EEE3351 EXAM SOLUTIONS
MARCH 2014

1. (a) Analogy between electrical and thermal conduction fields:

Electrical conduction field	**Thermal conduction field**
Current, I ampere	Heat (Power), P, watt
Voltage difference, V, volt	Temperature difference, T, degrees C or K
Electrical resistance, R = V/I ohm	Thermal resistance, R_t = T/P, °C/W
Resistivity, ρ, ohm metre	Thermal resistivity, t., °Cm /W
Capacitance, C, farad (coulomb/ volt)	Heat capacity, (joule/ °C)

(b) i. Insulation resistance

Insulation resistance-is the property, by the virtue of which, a material resists flow of electrical current. It should be high as possible. Insulation resistance is of two types:
(i) Volume resistance; (ii) Surface resistance.
The resistance offered to the current, which flows through the material is called **volume resistance.** The resistance offered to the current, which flows over the surface of the insulating material is called **surface resistance**. Factors that affect the insulation resistance are-temperature variations, exposure to moisture, voltage applied, aging.

ii. Dielectric strength

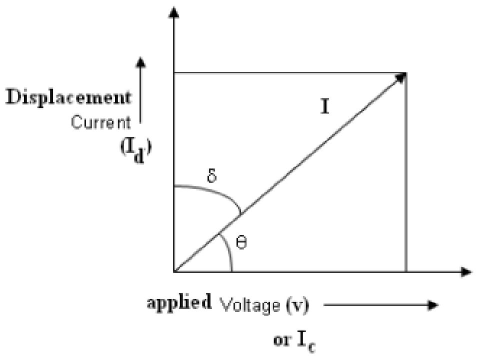
Dielectric Strength- is therefore the minimum voltage which when applied to an insulating material will result in the destruction of its insulating properties. It can also be defined as the maximum potential gradient that the material can withstand without rupture, or without loosing dielectric properties. This value is expressed in volts or kilovolts per unit thickness of the insulating material. This value is greatly affected by the conditions under which the material is operated. Factors affecting the dielectric strength are temperature and humidity.

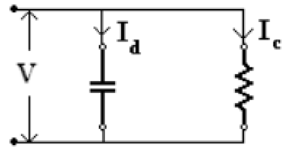
iii. Dielectric constant

The property of insulating materials that causes the difference in the value of capacitance, with the physical dimensions remaining the same, is called the dielectric constant or permittivity ε and $\varepsilon = C/C_o$, where C is capacitance in the presence of the dielectric and Co is the capacitance in air or vacuum or absence of dielectric.

iv. Dielectric dissipation factor

Dielectric loss and Loss angle: When a perfect insulation is subjected to alternating voltage, it is like applying alternate voltage to a perfect capacitor. In a perfect capacitor the charging current would lead the applied voltage by 90^0 exactly. This means that there is no power loss in the insulation. In most insulating materials this is not the case. There is a definite amount of dissipation of energy when an insulator is subjected to alternating voltage. This dissipation of energy is called dielectric loss. Factors affecting dielectric loss are – Frequency of applied voltage, humidity, temperature rise and voltage.
The dielectric phase angle is θ and $\delta = 90^0 - \theta$ is the dielectric loss angle as shown in the fig. below.





Also I is the phasor sum of I_d and I_c , where Ic is the conduction current which is in phase with the applied voltage and Id is the displacement current which is in quadrature phase with applied voltage.

(C) i. In order that q might not disturb the electric field of Q.

ii. Solution. 30 kV/cm = 3000 kV/m = 3×10^6 V/m.

$$3 \times 10^6 = Q_0 \Big/ \left[4\pi \times \frac{1000}{36\pi} \times 10^{-12} \times 10^{-4} \right]$$

$$= 9 \times 10^{13} Q_0$$

giving $Q_0 = 3.33 \times 10^{-8}$ coulomb $= 0.033$ µC.

The potential of the sphere is

$$V = 3 \times 10^6 \times 10^{-2} = 30 \text{ kV}.$$

2. (a) The mean length is that length which makes it possible to calculate the reluctance or magnetomotive force of a magnetic circuit.

