**Electrical Engineering**

[redacted]

Electrical Machine

CHAPTER : Transformer

[redacted]

Lecture No.1

By- Varun Srivastava Sir


1. GATE Syllabus / ESE Syll.
2. Course Structure
3. Books and Authors
4. Transformer and it's use
5. Types of Transformers
6. Magnetic Circuit
7. Right Hand Curl Rule
8. Faraday's Law of EM Induction
9. Lenz's Law

## Topic : ~~ESE~~ GATE Syllabus - Transformer

- Single Phase Transformer
- Three Phase Transformer
  - Connections and Vector Groups
  - Parallel Operation
- Auto-Transformer

## Topic : ESE Syllabus - Transformer

- Single Phase Transformer
- Three Phase Transformer
  - Connections and Vector Groups
- Auto-Transformer
- Parallel Operation

## Topic : Course Structure - Transformer

LONG NOTES

- Introduction
- Ideal Transformer
- Impedance Transformation
- Practical Transformer
- Phasor Diagram and Numerical Session
- Testing of Transformers – I
- Per Unit System and Testing of Transformers – II
- Transformer Losses
- Voltage Regulation and Transformer's Efficiency
- Mixed Numerical Session

## Topic : Course Structure - Transformer

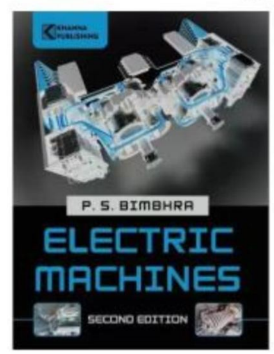
- Auto Transformer
- Auto and Multi winding Transformer
- Numerical on Auto Transformer
- Three Phase Transformer
- Three Phase Transformer Connections
- Numerical on Three Phase Transformer - I
- Numerical on Three Phase Transformer - II
- Open delta and Scott Connections
- Concept of harmonics in Transformers
- Numerical on Transformer Harmonics

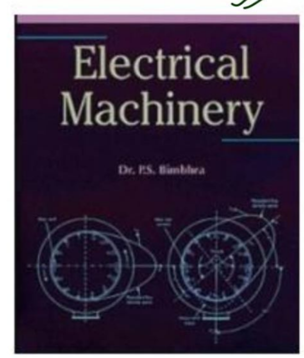
## Topic : Course Structure - Transformer

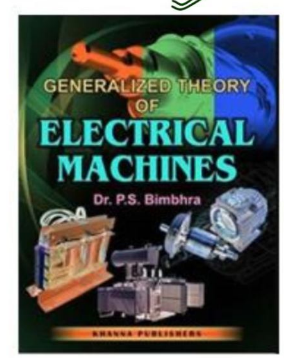
- Zig-Zag Connections
- Parallel Operation - I
- Parallel Operation – II
- Numerical on Parallel Operations
- Transformer as a Magnetically Coupled Circuit
- Concept of Magnetic Coupling
- Inrush of Magnetizing Current and Transformer's Construction
- Formula Revision

## Topic : Books and Authors – Electrical Machine

1. Electrical Machinery by Dr. P.S Bimbhra

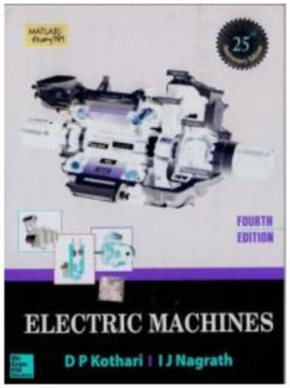


## Topic : Books and Authors – Electrical Machine

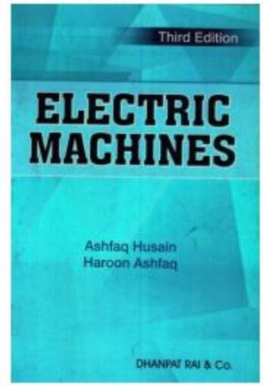
2. Electrical Machines by D P Kothari and I J Nagrath




@ Varun Sir P.W

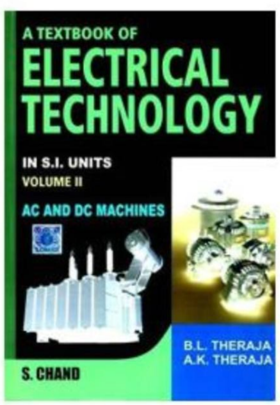
## Topic : Books and Authors – Electrical Machine

