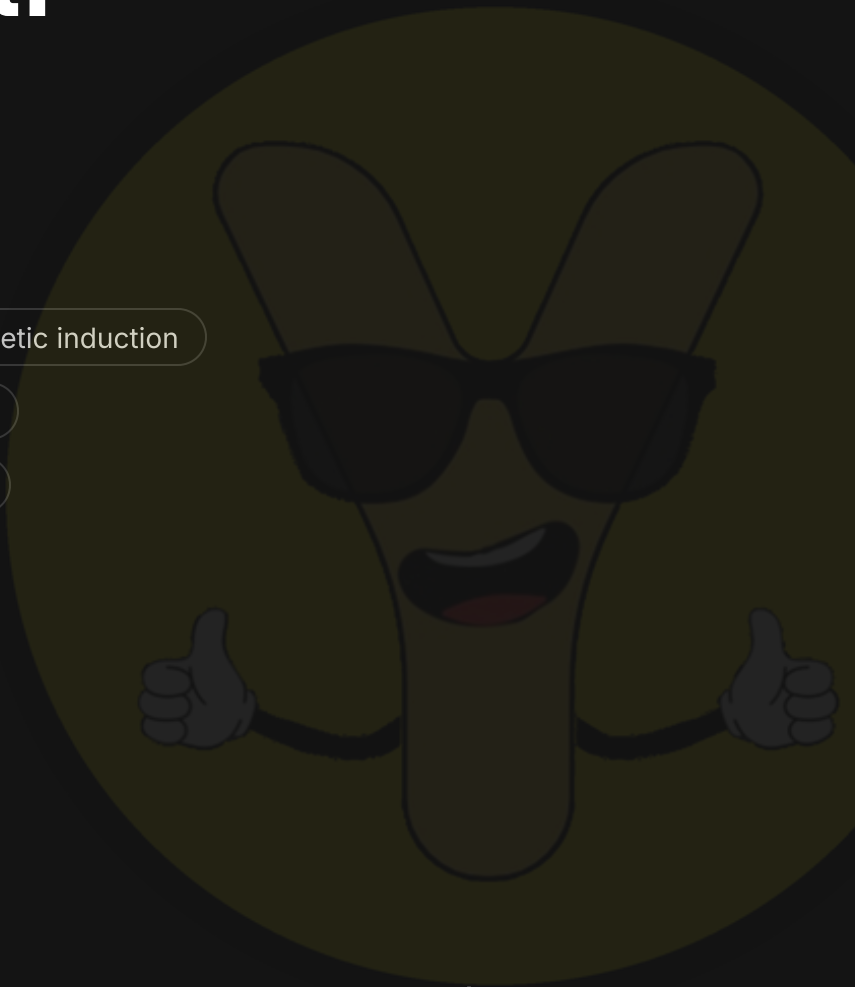
AKTU · 1ST YEAR · AEE101A / AEE201A

Fundamentals of Electrical Engineering

Unit 4 — Magnetic Circuits, Transformers

- Magnetic flux, flux density, MMF, reluctance
- Simple series magnetic circuit
- Faraday's law of electromagnetic induction
- Self-inductance and mutual inductance
- Principle of operation of single-phase transformer
- EMF equation
- Ideal transformer - voltage ratio, current ratio, turns ratio
- Basic equivalent circuit of single phase transformer
- Losses (core and copper)
- Efficiency



DECODED BY

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Founder, Ycotes · Gold Medalist in Artificial Intelligence, IIT Madras · taught 10,000+ students

