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Electrical and Electronics engineering

IV YEAR/ VIIth Semester

EE8701 HIGH VOLTAGE ENGINEERING

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TOPIC NAME

UNIT 02 –Dielectric Breakdown

"**Learning** is not attained by chance, it must be sought for with ardor and attended to with diligence."

—Abigail Adams

Dielectric Breakdown

- Properties of Dielectric materials
- Gaseous breakdown in uniform and nonuniform FIELDS
- Corona discharge
- Vacuum breakdown
- Conduction and breakdown in pure and commercial liquids
- Maintenance of oil quality
- Breakdown mechanism in solid and composite dielectrics
- Application of insulating materials in electrical equipment's

GASEOUS BREAKDOWN IN UNIFORM FIELDS

- In uniform fields, the Townsend's criterion for breakdown in electropositive gases is given by the following equation,

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

- where the coefficients α and γ are functions of E/p and are given as follows

$$\alpha = p\, f_1 \left(\frac{E_0}{p}\right) \qquad \gamma = f_2 \left(\frac{E_0}{p}\right)$$

GASEOUS BREAKDOWN IN UNIFORM FIELDS

- where E0 is the applied electric field, and p the gas pressure. In a uniform field electrode system of gap distance d,

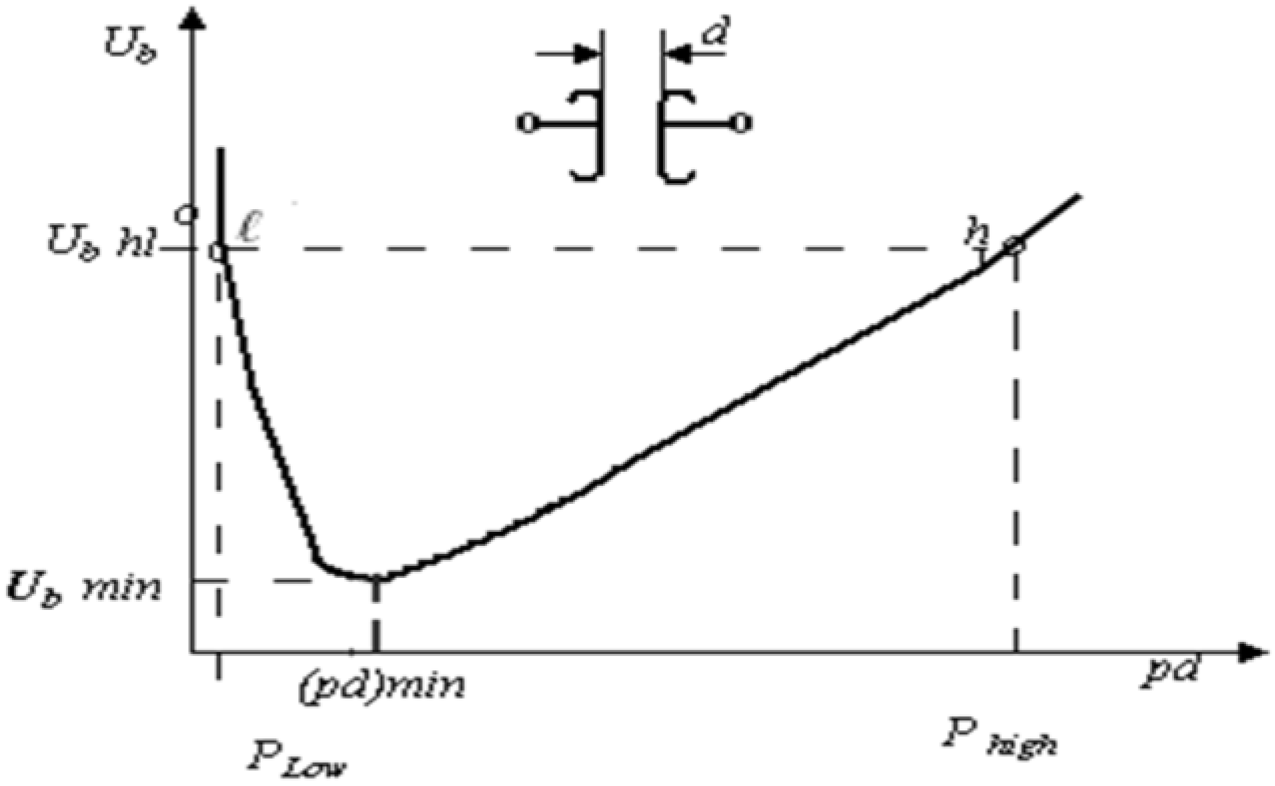
$$E_b = \frac{U_b}{d}$$

- Ub is the breakdown voltage and Eb the corresponding field intensity. Eb is equal to the electric strength of the dielectric under given conditions. When the applied field intensity E0 = Eb

$$f_2\left(\frac{U_b}{pd}\right)\left\{\exp\left[pd f_1\left(\frac{U_b}{pd}\right)\right]-1\right\}=1$$

$$U_b = f(pd)$$

GASEOUS BREAKDOWN IN UNIFORM FIELDS



BREAKDOWN IN NON-UNIFORM FIELDS

- The breakdown voltages were also observed to depend on humidity in air.
- In rod gaps the fields are non-uniform.
