Subject Name & Code:

BASIC ELECTRICAL ENGINEERING- BE01R00051

Assignment – 3

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

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:

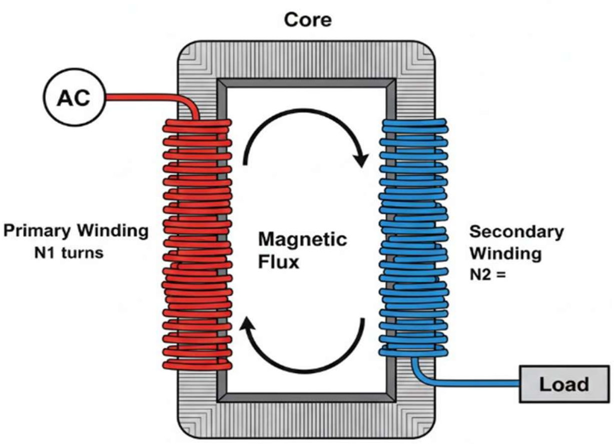
- **Core:** Made of laminated silicon steel to reduce eddy current losses. The core provides a low-reluctance magnetic path.
- **Windings:** Two windings are wound on the core:
    - **Primary winding:** Connected to the AC supply.
    - **Secondary winding:** Connected to the load.
- **Insulation:** 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: 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-3: Explain hysteresis and eddy current losses in transformer and methods to minimize them.

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-4: 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-5: Define transformer losses and explain them in detail.

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:

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

These vary with load.

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

Q-6: 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.

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

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:

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

Q-7: Define voltage regulation of transformer and explain its significance.

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-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.
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.

9. Explain generation of rotating magnetic field and its importance in induction motors.

Answer:

Generation:
When a three-phase supply is applied to three stator windings displaced by 120° in space, each winding carries a current displaced by 120° in time. The resultant magnetic field has constant magnitude and rotates at synchronous speed $N_s = 120f/P$.

Importance:
The rotating magnetic field induces EMF in the rotor conductors (by Faraday's law), producing rotor current. Interaction of rotor current with the rotating field generates torque, causing the rotor to rotate. Without RMF, induction motors cannot start or run.

10. Explain construction, working and applications of single-phase induction motors.

Answer:

Construction:

- **Stator:** Single-phase winding on stator core.
- **Rotor:** Squirrel cage type (conducting bars shorted by end rings).
- **Auxiliary winding (starting):** Displaced 90° electrical, often with a capacitor or resistance.

Working:
Single-phase supply alone produces pulsating (not rotating) field → no starting torque. Starting mechanism (split-phase, capacitor) creates a phase shift → artificial rotating field → motor starts. After starting, main winding alone can sustain rotation.

Applications:
Fans, pumps, refrigerators, compressors, washing machines, small drills.

11. Compare split-phase, capacitor-start, permanent split capacitor and capacitor start–capacitor run motors.

Answer:

Feature	Split-phase	Capacitor-start	Permanent split capacitor (PSC)	Cap start–cap run
Starting torque	Low (1.5–2× FL)	High (3–4× FL)	Low to medium	High
Starting capacitor	No	Yes (electrolytic)	No (run cap only)	Yes + run cap
Run capacitor	No	No	Yes (always in circuit)	Yes
Switching device	Centrifugal switch	Centrifugal switch	No switch	Centrifugal switch for start cap
Efficiency	Low	Medium	High	Highest
Applications	Fans, blowers	Pumps, compressors	Fans, AC blowers	Heavy loads, refrigerators

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12. Explain torque–speed characteristics of various single-phase induction motors.

Answer:

- **Split-phase:** Low starting torque, torque increases slightly then drops near synchronous speed.
- **Capacitor-start:** High starting torque, torque decreases gradually after start, then drops near N_s.
- **Permanent split capacitor (PSC):** Low starting torque, smooth torque-speed curve, no dip.
- **Capacitor start–capacitor run:** High starting torque, high pull-out torque, flat characteristic at full load.

General shape: Torque zero at N_s, maximum at slip 15–25%, zero at standstill only for PSC (others have positive starting torque).

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13. Explain construction and working of BLDC motor with neat diagram.

