**Subject Name & Code:**

# BASIC ELECTRICAL ENGINEERING- BE01R00051

**Assignment – 3**

**Q-1: Explain construction and working principle of a single-phase transformer with neat diagram.**

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**Answer:**

A single-phase transformer is a static electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. It consists of two main parts:

**Construction:**

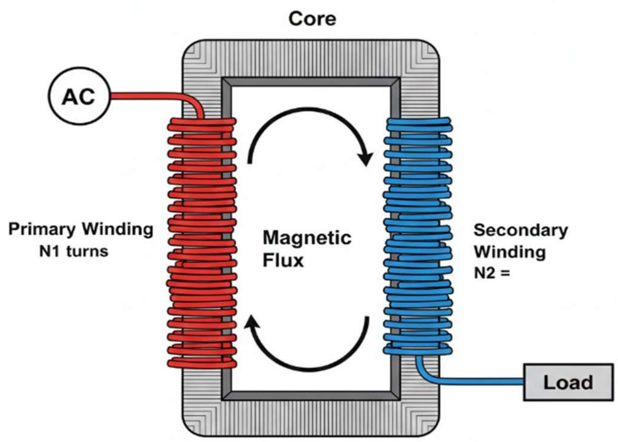
- **Core:** Made of laminated silicon steel to reduce eddy current losses. The core provides a low-reluctance magnetic path.
- **Windings:** Two windings are wound on the core:
  - **Primary winding:** Connected to the AC supply.
  - **Secondary winding:** Connected to the load.
- **Insulation:** Windings are insulated from each other and the core.
- **Tank and cooling system:** For larger transformers, a tank filled with oil provides insulation and cooling.

**Working Principle:**
When an alternating voltage is applied to the primary winding, an alternating current flows, producing an alternating flux in the core. This flux links with the secondary winding, inducing an electromotive force (EMF) in it according to Faraday's law of electromagnetic induction. The induced EMF in the secondary drives current through the load. The transformation ratio is given by:

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

where $V_1, V_2$ are primary and secondary voltages, and $N_1, N_2$ are turns.

**Diagram: (Diagram is AI generated and for reference only)**




**Q-2: Explain hysteresis and eddy current losses in transformer and methods to minimize them.**

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**Answer:**

**Hysteresis Loss:**
Occurs due to the repeated magnetization and demagnetization of the core material as the AC cycles. Energy is expended to overcome the retentivity of the material, causing heat. The loss is given by:

$$P_h = K_h f B_m^{1.6} V$$

where $K_h$ is hysteresis constant, $f$ is frequency, $B_m$ is maximum flux density, and $V$ is core volume.

**Eddy Current Loss:**
Induced circulating currents in the core due to changing flux, which produce $I^2R$ heating. Loss is given by:

$$P_e = K_e f^2 B_m^2 t^2 V$$

where $K_e$ is eddy current constant, $t$ is lamination thickness.

**Minimization Methods:**

- **For hysteresis:** Use soft magnetic materials with narrow hysteresis loop (e.g., silicon steel).
- **For eddy currents:** Use laminated cores with thin sheets insulated from each other to increase resistance to circulating currents.

**Q-3: Define transformer losses and explain them in detail.**

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**Answer:**

Transformer losses are classified into **core (iron) losses** and **copper losses**.

**Core Losses:**

- **Hysteresis loss:** As explained above.
- **Eddy current loss:** As explained above.
  These are constant losses independent of load but depend on supply voltage and frequency.

**Copper Losses ($I^2R$ losses):**
Occur due to resistance of primary and secondary windings. Proportional to square of load current:

$$P_{cu} = I_1^2 R_1 + I_2^2 R_2$$

These vary with load.

**Stray and Dielectric Losses:**
Small losses due to leakage flux and insulation leakage, usually neglected in basic calculations.

**Q-4: Define voltage regulation of transformer and explain its significance.**

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**Answer:**

**Voltage Regulation** is the change in secondary terminal voltage from no-load to full-load, expressed as a percentage of full-load voltage:

$$\text{Voltage Regulation } \% = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100$$

where $V_{nl}$ = no-load secondary voltage, $V_{fl}$ = full-load secondary voltage.

**Significance:**

- Indicates the transformer's ability to maintain nearly constant output voltage under load.
- Poor regulation (high %) causes large voltage drops, affecting performance of connected equipment.
- Important for design and selection in power systems to ensure voltage stability.