Magnetic Circuit Fundamentals

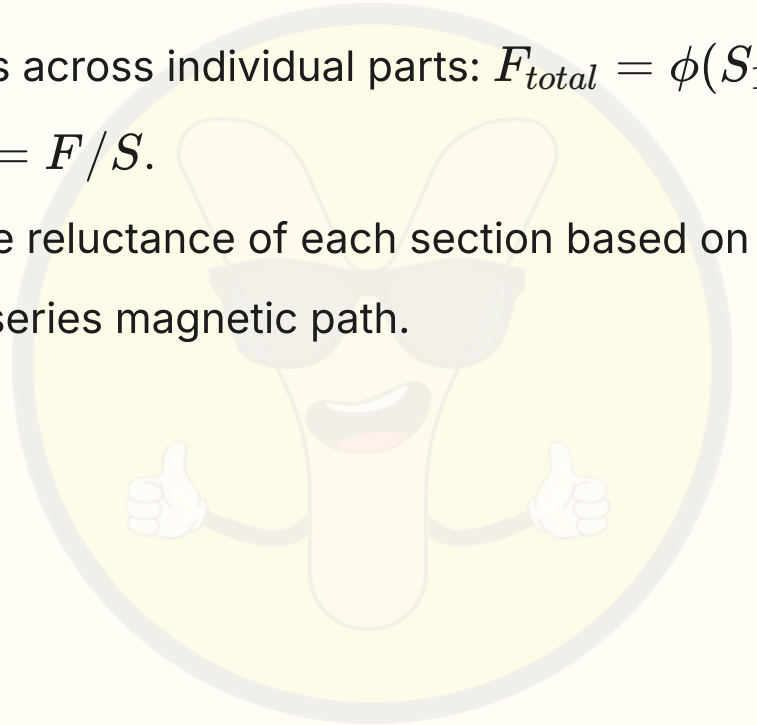
Basic parameters governing magnetic circuits are analogous to electric circuits.

- Magnetic Flux (ϕ): Total number of magnetic field lines passing through a surface, measured in Webers (Wb).
- Flux Density (B): Flux per unit area, $B = \phi / A$, measured in Tesla (T).
- Magnetomotive Force (MMF): The driving force for flux, $F = NI$, measured in Ampere-turns (AT).
- Reluctance (S): Opposition to flux, $S = l / (\mu A)$, analogous to resistance in electric circuits.

Simple Series Magnetic Circuit

A series magnetic circuit consists of components connected such that the same flux flows through each.

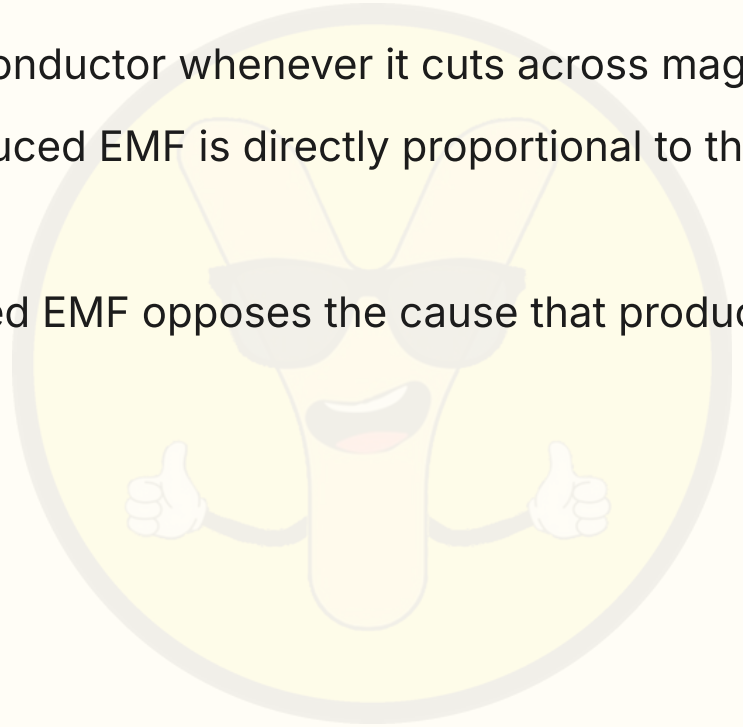
- Total MMF is the sum of MMF drops across individual parts: $F_{total} = \phi(S_1 + S_2 + ... + S_n)$.
- Ohm's law for magnetic circuits: $\phi = F/S$.
- Calculation involves determining the reluctance of each section based on length, area, and permeability.
- Total flux is constant throughout a series magnetic path.



Faraday’s Law of Electromagnetic Induction

The foundation of transformer and generator operation.

