E/p below which no Breakdown is possible irrespective of 'd'. & the Limit value is called critical E/p.

E/p for SF_6 - 117 $cm^{-1} torr^{-1}$

CCl_2F_2 - 121 $cm^{-1} torr^{-1}$ (20°

drawback in Townsend's theory

→ Breakdown voltage depend on pressure & geometry of gap

→ Time Lag : theory - 10^{-5}
practical - 10^{-8}

→ diffused form of discharge in theory / filamentary & irregular form in practice.

Streamer mechanism (Breakdown in uniform field)

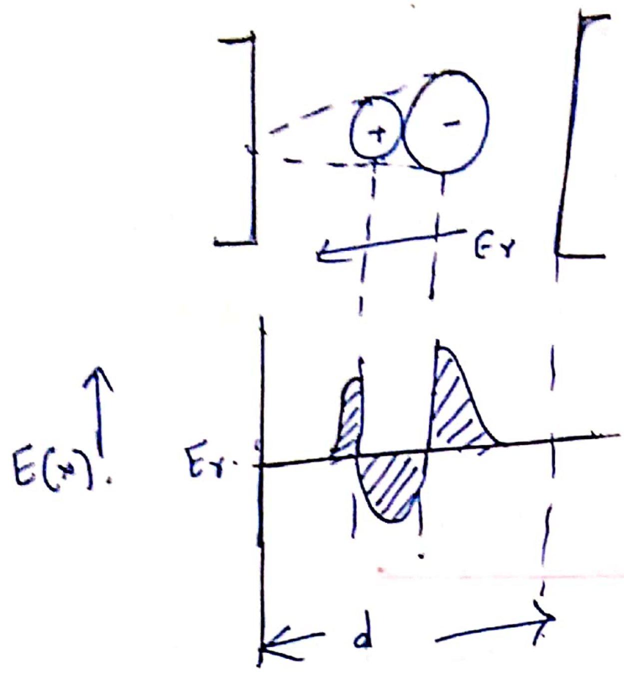
The growth of charge carrier in an avalanche is a uniform field is described by $e^{\alpha d}$.

Space charge due to ion is very small compared to the Electric field.

Rather → charge concentration ($10^6 - 10^8$).
growth of avalanche become weak.
→ charge concentration higher than 10^8.
Avalanche ct flows. is steep rise.
leading to b/d. of the gap.

The space charge at the head of the avalanche is assumed to be have a sphere containing negative charge at its top.

Due to field lines from the anode, the field get enhanced at the top of avalance.



At the bottom of the avalanche, E is reduce since positive ion gets enhanced.

→ field distortion occur & charge carrier number $n > 10^6$. Streamer b/d occur.

Now, Space charge field = Applied electric field.

Space charge field plays an important role in the growth of avalanche in corona & non uniform field gap.

Transformation of avalanche to Streamer occurs

when

$$n_0 e^{\alpha x_c} = 10^8$$

$$\alpha x_c = 18 \text{ to } 20 .$$

Where,

X_c — Length of the avalanche in which the secondary electrons are produced by photo ionization .

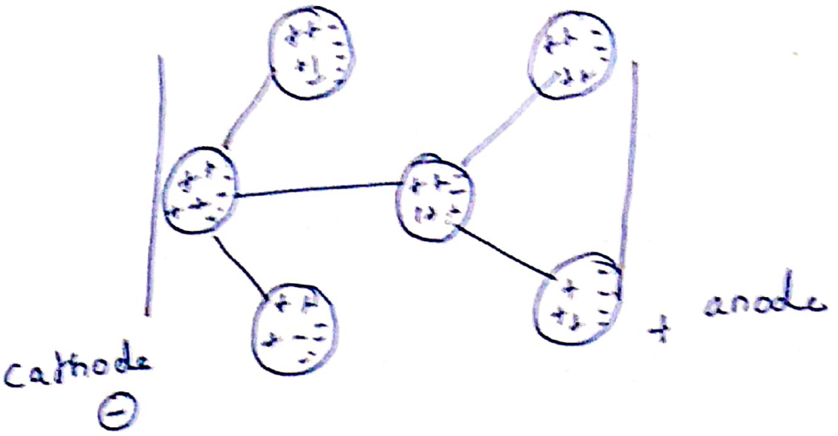
Formation of secondary Avalanche

At critical condition , the applied field & space charge field cause intense ionization and accelerate the gap particle in front of the avalanche .

→ positive ion & electron recombine to produce photons .

→ These photons produce secondary electron by photo ionization .

→ These electron develops into seconda[ry] avalanche when the electric field is applied .



Streamer spark criterion is

$$\alpha x_c = 17.7 + \ln x_c + \ln \left[\frac{E_r}{E} \right].$$

E_r = space charge field.

$E \rightarrow$ Applied electric field.

condition for transition from avalanche to streamer is $E_r = E$.

b/d criterion becomes $\alpha x_c = 17.7 + \ln x_c$.

minimum b/d occurs $x_c = d$.

where 'd' - gap length.

Breakdown criterion is $\alpha d = 17.7 + \ln d$.

<u>meek's expression</u>

$$E_r = 5.27 \times 10^{-7} \frac{\alpha e^{\alpha x}}{(x/p)^{1/2}} \text{ V/cm}.$$

Where,

α - Townsend's ionization coefficient

P - Gas pressure in torr.

minimum b/d. $E_r = G$, $x = d$.

$$E = 5.27 \times 10^{-7} \frac{\alpha e^{\alpha x}}{\left(\frac{d}{p}\right)^{1/2}}$$

$$\ln E = \ln \left[5.27 \times 10^{-7} \frac{\alpha e^{\alpha x}}{\left(d/p\right)^{1/2}} \right]$$

$$\alpha d + \ln \left(\alpha/p\right) = 14.5 + \ln \left(E/p\right) + \frac{1}{2} \ln \left(d/p\right)$$

pd values plays an important role in Streamer theory.

paschen's Law

The breakdown criterion in gases is given as

$$\gamma (e^{\alpha d} - 1) = 1$$

Where α & γ are function of E/p ie

$$\left(\frac{\alpha}{p}\right) = f_1 \left(E/p\right)$$

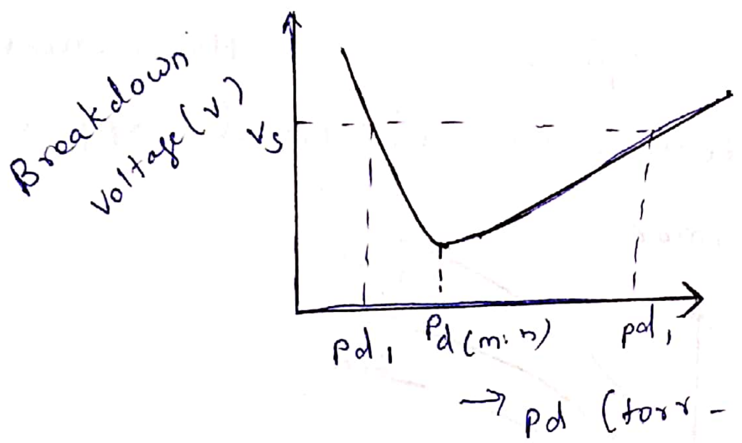
$$V = f_2\left(\frac{E}{p}\right)$$

$$E = \frac{V}{d}.$$

$$\boxed{V = f(pd)}$$

This equation is known as paschen's law.

The breakdown voltage of a uniform field gap is a unique function of the product of gas pressure p & gap Length d for a particular gas & electrode material.



Breakdown voltage Pd curve

Breakdown in Non uniform field.

In non uniform field, Such as Coaxial cylinder, point-plane & sphere plane.

Townsend's 1st ionization coefficient.

α → Varies with gap.

αd ⇒ Townsend's criterion, is replaced by $\int_0^d \alpha\, dx$.

Townsend's criterion for breakdown now

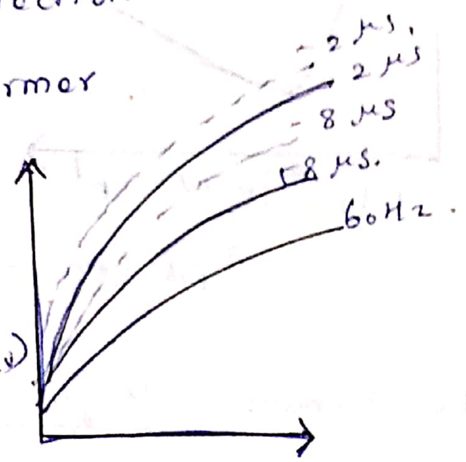
becomes,

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

meek's expression for radial field.

$$E_r = \frac{5.27 \times 10^{-7} \alpha_x \, e^{\int_0^x \alpha dx}}{\left(\frac{x}{p}\right)^{1/2}} \quad V/cm$$

Rod - Rod gap, sphere - sphere gap — Measurement of HV & protection of electrical apparatus such as transformer.



from this curve,
Breakdown voltage high for negative polarity. It depends humidity in air. Rod- Rod gap is non uniform, so sphere gap is used for breakdown voltage.

Corona discharge

→ If the electric field is uniform, a gradual increase in voltage across a gap produces a breakdown of a gap in the form of a spark without any preliminary discharge.

→ If the electric field is non uniform, an increase in the voltage will first cause discharge in the gas to appear at point with highest electric field intensity, namely sharp points or where the electrodes are curved or on Transmission Lines.

→ This form of discharge is called corona discharge.

→ It is observed as bluish Luminance. It is accompanied by hissing noise and the air surrounding the corona region becomes converted into ozone.

Corona is responsible for

→ Loss of power from high T/m Line

→ deterioration of insulation

→ radio interference.

Corona inception field.

The voltage gradient required to produce visual ac corona in air at a conductor surface

Let,

$r \rightarrow$ radius of wire

δ - density correction factor.

$$\delta = \frac{0.392\, b}{273 + t}.$$

Where,

b – atmospheric pressure in torr

t - temperature in °C.

Electric field intensity (for two parallel wires)

$$E = 30 m \delta \left[1 + \frac{0.301}{\sqrt{r \delta}} \right] kv/cm$$

Electric field intensity for coaxial wires.

$$E_c = 31 m \delta \left[1 + \frac{0.308}{\sqrt{r \delta}} \right] kv/cm.$$

Where,

m - Surface irregularity factor

m = 1 for polished smooth wires.

In high voltage Transmission Lines, appearance of Corona differs when positive & negative polarities of applied voltage.

When positive polarities are applied, corona appears as bluish white sheath over the entire surface of the line. When negative polarities are applied, corona appears as reddish glowing spots distributed along the lines.

Negative point-plane corona

→ When point is negative,

→ the corona current flows in very irregular pulses called as Trichel pulses. Whose repetition frequency increases with current.

→ This frequency is independent of the gap length but increases with the point sharpness.

→ for studying corona, the point-plane gap with the point is connected to high voltage source.

→ The plate is connected to earth through Resistance & voltage drop can be measured using CRO.

→ A decrease in pressure, decrease the frequency of Tricheal pulses.

Formation of Negative corona.

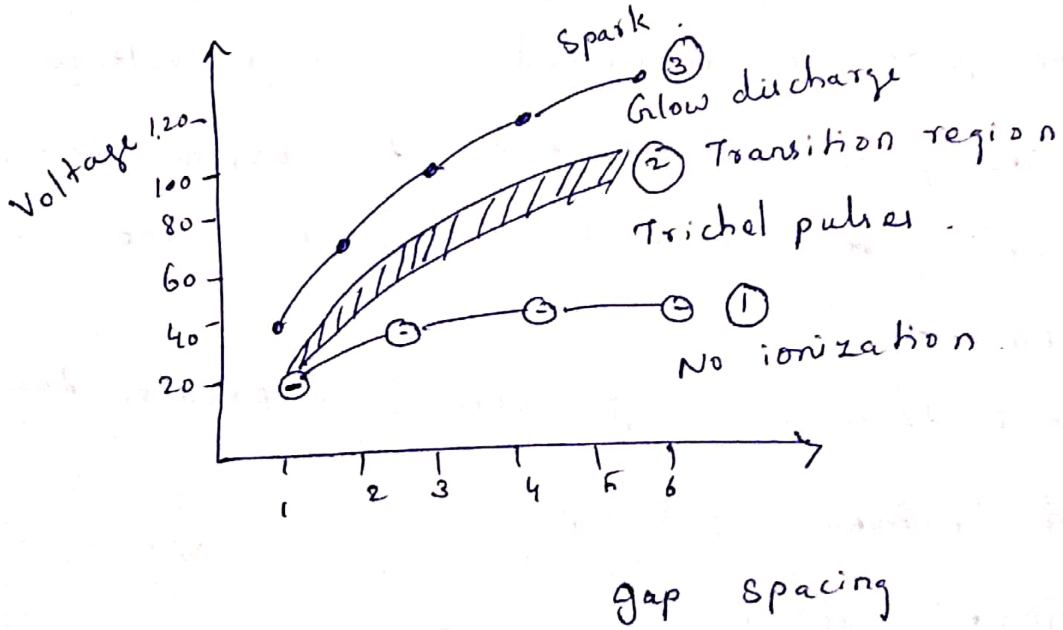
A random positive ion impact at the cathode & an electron is produced. The electron collide with neutral particle & produce a positive ion (photon) & an electron.

→ The photon collide with cathode & produce a new avalanche. This process repeats and current increases due to ionization.

→ The positive ions liberated may have sufficient energy to cause liberation of electrons when impinge on the cathode and increase the field strength.

→ The last few ions are being driven into the point, the field strength again increases to accelerate one of them to trigger an electron and this process repeats.

→ Thus negative corona is formed.



Below the curve (1) → no ionization take place.

Between curve ① & ② → ionization takes place
Trichel pulse formed
No corona

→ When applied voltage is increased further, transition region occurs.

→ At the end of this region, corona discharge can be seen upto breakdown occurs.

At curve (3) → breakdown occurs & spark is formed.

→ Breakdown under negative polarity needs higher voltage than that under positive polarity.

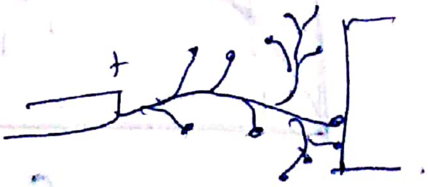
∴ breakdown of non uniform field gap occurs during the positive half cycle of the voltage wave.

Positive plane corona

When point is positive, a large portion of the work is concerned with the study of the nature of streamers. They are common to the mechanism of positive point corona & breakdown mechanism in non uniform fields.

Formation of streamer

When a positive voltage pulse is applied to a point electrode, a filamentary branch is formed by ionization. This discharge is called streamer.



→ As the impulse voltage is increased, the streamer grows into number of branches, but doesn't cross each other.

Breakdown Mechanism

→ When the applied voltage is increased further, the streamer become more frequent upto transient state.

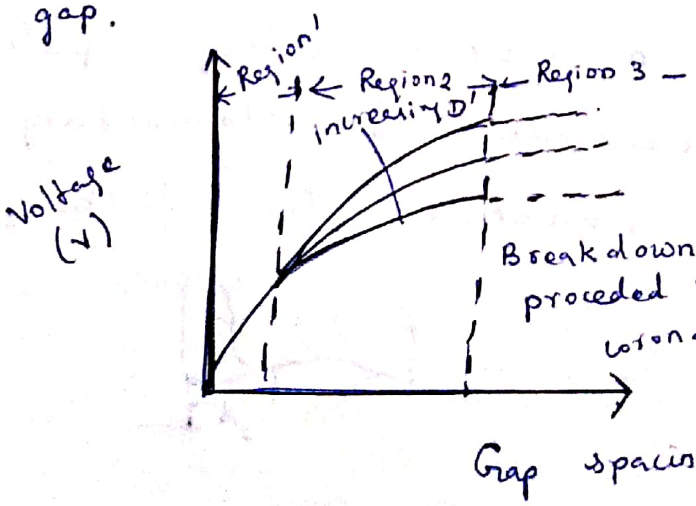
→ A steady corona flow appears close to the anode. Again increasing the voltage, the luminosity of the glow increases.

→ corona current increases steadily with voltage.

→ After a current of about 10^{-7} A, the current becomes pulsed with repetition frequency of about 1kHz, consist of small bursts.

→ This form of corona is called burst corona.

→ on increasing the voltage further, more rigorous streamers appear & lead to breakdown of the gap.



3

height & temperature.

→ When such freezing occur, the crystal grow into Large masses. due to weight & gravitational force, it fall downward.

→ Thunder cloud consist of super cooled water droplets moving upwards & Large hail stones moving downwards.

→ When upward moving super cooled water droplets act as a cooler hail stone it freeze partially.

→ The outer Layer of water droplets freezes forming a shell with water inside.

→ When the process of cooling extends to inside warmer water in the core, it expands thereby splintering & spraying the frozen ice shell.

→ Splinters being fine in size are moved up by air currents & carry net positive charge to the upper region of the cloud.

→ The hailstones that travel downwards carry an equivalent negative charge to the Lower region of the cloud & negative charge build.

Scanned by CamScanner

Breakdown & corona inception characteristics for sphere-plane gat at different gap spacing.

Region	Spacing	field	Dependence of Breakdown voltage
Region 1	Small	uniform	depends on gap spacing
Region 2	Fairly Large	Non uniform	depends on gap spacing & sphere diameter.
Region 3	Large	Non uniform	depends on sphere diameter & gap spacing. Breakdown is proceeded by corona.

Vacum Breakdown:

perfect Vaccum → No conduction → Insulator.

Application:

→ Circuit Breaker
→ Vaccum contactors & interrupter
→ Electrostatic generator

Vaccum:

A system which is used to create Vaccum in which the pressure is maintained at a value much below the Atmospheric pressure.

Classification of Vaccum:

High Vaccum → 1×10^{-3} to 1×10^{-6} torr
very high Vaccum → 1×10^{-6} to 1×10^{-8} torr
ultra high Vaccum → 1×10^{-9} torr & below.

Vaccum Breakdown:-

The different Mechanism of Breakdown are
→ Particle exchange Mechanism
→ Field emission theory
→ clump theory.

particle exchange Mechanism:

→ When high E is applied → A charged particle would be emitted from one electrode (cathode) to anode due to the ionization of absorbed gas.
→ This process repeats a chain reaction occurs which leads to breakdown.

This mechanism involves
→ electrons
→ positive ion
→ photons
→ absorbed gas at the electrode surface.

→ Electrons present in the vacuum gap accelerates towards the anode which release A - positive ions & C - photons.

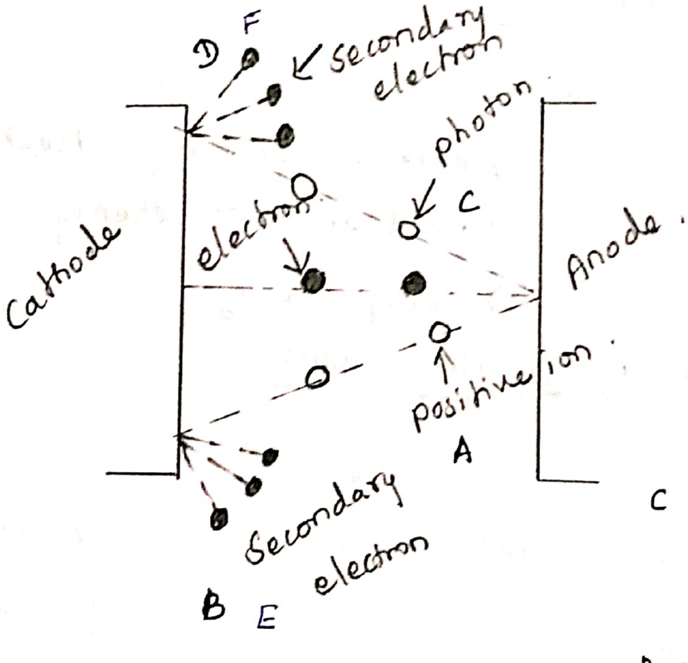
→ These positive ions (A) are accelerated towards the cathode & each positive ions (A) liberates (B) electrons & each photons liberates (D) electrons.

Condition for breakdown

$$(AB + CD) > 1$$

→ E & F represents the coefficient for negative & positive ion liberation by positive & negative ion.

The product of EF ≈ 1 for copper, Al, Stainless steel.



A → No. of +ive ion produced by accelerated electron

C → No. of photons produced by accelerated electron

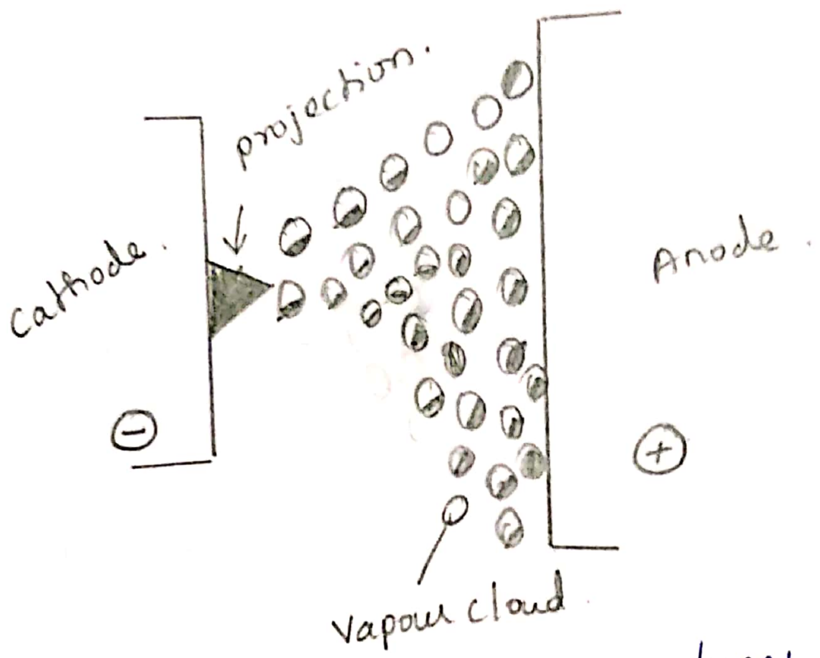
B → No. of electron produced by +ive ion

D → No. of electron produced due to to photon.

Field emission theory :-

When the gap voltage increases nearer to the breakdown voltage, the sharp point on the cathode surface are responsible for the existence of the prebreakdown current. This process is called field emission process.

(a) Anode heating Mechanism :-

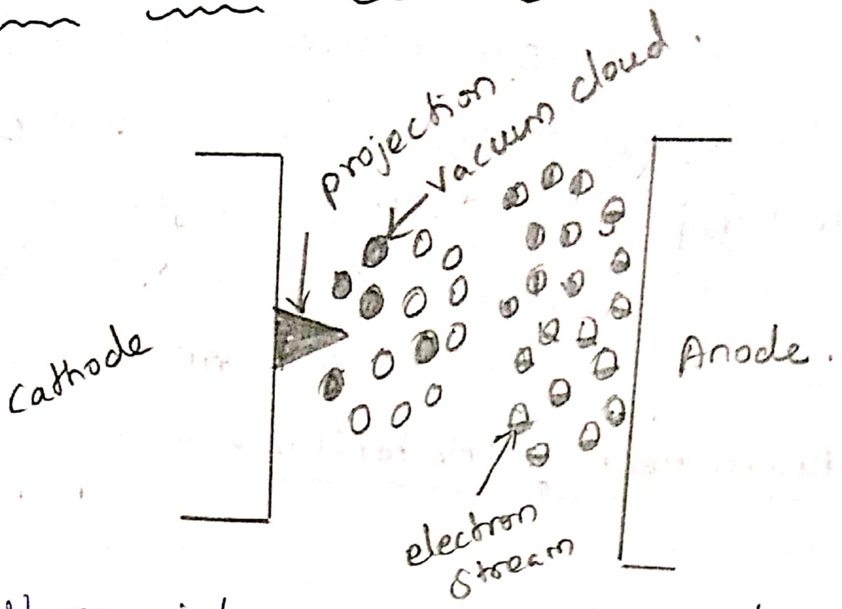


→ A small projection on the cathode produces electrons due to field emission & these electron bombard the anode which causes the local rise in temperature and release gases & vapours in to the vacuum gap.

→ These electrons ionize the gas atoms & produce the positive ions. these positive ions reaches the cathode & increases the primary electrode formation due to charge formation & produce secondary electrons.

→ This process repeats until the sufficient No. of electrons are give rise to breakdown.

b) Cathode heating Mechanism:



→ The sharp points on the cathode surface are responsible for the existence of pre breakdown current due to field emission process.

→ The pre breakdown current causes resistive heating at the projection in the cathode, the tip melts due to heating & explode the initial vacuum discharge. This is called cathode heating Mechanism.

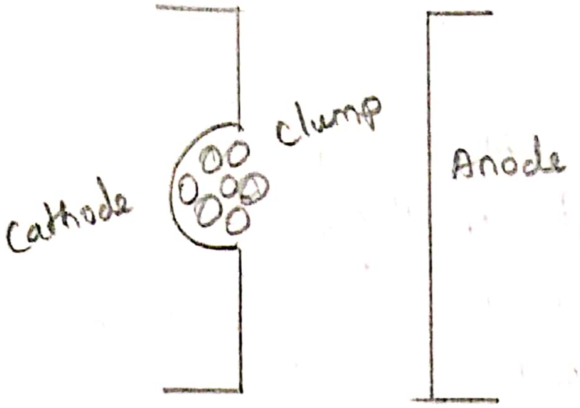
Initial breakdown ∝ properties of cathode surface.

Clump Mechanism:

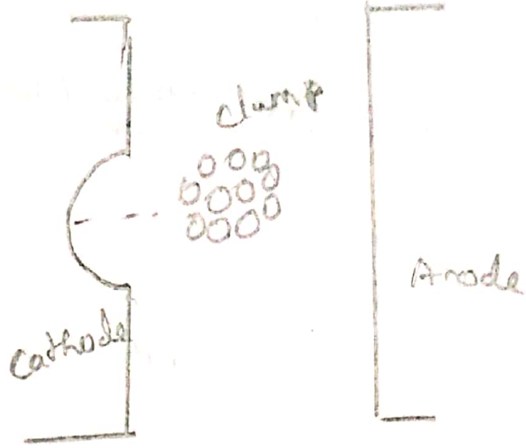
→ A clump particle exist on one of the electrode. The clump particle gets charged, accelerated in the gap when high voltage is applied.

→ This particle reaches other electrode & discharge vapour & breakdown occurs.

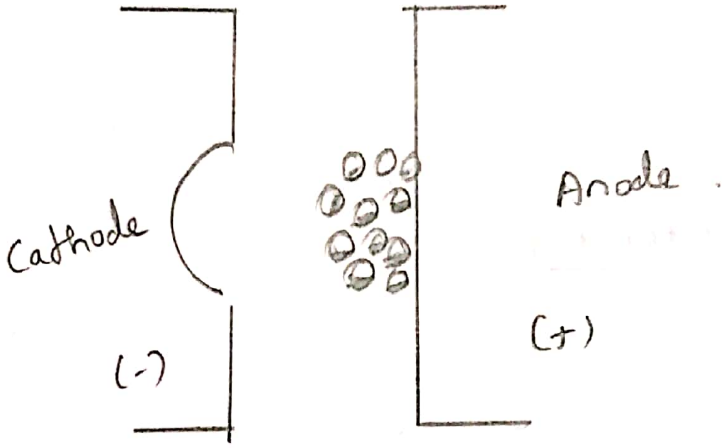
→ Breakdown occurs when the energy/unit area exceeds constant c' which depend on the characteristics of electrode.



(a)



(b)



(c)

Criterion for breakdown.

$$W = V \times E = c'$$

where,

$W \rightarrow$ energy / unit area.

$V \rightarrow$ gap voltage.

$E \rightarrow$ electric field. $E = V/d$.

$VE = c'$

$V \times \frac{V}{d} = c'$,

$V^2 = c'd$ $\quad \therefore \boxed{V = \sqrt{c'd}}$

Criterion for breakdown.