3. Electrical Machines by Ashfaq Husain



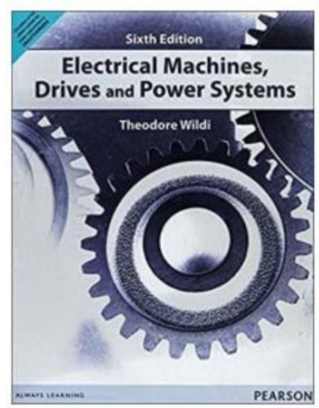

## Topic : Books and Authors – Electrical Machine

4. A Testbook of Electrical Technology Volume II by B. L Theraja

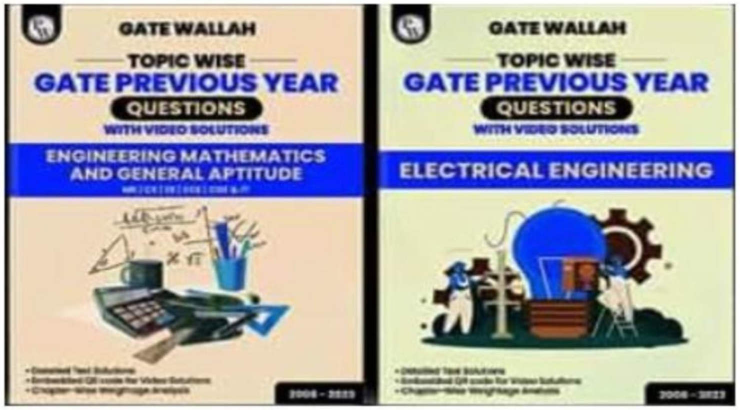



## Topic : Books and Authors – Electrical Machine

5. Electrical Machines, Drives and Power Systems by Theodore Wildi



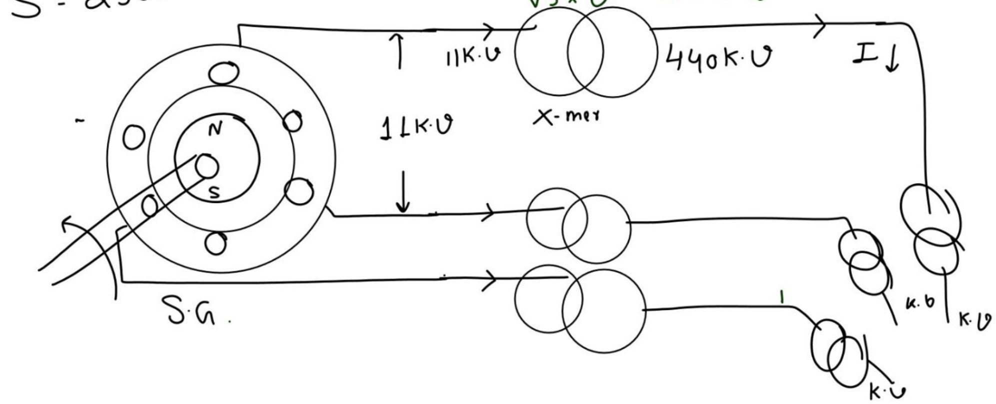
## PYQ BOOK



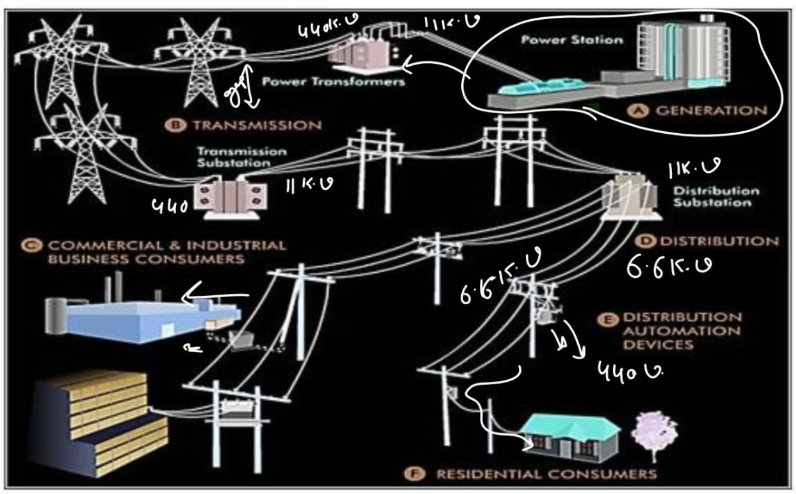

Transformer

$S = 250\,MVA$

$$I = \frac{S}{\sqrt{3} \times V} = \frac{250 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = 13.125\,kA$$




## Topic : Transformers




## Topic : Transformers

- Transformer is a static device that transfers electrical energy from one electrical circuit to another electrical circuit through magnetic field without change in frequency.

### Use of Transformer

- To step up or step down voltage levels.
- Imp In electronic control circuit, transformers are used for impedance matching so maximum power will transfer from source to load.
- For isolating d.c. while permitting the flow of a.c.
- In power electronics, transformers are used for gate pulse triggering.

