Subject Name & Code:

BASIC ELECTRICAL ENGINEERING- BE01R00051

PBL Assignment – 3

Q-1: Describe B–H curve and hysteresis loop with applications.

Answer:

B-H Curve (Magnetization Curve):
The B-H curve is a fundamental graphical representation that describes the magnetic properties of a ferromagnetic material. It plots the **Magnetic Flux Density (B)** against the **Magnetic Field Strength (H)**. The curve is non-linear, indicating that the permeability ($\mu = B/H$) of the material is not constant.

- **Initial Magnetization Curve:** Starting from an unmagnetized state (B=0, H=0), as H increases, B rises slowly (region of domain alignment), then rapidly (where most domains align), and finally saturates (B_s) where all domains are aligned and no further increase in B is possible with increasing H.
- **Saturation Flux Density (B_s):** The maximum flux density the material can achieve.

Hysteresis Loop:
When the applied H is cycled (increased to a maximum, decreased to zero, reversed, etc.), the B-H relationship does not retrace the initial curve, forming a closed loop called a hysteresis loop.

- **Retentivity or Remanence (B_r):** The flux density remaining in the material when H is reduced to zero.
- **Coercivity (H_c):** The reverse magnetic field strength required to reduce the flux density B to zero, i.e., to demagnetize the material.
- **Loop Area:** The area enclosed by the hysteresis loop represents the **energy loss per unit volume per cycle**, known as hysteresis loss. This energy is dissipated as heat in the material.

Applications:

- **Material Selection:** The shape of the loop is crucial for selecting materials.
  - **Soft Magnetic Materials (e.g., Silicon Steel):** Have a thin, tall hysteresis loop (low H_c, low B_r, small area). They are easily magnetized and demagnetized,

making them ideal for **transformer cores, AC motor stators, and inductors** where low energy loss is critical.

  - **Hard Magnetic Materials (e.g., Alnico, Neodymium):** Have a wide, fat loop (high H_c, high B_r, large area). They retain magnetization strongly and are used for **permanent magnets** in speakers, motors, and magnetic separators.

- **Core Loss Estimation:** The hysteresis loss is a primary component of iron loss in electrical machines and transformers, directly proportional to the loop area, frequency, and volume of the core.

Q-2: Explain ideal transformer and practical transformer.

Answer:

Ideal Transformer:
An ideal transformer is a theoretical, lossless device with perfect coupling between its windings. It is defined by the following characteristics:

1. **Zero Winding Resistance:** The primary and secondary coils have no ohmic resistance ($R_1 = R_2 = 0$).
2. **Infinite Core Permeability (μ):** The core requires zero magnetomotive force (MMF) to establish the mutual flux (ϕ). Therefore, the no-load current (I_0) is zero.
3. **Zero Core Losses:** No hysteresis or eddy current losses occur in the core.
4. **Perfect Magnetic Coupling:** All flux produced by the primary winding links completely with the secondary winding (leakage flux = 0; leakage reactance = 0).
5. **Constant Core Permeability:** It is independent of the magnetizing force.

Under these ideal conditions, the transformer obeys the fundamental relations:

- **Turns Ratio (a) = $N_1/N_2 = V_1/V_2 = I_2/I_1$**
- **Input Power = Output Power ($V_1I_1 = V_2I_2$)**

Practical Transformer:
A real-world transformer deviates from the ideal model due to inherent material and design limitations. Key deviations include:

1. **Winding Resistances (R_1, R_2):** Copper windings have finite resistance, leading to **copper losses (I^2R losses)** and voltage drops.
2. **Finite Core Permeability:** The core requires a finite magnetizing current (I_m) to establish the working flux.
3. **Core Losses:** Hysteresis and eddy currents in the ferromagnetic core cause **iron losses**, which occur whenever the transformer is energized.

4. **Leakage Flux:** Not all flux links both windings. This leakage flux creates **leakage reactance (X_1, X_2)**, which causes further voltage drop and affects regulation.
5. **Non-linear B-H Curve:** Leads to saturation and harmonic generation at high excitation.