Conduction and Breakdown in Liquid dielectric

Application (uses):

→ High voltage cable
→ High Voltage capacitor
→ Transformer
→ circuit breaker.

Liquid dielectrics:

→ Transformer oil (petroleum oil)
→ Synthetic hydrocarbon
→ chlorinated hydrocarbon.
→ Silicon oil
→ ester.

Characteristics:

→ Ability to withstand high electric stress.
→ permittivity ε of petroleum oil – 2 → 2.6.
→ Resistivity more than 10^{16} Ω m.
→ power factor, dielectric strength.
→ Heat transfer characteristics
→ chemical stability.

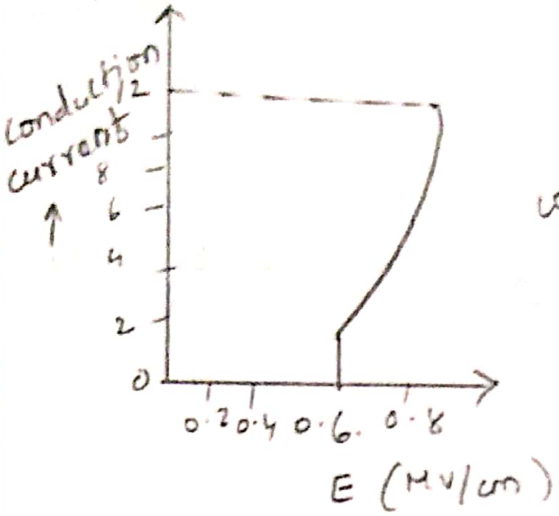
Conduction & Breakdown in pure Liquid.

pure Liquids → are chemically pure do not have any impurities.

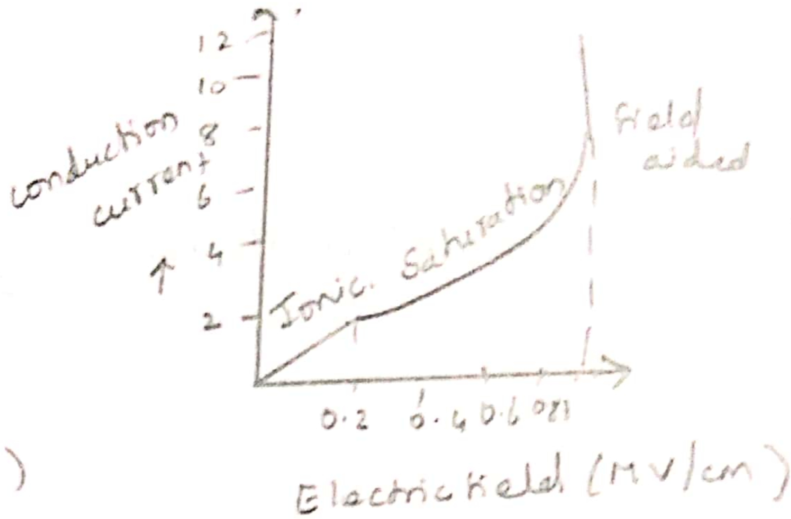
example:

→ n-Hexane
→ n-Heptane.
→ paraffin hydrocarbon.

When E > 100 kV/cm, I ↑, violent fluctuation.
cause breakdown for pure Liquids.



(a) Hexane



(b) Hydrocarbon Liquid

There are 3 region

→ Ionic region → At Low fields.

→ Saturation region → At intermediate fields.

→ field aided electron emission from cathode ↓ At High fields.

Electronic breakdown :-

When high E is applied, the current growth is due to electrons are generated from cathode by field emission of electrons & gets multiplied by Townsend's Mechanism. Breakdown of pure Liquids occurs due to increase of current by repetition of this process.

The breakdown voltage depends on

→ Field
→ gap separation
→ cathode work function
→ Temperature of the cathode
→ Liquid viscosity
→ Liquid temperature.
→ density
→ Breakdown strength of the Liquid.

Conduction & Breakdown in commerical Liquids.

commorcial Liquids → Not chemically pure & have impurities Like gas bubbles.

Breakdown Mechanism of commercial Liquids

The diffeent Mechanism of breakdown are

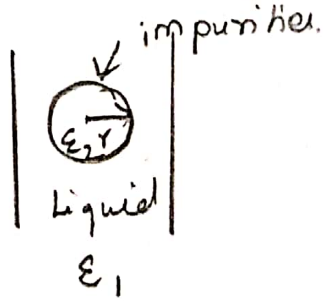
→ suspended particle Mechanism
→ cavitation & bubble Mechanism
→ Stressed oil volume Mechanism.

1) Suspended particle Mechanism:

In commercial Liquids, the presence of solid impurities can't be avoided. These impurities will be present as fiber (or) dispersed solid particles.

ε_1 → permittivity of Liquid
ε_2 → permittivity of impurities.

consider an impurities of spherical with radius r, and applied field is E



$$\text{Force } F = \frac{1}{2} r^3 \frac{(\varepsilon_2 - \varepsilon_1)}{2\varepsilon_1 + \varepsilon_2} \text{ grad } E^2.$$

→ If gas bubbles present in Liquids, $\varepsilon_2 < \varepsilon_1$, the force will be in the direction of area of Lower stress.

→ If solid particle present in Liquids, $\varepsilon_2 > \varepsilon_1$, the force will be towards the direction of area of Maximum stress.

→ If single conducting particle between electrode, there will be a rise of Local field depend on its shape.

If $E >$ breakdown strength of Liquid,

Local breakdown is occur near the particles.

which Leads to the formation of gas bubbles.

It causes the breakdown of Liquid.

2) Cavitation & bubble theory:

Vapour bubbles is responsible for breakdown.

Formation of vapour bubbles:

→ gas pockets at the surface of the electrodes.

→ electrostatic repulsive force between space charges which may be sufficient to overcome the surface tension.

→ gaseous products due to the dissociation of Liquid molecules by electron collision.

→ vapourization of the Liquid by corona type discharge from sharp points & irregularities on the electrode surface.

For a given gas bubble, breakdown field.

$$E_0 = \frac{1}{(\varepsilon_1 - \varepsilon_2)} \left[\frac{2\pi\sigma(2\varepsilon_1 + \varepsilon_2)}{r} \left\{ \frac{\pi}{4} \sqrt{\frac{V_b}{2r E_0}} - 1 \right\} \right]^{1/2}$$

where,

σ – surface tension of the Liquid

ε_1 – permittivity of the Liquid.

ε_2 – permittivity of the gas bubble.

r → radius.

V_b → voltage drop.

once a bubble is formed, it will elongate in the direction of the electric field under force.

Volume = constant.

Breakdown occurs when the length of the bubble becomes equal to the minimum value of Paschen's curve.

Thermal Mechanism of breakdown:

When the microscopic projections are present in the cathode, High current is produced leads to rise in temperature it causes the oil heating. due to this vapour bubbles are formed. & it elongates between the electrode & form a bridge and give rise to spark. this breakdown strength is depend on

- → pressure
- → temperature
- → molecular structure of Liquid.

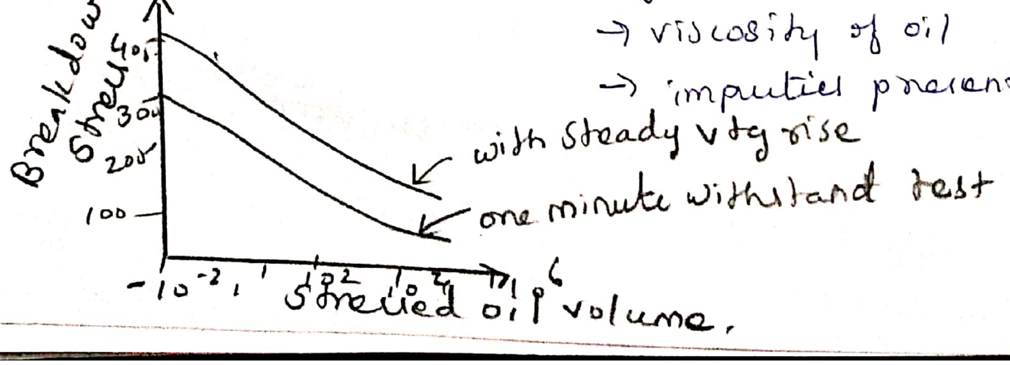
3) Stressed oil volume Mechanism:

In commerical Liquids, impurities are present. impurities reduces the breakdown strength of oil. Maximum stress will be occur.

According to stressed oil theory, breakdown strength is inversely proportional to the stressed oil volume.

Breakdown vtg depend ons

- → gas content in oil
- → viscosity of oil
- → impurities present in oil



Breakdown in Solid dielectrics.

Good dielectric

→ Low dielectric loss
→ high Mechanical strength
→ high breakdown strength.

Materials:

→ paper
→ wood & Rubber
→ glass
→ procelain
→ Synthetic polymer
  ↳ PVC
  ↳ perspex
  ↳ epoxy resin.

Breakdown Mechanism in solid dielectrics:

→ Intrinsic (or) ionic breakdown
→ Electro Mechanical breakdown.
→ thermal breakdown
→ Electrochemical breakdown
→ Failure due to treeing & tracking
→ Breakdown due to internal discharge.

(1) Intrinsic Breakdown:-

When voltages are applied only for short duration in the order of 10^{-8}s, the dielectric strength of the solid dielectric increases very rapidly to an upper limit called intrinsic electric strength.

dielectric strength α structure of material, temperature.

Max. dielectric strength - 5 MV/cm to 10 MV/cm

Breakdown:-

→ Intrinsic breakdown depends upon the

presence of free electrons which are capable of migration through the dielectric.

→ small No. of conduction electrons are present in the solid dielectrics along with some structural imperfections & small impurities.

→ due to applied field & temperature, these impurities acts as conduction electrons.

→ E ↑ → more No. of electron released → electron conduction take place → Breakdown occurs.

(i) Electronic breakdown :-

Intrinsic breakdown occurs in time of the order 10^{-8} s.

Assume, initial conduction of electron is large.

Electron - electron collision take places.

→ When E is applied, electron gains energy from the electric field & cross the forbidden energy gap from the valence to the conduction band.

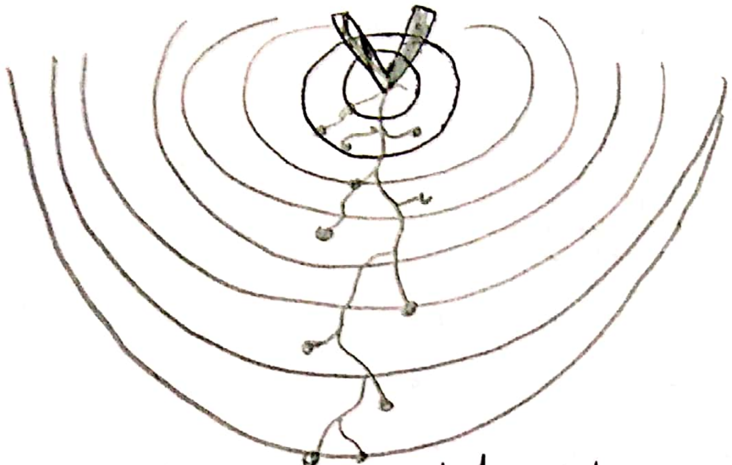
→ When this process repeated the more No. of electron become available in the conduction band. & breakdown occurs due to the conduction of electrons.

(ii) Avalanche or streamer breakdown.

The conduction electrons gains sufficient energy & causes the liberation of electron from the atoms by collision. Due to collision additional electrons are produced. this process repeats & electron avalanche is formed.

and this avalanche form the bridge between the gap and breakdown occurs.

→ Breakdown occurs due to this avalanche leads to streamer.



2) **Electro Mechanical breakdown:**

When solid dielectrics are subjected to high E, failure due to electrostatic forces exceeds its Mechanical compressive strength.

The compressive forces arises due to the attraction between the surface charges.

$$\varepsilon_0 \varepsilon_r \frac{V^2}{2d^2} = y \ln\left[\frac{d_0}{d}\right].$$

$$V^2 = \frac{2 y d^2}{\varepsilon_0 \varepsilon_r} \ln\left[\frac{d_0}{d}\right]$$

where, d_0 - thickness of the specimen (dielectric).

d - compressed thickness.

y - young's modulus.

ε_0 → permittivity of free space.

$\varepsilon_r \rightarrow$ relative permittivity

$V \rightarrow$ applied voltage.

Mechanical instability occurs when.

$$\frac{d}{d_o} = 0.6 \text{ (or) } 1.67.$$

the highest electric stress before breakdown

$$E_{max} = V/d_o = 0.6\left[\frac{Y}{\varepsilon_0 \varepsilon_r}\right]^{1/2}.$$

Thermal breakdown:

The breakdown voltage of a solid dielectric should increase with its thickness but only certain thickness, in which heat is generated in the dielectric due to the flow of current which determine the conduction.

→ When a field is applied to the solid dielectric at room temperature conduction current flows through the material. this current heats up the solid dielectric and the temperature rises.

→ This heat is generated is transferred to the surrounding medium by conduction through the solid dielectric & by radiation from its outer surface.

Heat generation > Heat conduction.

Heat generated under dc stress E

$$W_{dc} = E^2 \sigma \ \ W/cm^3$$

Where $\sigma \rightarrow$ dc conductivity of the solid dielectric.

Heat generated under ac field

$$W_{ac} = \frac{E^2 f \varepsilon_r \tan\delta}{1.8 \times 10^{12}} \quad W/cm^3$$

Where,

f → frequency

δ → Loss angle

E → rms voltage.

Heat dissipated is given by

$$W_T = c_v \frac{dT}{dt} + div\,(k\,grad\,T)$$

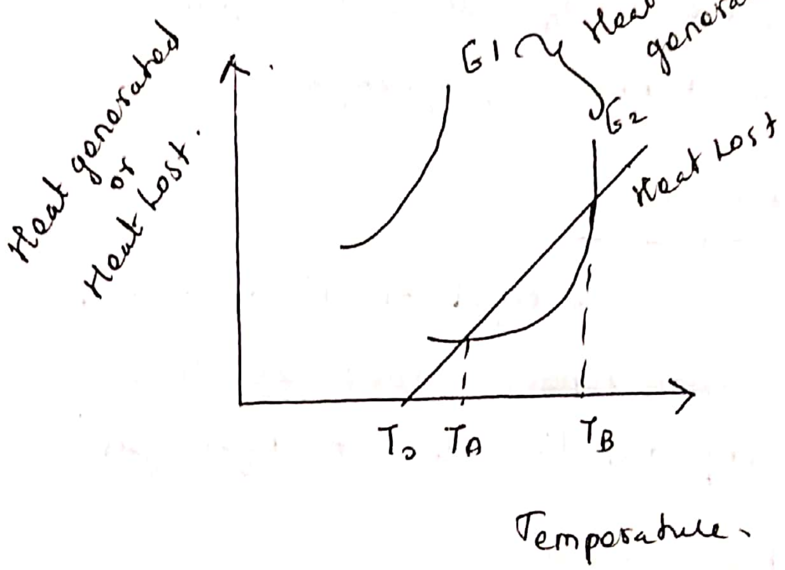
Where,

c_v = Specific heat of the specimen

T → Temperature of the specimen

k → thermal conductivity.

t → time over Heat is dissipated.



At equilibrium,

$$W_{dc} \text{ (or) } W_{ac} = W_T.$$

Electrochemical breakdown:

— x — x — x — x —

Electrochemical breakdown caused by

chemical deformation due to electrolysis, formation of ozone gas.

→ When Electric field is applied across the solid dielectric, breakdown occurs due to oxidation, hydrolysis & other chemical action.

→ Due to these action gas is formed in the cavities.

→ When gas breakdown occur the electrons are produced, when these electron impinge on the anode & produce electrons. This process repeats & breaks the insulation surface.

<u>Oxidation:</u>

Cracks are formed due to oxidation in the presence of air (or) oxygen in the material such as Rubber, polyethylene.

<u>Hydrolysis:</u>

Electrical or Mechanical properties of paper, cotton tape, other cellulose material deteriorate very rapidly due to Hydrolysis.

<u>chemical action:</u>

Solid dielectric Loss its electrical & Mechanical properties due to

→ chemical instability at high temp

→ oxidation & formation of crack in the presence of air (or) oxygen.

→ Hydrolysis due to moisture (or) water

Breakdown due to treeing & tracking:

When a solid dielectric is subjected to electrical stress during a long time breakdown take place.

→ Formation of conducting path across the surface of the insulation due to surface tension.

→ formation of spark due to Leakage current passes through the conducting path.

Tracking:

When the voltage is applied, a formation of continuous conducting path across the surface of the insulation due to surface erosion is called Tracking.

→ When the application of high voltage, the path starts conducting heat is generated & the surface starts becoming dry, the conducting film become separate due to drying & sparks are produced which damaging the dielectric surface.

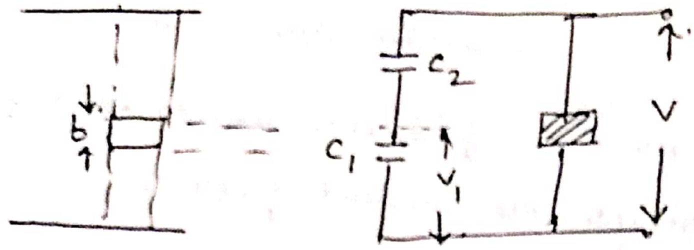
Treeing:

The spreading of spark channels during tracking in the form of branches of a tree is called Treeing.

Breakdown due to internal discharge

Solid dielectric contains void and cavities within the dielectric.

→ When voltage is applied, E is exceeds its breakdown strength & produce the internal discharge which leads to breakdown.



$$V_1 = V \cdot \varepsilon \cdot \left(t/d\right)$$

Where,

V → applied voltage

ε_r → relative permittivity of dielectric

Breakdown of composite dielectric :-

The different dielectric materials can be in parallel or series with one another such insulation system is composite dielectrics.

properties of composite dielectric

→ Effect of multiple layer

→ Effect of layer thickness

→ Effect of Interface.

Breakdown in composite dielectrics

→ short term Breakdown

→ Long term Breakdown.

Unit - III

Generation of High Voltage & high current

Necessity for generating high DC voltage

In the field of electrical engineering & applied physics, high dc & ac and impulse are required for several applications.

eg

- electron microscopes
- X rays unit

} high dc voltage of order of 100 kV or more.

- Electrostatic precipitators
- particle accelerator in nuclear physics

} high dc voltage of several kilo volts & even Mega volts.

Applications of high Voltages

→ Electron microscopes & X ray units in the order of 100kV or more.

→ HVDC is required for insulation test on cables, capacitor, electrostatic precipitators.

→ HVAC of one million volt is required for testing power apparatus rated for (400 kV & above)

→ High impulse voltages are required for testing purpose to simulate over voltage due to Lightning & switching.

→ High current testing is required to test surge diverters or SC testing of

Switchgear.

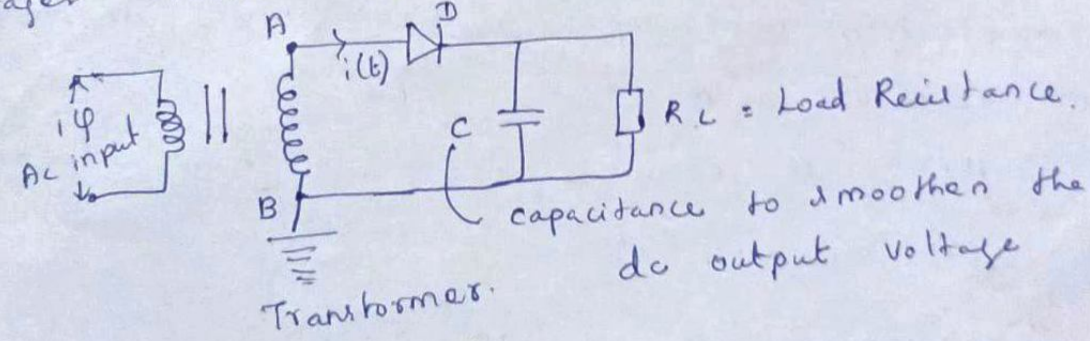
Generation of High Voltage D.C

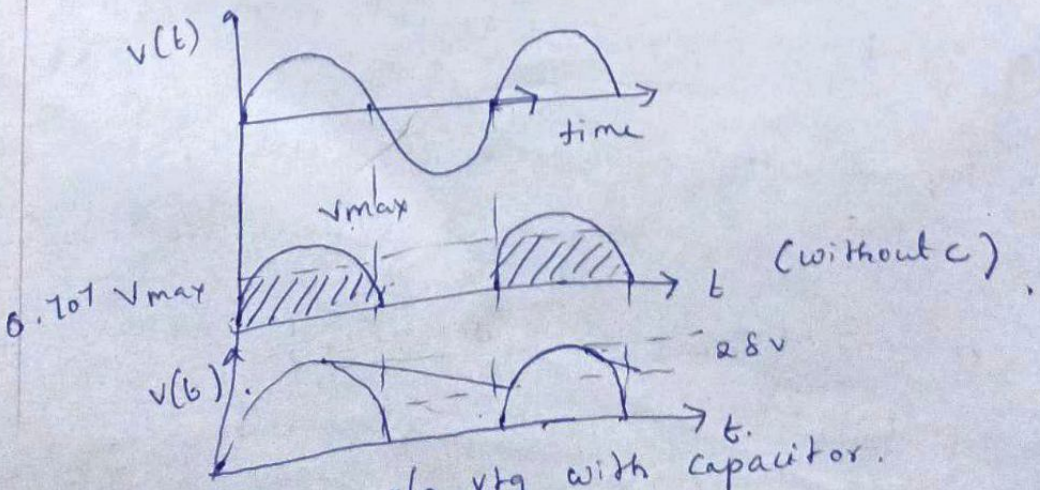
The circuits or equipments used to generate HVDC are

1. Half & full wave rectifier circuit
2. Voltage doubler circuit
3. Voltage multiplier circuit
4. Electrostatic machine
    - Electrostatic generator
    - Vande Graaff generator.

1. Half wave Rectifier

Rectifier circuits for producing high dc voltages from ac sources.





o/p vtg with capacitor.

mean value of Dc test voltage $V_{DC} = \frac{1}{T}\int_0^T v(t)\,dt$.

where,

T - time period of voltage wave

Ripple voltage $\delta V = \frac{1}{2}(V_{max} - V_{min})$

Ripple factor $= \frac{\text{Ripple Magnitude}}{\text{Mean Value}} = \frac{\delta V}{V_d}$.

Test voltage should not have ripple factor more than 5%.

with capacitor C, the pulsation at the output are reduced. Assuming the ideal transformer and small internal resistance of the diode during conduction, the capacitor is charged to the maximum voltage V_{max}.

Assuming No Load.

Dc voltage across the capacitance remains constant at V_{max} whereas the supply voltage across the oscillates between $\pm V_{max}$ & during negative half cycle the potential of point A becomes $-V_{max}$ and diode must be rated for $2V_{max}$.

Assuming Loaded condition,

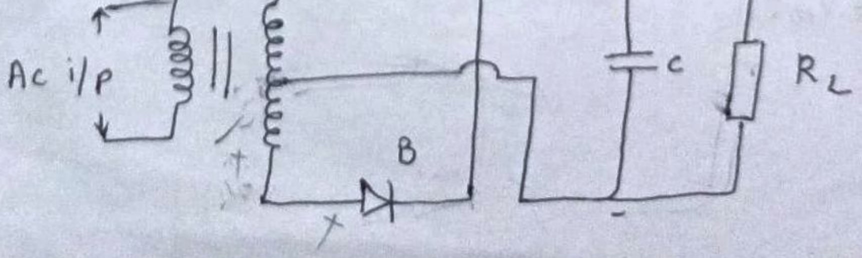
During the positive half cycle, capacitance is charged to V_{max}.

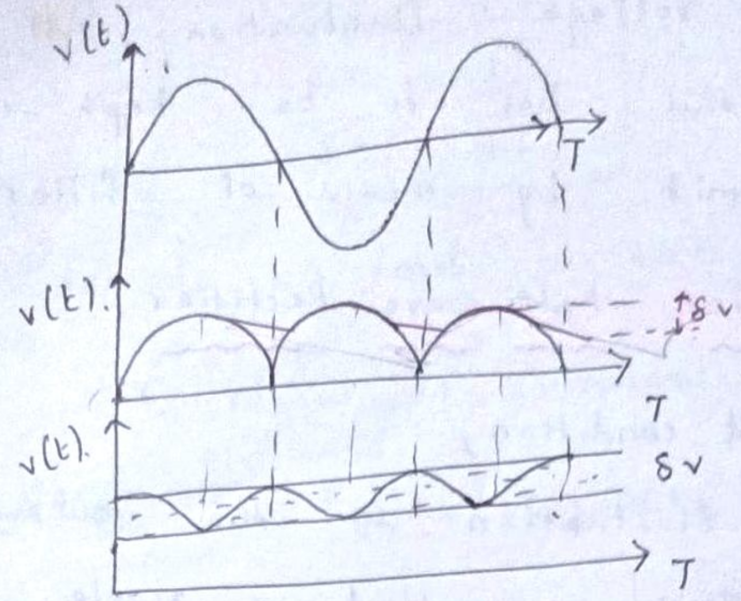
During negative half cycle, capacitance is discharges into Load.

output voltage does not remain constant at V_{max} value of C is choosen by using CR_L (time constant) is 10 times that of the period of Ac supply. To Limit the charging current, an additional resistance (R) is provided in series with the secondary of the transformer.

Full wave Rectifier circuit:

In the positive half cycle, the diode A conducts and charges the capacitor C, While in the Negative half cycle, the diode B conducts and charges the capacitor. The Source transformer requires a centre tapped secondary with a rating of 2V.





→ For application of HV of 50kV & above, the rectifier values are used for special construction. Apart from the filament, the cathode and anode, they contain a protective shield or grid around the filament and the cathode.

→ In morden high voltage Lab & testing installation, semiconductor rectifier stacks are commonly used for producing dc voltages.

→ Mostly silicon diodes with P.I.V (peak Inverse Voltage) of 1kV - 2kV.

→ for Lab applications, current requirement is less, so a selenium element stack with PIV of up to 500kV may be used.

→ Both half & full wave rectifier produce dc voltages less than ac maximum Voltage.

Also ripple or voltage fluctuation will be present, & this has to be kept within reasonable limit by means of filter. (6)

Ripple factor for half wave Rectifier:

During Loaded condition,

the fluctuation in the output Dc voltage δv appears. This is called as ripple.

$$i_c \geq i_L$$

Capacitor current   Load current

Q - charge transferred to the Load R_L,

$$Q = \int_0^T i_L(t)\,dt = \int_0^T \frac{v_L(t)}{R_L}\,dt = IT = \frac{I}{f}$$

I - mean value of dc output $i_L(t)$.

Suppose at any time, $V_c \simeq V$, & it decreases by an amount dv over the time dt, then charge delivered by the capacitor during this time is $dQ = c\,dv$.

$$\int dQ = \int_{V_{max}}^{V_{min}} c\,dv = c\left[V_{min} - V_{max}\right]$$

$$|Q| = c\left[V_{max} - V_{min}\right]$$

$$Q = 2\,\delta V C = IT$$

$$\delta v = \frac{IT}{2C} = \frac{I}{2fC}$$

Ripple depends on Load current, f, C.

f increases, C increases, δv decreases.

for half wave, Ripple frequency = Supply frequency

for full wave, Ripple frequency = 2 × Supply freq

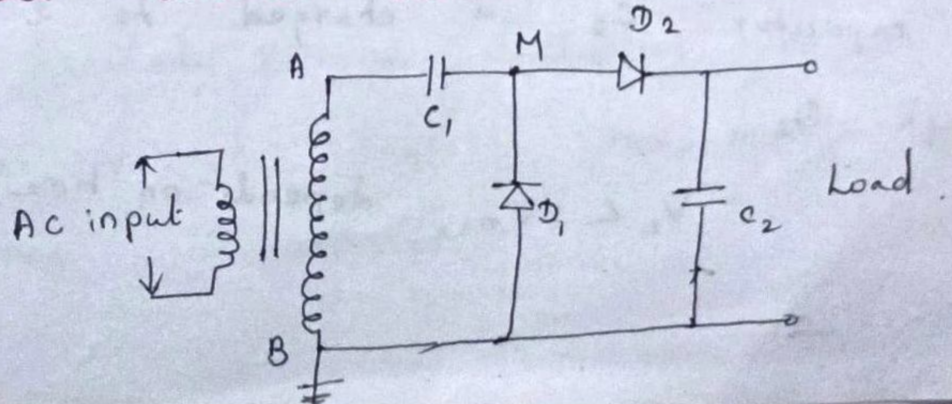
Dis Advantage.