- In the case of sphere gaps the field is uniform
- In sphere gaps, the breakdown voltage do not depend on humidity and are also independent of the voltage waveform
- The formative time lag is quite small (~0.5μs) even with 5% over-voltage.

VACUUM BREAKDOWN

It can be broadly divided into following categories

- Particle exchange mechanism.
- Field emission mechanism.
- Clump theory

BREAKDOWN IN LIQUID DIELECTRICS

- A very large number of external factors affect the breakdown strength of liquid dielectrics.
- For example, electrode configuration, their material, size and surface finish, the type of voltage, its period of application and magnitude, the temperature, pressure, purification of the liquid and its ageing condition.

- Dissolved water, gas or the presence of any other form of contamination and sludge also affect the breakdown strength considerably.

- It is, therefore, not possible to describe the breakdown mechanism by a single theoretical analysis which may take into account all known observed factors affecting the breakdown.

CORONA DISCHARGE

The field is non-uniform, an increase in voltage will first cause a discharge in the gas to appear at points with highest electric field intensity, namely at sharp points or where the electrodes are curved or on transmission lines. This form of discharge is called a corona discharge and can be observed as a bluish luminescence

CORONA DISCHARGE

- This is accompanied by a hissing noise.
- The air surrounding the corona region becomes converted into ozone.
- It is responsible for considerable loss of power from high voltage transmission lines.
- It leads to the deterioration of insulation due to the combined action of the bombardment of ions and of the chemical compounds formed during discharges.
- It also gives rise to radio interference.