(b) The solution is as shown below:

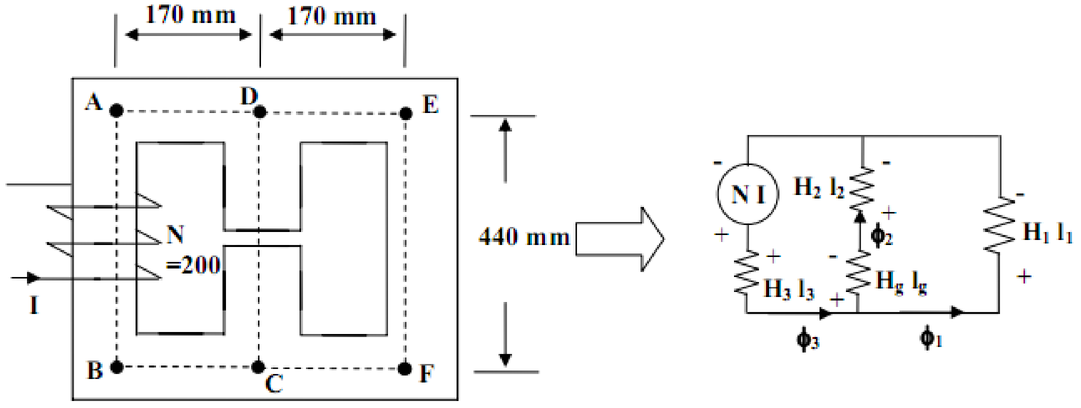


Figure 21.16: Circuit showing mean lengths.

$$\phi_g = \phi_2 \quad = \quad 1.28 \times 10^{-3}$$

$$\text{Cross sectional area of central limb } A_2 \quad = \quad 16 \times 10\text{-}4 \text{ m}^2$$

$$\text{Flux density } B_g = B_2 \quad = \quad \frac{1.28\times10^{-3}}{16\times10^{-4}} \text{ T}$$

$$= \quad 0.8 \text{ T}$$

$$\therefore, H_g = \frac{B_g}{\mu_0} \quad = \quad \frac{0.8}{4\pi\times10^{-7}} \text{ AT/m}$$

$$= \quad 63.66 \times 10^4 \text{ AT/m}$$

$$\text{mmf required for gap } H_g l_g \quad = \quad 63.66 \times 10^4 \times 1 \times 10^{-4} \text{ AT}$$

$$= \quad 63.66 \text{ AT}$$

Now we must calculate the mmf required in the iron portion of the central limb as follows:

$$\text{flux density, } B_2 \quad = \quad 0.8 \text{ T} \because \text{ fringing \& leakage neglected}$$

$$\text{corresponding H from graph, } H_2 \quad \approx \quad 500 \text{ AT /m}$$

$$\text{Mean iron length, } l_2 \quad = \quad (440 - 0.1) \text{ mm}$$

$$\approx \quad 0.44 \text{ m}$$

$$\text{mmf required for iron portion, } H_2 l_2 \quad = \quad 220 \text{ AT}$$

$$\text{Total mmf required for iron \& air gap,} \quad = \quad (220 + 63.66) \text{ AT}$$

$$mmf_{\text{CD}} = 283.66 \text{ AT.}$$

Step 5 Due to parallel connection, mmf acting across path 1 is same as mmf acting across path 2. Our intention here, will be to calculate ϕ_1 in path 1.

$$\text{mean length of the path, } l_1 = l_{DE} + l_{EF} + l_{FC}$$
$$= 2 \times 170 + 440 \text{ mm}$$
$$= 0.78 \text{ m}$$
$$\because H_1 = \frac{283.66}{0.78}$$
$$= 363.67 \text{ AT/m}$$
$$\text{corresponding flux density from graph, } B_1 \approx 0.39 \text{ T}$$
$$\therefore \text{flux, } \phi_1 = B_1 A_1$$
$$= 0.39 \times 24 \times 10^{-4} \text{ Wb}$$
$$\therefore \phi_1 = 0.94 \times 10^{-3} \text{ Wb}$$

Step 6 In this step we calculate the mmf necessary to drive ϕ_3 in path 3 as follows.

$$\text{flux in path 3, } \phi_3 = \phi_1 + \phi_2$$
$$= 2.22 \times 10^{-3} \text{ Wb}$$
$$\text{flux density, } B_3 = \frac{\phi_3}{A_3}$$
$$= \frac{2.22 \times 10^{-3}}{24 \times 10^{-4}}$$
$$\therefore B_3 = 0.925 \text{ T}$$
$$\text{corresponding H from graph, } H_3 \approx 562.5 \text{ AT/m}$$
$$\text{mean length of path 3, } l_3 = 2 \times 170 + 440 \text{ mm}$$
$$= 0.78 \text{ m}$$
$$\text{total mmf required for path 3} = H_3 l_3$$
$$= 562.5 \times 0.78 \text{ AT}$$
$$= 438.7 \text{ AT}$$
$$\therefore \text{mmf to be supplied by the coil, } NI = 283.66 + 438.7 \text{ AT}$$
$$\text{or } 200I = 722.36 \text{ AT}$$
$$\therefore \text{exciting current needed, } I = \frac{722.36}{200} \text{ A}$$
$$= 3.61 \text{ A}$$

