Power Point Presentation
on
Electrical Circuits

B.Tech IV-I Semester (R15)

Prepared

By

Mr.T.Anil Kumar, Assistant Professor

INSTITUTE OF AERONAUTICAL ENGINEERING
(Autonomous)
Dundigal, Hyderabad - 500 043
ELECTRICAL AND ELECTRONICS ENGINEERING

Unit-I
Gas, Liquid And Solid Mediums As Insualtions

In electrical equipment , materials are used as dielectrics , insulators

and coolants. In this unit we shall discuss about the breakdown phenomena in different kinds of dielectric materials. Before taking up the breakdown phenomena, let us see the major difference between a dielectric material

and an insulating material.

Difference between dielectrics and insulators:

- **Dielectric materials can store electrostatic energy by means of polarization taking place in them and also offer better insulation.**
- **Almost all dielectrics are good insulators but all insulators are not good dielectrics.**
- **Insulating materials offer good insulation but cannot store electrical energy.**

Ionization mechanism:

Depending upon the nature of the dielectric materials (whether polar or non-polar) the polarization mechanisms are classified as : i) Electronic polarization ii) Ionic polarization and iii) Orientational polarization.

Higher the quantum of polarization, the capacitance and hence the dielectric constant of the dielectric material increase enabling more electrostatic energy storing capacity (½ CV^2).

Dielectric parameters : Dielectric materials are characterized by the following parameters:

(i)Relative permittivity (Dielectric constant)

(ii)Dielectric strength (Breakdownstrength)

(iii)Dielectric loss (Loss factor / Dissipation factor)

A good dielectric material should have higher dielectric strength , higher dielectric constant and lower dielectric loss.

BREAKDOWN IN GASES

Air is used mostly as insulating medium and gases such as Nitrogen (N_2) , Carbon dioxide (CO_2) , Freon (CCl_2F_2) and Sulferhexafluoride (SF_6) are used to a lesser extent in electrical apparatus.

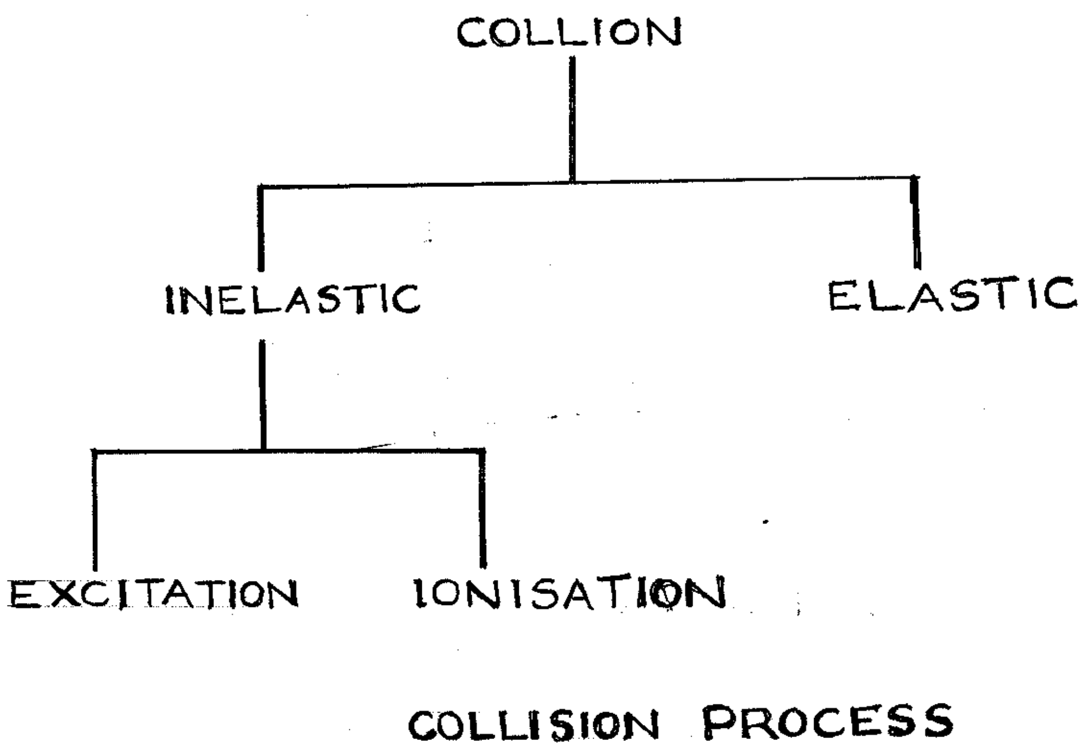
Collision mechanism: **Gaseous dielectrics follow Newton's laws of motion.When they are subjected to electric stress , the collision processes between the atoms and the molecules start.**

The collisions may be elastic or inelastic . During elastic collision the colliding particle returns with same energy after collision . Whereas in the inelastic collision the colliding particle returns with lesser energy after collision giving part of its energy to the collided particle. Inelastic collision results in excitation and ionization of the molecules as shown in the figure next slide.

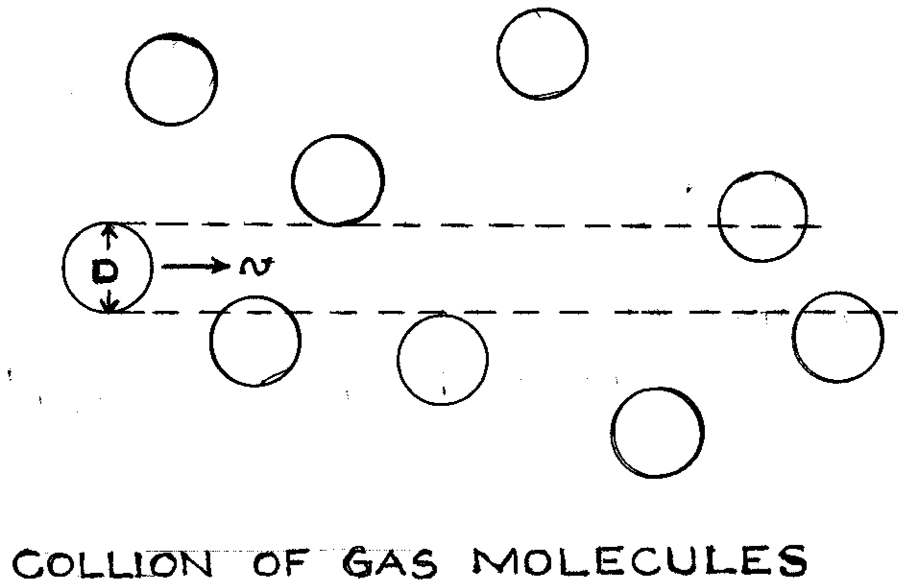
MEAN FREE PATH OF GAS MOLICULES :

Mean free of gas molecules is defined as the average distance traveled between each collision.

COLLISION



COLLISION PROCESS



COLLISION OF GAS MOLICULES

Assuming “ N “ as the number of molecules per unit volume , “ D “ as the diameter of each molecule and “ v “as the velocity of the particle ,

The volume of collision per sec, $= \pi D^2 v$

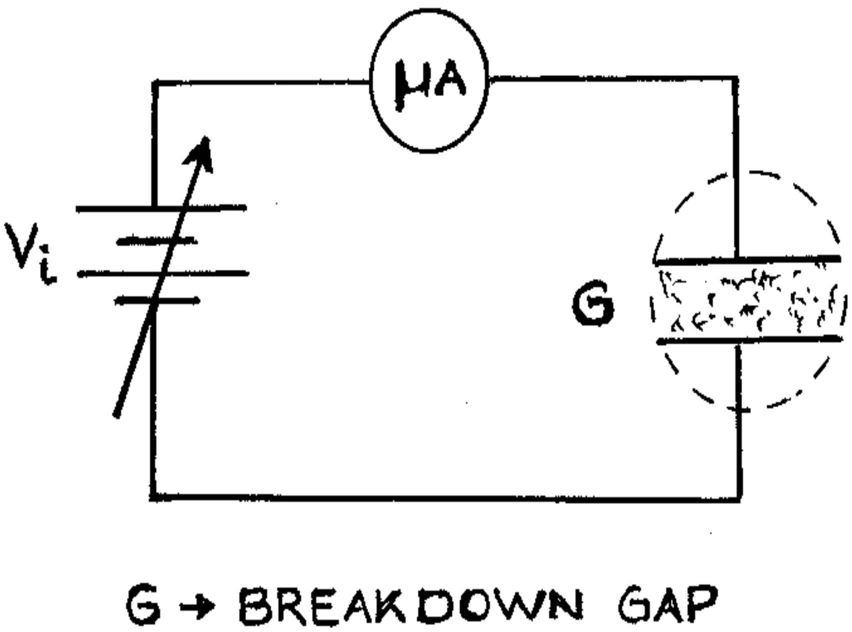
he total number of molecules in the volume $= \pi D^2 v N$

The distance traveled per sec $= v$

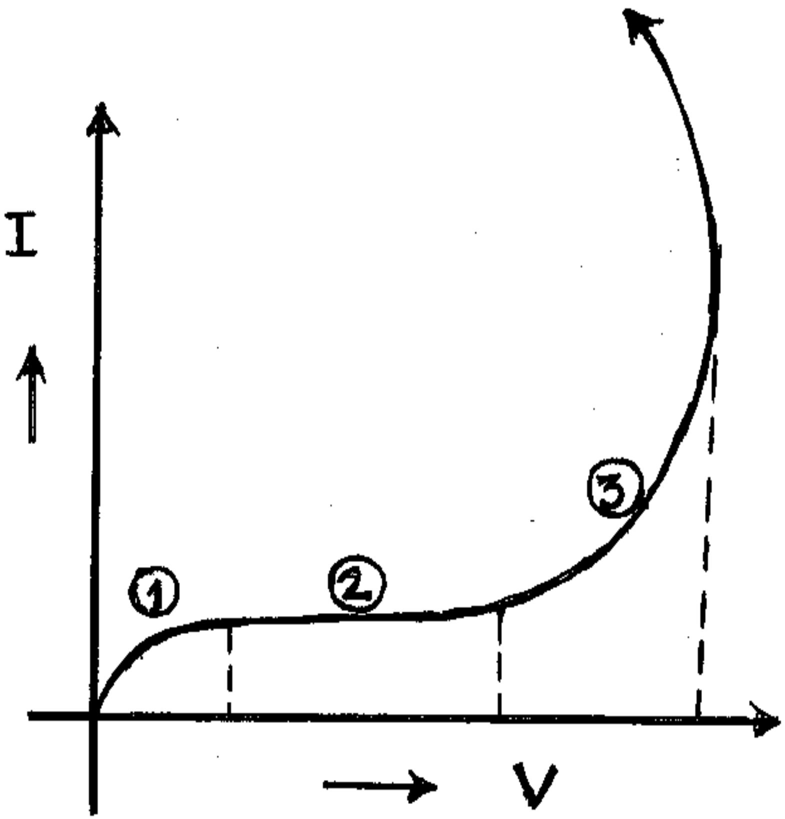
Hence, the mean free path of gas molecules $= v / \pi D^2 v N = 1/\pi D^2 N$ The mean free path is inversely proportional to the no. molecules.

Ionization of molecules :

During ionization process , a free electron collides with a neutral gas molecule and gives rise to new electrons and positive ions. These new electrons further collide with molecules leading to ionization.

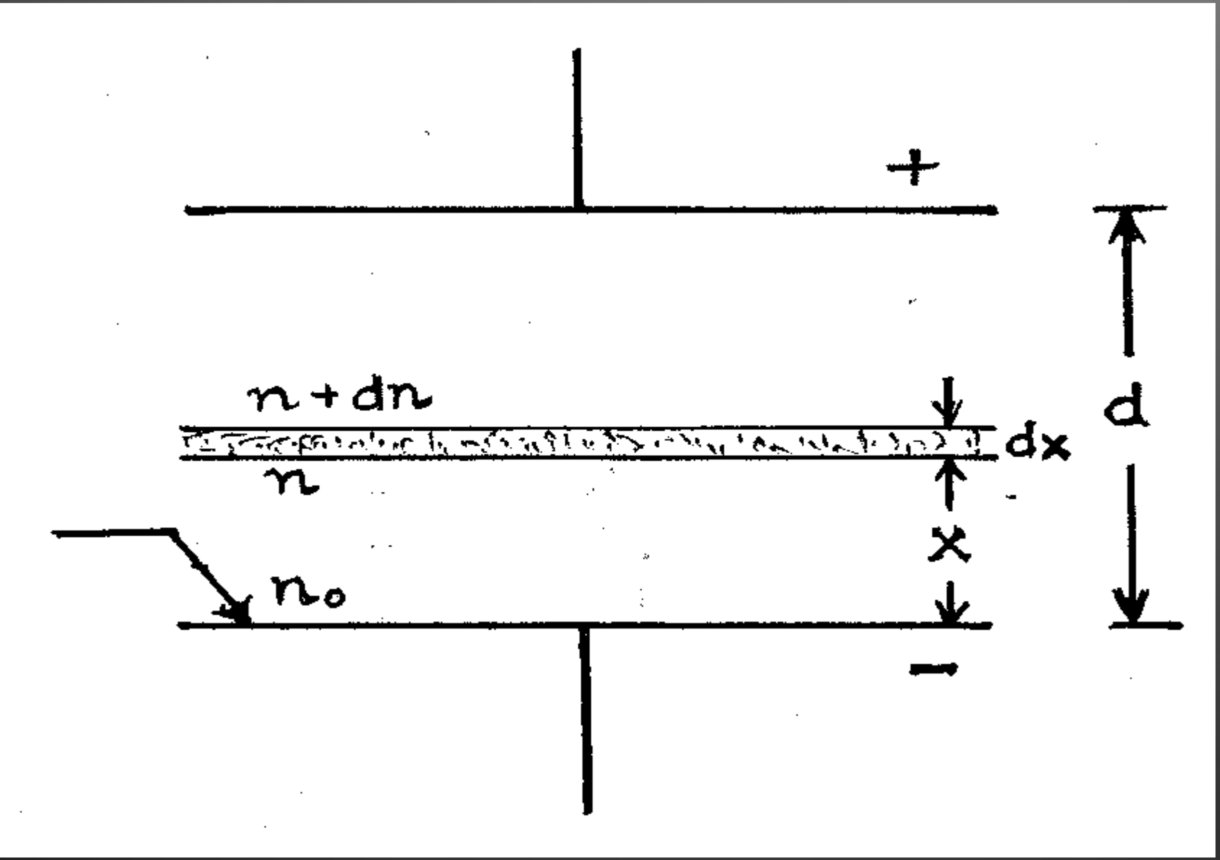


EXPERIMENTAL SET UP



CURRENT GROWTH CURVE

Townsend's primary ionization:



ELECTRODES CONFIGURATION

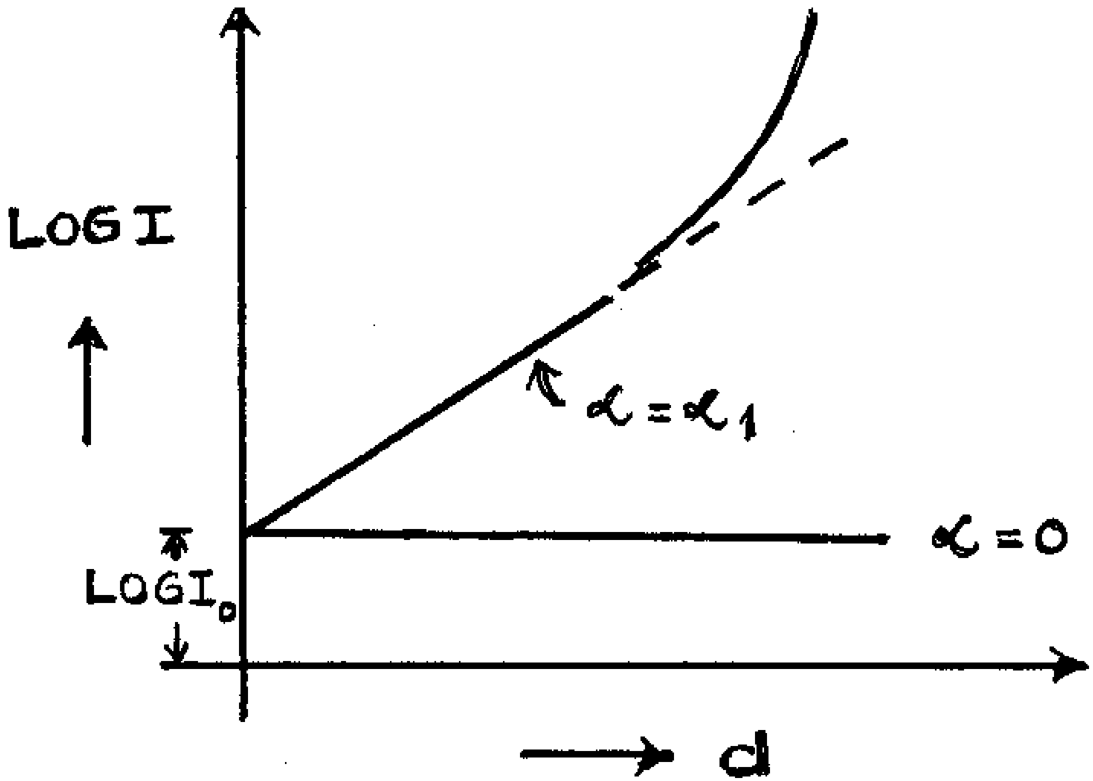
Let ‘α’ be the Townsend’s first ionization coefficient and is equal to the number of electrons created per electron per unit distance

and n_0 the initial number of electrons near the cathode.

Assuming ‘n ‘ as the number of electrons at distance ‘x’ from the cathode ,
the number of new electrons created ‘dn’ in a slab of thickness ‘dx’ , dn = n dx α : i.e., dn/n = α dx

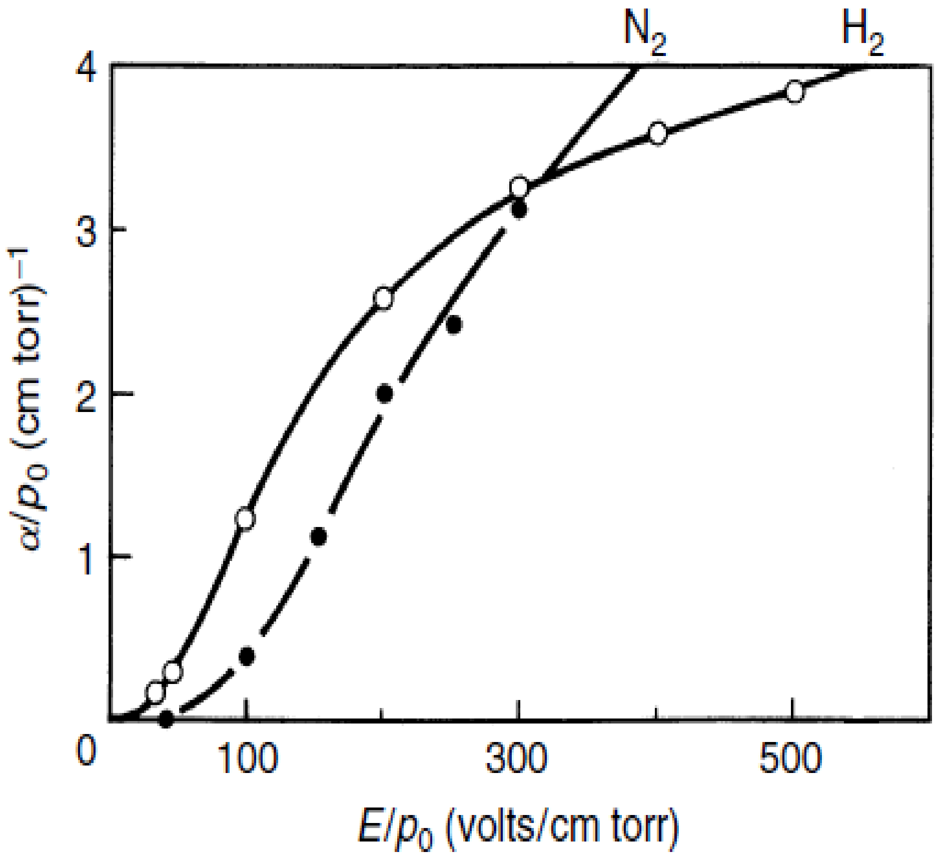
Integrating the above , we get $\log N/n_0 = \alpha d$
$N = n_0 \exp \alpha d$ As'I'is proportional to the no. of electrons , 'N', we can write , $I = I_0 \exp \alpha d$: i.e., $\log I = \log I_0 + \alpha d$
which is the equation of a straight line with slope 'ά'.

The growth of current is shown in the curve below:



LOG 'I' (VS) 'd' PLOT

Alpha'α' is a function of ' E/p' and the dependence of (α/p) on 'E/p' is given by, $\alpha/p = A \exp(-Bp/E)$



The table below shows the values of constants A&B , the ionization potential V_i and E/p for gases:

Gas	A ion pairs cm^{-1} $Torr^{-1}$	B $V\ cm^{-1}$ $Torr^{-1}$	E/p range $V\ cm^{-1}$ $Torr^{-1}$	V_i volts
H_2	5	130	150–600	15.4
N_2	12	342	100–600	15.5
air	15	365	100–800	–
CO_2	20	466	500–1000	12.6
He	3	34	20–150	24.5
Hg	20	370	200–600	–

Secondary ionization processes:

Once Townsend's primary ionization is initiated secondary ionization processes follow resulting in the final breakdown of gases. These processes are :

- **i)IONIZATION DUE TO POSITIVE IONS**
- **ii)PHOTO IONIZATION**
- **iii)LIBERATION OF ELECTRONS FROM CATHODE DUE TO POSITIVE IONS BOMBARDMENT**
- **iv)PHOTONS HITTING THE CATHODE SURFACE**
- **v)ATTACHMENT PROCESS IN ELECTRO-NEGATIVE GASES**

EFFECT OF POSITIVE IONS HITTING THE CATHODE

Of all the processes the liberation of electrons due to positive ions bombardment is very high and the breakdown ultimately takes place due to avalanche of electrons due to this process.

Let γ_i be the number of electrons released from the cathode per positive ion impinging on it,

and 'n_o' be the initial number of electrons at the cathode surface ,

'n_o' be the number of electrons at the cathode surface just before the breakdown and

'n ' be the total number of electrons at breakdown. The number of electrons created in the gas just before the instant of breakdown $= n - n_o'$ and $n_o' = n_0 + (n - n_o')\gamma i$

i.e., $n_o' = n_o + \gamma i\, n / (1 + \gamma i)$

The avalanche of electrons due to n_o' is given by $n = n_o' \exp\ '\alpha d'$

Substituting for n_0' and solving the above equation we get,

$n = n_o \exp \alpha d / 1 - \gamma_i (\exp \alpha d - 1)$

$= n_o \exp \alpha d / (1 - \gamma_i \exp \alpha d)$

ie., $I = I_o \exp \alpha d / (1 - \gamma_i \exp \alpha d)$ The above expression shows that both n_0 (initial electrons) and ά (Townsend's ionization coefficient) should exist to initiate the ionization process.