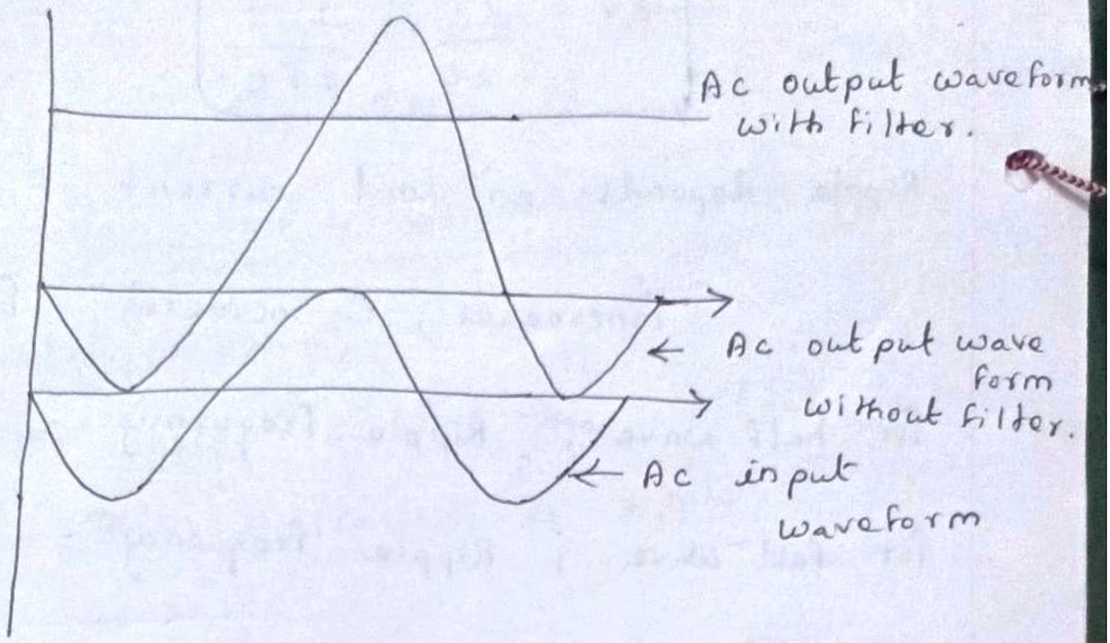
1. Size of the circuits is very Large if high and pure dc output voltage are desired.

2. H T transformer may get saturated if the amplitude of direct current is comparable with the nominal alternating current of the transformer.

∴ voltage doubler circuit or cascaded voltage multiplier is applicable.

2. Voltage doubler circuits.





Greinacher voltage doubler circuit & waveform is given above.

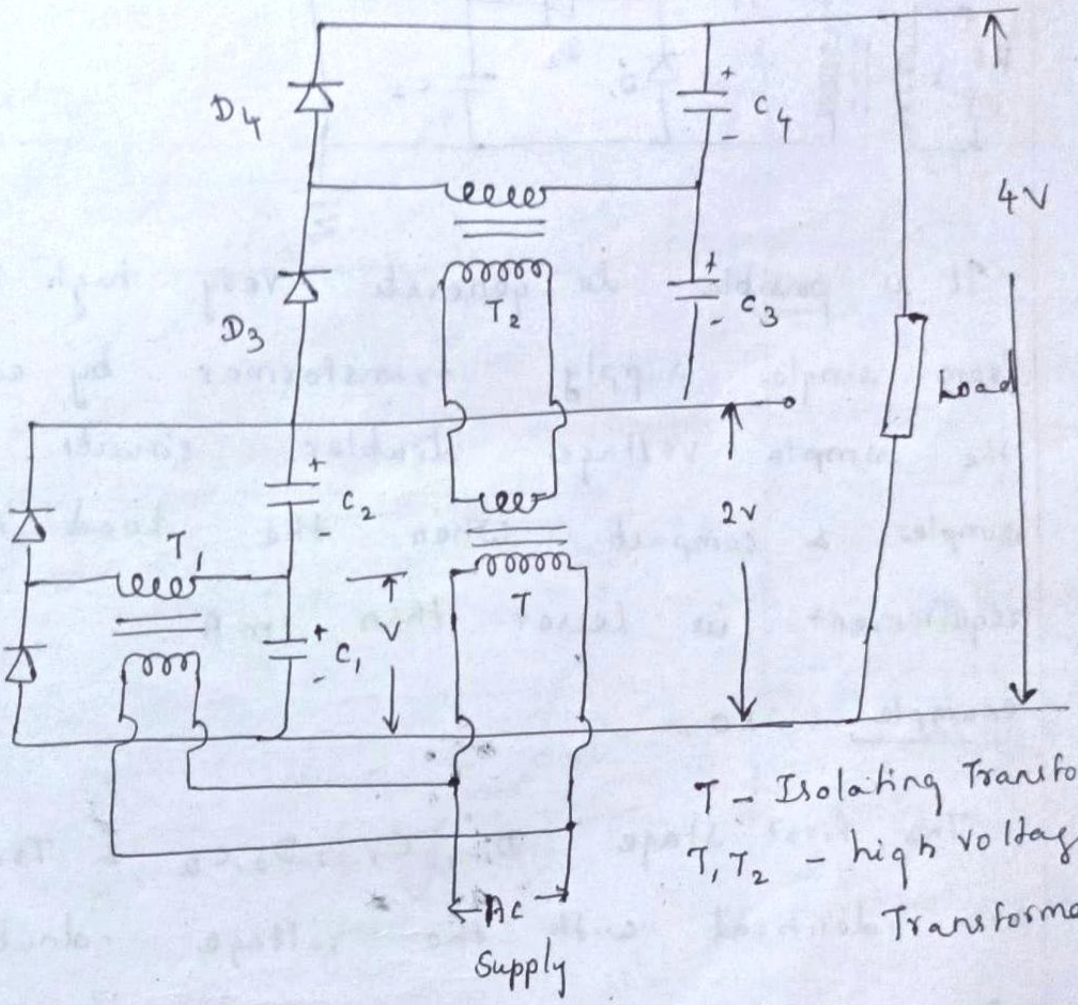
→ When high dc voltages are to be generated voltage doubler or cascaded voltage doubler circuit are used.

→ During negative half cycle diode D_1 conducts and charging the capacitor C_1 to V_{max} with polarity. During the next half cycle, terminal A of the capacitor C_1 rises to V_{max} & hence terminal M attains a potential of $2V_{max}$. Thus capacitor C_2 is charged to $2V_{max}$ through D_2.

$V_L < 2V_{max}$ depends on time constant $C_2 R_1$

Cascaded voltage doubler circuit.

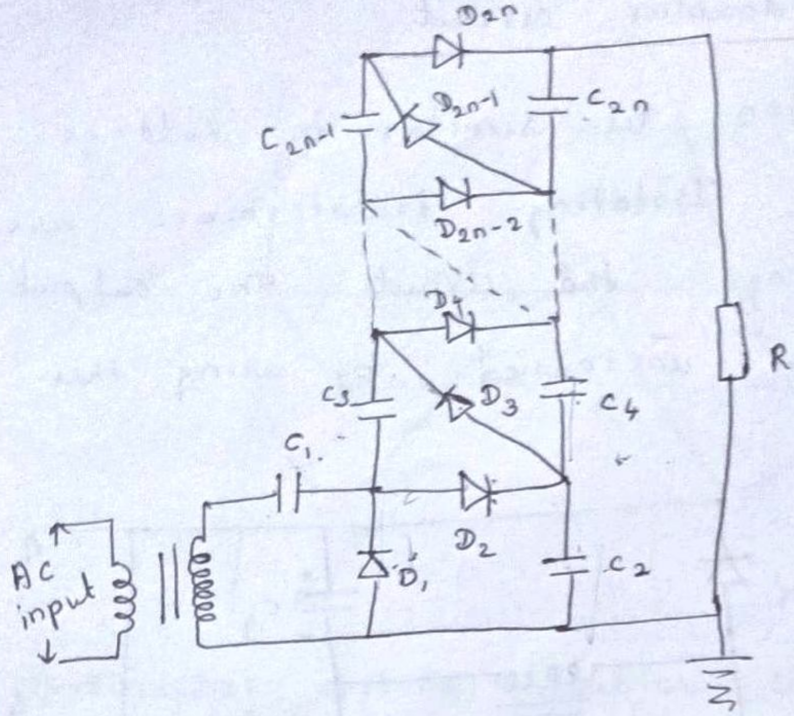
The operation is similar to voltage doubler circuit. Isolating transformers are used for coupling the circuits. The output voltage can be increased by using this arrangement.



T – Isolating Transformer
T_1, T_2 – high voltage Transformer.

cockcroft walton Voltage multiplier circuit.

Cascaded voltage multiplier circuit for higher voltage require too many supply & isolating Transformer.



It is possible to generate very high DC voltages from single supply transformer by extending the simple voltage doubler circuits. This is simple & compact When the Load current requirement is Lesser than 1mA.

<u>example</u> : CRO.

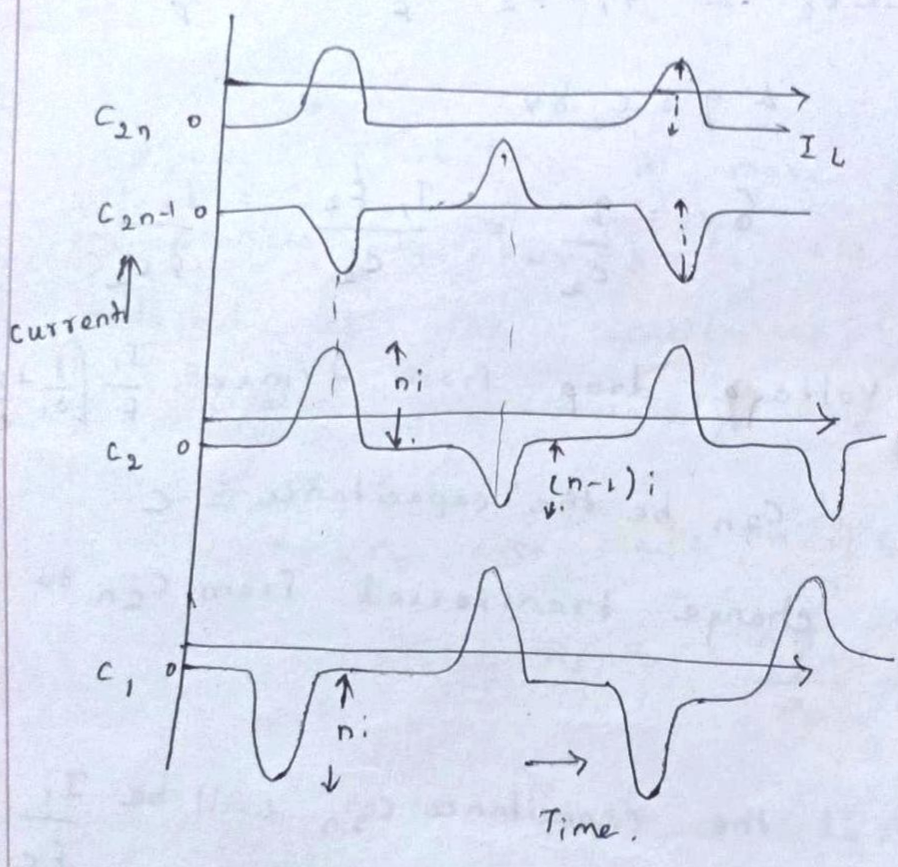
The first stage D_1, C_1, D_2, C_2 & Transformer are identical with the voltage doubler circuit for higher output voltages of 4, 6, ... 2n of the input voltage V, the circuit is Cascaded or series connection.

Now, C_4 is charged to $4 V_{max}$

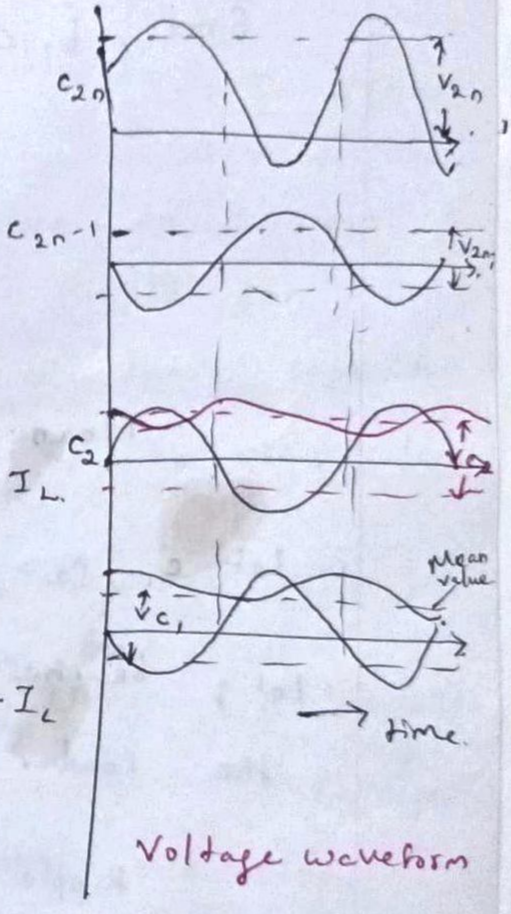
C_{2n} is charged to $2n V_{max}$

→ During negative half cycle, $D_1, D_3 \cdots D_{2n-1}$ will conduct & the capacitors $C_1, C_3 \cdots C_{2n-1}$ charged to a voltage of V_{max}

→ During positive half cycle, $D_2, D_4 \cdots D_{2n}$ will conduct & the capacitor $C_2, C_4 \cdots C_{2n}$ charged to a voltage of V_{max}.



current waveform



Voltage waveform

Ripple in cascaded voltage Multiplier circuit

Let

f - supply frequency

q - charge transferred in each cycle

I_1 - Load current from the rectifier.

t_1 - conduction period of rectifier

t_2 - Non conduction period of rectifier

δv - Ripple voltage (peak - peak)

$$I_1 = \frac{dq}{dt} = \frac{q}{t_2}.$$

Since, $t_1 << t_2$ & $t_1 + t_2 = 1/f$, $t_2 = 1/f$

$$\therefore q = C_2 \, \delta v$$

$$\delta v = \frac{q}{C_2} = \frac{I_1 t_2}{C_2} = \frac{I_1}{f C_2}$$

Mean voltage drop from $2V_{max} = \frac{I_1}{f}\left[\frac{1}{C_1} + \frac{2}{C_2}\right]$

Let $C_1, C_2 \cdots C_{2n}$ be the capacitance $= C$

Let q be the charge transferred from C_{2n} to the Load.

Ripple at the capacitance C_{2n} will be $\frac{I_1}{fC}$.

$$C_{2n-2} = \frac{2 I_1}{fC}$$

$$\vdots$$

$$C_2 = \frac{n I_1}{fC}$$

for n stages

Total ripple (δv) $= \frac{I_1}{fc}[1+2+3\ldots+n]$

$= \frac{I_1}{fc} \frac{n(n+1)}{2}$

Average ripple $= \frac{\text{Total ripple}}{2}$

$= \frac{\delta v}{2} = \frac{I_1}{4fc} n(n+1)$

Ripple contribution is more due to lowest capacitances c_1, c_2, c_3, c_4 etc. Ripple can be reduced if the capacitances of these capacitors is increased proportionately ie) c_1, c_2 are made nc.

c_3, c_4 are made $(n-1)c$ & so on

Total ripple $= \frac{nI_1}{fc}$ Where, n = Number of stage.

per cent ripple = % ripple $= \frac{\delta v \times 100}{nV_{max}}$.

Determination of optimum Number of stages.

change in voltage ΔV is caused due to ripple (δv).

Let $c_1, c_2 \ldots c_n = c$.

Capacitance c_{2n} is charged to $2V_{max}$ - Total ripple

$= 2V_{max} - \frac{nI_1}{fC}$

III^{rly} capacitance C_{2n-2} is charged to $2V_{max} - \frac{2nI_1}{fC} - \frac{(n-1)I_1}{fC}$

:

Capacitance V_2 is charged to $2V_{max} - \frac{2nI_1}{fC} - \frac{2(n-1)I_1}{fC} - \frac{2I_1}{fC} + \frac{I_1}{fC}$

Voltage drop across C_{2n} $(\Delta V_{2n}) = \frac{nI_1}{fC}$

" C_{2n-1} $(\Delta V_{2n-2}) = \frac{I_1}{fC}(2n + (n-1))$

" C_2 $(\Delta V_2) = \frac{I_1}{fC}(2n + 2(n-1) + \ldots 2 - 1)$.

Total voltage drop $= \Delta V_{2n} + \Delta V_{2n-2} \ldots \Delta V_2$

$$= \frac{I_1}{fC}\left[\sum_1^n 2n^2 - \sum_1^n n\right]$$

$$= \frac{I_1}{fC}\left[2 \cdot \frac{n(n+1)(2n+1)}{6} - \frac{n(n+1)}{2}\right]$$

$$= \frac{I_1}{fC}\left[\frac{n(n+1)}{2}\left[\frac{4n+2}{3} - 1\right]\right]$$

$$= \frac{I_1}{fC}\left[\frac{n(n+1)(4n-1)}{6}\right] = \frac{I_1}{fC}\left[\frac{2n^3}{3} + \frac{n^2}{2} - \frac{n}{6}\right]$$

$$\Delta V = \frac{I_1}{fC}\left[\frac{2n^3}{3} + \frac{n^2}{2} - \frac{n}{6}\right]$$

When No. of stage > 4, we can neglect n^2 & n

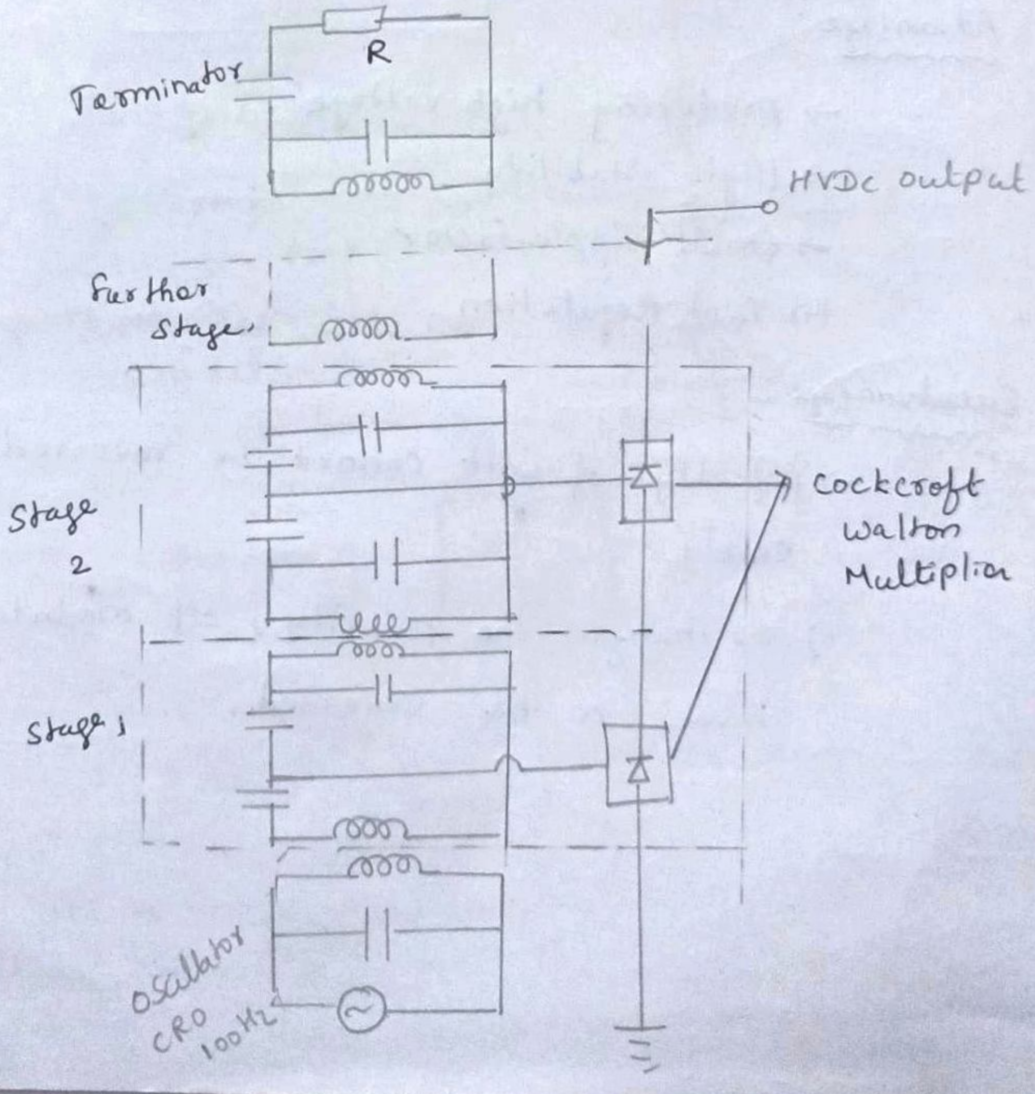
$$\therefore \Delta V = \frac{I}{fC}\left(\frac{2n^3}{3}\right)$$

$$\% \text{ regulation} = \frac{\Delta V}{2nV_{max}} \times 100$$

Optimum Stages:

$$n = \sqrt{\frac{V_{max} fC}{I_1}}$$

Deltatron (or) Engetron circuit.



→ It consist of series connection of Transformer but doesnot have any iron core.

→ These transformer are coupled by using series capacitor Cs. Cp → Capacitor Cp is connected in parallel

→ cockcroft walton multiplier are connected in series to produce high dc output voltage.

→ modules are cylindrical unit & insulated by SF_6.

freq → 50-150 kHz

→ voltage regulation is controlled by mixed RC voltage divider & high frequency oscillator.

Energy → small.

→ Regulation due to Load variation is very fast.

Advantage:

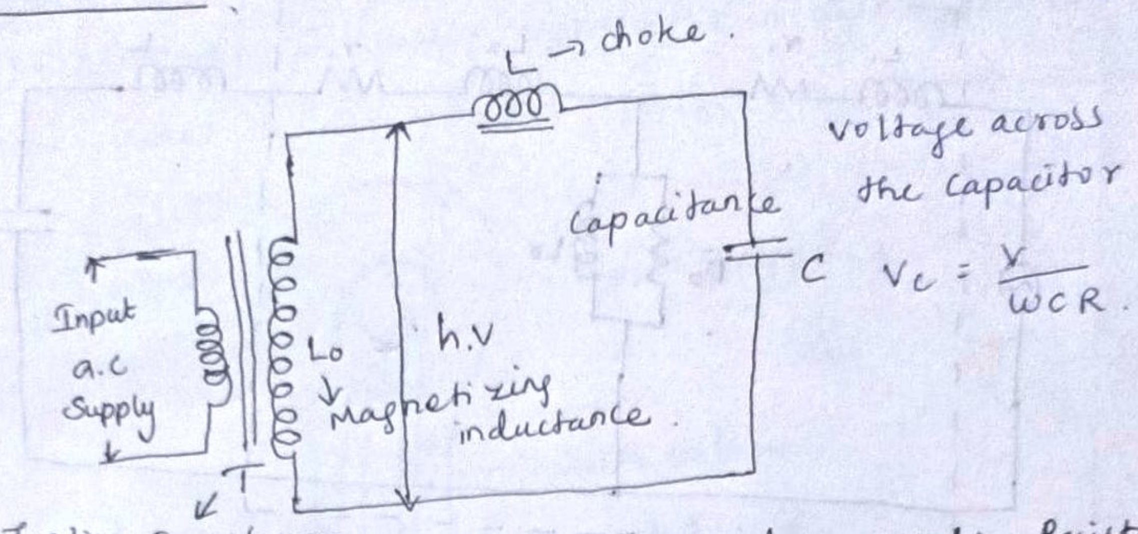
→ producing high voltage
→ High stability
→ Small ripple factor
→ fast Regulation.

Disadvantage:

→ polarity of unit cannot be reversed easily

→ To change the polarity, all modules have to be reversed.

Resonant transformer

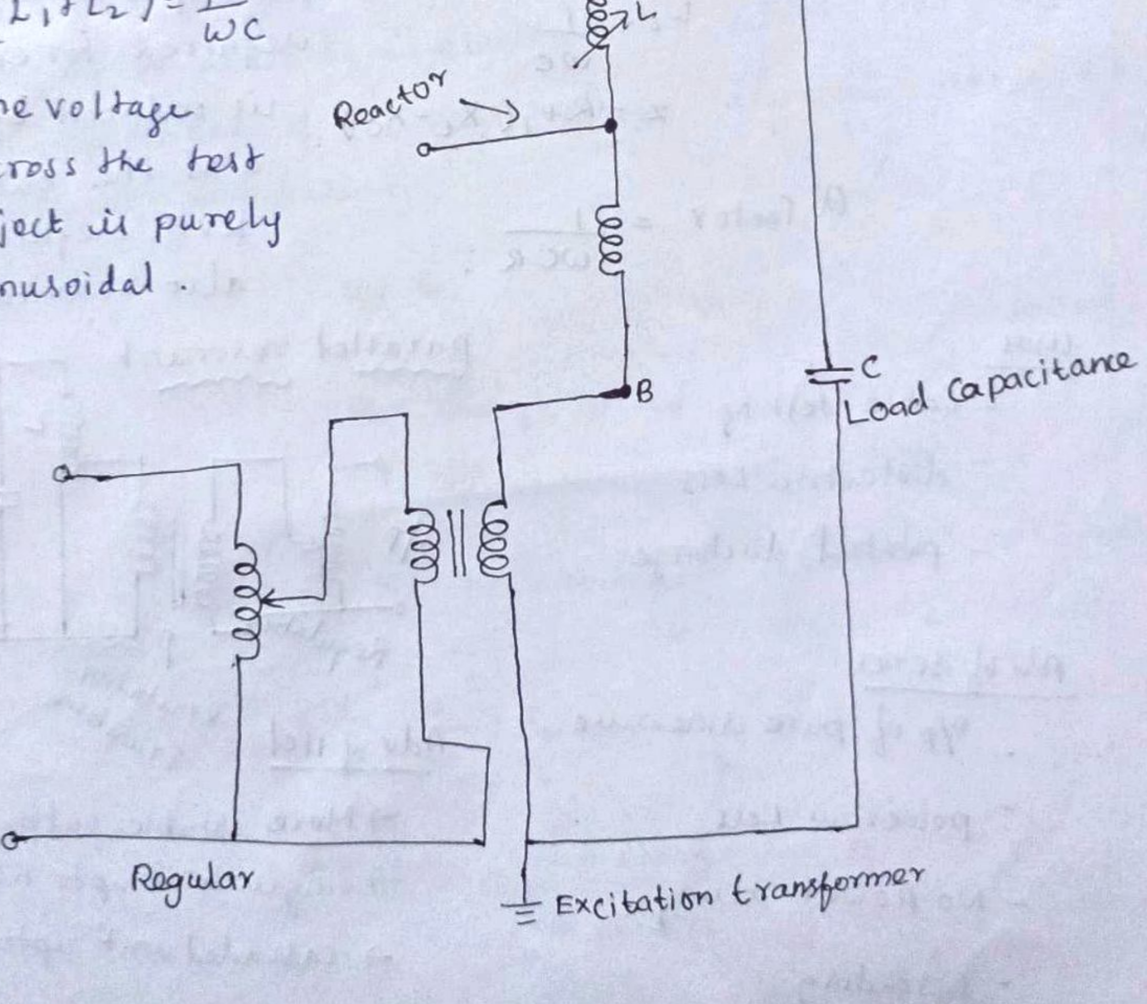


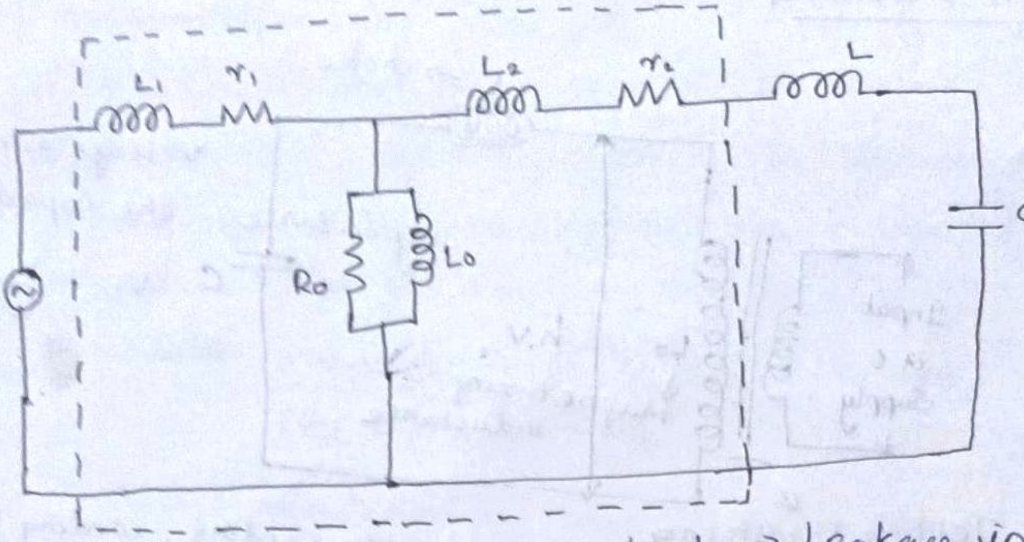
It consist of Leakage reactance of the winding, winding Resistance, magnetizing reactance & the shunt capacitance across the output terminal due to bushing of the high voltage & test object.