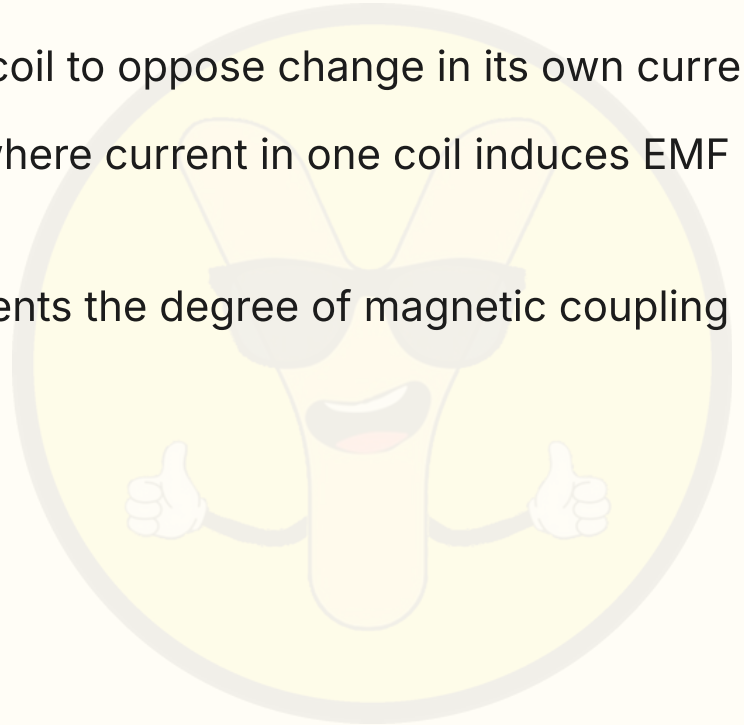
- First Law: An EMF is induced in a conductor whenever it cuts across magnetic flux.
- Second Law: The magnitude of induced EMF is directly proportional to the rate of change of flux linkage.
- Formula: $e = -N(d\phi/dt)$.
- Lenz's Law: The direction of induced EMF opposes the cause that produces it (negative sign).



Self and Mutual Inductance

Inductance describes the ability of a coil to store energy in a magnetic field.

- Self-Inductance (L): Property of a coil to oppose change in its own current. $L = N\phi/I$.
- Mutual Inductance (M): Property where current in one coil induces EMF in a neighboring coil. $M = k\sqrt{L_1 L_2}$.
- Coefficient of Coupling (k): Represents the degree of magnetic coupling between coils (0 to 1).



Transformer Principle

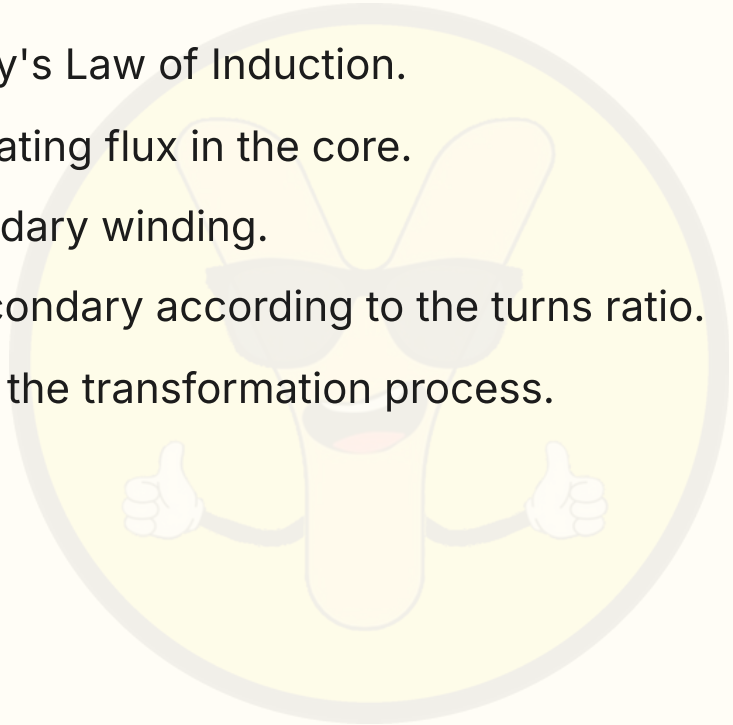


Energy transfer via mutual induction through a common magnetic core.