ATTACHMENT PROCESS

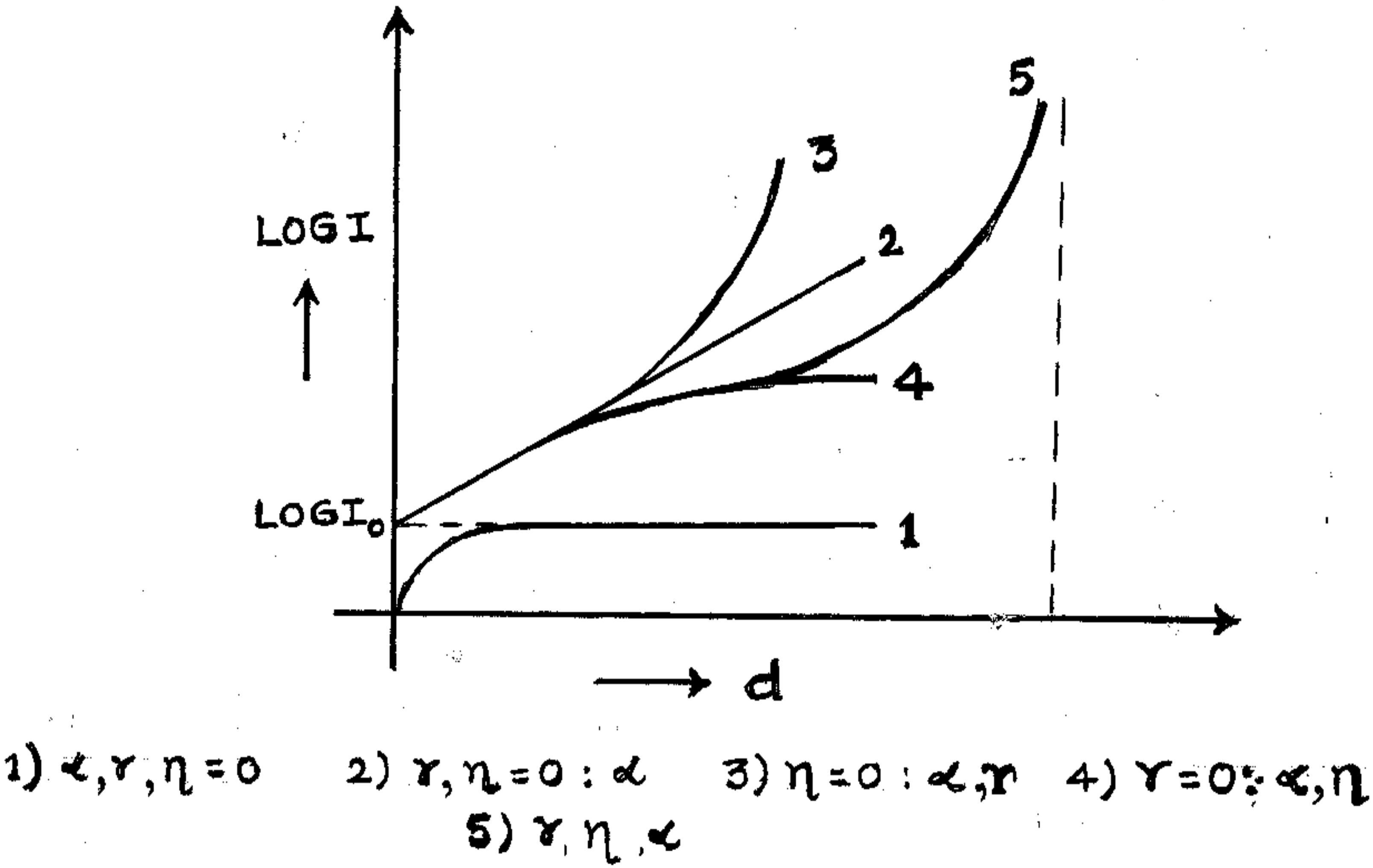
In Attachment Process free electrons get attached to neutral atoms or molecules to form negative ions. This results in removal of electrons which otherwise would have led to led to current growth resulting in breakdown at a lower voltage.

There are three types of attachment processes namely :

- Direct attachment --- ($AB + e \rightarrow AB^-$)
- Dissociation attachment --- ($AB + e \rightarrow A + B^-$)

Dissociation into ions --- ($AB + e \rightarrow A^+ + B^- + e$)

The growth of current due to various ionization processes (either alone or in combination) are shown in the next slide.



LOG ‘I’ (VS) ‘d’ PLOT

TOWNSEND'S DISCHARGE AND CRITERION FOR BREAKDOWN

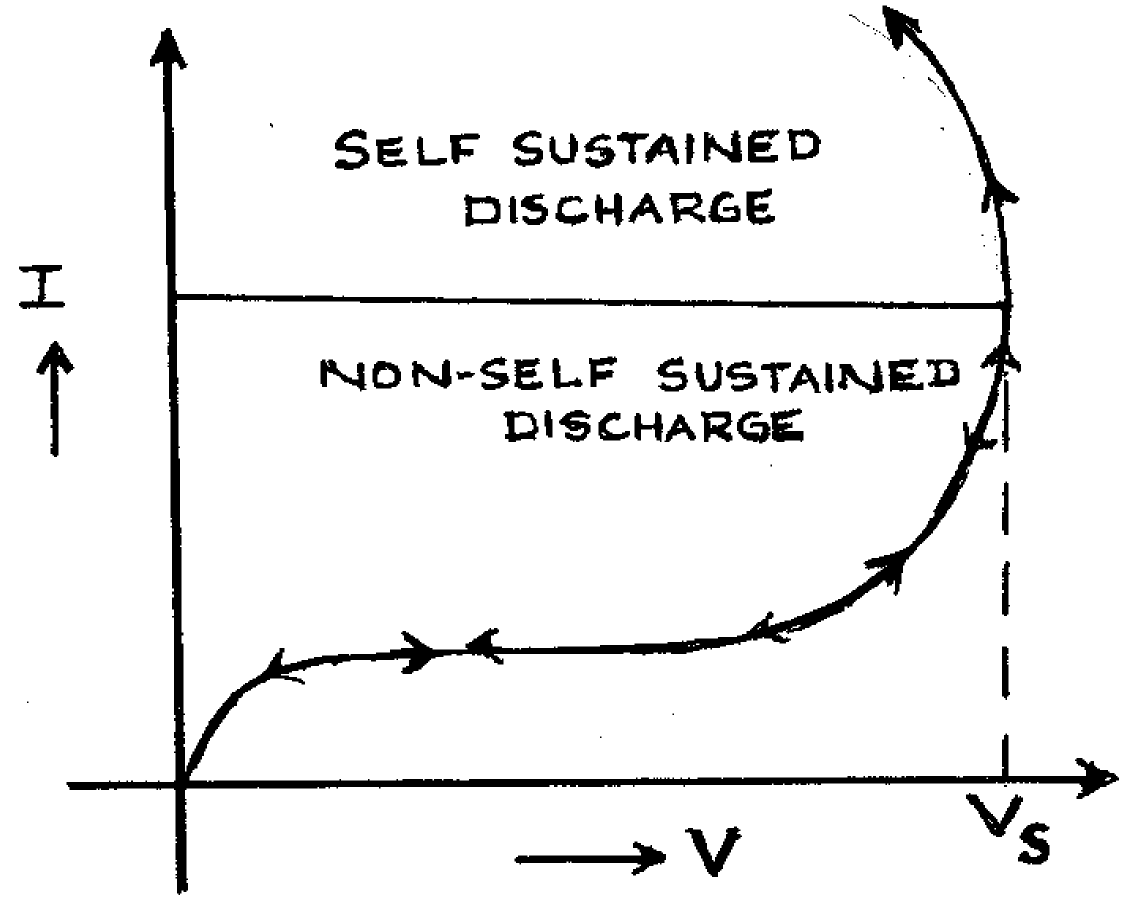
Referring to the growth of current due to positive ion bombardment on cathode , we can see that the current growth is beyond control and breakdown occurs when $(1 - \gamma \exp \alpha d) = 0$

ie., the criteria for sparking potential is $\gamma \exp \alpha d = 1$

When $\gamma \exp \alpha d < 1$, the discharge is non-self sustained (i.e., when the voltage is reduced the current starts decreasing).

When γ exp αd > 1 , the discharge is a self sustained one (i.e., even if the votage is reduced the current does not decrease and maintains itself).

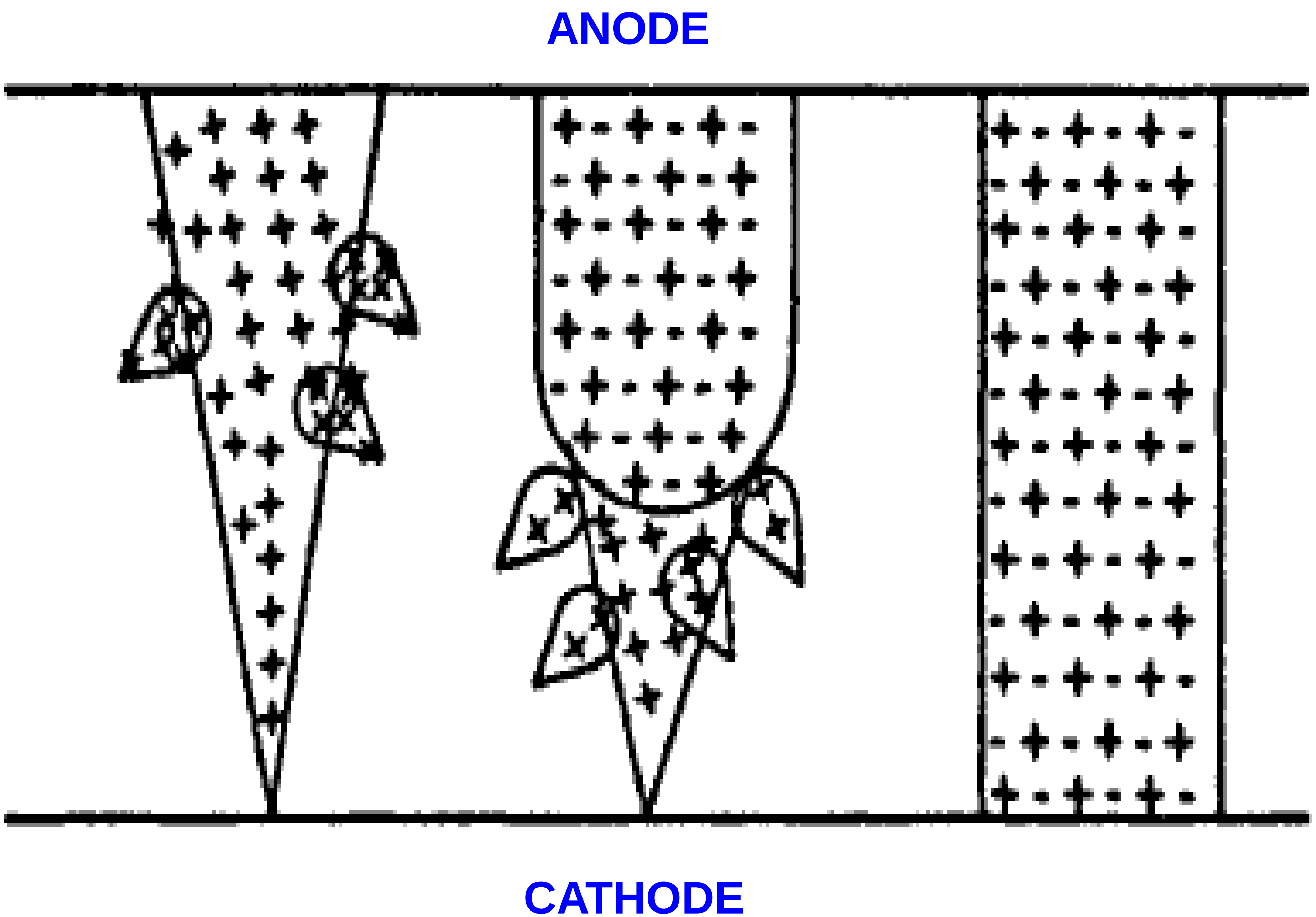
The non-self sustained discharge is known as Townsend’s Discharge and is shown in the next slide.



CURRENT GROWTH DUE TO TOWNSEND'S DISCHARGE

Streamer theory or Meek theory of breakdown :
In uniform fields under very low pressures the discharge takes place based on to series of avalanches due to Townsend's mechanism. Hence, the time taken for ultimate breakdown is more than 10^{-8} sec.

But in non uniform fields under high pressures the discharge takes place quickly (in less than 10^{-8} second)and is explained by Streamer theory of breakdown.



STREAMER BREAKDOWN

Townsend's discharge generally occurs for ' pd ' values lesser than 1000 mm Hg –cm in uniform fields.

Streamer breakdown generally takes place for ' pd ' values more than 1000 mm Hg-cm in non-uniform fields.

Paschen's Law :

The fact that the sparking potential is a function of the product of both pressure and distance (pd) and is neither dependant on pressure alone nor distance alone is known as Paschen's Law.

The critical condition for breakdown,

$\gamma \exp \alpha d = 1$: i.e., $\log 1/\gamma = \alpha d$ Since $\alpha = Ap \exp(-Bp/E)$

$\log 1/\gamma = Apd \exp(-Bpd/V_s)$

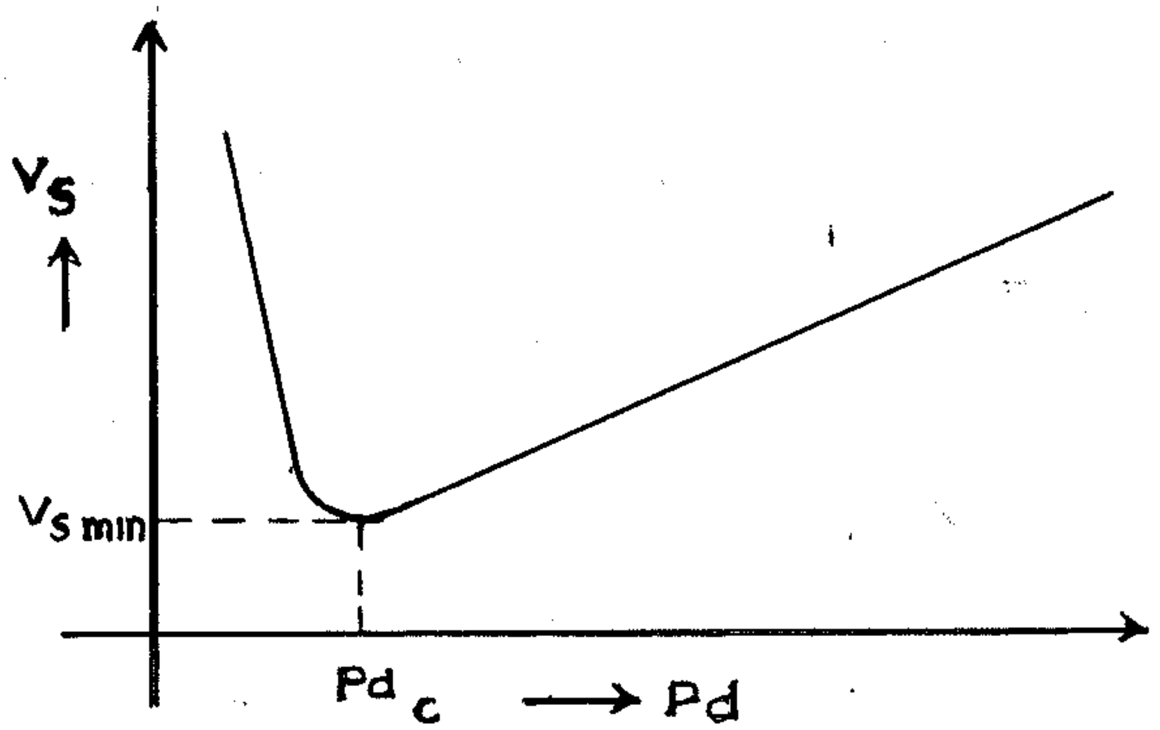
$(1/Apd) \log 1/\gamma = \exp(-Bpd/V_s)$

$V_s = (-Bpd) / \log(\log 1/\gamma / Apd)$

$\quad = Bpd / \log(Apd / \log 1/\gamma)$

i.e., $V_s = f(pd)$

The above equation shows that the sparking potential (Vs) is a function of (pd). The variation of Sparking Potential with pd values is shown in the next slide.



SPARKING POTENTIAL (VS) ‘ pd ‘ VALUES
(PACHEN’S LAW)

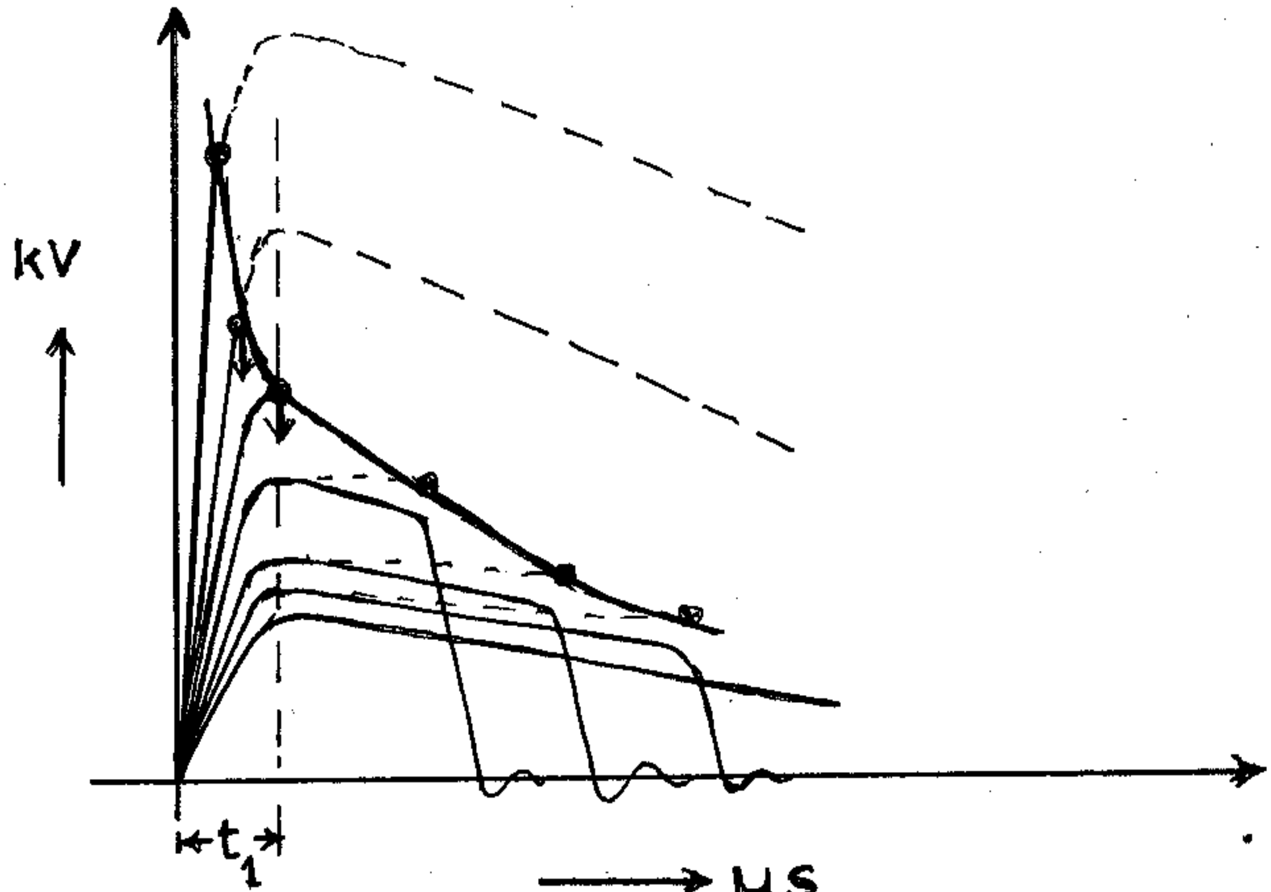
Time lag in breakdown :

The time lag in breakdown is defined as the time taken from the instant of application of the voltage sufficient to cause breakdown and the occurrence of breakdown. This time lag ‘t’ consists of statistical time lag ‘ts’ and formative time lag ‘ tf’ : The statistical time lag is the time taken to find electrons near the cathode surface to start the ionization process. The formative time lag is the time taken to complete the ionization process

and produce avalanche causing final breakdown .

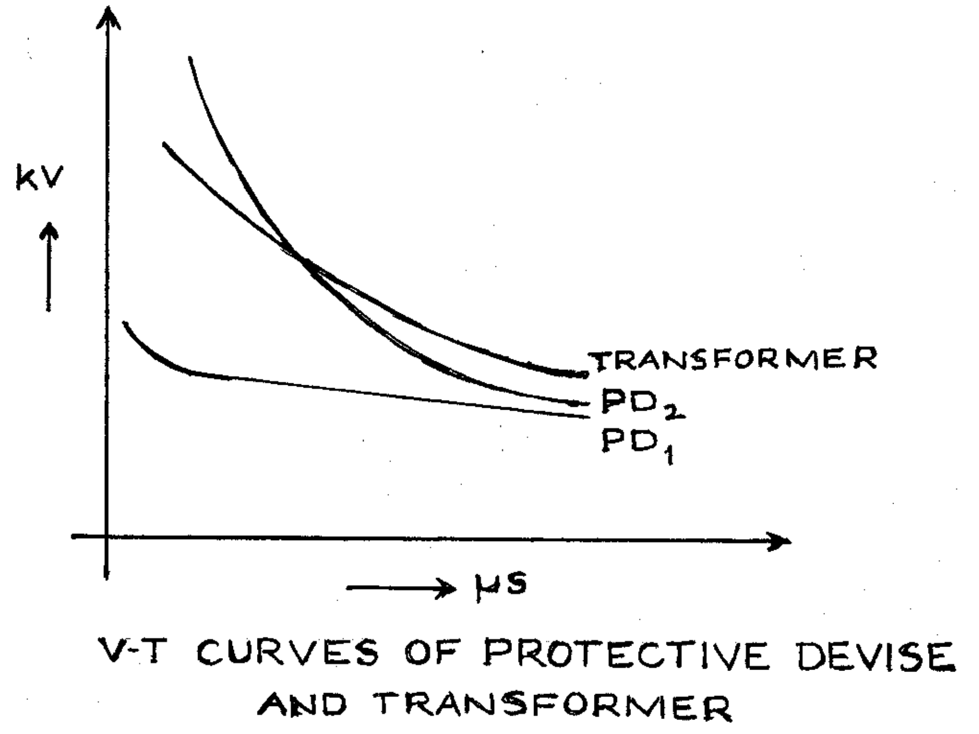
VOLTAGE - TIME (V-T) CHARACTERISTICS

Voltage–Time characteristics relates the breakdown voltage (kV) and time to breakdown (μs) as shown in the next slide.



VOLTAGE-TIME (V-T) CHARACTERISTICS

PROTECTION AGAINST LIGHTNING BASED ON VC TICS



V-T CURVES OF PROTECTIVE DEVICES AND TRANSFORMER

BREAKDOWN IN SOLID DIELECTRICS

Introduction :

- The factors influencing the breakdown strength of solid dielectrics arThickness and homogeneity
- Frequency and waveform of the voltage applied
- Presence of cavities and moisture
- Ambient medium

e :

- **Mechanical forces**
- **Nature of field**

A good dielectric should have the following properties:

i)Low dielectric loss

ii)High mechanical strength

iii)Free from gaseous inclusions and moisture

iv)Resistant to thermal and chemical deterioration

Solid dielectrics have higher dielectric strength and dielectric constant compared to liquids and gases.

