High Voltage Engineering

Lecture contents

- Breakdown in composite solids

- It is difficult to imagine a complete insulation system in an electrical equipment which does not consist of more than one type of insulation
- If an insulation system as a whole is considered, it will be found that more than one insulating material is used
- These different materials can be in parallel with each other, such as air or SF6 gas in parallel with solid insulation or in series with one another
- Such insulation systems are called composite dielectrics

- The composite nature of an insulation system arises from the mechanical requirements involved in separating electrical conductors which are at different potentials
- Also, parts of a single system that are normally composed of a single material are in fact composite in nature
- In actual practice, these single materials will normally have small volumes of another material present in their bulk
- For example, a solid will contain gas pockets or voids, while a liquid or gas will contain metallic or dust particles, gas bubbles etc

- A commonly encountered composite dielectric is the solid/liquid combination or liquid impregnated flexible solid like thin sheets of paper or plastic
- This type of composite dielectric is widely used in a variety of low and high voltage apparatus such as cables, capacitors, transformers, oil-filled switchgear, bushings etc. In recent years solid/SF6 gas technology has become more acceptable

Properties of Dielectric Material

- A composite dielectric generally consists of a large number of layers arranged one over the other
- This is called "the layered construction" and is widely used in cables, capacitors and transformers
- Three properties of composite dielectrics which are important to their performance are given below

(1) Effect of Multiple layers

- The simplest composite dielectric consists of two layers of the same material
- Here, advantage is taken of the fact that two thin sheets have a higher dielectric strength than a single sheet of the same total thickness
- The advantage is particularly significant in the case of materials having a wide variation in dielectric strength values measured at different points on its surface

(2) Effect of layer thickness

- Increase in layer thickness normally gives increased breakdown voltage
- In a layered construction, breakdown channels occur at the interfaces only and not directly through another layer
- Also, a discharge having penetrated one layer cannot enter the next layer until a part of the interface also attains the potential which can produce an electric field stress comparable to that of the discharge channel

- The use of layered construction is very important in the case of insulating paper since the paper thickness itself varies from point to point and consequently the dielectric strength across its surface is not homogeneous

- Various investigations on composite dielectrics have shown that;

(i) the discharge inception voltage depends on the thickness of the solid dielectric, as well as on the dielectric constant of both the liquid and solid dielectric, and;

(ii) the difference in the dielectric constants between the liquid and solid dielectrics does not significantly affect the rate of change of electric field at the electrode edge with the change in the dielectric thickness.

Effect of interfaces

- The interface between two dielectric surfaces in a composite dielectric system plays an important role in determining its pre-breakdown and breakdown strengths
- Discharges usually occur at the interfaces and the magnitude of the discharge depends on the associated surface resistance and capacitance
- When the surface conductivity increases, the discharge magnitude also increases, resulting in damage to the dielectric

- In a composite dielectric, it is essential to maintain low dielectric losses because they normally operate at high electric stresses
- However, even in an initially pure dielectric liquid, when used under industrial conditions for impregnating solid dielectrics, impurities arise, resulting in increased dielectric losses

Breakdowns in composite materials

- Short term Breakdown
- If the electric field stresses are very high, failure may occur in seconds or even faster without any substantial damage to the insulating surface prior to breakdown
- It has been observed that breakdown results from one or more discharges when the applied voltage is close to the observed breakdown value

- There exists a critical stress in the volume of the dielectric at which discharges of a given magnitude can enter the insulation from the surface and propagate rapidly into its volume to cause breakdown

- Experiments with single discharges on an insulating material have shown that breakdown occurs more rapidly when the electric field in the insulation is such that it assists the charged particles in the discharge to penetrate into the insulation, than when the field opposes their entry.

- Breakdown was observed to occur more readily when the bombarding particles are electrons, rather than positive ions
- In addition, there are local field intensifications due to the presence of impurities and variations in the thickness of solid insulation

Long term breakdown

- Long-term breakdown is also called the ageing of insulation
- The principal effects responsible for the ageing of the insulation which eventually leads to breakdown arise from the thermal processes and partial discharges
- Partial discharges normally occur within the volume of the composite insulation systems

- In addition, the charge accumulation and conduction on the surface of the insulation also contributes significantly towards the ageing and failure of insulation

Ageing due to partial discharges

- During the manufacturing of composite insulation, gas filled cavities will be present within the dielectric or adjacent to the interface between the conductor and the dielectric
- When a voltage is applied to such a system, discharges occur within the gas-filled cavities