## Topic : Types of Transformers

- Shell Type ✓
- Core Type ✓
- Single Phase Transformer ✓
- Three Phase Transformer ✓
- Auto Transformer ✓
- Scott Connection ✓
- High Frequency Transformer ✓

## Topic : Basics of Magnetic Circuit

**Permeability** ($\mu$)

- It is the ability of material to allow magnetic lines of force to pass through it. ( Ability of material to create internal magnetic field)

$$\boxed{\mu = \mu_0 \mu_r}$$

$\mu_r$ → Relative permeability

$\mu_0$ → permeability of free space $\underbrace{(4\pi \times 10^{-7}\ H/m)}$

### Magnetomotive Force(MMF)

- It is responsible for motion of magnetic flux.

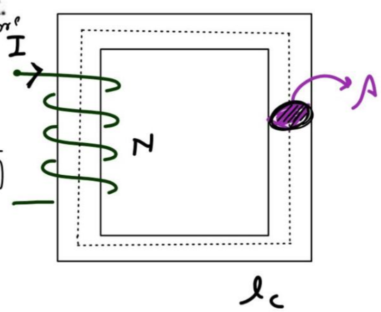
$$M.M.F = NI = H \times l$$

$N$ → no. of turns

$I$ → current through those turns

$H$ → magnetic field intensity

$l$ → mean core Length




### Magnetic Field Intensity

- It is defined as MMF per unit length.

$$\boxed{H = \frac{NI}{l}} = \left(\frac{m.m.f}{l}\right)$$

### Magnetic Flux and magnetic flux density

$$B = \mu \cdot H = \phi/A$$

(flux density) $B = \mu \cdot \left(\frac{NI}{l}\right) = [\phi/A]$

$$\phi = \mu \cdot A \cdot \frac{NI}{l} = \left[\frac{NI}{l/\mu A}\right] = \frac{M.M.F}{Reluctance}$$

$$Reluctance = \frac{l}{\mu A} = \left[\frac{l}{\mu_0 \mu_r A}\right]$$

**Reluctance**

- It defined as the opposition offered to magnetic flux by the magnetic circuit.

$$R_l = \frac{l}{\mu A} = \frac{l}{\mu_0 \mu_r A}$$

**(MCQ)**

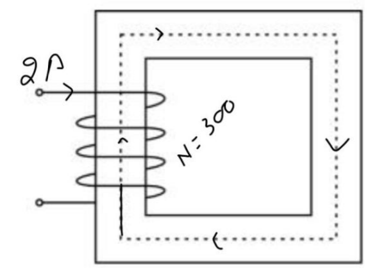
#Q. In the figure shown below the coil has 300 turns and carries a current of 2 A. The path of flux is shown by the dotted line. If mean length of the core is 50 cm, then the value of magnetic field intensity will be

**A** 1200 AT/m

**B** 600 AT/m

**C** 300 AT/m

**D** 900 AT/m

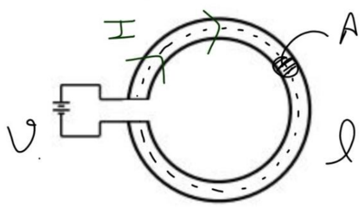



$$H = \frac{M.M.F}{l} = 300\times 2/50\times10^{-2} = 1200\,AT$$

$l_c = 50\,cm$

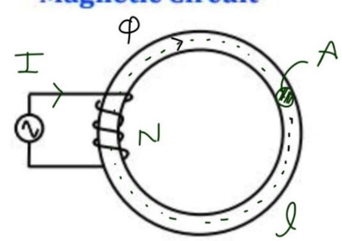
## Comparison - Electric and Magnetic Circuit

**Electric Circuit**




- Closed path for the electric current is called electric circuit.

**Magnetic Circuit**

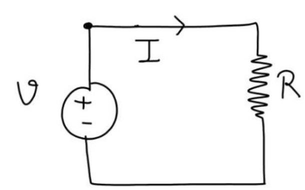



- Closed path for the magnetic flux is called magnetic circuit.

## Topic : Comparison - Electric and Magnetic Circuit

**Electric Circuit**

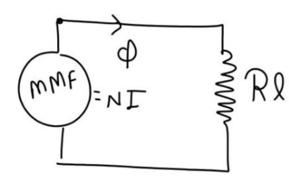
- Driving Force is EMF = V Volts




$$I = \frac{\text{driving force}}{\text{Resistance}} = \frac{V}{R}$$

**Magnetic Circuit**

- Driving Force is MMF = NI ATs )




$$\phi = \frac{\text{driving force}}{\text{Reluctance}} = \frac{NI}{\text{Reluctance}}$$