Q-3: Explain efficiency of transformer and derive its expression.

Answer:

The efficiency (η) of a transformer is defined as the ratio of its useful output power to its total input power. It is a measure of how effectively the transformer converts input electrical energy into output electrical energy.

$$\eta = \frac{\text{Output Power } (P_{\text{out}})}{\text{Input Power } (P_{\text{in}})} \times 100\%$$

Since Input Power = Output Power + Losses,

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

The losses in a transformer are classified into two main types:

1. **Constant Losses (Iron or Core Losses, P_i):** These depend on the supply voltage and frequency, not on the load current. They remain approximately constant from no-load to full-load for a fixed applied voltage. $P_i = P_{\text{hysteresis}} + P_{\text{eddy current}}$.

2. **Variable Losses (Copper Losses, P_c):** These are I^2R losses in the primary and

   secondary windings. They vary with the square of the load current. At any load x (where x is the fraction of full load), $P_c = x^2 \times P_{c(FL)}$, where $P_{c(FL)}$ is the full-load copper loss.

Let:

- x = Fraction of full load
- S = Transformer's rated kVA (Apparent power rating)
- $\cos\phi$ = Load power factor
- P_i = Constant iron loss
- $P_{c(FL)}$ = Full-load copper loss

Output power at fraction x of full load: $P_{\text{out}} = xS\cos\phi$
Copper loss at this load: $P_c = x^2 P_{c(FL)}$

Therefore, the efficiency expression becomes:

$$\eta = \frac{xS\cos\ \phi}{xS\cos\ \phi + P_i + x^2 P_{c(FL)}} \times 100\%$$

Q-4: Compare ideal and practical transformer in detail.

Answer:

Feature	Ideal Transformer	Practical Transformer
Winding Resistance	Zero. No I^2R loss.	Finite. Causes copper losses and voltage drop.
Core Permeability	Infinite. No magnetizing current required.	Finite. Requires a magnetizing current (I_m).
Core Losses	Zero. No hysteresis or eddy current loss.	Present. Constitutes constant iron losses.
Leakage Flux	Zero. Perfect magnetic coupling.	Present. Leads to leakage reactance and affects voltage regulation.
No-load Current (I_0)	Zero.	Small (2-6% of rated current), lags V_1 by a large angle.
Efficiency	100%.	Always less than 100% due to losses.
Voltage Regulation	Perfect (0%). Output voltage constant irrespective of load.	Finite. Output voltage changes with load due to impedance drop.
Equivalent Circuit	Simple, containing only an ideal transformer with turns ratio.	Complex, including R_1, X_1, R_m, X_m, R_2', X_2' referred to one side.

Feature	Ideal Transformer	Practical Transformer
Phasor Diagram	Simple, with V_1 and V_2 in phase or anti-phase.	Complex, showing I_0, voltage drops, and phase shifts.
Applications	Theoretical analysis and simplified circuit models.	All real-world power and distribution systems.

Q-5: A magnetic circuit consists of an iron core and a single air gap of 0.5 mm. If flux density in the air gap is 1.2 Wb/m², calculate the MMF required for the air gap alone.

Answer:

Given:
Air gap length, $l_g = 0.5 \text{ mm} = 0.5 \times 10^{-3} \text{ m}$
Flux density in gap, $B_g = 1.2 \text{ Wb/m}^2$
Permeability of free space, $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$

To Find: MMF required for the air gap alone ($\mathcal{F}_g$).

Formula:
For an air gap, $H_g = \frac{B_g}{\mu_0}$ and $\mathcal{F}_g = H_g \times l_g$.

Solution:

$$H_g = \frac{1.2}{4\pi \times 10^{-7}} = \frac{1.2}{1.2566 \times 10^{-6}} \approx 954930 \text{ AT/m}$$
$$\mathcal{F}_g = H_g \times l_g = 954930 \times (0.5 \times 10^{-3})$$
$$\mathcal{F}_g = 477.465 \text{ AT}$$

Final Answer:

$$\boxed{\mathcal{F}_{\text{gap}} \approx 477.5 \text{ Ampere-Turns}}$$

Q-6: The mean periphery of the steel ring is 70 cm and the cross-sectional area is 6 cm². Calculate the ampere turns necessary to produce flux of 0.9 mWb. If a saw cut of 3 mm is made in the ring and if the MMF remains constant, calculate the new value of the flux. Take μ_r of steel as 1400.

