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.

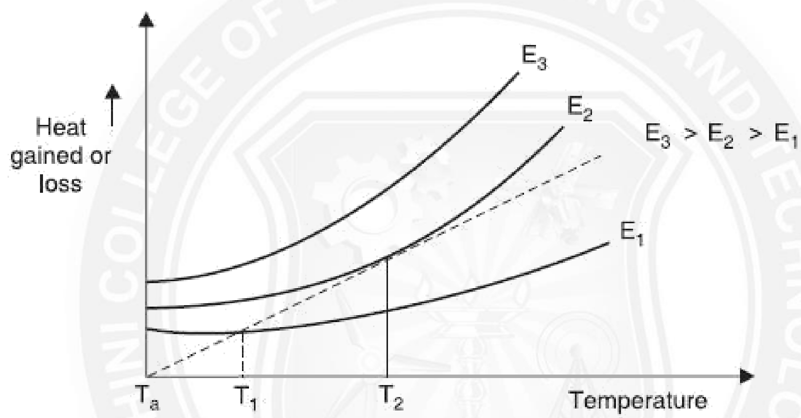

Figure 1.6.1 Thermal stability or instability of different fields

[Source: "High Voltage Engineering" by C.L. Wadhwa , Page – 230]

Figure shows various heating curves corresponding to different electric stresses as a function of specimen temperature. Assuming that the temperature difference between the ambient and the specimen temperature is small, Newton's law of cooling is represented by a straight line.

The test specimen is at thermal equilibrium corresponding to field E_1 at temperature T_1 as beyond that heat generated is less than heat lost. Unstable equilibrium exists for field E_2 at T_2, and for field E_3 the state of equilibrium is never reached and hence the specimen breaks down thermally.

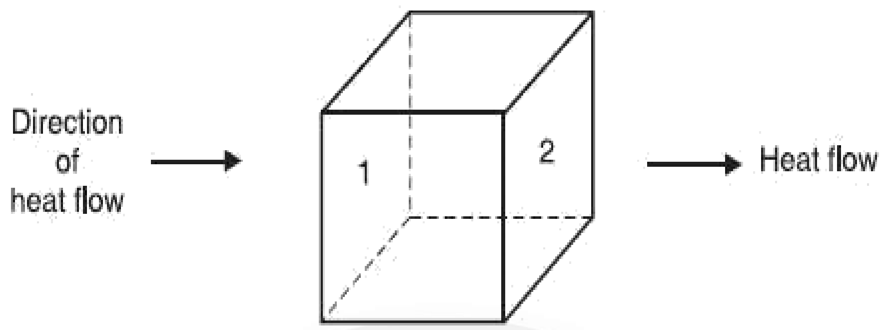

Figure 1.6.2 Cubical specimen—Heat flow

[Source: "High Voltage Engineering" by C.L. Wadhwa , Page – 235]

$$\frac{\Delta T}{\Delta x} \approx \frac{dT}{dx}$$

In order to obtain basic equation for studying thermal breakdown, let us consider a small cube (Fig. 2.14) within the dielectric specimen with side Δx and temperature difference across its faces in the direction of heat flow (assume here flow is along x-direction) is ΔT. Therefore, the temperature gradient is

Let $\Delta x2 = A$. The heat flow across face 1

$KA \frac{dT}{dx}$ Joules

Heat flow across face 2

$$KA \frac{dT}{dx} - KA \frac{d}{dx}\left(\frac{dT}{dx}\right) \Delta x$$

Here the second term indicates the heat input to the differential specimen. Therefore, the heat absorbed by the differential cube volume

$$= \frac{KA \frac{d}{dx}\left(\frac{dT}{dx}\right) \Delta x}{\Delta V} = K \frac{d}{dx}\left(\frac{dT}{dx}\right)$$

The heat input to the block will be partly dissipated into the surrounding.

Let C_V be the thermal capacity of the dielectric, σ the electrical conductivity, E the electric field intensity. The heat generated by the electric field = σE_2 watts, a power required to raise the temperature of the block by ΔT

$$C_v \frac{dT}{dt} \text{ watts}$$

Therefore, $$C_v \frac{dT}{dt} + K \frac{d}{dt}\left(\frac{dT}{dx}\right) = \sigma E^2$$

The solution of the above equation will give us the time required to reach the critical. Temperature T_C for which thermal instability will reach and the dielectric will lose its insulating properties.

However, unfortunately the equation can be solved in its present from C_V, K and σ is all functions of temperature and in fact σ may also depend on the intensity of electrical field.

Therefore, to obtain solution of the equation, we make certain practical assumptions and we consider two extreme situations for its solution