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Electromagnetic induction

1. Faraday's Law of Electromagnetic Induction:

Definition and Explanation:

Faraday's Law of Electromagnetic Induction states that a change in magnetic field within a closed loop induces an electromotive force (EMF) in the conductor encircling the magnetic field. This phenomenon is the basis for the generation of electric currents in generators and transformers.

Mathematical Expression:

The mathematical expression for Faraday's Law is given by:

$$\mathrm{EMF} = -\frac{d\Phi}{dt}$$

Where:

- EMF is the induced electromotive force,
- Φ is the magnetic flux,
- t is time.

Lenz's Law:

Lenz's Law states that the induced EMF will always work in a direction to oppose the change in magnetic flux that produced it. This is a consequence of the conservation of energy.

2. Magnetic Flux:

Definition:

Magnetic flux (Φ) is the measure of the quantity of magnetic field lines passing through a surface.

SI Unit and Dimension:

The SI unit of magnetic flux is the Weber (Wb), and its dimension is $[ML^2T^{-2}A^{-1}]$.

Calculation using $\Phi = B \cdot A \cdot \cos(\theta)$:

The magnetic flux can be calculated using the formula:

$$\Phi = B \cdot A \cdot \cos(\theta)$$

Where:

- B is the magnetic field strength,
- A is the area,
- θ is the angle between the magnetic field lines and the normal to the surface.

3. Motional Electromotive Force (EMF):

EMF Induced in a Straight Conductor Moving in a Magnetic Field:

When a straight conductor moves perpendicular to a magnetic field, an EMF is induced. The formula is:

$$\text{EMF} = B \cdot v \cdot L$$

Where:

- B is the magnetic field strength,
- v is the velocity of the conductor,
- L is the length of the conductor.

EMF Induced in a Rotating Coil:

For a rotating coil in a magnetic field, the EMF is given by:

$$\text{EMF} = B \cdot A \cdot \omega \cdot \cos(\theta)$$

Where:

- A is the area of the coil,
- ω is the angular velocity,
- θ is the angle between the normal to the coil and the magnetic field.

4. Eddy Currents:

Definition and Causes:

Eddy currents are circulating currents induced in a conductor due to a changing magnetic field. They result from electromagnetic induction and can occur in rotating or moving magnetic fields.

Applications and Drawbacks:

Applications include induction heating in cookware, metal detectors, and braking systems. Drawbacks involve energy losses and heating in conductive materials.

5. Power in AC Circuits:

Real Power, Reactive Power, and Apparent Power:

- Real power (P): Actual power consumed in the circuit, measured in watts (W).
- Reactive power (Q): Imaginary power, exchanged between the source and the circuit, measured in volt-amperes reactive (VAR).
- Apparent power (S): Total power in the circuit, measured in volt-amperes (VA).

Power Factor and its Significance:

Power factor (PF) is the ratio of real power to apparent power. A higher power factor indicates efficient power usage, reducing energy wastage.

6. LCR Circuits:

Series and Parallel Resonance:

In LCR circuits, resonance occurs when the inductive reactance (X_L) equals the capacitive reactance (X_C). In series resonance, the impedance is minimized, while in parallel resonance, the current is maximized.

Bandwidth and Sharpness of Resonance:

Bandwidth is the range of frequencies around the resonant frequency, and sharpness of resonance is quantified by the quality factor (Q), which is the ratio of resonance frequency to the bandwidth.

7. Transformers:

Construction and Working Principle:

Transformers consist of primary and secondary coils linked by a magnetic core. The working principle involves electromagnetic induction, where changing current in the primary coil induces a voltage in the secondary coil.

Turns Ratio and Voltage Ratio:

The turns ratio (N_1/N_2) determines the voltage ratio (V_1/V_2) between the primary and secondary coils.

Power Losses and Efficiency:

Power losses include core losses (eddy current and hysteresis) and copper losses. Efficiency is the ratio of output power to input power.

8. Three-Phase AC:

Generation and Advantages:

Three-phase AC is generated by power plants due to its efficiency and constant power delivery. Advantages include smaller conductors, higher efficiency, and smoother torque in motors.

Y and Δ Connections:

Three-phase systems can be connected in Y (star) or Δ (delta) configurations, affecting voltage and current relationships.