Answer:

Part A: Ampere-Turns for initial ring.

Given:
Mean length, $l_m = 70\text{ cm} = 0.7\text{ m}$
Cross-sectional area, $A = 6\text{ cm}^2 = 6 \times 10^{-4}\text{ m}^2$
Desired flux, $\phi = 0.9\text{ mWb} = 0.9 \times 10^{-3}\text{ Wb}$
Relative permeability, $\mu_r = 1400$

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

To Find: Ampere-turns ($\mathcal{F}$).

Formula:
Flux density, $B = \phi/A$. Magnetizing force, $H = B/(\mu_0\mu_r)$. MMF, $\mathcal{F} = H \times l_m$.

Solution:

$$B = \frac{0.9 \times 10^{-3}}{6 \times 10^{-4}} = 1.5\text{ T}$$
$$\mu = \mu_0\mu_r = 4\pi \times 10^{-7} \times 1400 \approx 1.759 \times 10^{-3}\text{ H/m}$$
$$H = \frac{B}{\mu} = \frac{1.5}{1.759 \times 10^{-3}} \approx 852.6\text{ AT/m}$$
$$\mathcal{F} = H \times l_m = 852.6 \times 0.7 \approx 596.8\text{ AT}$$

Final Answer (Part A):

$$\boxed{\mathcal{F} \approx 597\text{ Ampere-Turns}}$$

Part B: New flux with 3mm saw cut (air gap).

Given:
Original MMF, $\mathcal{F} = 596.8\text{ AT}$ (constant)
Air gap length, $l_g = 3\text{ mm} = 3 \times 10^{-3}\text{ m}$
The circuit is now a series magnetic circuit: steel path ($l_m = 0.7\text{ m}$) + air gap (l_g).

To Find: New flux (ϕ_{new}).

Formula:
Total MMF, $\mathcal{F}_{\text{total}} = \mathcal{F}_{\text{steel}} + \mathcal{F}_{\text{gap}} = H_m l_m + H_g l_g$.
Since $\phi = B \times A$ is the same in series, and $H_m = B/(\mu_0\mu_r)$, $H_g = B/\mu_0$.

$$\mathcal{F} = \frac{B l_m}{\mu_0\mu_r} + \frac{B l_g}{\mu_0} = \frac{B}{\mu_0}\left(\frac{l_m}{\mu_r} + l_g\right)$$

Solution:

$$596.8 = \frac{B}{4\pi \times 10^{-7}}\left(\frac{0.7}{1400} + 3 \times 10^{-3}\right)$$

$$596.8 = \frac{B}{1.2566 \times 10^{-6}}(5 \times 10^{-4} + 3 \times 10^{-3})$$
$$596.8 = \frac{B}{1.2566 \times 10^{-6}} \times (3.5 \times 10^{-3})$$
$$B = \frac{596.8 \times 1.2566 \times 10^{-6}}{3.5 \times 10^{-3}} \approx 0.2143\ \text{T}$$
$$\phi_{\text{new}} = B \times A = 0.2143 \times (6 \times 10^{-4}) = 1.286 \times 10^{-4}\ \text{Wb}$$

Final Answer (Part B):

$$\boxed{\phi_{\text{new}} \approx 0.1286\ \text{mWb}}$$

Q-7: Find the ampere turns required to produce a flux of 0.6 mWb in the air gap of a magnetic circuit which has an air gap of 0.3 mm. The iron ring has a cross section of 6 cm² and 70 cm mean length. Take μ_r = 2000 and leakage coefficient = 1.2

Answer:

Desired air-gap flux, $\phi_g = 0.6\ \text{mWb} = 0.6 \times 10^{-3}\ \text{Wb}$
Air gap length, $l_g = 0.3\ \text{mm} = 0.3 \times 10^{-3}\ \text{m}$
Iron ring cross-section, $A_{\text{iron}} = 6\ \text{cm}^2 = 6 \times 10^{-4}\ \text{m}^2$
Iron mean length, $l_m = 70\ \text{cm} = 0.7\ \text{m}$
Relative permeability, $\mu_r = 2000$
Leakage coefficient, $k = 1.2$ (defined as Total Flux / Useful Flux, or $\phi_{\text{total}}/\phi_g$)

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

To Find: Total ampere-turns required ($\mathcal{F}_{\text{total}}$).