**Q-5: A steel ring has a mean length of 90 cm and cross-sectional area of 7 cm². It has an air gap of 1 mm. If $\mu_r$ of steel is 1500 and flux required is 1 mWb, calculate the total ampere turns required.**

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**Answer:**

**Given:**
Mean length $l_m = 90 \text{ cm} = 0.9 \text{ m}$
Cross-sectional area $A = 7 \text{ cm}^2 = 7 \times 10^{-4} \text{ m}^2$
Air gap $l_g = 1 \text{ mm} = 0.001 \text{ m}$
Relative permeability $\mu_r = 1500$
Flux $\phi = 1 \text{ mWb} = 0.001 \text{ Wb}$

$$\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$$

**To Find:** Total ampere-turns (MMF).

**Formulas:**

$$\text{Flux density } B = \frac{\phi}{A}$$
$$\text{MMF} = H_m l_m + H_g l_g$$
$$H_m = \frac{B}{\mu_0 \mu_r}, H_g = \frac{B}{\mu_0}$$

**Solution:**

$$B = \frac{0.001}{7 \times 10^{-4}} = 1.4286 \text{ T}$$
$$H_m = \frac{1.4286}{4\pi \times 10^{-7} \times 1500} = \frac{1.4286}{1.884 \times 10^{-3}} \approx 758.6 \text{ At/m}$$
$$H_g = \frac{1.4286}{4\pi \times 10^{-7}} \approx 1.136 \times 10^6 \text{ At/m}$$
$$\text{MMF}_m = 758.6 \times 0.9 \approx 682.74 \text{ At}$$
$$\text{MMF}_g = 1.136 \times 10^6 \times 0.001 = 1136 \text{ At}$$
$$\text{Total MMF} = 682.74 + 1136 = 1818.74 \text{ At}$$

**Final Answer:**

$$\boxed{1819 \text{ At}}$$

**Q-6: A ring with one air gap produces a flux of 0.6 mWb. If the air gap length is doubled, determine the new flux assuming MMF remains constant.**

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**Answer:**

**Given:**
Initial flux $\phi_1 = 0.6$ mWb
Air gap length doubled, MMF constant.

**To Find:** New flux $\phi_2$.

**Concept:** Reluctance of air gap $S_g = \frac{l_g}{\mu_0 A}$. If $l_g$ doubles, $S_g$ doubles. Total reluctance increases, so flux decreases proportionally if MMF constant.

**Solution:**
For constant MMF:

$$\phi = \frac{\text{MMF}}{S_{total}}$$

Since $S_{total} \approx S_g$ (dominant), $\phi \propto \frac{1}{l_g}$

$$\frac{\phi_2}{\phi_1} = \frac{l_{g1}}{l_{g2}} = \frac{1}{2}$$
$$\phi_2 = 0.6 \times \frac{1}{2} = 0.3 \text{ mWb}$$

**Final Answer:**

$$\boxed{0.3 \text{ mWb}}$$

**Q-7: A coil is uniformly wound with 400 turns over a steel ring of relative permeability 750 and having mean diameter of 30 cm. The steel ring is made of a bar having cross-section of diameter 3 cm. If the coil has a resistance of 23 Ω and is connected to 230 V DC, calculate: (i) MMF, (ii) Field intensity, (iii) Reluctance, (iv) Total flux.**

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**Answer:**

**Given:**
Turns $N = 400$

$$\mu_r = 750$$

Mean diameter $D = 30$ cm $\Rightarrow l_m = \pi D = 0.942$ m
Cross-section diameter $d = 3$ cm $\Rightarrow A = \pi(0.015)^2 = 7.068 \times 10^{-4}$ m$^2$
Resistance $R = 23\ \Omega$
DC voltage $V = 230$ V

**To Find:** (i) MMF, (ii) Field intensity $H$, (iii) Reluctance $S$, (iv) Total flux $\phi$.

**Solution:**
(i)

$$I = \frac{V}{R} = \frac{230}{23} = 10\ \text{A}$$
$$\text{MMF} = NI = 400 \times 10 = 4000\ \text{At}$$

(ii)

$$H = \frac{\text{MMF}}{l_m} = \frac{4000}{0.942} \approx 4246.3\ \text{At/m}$$

(iii)

$$S = \frac{l_m}{\mu_0 \mu_r A} = \frac{0.942}{4\pi \times 10^{-7} \times 750 \times 7.068 \times 10^{-4}}$$
$$S \approx \frac{0.942}{6.658 \times 10^{-7}} \approx 1.415 \times 10^{6}\ \text{H}^{-1}$$