Series Resonance

$(L_1 + L_2) = \frac{1}{\omega C}$

→ The voltage across the test object is purely sinusoidal.





Series Resonance circuit.

$L_1, L_2 \rightarrow$ Leakage inductance of transformer.

$r_1, r_2 \rightarrow$ Resistance of winding.

$R_o \rightarrow$ Resistance due to core loss.

condition for series

$X_L = X_C$

$\omega L = \frac{1}{\omega C}$

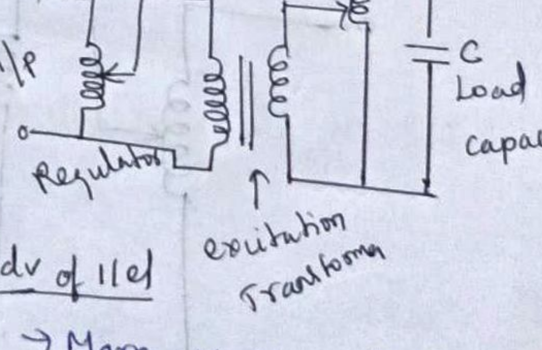
$Z = R + j(X_L - X_C)$.

Q factor $= \frac{1}{\omega C R}$.

* The input voltage required for excitation is reduced by 1/2 and the output KVA required is also reduced by 1/2.

Uses
- Cable testing
- dielectric Loss
- partial discharge

Parallel resonant

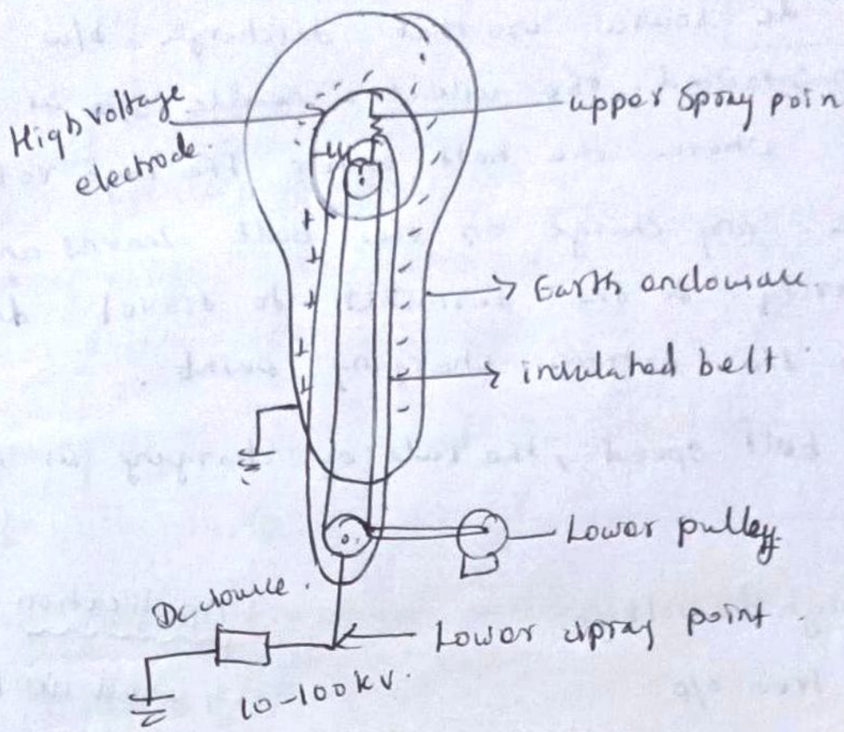


Adv of series
- O/p of pure sinewave.
- power is Less
- No power arcing
- cascading
- Simple & compact.

Adv of ||el
- → More stable output
- → single unit upto 500kV
- → cascaded unit upto 3000 kV

Vandegraff generator

The generator is usually enclosed in an earthed metallic cylindrical vessel & is operated under pressure (or) vacuum.



The belt is driven by an electric motor. at N = 1000 - 2000m/minute.

The potential of the high voltage electrode above the earth at any instant is

$$V = Q/C.$$

Q - charge stored

C - capacitance.

The potential of the high voltage electrode rise at the rate

$$\frac{dv}{dt} = \frac{1}{C} \cdot \frac{dQ}{dt} = I/C.$$

$I = \delta b v$. δ - charge density

b - width

v → belt speed in m/sec.

working

The charging belt is done by the Lower spray point the Lower spray unit consist of No. of. needles connected to the controlled dc source so that discharge b/w the point & belt is maintained. The collector needle s/m is placed near the point where the belt enter the high voltage terminal. This neutralize any charge on the belt leaves an excess of opposite polarity to the terminal to travel down with the belt to the bottom charging point.

∴ belt speed, the rate of charging is doubled

Adv:

→ Very high dc voltage
→ Ripple free o/p
→ precision & flexibility

Application

→ used in Nuclear physics Laboratories

Limitation

- Low current o/p
- Limitation on belt velocity
- Maintenance.

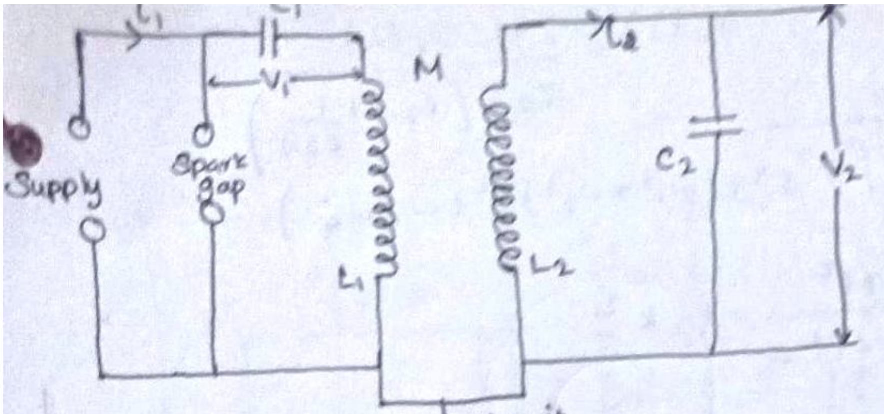
Generation of High frequency AC high voltage (Tesla coil) (doubly tuned Resonant circuit).

Adv:

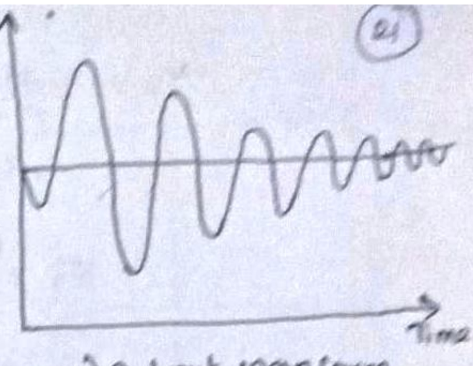
→ No iron core
→ o/p waveform is pure sinusoidal
→ No damage due to switching.
→ uniform distribution of voltage.

Need:

→ testing electrical Apparatus for switching.



(a) Equivalent circuit



b) Output waveform

primary voltage = 10 kV

Secondary voltage = 500 - 1000 kV.

power rating : 10 kVA or more.

→ The primary coil are wound on insulated fibre tube which has few 10 of turns.

→ secondary coil is wound on concentric fibre (or) pyrex tube which has few 1000 turns.

→ This assembly is immersed in oil tank under pressure the spark gap 'G' is connected across the supply & is triggered when capacitor C_1 is charged to a voltage V and induces high self excitation in the secondary.

Let I_1 → primary current

I_2 → secondary current.

$$\text{input voltage } (V_1) = \frac{1}{C_1}\int_0^t i_1\,dt + L_1\frac{di_1}{dt} + M\frac{di_2}{dt} \rightarrow (1)$$

Taking Laplace Transform $\frac{V_1}{S} = \frac{1}{C_1}\frac{I_1(S)}{S} + L_1 S I_1(S) + MS I_2(S)$

$$\frac{1}{C_2}\int_0^t i_2\,dt + L_2\frac{di_2}{dt} + M\frac{di_1}{dt} = 0 \rightarrow (2)$$

$\frac{1}{C_2 S} I_2(S) + L_2 S I_2(S) + MS I_1(S) = 0$

$$V_2 = \frac{1}{C_2}\int_0^t i_2\,dt \rightarrow (3)$$

$$V_2(S) = \frac{1}{C_2 S} I_2(S)$$

$$V_2(s) = \frac{-MS\, I_1(s)}{C_2 S\left[L_2 S + \frac{1}{C_2 S}\right]}$$

$$V_2 = \frac{-M V_1 S}{L_1 L_2 C_2 \left[\sigma^2 S^4 + (\omega_1^2 + \omega_2^2) S^2 + \omega_1^2 \omega_2^2\right)}$$

$$\sigma_2 = 1 - \frac{M^2}{L_1 L_2} = 1 - k^2.$$

$$\sigma^2 S^4 + S^2(\omega_1^2 + \omega_2^2) + \omega_1^2 \omega_2^2 = 0$$

$$\alpha = \frac{-(\omega_1^2 + \omega_2^2) + \sqrt{(\omega_1^2 + \omega_2^2)^2 - 4\sigma^2 \omega_1^2 \omega_2^2}}{2\sigma^2}$$

$$V_2 = \frac{M V_1}{\sigma L_1 L_2 C_2 (\beta - \sigma)}$$

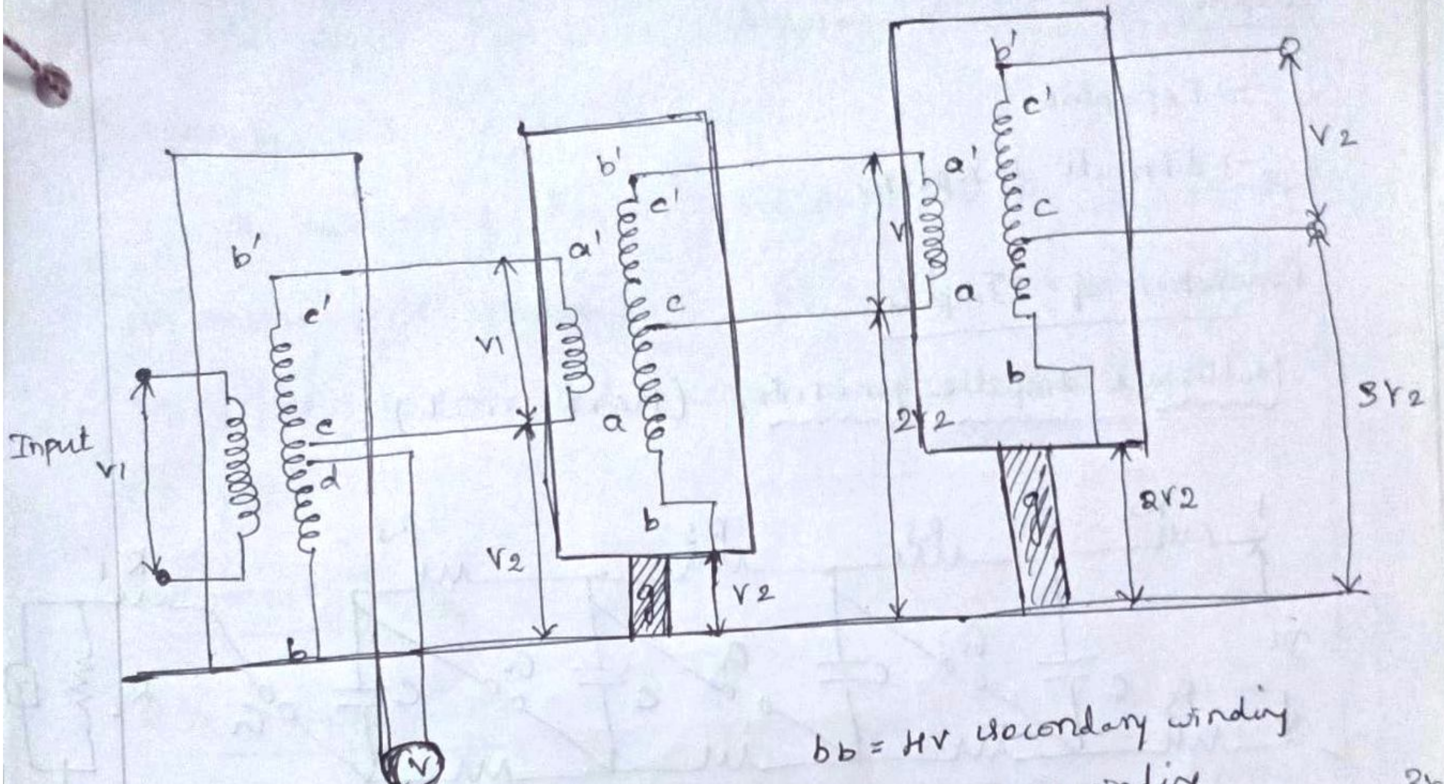
Turn ratio of Tesla coil is $\sqrt{L_2/L_1}$.

Cascaded transformer

The high voltage winding of the 1st unit is connected to the tank of the second unit, the 2nd transformer is kept on insulator & maintained at a potential of V_2. The LV winding of the second winding unit is supplied from the excitation winding of the 1st unit which is connected in series with HV winding of the 1st unit.

for small unit → primary winding = 130 or 400 V

for Large unit → Low voltage winding = 3.3 kV, 6.6 kV.



bb = HV secondary winding

bd - meter winding

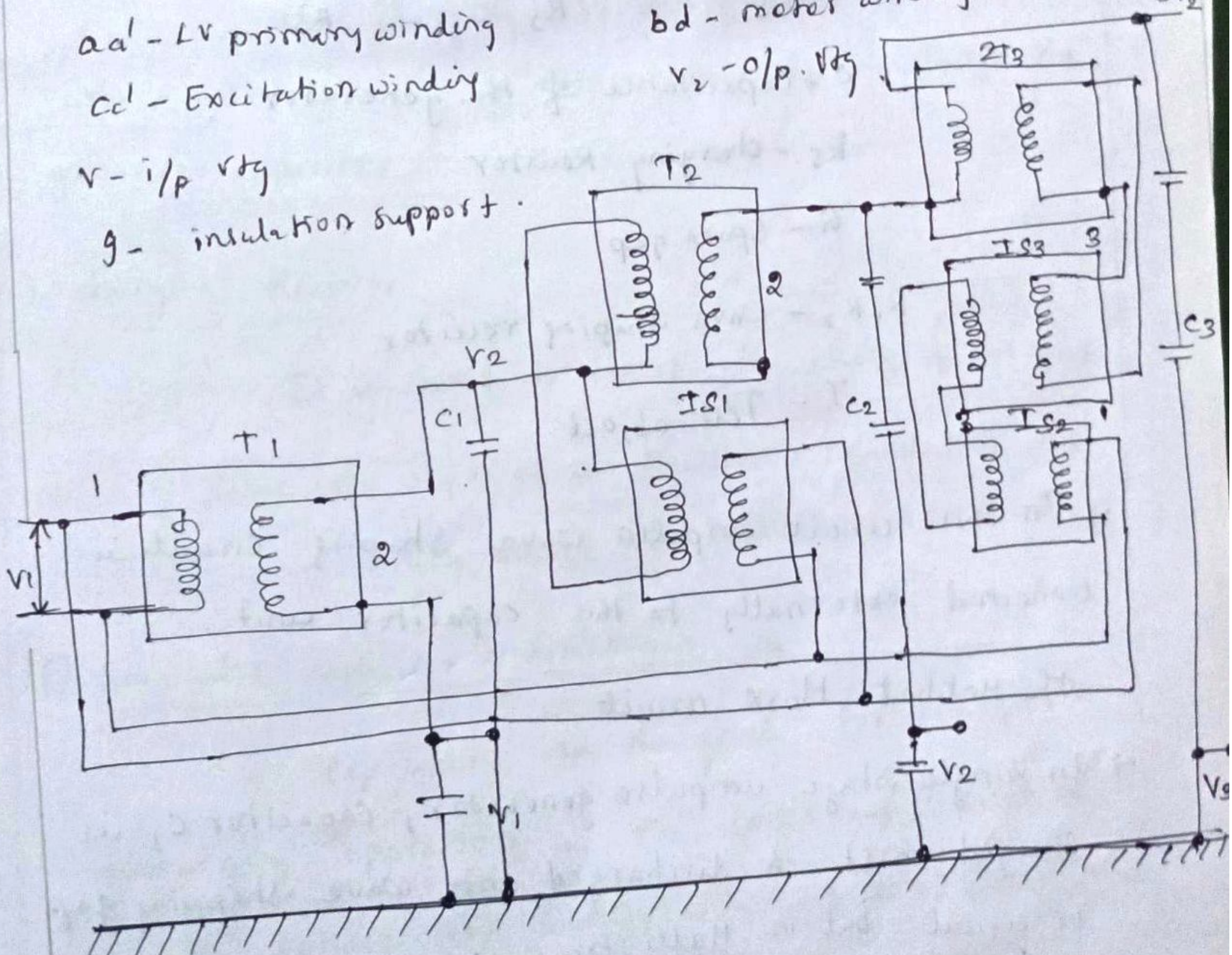
aa' - LV primary winding

cc' - Excitation winding

V2 - o/p. Vtg

v - i/p vtg

g - insulation support.



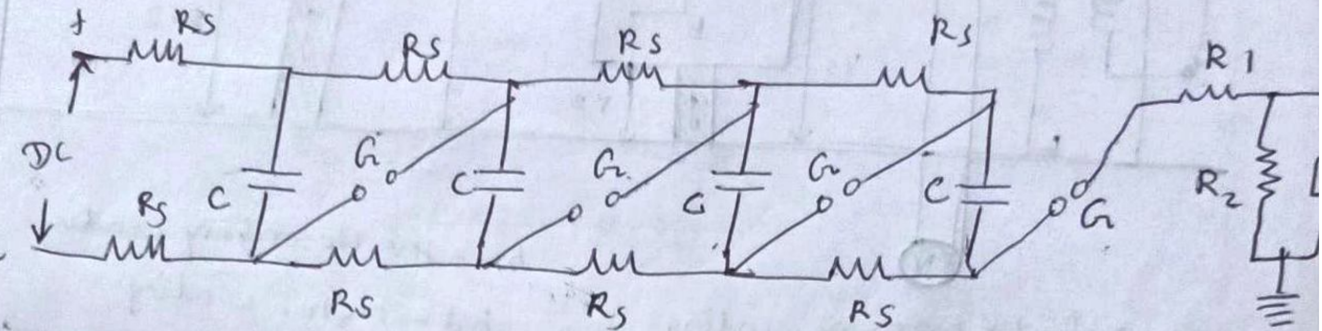
disadv

→ Expensive

→ difficult to repair.

Generation of Impulse.

• Multistage Impulse generator (Marx circuit)



C - Capacitance of the generator

Rs - charging Resistor

G - Spark gap

$R_1 R_2$ - Wave shaping resistor

T - Test object.

→ In this circuit impulse wave shaping circuits is connected externally to the capacitor unit.

The Modified Marx circuit.

→ In single stage impulse generator, capacitor C_1 is charged first & discharged into wave shapping gap or circuit. but in Multistage, Capacitor is parallel through ohmic resistance & discharged in series through spark gap.

In this ckt, the wave shaping Resistor R_1, R_2 are incorporated inside the unit.

R_1 is divided into n equal parts to $\frac{R_1}{n}$ & connected in series with the gap G. R_2 is also divided into 'n' equal part & connected across each capacitor unit after the gap.

Component

(1) Dc charging set.

The charging unit is capable of giving variable dc voltage of either polarity to charge the generator capacitor.

(2) charging Resistor:

It is used to limit the charging current.

Value of charging ct Resistor = 10 - 100 kΩ.

Vtg across the Resistor - 50 - 100 kv,

(3) Generator capacitor & spark gap

Capacitor are designed for charging & discharging operation. The spark gap will be usually sphere (or) hemisphere of 10-25cm diameter.

(26)

4) wave shaping Resistor & capacitor.

wave shaping Resistor are designed in such a way that they are capable of discharging impulse current of 1000A (or) more.

5) Triggering system:

It is used to trigger spark gap. to cause breakdown of the gap.

6). voltage divider.

To measure the voltage across the test object. Voltage divider with an oscilloscope is used.

operation:

When the 1st gap fires, the potential at a point A changes from -V to 0. & the point 'p' increases from 0 to +V. during charging the values are choosen such that:

CR_s = 10 sec to 1 min.

Energy stored = $\frac{1}{2}CV^2$.

Adv:

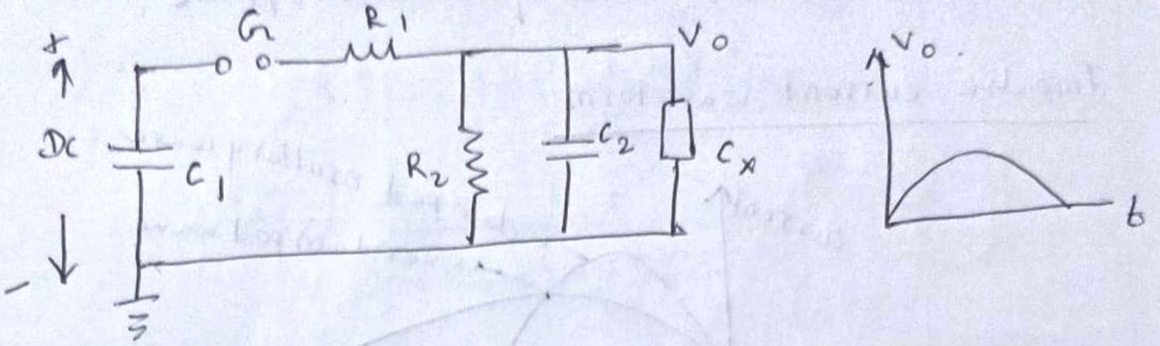
- Cost is Less
- Space is Less.
- η is high
- simple & compact

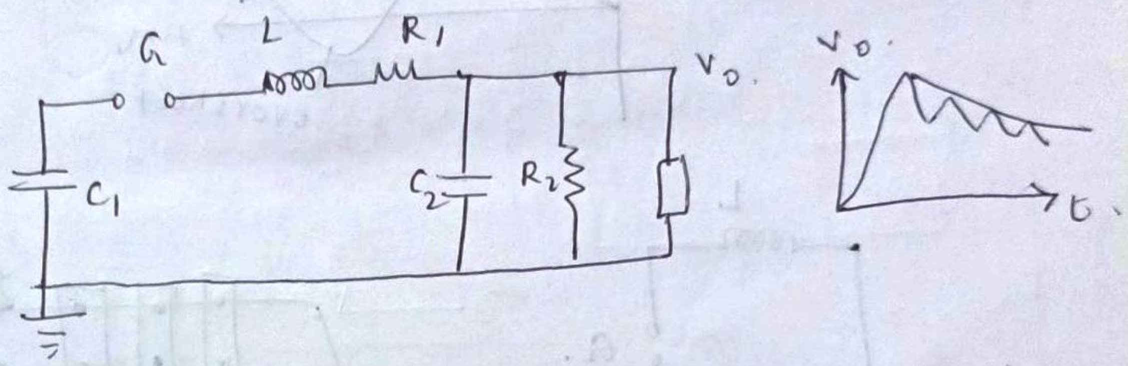
Generation of switching surge

There are 2 methods for producing switching surges.

(1) Impulse generator ckt.

(2) power transformer (or) Testing Transformer.





The spark gap act as a voltage limiting & voltage sensitive switch. Whose ignition time is short.

$$V_0 = 200 - 250\,kV$$

$$freq = 1 - 10\,kHz$$

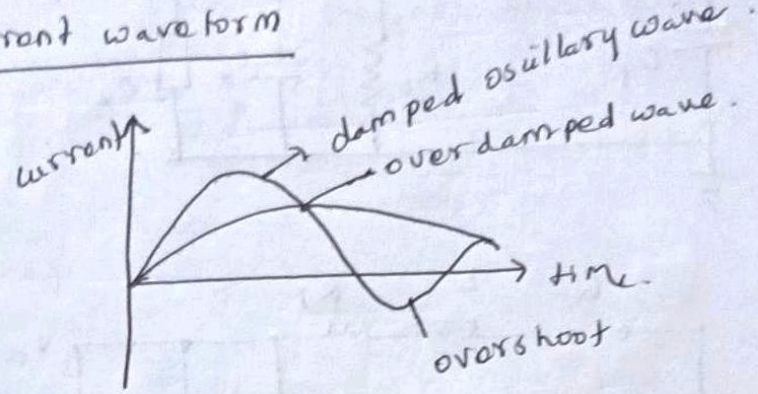
A sphere gap was included in parallel with the test object for voltage measurement & also for producing chopped waves.

