Module 3: Electrical Machines (CO3)

3.1 Single Phase Transformer

A **transformer** is a static electrical machine that transfers electrical energy between two or more circuits through electromagnetic induction.

Construction

- **Core**:
  - Made of laminated sheets of silicon steel to minimize eddy current losses.
  - Serves as a path for the magnetic flux.
- **Windings**:
  - **Primary Winding**: Connected to the input (supply) side.
  - **Secondary Winding**: Connected to the output (load) side.
  - Insulated from each other and the core.

Principle of Working

- Operates on the principle of **mutual induction**:
  - Alternating current in the primary winding produces a time-varying magnetic flux.
  - This flux links the secondary winding, inducing an EMF (electromotive force) in it.
  - **EMF Equation**:

$$E = 4.44 \cdot f \cdot \phi_m \cdot N$$

    where:

    - E = EMF induced,
    - f = frequency,
    - ϕ_m = maximum flux,
    - N = number of turns in the winding.
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Losses in Transformer

1. **Core Losses**:
   - Hysteresis Loss: Due to magnetization and demagnetization.
   - Eddy Current Loss: Caused by induced currents in the core.
2. **Copper Losses**:
   - Caused by the resistance of windings (I2R(I^2R losses).

Equivalent Circuit

- **Ideal Transformer**: Assumes no losses and perfect magnetic coupling.
- **Practical Transformer**: Accounts for:
  - Resistance of windings (R_1, R_2).
  - Leakage reactance (X_1, X_2).
  - Core losses represented by a parallel resistance and reactance.

Voltage Regulation

- It is the change in secondary voltage when the load varies from no-load to full-load:

$$\text{Voltage Regulation (\%)} = \frac{V_{\text{no-load}} - V_{\text{full-load}}}{V_{\text{full-load}}} \times 100$$

Efficiency

$$\text{Efficiency (\%)} = \frac{\text{Output Power}}{\text{Input Power}} \times 100$$

Phasor Diagram

- Represents voltage and current in primary and secondary windings under different load conditions:
  - **No-load condition**: Magnetizing current dominates.
  - **Lagging load**: Current lags the voltage (e.g., inductive load).
  - **Leading load**: Current leads the voltage (e.g., capacitive load).
  - **Resistive load**: Voltage and current are in phase.

3.2 DC Motors

DC motors are electromechanical devices that convert electrical energy into mechanical energy.

Types and Construction

1. **Series Motor**:
   - Field winding connected in series with the armature.
   - High starting torque.
2. **Shunt Motor**:
   - Field winding connected parallel to the armature.
   - Nearly constant speed under varying loads.

3. **Compound Motor**:
    - Combination of series and shunt windings.
    - Provides good starting torque and stable speed.

Working Principle

- Based on **Lorentz Force**: When a current-carrying conductor is placed in a magnetic field, a force is exerted on the conductor, producing torque.

Torque-Speed Characteristics

- **Series Motor**: High torque at low speed; torque decreases as speed increases.
- **Shunt Motor**: Flat torque-speed curve; maintains constant speed.
- **Compound Motor**: Intermediate characteristics between series and shunt motors.

Selection Criteria

- Load type (constant or variable).
- Starting torque requirements.
- Speed regulation.

Applications

- **Series Motor**: Cranes, traction systems.
- **Shunt Motor**: Fans, blowers, lathes.
- **Compound Motor**: Elevators, rolling mills.

3.3 Single Phase Induction Motor

A **single-phase induction motor** is a self-starting AC motor that operates on single-phase supply.

Construction

1. **Stator**:
    - Laminated core with a single-phase winding.
2. **Rotor**:
    - **Squirrel Cage**: Simple, robust.
    - **Wound Rotor**: More complex, used in specific applications.

Working Principle

- Based on **electromagnetic induction**:
    - Alternating current in the stator winding creates a rotating magnetic field (RMF).
    - This RMF induces a current in the rotor, which interacts with the RMF to produce torque.

Double Field Revolving Theory

- A single-phase AC current creates two equal and opposite RMFs.
- The interaction between the rotor and these RMFs produces the resultant torque.

Types

1. **Split Phase Motor**:
   - Moderate starting torque.
   - Used in fans and blowers.
2. **Capacitor Start Motor**:
   - High starting torque.
   - Used in compressors and refrigerators.
3. **Shaded Pole Motor**:
   - Low torque, simple design.
   - Used in small appliances like table fans.

Applications

- Domestic appliances, fans, pumps, and compressors.

3.4 Three Phase Induction Motor

Three-phase induction motors are widely used in industrial applications for their efficiency and robustness.

Construction

1. **Stator**:
   - Laminated core with three-phase windings.
2. **Rotor**:
   - **Squirrel Cage**: Simplest and most common type.
   - **Wound Rotor**: Used in specific applications requiring controlled starting torque.

Working Principle

- **Generation of Rotating Magnetic Field (RMF)**:
  - Three-phase currents in the stator produce a magnetic field that rotates at synchronous speed.
  - The relative motion between the rotor and RMF induces a current in the rotor.
  - This induced current generates torque due to electromagnetic interaction.

Applications

- Pumps, compressors, conveyors, industrial machines.