Breakdown mechanisms in The various breakdown mechanisms in solids can be classified as :

i)Intrinsic breakdown / electronic breakdown

ii)Electromechanical breakdown

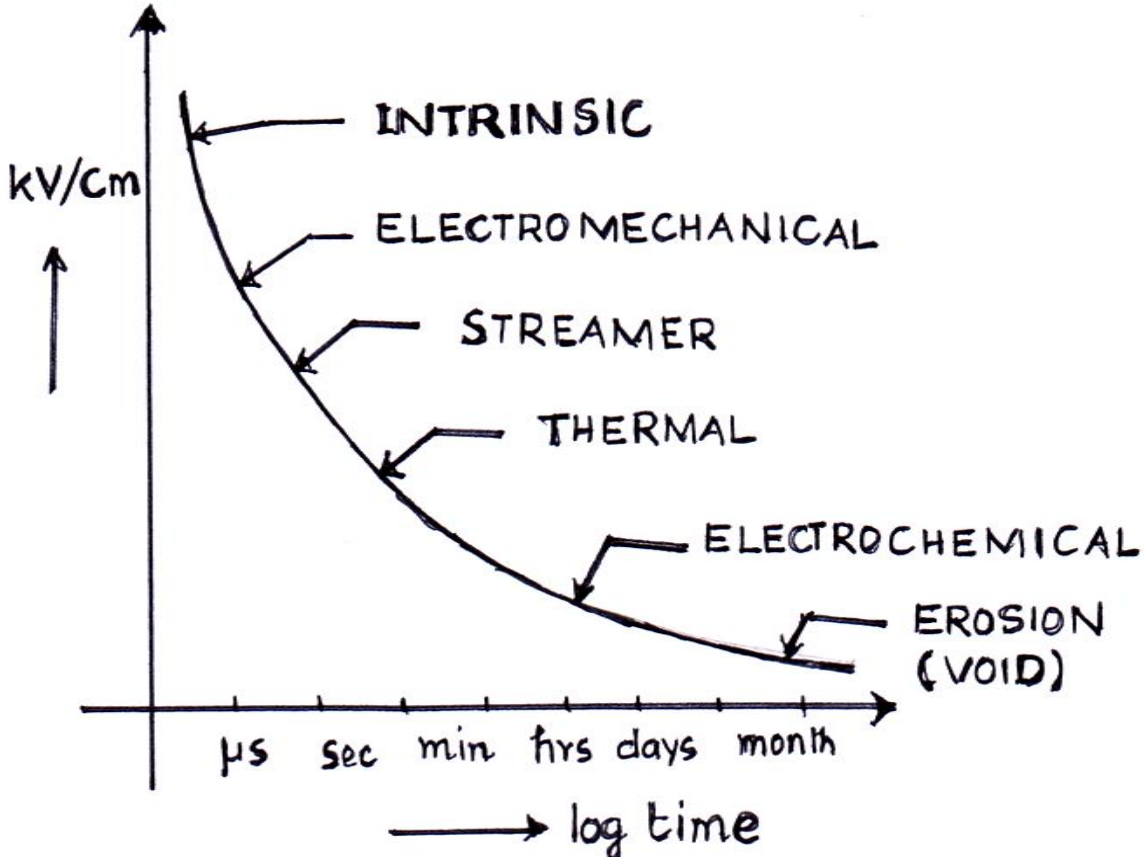
solid dielectrics :

iii) **Streamer breakdown**

iv) **Thermal breakdown**

v) **Electrochemical breakdown**

vi) **Breakdown due to voids / partial discharges**



BREAKDOWN STRENGTH (VS) LOG TIME

i)INTRINSIC BREAKDOWN

In a pure and homogeneous dielectric under controlled temperature and environmental conditions we get a very high dielectric (breakdown) strength. This is known as the intrinsic dielectric strength which depends mainly on the characteristics and structure of the material. The dielectric strength obtained under such conditions is around MV/cm which is generally not obtained in practical conditions.

ii)ELECTROMECHANICAL BREAKDOWN

- When a dielectric material is subjected to an electric field charges of opposite nature are induced on two opposite surfaces of the material and Hence a force of attraction is developed and the material is compressed.
- When these electrostatic compressive forces exceed the mechanical withstand strength of the material the material collapse.

Normally these kinds of breakdown take place in soft materials where ionic polarization is predominant.

Let the initial thickness of the material = d_0 , and thickness after compression = d
Then the compressive stress 'F' , developed due to an applied voltage 'V' , $F = \frac{1}{2} \varepsilon_0 \varepsilon_r V^2 / d^2$

For an Young's modulus ' Y' the mechanical compressive strength is = $Y \log d_0 / d$

Equating the above two equations and assuming $d = 0.6\, d_0$, we get

the highest breakdown strength as, $E = V / d_0 = 0.6\ (V / \varepsilon_0\ \varepsilon_r)^{½}$

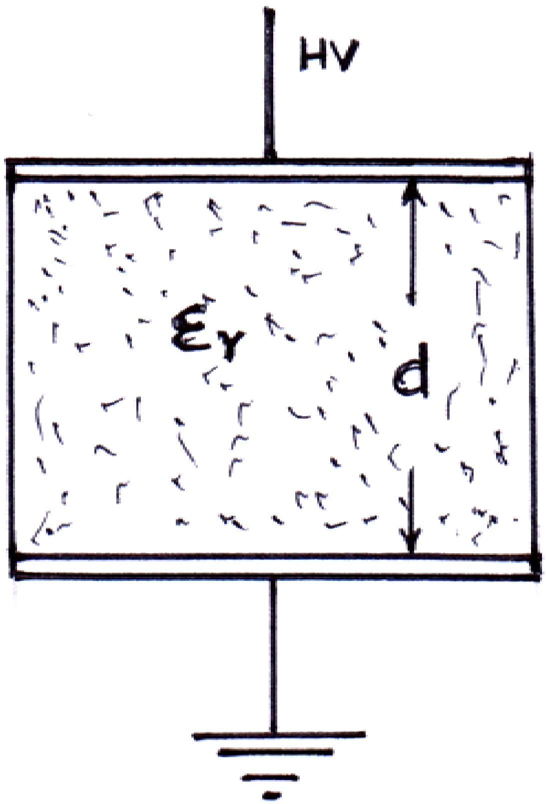
iii) BREAKDOWN DUE TO TREEING AND RACKING

We know that the strength of a chain is given by the weakest link in the chain. Similarly , whenever he solid material has some impurities like gas pockets in it , the dielectric strength of the solid is reduced to that of the weakest impurity.

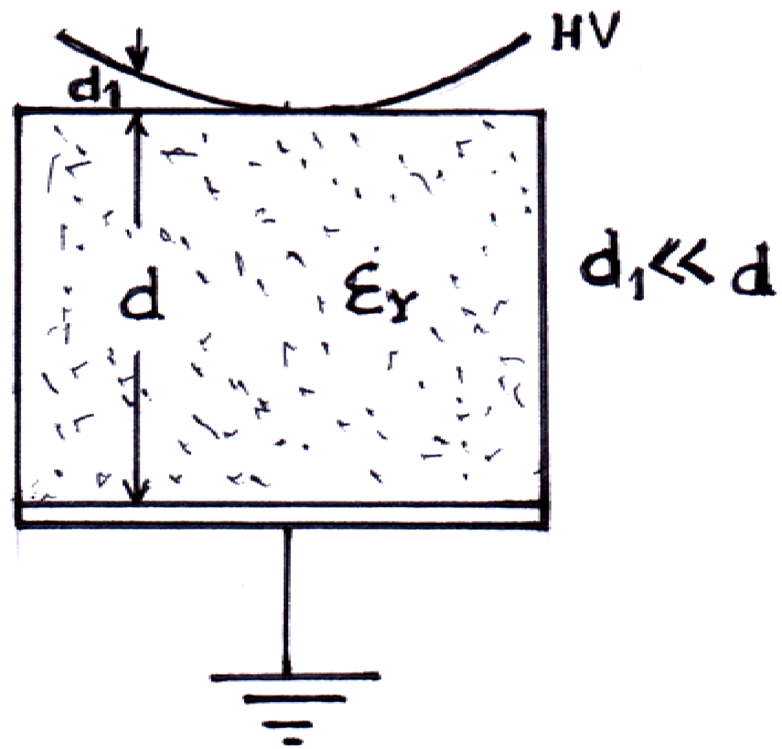
The charge concentration in such voids is found to be quite large to

produce a field of 10 MV / cm which is higher than even the intrinsic breakdown.
The breakdown is not caused by a single discharge channel and assumes a tree like structure. Referring to the figure 1, the stress in the dielectric=V / d,which is very less than the breakdown strength .

In figure 2 , the stress in the air gap is given by, $(V/d)(\varepsilon_r / \varepsilon_0)$, which is much higher than the stress in the solid dielectric . Hence the



(A)



(B)

ARRANGEMENT FOR TREEING PHENOMENA

breakdown is initiated in the air gap and slowly leads to breakdown in the entire dielectric. **The discharge assumes a tree like structure** as shown in the next figure.

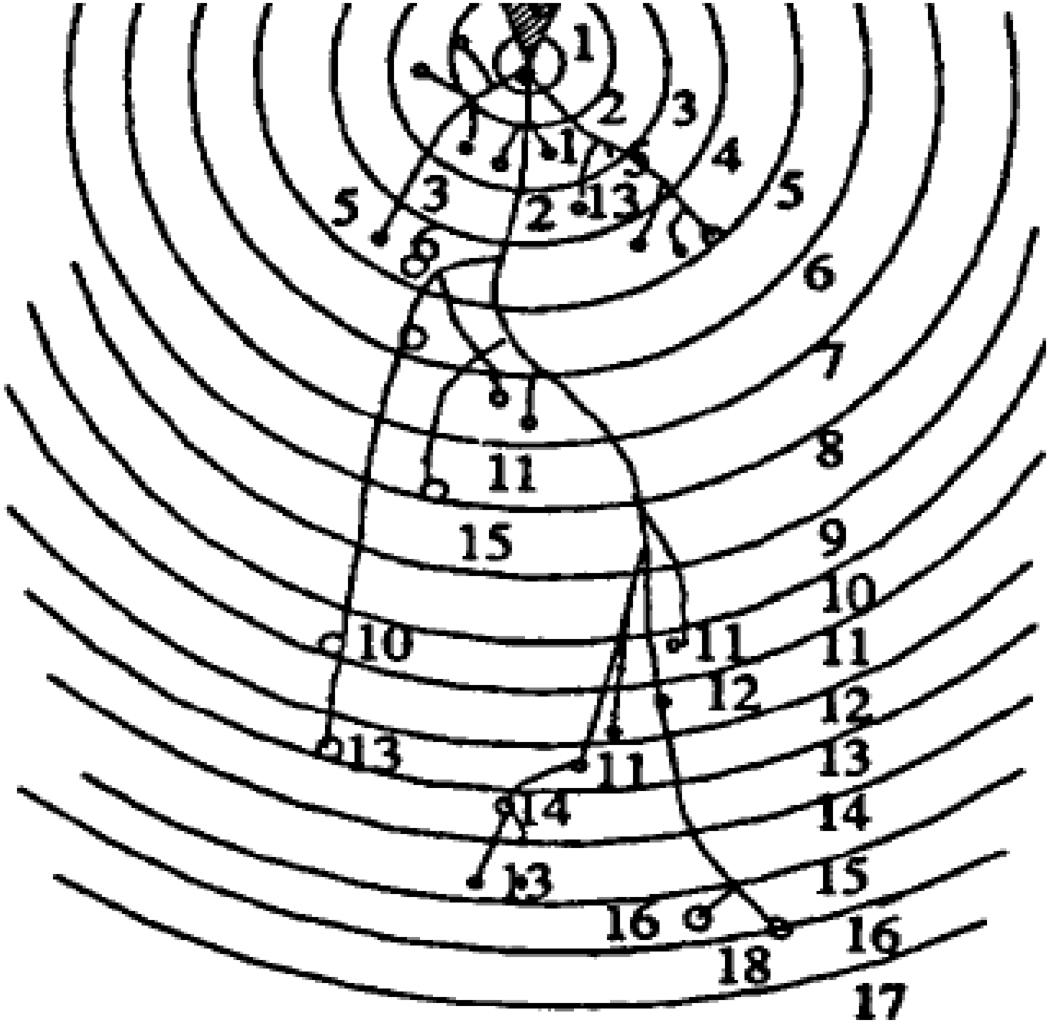
iv) THERMAL BREAKDOWN

When electric field is applied to a solid specimen heat is produced due to dielectric losses in the specimen.

The losses are due to :

- Ohmic losses
- Dipole oscillations
- Partial discharges due to voids

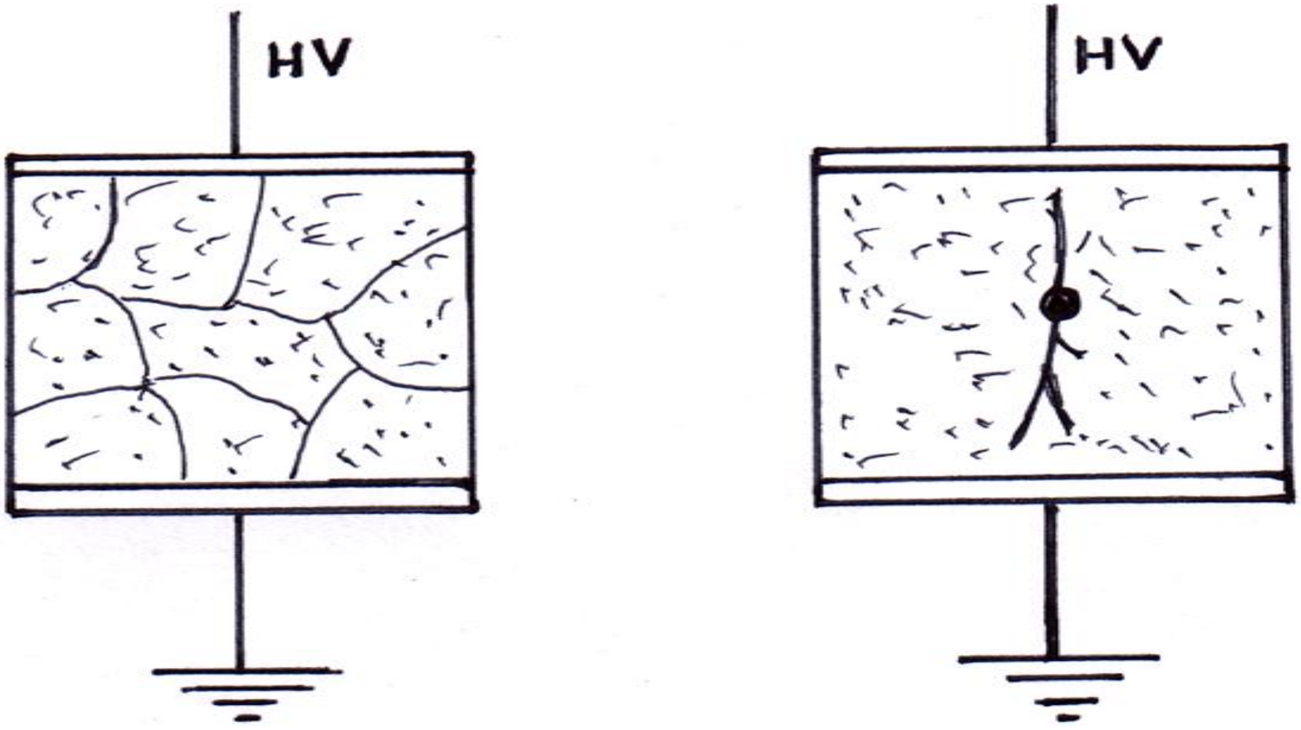
Due to losses, heat is generated



BREAKDOWN DUE TO TRACKING

in the specimen and the same is dissipated due to conduction and radiation.

In practice the solid dielectric is heterogeneous and different domains attain different temperatures due to remaining



(A)   (B)

THERMAL BREAKDOWN

heat. The temperature in a given domain reaches a very high value and burns the material resulting in carbonization and increase of conductivity. This increases the losses and hence the heat developed resulting in further burning and increase of conductivity. This process continues leading to thermal breakdown as shown in the previous figure.

v) ELECTROCHEMICAL BREAKDOWN

In the presence of air and other gases some dielectric materials undergo chemical changes when subjected to continuous electric stresses. Some of the important chemical reactions are :

Oxidation, hydrolysis and chemical actions. The above chemical actions result in surface cracks, reduction of electrical and mechanical strength and
reduction of electrical and mechanical properties. **The life of the specimen considerably reduces.**

vi) DISCHARGE / VOID BREAKDOWN:

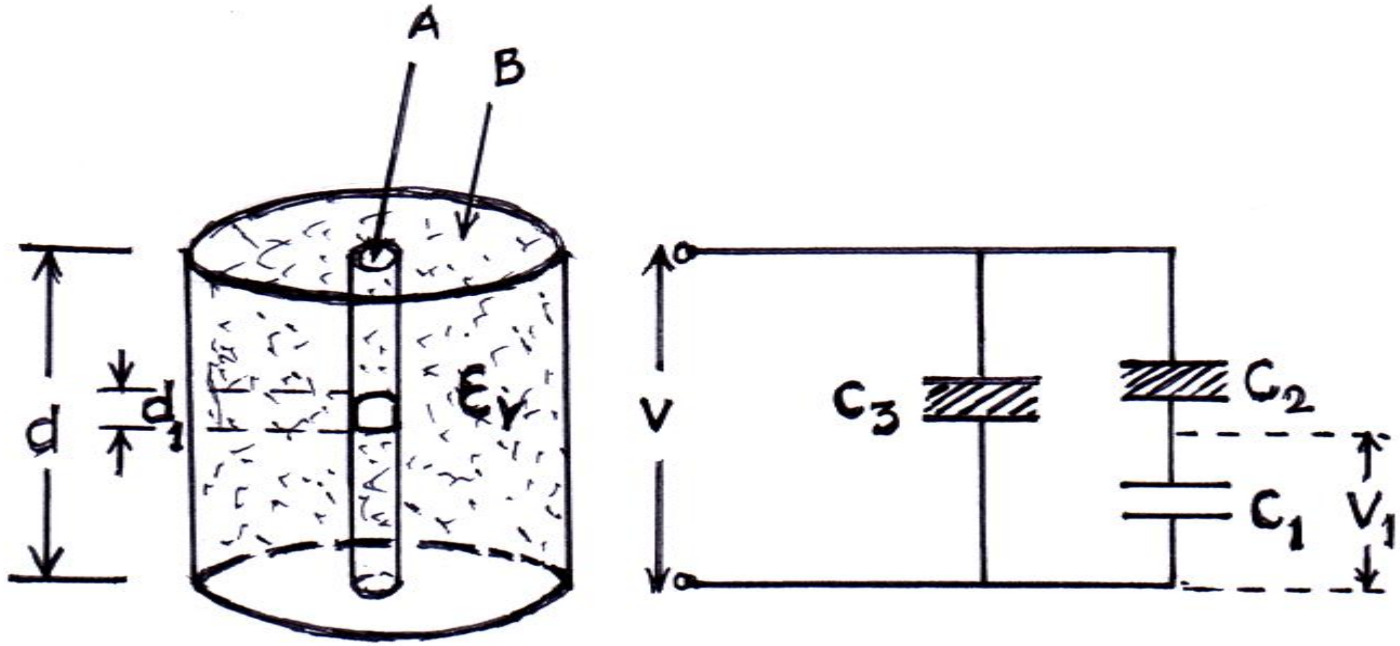
Due to presence of void /gas in
the solid dielectric , the discharge in the void is initiated at much lower stress in the solid dielectric

as the dielectric constant of void is very less. The following figure shows the equivalent circuit of dielectric with void.

C_1 - Capacitance of void in column ‘A’

C_2--- Capacitance of dielectric but for the void in column ‘A’

C_3--- Capacitance of the dielectric



REPRESENTATION OF VOID IN A SOLID DIELECTRIC in column 'B'

The voltage across the void , V_1 , for an applied voltage 'V' is , $V_1 = V (C_2 / C_1 + C_2)$

i.e., $V = V_1 (C_1 + C_2) / C_2$

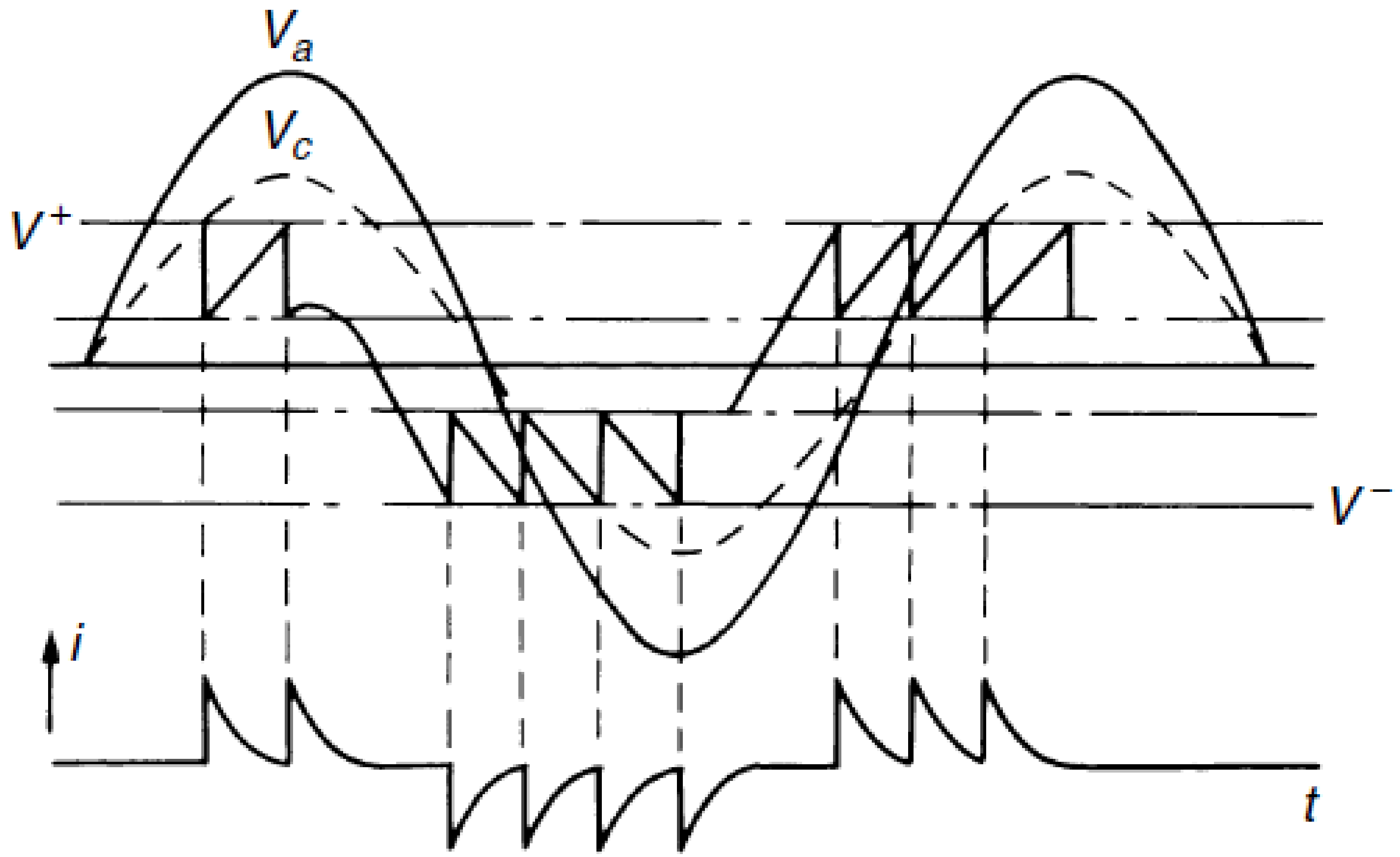
$= Eg\ d_1 (1 + C_1/C_2)$

Substituting for $C_1 = A\varepsilon_0 / d_1$ and

$C_2 = A\varepsilon_0\ \varepsilon_r / (d - d_1)$,we get , $V = Eg\ d_1 ((1 - (d - d_1) / d_1\varepsilon_r))$ Since $d_1 << d$,

$V = Eg\ d_1(1/\varepsilon_r)\ d/d_1 = V_1 (d / \varepsilon_r d_1)$

The input voltage applied just sufficient to cause discharge in the void is known as **Discharge Inception** voltage.