Single-Phase Transformer Operation

A static device that transfers electrical energy between two circuits via electromagnetic induction.

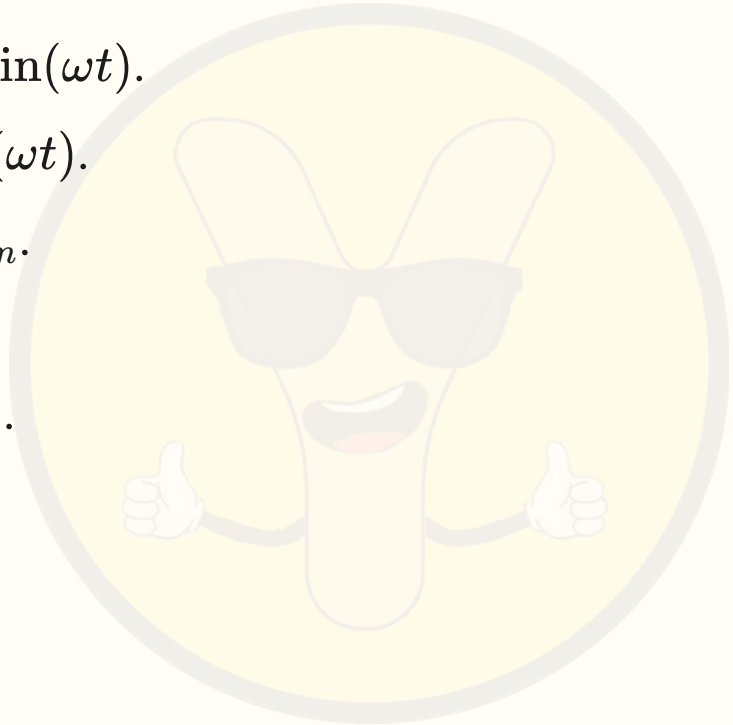
- Operates on the principle of Faraday's Law of Induction.
- AC supply to primary creates alternating flux in the core.
- Alternating flux links with the secondary winding.
- Induced EMF is produced in the secondary according to the turns ratio.
- Frequency remains constant during the transformation process.



EMF Equation of a Transformer

Derivation of the induced EMF in primary and secondary windings.

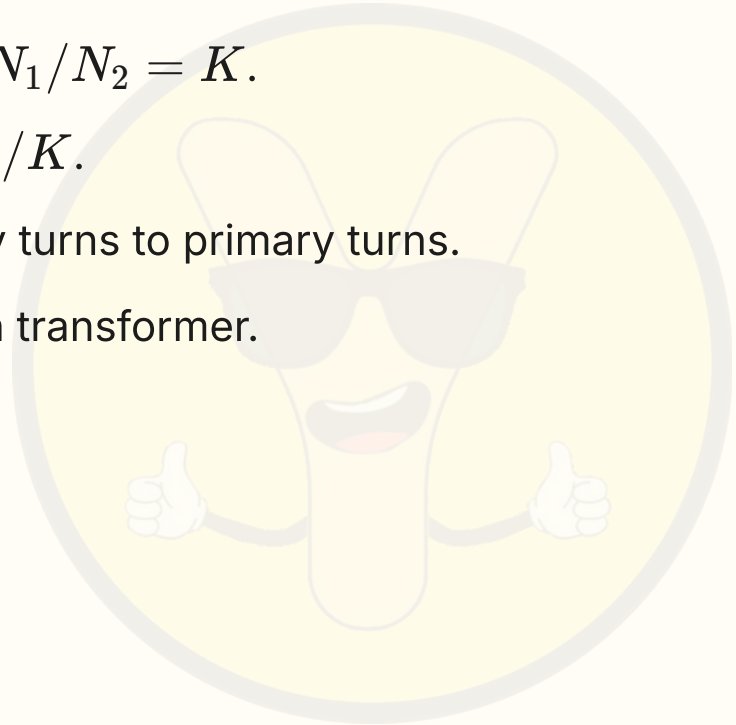
- Assuming sinusoidal flux: $\phi = \phi_m \sin(\omega t)$.
- Rate of change: $d\phi/dt = \omega \phi_m \cos(\omega t)$.
- RMS value of EMF: $E = 4.44 f N \phi_m$.
- Primary EMF: $E_1 = 4.44 f N_1 \phi_m$.
- Secondary EMF: $E_2 = 4.44 f N_2 \phi_m$.