3. Solution

(i) Turns ratio **a=500/250=2**

OC test:

The HV side is kept open

$$(I_0)_{lv} = 1.5\text{A}$$

i.e., $\dfrac{(I_0)_{hv}}{(I_0)_{lv}} = \dfrac{1}{a}$

i.e., $(I_0)_{hv} = \dfrac{(I_0)_{lv}}{a} = \dfrac{1.5}{2} = 0.74\text{ A}$

Instruments readings when they are placed on HV side:

$V_1 = 500$, $I_0 = 0.75$ A and $W_0 = 80$ W

$$\cos\theta_0 = \frac{W_0}{V_1 I_0} = \frac{80}{500\times 0.75} = 0.214$$

$$I_W = I_0 \cos\theta_0 = 0.75 \times 0.214 = 0.1605\text{ A}$$

and $I_\mu = I_0 \sin\theta_0 = 0.75\times\sqrt{1-\cos^2\theta_0} = 0.75\times 0.976 = 0.732\text{A}$

$$R_0 = \frac{V_1}{I_W} = \frac{500}{0.1605} = 3{,}115.26\ \Omega \quad \text{and} \quad X_0 = \frac{V_1}{I_\mu} = \frac{500}{0.732} = 683.06\ \Omega$$

referred to HV side.

SC test:

Instruments placed on HV side.

$V_{SC} = 22$ V, $I_{SC} = 10$ A, $P_{SC} = 90$ W

$$Z_{01} = \frac{V_{SC}}{I_{SC}} = \frac{22}{10} = 2.2\ \Omega,\ R_{01} = \frac{P_{SC}}{I_{SC}^2} = \frac{90}{10^2} = 0.9\ \Omega$$

and $X_{01} = \sqrt{Z_{01}^2 - R_{01}^2} = 2.0\ \Omega$

The equivalent circuit is shown in Figure Q3.

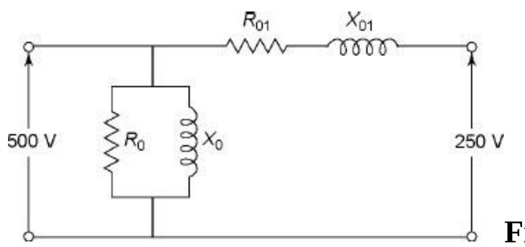


Figure Q3

(ii) Full-load secondary current of the transformer

$$I_2 = \frac{6 \times 10^3}{250} = 24\,\text{A}$$

Approximate voltage drop of the transformer referred to secondary:

$$V = I_2(R_{02}\cos\theta + X_{02}\sin\theta)$$

Now $R_{02} = \frac{R_{01}}{a^2} = \frac{0.9}{4} = 0.225\ \Omega$ and $X_{02} = \frac{X_{01}}{a^2} = \frac{2}{4} = 0.5\ \Omega$

Here $\cos\theta = 0.8$ (lagging)

$\sin\theta = 0.6$

$V = 24 \times (0.225 \times 0.8 + 0.5 \times 0.6) = 11.52$ V

Regulation of the transformer= $\frac{11.52}{250}$ =0.046 p.u=4.6%

From OC test: iron loss of the transformer = 80 W

From SC test: copper loss of the transformer = 90 W when primary current is 10 A, that is, secondary current is 20 A.

Full-load copper loss of the transformer= $\left(\frac{24}{20}\right)^2 \times \mathbf{90} = 129.6$ W

Total losses of the transformer at full load = 80 + 129.6 = 209.6 W

Output of the transformer at full load and 0.8 p.f. lagging = $V_2 I_2 \cos\theta_2$

Secondary terminal voltage (V_2) = 250 – Approximate voltage drop = 250 – 11.52 = 238.48 V

Output power = 238.48 × 24 × 0.8 = 4,578.816 W

Efficiency of the transformer

$$= \frac{\text{Output}}{\text{Output} + \text{Total loss}} = \frac{4{,}578.816}{4{,}578.816 + 209.6} = 0.9562\,\text{p.u.} = 95.62\%$$