CAVITY BREAKDOWN UNDER ALTERNATING VOLTAGES

BREAKDOWN IN LIQUID DIELECTRICS

Introduction:

Liquid dielectrics are used both as dielectrics and coolants to dissipate heat. They can easily fill up the gaps in the volume of insulation and are also used for impregnation of solid dielectrics.

Liquid dielectrics are classified as:

- **Transformer oil (Mineral oil)**
- **Synthetic hydrocarbons Chlorinated hydrocarbons**
- **Silicone oil**
- **Esters**

Breakdown mechanisms in liquids:

i) Electronic breakdown in pure liquids
ii) Suspended particle mechanism
iii)Bubble mechanism

Of the three above,the (ii) and (iii) mechanisms take place in commercial liquid insulants.

i) ELECTRONIC BREAKDOWN

In pure liquids breakdown takes place due to electron avalanche and is considered to be electronic in nature.The breakdown strength

is very high of the order of 100 kV/ cm.

ii) SUSPENDED PARTICLE MECHANISM

Due to conducting particles between electrodes there is a rise in the field enhancement. When the field exceeds thebreakdown strength of the liquid local breakdown will occur leading to formation of gas bubbles resulting in breakdown.

iii) BUBBLE THEORY

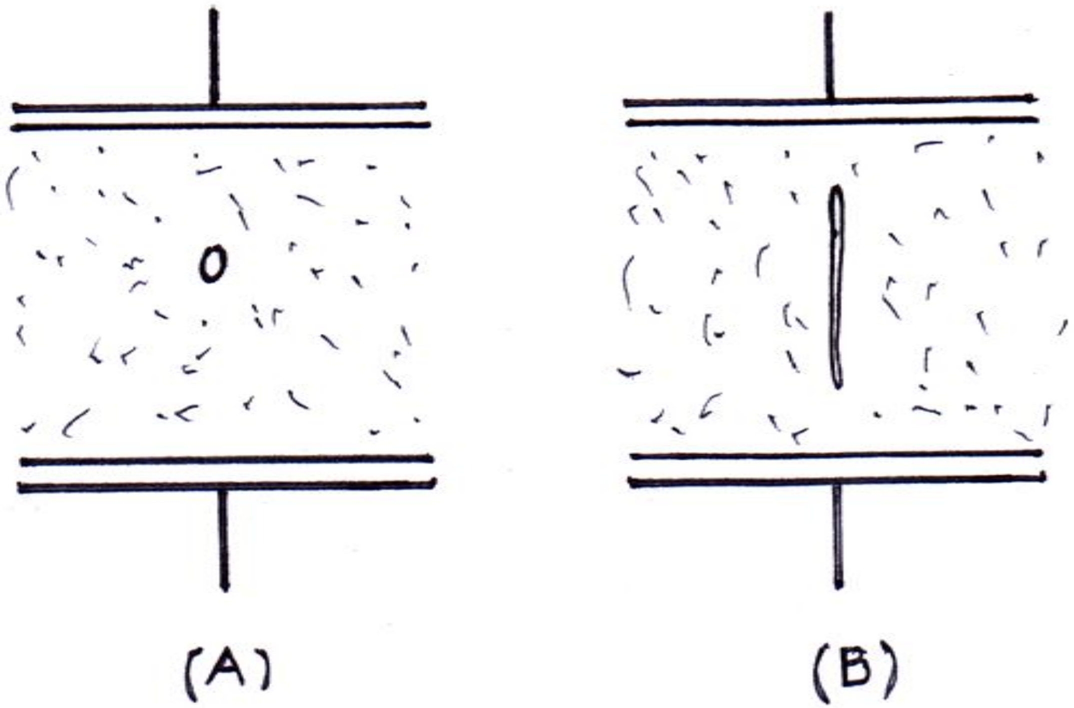
The bubbles formed in the liquid dielectrics due to various reasons will elongate in the

direction of the electric field under the influence of the electrostatic forces.The volume of the bubble remains constant during elongation.

Breakdown occurs when the voltage drop along the length of the bubble becomes equal to the minimum value on the Pachen's curve. The breakdown process is shown in the figure next page.

BREAKDOWN IN VACUUM

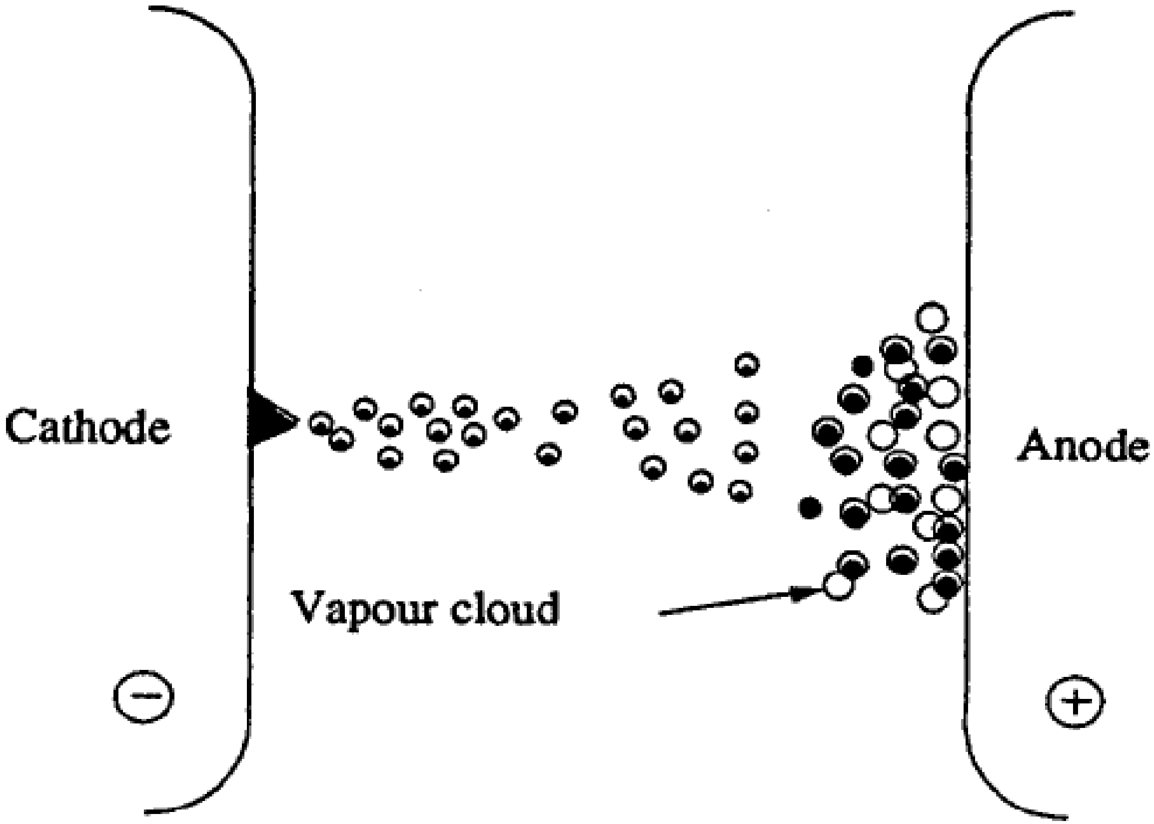
The breakdown in vacuum mainly takes place due to :
i) Field emission and **ii) Clump mechanism**



BUBBLE BREAKDOWN IN LIQUID

i) FIELD EMISSION:

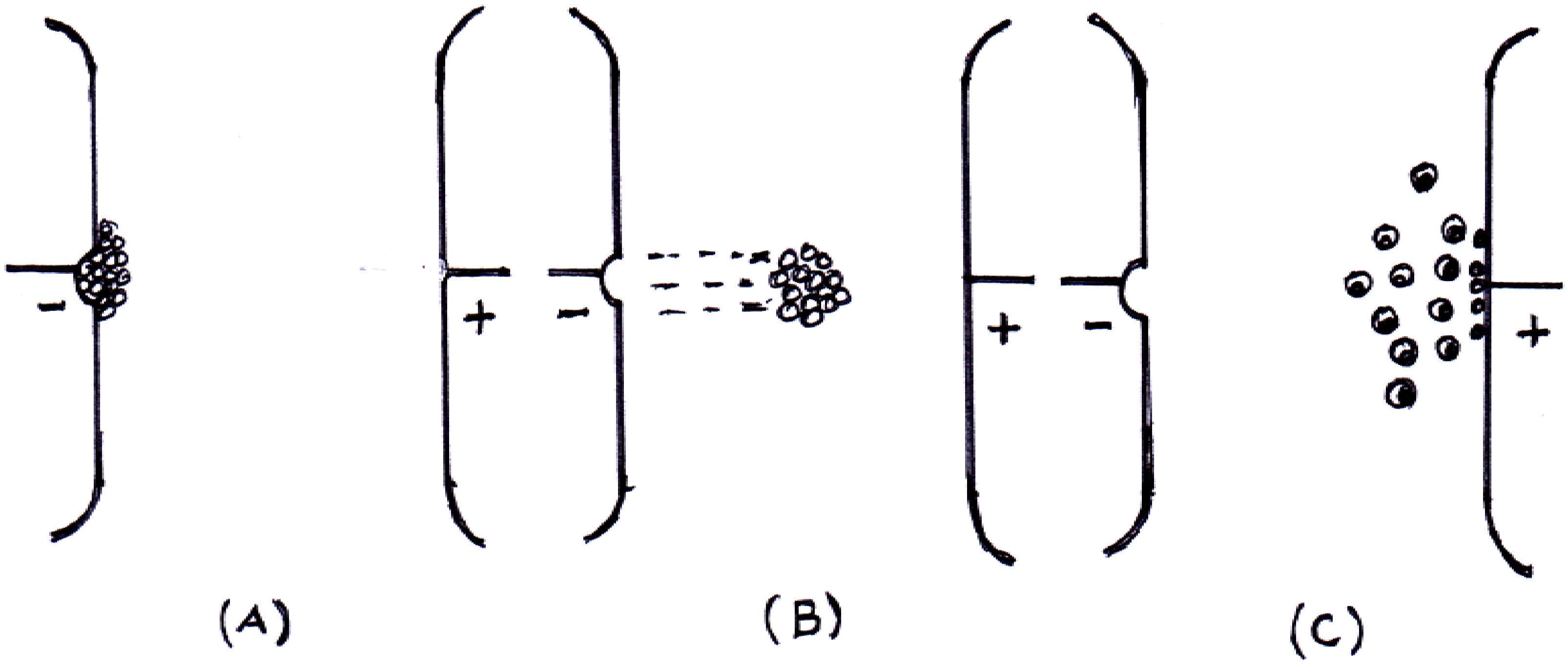
This theory postulates that electrons produced at small micro projections on the cathode due to field emission bombard the anode causing a local rise in temperature and release gases and vapors into the vacuum. These electrons ionize the gas and produce positive ions.These positive ions produce secondary electrons and also bombard the cathode surface producing more electrons causing breakdown.



ANODE HEATING MECHANISM OF VACUUM BREAKDOWN

ii) CLUMP MECHANISM

A loosely bound particle known as 'clump' exists on one of the electrode surfaces. When a high voltage is applied between the two electrodes , this clump gets charged and gets detached from the mother electrode and is attracted by other electrode. The breakdown occurs due to a discharge in the vapor or gas released by the impact to the particle at the opposite electrode.



BREAKDOWN DUE TO CLUMP MECHANISM

NOMENCLATURES USED WITH REGARD TO NATURE OF FIELD AND TYPES OF DISRUPTIVE DISCHARGES

NATURE OF FIELD:

Depending upon the type of electrodes used we have i) uniform and ii) non-uniform field.

Uniform field:

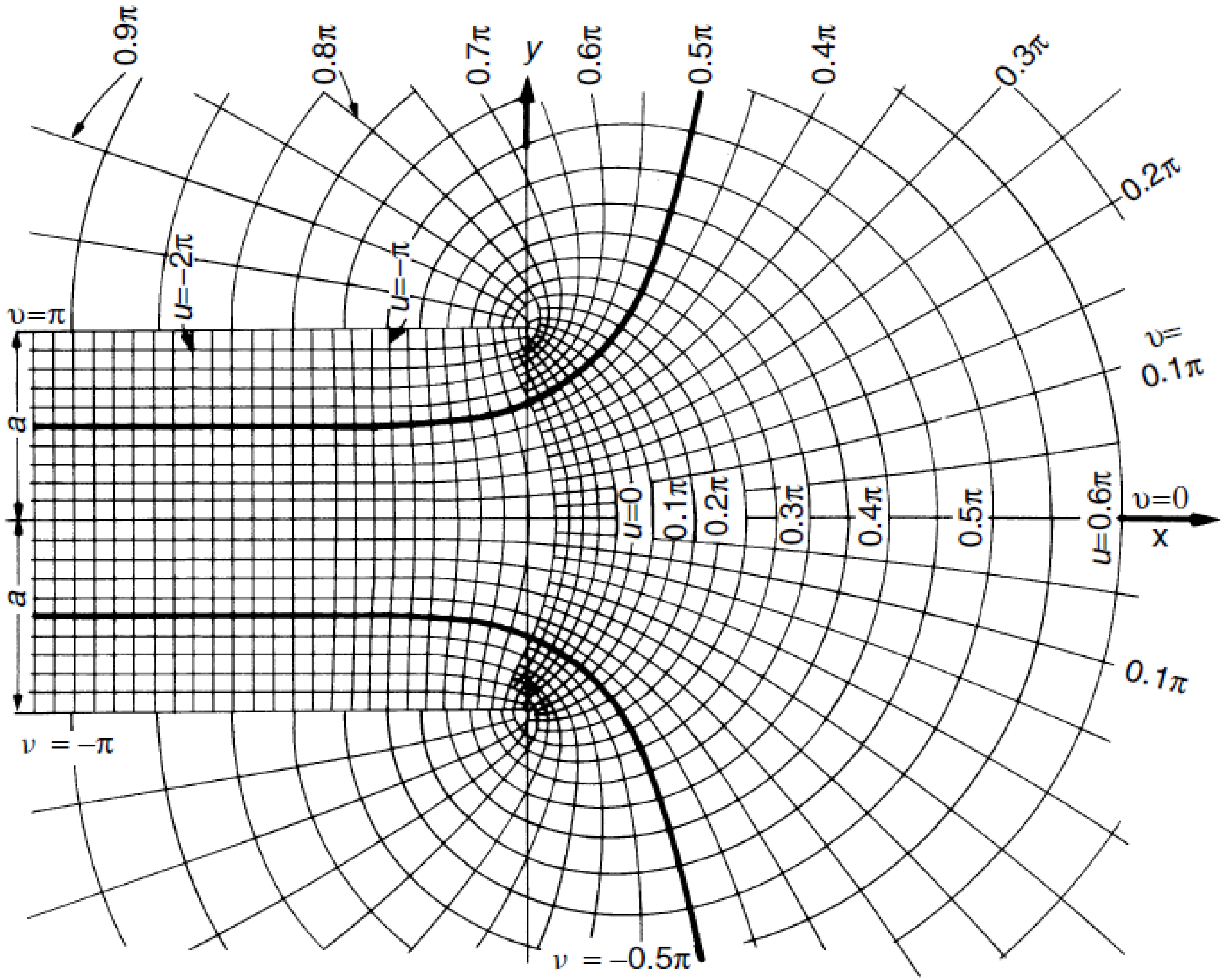
When the field lines and equipotential lines cut each other they make curvilinear squares. When these squares approach exact squares we get

uniform field.

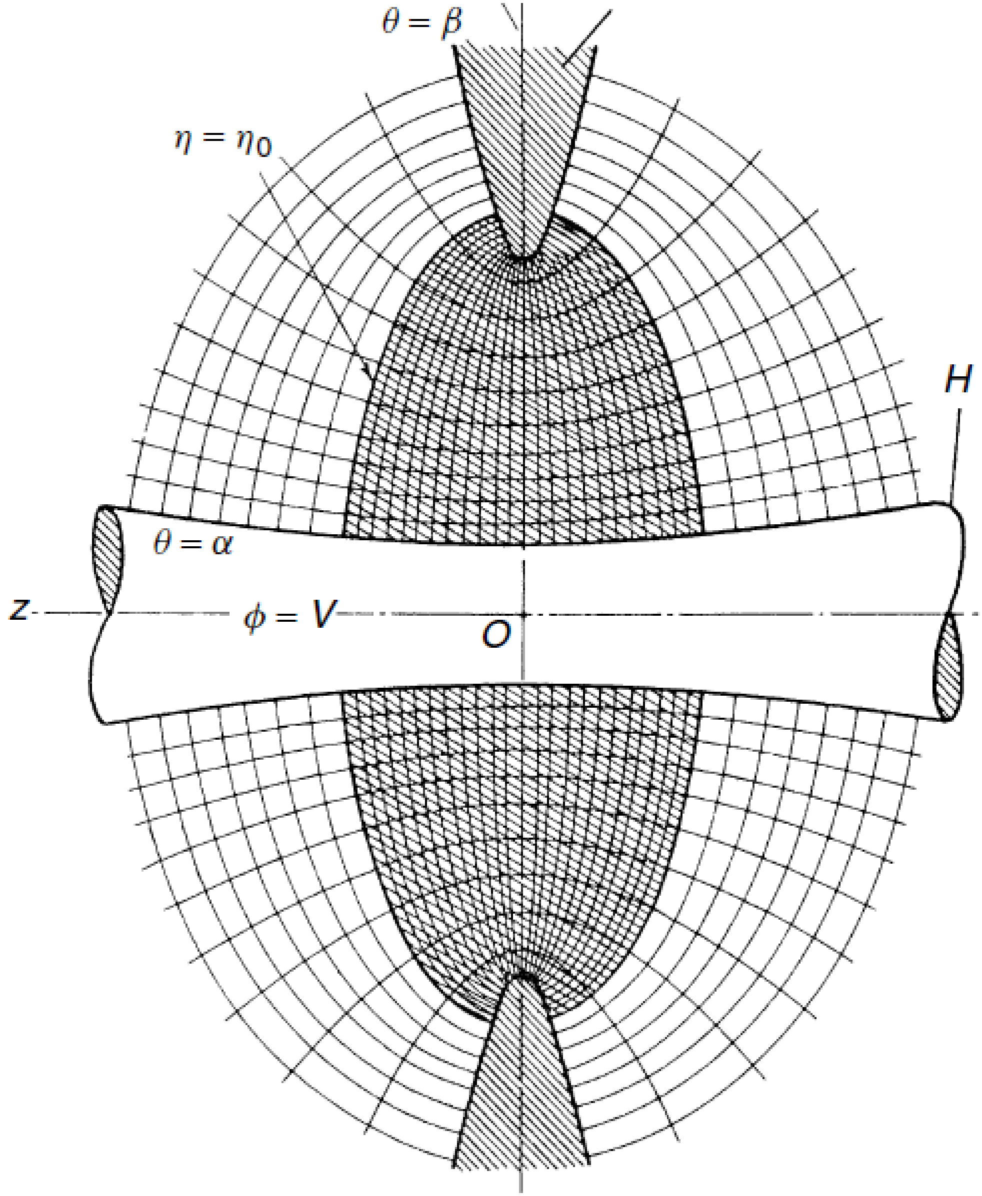
Non-uniform field :

When the curvilinear squares seize to be exact squares it becomes a non-uniform field.

Depending upon the usage and location of insulation and ability to recover back its insulating



UNIFORM FIELD



NON UNIFORM FIELD

property , insulation can be classified as follows:

(I)External and internal insulation.

(II) Self-restoring and non-self restoring insulation.

When the insulation is externally provided it is called external insulation and when it is internal inside the equipment it is called internal insulation.

As examples, in a transformer the winding insulation and the oil medium inside are the internal insulations,where as,the bushings

outside on the top of the transformer are the external insulations.

Self restoring insulation can recover back its insulating property after a disruptive discharge occurs.Ex., breakdown in air or oil medium.

Non-self restoring insulation cannot recover back its insulating property after a disruptive discharge occurs and causes a permanent damage.Ex. Breakdown through a solid dielectric.

Disruptive discharges occurring in dielectrics can be classified as :

(i) Flashover ii) Sparkover

and iii)Punture.

Disruptive discharge taking place across a solid dielectric in air medium is called flashover.

Disruptive discharge taking place through air or liquid medium between electrodes is called sparkover.

Disruptive discharge taking place through a solid dielectric causing a permanent damage is called puncture.

