BREAKDOWN IN LIQUID

Liquids as Insulating Materials

- Liquid dielectrics are more useful as insulating materials than either solids or gases.

- liquids and solids are usually 10^3 times denser than gases.

- Oil is about 10 times more efficient than air or nitrogen in its heat transfer capability when used in transformers.

- Liquids are expected to give very high dielectric strength of the order of 10 MV/cm, in actual practice the strengths obtained are only of the order of 100 kV/cm.

- Most Commonly Used Liquids insulating oils:
  Mineral Oils, n-Hexane, n-heptane, Castor Oils, Silicon Oils, Transformer oils, Liquid Nitrogen etc.

Liquids as Insulating Materials

- Major Impurities in Liquids:
  1. Dust
  2. Carbon and Sulphur ions
  3. Water Particles
  4. Water Vapour
  5. Ionic Particles
  6. Dissolved Gases such as Co_2

- The presence of even 0.01% water in transformer oil reduces its electrical strength to 20% of the dry oil value.

- Liquid dielectrics are used mainly in high voltage cables and capacitors, and for filling up of transformers, circuit breakers etc. Liquid dielectrics also act as heat transfer agents in transformers and as arc quenching media in circuit breakers.

Liquids as Insulating Materials

- Properties of Dielectric Materials:

1. ***Permittivity***:

- It is the ratio of electrical flux density in the material to produce the free space by the same electric force.

- Capacitance of capacitor is directly proportional to the permittivity (ε)

- As $C = q/V = \varepsilon A/x$

  $q/V = \varepsilon A/x$

  $q/\varepsilon A = V/x$ = Voltage Gradient

- Measure of electrostatic energy stored in insulating medium.

- The permittivity of dielectric materials should be high as possible.

Liquids as Insulating Materials

- Properties of Dielectric Materials:

1. Dielectric Strength or Breakdown Strength:

- Defines as Maximum electric voltage that dielectric material can successfully withstand.

- Expressed in terms of kV/cm

- Dielectric strength also depends on the following factors:

    1. **Temperature :** Dielectric Strength decrease with increase in Temperature.

    - In Higher temperature Electrical Breakdown occurs at lower amount of voltage. Due to higher temperature particle get loosely bound to another. The particle become unstable and breakdown easily take place.

Liquids as Insulating Materials

2. Moisture:

- The presence of even 0.01% moistures reduces its electrical strength to 20% . It is due to that moisture increases the conductivity of the medium.

3. Time Lag:

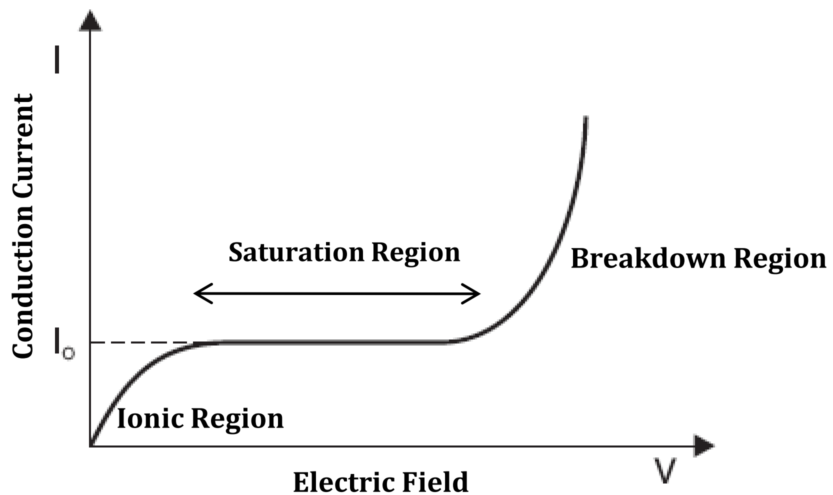
- Dielectric material withstand higher voltage for short time or short time lag. It means higher the voltage lesser will be time lag.