$R = \rho\, l/A$

- Electric field intensity

$$\boxed{E = \frac{V}{l}}$$

$$E = \frac{I \cdot R}{l} = \frac{I}{\cancel{l}} \cdot \rho \frac{\cancel{l}}{A}$$

$$E = \frac{I}{A} \cdot \rho = J \cdot \rho$$

(current density) $J = \frac{1}{\rho} \cdot E = \sigma E$

$$Rl = \left[\frac{l}{\mu \cdot A}\right]$$

- Magnetic field intensity

$$H = \frac{M.M.F}{l} = \frac{NI}{l} = \frac{\phi \times Rl}{l}$$

$$H = \frac{\phi}{\cancel{l}} \times \frac{\cancel{l}}{\mu \times A} = \frac{\phi}{A} \times \frac{1}{\mu}$$

$$\boxed{B = \mu H} = \mu_0 \mu_r \cdot H$$

**(MCQ)**

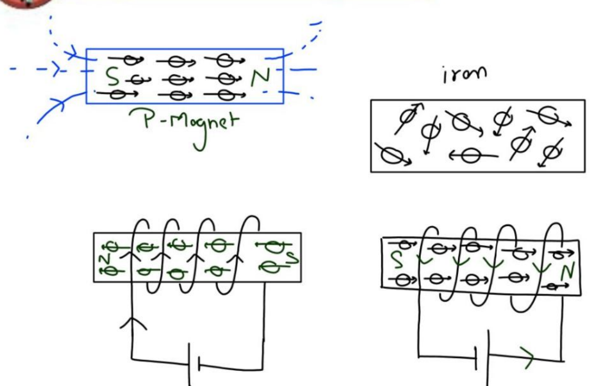
#Q. Match List-I with List-II and select the correct answer using the code given below the lists: **[ESE-2012]**

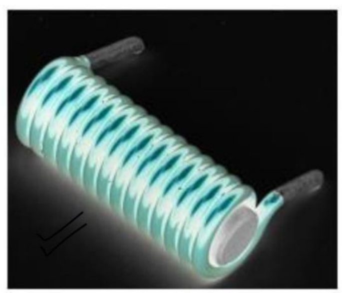
| List-I | List-I |
|---|---|
| 2 → A. Magnetic flux | 1. Resistance |
| 4 → B. Magneto motive force | 2. Electric current |
| 1 - C. Reluctance | 3. Conductivity |
| 3 - D. Permeability | 4. Electromotive force |

**Codes:**

| | A | B | C | D |
|---|---|---|---|---|
| **A** | 2 | 1 | 4 | 3 |
| **B** | 3 | 1 | 4 | 2 |
| **C** | 2 | 4 | 1 | 3 |
| **D** | 3 | 4 | 1 | 2 |