UNIT-II

GENERATION OF HIGH VOLTAGES AND HIGH CURRENTS

GENERATION OF HIGH D.C VOLTAGE

DIFFERENT METHODS TO GENERATE HIGH D,C VOLTAGE:

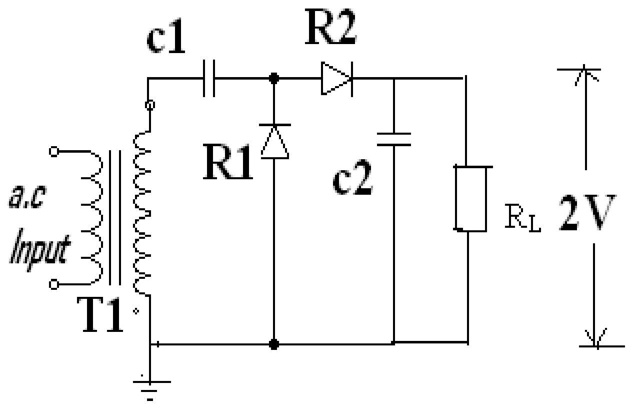
1. Half and full wave rectifier circuits
2. Voltage doubler circuits
3. Voltage multiplier circuits
4. Van de Graaff generator

HALF AND FULL WAVE RECTIFIER CIRCUITS

- This method can be used to produce DC voltage up to 20 kV
- For high voltages several units can be connected in series
- For the first half cycle of the given AC input voltage, capacitor is charged to Vmax and for the next half cycle the capacitor is dischar5ged to the load
- The capacitor C is chosen such that the time constant CR_l is 10 times that of AC supply

VOLTAGE DOUBLER CIRCUIT

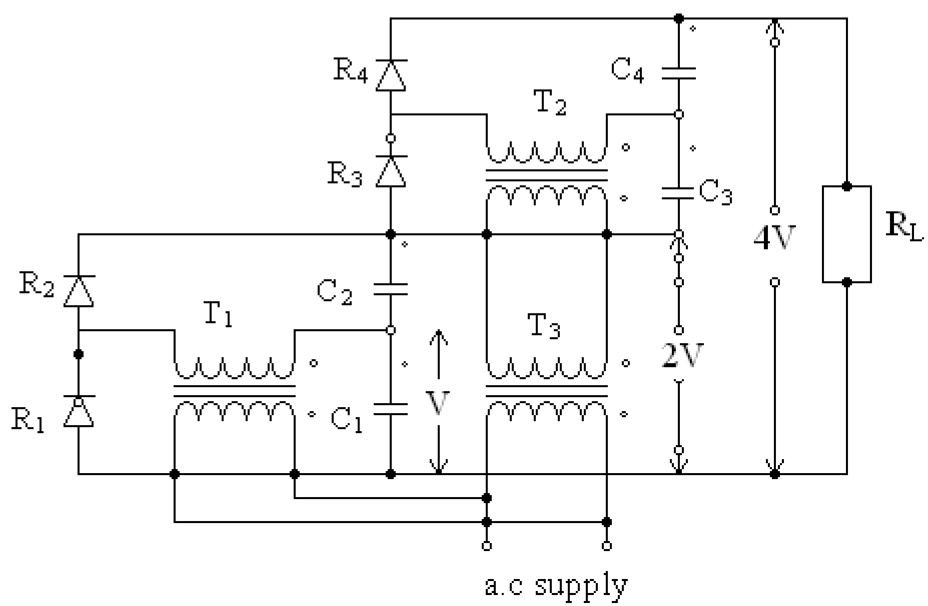
- In this method, during –ve half cycle, the Capacitor $C_1$is charged through rectifier R to a voltage $+V_{max}$. During next cycle. C_1rises to $+2V_{max}$.
- $C_{2.}$is charged to $2V_{max.}$
- Cascaded voltage doublers can be used for producing larger output voltage



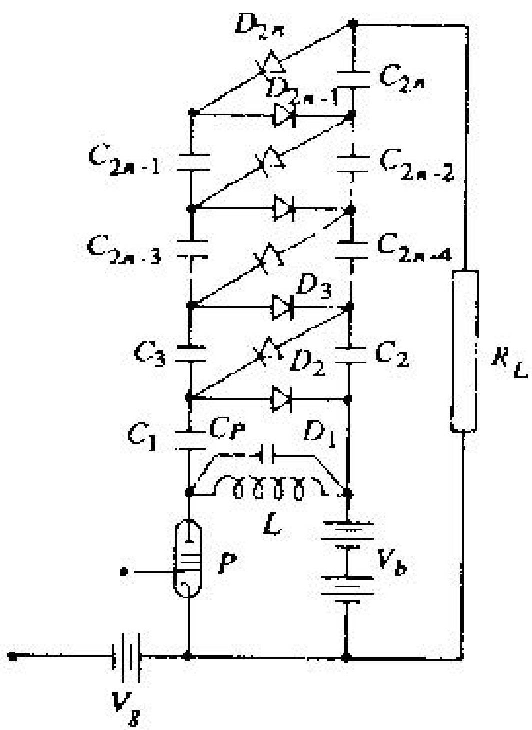
Simple voltage doubler

CASCADED VOLTAGE DOUBLERS

- Cascaded voltage doublers can be used for producing larger output voltage

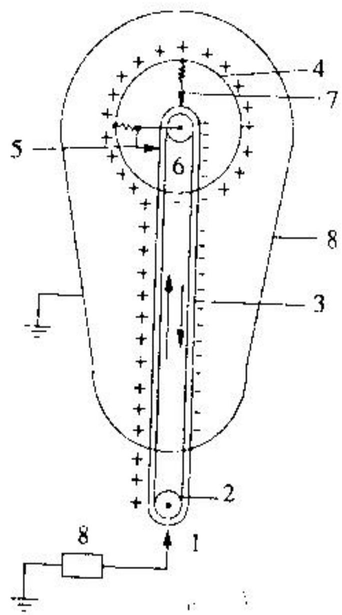


VOLTAGE MULTIPLIER CIRCUITS



- Here n no. of capacitors and diodes are used.
- Voltage is cascaded to produce output of $2nV_{max}$.
- Voltage multiplier circuit using Cockcroft–Walton principle can be used.

VAN DE GRAFF GENERATOR



Van de Graaff generator

- In electrostatic machines charged bodies are moved in an electrostatic field
- If an insulated belt with a charge density δ moves in an electric field between two electrodes with separation 's'
- If the belt moves with a velocity v then mechanical power require to move the belt is P=F.v=V.I

1. Lower spray point
2. Motor driven pulley
3. Insulated belt
4. High voltage terminal
5. Collector
6. Upper pulley insulated from terminal
7. Upper spray point
8. Earthed enclosure

Electrostatic generator

- It consists of a stator with interleaved rotor vanes forming a variable capacitor and operates in vacuum
- The power input into the circuit $P=VI=CVdV/dt+V^2dC/dt$
- The rotor is insulated from the ground,maintained at a potential of +V.
- The rotor to stator capacitance varies from C_0 to C_m
- Stator is connected to a common point between two rectifiers across -E volts.
- As the rotor rotates, the capacitance decreases and the voltage across C increases.
- Output voltage of 1MV can be generated.

GENERATION OF HIGH ALTERNETING VOLTAGES

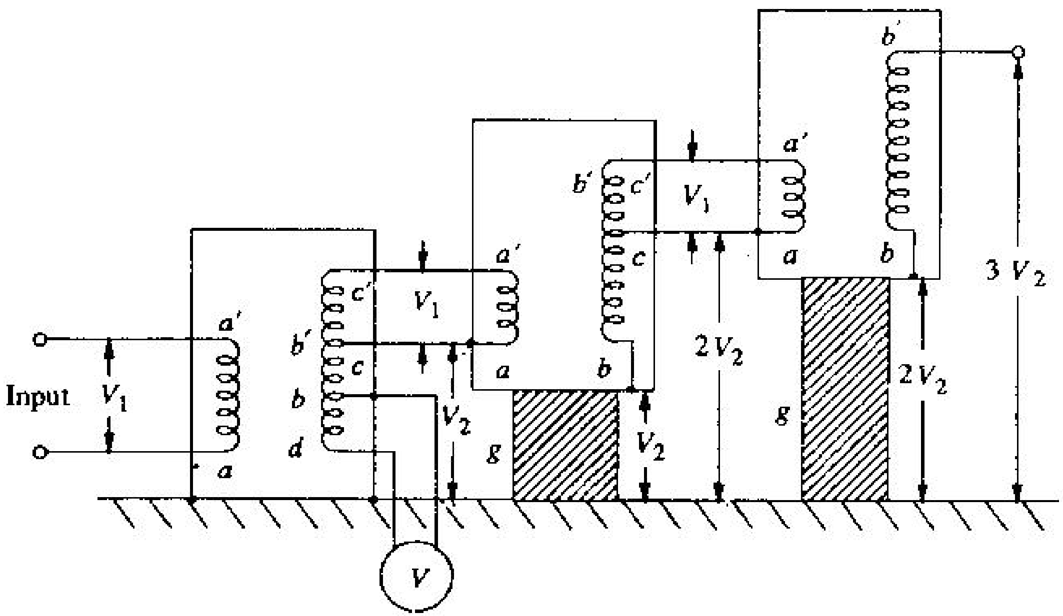
- When test voltage requirements are less than about 300 kV,a single transformer can be used.
- Each transformer unit consists of low,high and meter winding.
- Series connection of the several units of transformers used to produce very high voltage.

CASCADE TRANSFORMERS

- First transformer is at ground potential along with its tank.The 2nd transformer is kept on insulators and maintained at a potential of V_2.
- The high voltage winding of the 1st unit is connected to the tank of the 2nd unit,the low voltage winging of this unit is supplied from the excitation winding of the 1st transformer,which is in series with the high voltage winding of the 1st transformer at its high voltage end.
- The rating of the excitation winding is same as that of low voltage winding.3rd transformer is kept on insulator above the ground at a potential of $2V_2$.output of 3 stage is $3V_{2.}$
- The rating of the low voltage winding of 230 or 400 Vcan be used to produce 3.3 kV,6.6 kV or 11 kV.\

GENERATION OF HIGH AC VOLTAGE

CASCADE TRANSFORMER

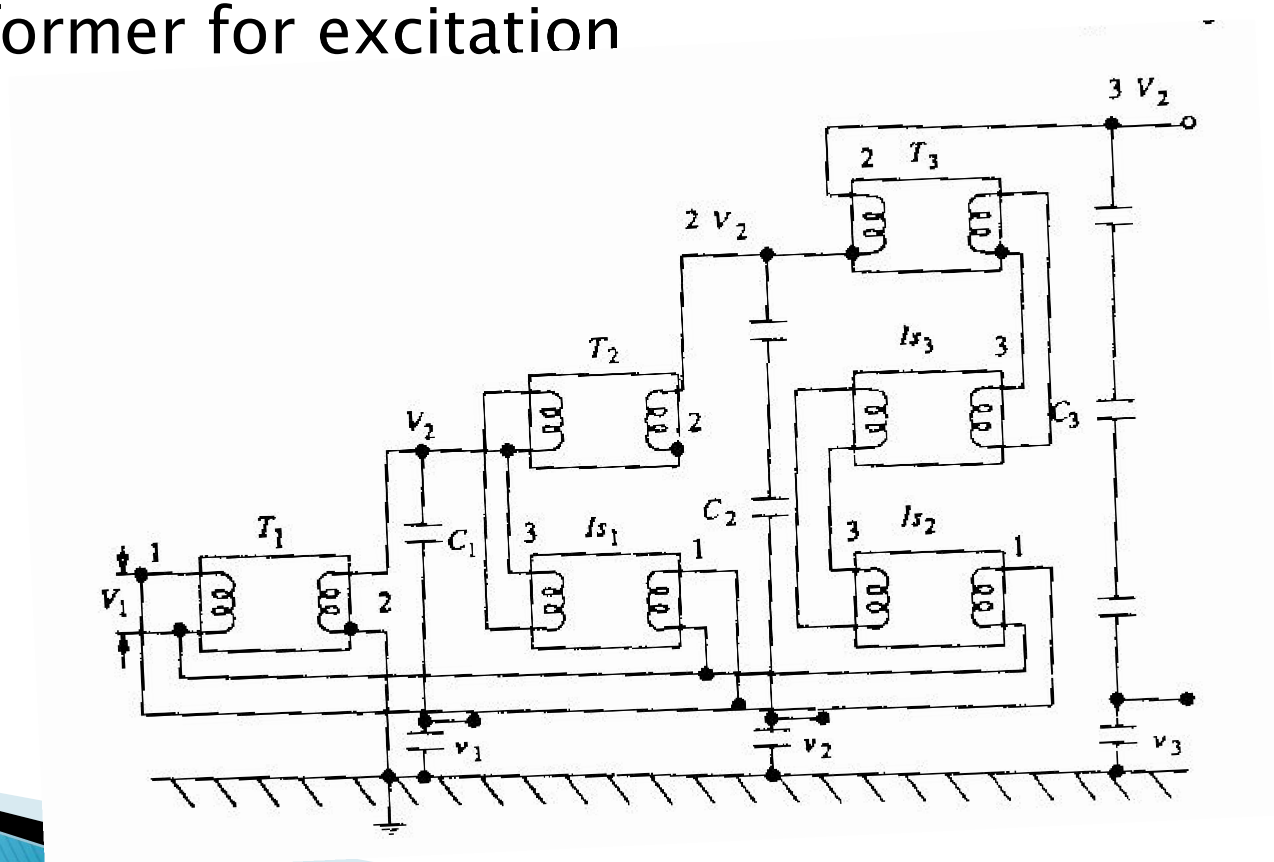


V_1 — Input voltage
V_2 — Output voltage
aa' — L.V. primary winding
bb' — H.V. secondary winding
cc' — Excitation winding
bd — Meter winding (200 to 500 V)

Cascade transformer connection (schematic)

GENERATION OF HIGH AC VOLTAGE

Cascade transformer with isolating transformer for excitation



GENERATION OF HIGH FREQUENCY A.C HIGH VOLTAGES

- High frequency high voltage damped oscillations are needed which need high voltage high frequency transformer which is a Tesla coil.
- Tesla coil is a doubly tuned resonant circuit,primary voltage rating is 10 kV and secondary voltage rated from 500 to 1000 kV.
- The primary is fed from DC or AC supply through C1.A spark gap G connected across the primary is triggered at V1 which induces a high self excitation in the secondary.The windings are tuned to a frequency of 10 to 100 kHz.

GENERATION OF IMPULSE VOLTAGES

STANDARD IMPULSE WAVESHAPE

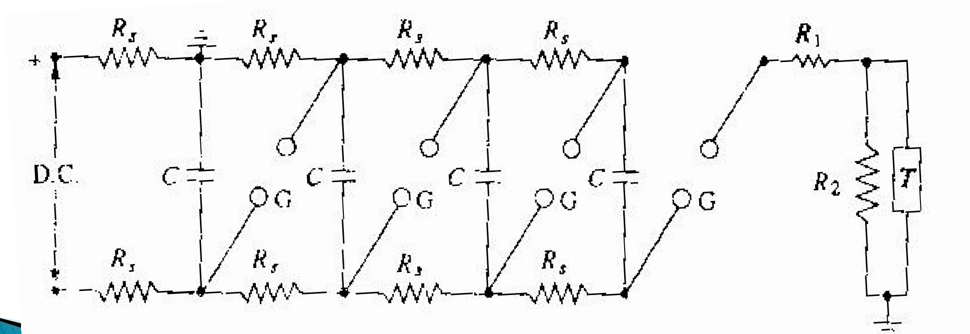
- It is specified by rise or front time,fall or tail time to 50% peak value and peak value.
- 1.2/50 μ s,1000 kV.

MARX CIRCUIT

- Charging resistance Rs is liming the charging current from 50 to 100 mA. CRs is about 10s to 1 min.
- The gap spacing G is grater than the charging voltage V.All the capacitance s are charged to the voltage V in 1 min.
- The spark gap G is made spark over, then all the capacitor C get connected in series and discharge into the load load
- In modified Marx circuit,R1is divided into n parts equal to R1/n and put in series with the gap G, R2is divided into n parts equal to R2/n and connected across each capacitor unit after the gap G.
- The nominal output is the number of stages multiplied by the charging voltage.

MULTISTAGE IMPULSE GENERATOR MARX CIRCUIT

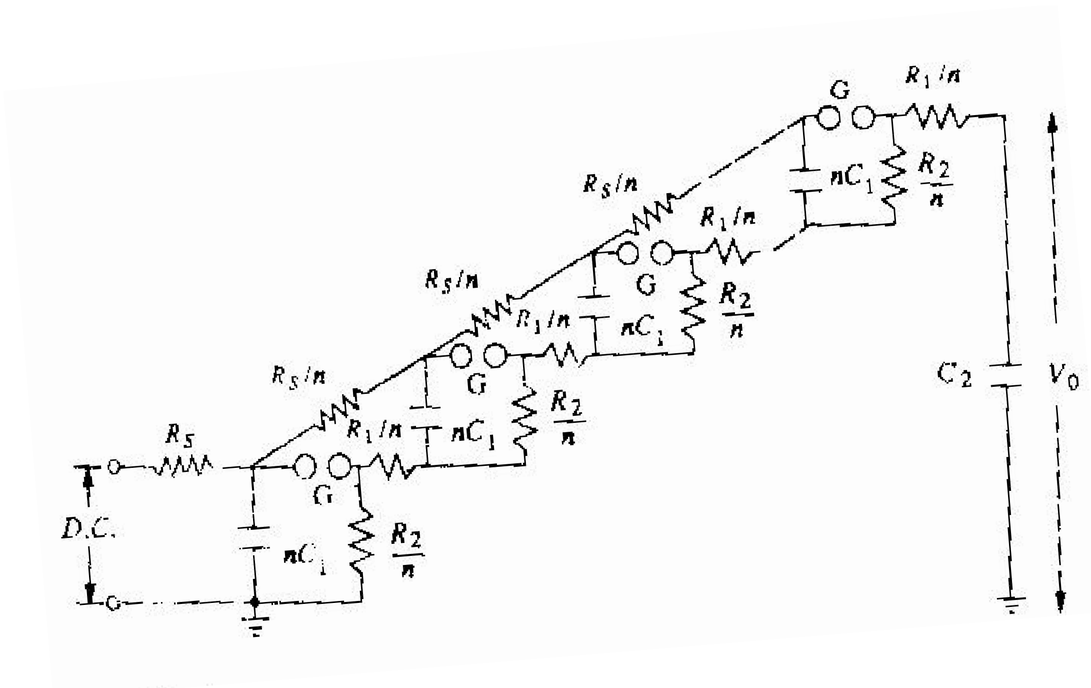
- A single capacitor C1 is to be charged first and then discharged into wave shaping circuits and it is limited to 200 kV
- For producing very high voltages a bank of capacitors are charged in parallel and then discharged in series.



C — Capacitance of the generator
R_s — Charging resistors
G — Spark gap
R_1, R_2 — Wave shaping resistors
T — Test object

MULTI STAGE IMPULSE GENERATORS

Modified Marx Circuit



COMPONENTS OF A MULTISTAGE IMPULSE GENERATOR

- DC Charging set
- Charging resistors
- Generator capacitors and spark gaps
- Wave shaping resistors and capacitors
- Triggering system
- Voltage dividers

GENERATION OF SWITCHING SURGES

- A switching surge is a short duration transient voltage produced in the system due to a sudden opening or closing of a switch or c.b or due to an arcing at a fault in the system.
- Impulse generator circuit is modified to give longer duration wave shape,100/1000 μs,R1 is increased to very high value and it is parallel to R2 in the discharge circuit.
- Power transformer excited by DC voltages giving oscillatory waves which produces unidirectional damped oscillations.Frequency of 1to 10 kHz
- Switching surges of very high peaks and long duration can be obtained by one circuit,In this circuit C1 charged to a low voltage d.c(20 to 25 kV) is discharged into the low voltage winding of a power transformer.The high voltage winding is connected inparallel to a load capacitance C2,potential divider R2,gap S and test object.

GENERATION OF IMPULSE CURRENTS

- For producing impulse currents of large value,a bank of capacitors connected in parallel are charged to a specified value and are discharged through a series R-Lcircuit.
- $I_m = V(\exp(-\alpha t))\sin(\omega t)/\omega L$

GENERATION OF HIGH IMPULSE CURRENTS

- For producing large values of impulse,a no.of capacitors are charged in parallel and discharged in parallel into the circuit.
- The essential parts of an impulse current generator are:
- (i) a.d.c. charging unit
- (ii) capacitors of high value (0.5 to 5 μF)
- (iii) an additional air cored inductor
- (iv) proper shunts and oscillograph for measurement purposes, and
- (v) a triggering unit and spark gap for the initiation of the current generator.

TRIPPING AND CONTROL OF IMPULSE GENERATORS

- In large impulse generators, the spark gaps are generally sphere gaps or gaps formed by hemispherical electrodes.
- The gaps are arranged such that sparking of one gap results in automatic sparking of other gaps as overvoltage is impressed on the other.
- A simple method of controlled tripping consists of making the first gap a three electrode gap and firing it from a controlled source.

TRIPPING AND CONTROL OF IMPULSE GENERATORS

- The first stage of the impulse generator is fitted with a three electrode gap, and the central electrode is maintained at a potential in between that of the top and the bottom electrodes with the resistors *R*1 and *RL*.
- The tripping is initiated by applying a pulse to the thyration G by closing the switch S.
- C produces an exponentially decaying pulse of positive polarity.
- The Thyraton conducts on receiving the pulse from the switch S and produces a negative pulse through the capacitance C1 at central electrode.
- Voltage between central electrode and the top electrode those above sparking potential and gap contacts.

TRIPPING CIRCUIT USING A TRIGATRON

- This requires much smaller voltage for operation compared to the three electrode gap.
- A trigatron gap consists of a high voltage spherical electrode, an earthed main electrode of spherical shape, and a trigger electrode through the main electrode.
- Tripping of the impulse generator is effected by a trip pulse which produces a spark between the trigger electrode and the earthed sphere.
- Due to space charge effects and distortion of the field in the main gap, spark over of the main gap occurs and it is polarity sensitive.

UNIT–III

INSULATION COORDINATION COURSE

CONTENT

- Specifying Insulation Strength
- Insulation Strength Characteristics
- Ph.–Ground Sw. OVs, Transmission Lines
- Ph.–Ph. Sw. OVs, Transmission Lines
- Sw. OVs, Substation
- Lightning Flash
- Shielding of Transmission Lines
- Shielding of Substations

Content ….

- Incoming Surge & Open Breaker Protection
- Metal Oxide Surge Arresters
- Station Lightning Insulation Coordination
- Line Arresters
- Induced Over voltages
- Contamination
- National Electrical Safety Code
- Line Insulation Design

OUTLINE of THIS CLASS on INSULATION COORDINATION

- INTRODUCTION to Definitions, Goals & Processes
- Specifying Insulation Strength

INTRODUCTION :
Definitions & Goals

- Definition of Insulation Coordination:

"***Selection of Insulation Strength consistent with expected Risk of Failure***"

engineers prefer following Definition*:*

"Process of Bringing Insulation Strengths of Elec. Equip. into proper relationship with expected OVs and characteristics of Surge Protective Devices so as to reduce to an economically & operationally acceptable level the risk of failure"

Goal and Process

- Select minimum insulation strength, or minimum clearance
- Process:

  1- **selection of *reliability criteria***

  2- **determine *stress*** placed on equipment or *air clearance*

  3- *Stress* **then compared to *Ins. Strength*** *Characteristic*

  4- from above ***a strength*** selected
- Feedback Process

  1- then if considered to be excessive,

  2- stress **can be reduced** by use of ***ameliorating measures*** such as surge arresters, protective gaps, shield wires, closing resistors in CCT. B.