4. Frequency:

- Dielectric loss is directly proportional to the frequency of supply. Permittivity of liquid dielectric is inversely proportional to the frequency.

schottkey effect

- Breakdown and conduction of current in liquid dielectrics is explained by schottkey effect.
- It state that the conduction in insulating oil at low electric field (1kV/cm) is largely ionic due to dissociation of impurities and increase linearly with applied field.
- At High electric field (100kV/cm) the conduction current saturates rapidly and breakdown take place.



Breakdown in Liquids

1. ***Suspended Particle in Liquids or Impurities present in liquids:***
   - Carbon Particles
   - Sulphur Particles
   - Ionic Impurities
   - Water Droplets and water Vapours
   - Dissolved Gases
2. ***Formation of bubbles and cavitations:***
   - Temperature and pressure of Liquids
   - Distance of separation gap between the electrodes
   - Nature of materials
   - Surface of electrodes
   - Viscosity

- ***Various theories has been proposed for the breakdown of liquids***

1. Suspended Particle Theory
2. Cavitations and bubble Theory
3. Stressed oil volume Theory.

Breakdown in Liquids

1. Suspended Particle Theory:

- Commercial liquids will always contain solid impurities either as fibers or as dispersed solid particles.

- The permittivity of these solids ($\boldsymbol{\varepsilon_1}$) will always be different from that of the liquid ($\boldsymbol{\varepsilon_2}$).

- When H.V applied across two electrodes immerse into the liquids, the particle get polarized in electric field **E** applied between electrodes.

- Assume these particles to be sphere of radius **r**. These particles get polarized in an electric field **E** and experience a force which is given as:

$$F = r^3 \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + 2\varepsilon_2} E \cdot \frac{dE}{dx}$$

Breakdown in Liquids

- This force is directed towards areas of maximum stress, if $\boldsymbol{\varepsilon_2 > \varepsilon_1}$
- For example, in the case of the presence of solid particles like paper in the liquid.
- If only gas bubbles are present in the liquid, i.e. $\boldsymbol{\varepsilon_2 < \varepsilon_1}$, the force will be in the direction of areas of lower stress.
- If the voltage is continuously applied (d.c.) or the duration of the voltage is long (a.c.), then this force drives the particles towards the areas of maximum stress. If the number of particles present are large, they becomes aligned due to these forces, and thus form a stable chain bridging the electrode gap causing a breakdown between the electrodes.
- If there is only a single conducting particle between the electrodes, it will give rise to local field enhancement depending on its shape.

Breakdown in Liquids

- If this field exceeds the breakdown strength of the liquid, local breakdown will occur near the particle, and this will result in the formation of gas bubbles which may lead to the breakdown of the liquid.

- The vales of the breakdown strength of liquids containing solid impurities was found to be much less than the values for pure liquids.

- The impurity particles reduce the breakdown strength, and it was also observed that the larger the size of the particles the lower were the breakdown strengths.

Breakdown in Liquids

2. Cavitations and the Bubble Theory:

- In practice, it is difficult to achieve hundred percent pure dielectric without any sort of impurities.
- The more common factor responsible for breakdown of liquid insulating material is the formation of cavity and bubbles in liquids.
- processes have been suggested to be responsible for the formation of the vapour bubbles:

1. Gas pockets at the surfaces of the electrodes
2. electrostatic repulsive forces between space charges which may be sufficient to overcome the surface tension
3. gaseous products due to the dissociation of liquid molecules by electron collisions
4. vaporization of the liquid by corona type discharge from sharp points and irregularities on the electrode surfaces.

Breakdown in Liquids

- It has been suggested that the electric field in a gas bubble which is immersed in a liquid of permittivity $\boldsymbol{\varepsilon_2}$ is given by:

$$E_b = \frac{3E_0}{\varepsilon_2 + 2}$$

- Where $\mathbf{E_0}$ is the field in the liquid in absence of the bubble.
- When the field $\mathbf{E_b}$ equals the gaseous ionization field, discharge takes place which will lead to decomposition of liquid and breakdown may follow.