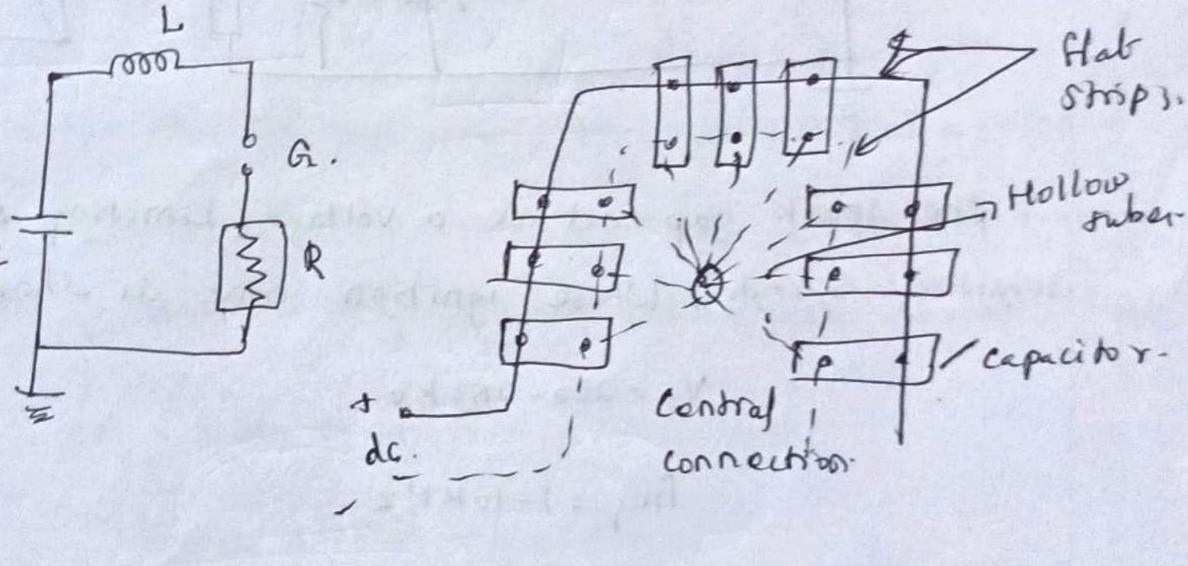
Generation of impulse current

Application:

- To test non linear Resistor
- To study electric arc
- studies relating to electrophase.

Impulse current waveform





A bank of capacitor connected in parallel are charged to a specified value & are discharged through a series RL circuit to produce large value impulse current.

If the capacitor is charged to a voltage V, the gap will be triggered, now the capacitor discharge.

$$\int v\,dt = iR + L\frac{di}{dt} + \frac{1}{C}\int i\,dt$$

Taking Laplace transform.

$$\frac{V}{s} = R\,I(s) + Ls\,I(s) + \frac{1}{Cs}I(s)$$

$$I(s) = \frac{V}{s\left[R + Ls + \frac{1}{Cs}\right]}.$$

$$I(s) = \frac{VC}{LC\left[s^2 + \frac{R}{L}s + \frac{1}{LC}\right)}$$

$$s^2 + \frac{R}{L}s + \frac{1}{LC} = 0.$$

$$s = \frac{-R}{2L} \pm \sqrt{\frac{R^2}{4L^2} - \frac{1}{LC}}$$

$$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}.$$

For under damped system,

$$\frac{R^2}{4L^2} < \frac{1}{LC}$$

$$\frac{R}{2} < \sqrt{\frac{L}{C}}.$$

Taking inverse Laplace Transform.

$$I(s) = \frac{V}{L\,(s+\alpha)^2 + (\omega t)^2}.$$

$$i(t) = \frac{V}{\omega L} e^{-\alpha t} \sin \omega t.$$

Time taken for max. current.

$$t_1 = \frac{1}{\omega} \tan^{-1} \frac{\omega}{\alpha}.$$

$$t_2 = \frac{\pi}{\omega} = \frac{\pi}{\sqrt{\frac{1}{LC} - \frac{L^2}{\omega L^2}}}.$$

$$\text{Max. current} = \frac{V}{\omega L} e^{-\alpha t_1}.$$

$$\text{Energy} = \frac{1}{2} C V^2.$$

Operation of Tripping control:

→ When closing the switch 'S', the triggering is initiated by applying a pulse to the thyratron C_1. The pulse also initiates the oscilloscopes time base.

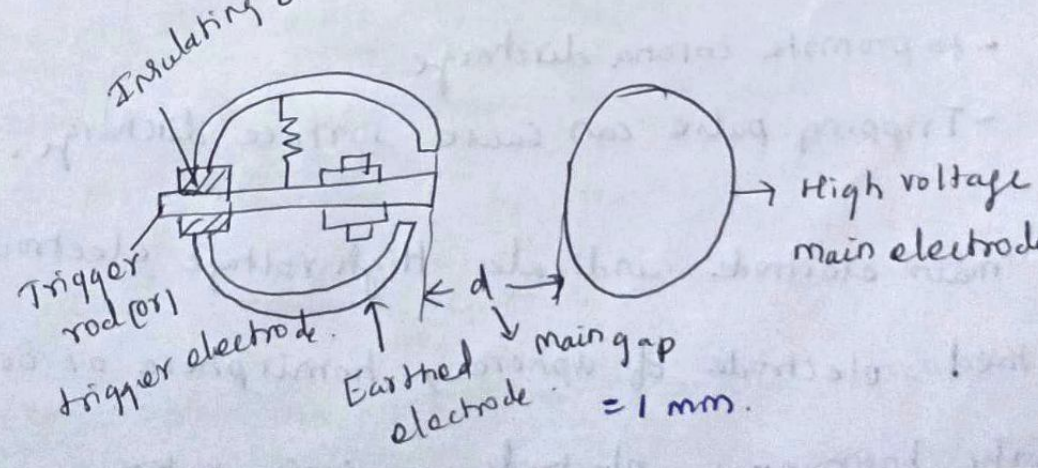
→ The thyraton conducts & produce negative pulse to the central electrode of three electrode gap through capacitance C_1.

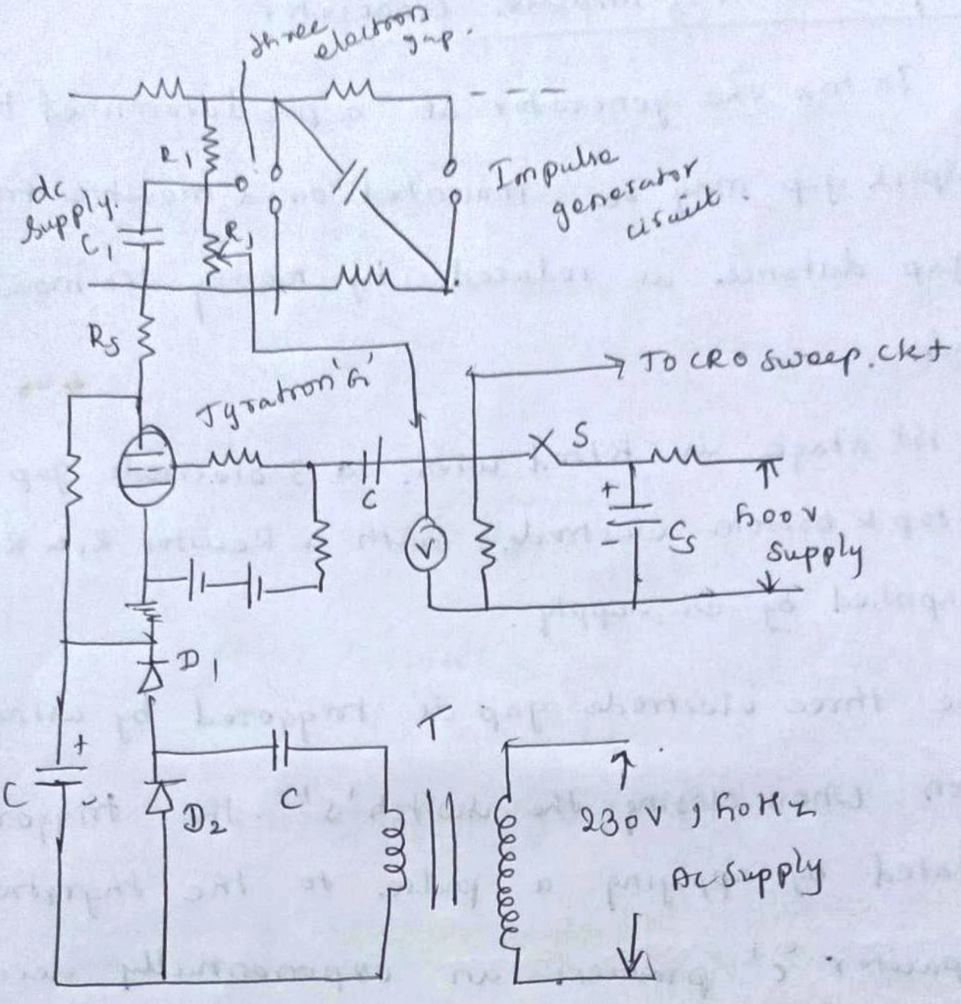
Tripping & control of impulse Generator

→ To trip the generator at a predetermined time, the spark gap may be mounted on a movable frame. The gap distance is reduced by moving the movable electrodes.

→ The 1st stage is fitted with a 3 electrode gap. The top & bottom electrode with a Resistor R_1 & R_2 is supplied by DC supply.

→ The three electrode gap is triggered by using thyratron. When closing the switch 'S'. The triggering is initiated by applying a pulse to the thyratron G. The capacitor 'c' produces an exponentially decaying pulse of positive polarity. The pulse goes & initiates the oscilloscopes.





Advantage:

- to promote corona discharge.
- Tripping pulse can cause surface discharge.

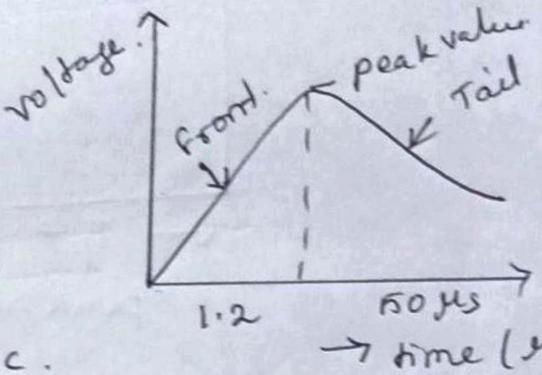
The main electrode indicates High voltage electrode, earthed electrode of sphere, hemisphere or other nearly homogeous electrode configuration.

Standard Impulse wave shapes: (54)

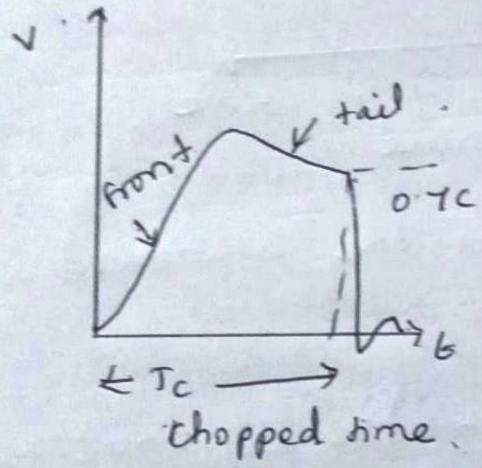
Standard lightning impulse voltage waveshape is an aperiodic voltage impulse that does not cross the zero line which reaches its peak in 1.2 μsec and then decreases slowly in 50 μsec.

Specification:

→ Rise (or) Front time
→ Fall (or) Tail time to 50% peak value
→ Peak value.
→ delay time.



Impulse wave



Impulse wave chopped.

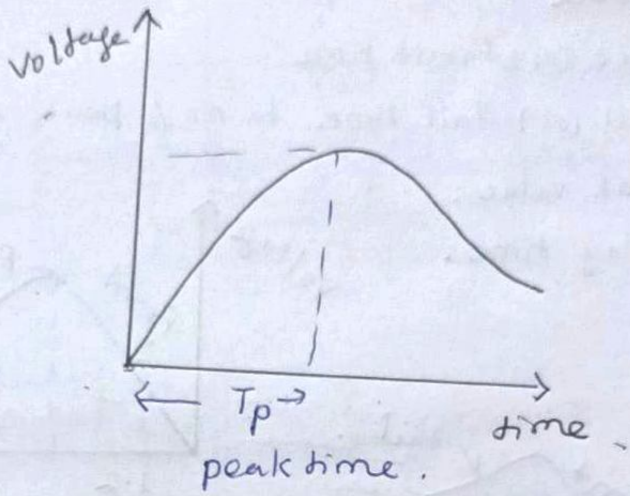
Rise (or) Front time: It is the time required for the response to raise from 10% to 90% (or) 0 to 100% of the final value. $t_f = 1.2\,\mu s$

Fall time:- Time to reach 50% of the peak value $t_t = 50\,\mu s$

peak value: The maximum positive deviation of the output with respect to its desired value is known as peak value.

Generation of switching surges:

A switching surges is a short duration transient voltage produced in the system due to a sudden opening (or) closing of a switch (or) circuit breaker (or) due to an arcing at fault in the system.



→ 250/2500 μs wave is the standard switching impulse voltage wave.

Tolerance for front time ie) 250 ± 50 μs

for tail time ie) 2500 ± 500 μs.

Measurement of High Voltage & High current

High Resistance with series ammeter, Dividers, Resistance, Capacitance & Mixed divider, peak voltmeter, Generating voltmeter, Capacitance voltage Transformer, Electrostatic voltmeter, sphere gap. High current shunt - Digital technique in HV measurement.

Measurement of High DC Voltage

- Series Resistance of High DC voltage
- Resistance potential divider
- Generating voltmeter
- Sphere gaps.

Measurement of High AC voltage

- Series impedance voltmeter
- potential transformer (CVT)
- Electrostatic voltmeter
- potential divider
- Sphere gap.

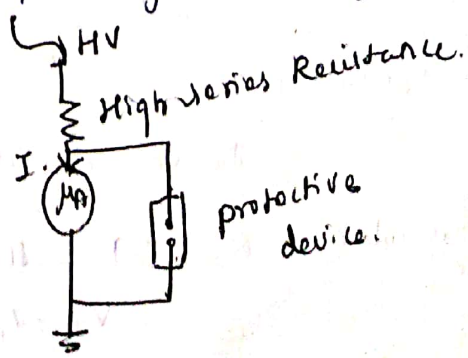
Measurement of High AC freq & impulse voltage

- potential divider (RLC)
- peak voltmeter
- Sphere gap.

1. Series Resistance micro ammeter

Construction: A Large value of resistance (few 100 of Megaohms) is connected in series with μA.

* protective device (zener diode, neon glow tube) connected across the μA.



Operation:

- R should be high
- high DC voltage is applied.
- Voltage drop across the Resistance
- The current flowing through 'R' is measured in μA.

Voltage $V = IR$

drop in Ammeter is negligible

- R should be chosen such that 1-10μA is allowed for full Scale deflection.
- 500kV can be measured.

Accuracy: 0.2%.

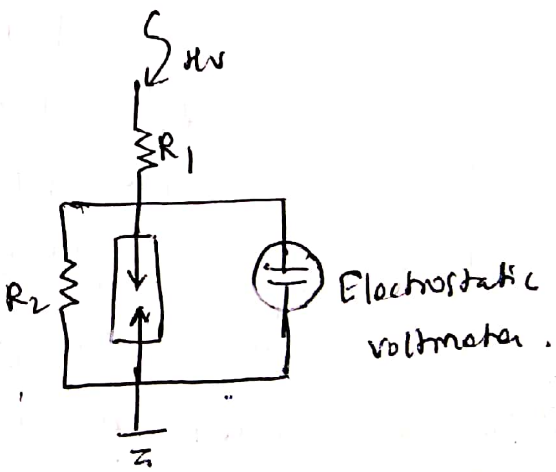
Need for protective devices

If R fails, heavy current will flow through μA to divert protective device is used.

drawback:

- more power dissipation
- Temperature effects.

2. Resistance potential divider



Need:

- To avoid high Loading of R
- Another resistor is added.

Construction

- $R_1 R_2$ connected in series
- voltage is measured across R_2

Operation:

DC voltage is measured using Resistance voltage divider. $R_2 << 1$, High dc is applied, drop across R_1

$$V_2 = V_1 \frac{R_2}{R_1 + R_2}, \quad V_1 = V_2 \frac{R_1 + R_2}{R_2}$$

Sudden voltage changes occur during transient period due to

→ switching operation

→ Flashover of test object

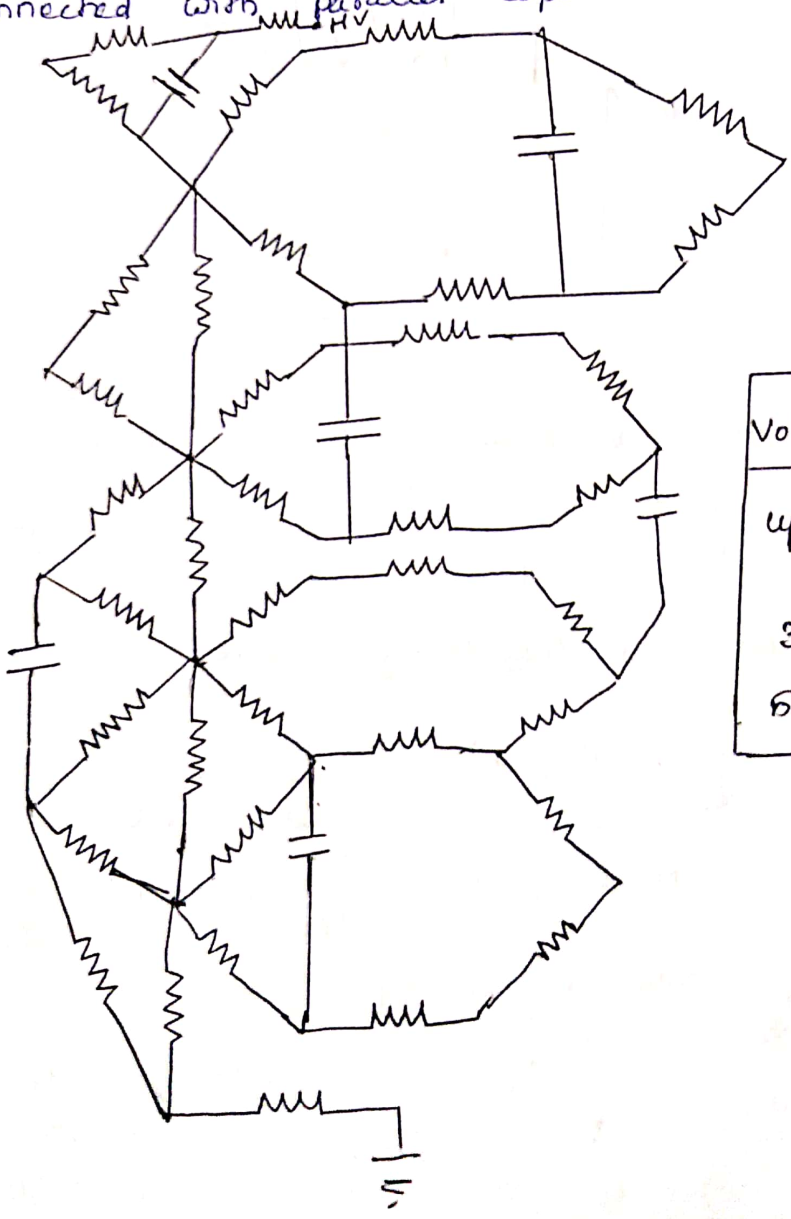
→ Damage may occur the diverter element due to stray capacitance across the elements & due to ground capacitance.

Transient voltage can be avoided by.

→ connecting voltage controlling capacitor across the elemen

→ corona free termination

For transient Potential Distribution, a series resistor is connected with parallel capacitor.



Voltage	Accuracy
upto 100kV	0.05 %
300kV	0.1 %
500kV	0.5 %

Generating Voltmeter:

Generating voltmeter is a Variable capacitor electrostatic voltage generator which generates current proportional to the voltage to be measured.

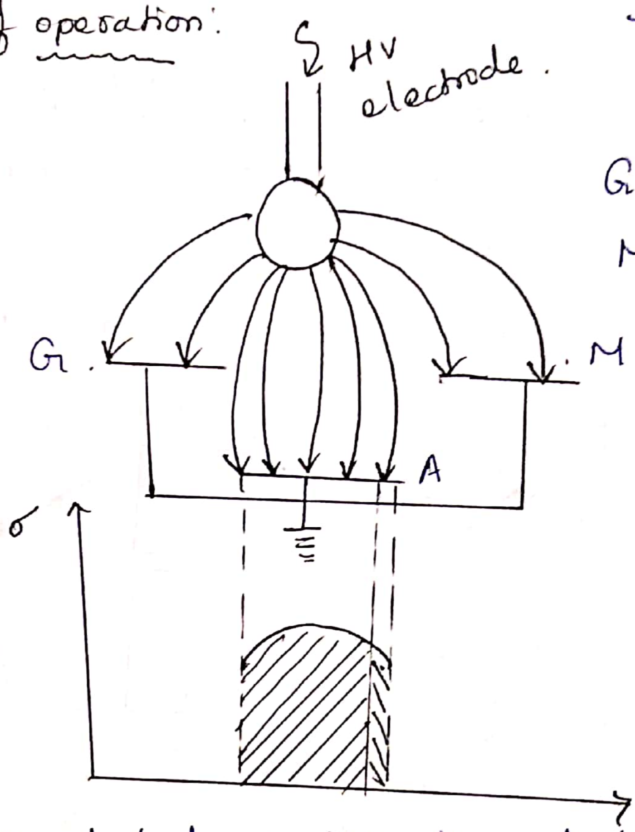
→ It provide Loss free measurement of DC & AC voltage.

Limitation:

→ Need calibration

→ Careful construction

principle of operation:



G → Gaurd electrode

M → movable electrode

M. A → pickup electrode.

High voltage electrode excites the electrostatic field within a highly insulated medium (gas (or) vaccum) & ground potential.

Let q be the charge stored,

$$i = \frac{dq}{dt} = \frac{d}{dt}(vc) = v\frac{dc}{dt} + c\frac{dv}{dt},$$

Since M is fixed, $\frac{dv}{dt} = 0$, $i = v\frac{dc}{dt}$,

Where $C = C_0 + c_m \sin\omega t$.

$$i = v c_m \cos\omega t \cdot \omega, \quad i_m = v c_m \omega$$

$$i_{rms} = \frac{v c_m \omega}{\sqrt{2}}$$

$$\boxed{i = i_m \cos\omega t}$$

re the voltage directly across R_2.
per dissipation in Resistor R_1
eed for cooling
series connection of resistor.

Advantage:

→ Scale is Linear.
→ Source Loading is zero
→ No direct connection to HV electrode.

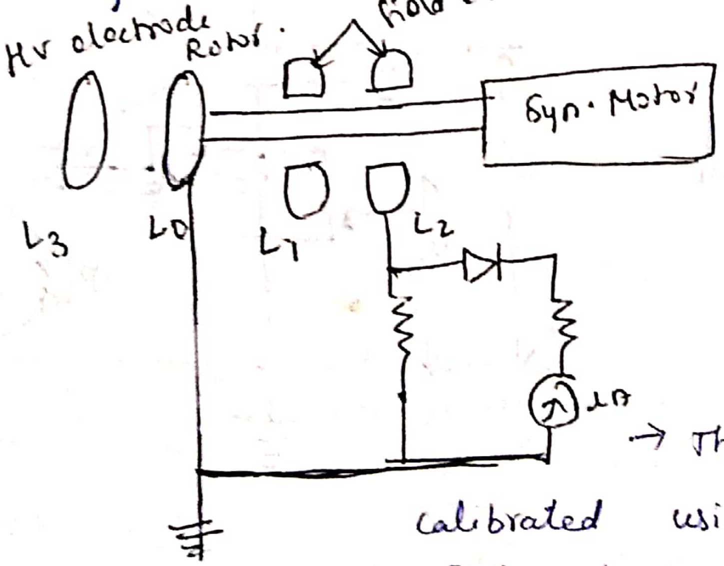
Generating Voltmeter

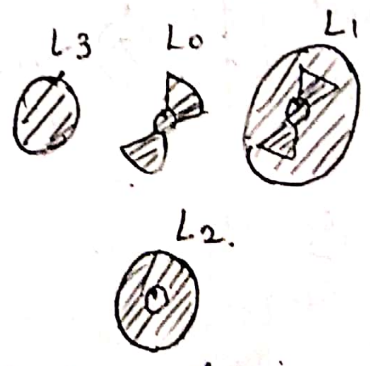
principle :- Variable electrostatic generator which generates a current proportional to the applied external voltage. Time variant capacitance system can be developed between the high voltage electrode & earthed electrode, then the current flowing to earth electrode will be measure of the voltage.

- Connect High voltage source to disc electrode H. $L_1 L_2 L_3$ are earthed electrode
- The L_1 has a vanes & its rotated at const. speed.
- The rotor vane of L_1 periodically cover & uncover the static sensing electrode L_3.
- Capacitance b/w H & H changes periodically.
- The shape & No. of vanes of L_1 L_2 are designed that they produce sinusoidal variation in the capacitance.

operation:

- The generated ac current is rectified & read by a moving coil instrument.





→ The instrument is calibrated using potential divider (or) sphere gap.

Measurement of High AC voltages.

1) Potential divider.

Resistance divider

✓ Power Loss

✓ Temperature effects.

Capacitance divider.

Series capacitance Divider.

- Apply the voltage
- Drop across capacitor.
- charging current is measured using micro ammeter.

Construction of CPD:

→ A standard compressed air condensed gas is used in C_1 and large value capacitor C_2 has insulating media like mica, paper etc.

→ C_1 is the three terminal capacitor & it is connected through shielded cable.

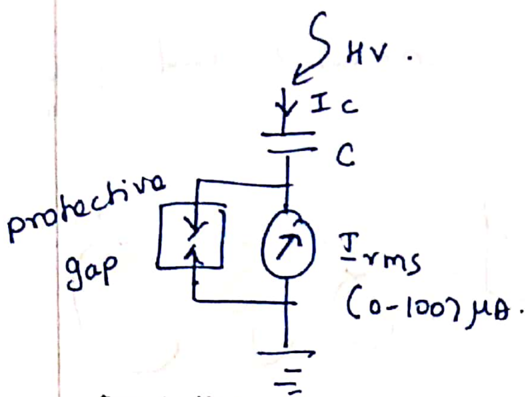
→ To avoid stray capacitance C_2 is shielded in a box.

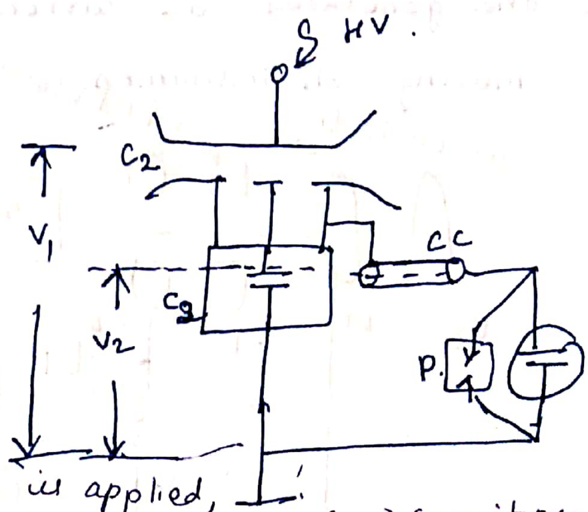
Capacitance potential divider → used to eliminate errors due to harmonics.

Need

1) withstand - RMS voltage
2) Breakdown - peak voltage

RMS = Peak $/\sqrt{2}$ for only sine wave.





Operation:

→ When high voltage source is applied, it can be measured using electrostatic voltmeter.

$$V_1 = V_2\left[\frac{C_1 + C_2 + C_m}{C_1}\right]$$

C_m → capacitance at meter.

C_1 - Std. compressed gas

C_2 → Std Low vtg condensor.

V_2 - meter reading

value measurement

1) chubb - frotscue method (Series capacitor peak voltmeter)

2) peak voltmeter with potential divider.

3) Digital peak voltmeter

4) sphere gap.

RMS value measurement

1) peak voltmeter

2) Electrostatic voltmeter.