## Topic : Electromagnet

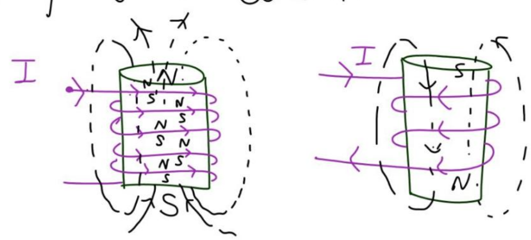


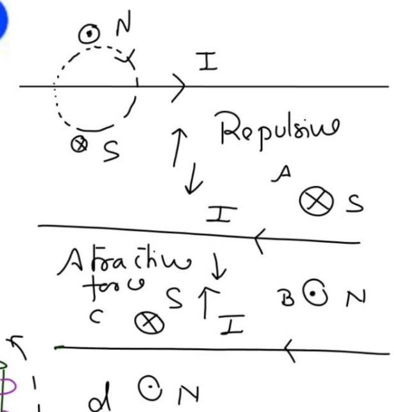



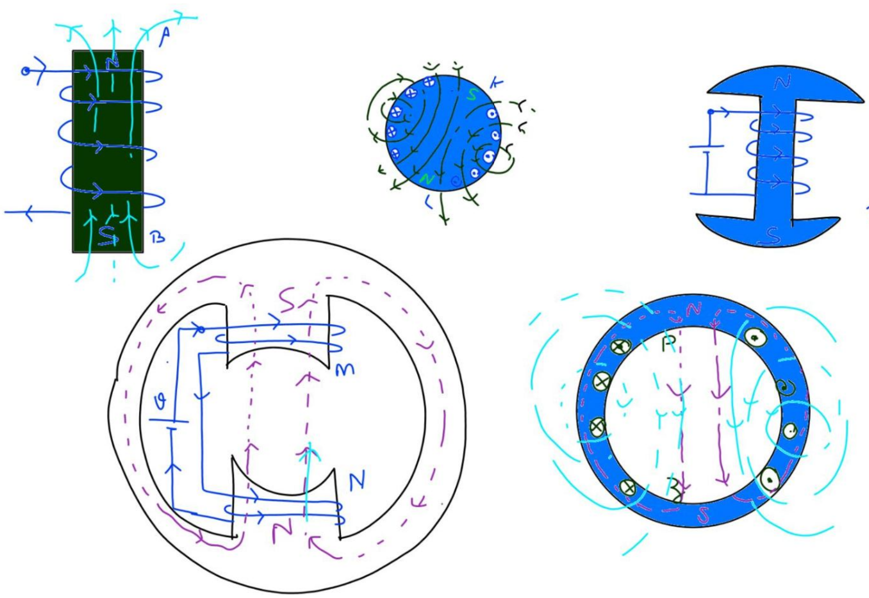
## Topic : Right Hand Curl Rule

Thumb      R-H curl

1) Current → magnetic field
2) magnetic field ← current



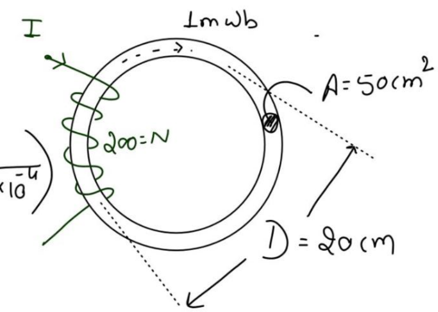



# (NAT)

#Q. A mild steel has mean diameter of 20 cm cross sectional area of 50 cm$^2$. For a relative permeability of 800, calculate

(a) Reluctance of the ring

(b) Current required in 200-turns coil to produce a flux of 1 mWb in the ring.




- $l$ = mean length of Core $= 2\pi R = \pi D$
- $R_l = \dfrac{l}{\mu A} = \left(\dfrac{\pi \times 20 \times 10^{-2}}{4\pi \times 10^{-7} \times 800 \times 50 \times 10^{-4}}\right)$

$R_l = 125000$

$1\,mWb = 10^{-3}\,Wb$

$$\phi = \frac{M.M.F}{R_l} = \frac{NI}{R_l}$$

$$I = \frac{1 \times 10^{-3} \times 125000}{200} = 0.625A$$

# (MCQ) H.W

#Q. A magnetic circuit has 150 turns-coil, the cross sectional area $5 \times 10^{-4}$ m$^2$ and the length of the magnetic circuit $25 \times 10^{-2}$ m. What are the values of magnetic field intensity and relative permeability when the current is 2 A and total flux is $0.3 \times 10^{-3}$ Wb ? **[ESE-2015]**

**A** 1200 AT/m and 397.9

**B** 300 AT/m and $500 \times 10^{-6}$

**C** 300 AT/m and 397.9

**D** 1200 AT/m and $500 \times 10^{-6}$

**(MCQ)** H.W

#Q. A coil of 1000 turns is wound on a core. A current of 1 A flowing through the coil creates a core flux of 1 mWb. What is the energy stored in the magnetic field? **[ESE-2005]**

A. $\frac{1}{4}$ J

B. $\frac{1}{2}$ J

C. 1 J

D. 2 J

## 2 Minutes Summary

1. GATE Syllabus / ESE Syll.
2. Course Structure
3. Books and Authors
4. Transformer and it's use
5. Types of Transformers
6. Magnetic Circuit
7. Right Hand Curl Rule
8. Faraday's Law of EM Induction
9. Lenz's Law

# Thank you GW Soldiers!

# Electrical Engineering

## Electrical Machine

**CHAPTER : Transformer**

[redacted]

**Lecture No.2**

By- Varun Srivastava Sir

T→ @ Varun Sir PW


1. GATE Syllabus
2. Course Structure
3. Books and Authors
4. Transformer and it's use
5. Types of Transformers
6. Magnetic Circuit
7. Right Hand Curl Rule


1. Faraday's Law of EM Induction
2. Lenz's Law
3. Ideal Transformer
4. Impedance Transformation

## Topic : Faraday's Law of Electromagnetic Induction

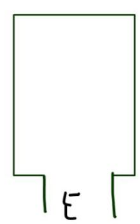
- It states that an emf is induced in coil when the magnetic flux linking the coil changes with time.

Or

- If the flux linking a coil varies as a function of time, a voltage is induced across the terminals of that coil and expressed as