Concept:
The leakage coefficient $k > 1$ indicates that the flux in the iron core (ϕ_{iron}) is greater than the useful flux in the air gap (ϕ_g) because some flux leaks.

$$\phi_{\text{iron}} = k \times \phi_g$$

Step 1: Calculate MMF for the air gap ($\mathcal{F}_g$).

Air-gap flux density: $B_g = \frac{\phi_g}{A_{\text{iron}}}$ (assuming air-gap area = iron area).

$$B_g = \frac{0.6 \times 10^{-3}}{6 \times 10^{-4}} = 1.0\ \text{T}$$
$$H_g = \frac{B_g}{\mu_0} = \frac{1.0}{4\pi \times 10^{-7}} \approx 795775\ \text{AT/m}$$
$$\mathcal{F}_g = H_g \times l_g = 795775 \times (0.3 \times 10^{-3}) \approx 238.7\ \text{AT}$$

Step 2: Calculate MMF for the iron path ($\mathcal{F}_m$).
Flux in iron: $\phi_{\text{iron}} = 1.2 \times 0.6 \times 10^{-3} = 0.72 \times 10^{-3}$ Wb
Flux density in iron: $B_m = \frac{\phi_{\text{iron}}}{A_{\text{iron}}} = \frac{0.72\times10^{-3}}{6\times10^{-4}} = 1.2$ T
Magnetizing force in iron:

$$H_m = \frac{B_m}{\mu_0 \mu_r} = \frac{1.2}{4\pi \times 10^{-7} \times 2000} = \frac{1.2}{2.513 \times 10^{-3}} \approx 477.5 \text{ AT/m}$$
$$\mathcal{F}_m = H_m \times l_m = 477.5 \times 0.7 \approx 334.25 \text{ AT}$$

Step 3: Total MMF.
For a series magnetic circuit:

$$\mathcal{F}_{\text{total}} = \mathcal{F}_g + \mathcal{F}_m = 238.7 + 334.25 = 572.95 \text{ AT}$$

Final Answer:

$$\boxed{\mathcal{F}_{\text{total}} \approx 573 \text{ Ampere-Turns}}$$

Q-8: An iron core operates at frequency = 50 Hz, maximum flux density = 1.3 Wb/m², Volume = 0.01 m³, hysteresis coefficient is 0.003 Calculate hysteresis loss.

Answer:

Given:
Frequency, $f = 50$ Hz
Maximum flux density, $B_m = 1.3$ Wb/m^2
Core volume, $V = 0.01$ m^3
Hysteresis coefficient, $k_h = 0.003$

Assumption: The problem likely intends the classic hysteresis loss formula per volume:

$$P_h = \eta f B_m^{1.6} V$$

But here $k_h = 0.003$ is provided directly, likely as the constant for the formula $P_h = k_h f B_m^x V$. Since exponent x is not stated, the most common academic simplification for such problems is $P_h = k_h f B_m^2 V$.

To Find: Hysteresis loss (P_h).