BREAKDOWN IN COMPOSITE DIELECTRICS

Mechanism of breakdown in composite dielectric

1. Short-term breakdown

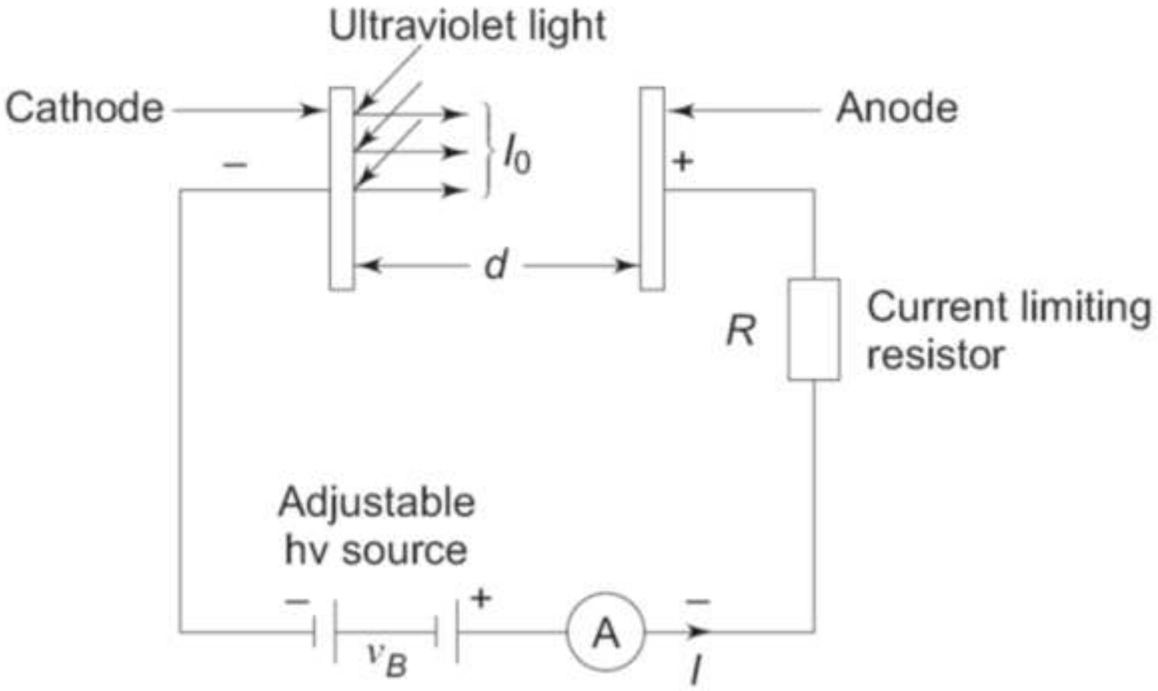
2. Long-term breakdown

CONDUCTION & BREAKDOWN IN PURE LIQUIDS

- Low electric fields less than 1 kV/cm are applied, conductivities of 10^{-18}–10^{-20} mho/cm are obtained.
- These are due to impurities remaining after purification.
- When the fields are high the currents not only increase rapidly.

TOWNSENDS FIRST IONIZATION PROCESS

The process of emitting an electron from a gas molecule with the simultaneous production of a positive ion is called ionization



TOWNSEND'S SECOND IONIZATION

Mechanisms for producing additional electrons to create avalanches

- The positive ions produced may have sufficient energy to cause production of electrons from the cathode when they imping on it
- The excited atoms in avalanches may emit photons due to photo emission process emission of electrons takes place
- The excited particle or metastable particles may diffuse back causing electron emission

Time lag in the breakdown of dielectric

There is a time difference between the application of voltage sufficient to cause breakdown and the occurrence of breakdown in the dielectric this time difference is called as time lag

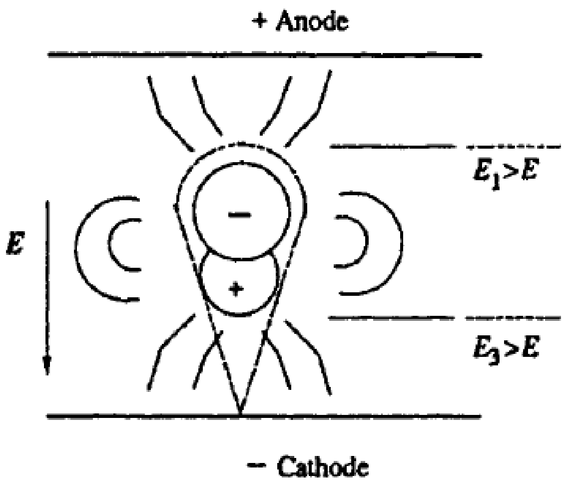
STREAMER MECHANISM(BREAKDOWN IN UNIFORM FIELD)

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

- Firstly, according to the Townsend theory, current growth occurs as a result of ionization processes only. But in practice, breakdown voltages were found to depend on the gas pressure and the geometry of the gap.

- When the field is uniform and space charges due to ions lesser than electric field E the charges present in between the electrodes increase by a factor

A single electron starting at the cathode by ionization builds up an avalanche that crosses the gap. The electrons in the avalanche move very fast compared with the positive ions.