1) Series capacitor peak Voltmeter (chubb - frotscue Method).

principle

measure of charging current

$I_c = V\omega C$

Adv:

→ When sinusoidal waveform is used the measurement is accurate

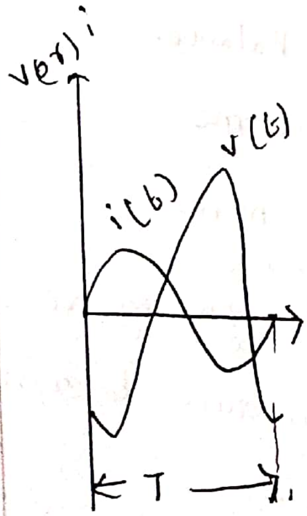
construction

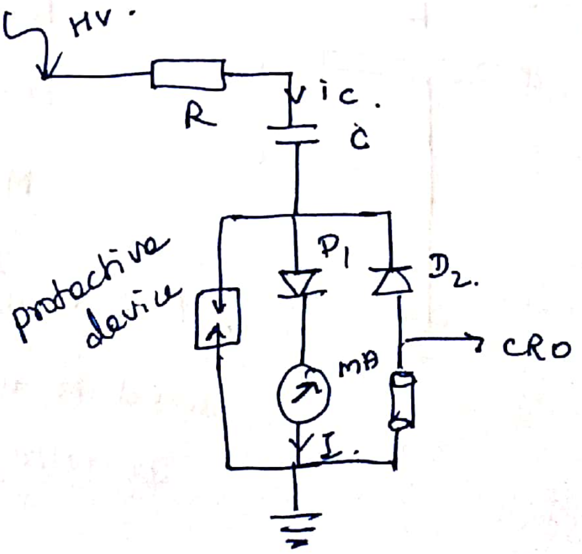
It consist of Standard, capacitor diode & meter.

→ diode is connected antiparallel. protective device is connected across the diode to protect the equipment.

operation

- Apply voltage
- charging current is rectified by D_1 & measured.
- other half cycle no conduction.





$$I = C\int_0^t V\,dt$$

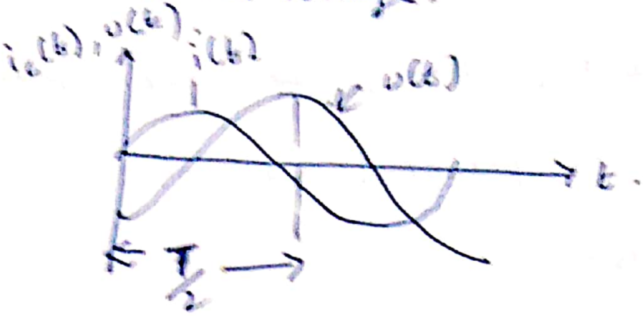
$$= j\omega C V.$$

Errors occurs due to

→ imperfect Rectifier

→ Non sinusoidal Voltage, etc.

current Leads the voltage.



drawback

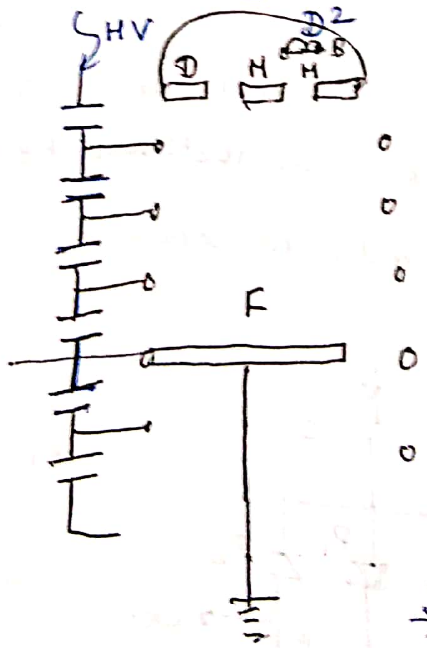
- voltage wave shaping is not pure sinusoidal. contain osuillation.
- current may not be uniform
- calibration is wrong.

Electrostatic voltmeter

principle.

Force between the parallel plate electrode is given by

$$F = \frac{1}{2}\frac{\varepsilon V^2 A}{D^2}$$

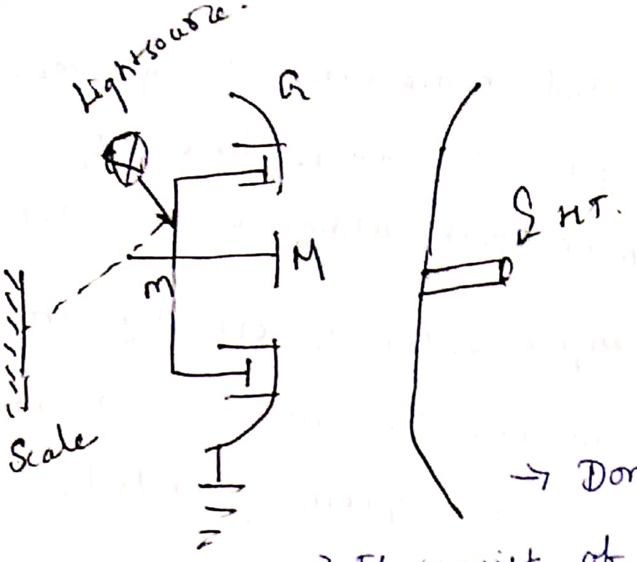


→ In electrostatic voltmeter. one the plate is fixed and the other is movable.

M - mounting plate
F - fixed plate
B - Balance
D - Dome
M - mirror.

→ $F \propto V_{rms}^2$. The meter can be used to measure both Ac or Dc voltage.

Scanned by CamScanner



G - Guard plate

H - Guard ring

C - capacitance divider

B - Balancing weight.

→ Dome D encloses a balance & moving disc C.

→ It consist of a parallel plate disc electrode the moving disc M forms the central core of the guard ring which has the same direction as that fixed plate.

→ Guard ring are used to make the electric field uniform in the central region & to avoid corona.

→ controlling torque is provided by a balancing weight

Construction

- HV electrode insulated from earth
- LV electrode - central point movable
- Light beam
- Scale.

operation:

- High voltage is applied.
- Due to electrostatic force deflection of rotating element
- Light focused on the mirror
- gets reflected & measured.

→ Disc diameter ↑ gap distance ↓

Drawback

- for const distance d, the sensitivity is small.

Adv

- No source Loading
- continuous Reading also possible.

Accuracy of DC vtg = ± 1 % or Less

Sphere gap:

Sphere gap is used to measure voltage measur...

A uniform field spark gap will always have sparkover with known tolerance under const. Atmospheric condition.

Sphere gap can be arranged either (i) vertically with Lower sphere ground. (or) (ii) horizontally with both spheres connect to the source voltage (or) one sphere grounded.

Two spheres are identical in size & shape.

Spacing S.

Series Resistance

- Limit the breakdown current
- to suppress the unwanted oscillation in the source voltage.

ac → 100 – 1000 kΩ

dc → 500Ω

impulse → not more than 500Ω.

Operation:

The applied voltage is uniformly increased until sparkover occurs in the gap. Generally a mean of about 5 breakdown value is taken when they agree to within ± 3%.

Working
→ For dc
the ...
un...

Working:

→ For dc voltage & AC peak voltage Measurement, the applied voltage is uniformly increased until sparkover occurs in the gap. Average of 5 readings gives the disruptive voltage with an Accuracy of ± 3%.

→ For impulse voltage measurement, 50% flashover voltage, two voltage limits differing by not more than 2% are set by adjusting the sphere gap.

→ Applying Lower Limit value & take 2 or 4 Flash over values & similarly applying upper Limit value & take 6 or 8 flashover voltage, then take the average of these two Limits which is 50% Flashover Voltage.

Factors affecting the spark over voltage:

- → Nearby earth object
- → Atmospheric condition
- → Influence of humidity
- → Irradiation
- → polarity & rise time of voltage waveform.
- → switching surge.

Effect of Nearby earth object:-

→ The sparkover voltage is reduced due to the presence of near by earth object

Voltage reduction $\Delta V = m \log\left(\frac{B}{D}\right) + c$

B → diameter of earthed enclosing cylinder

D → diameter of sphere.

S - gap distance.

$\frac{S}{D} \leq 0.5$, $\frac{B}{D} \geq 0.8$ → percentage reduction is 2%.

$S/D = 1$, $\frac{B}{D} \geq 1$ → percentage reduction is 3%.

Reduction voltage is within accuracy limit $S/D < 0.6$

Effect of Atmospheric condition:

→ Air density measurement differs due to temperature & pressure variation.

Spark over voltage density depends on air density factor.

Spark over voltage $V = k V_0$.

$$\delta = \frac{P}{760}\left(\frac{273 + t_0}{273 + T}\right)$$

t_0 → std. temperature.

T → temperature at test condition

Influence of Humidity:

Sparkover voltage increases with humidity of spark over voltage due to humidity is less than 3%.

Humidity effect increases with size of sphere, partial of water, vapour in air, increase in gap length.

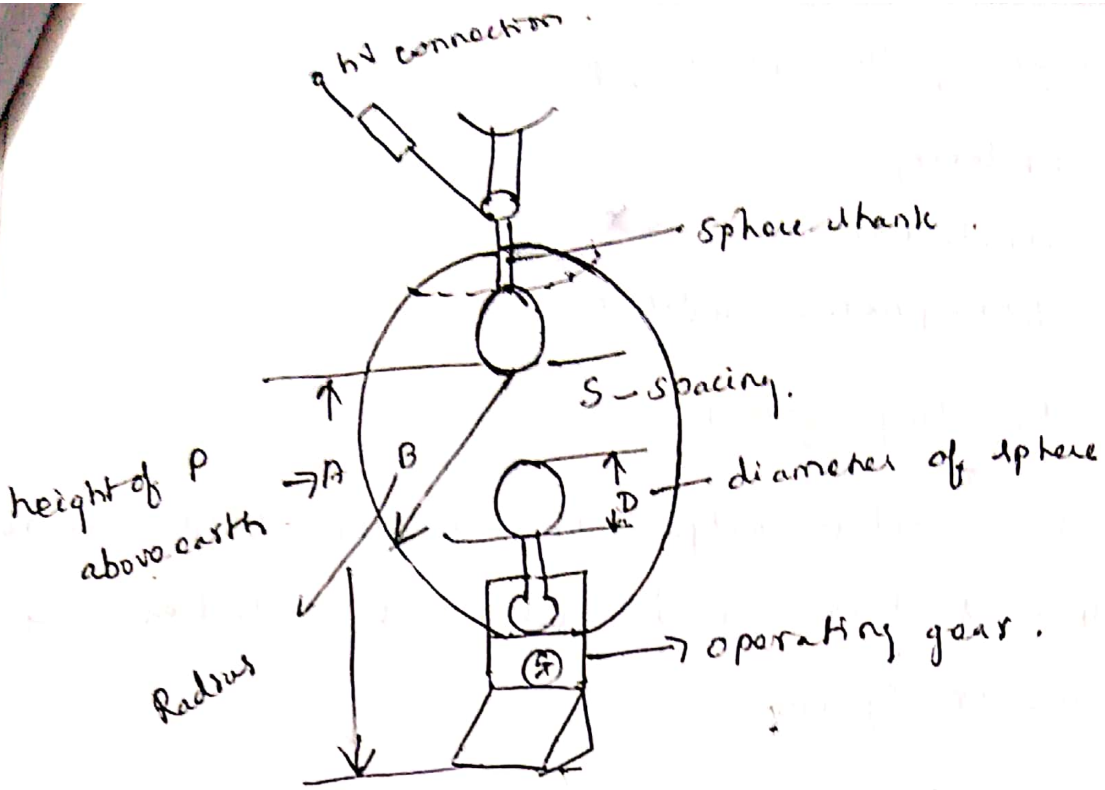
Effect of Irradiation:

→ Irradiation is necessary for smaller sphere gap spacing less than 1cm.

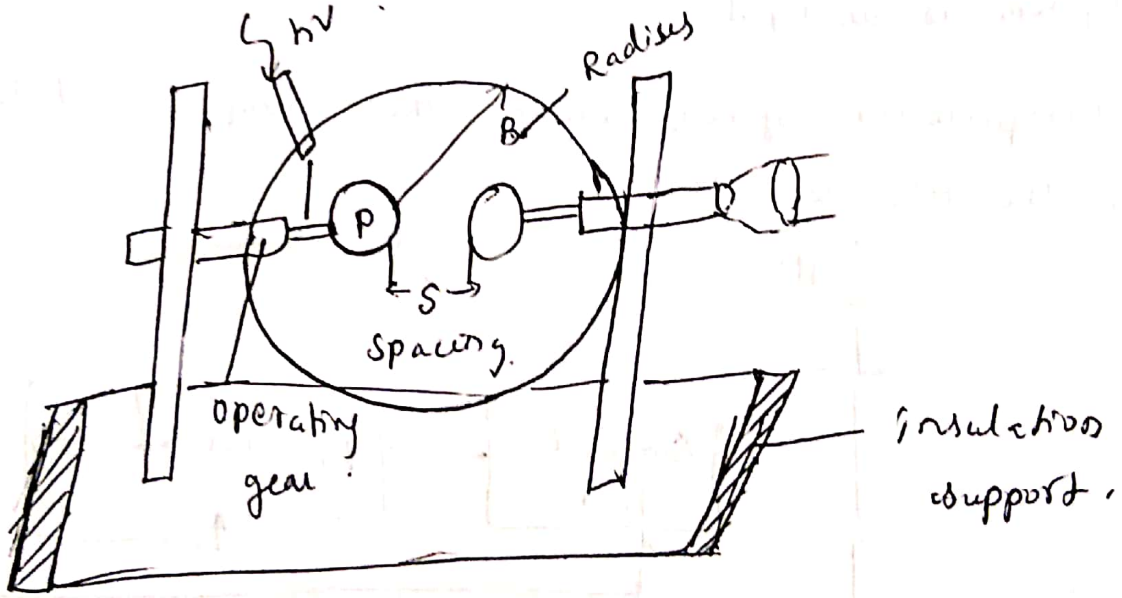
→ ultraviolet / x-rays are used to ionize the air in the gap.

Effect of polarity:- → positive & negative impulse are different.

→ Spark over voltage are varied by switching surge.



Vertical arrangement



sphere gap is made up of copper, brass or Aluminium,

D = 2, 5, 6.5, 10, 12.5, 15, 25, 50, 75, 100, 150, 200cm.

radius = 0.3 D

Factors affecting the sphere gap

→ polarity

→ irradiation

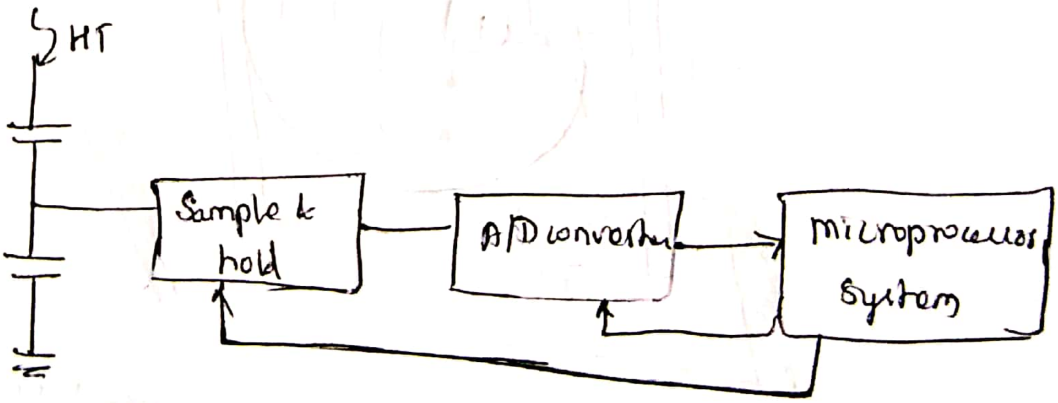
→ Atmospheric condition.

Digital Recording System

→ The Low voltage output of capacitor divider is fed to a sample & hold circuit which is controlled by a microprocessor system.

→ The output of sample & hold ckt is fed to an analog to digital converter, the proportional digital output of which is fed to the microprocessor based system as an input.

→ Microprocessor system control the sample & hold circuit & the A/D converter:



Measurement of High Ac, Dc & Impulse current.

(i) Measurement of High Dc current.

(1) Reistive shunt

(2) Hall generator.

2) Measurement of High power frequency Ac current.

(1) current Transformer with electro optical Techniques.

3) Measurement of High frequency & Impulse current.

(1) Resistive shunts.

(2) Magnetic potentiometer (or) Probes

(3) Magnetic Links.

(4) Hall generator

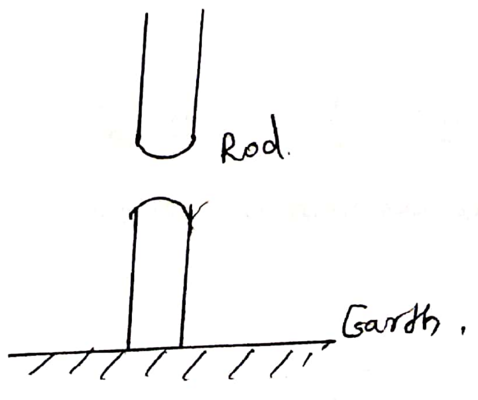
5) Faraday generator.

4) Measurement of Impulse voltage & current.

(1) cathode ray oscilloscopes.

Rod gaps:

→ It is used to measure peak value of impulse voltage & power frequency.



phasor diagram:

The motor is taken as a resistive Load & X_m' neglected V_2' be the voltage across the motor

$$V_2' = I_m R_m'$$

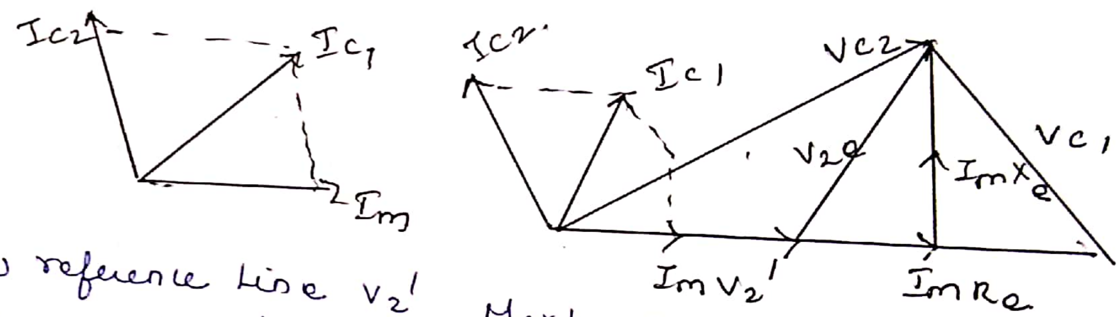
$$V_{c2} = V_2' + V_{2e}$$

$$= V_2' + I_m (R_e + X_e)$$

input voltage $V_1 = V_{c1} + V_{c2}$ ∴ $a = \frac{V_{c1} + V_{2e} + V_2'}{V_2'}$

Voltage ratio $a = \frac{V_1}{V_2}$.

$$I_{c1} = I_m + I_{c2}'$$



→ Draw reference Line V_2'. Mark $V_2' = I_m R_m'$ neglecting $I_m X_m'$.

→ from V_2' mark $I_m R_e$ in the same Line. Draw the perpendicular Line from V_{c2} which is I_{c2}.

→ I_{c2} Leads V_{c2} by 90°.

→ the vector sum of I_m & I_{c2} gives I_{c1}.

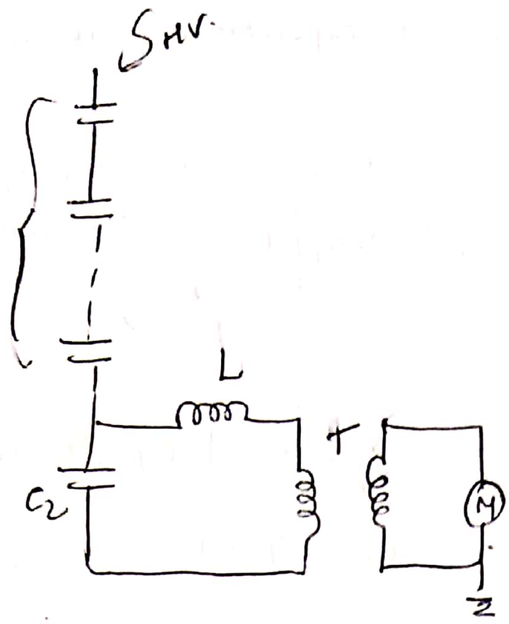
→ from V_{c2} draw perpendicular Lines for I_{c1} which is V_{c1} (ie) I_{c1} Leads V_{c1} by 90°.

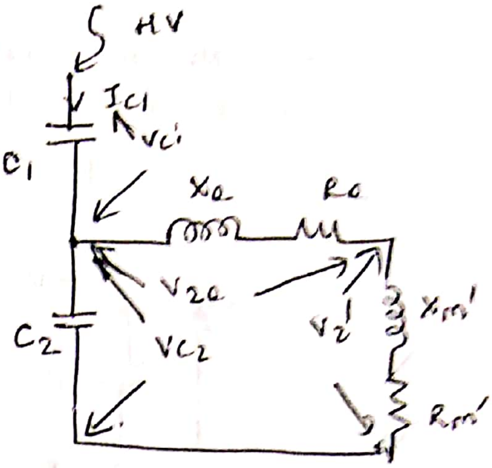
disadv:

→ voltage ratio is susceptible.

→ Ferro Resonance occur.

Capacitance voltage Transformer.





$C_1 = 1000pF$

→ Capacitance Voltage transformer is a device used in powersystem to measure voltage.

→ It consist of Capacitor divider with suitable matching transformer

→ It is connected to Low impedance coil.

Operation:

choke L is connected to the primary side of the potential transformer used to bring Resonance condition.

$$\omega(L + L_T) = \frac{1}{\omega(C_1 + C_2)}$$

High voltage = 10-30kV

Low voltage = 100 - 500V.

Adv:

- Simple design
- It provide isolation b/w HV & LV
- voltage distribution is independent of frequency.

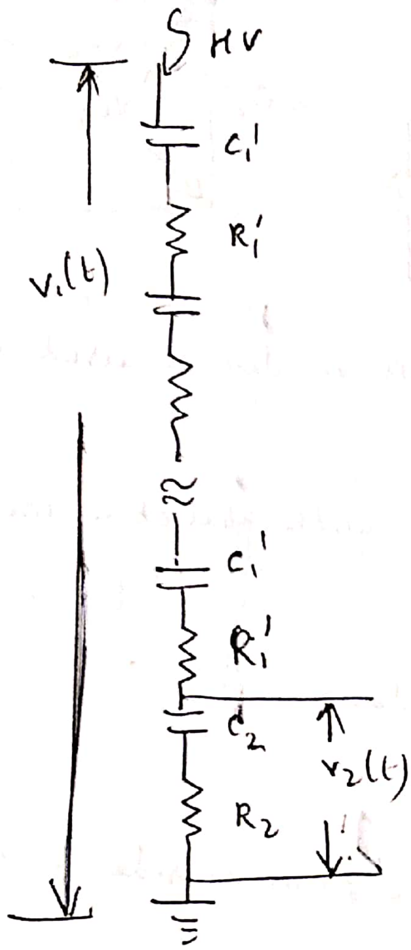
mixed RC potential divider

In this Resistance & capacitance are connected

series with or parallel.

mixed potential divider with Resistance & capacitor are connected in series

$$R_1' = \frac{R_1}{n} \qquad C_1' = nC_1\left(1 - \frac{C_g}{6C_1}\right)$$

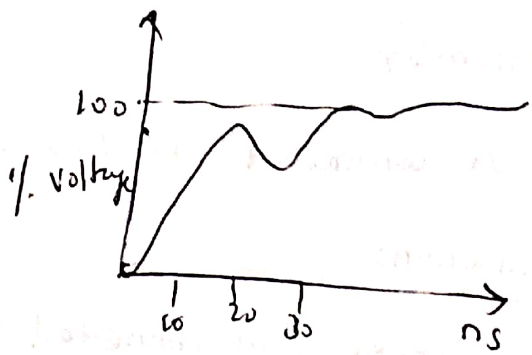


C_g - ground capacitance

C_1 - Total series capacitance

R_1 - Total Resistance

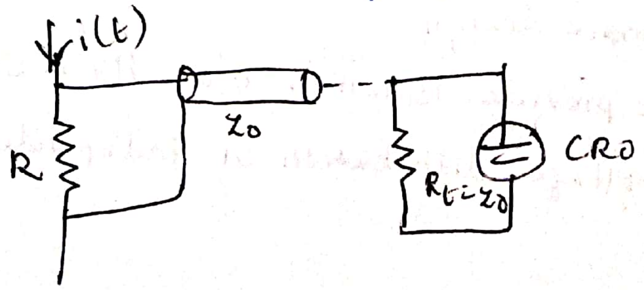
$$R_1C_1 = R_2C_2$$



High current shunt

Resistive shunt :

The high impulse current which is to be measured is passed through a Low ohmic pure Resistance.



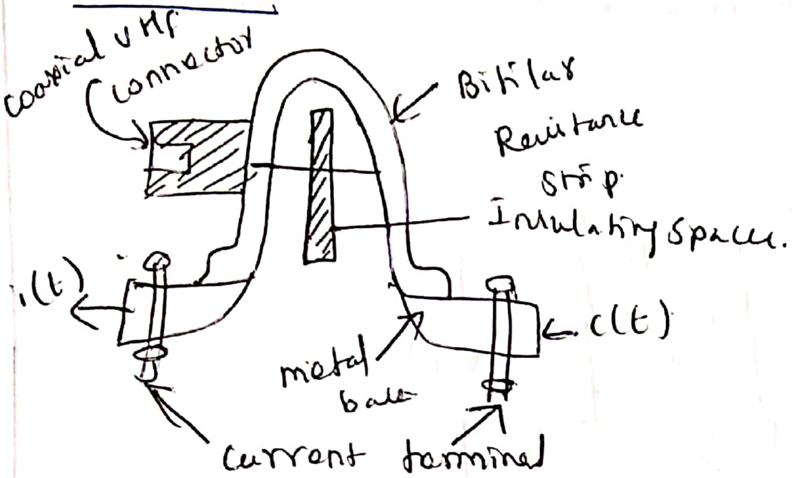
reduce stray effect, Resistance shunt is designed.

(1) Bifilar flat strip design

(2) coaxial tube (or) park's shunt design

(3) coaxial squirrel cage design.

Bifilar flat



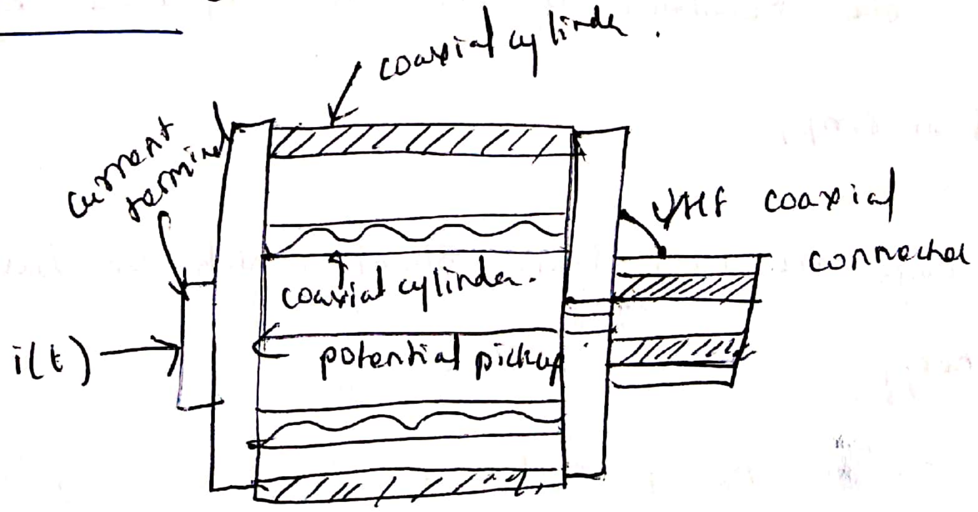
→ It consist of R element are wound in opposite direction & folded back

→ Both ends are insulated by teflon.

→ ultra high freq voltage signal is collected by a coaxial connector.

disadv → affected by stray inductance.

Coaxial tubular (or) Park's shunt.



The current is passed through the pickup point.