Ideal Transformer Ratios

An ideal transformer has no losses and infinite permeability.

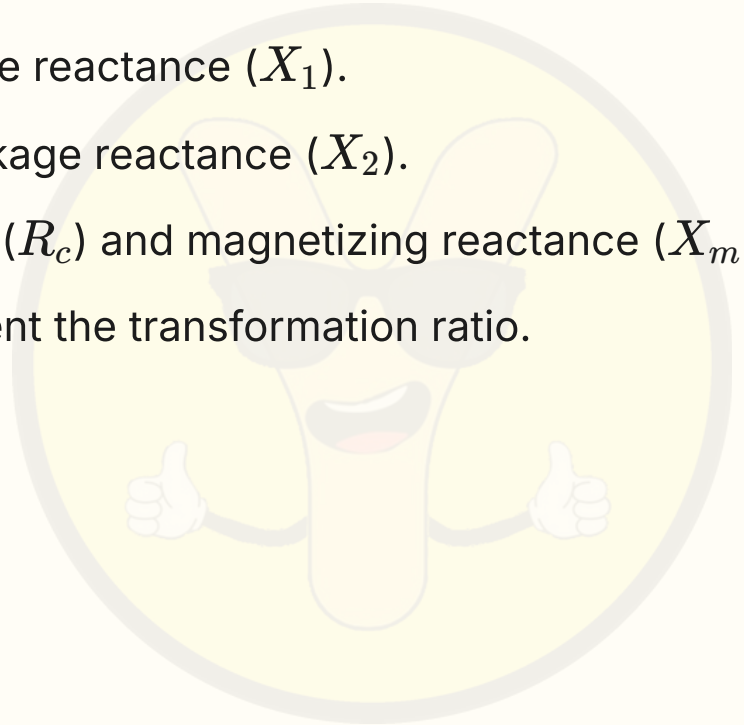
- Voltage Ratio: $V_1/V_2 = E_1/E_2 = N_1/N_2 = K$.
- Current Ratio: $I_1/I_2 = N_2/N_1 = 1/K$.
- Turns Ratio (K): Ratio of secondary turns to primary turns.
- K > 1 is Step-up, K < 1 is Step-down transformer.



Basic Equivalent Circuit

Modeling the transformer using lumped circuit parameters.

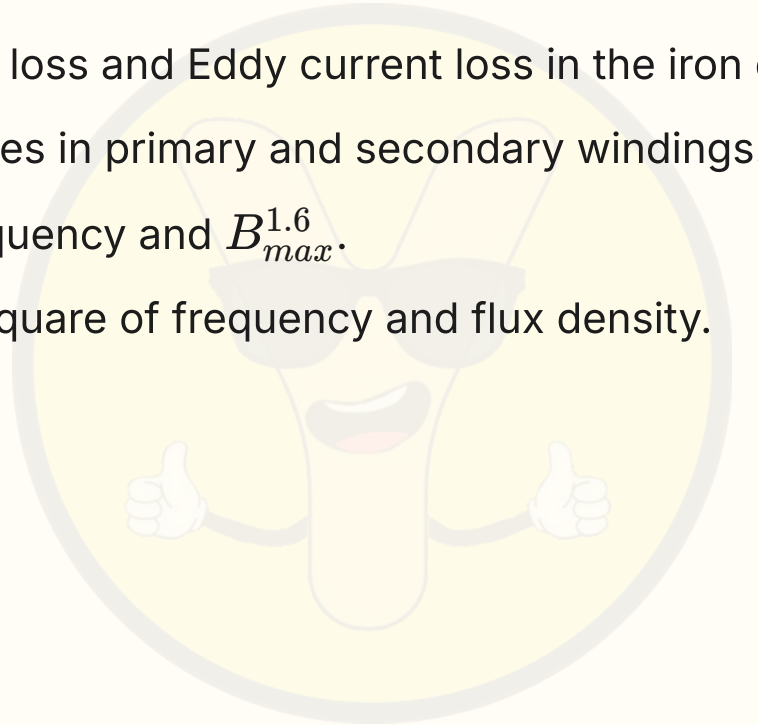
- Primary resistance (R_1) and leakage reactance (X_1).
- Secondary resistance (R_2) and leakage reactance (X_2).
- Core loss branch: Shunt resistance (R_c) and magnetizing reactance (X_m).
- Ideal transformer is used to represent the transformation ratio.