Power in Three-Phase Circuits:

The power in three-phase circuits is calculated using the formula:

$$P = \sqrt{3} \cdot V_{\text{line}} \cdot I_{\text{line}} \cdot \cos(\phi)$$

Where:

- V_{line} is the line voltage,
- I_{line} is the line current,
- ϕ is the power factor angle.

Alternating Current

1. Basics of Alternating Current (AC):

Definition and Explanation of AC:

- **Definition:** Alternating Current (AC) is an electric current that reverses direction periodically.
- **Explanation:** AC is the type of current used in most household and industrial applications. It's characterized by a sinusoidal waveform.

Representation of AC using Phasors:

- **Explanation:** Phasors are mathematical representations used to analyze AC circuits. A phasor is a complex number representing the amplitude and phase of an AC quantity.

2. AC Circuit Elements:

Resistance, Inductance, and Capacitance in AC Circuits:

- **Resistance:** In an AC circuit, resistance remains the same as in a DC circuit.
- **Inductance:** Inductive reactance (X_L) is given by $X_L = 2\pi fL$, where f is the frequency and L is the inductance.
- **Capacitance:** Capacitive reactance (X_C) is given by $X_C = 1/(2\pi fC)$, where f is the frequency and C is the capacitance.

Impedance and its Calculation:

- **Explanation:** Impedance (Z) is the total opposition that a circuit presents to the flow of alternating current. It is a complex quantity given by $Z = R + j(X_L - X_C)$, where R is resistance, X_L is inductive reactance, X_C is capacitive reactance, and j is the imaginary unit.

3. AC Voltage and Current:

Instantaneous, Average, and RMS Values of AC Voltage and Current:

- **Instantaneous Values:** $V(t) = V_m \sin(\omega t)$, where V_m is the maximum voltage and ω is the angular frequency.
- **Average Value:** The average value of a sinusoidal waveform over one complete cycle is zero.
- **RMS Value:** $V_{rms} = V_m / \sqrt{2}$.

Phase Difference between Voltage and Current:

- **Explanation:** The phase difference (ϕ) between voltage and current is crucial in AC circuits. It determines the behavior of the circuit, especially in terms of power.

4. AC Power:

Real Power, Reactive Power, and Apparent Power in AC Circuits:

- **Real Power (P):** Represents actual power consumed by the circuit.
- **Reactive Power (Q):** Represents the non-working power stored and returned to the source.
- **Apparent Power (S):** The vector sum of real and reactive power, given by $S = \sqrt{P^2 + Q^2}$.

Power Factor and its Significance:

- **Explanation:** Power factor (PF) is the cosine of the phase angle between voltage and current. It indicates the efficiency of power utilization in a circuit.

Power in Terms of Voltage and Current:

- **Formula:** $P = V_{rms} * I_{rms} * PF$.

5. Resonance:

Resonance in RLC Circuits:

- **Explanation:** Resonance occurs when the inductive reactance equals the capacitive reactance ($X_L = X_C$). This leads to a sharp increase in current and voltage amplitudes.

Bandwidth and Quality Factor:

- **Bandwidth (BW):** The range of frequencies over which the circuit can effectively operate.
- **Quality Factor (Q):** A measure of the selectivity of a resonant circuit, given by $Q = \omega_{res} / BW$.

6. Transformer:

Working Principle of a Transformer:

- **Explanation:** Transformers work on the principle of electromagnetic induction, transferring electrical energy between two or more coils through mutual induction.

Transformation Ratio and its Significance:

- **Formula:** Transformation ratio (N) = $V_2 / V_1 = N_2 / N_1$, where V is voltage and N is the number of turns.
- **Significance:** Determines the voltage transformation between the primary and secondary coils.

Efficiency and Losses in Transformers:

- **Efficiency (η):** The ratio of output power to input power, expressed as a percentage.
- **Losses:** Include core losses (hysteresis and eddy current losses) and copper losses.

7. AC Generator:

Construction and Working of an AC Generator:

- **Explanation:** AC generators convert mechanical energy into electrical energy through the process of electromagnetic induction.

EMF Generation in a Generator:

- **Explanation:** The induced electromotive force (EMF) in a generator is given by Faraday's law, $EMF = N * d\Phi/dt$, where N is the number of turns and Φ is the magnetic flux.

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