Major Components of INSULATION COORDINATION

- **Line Insulation Coordination** which can be further separated into Trans. & Dis. Lines
- **Station Ins. Coord.** Which includes generation, transmission and Dist. Substations

- To These may be added other areas:

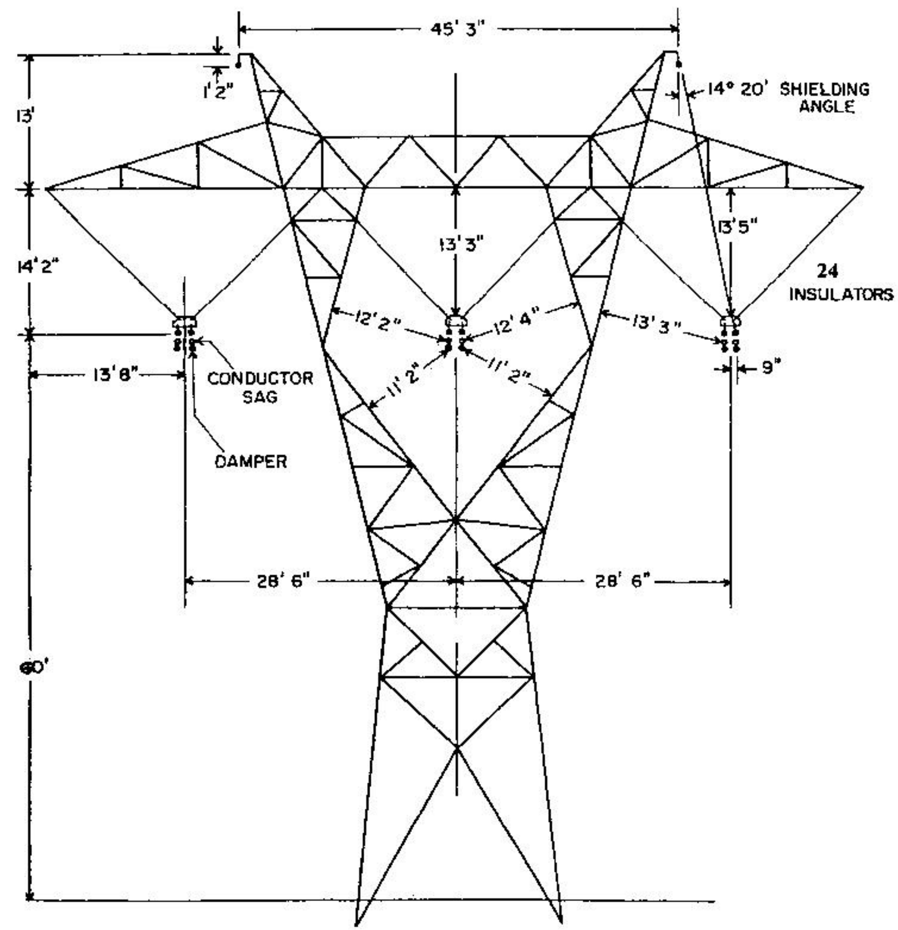
  –*Ins. Coord. of* :

  1- rotating mach.s **2- shunt & series cap.**
- *Subjects of Interest* : Two Major Top Categories

INTRODUCTION
LINE INSULATION COORDINATION

- Goal: to specify all dimensions or characteristics of trans. or dist. line tower which affect reliability of Line
- 1- clearances between ph. Cond. & Grounded tower sides & upper truss
- 2- Insulator string length
- 3- No. & type of insulators
- 4- Need & type of supplement Grounding
- 5- Location and No. O.H. shield wires
- 6- Ph. To G. mid-span clearance
- 7- Ph-ph clearance
- 8- Need for, rating & location of surge arresters

TYPICAL 500 kV TOWER STRIKE DISTANCES



STATION INSULATION COORDINATION

- To specify:
- **equipment insulation strength**; BIL,BSL of all equip.s
- Ph-G & ph-ph clearances (Figure next)
- Need for , location, rating & No. of Surge Arresters
- Need for, location, configuration & spacing of prot. Gaps
- Need for, location, & type of substation shielding
- Need for, amount, & method of achieving an improvement in lightning performance of line adjacent to station

STATION INSULATION COORDINATION

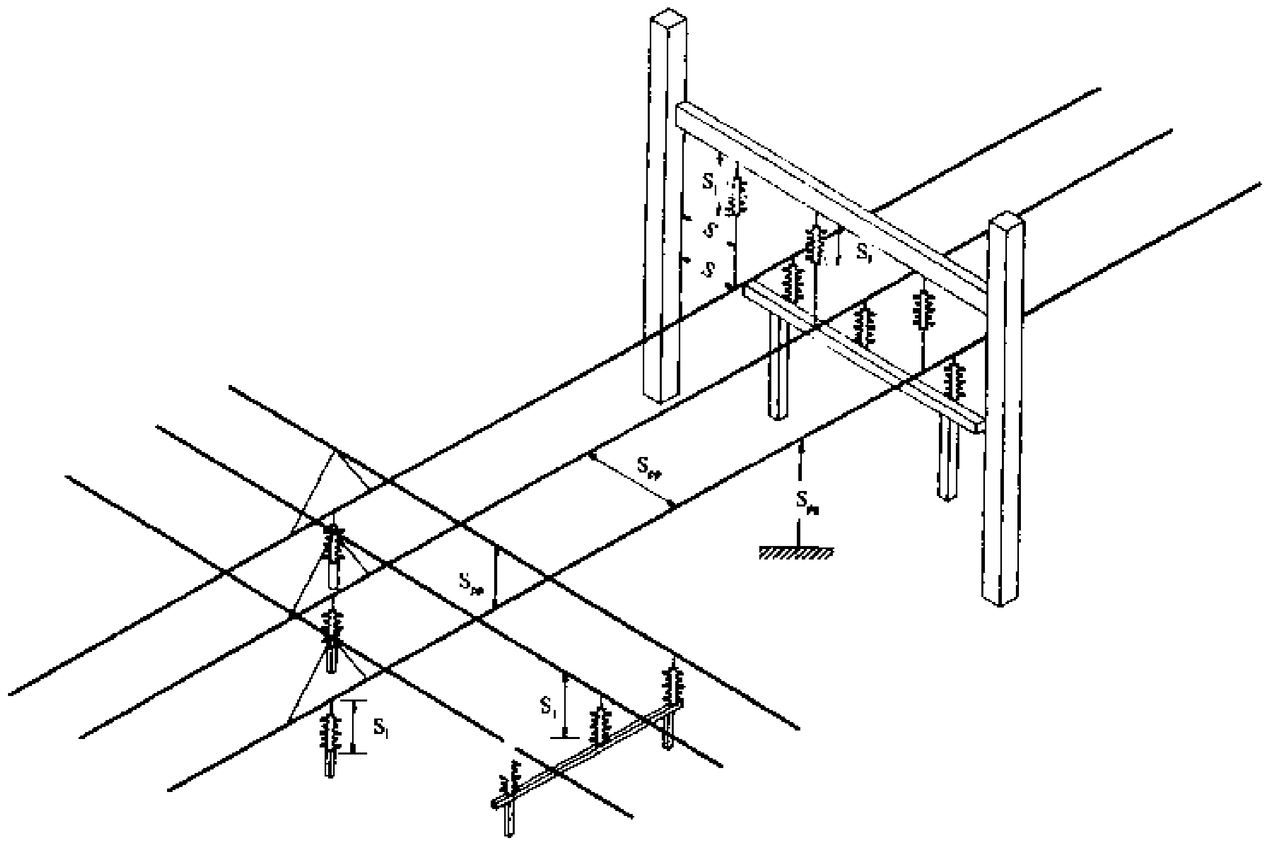


Figure 2 The strike distances and insulation lengths in a substation.

STATION INSULATION COORDINATION ….

- Engineer must consider all ***sources of stress***:
- *1- Lightning OVs*
- *2- Switching OVs by sw. B. or Dis. Sw. s*
- *3- TOV, by : Faults, Gen. over-speed, Ferro-resonance*
- *4- P.F. voltage in presence of contamination*
- in some of the **specifications**, **only one** of these stresses important

  - for transmission line, ***lightning*** dictates location & No. of ***shield wires*** needed & specification of ***supplemental tower grounding***

STATION INSULATION COORDINATION ….

- However subjective judgment required, to determine if shield wires should be used
- Arresters rating dictated by TOV
- No. & location of ***surge Arresters*** dictated by lightning
- For line & station, No. & type of ***insulators*** dictated by contamination
- However, in many specifications, 2 or more OVs must be considered: for ***Transmission lines***, Sw. OVs, Lightning, or contamination may dictate: *strike distances & insulator string length*
- In ***Substation***; Lightning, Sw. surges, or contamination dictate: *BIL, BSL, & clearances*

STATION INSULATION COORDINATION ….

- **Primary objective**: to specify Min. Ins. Strength
- So: No one of OVs should dominate the design
- That means: if considering Sw. OVs results in a specification of tower strike distances, methods should be sought to decrease Sw. OVs.
- And the objective is: not to permit one source of OV stress, dictate the design
- Carrying this philosophy to the ultimate; results in objective that Ins. Strength be dictated only by P.F. voltage

STATION INSULATION COORDINATION ….

- Although the last may not seem reasonable, it is achieved with regards to transformers; for which 1 hr p.f. test considered by many to be most severe test on insulation
- In addition, in most cases, Sw. surges important only for above 345 kV
- It means: for the lower voltages lightning dictates larger clearances & insulator lengths

This may be untrue for "Compact" designs

MODIFICATION of STRESSES

- If Ins. Strength specifications results in **“higher –than-desired”** clearances or Ins. Strength;

  stresses by lightning & Sw. may be decreased ➔
- Through application of:

  surge **arresters**; pre-insertion **resistors** in C.B.s; use of additional **shield wires**; additional tower **grounding** & additional **shielding in station**

TWO METHODS of INS. COORD.

- 1- **Conventional** or **Deterministic** Method
- 2- **Probabilistic** Method
- **Conventional**: specifying min. strength by setting it equal to max. stress
- rule is: *minimum strength=maximum stress*
- **Probabilistic***:* selecting Ins. Strength or clearances based on specific reliabilities criterion

TWO METHODS of INS. COORD. …

- An engineer may select Ins. Strength
- **for a line:** based on Lightning Flashover Rate of:

  One flashover/100 km-years
- **for a station:** based on mean time between failure

  (MTBF) of 100 or 500 yrs
- Choice of method not only on engineer’s desire but also on characteristic of the insulation
- i.e. Ins. Strength of air described statistically by GCD (Gaussian Cumulative Distribution)
- Therefore, this strength Dis. May be convolved with stress Dis. to determine Prob. of Flashover

TWO METHODS of INS. COORD. …

- While, Ins. Strength of a transformer internal Ins. Specified by a single value for lightning & a single value for Sw. called BIL & BSL
- This BIL or BSL proved only by one application of test voltage & no statistical Dis. of strength is available & conv. method must be used
- However, even when conv. method is used a prob. of Failure or F.O. exists (although is not evaluated)

TWO METHODS of INS. COORD. …

- Selected reliability criterion is primarily a function of consequence of failure & life of equipment
- Ex1: reliability criterion for a station may be more stringent than that for a line because a F.O. in station is of greater consequence
- Even with a station, reliability criterion may change according to type of apparatus (consequences of failure of a transformer required a higher order of protection)
- Ex2: design Flashover Rate for EHV lines lower than lower voltage lines

Chapter one :
Specifying Insulation Strength

- **Job**: selection of *strength of insulation*
- First : usual, normal and standard conditions

  used should be known
- Several methods of describing strength: **BIL, BSL, CFO**
- **Goal:** to **define** alternate methods of describing **strength** & **related test methods**

1

Specifying Insulation Strength

- STANDARD ATMOSPHERIC CONDITIONS

1- Ambient temperature 20∘ C
2- Air pressure: 101.3 kPa ~ 760 mm Hg
3- Absolute humidity: 11 grams of water/m^3 of air
4- for wet tests: 1 to 1.5 mm of water/minute

If actual Atm. Cond.s Differ from these values, ***Strength in terms of voltage*** is corrected to these standard values

Specifying Insulation Strength

- TYPES of INSULATION
  according to ANSI C92.1 (IEEE 1313.1)
  1- classified as :
  INTERNAL or EXTERNAL
  2- classified as:
  SELF-RESTORING &
  NON-SELF-RESTORING

Specifying Insulation Strength

- **EXTERNAL INSULATION:**
- Distances in open air or Across surfaces of solid insulation in contact with open air subjected to effects of Atm.,
- examples:
  - porcelain shell bushing
  - bus support insulators
  - disconnecting switches

Specifying Insulation Strength

- INTERNAL INSULATION

– internal solid, liquid, or gaseous parts of equipment insulation, protected by equipment enclosures

– Exs : transformer insulation

– :internal insulation of bushings

Note: equipment may be a combination of internal & external insulation, such as a bushing and a C.B.

Specifying Insulation Strength

- SELFRESTORING (SR)INSULATION
- Insulation completely recovers insulating properties after a disruptive discharge
- generally is external insulation
- NON-SELF-RESTORING (NSR) INSULATION
- Opposite of (SR) insulators
- Insulation loses insulating properties or doesn’t recover after a disruptive discharge
- generally external insulation

1 Specifying Insulation Strength

Definition of apparatus strength, BIL, BSL

- **BIL** – Basic Lightning Impulse Insulation Level
- Is the electrical strength of insulation expressed in crest of "standard lightning impulse"
- BIL is tied to a specific wave shape & standard Atm. Condition
- BIL may be either; a statistical BIL or a conventional BIL
- Statistical BIL only for SR insulations
- Conventional BIL only for NSR insulations
- BIL universally for dry conditions

1 Specifying Insulation Strength

Definition of apparatus strength, BIL, BSL

- Statistical BIL is crest of standard lightning imp. for which insulation exhibits %90 prob. of withstand, and a %10 failure
- Conventional BIL is crest of standard lightning imp. for which insulation does not exhibit disrup. discharge subjected to a specific No. of impulse
- IEC publication 71, BIL is known as lightning Imp. Withstand Voltage
- However in IEC it is not divided into two different names as above

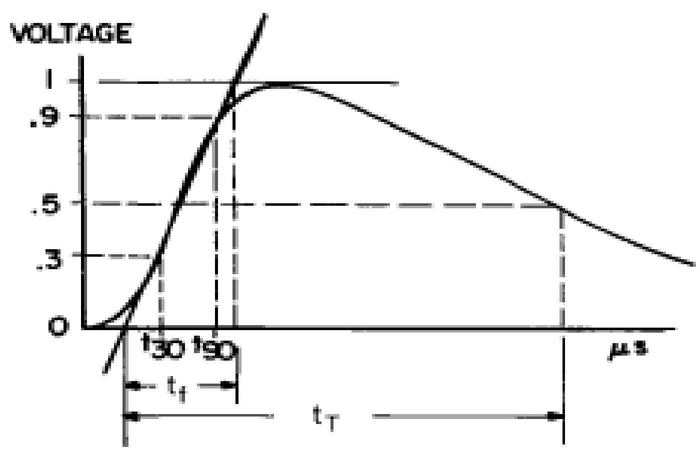
1 Specifying Insulation Strength
Definition of apparatus strength, BIL, BSL

- BSL : basic switching impulse insulation level
- BSL is electrical strength of Ins. expressed in crest value of standard sw. imp.
- BSL may be either: conventional or statistical
- Statistical BSL applicable only to SR insulations
- Conventional BSL applicable to NSR insulations
- Insulation BSLs are universally for wet condition
- Definitions similar to BILs of conv. & statistic
- IEC publication 71, BSL called “switching imp. Withstand voltage” and not divided to two definitions

1 Specifying Insulation Strength

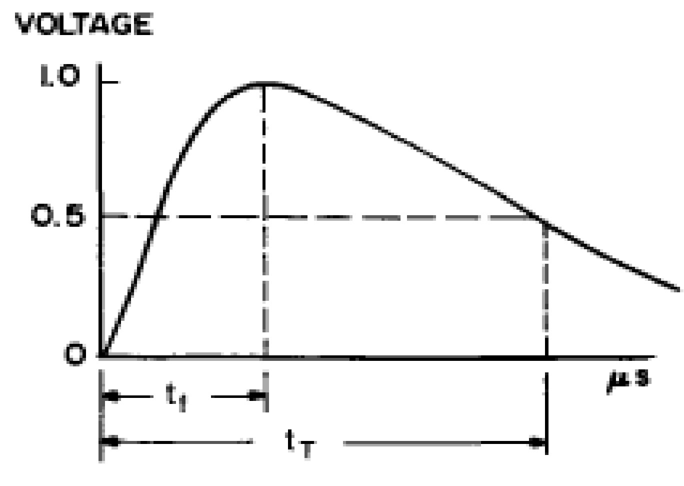
Definition of apparatus strength, BIL, BSL

- Standard Wave Shapes
- General lightning & switching imp. wave shapes shown below



LIGHTNING IMPULSE

Figure 1 Lightning impulse wave shape.



SWITCHING IMPULSE

Figure 2 Switching impulse wave shape.

1 Specifying Insulation Strength
Definition of apparatus strength, BIL, BSL

- Important Parameters (for both waves):
  - Time to crest (called simply "front")
  - Time to half value (called simply "tail")
- However :
  - Time to crest for Lightning starts from a virtual zero (intersection of line passing 30% & 90% with time axis)
  - $t_f = 1.67\,(t_{90} - t_{30})$

1 Specifying Insulation Strength
Definition of apparatus strength, BIL, BSL

- Standard Lightning wave shape is 1.2/50 μs
- This reflects the short front and relative short tails observed in the records
- All laboratories can produce it easily the
- The standard switching wave is 250/2500 μs

Standard Impulse Wave Shapes and Tolerances

Imp. Type Nominal Wave shape	lightning 1.2 / 50 μs	Switching 250 /2500 μs
Tolerances front	± 30 %	± 20%
Tail	± 20%	± 60%

1 Specifying Insulation Strength

Definition of apparatus strength, BIL, BSL

- A 1000 kV, 200/3000 μs sw. imp. has a crest voltage of 1000 kV, a front of 200 μs, a tail of 3000 μs
- The standard lightning & switching imp. wave shapes and their tolerances listed in last table

1 Specifying Insulation Strength
Definition of apparatus strength, BIL, BSL

- *Statistical vs. Conventional BIL/BSL*
- The statistical BIL or BSL is defined statistically or probabilistically
- probability of F.O. (failure) for application of an standard imp.(with crest of BIL or BSL) is 10%
- Insulation strength characteristic may be represented by a cumulative Gaussian Dis.

1 Specifying Insulation Strength

Definition of apparatus strength, BIL, BSL

- Ins. Strength Characteristic for self-restoring Insulation

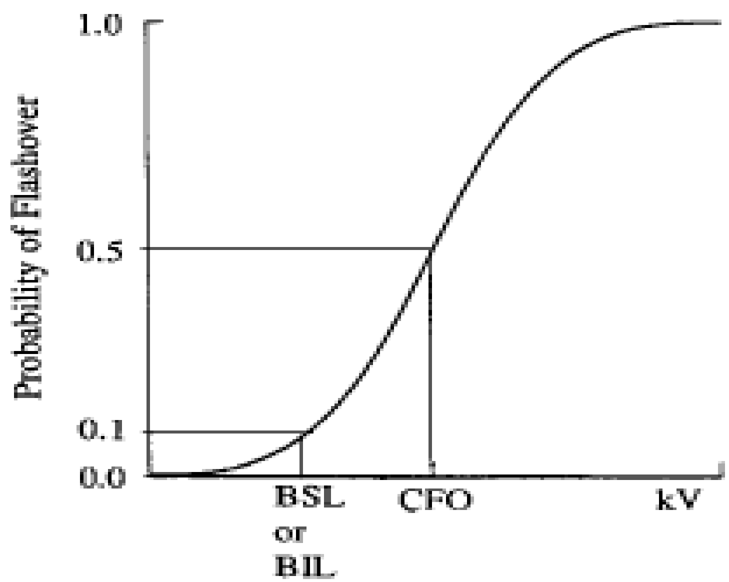


Figure 3 Insulation strength characteristic for self-restoring insulation.

1 Specifying Insulation Strength

Definition of apparatus strength, BIL, BSL

- Mean of Dis. Is defined as critical F.O. voltage or CFO
- Applying CFO to insulation results in a 50 % prob. of F.O.
- Locating BIL or BSL at the 10% point results in definition that : BIL or BSL is 1.28 standard deviation, σf, below CFO:
- $BIL = CFO\,(1 - 1.28 \times \sigma f / CFO)$

  $BSL = CFO\,(1 - 1.28 \times \sigma f / CFO)$

1 Specifying Insulation Strength
Definition of apparatus strength, BIL, BSL

- σ_f is in P.U. of CFO & a sigma of 5% interpreted as a standard deviation of 5% of CFO
- Standard Deviations for lightning & switching imp. Differ
- For lightning, sigma is 2 to 3%
- For switching ranges from 5% for tower insulation, to about 7% for station type insulations
- **Conventional BIL or BSL** more simply defined in 3 steps:
- One or more standard imp.s with crest of BIL or BSL applied to insulations
- If no F.O. s occur, insulation posses a BIL or BSL applied to it
- Thus insulation strength rise from zero prob. of F.O. at BIL or BSL voltage to 100% prob. of F.O. at the same BIL or BSL (shown in next fig.)

1 Specifying Insulation Strength
Definition of apparatus strength, BIL, BSL

- Ins. Strength Charac. for non-self-restoring Ins.

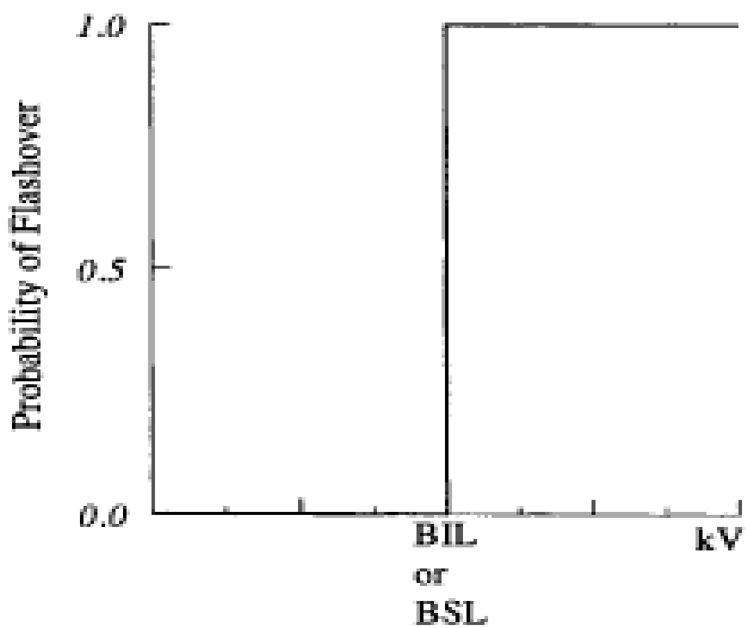


Figure 4 Insulation strength characteristic for non-self-restoring insulation.

1 Specifying Insulation Strength

Definition of apparatus strength, BIL, BSL

- *Tests to "Prove" BIL and BSL*
- tests may be divided between conventional & the statistical
- Conv. BIL or BSL tied to non-self-restoring insulation it is more desirable that tests be nondestructive
- Test is simply to apply one or more imp.s with standard wave shape & crest equals BIL or BSL
- If no failure occurs the test is passed, while it is true that some failures on test floor occur, the failure rate is extremely low
- That is, a manufacturer can't afford having failure rates on power transformers exceeding 1% –& if occur production stopped & all designs are reviewed

1 Specifying Insulation Strength

Definition of apparatus strength, BIL, BSL

- Considering establishment of statistical BIL or BSL
- Theoretically no test can conclusively prove that insulation has a 10% prob. of failure
- However there are several types of tests possible, from which (as shown in fig.3) BIL or BSL can be obtained
- These tests are not made except in the equipment design stage

1 Specifying Insulation Strength
Definition of apparatus strength, BIL, BSL

- For standardization two types of tests exist:

- n/m test :
  - m imp. Applied, is passed if no more than n F.O.
  - preferred test in IEC is 2/15; if 2 or fewer F.O.
- n+m test :
  - n imp. Applied if none F.O. test is passed
  - if there are 2 or more F.O. test failed
  - if only 1 F.O., m addition imp. Applied & test is passed if none F.O.
  - present test on C.B.s is 3+3; in IEC an alternate but less preferred test to 2/15 test is 3+9 test

Summary and Conclusions

- **INTRODUCTION, Goals & Process of Insulation coordination**
- **First step** in **Insulation Coordination**:
- *Specifying the Insulation Strength*
- Different Classifications of Insulation presented
- statistical & Conventional BIL & BSL defined
- Their Relations with CFO presented
- **IEC definition** for :
- **1- L**ightning **Imp**ulse **Withstand Voltage** &
- **2- Sw**itching **Imp**ulse **Withstand Voltage**

UNIT-IV
TESTING OF INSULATION

TESTS OF INSULATORS

- Type Test To Check The Design Features
- Routine Test To Check The Quality Of The Individual Test Piece.
- High Voltage Tests Include

  (i) Power frequency tests

  (ii) Impulse tests

TESTS OF INSULATORS

POWER FREQUENCY TESTS

(a) Dry and wet flashover tests:

- a.c voltage of power frequency is applied across the insulator and increased at a uniform rate of 2% per second of 75%of ther estimated test voltage.
- If the test is conducted under normal conditions without any rain – dry flashover test.
- If the test is conducted under normal conditions of rain –wet flashover test

(b) Dry and wet withstand tests(one minute)

The test piece should withstand the specified voltage which is applied under dry or wet conditions.

IMPULSE TESTS ON INSULATORS

- **Impulse withstand voltage test:**

  If the test object has withstood the subsequent applications of standard impulse voltage then it is passed the test

- **Impulse flashover test:**

  The average value between 40% and 60% failure is taken, then the insulator surface should not be damaged.

- **Pollution Testing:**

  Pollution causes corrosion ,deterioration of the material, partial discharges and radio interference. Salt fog test is done.