$$\boxed{E = \pm N\frac{d\phi}{dt}}$$

→ LENZ-LAW

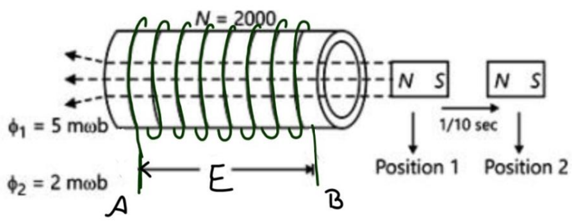


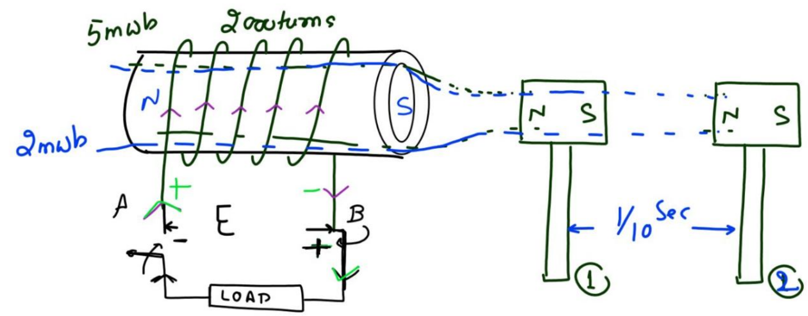

## Topic : Lenz's Law

- It states that the polarity of induced emf is such that, if it allow to cause a current, then current so produced must oppose the cause.

**(NAT)**

#Q. A coil having 2000 tums surrounds a flux of 5 mwb produced by a permanent magnet (shown in figure). The magnet is suddenly withdrawn causing the flux inside the coil uniformly drops to 2 mWb in 1/10 of a second. What is the induced voltage ?



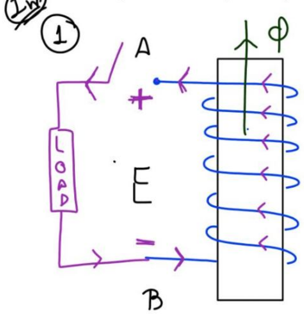

$$E = \pm N\frac{d\phi}{dt} = \pm 2000 \times \left|\frac{(5-2)\times 10^{-3}}{1/10}\right| = \pm 60 \text{ volts}$$

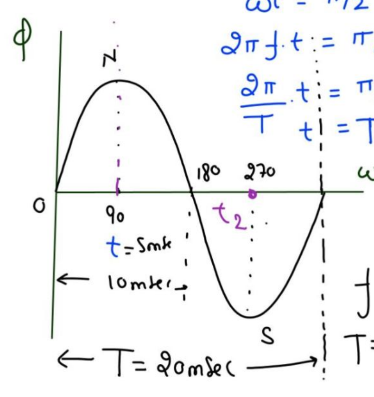
When B → +ive & A → -ive
$E = +60$ volts

A → +ive & B = -ive
$E = -60$ volts

Consider an ideal core on which winding is wound as shown for instantenous flux, mark polarity across terminal AB in following figures.

(Imp) 1




$\omega t = \pi/2$

$2\pi f \cdot t = \pi/2$

$\frac{2\pi}{T} \cdot t = \pi/2$

$t = T/4 = \frac{20}{4}$

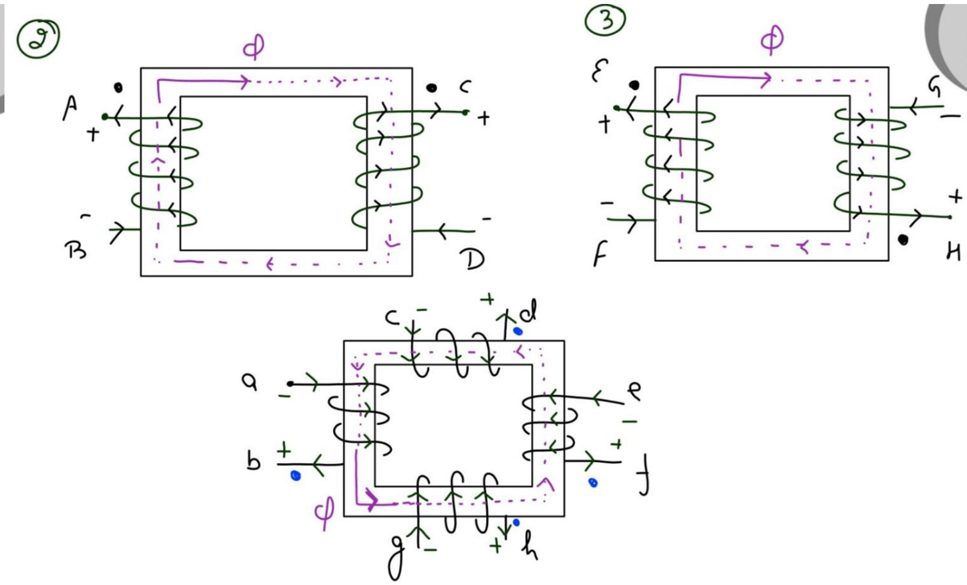
$= 5$ msec

$f = 50$ Hz

$T = \frac{1}{f} = 20$ msec.