- These discharges are called the 'partial discharges" and involve the transfer of electric charge between the two points in sufficient quantity to cause the discharge of the local capacitance
- The degree of ageing depends on the discharge inception voltage, *Vi and the* discharge magnitude
- It has been shown that Vi is strongly dependent on the permittivity of the dielectric εr and the thickness of the cavity *g*
- *Vi can be estimated* approximately by;

$$v_i = \left(\frac{E_g}{\varepsilon_r} \right) (t + \varepsilon_r g)$$

Ageing and breakdown due to accumulation of charges on insulator surfaces

- During discharges at the solid or liquid or solid-gas or solid-vacuum interfaces, certain quantity of charge (electrons or positive ions) gets deposited on the solid insulator surface
- The charge thus deposited can stay there for very long durations, lasting for days or even weeks
- The presence of this charge increases the surface conductivity thereby increasing the discharge magnitude in subsequent discharges
- Increased discharge magnitude in subsequent discharges causes damage to the dielectric surface

- It has been generally observed that the discharge characteristics change with the life of the insulation
- This can be explained as follows: for clean surfaces, at the discharge inception voltage Vi the discharge characteristic depends on the nature of the dielectric, its size and shape

Example A solid specimen of dielectric has a dielectric constant of 4.2, and $\tan\delta = 0.001$ at a frequency of 50 Hz. If it is subjected to an alternating field of 50 kV/cm, calculate the heat generated in the specimen due to the dielectric loss.

Solution: Dielectric heat loss at any electric stress E [Eq. (4.5)]

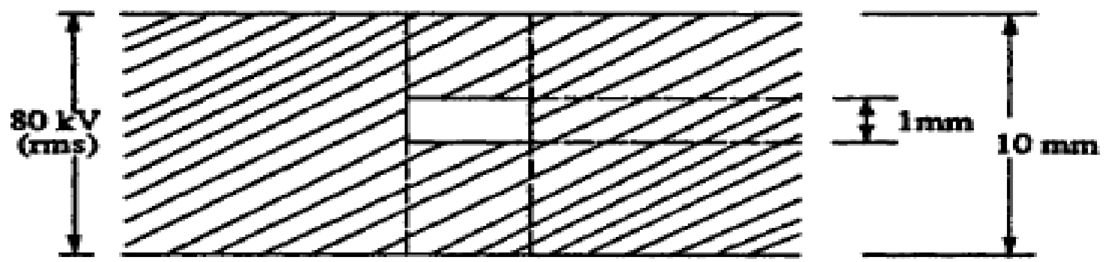
$$= \frac{E^2 f \varepsilon_r \tan\delta}{1.8 \times 10^{12}} \quad \text{W/cm}^3$$

For the specimen under study, the heat loss will be

$$= \frac{50 \times 50 \times 10^6 \times 50 \times 4.2 \times .001}{1.8 \times 10^{12}}$$

$$= 0.291 \text{ mW/cm}^3$$

Example 4.2: A solid dielectric specimen of dielectric constant of 4.0 shown in the figure has an internal void of thickness 1 mm. The specimen is 1 cm thick and is subjected to a voltage of 80 kV (rms). If the void is filled with air and if the breakdown strength of air can be taken as 30 kV (peak)/cm, find the voltage at which an internal discharge can occur.



Solution: Referring to Fig. 4.5(a) and Eqs. (4.7) and (4.8), the voltage that appears across the void is given as

$$V_1 = \frac{Vd_1}{\left(d_1 + \frac{\varepsilon_0}{\varepsilon_1} d_2\right)}$$

where,

$$d_1 = 1 \text{ mm}$$

$$d_2 = 9 \text{ mm}$$

$$\varepsilon_0 = 8.89 \times 10^{-12} \text{ F/m}$$

$$\varepsilon_1 = \varepsilon_r \varepsilon_0 = 4.0\, \varepsilon_0$$

$$V_1 = \frac{V \times 1}{\left(1 + \frac{9}{4}\right)}$$

- The voltage at which the air void of 1 mm thickness breaks down is 3 kV/mm x 1 mm = 3kV
- *V =13V/4=(13X3)/4= 39/4*

  = 9.75 kV (peak)
- The internal discharges appear in the sinusoidal voltage 80 sin wt kV *when the* voltage reaches a value of 9.75 kV

- High voltage Generation