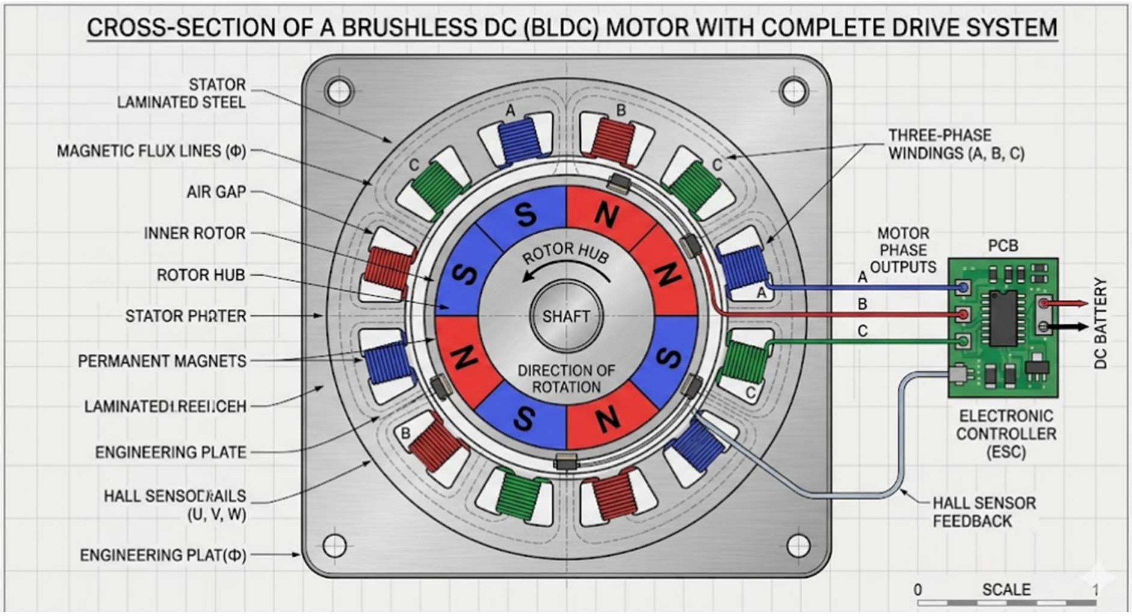
Answer:

Construction:

- **Stator:** Wound with three-phase coils (similar to induction motor stator).
- **Rotor:** Permanent magnets (usually Neodymium) mounted on rotor core.
- **Sensors:** Hall effect sensors (or encoder) to detect rotor position.
- **Electronic controller:** Switches DC supply to stator windings electronically.

Working:
Controller energizes stator windings in sequence based on rotor position feedback. Magnetic attraction between stator poles and rotor magnets produces smooth rotation. Electronic commutation replaces mechanical brushes.

Diagram:



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14. Compare BLDC motor and conventional DC motor.

Answer:

Feature	BLDC motor	Conventional DC motor
Commutation	Electronic (transistors)	Mechanical (brushes & commutator)
Brushes	No	Yes
Maintenance	Low (brushless)	High (brush wear)
Lifetime	Longer	Shorter
Efficiency	High (85–90%)	Moderate (75–85%)
Speed control	Complex (requires controller)	Simple (voltage control)
Cost	Higher	Lower
Noise	Low	Medium (brush noise)
Applications	EVs, drones, robotics	Toys, small tools, wipers

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15. Explain advantages of BLDC motors over induction motors.

Answer:

1. **Higher efficiency** – No rotor copper loss (permanent magnets).
2. **Better speed control** – Wide range with precise electronic control.
3. **High power density** – Smaller size for same power output.
4. **No slip** – Synchronous operation, exact speed control.
5. **Low maintenance** – No brushes, rugged construction.
6. **High start torque** – Available from zero speed.
7. **Smooth operation** – Low vibration and noise at all speeds.

Disadvantage: Higher cost and need for controller and position sensor.

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16. Explain applications of BLDC motor in Electric Vehicles.

Answer:

Applications in EVs:

- Main traction motor for propulsion in scooters, three-wheelers, and cars.
- Electric power steering (EPS).
- Cooling fans for battery pack and motor controller.
- Water pumps for coolant circulation.
- HVAC blowers (heating/ventilation).
- Electric window lifts and seat adjusters.

Why preferred in EVs:
High efficiency (extends battery range), high torque at low speed (good acceleration), regenerative braking possible, compact size, low noise, and maintenance-free operation.

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