UNIT 1: BREAKDOWN IN VACUUM

1.) **Introduction:** According to the Townsend’s theory, the growth of current in a gap depends on the drift of the charged particles. Hence if there are no charged particles available as in the case of perfect vacuum then there should not be any conduction and the vacuum should be a perfect insulating medium. However in practice the presence of metallic electrodes and insulating surfaces within the vacuum complicate the issue and therefore even in vacuum a sufficiently high voltage will cause a breakdown.

A vacuum system which is used to create vacuum is a system in which the pressure is maintained at a value much below the atmospheric pressure. In vacuum systems the pressure is always measured in terms of millimeters of mercury where one standard atmosphere is equal to 760 millimeters of mercury at a temperature of 0°C. The term millimeters of mercury has been standardized as Torr where one Torr is equal to one millimeter of mercury. The vacuum may be classified as

- High vacuum – 10⁻³ to 10⁻⁶ Torr
- Very high vacuum – 10⁻⁶ to 10⁻⁸ Torr
- Ultra high vacuum – 10⁻⁹ Torr and below

For electrical insulation purposes, the range of vacuum generally used is the high vacuum in the pressure range of 10⁻³ Torr to 10⁻⁶ Torr

2.) **Breakdown in Vacuum:** In the case of vacuum the growth of the current prior to the breakdown cannot be due to the formation of electron avalanches because an electron crosses the gap without encountering any collision. However if a gas is liberated in the vacuum gap then breakdown in the manner described by the Townsend process. The following different mechanisms have been proposed for explaining the breakdown in vacuum:

i. Particle exchange mechanism

ii. Field emission mechanism

iii. Clump theory

3.) **Particle Exchange Mechanism:** In this mechanism it is assumed that a charged particle is emitted from one electrode under the effect of high electric field and when it impinges the other electrode, it liberates oppositely charged particles due to ionization of adsorbed gases. These particles are accelerated by the applied voltage back to the first electrode where they release more of the original type of particles. When this process becomes cumulative, a chain reaction occurs which leads to the breakdown of the gap.

This mechanism involves electrons, positive ions, photons and the absorbed gases at the electrode surfaces. If an electron present in the vacuum gap releases ‘A’ no. of positive ions and ‘C’ no of photons when it moves under the influence of the field and impinges the anode. These positive ions are accelerated towards the cathode and on impact each positive ion release ‘B’ no. of electrons and each photon liberates ‘D’ no. of electrons then the breakdown will occur when the following condition is satisfied:

\[(AB + CD) > 1\]

However later on it was found that the coefficients for positive ions and photons were too small for this process to take place. Therefore the breakdown mechanism also involves the presence of negative ions. Accordingly the breakdown will occur when the following condition is satisfied:

\[(AB + EF) > 1\]

Where A and B are same as before while E is no. of positive ions liberated by negative ions and F is no. of negative ions liberated by positive ions.
It was found experimentally that the values of the product $EF$ were close enough to unity for copper, aluminium and stainless steel electrodes to make this mechanism applicable at voltage above 250 kV.

4.) **Field Emission Theory:** In this mechanism two types of theories have been given as follows:

(a) **Anode Heating Mechanism** – 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 vapours into the vacuum gap. These electrons ionize the atoms of the gas and produce positive ions. These positive ions arrive at the cathode, increase the primary electron emission due to space charge formation and produce secondary electrons by bombarding the surface. The process continues until a sufficient number of electrons are produced to give rise to breakdown. This is shown schematically in fig.2 (a)
(b) **Cathode Heating Mechanism** – This theory postulates that near the breakdown voltages of the gap, sharp points on the cathode surface are responsible for the existence of the pre-breakdown current. This current causes resistive heating at the tip of a point and when a critical current density is reached, the tip melts and explodes thus resulting in initiation of vacuum discharge. This mechanism is called field emission as shown schematically in fig.2(b).

![Electron stream](image1)

**Fig.2 (b) – Breakdown due heating of microprojection on the cathode**

5.) **Clump Mechanism:** In this mechanism it is assumed that a loosely bound particle (clump) exists on one of the electrode surfaces. When a high voltage is applied across the electrodes then this clump gets detached from the mother electrode and gets accelerated across the gap between the electrodes. This clump on reaching the target electrode impinges on it thereby producing a vapour or gas (adsorbed on the surface of electrode). According this theory the breakdown will occur when the energy per unit area W delivered to the target electrode exceeds a constant C which is a characteristic of the given pair of electrodes. The quantity W is the product of gap voltage (V) and the charge density on the clump. The generalized criteria for breakdown is given by

\[ V = Cd^\alpha \]

Where \( \alpha \) varies between 0.2 and 1.2 depending upon the gap length and the electrode material with a maximum at 0.6. The dependence of V on the electrode material comes from the observations of markings on the electrode surfaces.

![Clump](image2)

**Fig.3 (a) Clump is loosely attached to the surface**
The dielectric strength of vacuum is defined in different ways. In case of vacuum insulated switchgear it is the value of the voltage which causes the first breakdown that is important. When the gap breaks down repeatedly the breakdown voltage increases with the number of breakdowns until it reaches a steady or conditioned value which is often taken as the breakdown strength of the vacuum gap. So far no single theory has been able to explain the breakdown phenomenon. The most significant factors which influence the breakdown mechanism are gap length, geometry and material of the electrodes, surface uniformity and treatment of surface, presence of extra particles and residual gas pressure in the vacuum gap. It was observed that the correct choice of electrode material and use of thin insulating coatings on electrodes in long gaps can increase the breakdown voltage of a vacuum gap. On the other hand an increase of electrode area or the presence of particles in the vacuum gap will reduce the breakdown voltage.

Conclusion – The dielectric strength of vacuum is defined in different ways. In case of vacuum insulated switchgear it is the value of the voltage which causes the first breakdown that is important. When the gap breaks down repeatedly the breakdown voltage increases with the number of breakdowns until it reaches a steady or conditioned value which is often taken as the breakdown strength of the vacuum gap. So far no single theory has been able to explain the breakdown phenomenon. The most significant factors which influence the breakdown mechanism are gap length, geometry and material of the electrodes, surface uniformity and treatment of surface, presence of extra particles and residual gas pressure in the vacuum gap. It was observed that the correct choice of electrode material and use of thin insulating coatings on electrodes in long gaps can increase the breakdown voltage of a vacuum gap. On the other hand an increase of electrode area or the presence of particles in the vacuum gap will reduce the breakdown voltage.