TESTING OF BUSHINGS

Power frequency tests

(a) **Power Factor-Voltage Test:**

- Set up as in service or immersed in oil.
- Conductor to HV and tank to earth.
- Voltage is applied up to the line value in increasing steps and then reduced.
- The capacitance and power factor are recorded in each step.

(b) **Internal or Partial discharge Test:**

- To find the deterioration or failure due to internal discharges
- Conducted using partial discharge arrangements
- Performance is observed from voltage Vs discharge magnitude.
- It is a routine test.

(c) **Momentary Withstand Test at Power frequency**

- Based on IS:2009
- The bushing has to withstand the applied test voltage without flashover or puncture for 30 sec.

TESTING OF BUSHINGS

(d) One Minute withstand Test at Power Frequency

- Most common & routine test
- Test is carried in dry &wet for one minute.
- In wet test, rain arrangement is mounted as in service.
- Properly designed bushing should withstand without flashover for one minute.

(e) Visible Discharge Test at Power Frequency

- Conducted based on IS:2009
- Conducted to determine radio interference during service
- Conducted in dark room
- Should not be any visible discharges other than arcing horns/ guard rings.

TESTING OF BUSHINGS

Impulse voltage tests:

- **Full wave Withstand Test**
  - The bushing is tested for either polarity voltages
  - Five consecutive full wave is applied
  - If two of them flashed over, then 10 additional applications are done.
  - If the test object has withstood the subsequent applications of standard impulse voltage then it is passed the test.
- **Chopper Wave withstand Test**
  - Sometimes done on HV bushings (220kV, 400kV and above)
  - Switching surge flashover test is included for HV bushings.
  - This is also carried out same as above full wave test.

TESTING OF BUSHINGS

Temperature Rise and Thermal Stability Tests

- To observe the temperature rise and to ensure that it doesn't go into 'thermal runaway' condition.
- Temperature rise test is done at ambient temperature (below 40^0C) at a rated power frequency.
- The steady temperature rise should not exceed 45^0C.
- Test is carried out for long time & increase in temperature is less than 1^0C/hr.
- This test is enough to produce large dielectric loss and thermal in stability.
- **Thermal stability test** is done for bushing rated for 132 kV above.
- Carried out on the bushing immersed in oil at max. service temperature with 86% of normal system voltage.
- This is a type test for low rating and routine test for high ratings.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Isolator:

- Off-load or minimum current breaking mechanical switch.
- Explained according to “IS:9921 Part-1, 1981”.
- Interrupting small currents(0.5A): Capacitive currents of bushings, busbars etc.,

Circuit Breaker:

- Onload or high current breaking switch

Testing of Circuit Breaker:

- To evalute,
  - Constructional & operating characteristics
  - Electrical characteristics

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Electrical Characteristics:

- Arcing voltage
- Current chopping characteristics
- Residual currents
- Rate of decrease of conductance of the arc space and the plasma
- Shunting effects in interruption

Physical Characteristics:

- Arc extinguishing medium
- Pressure developed at the point of interruption
- Speed of contact travelling
- Number of breaks
- Size of the arcing chamber
- Material and configuration of the circuit interruption

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Circuit Characteristics:

- Degree of electrical loading
- Applied voltage
- Type of fault
- Time of interruption
- Frequency
- Power factor
- Rate of rise of recovery voltage
- Re-stricking voltage
- Decrease in AC component of the short circuit current
- DC component of the short circuit current

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

- **Dielectric tests:**
  - Consists of over voltage withstand tests of power frequency, lightning and switching impulse voltages
  - Tested for internal & 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 insulators above ground to avoid ground flash over.
- **Impulse tests:**
  - Impulse test and switching surge tests with switching over voltage are done.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

- **Thermal tests:**
  - To check the thermal behaviour of the breakers
  - Rated current through all three phases of the switchgear is passed continuously for a period long enough to achieve steady state conditions
  - Temperature rise must not exceed 40°C when the rated normal current is less than 800 amps and 50°C if it is 800 amps and above
  - Contact resistances between the isolating contacts and between the moving and fixed contacts is important. These points are generally the main sources of excessive heat generation.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

- **Mechanical Test:**
  - To ensure the open and closing with out mechanical failure
  - It requires 500(some times 20,000) operations without failure and with no adjustment of the mechanism.
  - A resulting change in the material or dimensions of a particular component may considerably improve the life and efficiency of the mechanism.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Short circuit tests:

- To check the ability to safely interrupt the fault currents.
- To determine the making and breaking capacities at different load currents
- Methods of conducting short circuit tests,
  1. Direct tests
     1. Using the power utility system as the source.
     2. Using a short circuit generator as the source
  2. Synthetic Tests

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Direct tests -Using the power utility system as the source:

- To check the ability to make or break in normal load conditions or short circuit conditions in the network itself
- Done during limited energy consumption
- Advantages:

1. Tested under actual conditions in a network
2. Special cases (like breaking of charging current of long lines, very short line faults etc.,) can be tested
3. Thermal & dynamic effects of short circuit currents and applications of safety devices can be studied

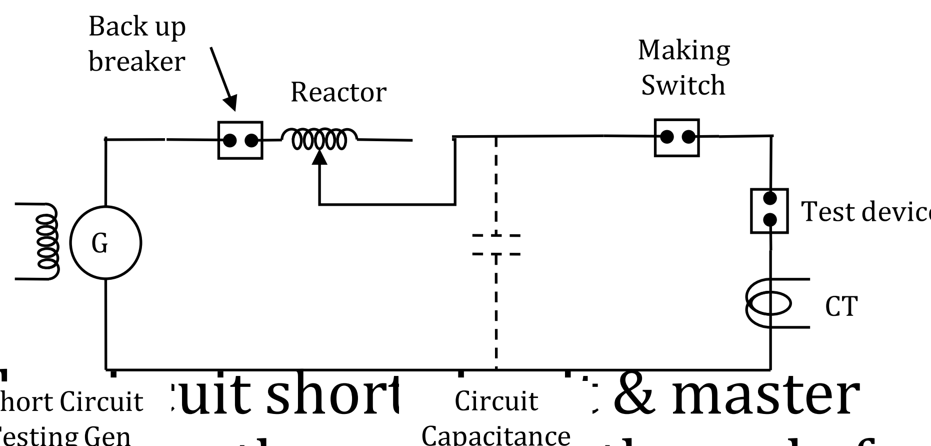
- Disadvantages:

1. Can be tested only in rated voltage and capacity of the network
2. Test is only at light load conditions
3. Inconvenience and expensive installation of control and measuring equipment is required in the field.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

Direct Testing-Short circuit test in laboratories:

- To test the CBs at different voltages & different SC currents
- The setup consists of,
  - A SC generator
  - Master CB
  - Resistors
  - Reactors and
  - Measuring devices

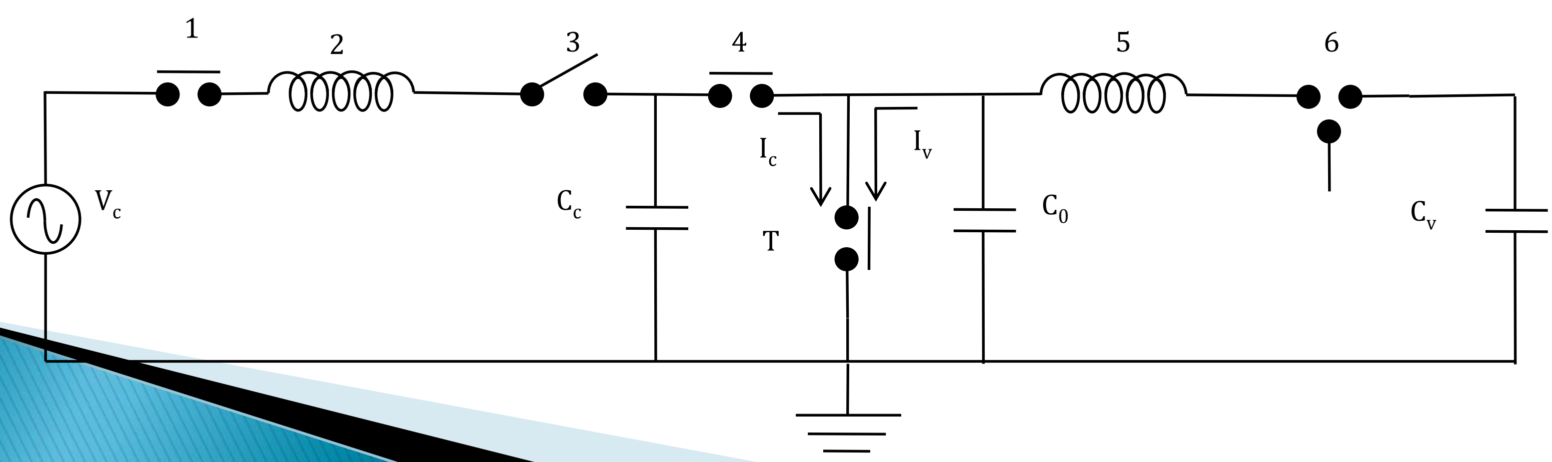


- The make switch initiates t[illegible]uit short [illegible] & master switch isolates the test dev[illegible]om the so[illegible] the end of predetermined time.
- If the test device failed to operate, master CB can be tripped.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

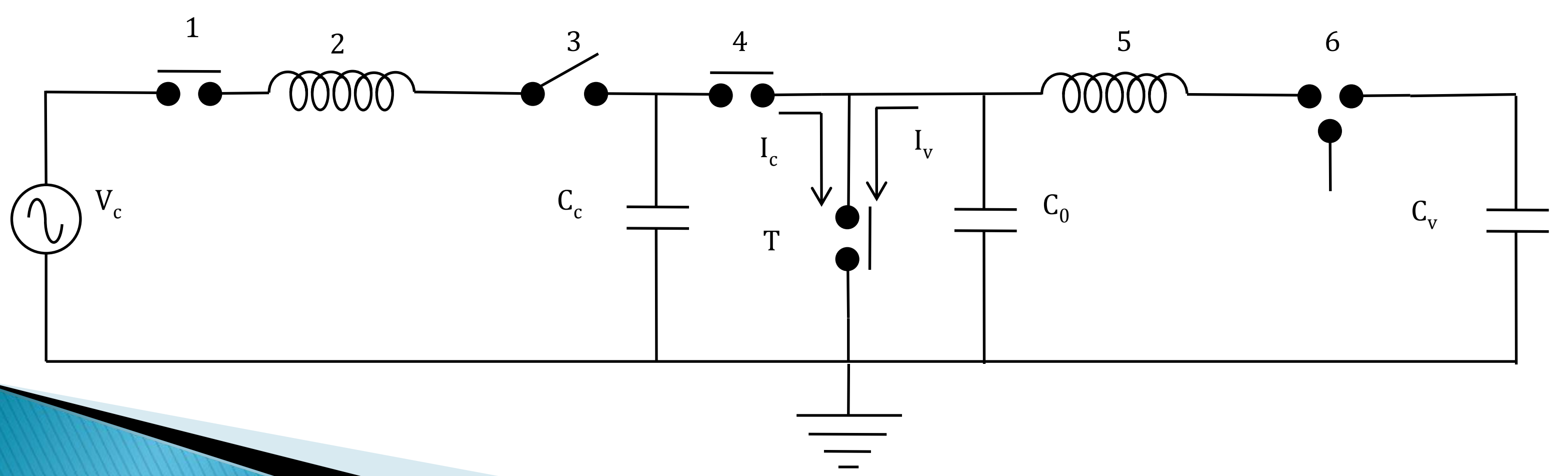
Synthetic Testing of CBs:

- Heavy current at low voltage is applied
- Recovery voltage is simulated by high voltage, small current source
- Procedure:
  - Auxiliary breaker **3** and 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 and the master breaker **1** becomes to clear the gen circuit.



TESTING OF ISOLATORS AND CIRCUIT BREAKERS

- At time t_1, just before zero of the gen current, the trigger gap **6** closes and high frequency current from capacitance $\mathbf{C_v}$ flows through the arc of the gap
- At time $\mathbf{t_2}$, gen current is zero. Master CB **1** is opened
- The current from $\mathbf{C_v}$ will flow through test CB and full voltage will be available
- At the instant of breaking, the source is disconnected and high voltage is supplied by auxiliary CB **4**



TESTING OF CABLES

Different tests on cables are

i. Mechanical tests like bending test,dripping and drainage test, and fire resistance and corrosion tests
ii. Thermal duty tests
iii. Dielectric power factor tests
iv. Power frequency withstand voltage tests
v. Impulse withstand voltage tests
vi. Partial discharge test
vii. Life expectancy tests

TESTING OF CABLES

Dielectric power factor tests:

- Done using HV Schering Bridge
- The p.f or dissipation factor ‘tanδ’ is measured at 0.5, 1.0, 1.66 and 2.0 times the rated phase-to-ground voltage of the cable
- Max. value of p.f and difference in p.f b/w rated voltage and 1.66 times of rated voltage is specified.
- The difference between the rated voltage and 2.0 times of rated voltage is also specified
- A choke is used in series with the cable to form a resonant circuit.
- This improves the power factor and rises the test voltage b/w the cable core and the sheath to the required value when a HV and high capacity source is used.

TESTING OF CABLES

High voltage testing on Cables:

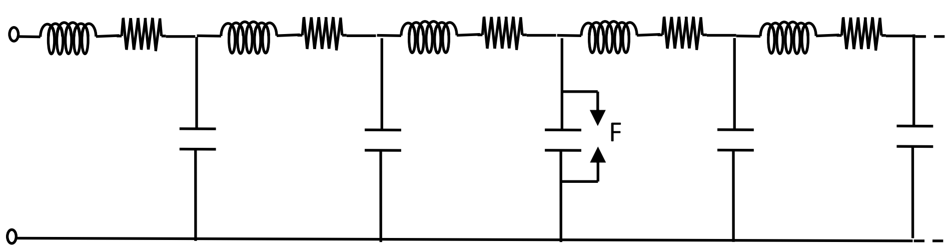
- Power frequency HV A.C, DC and impulse voltages are applied to test the withstanding capability
- Continuity is checked with high voltage at the time of manufacturing
- **Routine test:**
  - Cable should withstand 2.5 times of the rated voltage for 10 mins without damage in insulation
- **Type test:**
  - Done on samples with HVDC & impulses
  - DC Test:1.8 times of the rated voltage (-ve) applied for 30 mins.
  - Impulse Test: 1.2/50μS wave applied. Cable should withstand 5 consecutive impulses without any damage
  - After impulse test, power frequency & power factor test is conducted to ensure that no failure occurred during impulse test.

TESTING OF CABLES

Partial Discharge test:

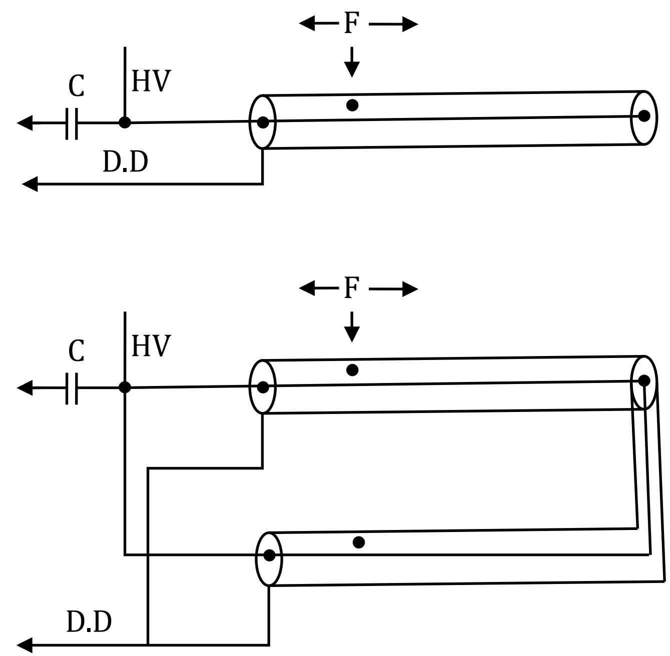
i. Discharge measurement:

- Life time of insulation depends on the internal discharges. So, PD measurement is important.
- In this test, weakness of insulation or faults can be detected
- Fig(i) and (ii) shows the connection to discharge detector through coupling capacitor.



Equivalent Circuit of Cable for discharges

(i)



(ii)

TESTING OF CABLES

- If the coupling capacitor connected, transient wave will be received directly from the discharge cavity and second wave from the wave end i.e., two transient pulses is detected
- In circuit shown in fig (ii), no severe reflection is occurred except a second order effect of negligible magnitude.
- Two transients arrive at both ends of the cable-super imposition of the two pulses detected-give serious error in measurement of discharge

ii. Location of discharges

- Voltage dip caused by discharge or fault is travelled along the length & determined at the ends
- Time duration b/w the consecutive pulses can be determined
- The shape of the voltage gives information on the nature of discharges

TESTING OF CABLES

iii. Scanning Method:

- Cable is passed through high electric field and discharge location is identified.
- Cable core is passed through a tube of insulating material filled with distilled water
- Four ring electrodes (two @ ends+two @ middle) mounted in contact with water.
- Middle electrode given to HV. If a discharge occurs in the portion b/w the middle electrodes, as the cable is passed b/w the middle electrode's portion, the discharge is detected and located at the length of cable.

iv. Life Test

- For reliability studies in service.
- Accelerated life tests conducted with increased voltages to determine the expected life time.

$$E_m = Kt^{-\left(\frac{1}{n}\right)}$$

- K-Constant depends on Field condition and material
- n- Life index depends on material

TESTING OF TRANSFORMERS

- Transformer is one of the most expensive and important equipment in power system.
- If it is not suitably designed its failure may cause a lengthy and costly outage.
- Therefore, it is very important to be cautious while designing its insulation, so that it can withstand transient over voltage both due to switching and lightning.
- The high voltage testing of transformers is, therefore, very important and would be discussed here. Other tests like temperature rise, short circuit, open circuit etc. are not considered here.
- However,these can be found in the relevant standard specification.

TESTING OF TRANSFORMERS

- Induced over voltage test:
  - Transformer secondary is excited by HFAC(100 to 400Hz) to about twice the rated voltage
  - This reduces the core saturation and also limits the charging current necessary in large X-mer
  - The insulation withstand strength can also be checked
- Partial Discharge test:
  - To assess the magnitude of discharges
  - Transformer is connected as a test specimen and the discharge measurements are made
  - Location and severity of fault is ascertained using the travelling wave theory technique
  - Measurements are to be made at all the terminals of the transformer
  - Insulation should be so designed that the discharge measurement should be much below the value of 10^4 pC.

TESTING OF TRANSFORMERS

Impulse Testing of Transformer:

- To determine the ability of the insulation to withstand transient voltages
- In short rise time of impulses, the voltage distribution along the winding will not be uniform
- The equivalent circuit of the transformer winding for impulses is shown in Fig.1.

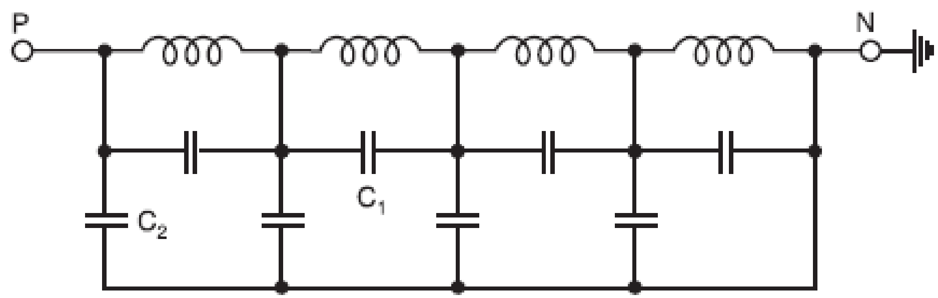


Fig.1: Equivalent circuit of a transformer for impulse voltage

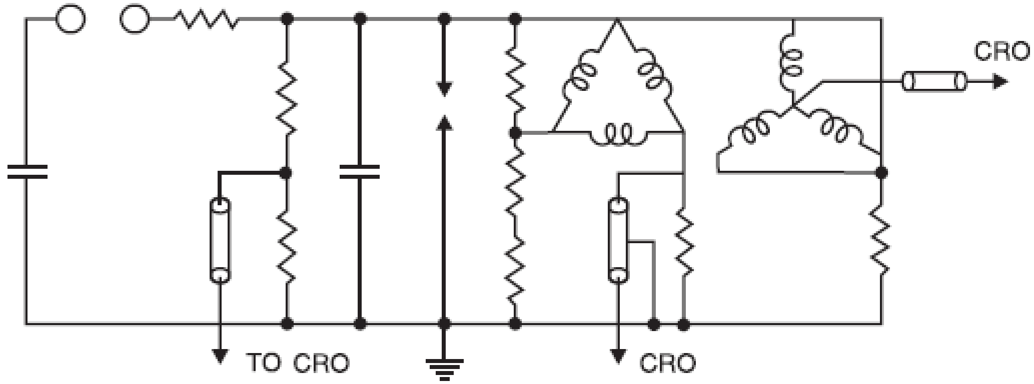
TESTING OF TRANSFORMERS

- Impulse voltage applied to the equivalent sets up uneven voltage distribution and oscillatory voltage higher than the applied voltage
- Impulse tests:
  - Full wave standard impulse
  - Chopped wave standard impulse (Chopping time: 3 to 6μS)
- The winding which is not subjected to test are short circuited and connected to ground
- Short circuiting reduces the impedance of transformer and hence create problems in adjusting the standard waveshape of impulse generators

TESTING OF TRANSFORMERS

Procedure for Impulse Test:

- The schematic diagram of the transformer connection for impulse test is shown in Fig.2



- The voltage and current waveforms are recorded during test. Sometimes, the transferred voltage in secondary and neutral current are also recorded.

TESTING OF TRANSFORMERS

Impulse testing consists 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% BIL and*
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 the Oscilloscope as a partial or complete collapse of the applied voltage.
- Study of the wave form of the neutral current also indicated the type of fault.

TESTING OF TRANSFORMERS

- If an arc occurs between the turns or from turn to the ground, a train of high frequency pulses are seen on the oscilloscope and wave shape of impulse changes.
- If it is only a partial discharge, high frequency oscillations are observed but no change in wave shape occurs.
- Impulse strength of the transformer winding is same for either polarity of wave whereas the flash over voltage for bushing is different for different polarity.

TESTING OF SURGE DIVERTERS

(i) Power frequency spark over test

- It is a routine test.
- The test is conducted using a series resistance to limit the current in case a spark over occurs.
- It has to withstand 1.5 times the rated value of the voltage for 5 successive applications.
- Test is done under both dry and wet conditions.

(ii) 100% standard impulse spark over test

- This test is conducted to ensure that the diverter operates positively when over voltage of impulse nature occur.
- The test is done with both positive and negative polarity waveforms.
- The magnitude of the voltage at which 100% flashover occurs is the required spark over voltage.