- A more accurate expression for the bubble breakdown strength is given as

$$E_b = \frac{1}{\varepsilon_2 - \varepsilon_1}\left\{\frac{2\pi\sigma(2\varepsilon_2 + \varepsilon_1)}{r}\left[\frac{\pi}{4}\sqrt{\frac{V_b}{2rE_0} - 1}\right]\right\}^{1/2}$$

Breakdown in Liquids

- where $\boldsymbol{\sigma}$ is the surface tension of the liquid, $\boldsymbol{\varepsilon_2}$ and $\boldsymbol{\varepsilon_1}$ are the permittivities of the liquid and bubble, respectively, $\boldsymbol{r}$ the initial radius of the bubble and $\mathbf{V_b}$ the voltage drop in the bubble.

- it can be seen that the breakdown strength depends on the initial size of the bubble which of course depends upon the hydrostatic pressure above the bubble and temperature of the liquid.

- This theory does not take into account the production of the initial bubble and hence the results given by this theory do not agree well with the experimental results.

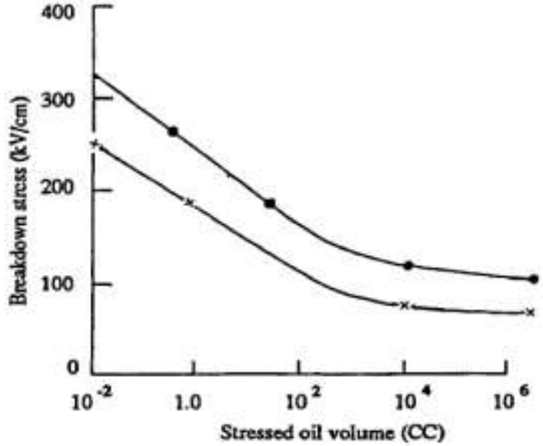
Breakdown in Liquids

3. Stressed Oil Volume Theory:

- The dielectric Field or breakdown strength of liquids is function of:
- largest possible impurity or weak link

- It was proposed that the electrical breakdown strength of the oil is defined by the weakest region in the oil, namely, the region which is stressed to the maximum and by the volume of oil included in that region.

- The breakdown voltage is highly influenced by the gas content in the oil, the viscosity of the oil, and the presence of other impurities.



Breakdown in Solids

- Function of any dielectric materials is to isolate one current carrying circuit from other circuit.
- Solid materials have higher breakdown strength than gaseous and liquids.
- ***Facts and Factors***:
- When breakdown occurred in solid, it is permanently damaged.
- Damaged Solid materials can not recover their original breakdown strength.

➢ Good Solids Dielectric Must Have:

- High Breakdown Strength
- Low dielectric loss
- High mechanical Strength
- Should be free from moisture

Breakdown in Solids

- *Factor Affecting the breakdown of Solids*:

- Ambient Temperature.
- Mechanical Strength
- Impurities, Gaseous inclusion, water and moistures.
- Chemical deterioration.
- Permittivity.

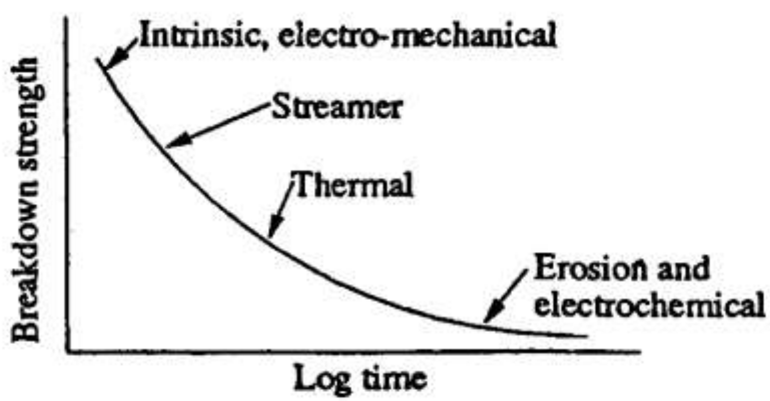
- *The principal mechanisms* for breakdown of Solid materials:

- Intrinsic Breakdown or ionic Breakdown
- Electromechanical Breakdown.
- Thermal Breakdown
- Electrochemical Breakdown
- Treeing and tracking mechanism

Breakdown in Solids

- The mechanism of breakdown is a complex phenomena in the case of solids, and varies depending on the time of application of voltage.

- Time of application plays an important role in breakdown process, for discussion purposes, it is convenient to divide the time scale of voltage application into regions in which different mechanisms operate.



Variation of breakdown strength with time after application of voltage

Intrinsic Breakdown

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

- Experimentally, this highest dielectric strength can be obtained only under the best experimental conditions.

- The maximum electrical strength recorded is 15 MV*/cm for poly vinyl-alcohol* at - 196˚C.

- Intrinsic breakdown depends upon the presence of free electrons which are capable of migration through the lattice of the dielectric.

- A small number of conduction elections are present in solid dielectrics, along with some structural imperfections and small amounts of impurities.

Intrinsic Breakdown

- Types of Intrinsic Breakdown:
  1. Electronic Breakdown
  2. Avalanche or Streamer Breakdown

- ***Electronic Breakdown***
- Intrinsic breakdown occurs in time of the order of 10^{-8}s and therefore is assumed to be electronic in nature.

- When an electric field is applied, electrons gain energy from the electric field and cross the forbidden energy gap from the valence to the conduction band.

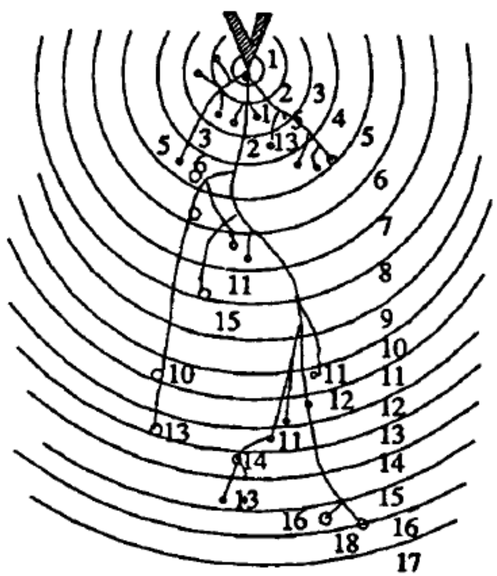
- When this process proceeds continuously, more and more electrons get collected in conduction band, and it leads breakdown.

Intrinsic Breakdown

- ***Avalanche or Streamer Breakdown***
- This is similar to breakdown in gases due to cumulative ionization.

- Conduction electrons gain sufficient energy above a certain critical electric field and cause liberation of electrons from the lattice atoms by collisions.

- Under uniform field conditions, if the electrodes are embedded in the specimen, breakdown will occur when an electron avalanche bridges the electrode gap.



Electromechanical breakdown

- When a dielectric material is subjected to an electric field, charges of opposite nature are induced on the two opposite surfaces of the material and hence a force of attraction is developed and the specimen is subjected to electrostatic compressive forces.

- when these forces exceed the mechanical withstand strength of the material, the material collapses.