2

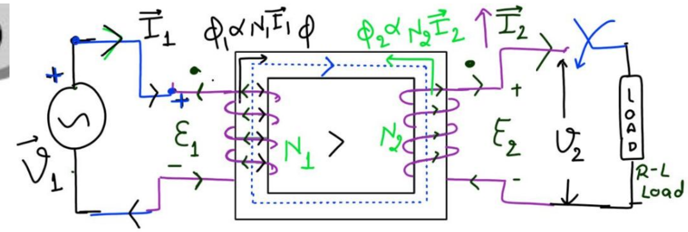
3

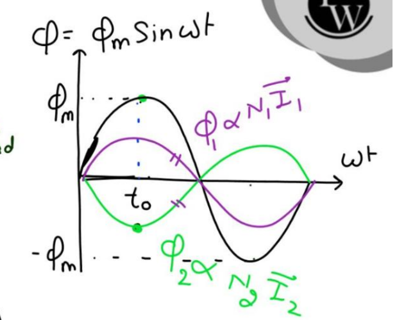


## Topic : Ideal Transformer

- No losses (i.e. All wire are loss-less and core is lossles).
- No leakage flux (All the flux is mutual).
- Infinite permeability ($\mu = \infty$). i.e. [flux established in core without any magnetizing current].

Slide 8




Let $\phi = \phi_m \sin \omega t$.

$$E_2 = +N_2 \frac{d\phi}{dt} = +N_2 \frac{d}{dt}(\phi_m \sin \omega t)$$

(1)

$$E_2 = N_2 \phi_m \omega \cos \omega t = N_2 \phi_m \omega \sin(\omega t + 90) = E_{m_2} \sin(\omega t + 90)$$

(2)

$$E_1 = +N_1 \frac{d\phi}{dt} = +N_1 \frac{d}{dt} \phi_m \sin \omega t = N_1 \phi_m \omega \cos \omega t$$

$$\boxed{E_1 = N_1 \phi_m \omega \sin(\omega t + 90)}$$

- $E_{1(r.m.s)} = \dfrac{N_1 \phi_m \omega}{\sqrt{2}} = \dfrac{N_1 \phi_m (2\pi f)}{\sqrt{2}} = \sqrt{2}\pi f \phi_m N_1$
- $E_{2(r.m.s)} = \dfrac{N_2 \phi_m \omega}{\sqrt{2}} = \sqrt{2}\pi f \phi_m N_2 = 4.44 f \phi_m N_2$.
- $\boxed{\dfrac{E_1}{E_2} = \dfrac{N_1}{N_2} = a = \text{turn ratio}}$

(3)

E.M.F equation

$$\boxed{E = \sqrt{2}\pi f \phi_m N}$$

$$\frac{E}{N} = \sqrt{2}\pi f \phi_m$$

$\dfrac{E}{N} \propto \phi_m$ [e.m.f per turn].

For Common flux e.m.f per turn must be same.

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} \Rightarrow \left(\frac{E_1}{E_2}\right) = \left(\frac{N_1}{N_2}\right)$$

## Topic : MMF Balance

$N_1 \vec{I}_1 = N_2 \vec{I}_2$

$\vec{I}_1 = \frac{N_2}{N_1} \vec{I}_2$

$\boxed{\frac{\vec{I}_1}{\vec{I}_2} = \frac{N_2}{N_1}}$

[NOTE :- Transformer can only operates in magnetic subtractive polarity]

Slide 10

4

For ideal x-mer

$$\boxed{\frac{V_1}{V_2} = \frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = a}$$

$$K = \text{transformation ratio} = \frac{N_2}{N_1}$$

## Topic : Time Phasor Diagram

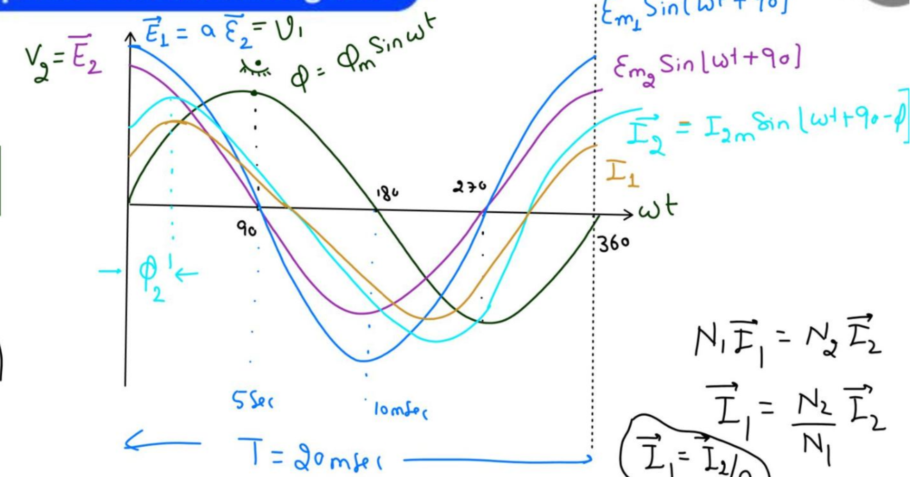
$\frac{\vec{E}_1}{N_1} = \frac{\vec{E}_2}{N_2}$