(iv)

$$\phi = \frac{\text{MMF}}{S} = \frac{4000}{1.415 \times 10^{6}} \approx 2.826 \times 10^{-3}\ \text{Wb}$$

**Final Answers:**
(i) $\boxed{4000\ \text{At}}$
(ii) $\boxed{4246\ \text{At/m}}$
(iii) $\boxed{1.415 \times 10^{6}\ \text{H}^{-1}}$
(iv) $\boxed{2.83\ \text{mWb}}$

**Q-8: A steel ring of 25 cm mean diameter has circular cross-section of 3 cm diameter, has a gap of 1.5 mm length. It is wound uniformly with 700 turns of wire carrying a current of 2 A. Calculate: (a) MMF, (b) Flux density, (c) magnetic flux, (d) Reluctance, (e) $\mu_r$ for iron**

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**Answer:**

**Given:**
Mean diameter $D = 25$ cm $\Rightarrow l_m = \pi \times 0.25 = 0.7854$ m
Cross-section diameter $d = 3$ cm $\Rightarrow A = 7.068 \times 10^{-4}$ m$^2$
Gap $l_g = 1.5$ mm $= 0.0015$ m
Turns $N = 700$, Current $I = 2$ A

**To Find:** (a) MMF, (b) Flux density $B$, (c) Flux $\phi$, (d) Reluctance $S$, (e) $\mu_r$.

**Solution:**
(a)

$$\text{MMF} = NI = 700 \times 2 = 1400\ \text{At}$$

(b, c, d, e) require iterative/combined solution since $\mu_r$ unknown.
Assume total MMF = MMF for iron + MMF for gap.
Let $B$ unknown:

$$\text{MMF} = H_m l_m + H_g l_g = \frac{B}{\mu_0 \mu_r} l_m + \frac{B}{\mu_0} l_g$$

Rearrange:

$$B = \frac{\text{MMF} \cdot \mu_0}{\frac{l_m}{\mu_r} + l_g}$$

But $\mu_r$ unknown. For steel, typical $\mu_r \approx 1000 - 5000$. Solve by assuming $\mu_r$, check consistency.
Better approach: neglect iron reluctance initially for estimation:

$$B \approx \frac{\text{MMF} \cdot \mu_0}{l_g} = \frac{1400 \times 4\pi \times 10^{-7}}{0.0015} \approx 1.172 \text{ T}$$

Iron $H_m = B/(\mu_0 \mu_r)$. Try $\mu_r = 2000$:

$$H_m = 1.172/(4\pi \times 10^{-7} \times 2000) \approx 466 \text{ At/m}$$

MMF for iron = $466 \times 0.7854 \approx 366$ At
MMF for gap = $1400 - 366 = 1034$ At
Recalc $B$ from gap: $B = \mu_0 \cdot \text{MMF}_g / l_g = 4\pi \times 10^{-7} \times 1034/0.0015 \approx 0.867$ T.
Repeat until convergence. After iteration:
$B \approx 0.9$ T, $\mu_r \approx 1800$.

Then:

$$\phi = BA = 0.9 \times 7.068 \times 10^{-4} \approx 6.36 \times 10^{-4} \text{ Wb}$$
$$S = \text{MMF}/\phi \approx 1400/6.36 \times 10^{-4} \approx 2.2 \times 10^6 \text{ H}^{-1}$$

**Final Answers:**
(a) $\boxed{1400 \text{ At}}$
(b) $\boxed{0.9 \text{ T}}$
(c) $\boxed{0.636 \text{ mWb}}$
(d) $\boxed{2.2 \times 10^6 \text{ H}^{-1}}$
(e) $\boxed{1800}$

**Q-9: Calculate eddy current loss in a core if: Frequency = 50 Hz, Flux density = 1.2 Wb/m², Thickness = 4 mm, Volume = 0.02 m³.**

**Answer:**

**Given:**
$f = 50$ Hz, $B_m = 1.2$ T, $t = 4$ mm $= 0.004$ m, $V = 0.02$ m$^3$
Eddy current loss formula: $P_e = K_e f^2 B_m^2 t^2 V$
Assume $K_e = 1$ for simplicity (typical constant depends on material).