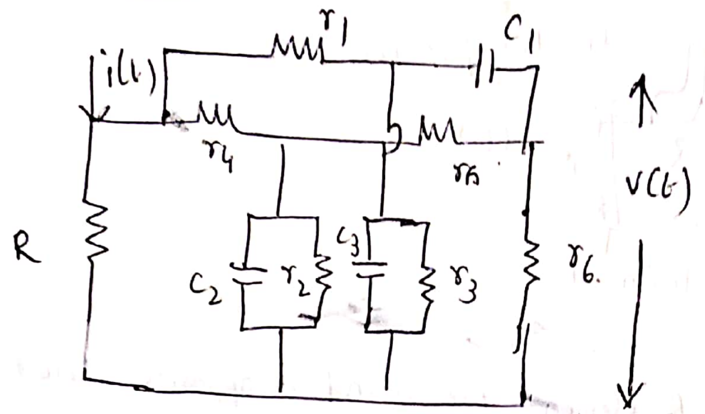
outer cylinder → copper or brass.

Max. freq Limit - 1000 MHz.

Response freq time = few nano sec.

upper frequency Limit is governed by skin effect

Squirrel cage shunts:



R → Shunt Resistance

$r_1 - r_6$ → resistance in compensating double T network

$C_1 - C_3$ → Capacitance in Compensating "

To overcome the problem of heat dissipation & skin effect, the Resistance cylinder is replaced by the rod or strips.

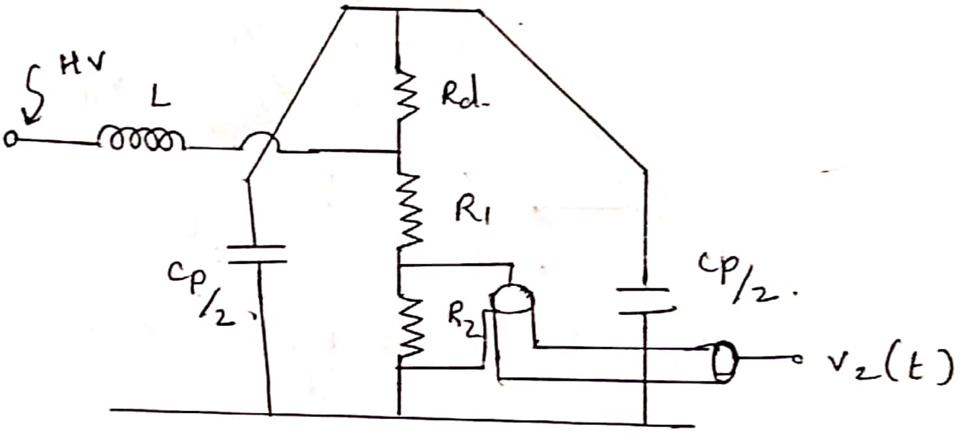
Squirrel cage are high ohmic shunt which can dissipate Large energy.

Skin effect :- When AC passed through the resistive element, the concentration of alternating current near the surface is called skin effect.

Field controlled voltage divider:

→ The electrostatic (or) capacitive field distribution of a shield (or) guard ring is placed over a Resistive divider. This arrangement is used to measure high voltage.

→ The field controlled voltage divider with damping Resistor is given. The shield has cone like structure.



R_1 - non linear Resistance

R_2 - parallel Resistance

Rd - damping Resistor

L - Lead inductance

Cp = capacitance of the shield to Ground

S - Shield.

→ oscillations will be produced due to Rd together with the Load inductance & shunt capacitance.

→ damping Resistance Rd → used to reduce oscillations. It is used for measuring very high voltage upto 2MV

Adv:

→ capacitance per unit Length is small

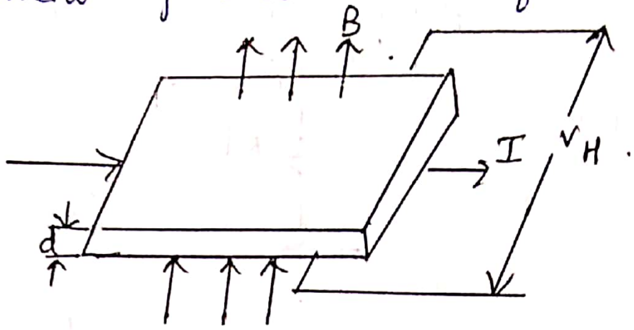
→ Loading effect is reduced.

→ Response time is less

→ overshoot is reduced.

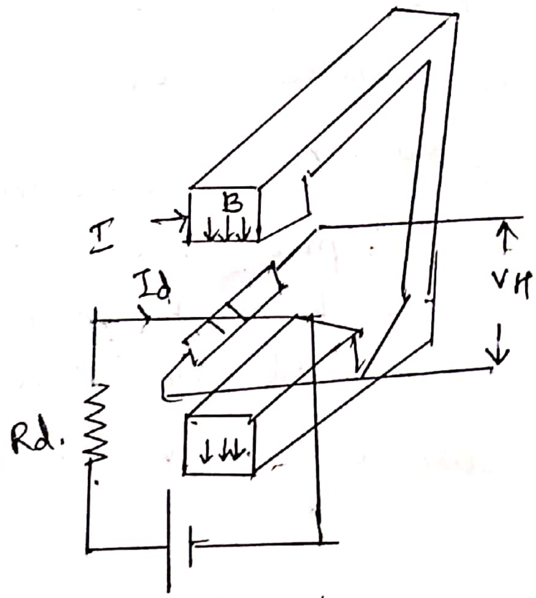
Hall Generator for Dc measurement:

Hall effect: Whenever an electric current flows a metal plate placed in a magnetic field perp. to it, Lorenz force will deflect the electrons in to metal plate in a direction perpendicular to both the magnetic field and flow of current. The change in displacement generate an emf called Hall voltage.



$V_H \propto \frac{BI}{d} = R.\frac{BI}{d}$ R: Hall coefficient.

Construction of Hall Generator.



→ Dc current which is to be measured is passed through the conductor. The conductor is wound on an iron core magnetic circuit. The magnetic circuit produce magnetic field in the airgap

$H = \frac{I}{\delta}$ δ → airgap distance (or) depth.

the Hall current (or) metal plate is placed in the airgap formed by the iron core magnetic circuit. It is connected in series with resistor & a battery.

→ A small dc current Id is passed through this Hall element.

→ According to Faraday's Law, whenever a current carrying conductor is placed in a magnetic field, emf is induced in it.

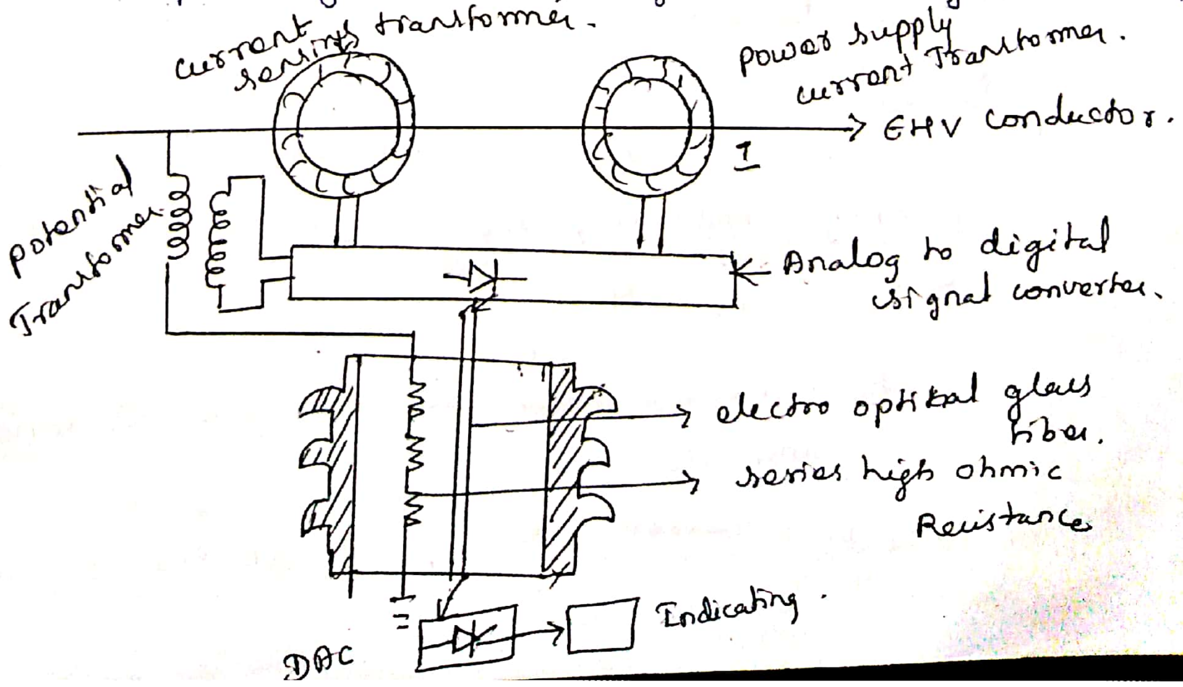
$$V_H \propto I \text{ (dc current)}$$

$$V_H = \frac{R \cdot B I}{d}.$$

R → Hall coefficient which depends on the temperature & high magnetic field strength & compensation provided for measuring High current.

current Transformer with electro-optical signal.

current transformer with electro optical signal converter for EHV system consist of current sensing Transformer, power supply current Transformer, potential Transformer, Analog to Digital signal converter, electro-optical glass fiber, Digital to Analog converter.



Operation:-

→ A voltage signal proportional to the measuring current is passed through the EHV conductor

→ A current transformer is used in the power circuit to step down the current to very Low value.

→ potential transformer is used in the power to step down voltage to a very Low value EHV conductor act as primary side of current transformer.

→ potential transformer primary is connected between EHV conductor & the ground through High series Resistance.

→ the secondary side of current Transformer and potential transformer (power to signal converter) are given to the Analog to Digital converter which converts the analog signal into Digital signal.

→ the digital signal is given to Analog converter converts the digital signal into Analog signal. this analog signal is given to the Recording unit.

Accuracy is ±5 % at rated current.

Magnetic potentiometer:-

principle:-

When a coil is wound surrounding a current carrying conductor, the voltage is induced in the coil

$$v(t) = M \cdot \frac{di(t)}{dt}$$

M → mutual inductance between the conductor and the coil

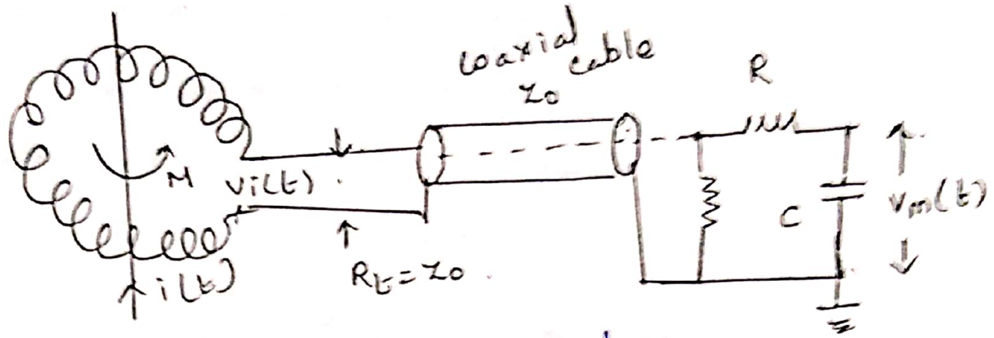
i(t) = current flowing through the conductor.

Construction:

→ The coil is wound on a non magnetic former of Toroidal shape and is placed surrounding the current carrying conductor.

→ To reduce the leakage reactance, the coil is wound crosswire.

→ To get enough signal induced, the No. of Turns on the coil is chosen to be Large.



Z_o → coaxial cable of surge impedance

R, C → Integrating circuit

Rogowski coil with integrating circuit is given above.

output voltage $V_m(t) = \frac{1}{RC}\int_0^t v_i(t) = \frac{1}{RC}\int_0^t M\frac{di(t)}{dt}$.

$$V_m(t) = \frac{M}{RC}\, i(t)$$

Voltage ∝ current to be measured.

For high frequency above 100 MHz, the response is affected by

→ Capacitance per unit Length along the coil

→ Skin effect

→ Electromagnetic interference.

Magnetic Links:

It is used for the measurement of peak value of impulse current but it is not used to give impulse waveshape.

Construction:

→ It consist of steel strips having high retentivity and area arranged on a circular wheel. These strips are used for the measurement of peak value of impulse current because it has the property of permanent magnetism for the current pulse 0.5/5 μs is same as that caused by a DC current of same value.

Operation:

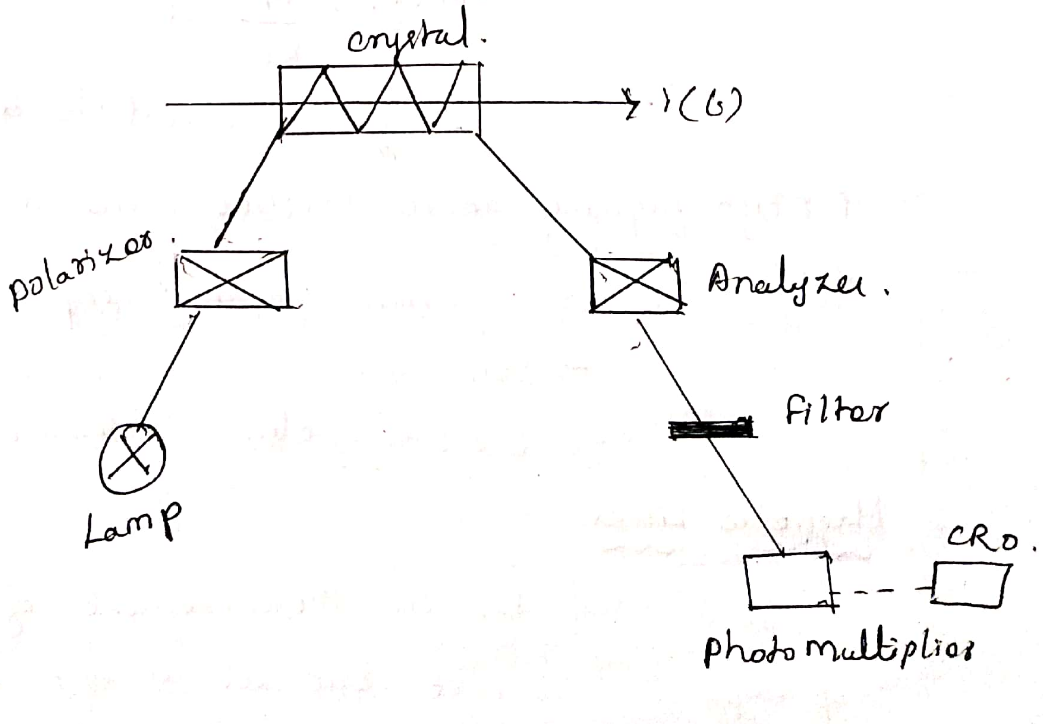
→ The strips were kept at a known distance from the current carrying conductor & placed parallel to it. The peak value of current is measured by measuring the permanent magnetism.

→ By increasing the No. of strips for accurate measurement of peak value.

uses:

→ Estimating the Lightning current on the transmission Lines & tower.

Faraday Generator (or) Magneto optic method



...iple: Faradey effect.

→ When a Linearly polarized Light beam passes through a transparent crystal in the presence of Magnetic field, the plane (or) polarization of the Light beam undergoes rotation. These rotation of the plane of polarization is proportional to the current.

angle of rotation $\propto B l$.

$= VBl$.

V → constant
B → Magnetic flux density
l – length of crystal.

Construction & operation:

→ A stabilized Light beam sources (Lamp) omits beam of Light. these beam of Light felt on the crystal through a polarizer.

→ the crystal is placed parallel to the magnetic field produced by the current i(t).

→ Due to Faraday effect, Light beam undergoes the Analyser then filtered by using filter to allow only monochromatic Light & is passed to the CRO through photo Multiplier.

→ By seeing the output display of oscillograph, the current can be measured. this device can't be operated for dc circuits.

Advantage:

→ No current connection between the source & the device.

→ No thermal problems even for Large current

→ No insulation problem arise for EHV system.

Cathode Ray Oscillogram:-

→ To record the impulse measurement. CRO is used

input voltage Range = 5 mV/cm to 20 V/cm

output voltage = 600 V (peak to peak)

Rise time = 5 Nanosec

Bandwidth = 500 MHz.

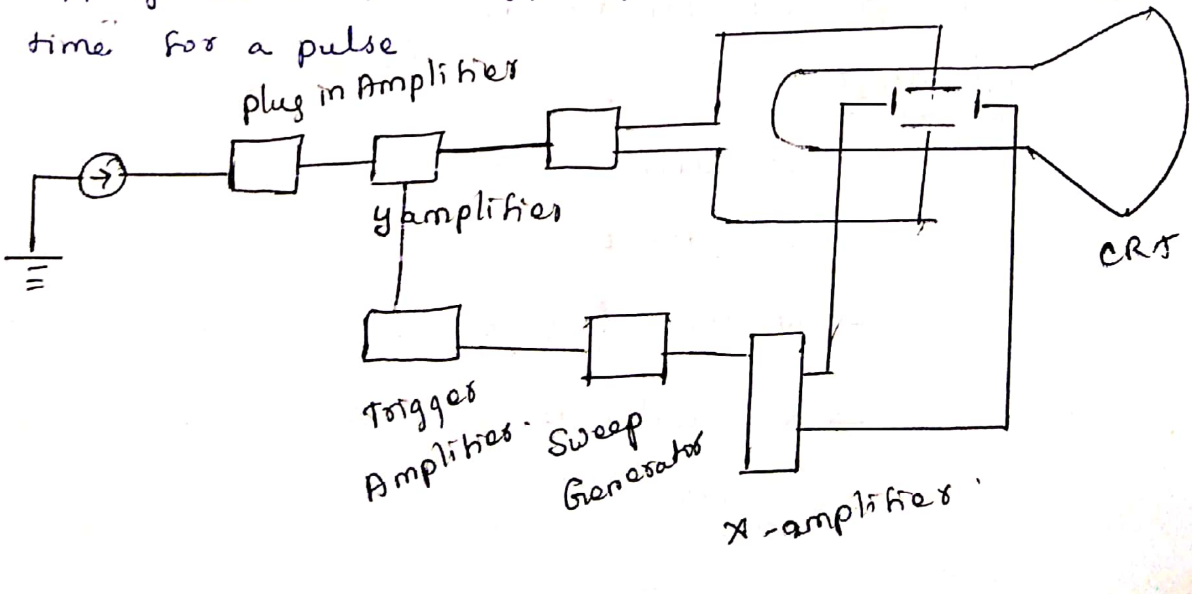
→ oscilloscopes have a good camera to record the waveform.

→ The input signal v(t) is given to the plug-in-Amplifier the amplified signal is given to the y-amplifier. and the Trigger circuit.

→ y-amplifier amplifies the magnitude of the signal and it is given to delay time for giving delay then is given to the Horizontal plates. The trigger circuits triggered the sweep generator to produce saw tooth waveform & it is given to the Horizontal (x) amplifier. & then it is given to the vertical plates.

→ the delay line gives delay, delay = 0.1 - 0.5 μs

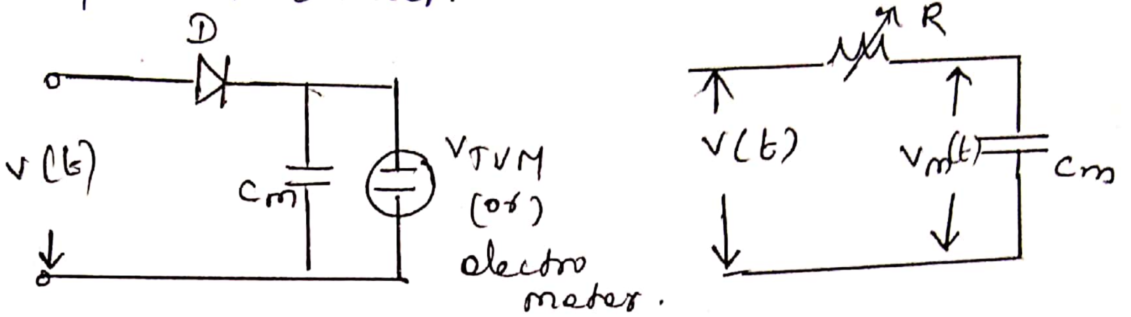
→ A Long interconnecting coaxial cable, using electronic tripping device for triggering & set a predetermined time for a pulse



peak reading voltmeter for Impulse Voltage.

peak reading voltmeter are used to measure impulse Voltage wave.

→ measuring instrument is connected to the Low voltage of the potential divider.



→ During (+ive) half cycle, diode D conducts & a impulse voltage v(t) appears across the Low voltage arm of the potential divider. the capacitor Cm charges to the peak value. Forward resistance of the diode is assumed to be finite.

→ During (-ive) half cycle, diode D conducts is reverse biased. Amplitude of the signal starts decreasing & prevents discharging of capacitor Cm.

→ voltage across Cm is measured by using VTVM (or) electrostatic voltmeter (or) electrometer.

measured voltage < Actual peak value.

UNIT - 5

High Voltage Testing & Insulation Coordination

→ High Voltage Testing of Electrical Power Apparatus as per International & Indian standards.

→ power frequency, impulse voltage & DC testing of
- → Insulator
- → circuit breaker
- → Bushing
- → Isolator
- → Transformer

→ Insulation coordination

→ Testing of cables.

Need of Testing for over voltages:

→ High Voltage Testing of electrical Apparatus is essential to ensure that the electrical equipment is capable of withstanding the over voltage.

→ The over voltages may be either due to Natural causes like Lightning or switching or power frequency transient voltage.

Disruptive Discharge Voltage:-

It is defined as the voltage which produces Loss of dielectric strength of an insulator.

Solid → permanent Loss of strength

Liquid or gases → temporary Loss

Flashover:-

When a discharge take place between two electrode in gas or a Liquid over a solid surface in air. It is called Flashover.

Puncture:-

If the discharge occur through a solid insulation it is called puncture.

withstand voltage:-

The voltage which has to be applied to a test object under specific conditions in a withstand test is called withstand voltage.

Flashover voltage:-

The voltage that causes a flashover at each of its application (Liquid or gas) under specific condition when applied to test object.

50% flashover voltage:-

→ The voltage which has a probability of 50% of flashover, when applied to test object.

→ This is normally applied in impulse test in which the Loss of insulation strength is temporary.

100% flashover voltage:-

The voltage that causes a flash over at each of its application under specified condition when applied to test objects as specified in 100 % flashover voltage.

wet & dry flashover Power frequency test :-

In these tests, the voltage specified in the specification is applied under wet (or) dry condition for a specified period. The test object should withstand the voltage.

creepage distance :-

It is the shortest distance on the contour of the external surface of the insulator unit or between two metal fittings on the insulator.

Ac Test voltages:

→ Alternating test voltage of power frequency should have a frequency range from 40 Hz to 60 Hz and should be approximately sine wave.

→ the deviation allowed from the standard sinewave is about 7%. the deviation is checked by measuring instantaneous values over specified intervals & computing the rms value, the average value & Form factor.

Impulse voltage :-

→ Impulse voltage is characterised by polarity, peak value time to front (t_f) & time to half the peak value after the peak (t_t).

Time to Front (t_f)

It is defined as 1.67 times to time between 30% & 90% of the peak value in the Rising portion of the wave.

The standard impulse wave is defined one with $t_f = 1.2 \mu s$ & $t_t = 50 \mu s$.

Tolerance :-

± 3% of peak value.

± 30% of front time (t_f)

± 20% of tail time,

Indian & International standard specification.

→ According to Indian standard specificiation,

Temp : 27°c

pressure : 1013 millibars (or 760 torr)

Absolute humidity : 17 gm/m^3

→ According to British standard specification.

Temp = 20°c

pressure = 1013 millibars (760 torr).

Absolute humidity = 11 gm/m^3.

Flash over voltage :-

The flashover voltage of Test object is given by $V_s = V_a \times \frac{h}{d}$.

V_a → Voltage under actual test condition

V_s → Voltage under reference Atmosphere.

h → humidity correction factor

d → air density correction factor.

Air density correction Factor :-

$$d = \frac{0.289\,b}{273+t} \quad \text{for } 20^\circ C$$

$$d = \frac{0.296\,b}{273+t} \quad \text{for } 27^\circ C$$

where, b → atmospheric pressure in millibars

t → Atmospheric temperature in °C.

Humidity correction Factor :-

Humidity correction Factors is obtained from the temperature of wet & dry bulb thermometer, by obtaining the absolute humidity.

Testing of Insulator :-

Insulator are the element which provide necessary insulation between line conductor & support and thus prevent any leakage current from the conductor to earth.

Types of Insulator :-

→ pin type Insulator

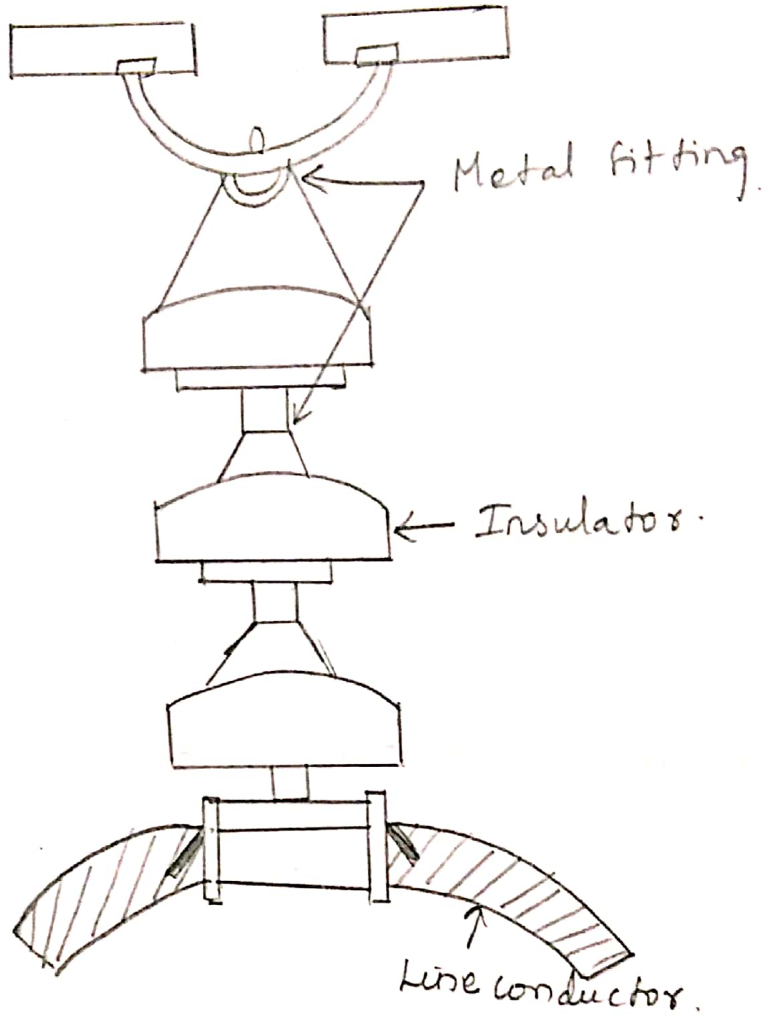
→ Suspension type Insulator

→ Strain Insulator

→ Shackle Insulator.

→ stay insulator
→ stack insulator.

Suspension type insulator



The test that are normally conducted are divided into,

(i) Type test

(ii) Routine test.

Type Test	Routine Test.
→ these tests are intended to prove (or) check the design features and the quality.	→ these test are intended to check the quality of the individual test piece.

→ Type test are done on samples when new designs (or) design changes are introduced.	→ Routine tests are done to ensure the reliability of the individual test objects and quality and consistency of the materials used in their manufacture.

High voltage test include

(1) power frequency test

(2) Impulse test.

1) power frequency test :-

(1) Dry & wet flashover test

(2) Dry & wet withstand test (one minute)

(i) Dry & wet flashover test :-

→ In these tests, the AC voltage of power frequency is applied across the insulator & increased at a uniform rate of about 2% per second of 75% of the estimated test voltage.