Formula (using B^2 dependence):

$$P_h = k_h \cdot f \cdot B_m^2 \cdot V$$

Solution:

$P_h = 0.003 \times 50 \times (1.3)^2 \times 0.01$
$P_h = 0.003 \times 50 \times 1.69 \times 0.01$
$P_h = 0.003 \times 50 \times 0.0169 = 0.003 \times 0.845 = 0.002535 \text{ kW}$
$P_h = 2.535 \text{ W}$

Final Answer:

$$\boxed{P_{\text{hysteresis}} \approx 2.54 \text{ W}}$$

Q-9: A single-phase transformer has 400 primary turns and 100 secondary turns. If primary voltage is 240 V, calculate: (a) Secondary voltage, (b) Turns ratio

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Answer:

Given:
Primary turns, $N_1 = 400$
Secondary turns, $N_2 = 100$
Primary voltage, $V_1 = 240 \text{ V}$

To Find:
(a) Secondary voltage (V_2)
(b) Turns ratio (a)

Formulas:
For an ideal transformer:
Turns ratio, $a = \frac{N_1}{N_2}$

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

Solution:
(a)

$$V_2 = V_1 \times \frac{N_2}{N_1} = 240 \times \frac{100}{400} = 240 \times 0.25 = 60 \text{ V}$$

(b)

$$a = \frac{N_1}{N_2} = \frac{400}{100} = 4$$

(The turns ratio is 4:1, step-down transformer).

Final Answer:

$$\boxed{(a)\ V_2 = 60\ \text{V}\ (b)\ \text{Turns Ratio} = 4}$$

Q-10: The iron loss of a transformer is 300W and copper loss at full load is 400W. Calculate efficiency at full load and 0.8 power factor.

Answer:

Given:
Iron loss (constant loss), $P_i = 300$ W
Full-load copper loss, $P_{c(FL)} = 400$ W
Full load, $x = 1$
Load power factor, $\cos\,\phi = 0.8$

To Find: Efficiency at full load (η_{FL}).

Formula:

$$\eta = \frac{xS\cos\,\phi}{xS\cos\,\phi + P_i + x^2 P_{c(FL)}} \times 100\%$$

Assumption: $S = 5000$ VA

Solution:
Full-load output power:

$$P_{\text{out(FL)}} = S\cos\,\phi = 5000 \times 0.8 = 4000\ \text{W}$$

Total losses at full load:

$$P_{\text{loss}} = P_i + P_{c(FL)} = 300 + 400 = 700\ \text{W}$$

Efficiency:

$$\eta_{FL} = \frac{4000}{4000 + 700} \times 100\% = \frac{4000}{4700} \times 100\% \approx 85.11\%$$

Final Answer (with assumption $S = 5$ kVA):

$$\boxed{\eta_{\text{full load}} \approx 85.1\%}$$

Q-11: A transformer has no-load loss of 200 W and full-load copper loss of 300 W. At what load will the transformer have maximum efficiency?

Answer:

Given:
No-load loss (iron loss), $P_i = 200$ W
Full-load copper loss, $P_{c(FL)} = 300$ W

To Find: The load (as fraction of full load, x) at which maximum efficiency occurs.

Concept:
Maximum efficiency occurs when **variable losses = constant losses**, i.e.,

$$x^2 P_{c(FL)} = P_i$$

Formula:

$$x = \sqrt{\frac{P_i}{P_{c(FL)}}}$$

Solution:

$$x = \sqrt{\frac{200}{300}} = \sqrt{\frac{2}{3}} \approx \sqrt{0.6667} \approx 0.8165$$

Final Answer:

$$\boxed{\text{Maximum efficiency occurs at about 81.65\% of full load.}}$$

Q-12: Find the percentage regulation of a transformer supplying a unity power factor load if secondary induced voltage is 220 V and terminal voltage is 210 V.

Answer:

Given:
Secondary induced voltage (no-load voltage), $E_2 = 220$ V
Secondary terminal voltage on load, $V_2 = 210$ V
Load power factor = 1 (unity)

To Find: Percentage regulation (% Reg).

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

$$\%\text{Reg} = \frac{E_2 - V_2}{V_2} \times 100\% (\text{often uses } E_2 \text{ in denominator})$$

The more common and precise definition:

$$\%\text{Reg} = \frac{E_2 - V_2}{E_2} \times 100\%$$

Solution:

$$\%\text{Reg} = \frac{220 - 210}{220} \times 100\% = \frac{10}{220} \times 100\% \approx 4.545\%$$

Final Answer:

$$\boxed{\%\text{Regulation} \approx 4.55\%}$$

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