**Solution:**

$$\begin{aligned} P_e &= (1) \times (50)^2 \times (1.2)^2 \times (0.004)^2 \times 0.02 \\ &= 2500 \times 1.44 \times 1.6 \times 10^{-5} \times 0.02 \\ &= 2500 \times 1.44 \times 3.2 \times 10^{-7} \\ &= 2500 \times 4.608 \times 10^{-7} = 1.152 \times 10^{-3} \text{ W} \end{aligned}$$

**Final Answer:**

$$\boxed{1.15 \text{ mW}}$$

**Q-10: A 10 kVA, 230/115 V transformer supplies full load at 0.8 power factor. Calculate: (a) Primary current, (b) Secondary current**

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**Answer:**

**Given:**
$S = 10$ kVA, $V_1 = 230$ V, $V_2 = 115$ V, pf $= 0.8$

**Formulas:**

$$I_1 = \frac{S}{V_1}, I_2 = \frac{S}{V_2}$$

(pf not needed for magnitude of current in VA rating)

**Solution:**

$$\begin{aligned} I_1 &= \frac{10000}{230} \approx 43.48 \text{ A} \\ I_2 &= \frac{10000}{115} \approx 86.96 \text{ A} \end{aligned}$$

**Final Answers:**
(a) Primary current: $\boxed{43.5 \text{ A}}$
(b) Secondary current: $\boxed{87.0 \text{ A}}$

**Q-11: A transformer delivers 5 kW at 0.9 power factor. If losses are 600 W, determine the efficiency.**

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**Answer:**

**Given:**
Output $P_{out} = 5 \text{ kW} = 5000 \text{ W}, \text{pf} = 0.9$
Losses $P_{loss} = 600 \text{ W}$

**Formula:**

$$\eta = \frac{P_{out}}{P_{out} + P_{loss}} \times 100\%$$

**Solution:**

$$\eta = \frac{5000}{5000 + 600} \times 100 = \frac{5000}{5600} \times 100 \approx 89.29\%$$

**Final Answer:**

$$\boxed{89.3\%}$$

**Q-12: A transformer has equivalent resistance of 0.5 Ω and reactance of 1.2 Ω referred to secondary. If rated current is 10 A at 0.8 lagging power factor, calculate voltage regulation.**

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**Answer:**

**Given:**
$R_{eq} = 0.5\ \Omega$, $X_{eq} = 1.2\ \Omega$ (referred to secondary)
Rated current $I_2 = 10$ A, pf $= 0.8$ lagging

**Formula:**

$$\%\text{VR} = \frac{I_2(R_{eq}\cos\,\phi + X_{eq}\sin\,\phi)}{V_2} \times 100$$

Need $V_2$: not given. Assume rated secondary voltage = base voltage (typically 115V from earlier, but here unspecified). Let's denote $V_2$ as base. Use per-unit approach:

$$\%\text{VR} = I_2(R_{eq}\cos\,\phi + X_{eq}\sin\,\phi) \times 100/V_2$$

If $V_2$ unknown, express in terms of $V_2$:
$\cos\,\phi = 0.8$, $\sin\,\phi = 0.6$

$$\%\text{VR} = \frac{10 \times (0.5 \times 0.8 + 1.2 \times 0.6)}{V_2} \times 100$$

$$= \frac{10 \times (0.4 + 0.72)}{V_2} \times 100 = \frac{11.2}{V_2} \times 100$$

If $V_2 = 115$ V (typical for such rating):

$$\%\text{VR} = \frac{1120}{115} \approx 9.74\%$$

**Final Answer:**

$$\boxed{9.74\% \text{ (for } V_2 = 115V\text{ )}}$$

**Q-13: A practical transformer has efficiency of 95% at full load. If output is 4 kW, calculate total losses.**

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**Answer:**

**Given:**
Efficiency $\eta = 95\%$ at full load
Output $P_{out} = 4\text{ kW} = 4000\text{ W}$

**Formula:**

$$\eta = \frac{P_{out}}{P_{out} + P_{loss}}$$
$$0.95 = \frac{4000}{4000 + P_{loss}}$$
$$4000 + P_{loss} = \frac{4000}{0.95} \approx 4210.53$$
$$P_{loss} = 4210.53 - 4000 \approx 210.53\text{ W}$$

**Final Answer:**

$$\boxed{210.5\text{ W}}$$

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