→ power frequency voltage is maintained for one minutes. The voltage is then increased gradually until the flashover occurs.

→ The insulator is then flashed over at least Four times.

→ The voltage is raised gradually to reach flash over in about 10 sec.

→ the polarity of the impulse voltage of 1.2/50μs wave is Reversed & procedure is repeated.

→ The mean of flashover voltage must not be than the value specified in the specification.

Dry flashover Test :-

If the test is conducted at under normal conditions without any rain (or) precipitation, it is called Dry flashover test.

Wet flashover voltage:- (or) wet withstand test

→ If the test is carried under condition of artificial rain it is called wet flashover test.

→ The test object is subjected to a spray of water of given conductivity by means of nozzles.

→ The spray is arranged such that the water drops fall approximately at an inclination of 45° to the vertical.

→ The test object is sprayed for atleast one minutes before the voltage application, & a spray is continued during the voltage application.

Characteristics of the spray (or) specification.

precipitation Rate → 3 ± 10% (mm/min)

Direction → 45° to the vertical

conductivity of water → 100 μ siemens ± 10%

water temperature → Ambient ± 15°C.

If more than two flash over occur of five flashover test, then the insulator is deemed to have failed the test.

(ii) Wet and Dry withstand test: (one minute).

→ In these tests, the test voltage is applied under dry and wet condition for a period of one minute with an insulator mounted as in service condition.

→ The test piece should withstand the specified voltage.

2) Impulse test :-

- Impulse withstand voltage test
- 50% dry impulse flashover test.
- pollution test.

(i) Impulse withstand voltage test :-

→ This test is done to applying standard impulse voltage of 1.2/50 μs wave under dry condition with both polarities (positive & negative) of the wave.

→ If five consecutive waves donot cause a flashover (or) Puncture, the insulator is deemed to have passed the test.

→ If two applications cause flashover the insulator is deemed to have failed.

→ If there is only one failure, additional ten applications of the voltage wave are made.

→ If the test object has withstood the subsequent application, it is said to have passed the test.

Wet withstand test :-

If the test is carried out under artificial rain, it is called wet withstand test (or) wet withstand flash over test. The insulator is subjected to spray of water.

Specification of water :-

precipitation rate : 3 ± 10% (mm/min)

Direction : 45° to the vertical.

continuity of water : 100 μsiemens ± 10%.

Ambient Temperature : +15°c.

→ The insulator with 50% of the one minute rain test voltage is applied & sprayed rain water for two minutes, the voltage is raised to one minute test voltage for 10sec, and maintained for one minutes. Now voltage is increased gradually till flashover occurs.

→ Insulator is flashed at least four times, the time taken to reach flashover voltage is about 10 sec.

→ Flashover voltage > specified value.

(ii) 50% Dry Impulse Flashover test :

→ 50% Dry Impulse flashover test is done by applying standard impulse voltage of specified value under dry condition with both positive & negative polarities of the wave.

→ Here the probability of Failure is determined for 40% & 60% failure value (or) 20% and 80% failure values, since it is difficult to adjust the test voltage for extract 50% flashover values. The average value of the upper & lower limits are taken.

→ The insulator surface should not be damaged by these test, but slight marking on its surface or chipping off of the cement is allowed.

(iii) Pollution testing :

Types of pollutions are.

(i) Dust, micro organism, bird secretions, flies etc.

(ii) Industrial smoke, petroleum vapours, dusts & other objects.

(iii) coastal pollution in which corrosive & hygroscopic salt layer are deposited on the insulator surface.

(iv) Desert pollution in which sand storm cause deposition of sand & dust layer.

(v) In polar countries, Ice & fog deposits at high altitudes.

these pollution cause corrosion, non-uniform gradient along the insulator surfaces, deterioration partial discharge & Radio Interference.

Salt fog test :-

→ In these test, the maximum normal withstand voltage is applied on the insulator and then the artificial salt fog is created around the insulator by jets of salt water & compressed air.

→ If flashover occur within one hour, the test is repeated with fog of Lower salinity.

→ If the flashover occur after one hour, the test is repeated with a fog of higher salinity.

→ If the maximum salinity at which the insulator withstands, Three out of Four tests without flashover, the insulator is deemed to have passed.

Testing of Bushing :

(1) power frequency test
- → power factor voltage test
- → partial discharge test
- → momentary withstand test
- → visible Discharge test

(2) Impulse voltage test
- → Full wave withstand test
- → chopped wave wet withstand.

(3) thermal test
- → temperature Rise test
- → Temperature Stability test

1) power frequency Test :

(a) power factor Voltage test :

Bushing are connected to the highvoltage side of the line and are immersed in the oil. The tank (or) earth is connected to the detector side of high voltage schering bridge.

→ Voltage is applied up to the Line Value in increasing steps & then reduced.

→ The capacitance & power factor are recorded in each step.

(b) Internal (or) Partial discharge test :

→ Bushings are made up of composite dielectric, when voltage is applied, partial discharge occur in the bushing because of presence of voids, cracks & imperfections.

→ A graph is drawn between voltage & discharge which gives the performance of bushing.

→ It is a routine test.

(c) momentary withstand test at power frequency.

→ When a standard impulse voltage of 1.2/50 μs wave is applied to bushing, check the working condition of bushing & voltage for a minimum time says 30 sec.

→ The bushing is said to have passed if no failure (or) puncture of bushing occurs.

(d) Visible Discharge test:

The specified voltage is applied to the bushing in a dark room. The bushing is said to have passed if no visible discharge other than arcing horns. This test can be conducted to determine whether radio interference occur in service.

(2) Impulse Voltage test :-

(i) Full wave withstand test :-

Standard impulse voltage of 1.2/50 μs wave. is applied for both (+ive) and (-ive) polarities.

out of 5 consecutive application of standard impulse wave.

→ The bushing is said to have failed, if two flash over take place.

→ If one flash over occurs, then ten consecutive applications of standard impulse wave A the bushing is said to have passed if no flash over take place.

(ii) chopped wet withstand & switching surge test :

The chopped wet withstand and switching surge test is conducted for high voltage (220kV & above), applications. The specified voltage applied to the bushings may be chopped wave (or) standard switching surge.

out of 15 consecutive application of standard impulse wave :-

→ the bushing said to have failed if two flash over take places.

→ If one flash over occurs, then ten consecutive application of standard impulse wave & bushing is said to have passed, if no flash over take place.

3) thermal test :

(i) Temperature rise test :

→ It is conducted in free air with an ambient Temperatures below 40°c at rated power frequency (50 Hz) A.C current. this test is conducted for a Long time.

→ Bushing is said to have passed the test if temperature rise is Less than 1°c.

(ii) Temperature Stability test :

→ Sometimes the bushing is operated with Transformer, the temperature may increase beyond 80°c & thermal run away condition occurs, so thermal stability test is essential.

→ When 86% of nominal System voltage is applied to the bushing which is immersed in oil & in service condition & working at maximum temperature.

→ this test is conducted for bushing used for above 132 kV, In high voltage application, the dielectric Losses are high.

Testing of cables:

The cables are used for transmission of electrical energy by underground means & is mostly used for High Voltages.

Different tests are conducted on cable are.

(i) Mechanical test
- Bending test
- Dripping & Drainage test
- Fire Resistor test
- Corrosion Test.

(ii) Thermal Duty test

(iii) Dielectric power factor Test

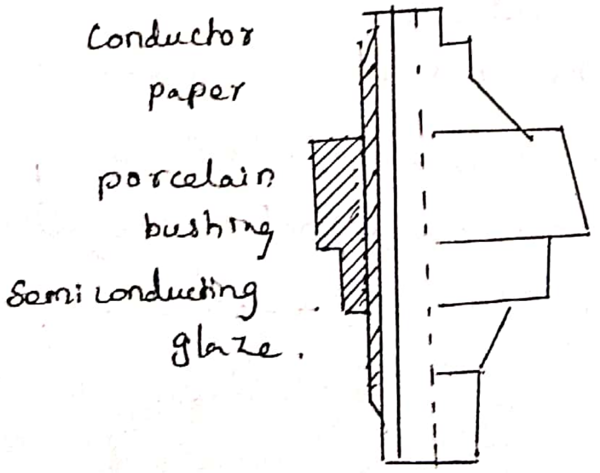
(iv) power frequency withstand voltage test

(v) Impulse withstand vtg test

(vi) Partial discharge test

(vii) Life expectancy test.

(i) Preparation of the cable samples.



Resistance grading.

Dielectric power Factor test:

→ It is done using HV schering Bridge

→ The powerFactor (or) dissipation factor '$\tan\delta$' is measured at 0.5, 1, 1.66, 2 times the rated phase to ground voltage of the cable.

→ Max value of powerFactor & difference in powerfactor between rated voltage & 1.66 times of rated voltage is specified.

→ The difference between the rated voltage & 2 times of rated voltage is also specified.

→ A choke is used in series with cable to form a Resonant circuit.

→ This improves the power Factor & rises the test voltage between the cable core & the sheath to the required value when a HV & high capacity source is used.

High voltage testing on cables:

→ power frequency HV AC, DC, impulse voltage are applied to test the withstanding capability.

→ continuity is checked with high voltage at the time of Manufacturing.

Routine test:

- Cable should withstand 2.5 times of the rated voltages for 10 mins without damage in insulation

Type test:

- Done on samples with HVDC & impulse

→ DC test:- 1.8 times of the rated voltage (-ive) applied for 30 mins.

→ Impulse test. 1.2/50 μs wave applied. Cable should withstand 5 consecutive impulses without any damage.

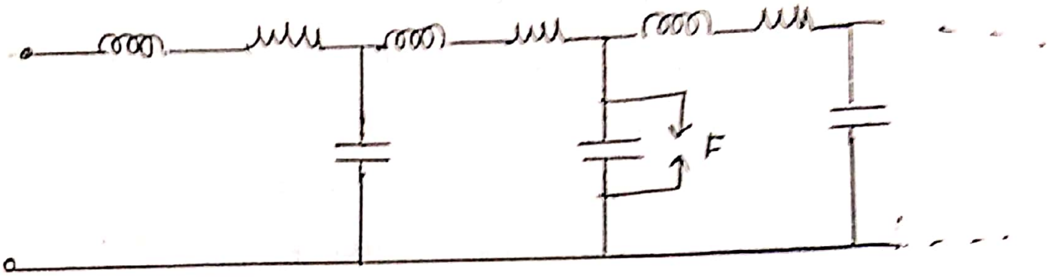
→ After impulse test, power frequency & power fre test is conducted to ensure that no failure o during impulse test.

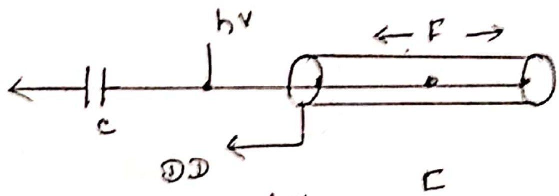
partial discharge test:

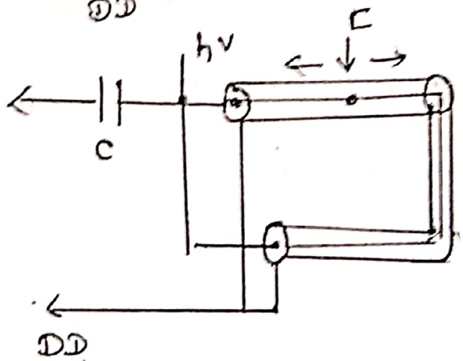
(i) Discharge measurement.

→ Life time of insulation depends on the internal discharge So PD measurement is important.

→ In this test, weakness of insulation or Failure can be detected.







→ If the coupling capacitor connected, transient wave will be received directly from the discharge cavity and second wave from the wave and ie) two transient pulses is detected.

→ Two transient arrive at both ends of the cable super imposition of the two pulses detected give serious error in measurement of discharge.

→ Time duration between consecutive pulses can be determined.
→ the shape of the voltage gives information on the nature of discharge.

(iii) Scanning method :-
→ Cable is passed through high electric field & discharge Location is identified.
→ cable core is passed through a tube of insulating material filled with distilled water.
→ Four ring electrodes mounted in contact with water
→ middle electrode given to HV. If a discharge occurs in the portion between the middle electrodes, as the cable is passed between the middle electrode's portion, the discharge is detected. and located at the length of the cable.

Life test:

For Reliability studies in serives.

Accelerated life tests conducted with increased voltage to determine the expected life time.

$$E_m = k_t(1/n).$$

Where,

k → constant depends on field condition & material

n → Life index depends on material.

Testing of Isolator & circuit Breaker:

Isolator:

- off Load or minimum current breaking Mechanical switch. IS:9921 part-1, 1981.
- Interrupting small currents (0.5A): Capacitive current of bushings, busbar etc.

Circuit Breaker:

- on Load (or) high current breaking Switch.

Testing of circuit breaker:

Testing on the circuitbreaker carried out to evaluate.

→ constructional & operating characteristics.

→ Electrical characteristics.

Electrical characteristics

- Arcing voltage
- current chopping characteristics.
- Residual current
- Shunting effect in interruption.

physical characteristics

→ Arc extinguishing medium

→ speed of contact

→ No. of. breaks

→ size of the arcing champer.

circuit characteristics.

→ Applied Voltage

→ Type of fault

→ frequency

→ power factor.

→ Restriking voltage

→ Rate of rise of recovery voltage.

→ Time of interruption.

→ Degree of electrical Loading.

Dielectric test:

→ consist of over voltage withstand test of power frequency Lightning & switching impulse voltage.

→ Tested for internal and external insulation with CB in both the open & closed position.

→ voltage in open position > 15% of that of closed position.

→ During test, CB is mounted on insulator above ground to avoid ground flashover.

Impulse test:

Impulse test & switching surge tests with switching over voltage are done.

Thermal test:-

→ To check the thermal behaviour of the breaker

→ Rated current through all three phases of the switchgear is passed continuously for a period long enough to achieve steady state condition.

→ Temperature rise must not exceed 40°C when the rated normal current is less than 800 A & 50°C if it is 800 A & above.

→ contact resistance between the isolating contacts, between the moving & fixed contact is important. These point are generally the main sources of excessive heat generation.

Mechanical Test:

→ To ensure the open & closing without Mechanical failure.

→ It requires 500 operations without Failure and with no adjustment of the mechanism.

→ A resulting change in the material (or) dimensions of a particular components may considerably improve the life and efficiency of the Mechanism.

Short circuit test:

→ To check the ability to safely interrupt the fault current.

→ To determine the making and breaking capacities at different load current.

→ Methods of conducting short circuit tests.

(i) Direct tests

→ using the power utility system as the source

→ using the short circuit generator as the source.

(ii) Synthetic tests.

(i) Direct tests → using the power utility system as the source

→ To check the ability to make or break in normal load condition (or) short circuit conditions in the network itself.

→ done during limited energy consumption

Advantage

→ Tested under actual condition

→ special case are tested.
- very short line fault

→ Thermal & dynamic effects of SC currents.

disadv:

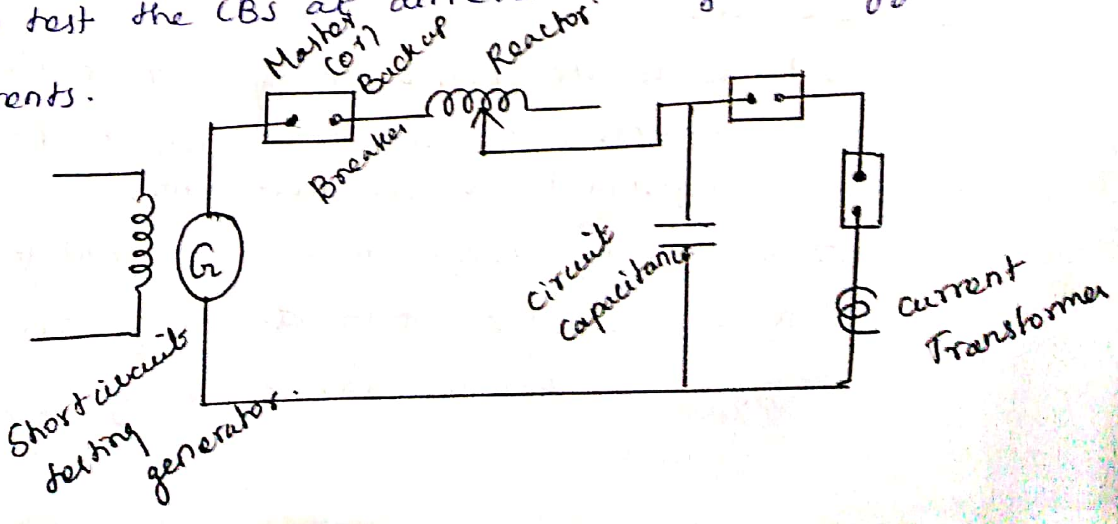
→ can be tested only in rated voltage & capacity of the network.

→ Test only light load.

→ Inconvienience.

(ii) Direct testing - Short circuit test in Laboratory

→ To test the CBs at different voltage & different SC currents.



The setup consist of

- → SC generator
- → Reactors
- → Master CB
- → Measuring devices.
- → Resistors.

→ The make switch initiates the circuit short circuit & master switch isolates the test device from the source at the end of predetermined time.

→ If the test device failed to operate, master CB can be triggered.

Synthetic testing of CB:-

→ Heavy current at low voltage is applied.

→ Recovery voltage is simulated by high voltage, small current source.

procedure:

→ Auxiliary Breaker 3 & test circuit breaker T closed, making switch 1 is closed. Current flows through test CB.

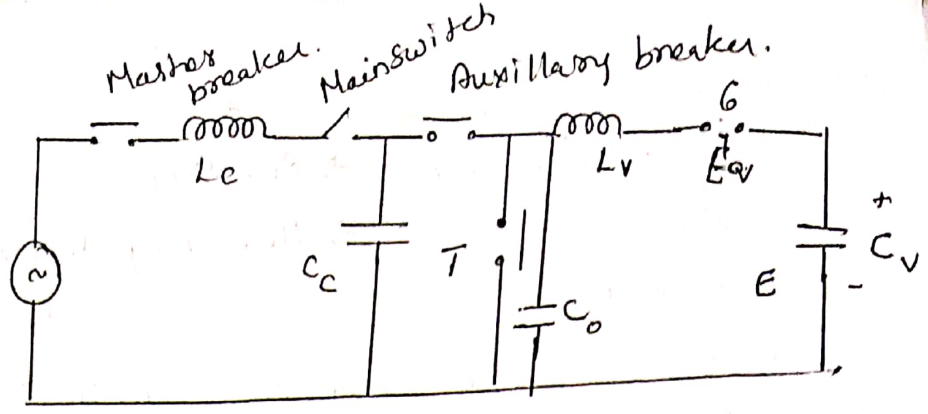
→ At time t_0, the test CB begins to open & the master breaker 1 becomes to clear the generator circuits.

→ At time t_1, just before zero of the generator circuit, the trigger gap 6 closes & high frequency current from capacitance C, flows through the arc of the gap.

→ At time t_2, generator circuits is zero, Master CB 1 is opened.

→ The current from will flow through test CB & full voltage will be available.

→ At the instant of breaking, the source is disconnected and high voltage is supplied by auxillary CB4.



Synthetic Testing of circuit Breaker.

Testing of Transformer:

Transformer is one of the most expensive & important equipment in power system.

Induced over voltage test:

→ Transformer secondary is excited by HVAC (100-400Hz) to about twice the rated voltage.

→ this reduce the core saturation & also limits the charging current necessary in Large Transformer.

→ the insulation withstand strength can be checked.

Partial Discharge test:

→ To assess the magnitude of discharge.

→ Transformer is connected as a test specimen & discharge measurements are made.

→ Location & severity of fault is ascertained using the travelling wave theory technique.

→ Measurements are to be made at all terminal of the transformer.

→ Insulation should be designed that the discharge measurement should be much below 10^4 pC.

Impulse Testing of Transformer:

→ To determine the ability of the insulation to withstand transient voltages.

→ In short rise time of impulse, the voltage distribution along the winding will not be uniform.

→ Impulse voltage applied to the equivalent set up uneven voltage distribution & oscillatory voltage higher than the applied voltage.

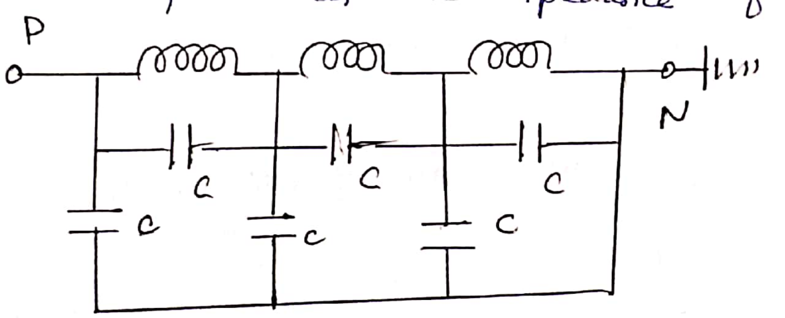
Impulse test:

→ Full wave std. impulse

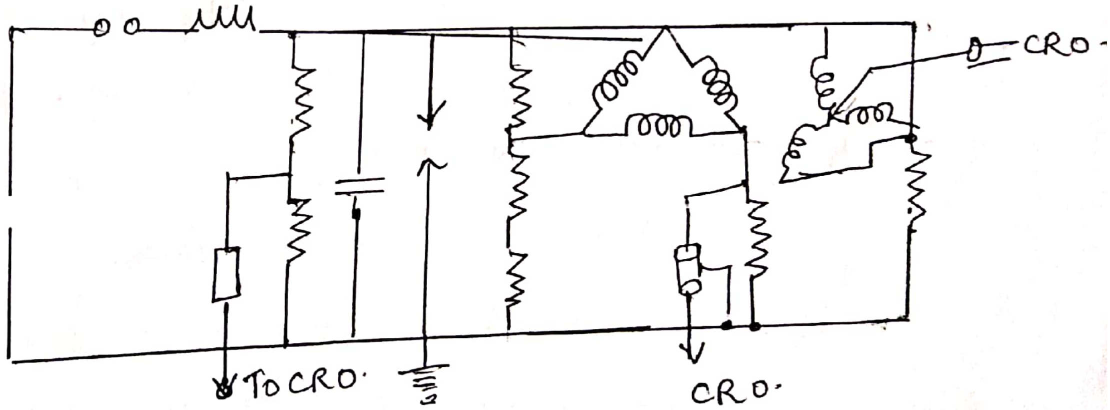
→ chopped wave std. impulse (chopping time → 3 - 6 μs)

→ the winding which is not subjected to test are short circuited & connected to ground.

→ Short circuiting reduces the impedance of the Transformer



procedure for Impulse test:



The voltage & current waveform are recorded during test. Sometimes the transferred voltage in secondary and neutral current are also recorded.

Impulse testing consist of the following steps.

(i) Application of impulse of magnitude 75% of the Basic Impulse Level (BIL) of the transformer under test.

(ii) one full wave of 100% of BIL

(iii) Two chopped wave of 115% of BIL.

(iv) one full wave of 100% of BIL

(v) one full wave of 75% of BIL.

→ During impulse testing the fault can be located by general observation like noise in the tank or smoke or bubble in the breather.

→ If there is a fault, it appears on oscilloscopes as a partial (or) complete collapse of the applied voltage.

→ Study of the waveform of the neutral current also indicated the type of fault.

→ If an arc occurs between the turns or from turn to the ground, a train of high frequency pulses are seen on the oscilloscopes & waveshape of impulse changes.

→ If it is only a partial discharge, high freq oscillation are observed but no change in waveshape occurs.

→ Impulse strength of the transformer winding is same for either polarity of wave whereas the flashover voltage for bushing is different for different polarity.

Insulation coordination:

The process of bringing the insulation strengths of electrical equipment and buses into the proper relationship with expected overvoltage and with the characteristics of the insulating media and surge protective devices to obtain an acceptable risk of failure.

BIL (Basics Lightning Impulse insulation Level)

The electrical strength of insulation expressed in terms of the crest value of standard Lightning impulse under standard Atmospheric condition.

BSL (Basic switching impulse insulation Level)

The electrical strength of the insulation expressed in terms of crest value of a standard switching impulse.

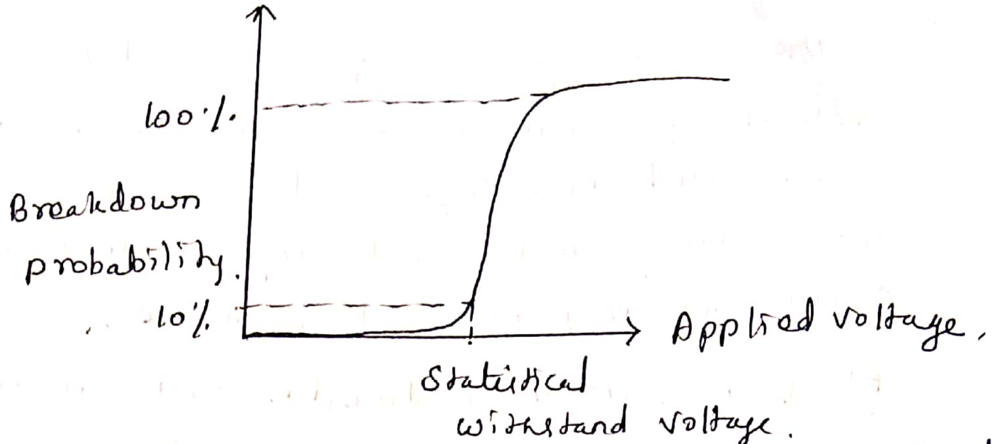
Factors of Earthing:

This is the ratio of the highest rms phase to earth power frequency voltage on a sound phase during an earth fault to the rms phase to phase power frequency voltage which would be obtained at the selected Location without fault.

A system is said to be effectively earthed, if the factor of earthing doesnot exceed 80% and non effectively earthed if it does.

Statistical Impulse withstand Voltage:

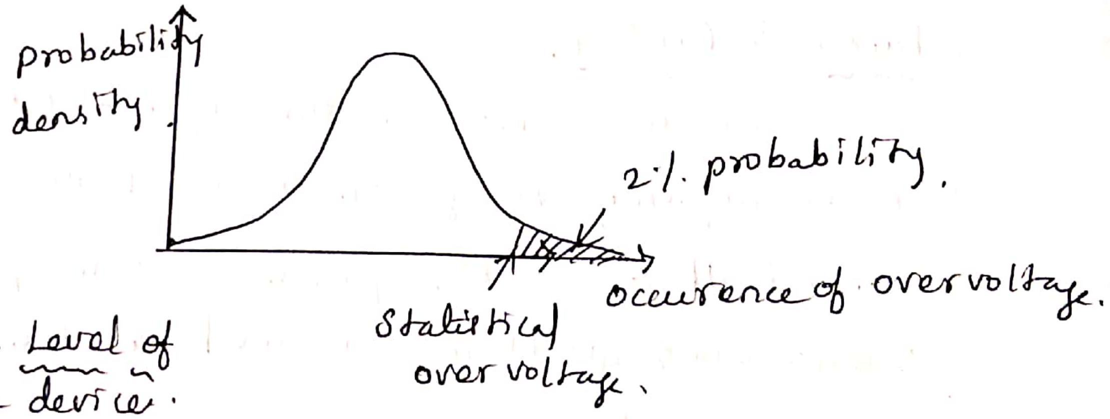
This is the peak value of a switching (or) Lightning test voltage at which insulation exhibits under the specified conditions, a 90% probability of withstand.



10% probability breakdown is chosen as statistical withstand voltage.

Statistical Impulse voltage :-

The switching (or) Lightning overvoltage applied to equipment as a result of an event of one specific type on the System, the peak value of 2% probability of being exceeded.



Protective Level of protective device:

→ Highest peak voltage value which should not be exceeded at the terminals of the protective device. When switching impulses & Lightning impulses of std. shape & rate value are applied under specific condition.

→ To ensure reliability & continuity of service

→ minimize the No. of failure

→ minimize the cost of design.