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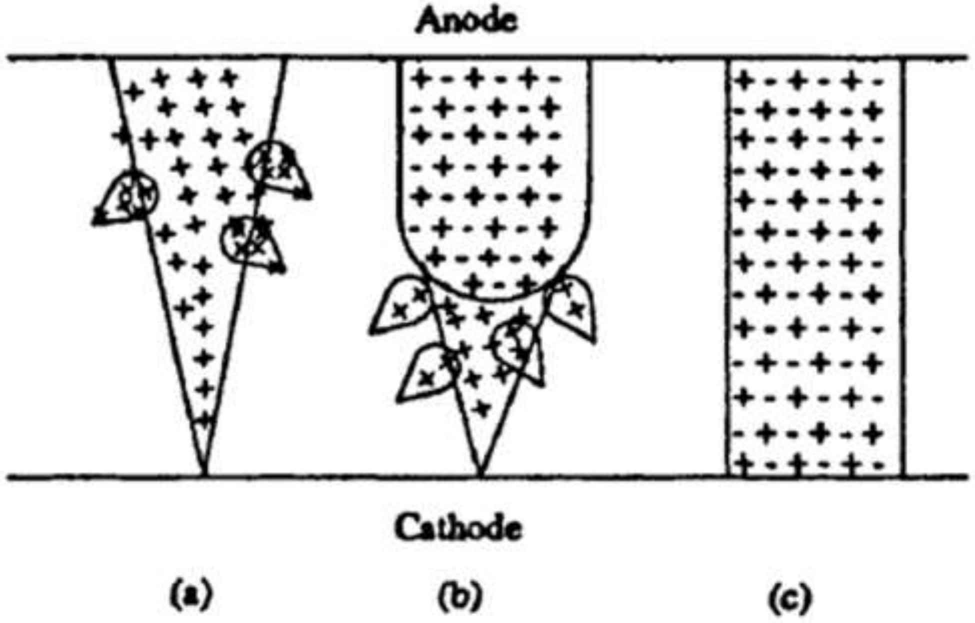
- By the time the electrons reach the anode the positive ions are virtually in their original positions and form a positive space charge at the anode.
- This enhances the field, and the secondary avalanches are formed from the few electrons produced due to photo-ionization in the space charge region.
- This occurs first near the anode where the space charge is maximum. This results in a further increase in the space charge. This process is very fast and the positive space charge extends to the cathode very rapidly resulting in the formation of a streamer. Comparatively narrow luminous tracks occurring at breakdown at high pressures are called streamers.
- As soon as the streamer tip approaches the cathode, a cathode spot is formed and a stream of electrons rush from the cathode to neutralize the positive space charge in the streamer; the result is a spark, and the spark breakdown has occurred.

The three successive stages in the development of the streamer are shown diagrammatically in Fig.

(a) shows the stage when avalanche has crossed the gap,

(b) shows that the streamer has crossed half the gap length, and

(c) shows that the gap has been bridged by a conducting channel.


Anode
Cathode
(a)
(b)
(c)

CONDUCTION AND BREAKDOWN IN COMMERCIAL LIQUIDS

Commercial liquids are insulating liquids like oils,which are not chemically pure consists of mixture of complex organic molecules and impurities like gas bubbles, suspended particles,etc.,

CAVITATION AND BUBBLE MECHANISM

Formation of vapour bubbles occur due to the following

- Gas pockets on the surface of the electrodes
- Changes in temperature and pressure
- Dissociation of products by electron collisions giving rise to gaseous products
- Liquid vaporization by corona-type discharges from points and irregularities on the electrodes

STRESSED OIL VOLUME MECHANISM

In commercial liquids minute particles of impurities present the reduce the breakdown strength of the oil region the region is stressed to the maximum and by the volume of oil in that region according to stressed oil volume theory the breakdown strength is inversely proportional to the stressed oil volume

