Electrical Technology Assignment No. 5 (Unit-5) Solutions

1. Self and Mutual Inductance

Self-Inductance (L)

- **Definition**: The property of a coil to oppose any change in current flowing through it by inducing an opposing EMF.
- **Formula**:
  [
  L = \frac{N \phi}{I}
  ]
  where:
  - (N) = Number of turns
  - (\phi) = Magnetic flux (Wb)
  - (I) = Current (A)
- **Self-Induced EMF**:
  [
  e = -L \frac{dI}{dt}
  ]
  (Negative sign indicates opposition to change, as per **Lenz's Law**).

Mutual Inductance (M)

- **Definition**: The ability of one coil to induce an EMF in a nearby coil due to a changing current.
- **Formula**:
  [
  M = \frac{N_2 \phi_{12}}{I_1}
  ]
  where:
  - (N_2) = Turns in secondary coil
  - (\phi_{12}) = Flux linking both coils
  - (I_1) = Current in primary coil
- **Mutually Induced EMF**:
  [

$$
e_2 = -M \frac{dI_1}{dt}
$$

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2. Magnetic Circuit & Key Terms

Magnetic Circuit

A closed path followed by **magnetic flux**, typically made of high-permeability materials (e.g., iron).

Key Terms

1. **Magnetomotive Force (MMF)**
   - **Definition**: The driving force that establishes magnetic flux.
   - **Formula**:
     $$
     \text{MMF} = N I \quad (\text{Ampere-turns})
     $$
2. **Reluctance (S)**
   - **Definition**: Opposition to magnetic flux (analogous to resistance in electric circuits).
   - **Formula**:
     $$
     S = \frac{l}{\mu A}
     $$
     where:
     - l = Length of magnetic path (m)
     - μ = Permeability (H/m)
     - A = Cross-sectional area (m^2)
3. **Permeance (P)**
   - **Definition**: Reciprocal of reluctance (ease of flux passage).
   - **Formula**:
     $$
     P = \frac{1}{S} = \frac{\mu A}{l}
     $$

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3. Working Principle of Single-Phase Transformer

- A transformer operates on **Faraday's Law of Electromagnetic Induction**.
- **Steps**:
  1. **Primary Coil**: AC supply creates a **changing magnetic flux** in the core.
  2. **Core**: Flux links the **secondary coil**.
  3. **Secondary Coil**: Changing flux induces an **EMF** (mutual induction).
- **Key Points**:
  - **No electrical connection** between primary and secondary.
  - **Voltage transformation** depends on turns ratio:
    $$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

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4. Derivation of EMF Equation

For a sinusoidal supply:

- **Flux Variation**: $\phi = \phi_m \sin \omega t$
- **Induced EMF**:
  $$e = -N \frac{d\phi}{dt} = -N \frac{d}{dt}(\phi_m \sin \omega t)$$
  $$e = -N \omega \phi_m \cos \omega t$$
- **RMS Value**:
  $$E_{\text{rms}} = \frac{N \omega \phi_m}{\sqrt{2}} = 4.44 f N \phi_m$$
  where:
  - f = Frequency (Hz)
  - ϕ_m = Maximum flux (Wb)

Final EMF Equation:

$$E = 4.44 f N \phi_m$$

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5. Losses in Transformer

1. Copper Losses ((I²R))

- Due to **resistance** of windings.
- **Formula**:
  [
  P_{\text{Cu}} = I_1^2 R_1 + I_2^2 R_2
  ]

2. Iron Losses (Core Losses)

- **Hysteresis Loss**:
  [
  P_h = k_h f B_m^x
  ]
- **Eddy Current Loss**:
  [
  P_e = k_e B_m^2 f^2 t^2
  ]
- **Total Iron Loss**:
  [
  P_{\text{Fe}} = P_h + P_e
  ]

3. Stray & Dielectric Losses

- Minimal and often neglected.

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6. Efficiency & Voltage Regulation

Efficiency (η)

- **Definition**: Ratio of output power to input power.
  [
  \eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100\%
  ]
- **Direct Load Test Method**:
  1. Connect the transformer to a **variable load**.
  2. Measure input power ((P_{\text{in}})) and output power ((P_{\text{out}})).

3. Calculate:
   [
   \eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\%
   ]

Voltage Regulation

- **Definition**: Percentage drop in secondary voltage from no-load to full-load.
  [
  % \text{Regulation} = \frac{V_{\text{no-load}} - V_{\text{full-load}}}{V_{\text{no-load}}} \times 100\%
  ]
- **Direct Load Test Method**:
  1. Measure **no-load voltage** ((V_{\text{OC}})).
  2. Apply full load and measure **loaded voltage** ((V_{\text{FL}})).
  3. Use the formula above.

Summary

Concept	Key Formula/Explanation
Self-Inductance	(L = \frac{N \phi}{I})
Mutual Inductance	(M = \frac{N_2 \phi_{12}}{I_1})
MMF	(\text{MMF} = NI)
Transformer EMF	(E = 4.44 f N \phi_m)
Copper Loss	(P_{\text{Cu}} = I_1^2 R_1 + I_2^2 R_2)
Efficiency	(\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\%)
Voltage Regulation	(% \text{Reg} = \frac{V_{\text{OC}} - V_{\text{FL}}}{V_{\text{OC}}} \times 100\%)

This assignment covers **inductance, magnetic circuits, transformer principles, losses, and performance testing**.