Transformer Losses

Energy dissipation within the transformer structure.

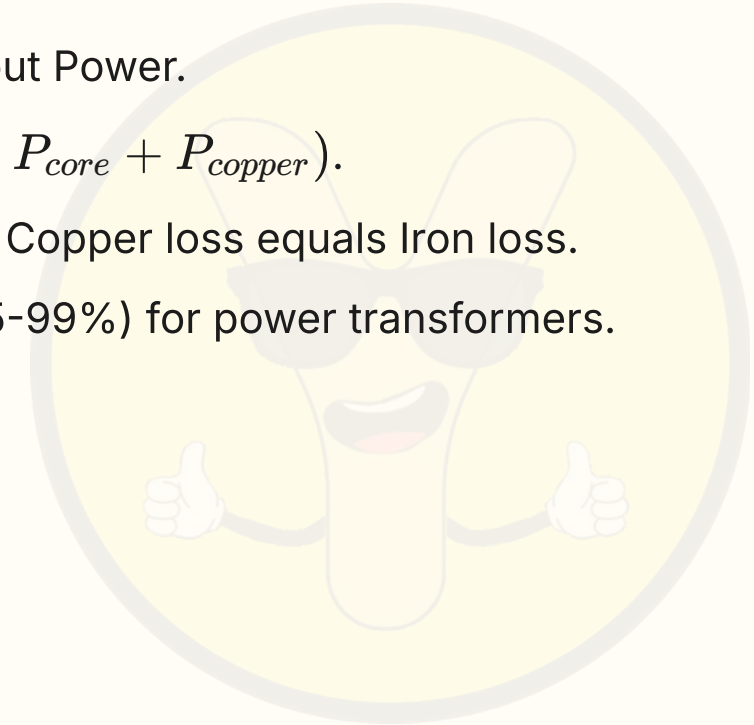
- Core Losses (Constant): Hysteresis loss and Eddy current loss in the iron core.
- Copper Losses (Variable): I^2R losses in primary and secondary windings.
- Hysteresis loss: Proportional to frequency and $B_{max}^{1.6}$.
- Eddy current loss: Proportional to square of frequency and flux density.



Efficiency of Transformer

Ratio of output power to input power.

- Efficiency (η) = Output Power / Input Power.
- $\eta = (V_2 I_2 \cos\phi_2)/(V_2 I_2 \cos\phi_2 + P_{core} + P_{copper})$.
- Condition for maximum efficiency: Copper loss equals Iron loss.
- Efficiency is typically very high (95-99%) for power transformers.