- If the initial thickness of the material is $\mathbf{d_0}$ and is compressed to a thickness **d** under the applied voltage **V** then the compressive stress developed due to electric field is:

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

- where Y is the Young's modulus

Electromechanical breakdown

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

- Usually, mechanical instability occurs when

$$d/d_0 = 0.6 \text{ or } d_0/d = 1.67$$

- the highest apparent electric stress before breakdown

$$E_{max} = \frac{V}{d_0} = 0.6\left[\frac{Y}{\varepsilon_0 \varepsilon_r}\right]^{\frac{1}{2}}$$

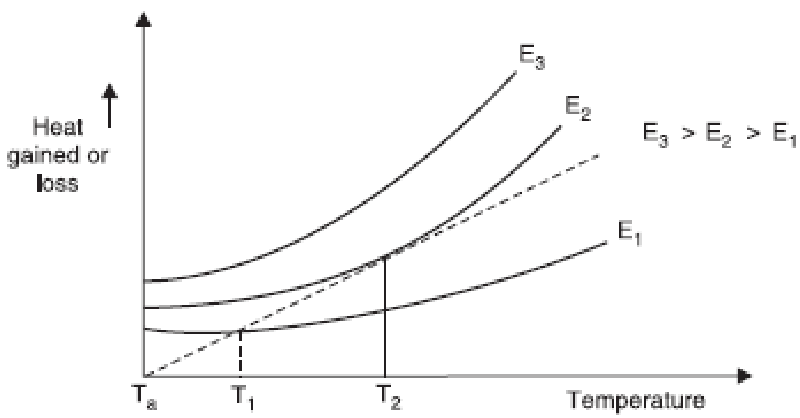
- The above equation is only approximate as Y depends on the mechanical stress.

Thermal Breakdown

- When an insulating material is subjected to an electric field, the material gets heated up due to conduction current and dielectric losses due to polarization.

- The conductivity of the material increases with increase in temperature and a condition of instability is reached when the heat generated exceeds the heat dissipated by the material and the material breaks down.

- various heating curves corresponding to different electric stresses as a function of specimen temperature.



Thermal Breakdown

- The heat generated under d.c. stress E is given as

$$W_{d.c.} = E^2\sigma \qquad \text{W/cm}^3$$

where, σ is the d.c. conductivity of the specimen.
Under a.c. fields, the heat generated

$$W_{a.c.} = \frac{E^2 f \varepsilon_r \tan\delta}{1.8 \times 10^{12}} \qquad \text{W/cm}^3$$

where, f = frequency in Hz,

δ = loss angle of the dielectric material, and

E = rms value.

The heat dissipated (W_T) is given by

$$W_T = C_V \frac{dT}{dt} + \text{div}\,(K \text{ grad } T)$$

where, C_V = specific heat of the specimen,

T = temperature of the specimen,

K = thermal conductivity of the specimen, and

t = time over which the heat is dissipated.

Thermal Breakdown

- The thermal instability condition is shown in Fig.

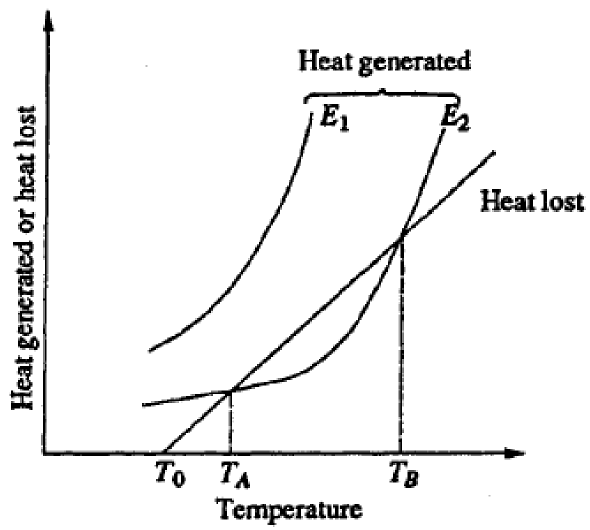


Fig. 4.3 Thermal instability in solid dielectrics

- Here, the heat lost is shown by a straight line, while the heat generated at fields E_1 and $E_2$are shown by separate curves. At field E_1 breakdown occurs both at temperatures T_A and T_B. In the temperature region of T_A and T_B heat generated is less than the heat lost for the field E_2 hence the breakdown will not occur.