Maintenance of oil quality

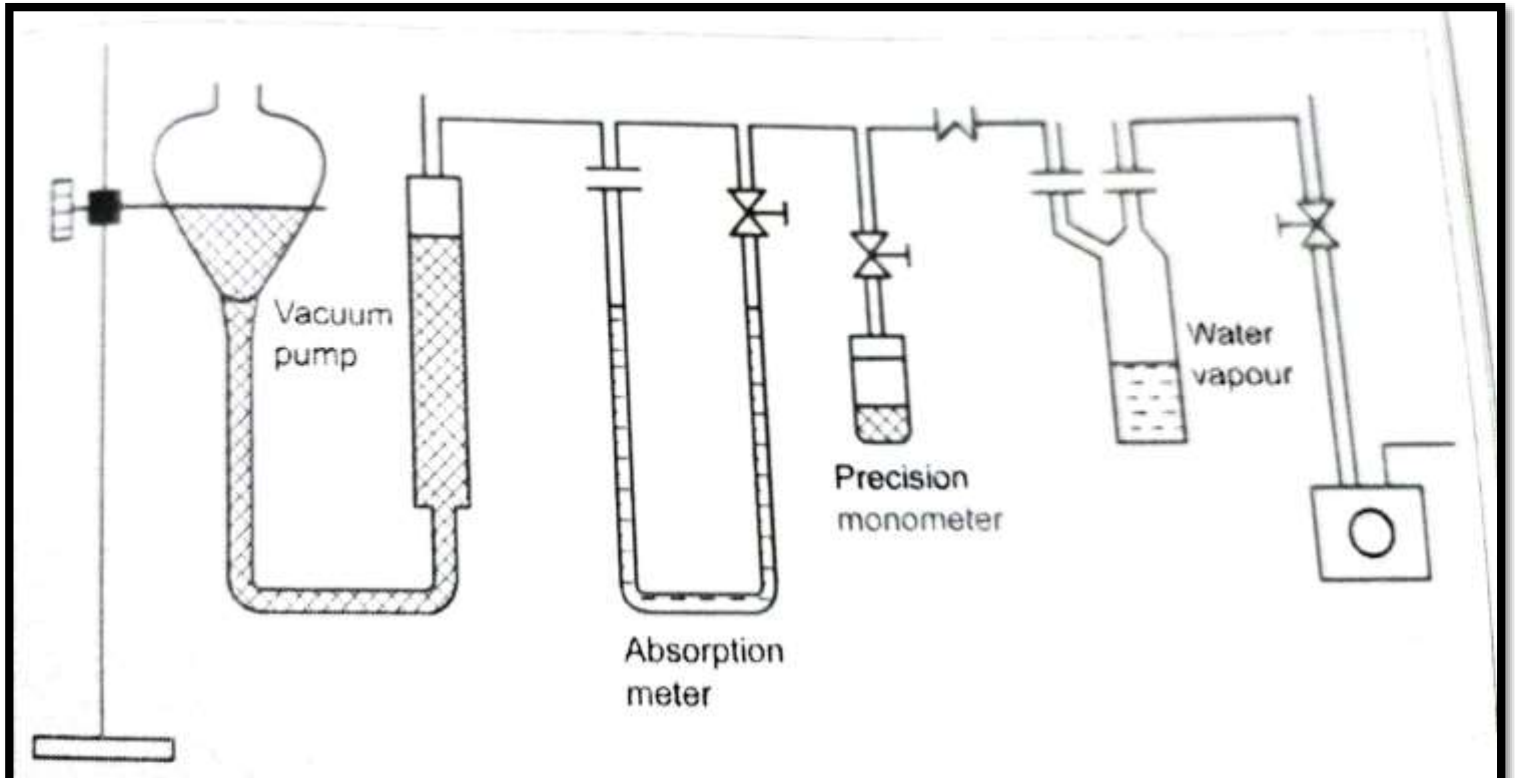


Fig. 2.20. Measurement of oil absorption

FILTRATION AND TREATMENT UNDER VACUUM

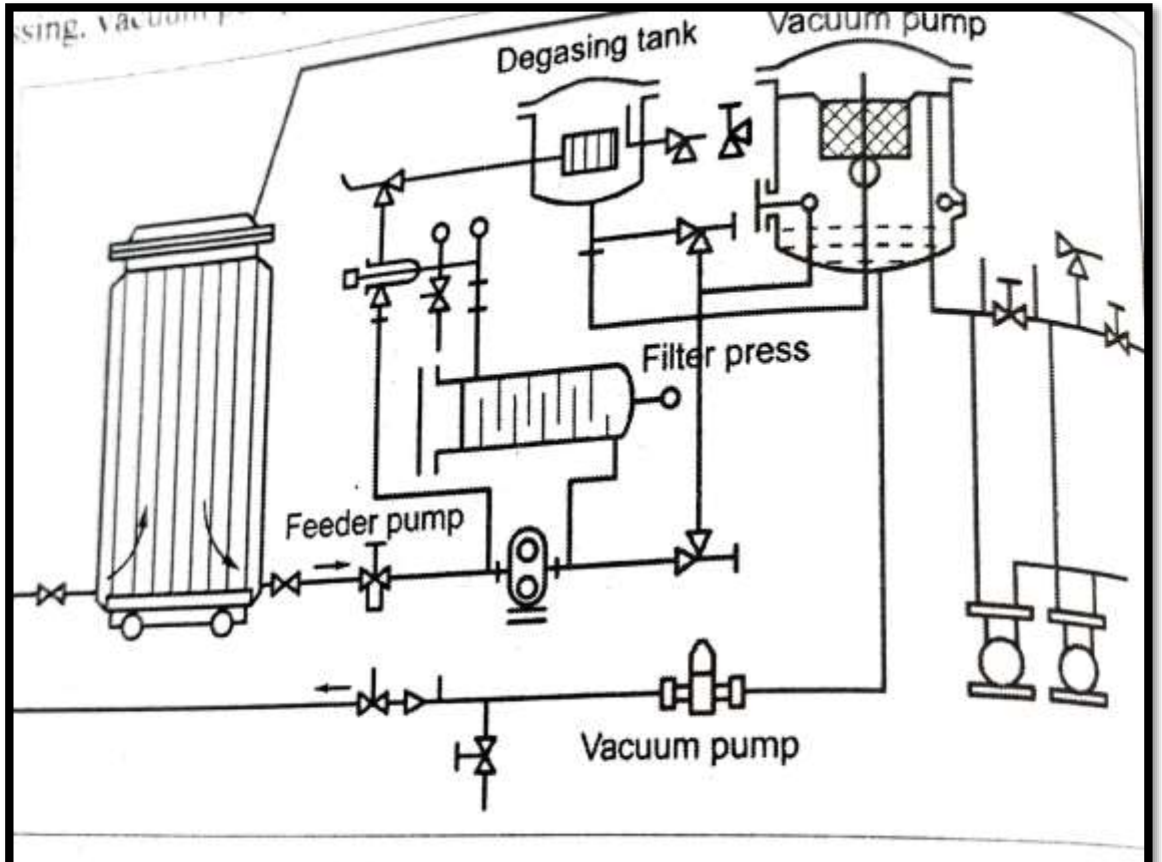


Fig. 2.21. Oil treatment plant

ELECTROMECHANICAL BREAKDOWN

When solid dielectrics are subjected to high electric fields, failure occurs due to electrostatic compressive forces which can exceed the mechanical compressive strength. If the thickness of the specimen is d and is compressed to thickness d under an applied voltage V, then the electrically developed compressive stress is in equilibrium.

ELECTROCHEMICAL BREAKDOWN

Oxidation

In the presence of air or oxygen materials such s rubber and polyethylene undergo oxidation giving rise to surface cracks.

Hydrolysis

When moisture or water vapour is present on surface of a solid dielectric hydrolysis occurs and the materials lose their electrical and mechanical properties.

Chemical action

- Chemical instability at high temperature
- Oxidation and formation of crack in the presence of air or oxygen
- Hydrolysis due to moisture and water

BREAKDOWN DUE TO TREEING TRACKING

Breakdown occurs due to the following process :

- Formation of conducting path across the surface of the insulation due to surface erosion.
- Formation of spark due to the leakage current passes through the conducting path

BREAKDOWN MECHANISM IN COMPOSITE DIELECTRICS

Short term breakdown

When the applied electric field is high failure may occur in seconds or even faster without damaging the insulating surface prior to breakdown is called as short-term breakdown

Long term breakdown

Long term breakdown occurs due to ageing of insulation from thermal process and partial discharges.