TESTING OF SURGE DIVERTERS

(iii) Residual voltage test:

- This test is conducted on pro-rated diverters of ratings in the range 3 to 12 kV only.
- Standard impulse wave of 1/50μS is applied, voltage across it is recorded.
- Magnitude of the current ≈ 2 X Rated current
- A graph is drawn b/w current magnitude and voltage across pro-rated unit and residual voltage is calculated
- V_1=rating of the complete unit
- V_2=rating of the prorated unit tested
- V_{R1}=residual voltage of the complete unit
- V_{R2}=residual voltage of the prorated unit
- $V_1/V_2= V_{R1}/ V_{R2}$
- $V_1/= V_2 .(V_{R1}/ V_{R2})$
- Let, V_{RM} – Max. permissible residual voltage of the unit

  Multiplying factor, $r = (V_{RM} /V_1)$

  Diverter is said to be passed when $V_{R2}<rV_2$

TESTING OF SURGE DIVERTERS

HIGH CURRENT IMPULSE TEST ON SURGE DIVERTERS

- Impulse current wave of 4/10μS is applied to pro-rated arrester in the range of 3 to 12kV.
- Test is repeated for 2 times
- Arrester is allowed to cool to room temperature

The unit is said to pass the test if

i. The power frequency sparkover voltage before and after the test does not differ by more than 10%
ii. The voltage and current waveforms of the diverter do not differ in the 2 applications
iii. The non linear resistance elements do not show any puncture or flashover

TESTING OF SURGE DIVERTERS

Other tests are

i. Mechanical tests like porosity test, temperature cycle tests
ii. Pressure relief test
iii. voltage withstand test on the insulator housing
iv. the switching surge flashover test
v. the pollution test

Unit-V
Insulation Co-ordination

INSULATION CO-ORDINATION

Insulation Coordination:

"The process of bringing the insulation strengths of electrical equipment and buses into the proper relationship with expected overvoltages and with the characteristics of the insulating media and surge protective devices to obtain an acceptable risk of failure."

Basic lightning impulse insulation level (BIL):

"The electrical strength of insulation expressed in terms of the crest value of a standard lightning impulse under standard atmospheric conditions."

Basic switching impulse insulation level (BSL)

"The electrical strength of insulation expressed in terms of the crest value of a standard switching impulse."

INSULATION CO-ORDINATION

Factor of Earthing:

This is the ratio of the highest r.m.s. phase-to-earth power frequency voltage on a sound phase during an earth fault to the r.m.s. phase-to-phase power frequency voltage which would be obtained at the selected location without the fault.

This ratio characterizes, in general terms, the earthing conditions of a system as viewed from the selected fault location.

Effectively Earthed System :

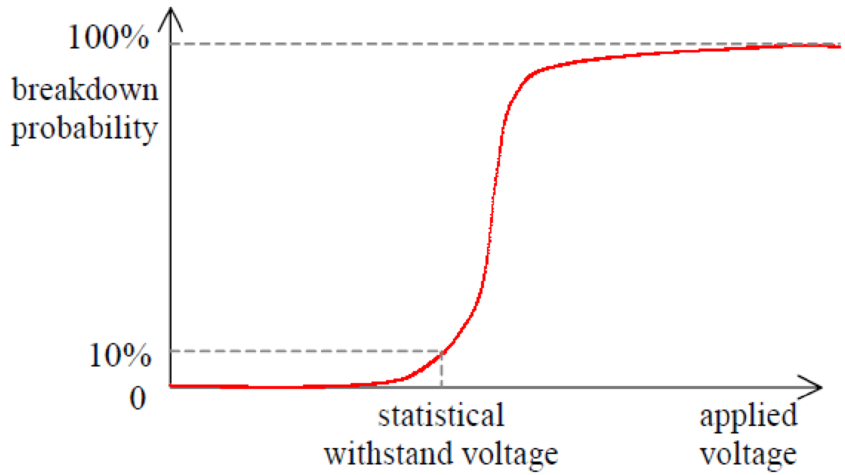
A system is said to be effectively earthed if the factor of earthing does not exceed 80%, and non-effectively earthed if it does.

INSULATION CO-ORDINATION

Statistical Impulse Withstand Voltage:

This is the peak value of a switching or lightning impulse test voltage at which insulation exhibits, under the specified conditions, a 90% probability of withstand.

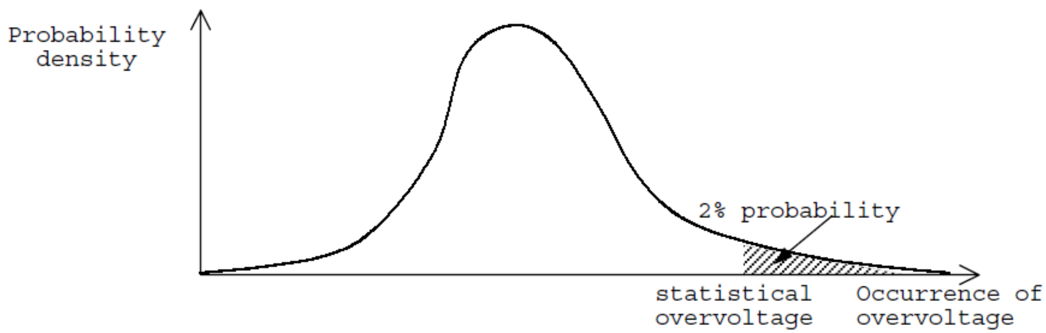
In practice, there is no 100% probability of withstand voltage. Thus the value chosen is that which has a 10% probability of breakdown.



INSULATION CO-ORDINATION

Statistical Impulse Voltage:

This is the switching or lightning overvoltage applied to equipment as a result of an event of one specific type on the system (line energising, reclosing, fault occurrence, lightning discharge, etc), the peak value of which has a 2% probability of being exceeded.



Protective Level of Protective Device:

These are the highest peak voltage value which should not be exceeded at the terminals of a protective device when switching impulses and lightning impulses of standard shape and rate values are applied under specific conditions.

INSULATION CO-ORDINATION

Necessity of Insulation Coordination:

i. To ensure the reliability & continuity of service
ii. To minimize the number of failures due to over voltages
iii. To minimize the cost of design, installation and operation

Requirements of Protective Devices:

- Should not usually flash over for power frequency overvoltages
- Volt-time characteristics of the device must lie below the withstand voltage of the protected apparatus
- Should be capable of discharging high energies in surges & recover insulation strength quickly
- Should not allow power frequency follow-on current.

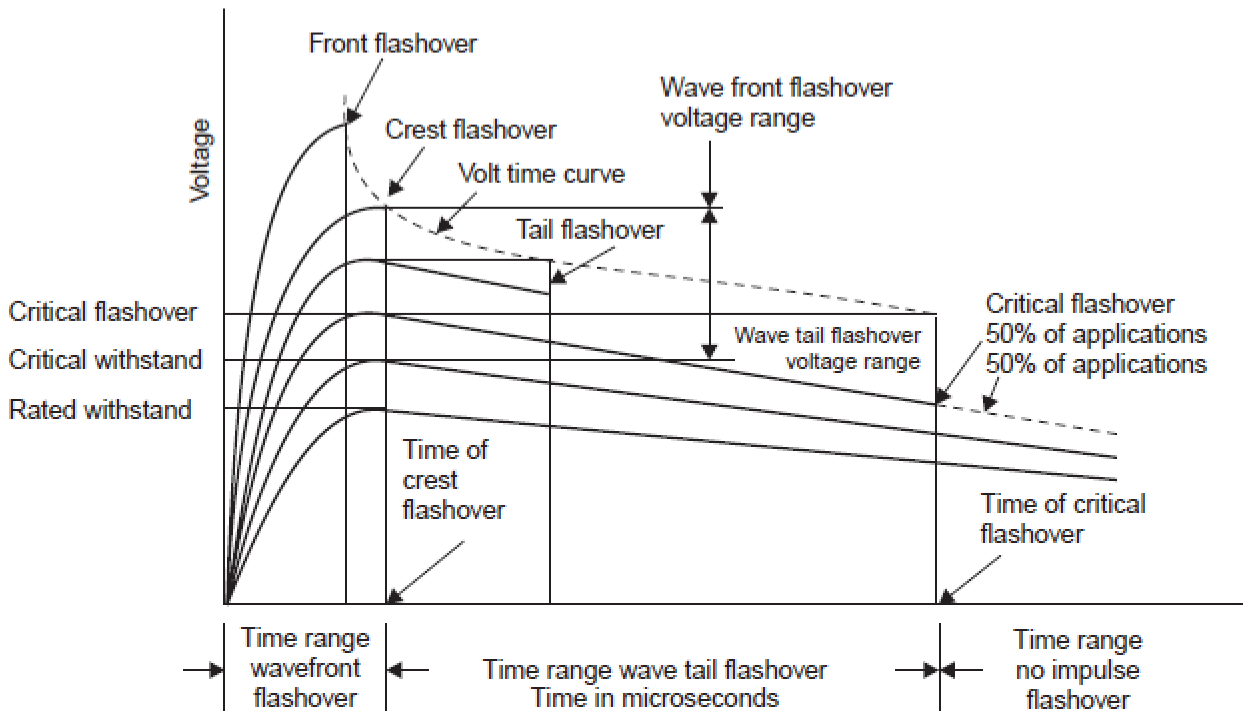
INSULATION CO-ORDINATION

Volt-Time Curve

- The breakdown voltage for a particular insulation of flashover voltage for a gap is a function of both the magnitude of voltage and the time of application of the voltage.
- Volt-time curve is a graph showing the relation between the crest flashover voltages and the time to flashover for a series of impulse applications of a given wave shape.
- Construction of Volt-Time Curve:
  - Waves of the same shape but of different peak values are applied to the insulation whose volt-time curve is required.
  - If flashover occurs on the front of the wave, the flashover point gives one point on the volt-time curve.
  - The other possibility is that the flashover occurs just at the peak value of the wave; this gives another point on the *V-T curve.*
  - The third possibility is that the flashover occurs on the tail side of the wave.

INSULATION CO-ORDINATION

- To find the point on the *V-T curve, draw a horizontal line from* the peak value of this wave and also draw a vertical line passing through the point where the flashover takes place
- The intersection of the horizontal and vertical lines gives the point on the *V-T curve.*



INSULATION CO-ORDINATION

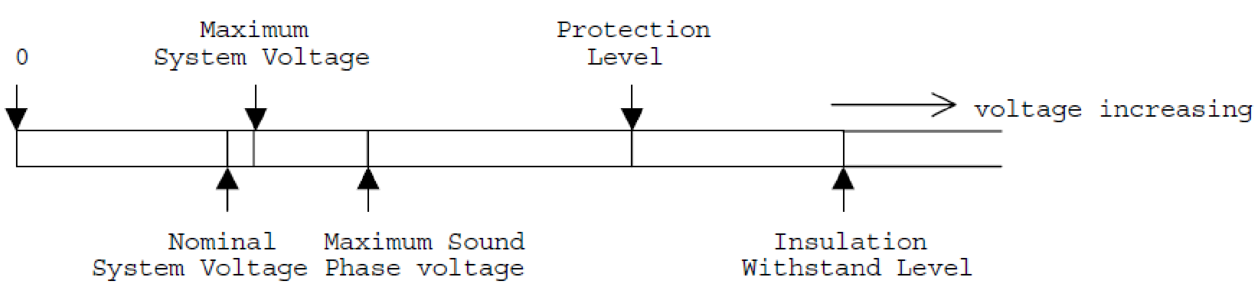
Steps for Insulation Coordination:

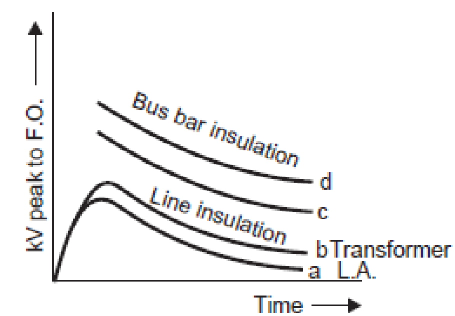
1. Selection of a suitable insulation which is a function of reference class voltage (*i.e., 1.05 X* Operating voltage of the system)
2. The design of the various equipments such that the breakdown or flashover strength of all insulation in the station equals or exceeds the selected level as in (1)
3. Selection of protective devices that will give the apparatus as good protection as can be justified economically

INSULATION CO-ORDINATION

Conventional method of insulation co-ordination:

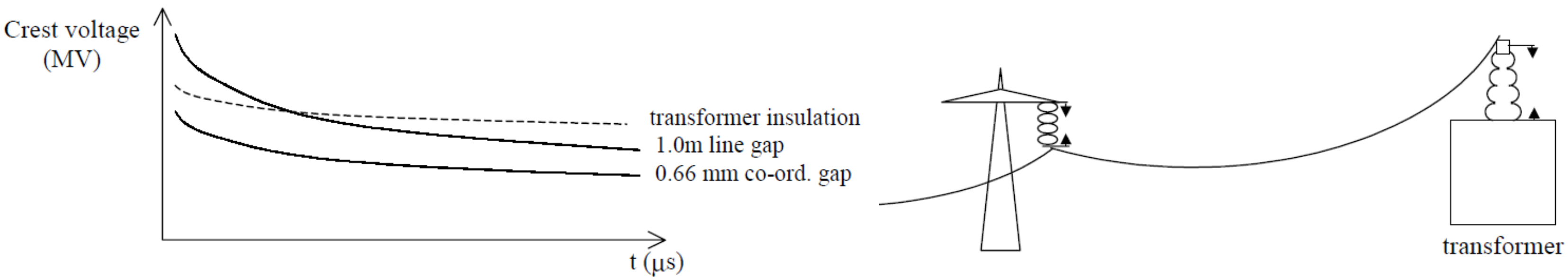
- In order to avoid insulation failure, the insulation level of different types of equipment connected to the system has to be higher than the magnitude of transient overvoltages that appear on the system.
- The magnitude of transient over-voltages are usually limited to a protective level by protective devices.
- Thus the insulation level has to be above the protective level by a safe margin. Normally the impulse insulation level is established at a value 15-25% above the protective level.





INSULATION CO-ORDINATION

Consider the typical co-ordination of a 132 kV transmission line between the transformer insulation, a line gap (across an insulator string) and a co-ordinating gap (across the transformer bushing). [Note: In a rural distribution transformer, a lightning arrester may not be used on account of the high cost and a co-ordinating gap mounted on the transformer bushing may be the main surge limiting device]



to ensure that the equipment used are protected, and that inadvertent interruptions are kept to a minimum.

The co-ordinating gap must be chosen so as to provide protection of the transformer under all conditions. However, the line gaps protecting the line insulation can be set to a higher characteristic to reduce unnecessary interruptions.

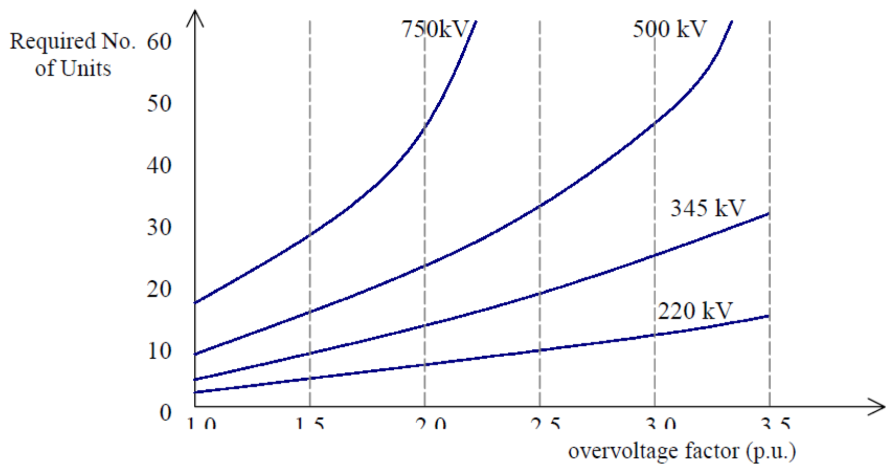
INSULATION CO-ORDINATION

For the higher system voltages, the simple approach used above is inadequate. Also, economic considerations dictate that insulation coordination be placed on a more scientific basis.

INSULATION CO-ORDINATION

Statistical Method of Insulation Co-ordination

At the higher transmission voltages, the length of insulator strings and the clearances in air do not increase linearly with voltage but approximately to $V^{1.6}$ The required number of suspension units for different overvoltage factors is shown below.



It is seen that the increase in the number of disc units is only slight for the 220 kV system, with the increase in the overvoltage factor from 2.0 to 3.5 ,but that there is a rapid increase in the 750kV system.

INSULATION CO-ORDINATION

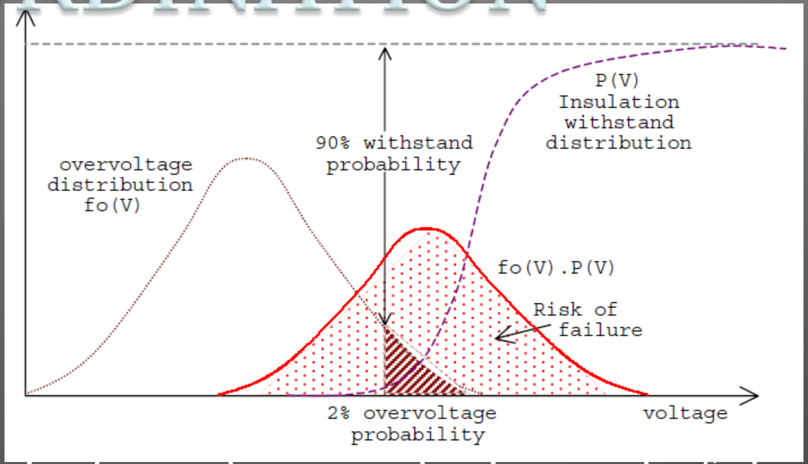
Thus, while it may be economically feasible to protect the lower voltage lines up to an overvoltage factor of 3.5 (say), it is definitely not economically feasible to have an overvoltage factor of more than about 2.0 or 2.5 on the higher voltage lines.

Switching overvoltages is predominant in the higher voltage systems. However, these may be controlled by proper design of switching devices.

In a statistical study, the statistical distribution of overvoltages has to be known instead of the possible highest overvoltage.

In statistical method, experimentation and analysis carried to find probability of occurrence of overvoltages and probability of failure of insulation.

INSULATION CO-ORDINATION



The aim of statistical methods is to quantify the risk of failure of insulation through numerical analysis of the statistical nature of the overvoltage magnitudes and of electrical withstand strength of insulation.

The risk of failure of the insulation is dependant on the integral of the product of the overvoltage density function $f_0(V)$ and the probability of insulation failure P(V).

Thus the risk of flashover per switching operation is equal to the area under the curve $\int f_0(V) * P(V) * dV$.

Since we cannot find suitable insulation such that the withstand distribution does not overlap with the overvoltage distribution, in the statistical method of analysis, the insulation is selected such that the 2% overvoltage probability coincides with the 90% withstand probability as shown.

Surge Arresters : Modern Surge arresters are of the gapless Zinc Oxide type. Previously, Silicon Carbide arresters were used, but their use has been superceeded by the ZnO arresters, which have a non-linear resistance characteristic. Thus, it is possible to eliminate the series gaps between the individual ZnO block making up the arrester.

Selection Procedure for Surge arresters:

1. Determine the continuous arrester voltage. This is usually the system rated voltage.
2. Select a rated voltage for the arrester.
3. Determine the normal lightning discharge current. Below 36kV, 5kA rated arresters are chosen. Otherwise, a 10kA rated arrester is used.
4. Determine the required long duration discharge capability.

For rated voltage < 36kV, light duty surge arrester may be specified.

For rated voltage between 36kV and 245kV, heavy duty arresters may be specified.

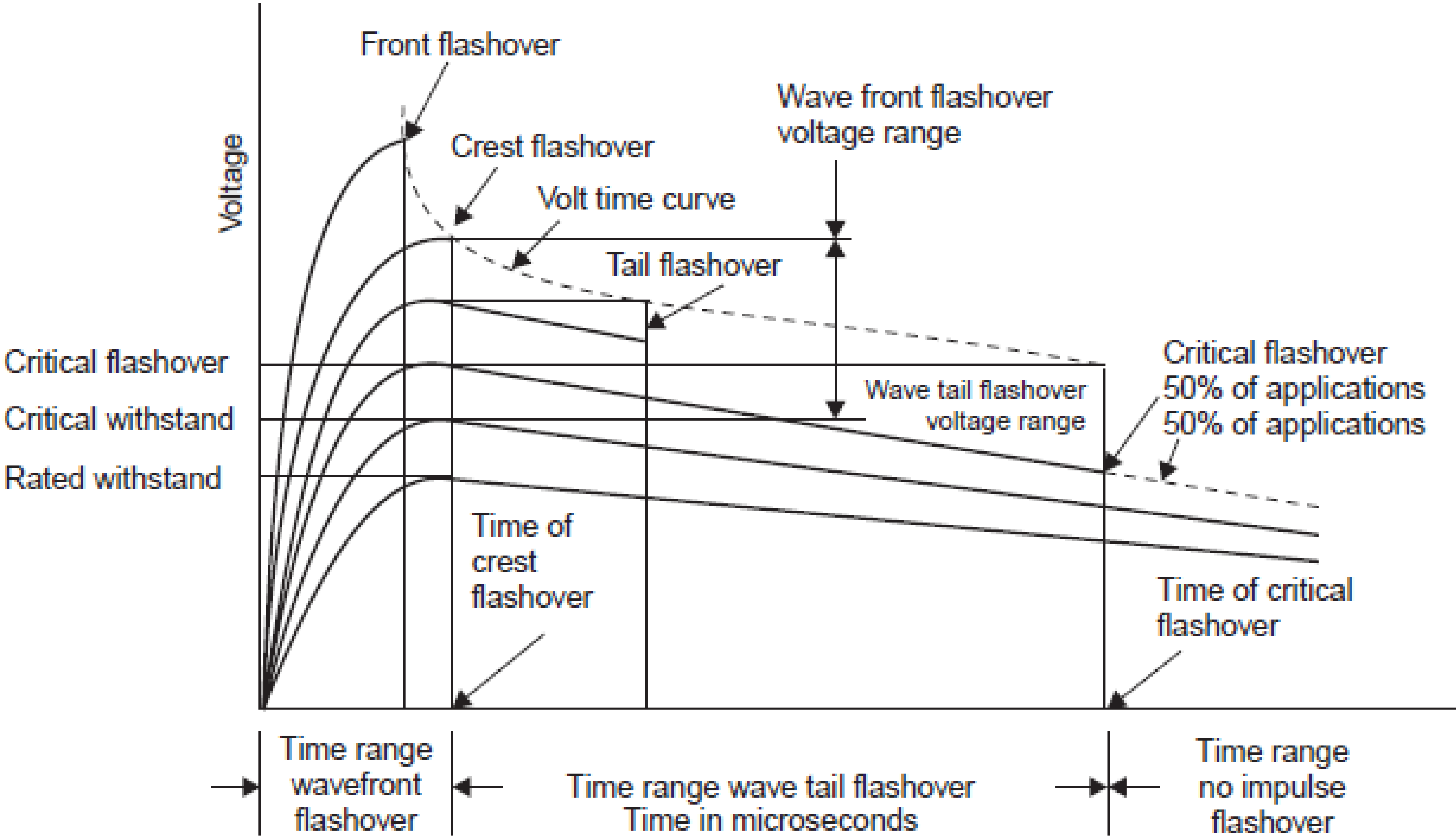
For rated voltage >245kV, long duration discharge capabilities may be specified.

5. Determine the maximum prospective fault current and protection tripping times at the location of the surge arrester

and match with the surge arrester duty.

6. Select the surge arrester having porcelain creepage distance in accordance with the environmental conditions.

7. Determine the surge arrester protection level and match with standard IEC 99 recommendations.


Front flashover
Wave front flashover
voltage range
Crest flashover
Volt time curve
Voltage
Tail flashover
Critical flashover
Critical withstand
Rated withstand
Wave tail flashover
voltage range
Critical flashover
50% of applications
50% of applications
Time of
crest
flashover
Time of critical
flashover
Time range
wavefront
flashover
Time range wave tail flashover
Time in microseconds
Time range
no impulse
flashover