Electrochemical Breakdown

- Whenever cavities are formed in solid dielectrics, the dielectric strength in these solid specimen decreases.

- It is related to thermal breakdown

- Electrochemical deterioration is due to the presence of mobility of ions which are responsible for leakage current and energy losses in material.

- In presence of air and gases due to the chemical reaction with insulating materials, dielectric strength affected.

- Due to the oxidation with some air or ozone. i.e. rubber is oxidize with ozone and cracks in pressure of ozone.

- Due to the contacts of different insulating materials with each other in any practice apparatus.

- Due to the presence of moistures and water particles.

Treeing and Tracking

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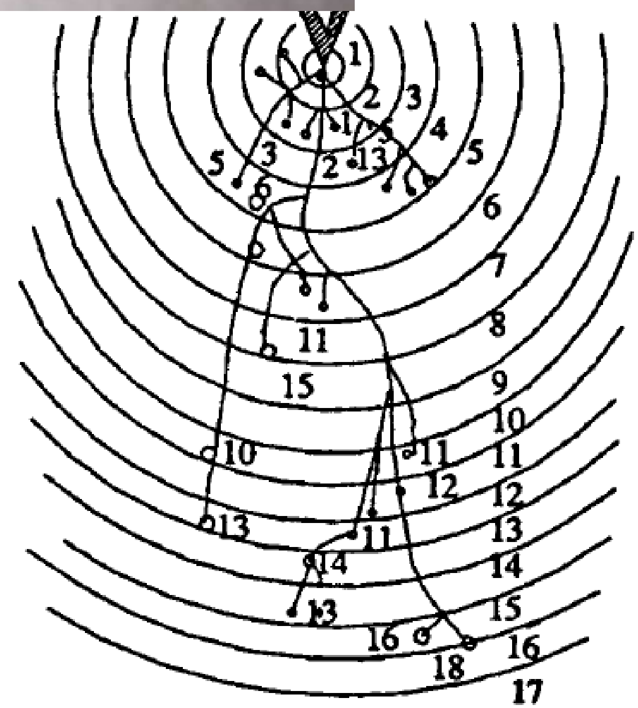


Treeing and Tracking

- ***Tracking:***
- When two electrodes separated by an insulating material and the assembly is placed in an outdoor environment.
- one contaminants in the form of moisture or dust particles will get deposited on the surface of the insulation and leakage current starts between the electrode through the contaminants say moisture.
- The current heats the moisture and causes breaks in the moisture films.
- These small films then act as electrodes and sparks are drawn between the films. The sparks cause carbonization and volatilization of the insulation and lead to formation of permanent carbon tracks on the surface of insulations.
- *Tracking is the formation of a permanent conducting path usually carbon across the surface of insulation.*