$\boxed{\vec{E}_1 = a\vec{E}_2}$

$N_1 > N_2$

$a > 1$

$|E_1| > |E_2|$

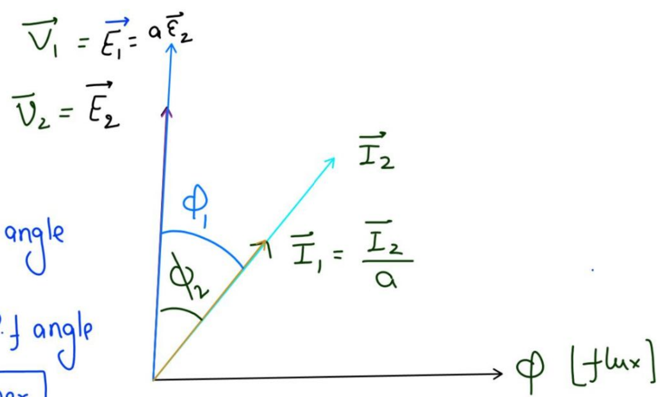



$N_1 \vec{I}_1 = N_2 \vec{I}_2$

$\vec{I}_1 = \frac{N_2}{N_1} \vec{I}_2$

$\vec{I}_1 = \vec{I}_2 / a$

Slide 11




$\phi_2$ = Load P.f angle

$\phi_1$ = Source P.f angle

For ideal x-mer

$\cos\phi_1$ = Source P.f = $\cos\phi_2$ = Load P.f

**(MCQ)**

#Q. When a single-phase two winding transformer is supplied by 50 Hz sinusoidal voltage source, a flux of peak value 9 mWb gets set up in the core. The valued of induced emf per turn in transformer's winding is

**A** 2 Volts/turn

**B** 1 Volts/turn

**C** 4 Volts/turn

**D** 6 Volts/turn

(peak flux)

$E = \sqrt{2}\pi f \cdot \phi_m \cdot N$

$\frac{E}{N} = 4.44 \times 50 \times 9 \times 10^{-3}$

e.m.f per turn $= \frac{E}{N} = 2$ volts

Slide 17

**(MCQ)**

#Q. An ideal transformer has $N_1 = 100$ turns $N_2 = 200$ turns with a mutual flux of $\phi_m(t) = 0.05(t^2 - 2t)$. The induced emf of secondary in volts is

**A** $-5(t-1)$

**B** $-10(t-1)$

**C** $-5(t^2-1)$

**D** $20(t-1)$

$$E_2 = \pm N_2 \cdot \frac{d\phi}{dt} = \pm 200 \times \frac{d}{dt}\left[0.05(t^2 - 2t)\right]$$

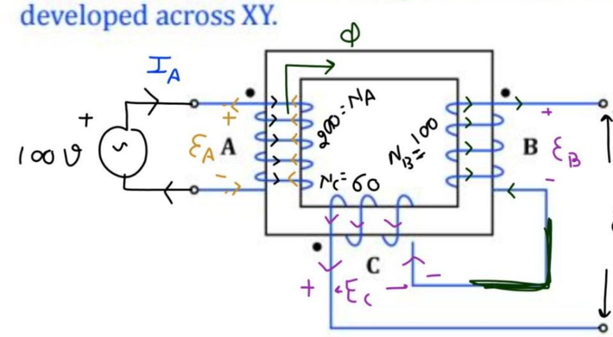
$$= \pm 200 \times 0.05\left[2t-2\right]$$

$$= \pm 10\left[2t-2\right]$$

$$= \pm 20(t-1)$$

**(NAT)**

#Q. A, B and C are 3 windings of a transformer having 200, 100 and 60 turns respectively. A voltage of 100 volts is applied across A. Find the voltage developed across XY.




$$\varepsilon_{xy} = \varepsilon_B - \varepsilon_C = 20 \text{ volts}$$

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For common flux e.m.f per turn must be same.

$$\frac{E_A}{N_A} = \frac{\varepsilon_B}{N_B} = \frac{\varepsilon_C}{N_C}$$

- $\varepsilon_B = \frac{N_B}{N_A} \cdot \varepsilon_A = \frac{100}{200} \times 100 = 50$ volts.
- $\varepsilon_C = \frac{N_C}{N_A} \cdot \varepsilon_A = \frac{60}{200} \times 100 = 30$ volts.

$$\varepsilon_{xy} = 50 - 30 = 20 \text{ volts}$$