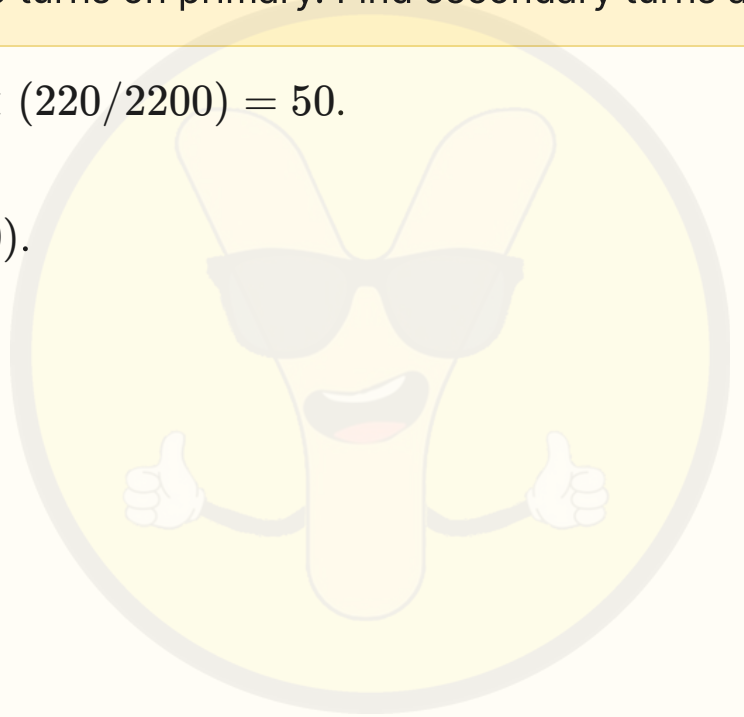


Transformer Calculation

A 2200/220V, 50Hz transformer has 500 turns on primary. Find secondary turns and max flux.

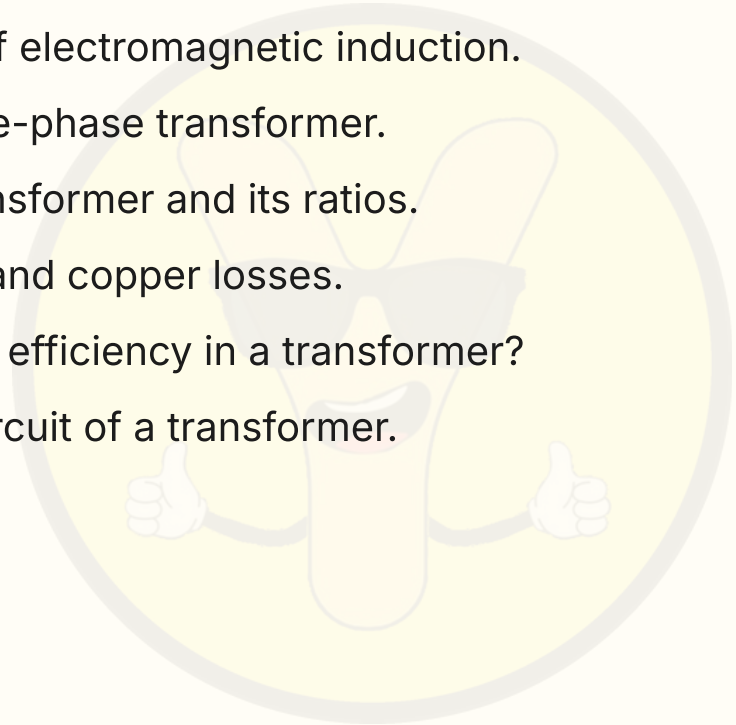
1. Use ratio: $N_2 = N_1 \times (V_2/V_1) = 500 \times (220/2200) = 50$.
2. Use EMF equation: $E_1 = 4.44 f N_1 \phi_m$.
3. Solve for $\phi_m = 2200/(4.44 \times 50 \times 500)$.

N2 = 50 turns, $\phi_m = 0.0198$ Wb.



Exam corner

- **Q1** Define MMF, Reluctance, and Flux Density with units.
- **Q2** State and explain Faraday's laws of electromagnetic induction.
- **Q3** Derive the EMF equation of a single-phase transformer.
- **Q4** Explain the concept of an ideal transformer and its ratios.
- **Q5** Differentiate between core losses and copper losses.
- **Q6** What is the condition for maximum efficiency in a transformer?
- **Q7** Draw and explain the equivalent circuit of a transformer.



Unit 4 done. You are exam-ready.

Revise the Exam corner once more, then open Unit 5 on theycotes.com. Every AKTU subject, unit by unit, free. Notes by Chirag Jain, Ycotes.