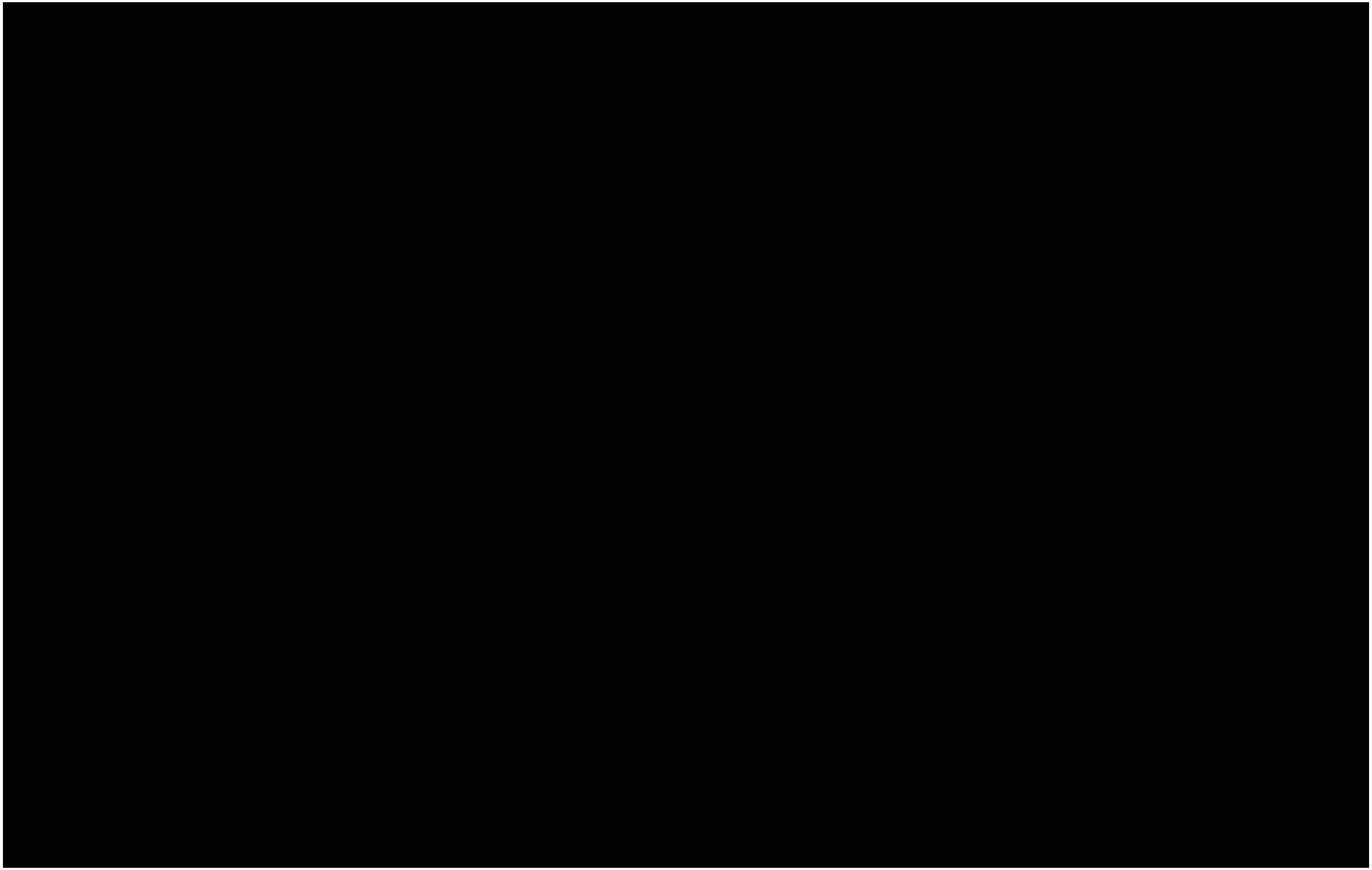
Partial Discharge

- Partial Discharges are defined as the internal discharges which cause the breakdown of voids or cavity or the gaseous pockets and which have the same effects of treeing on the insulating materials.
- When voltages are applied, due to the capacitance action, charges are induced in the voids. Voltages due to electric field, are developed in the voids.
- When voltage of voids reaches the breakdown strength of void-material, breakdown occurs .

Partial Discharge

- **Effects of partial Discharges**:
- The effects of partial Discharge on the insulating materials is the same as that of treeing.
- During partial discharge, charges are induced in the voids. The charge particles have sufficient energy to break the chemical bonds of dielectric specimen.
- During the discharge, heat is generated. The heat carbonizes the material of specimen in contact of void and thus causes the erosion.
- Chemical degradation and with the result, thickness of insulation is reduced.

Partial Discharge



Partial Discharge