EE221

Transformers

Tutorial

OBJECTIVES

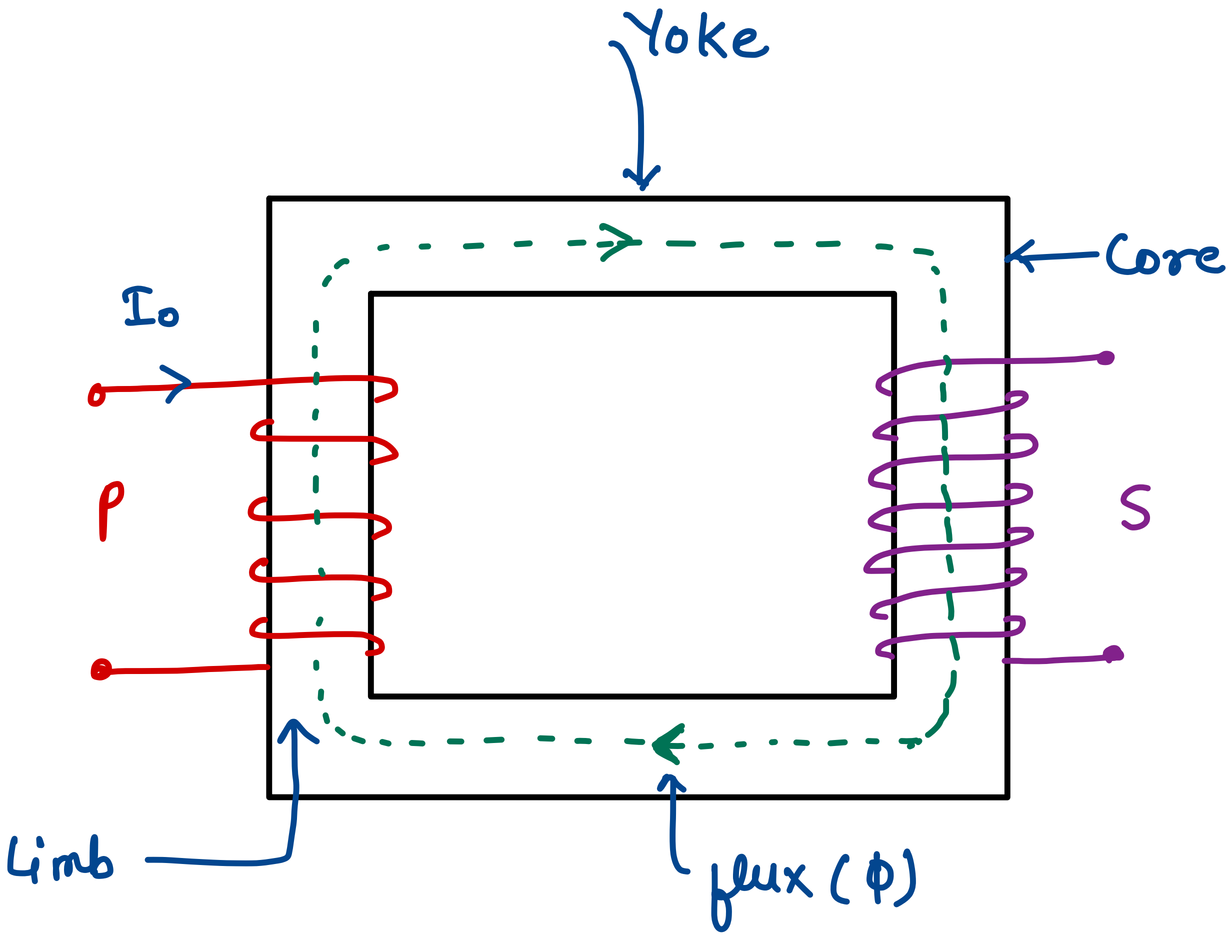
- Basic use of transformer (T/F)
- Types and Construction
- Ideal T/F
- Voltage and current ratio
- Dot Convention
- Equivalent Circuit of T/F
- Determining components values
- PU system
- Voltage Regulation

- Auto - T/F
- Advantages of Auto-T/F
- Three-phase T/F

Transformers

A transformer is a device that changes **ac electric power at one frequency and voltage level** to **ac electric power at the same frequency and another voltage level** through the action of a **magnetic field.**

It consists of two or more coils of wire wrapped around a common ferromagnetic core. These coils are (usually) not directly connected. **The only connection between the coils is the common magnetic flux present within the core.**



Applications

→ used to **step-up generator voltage** to an appropriate voltage level for **power transfer.**

→ **stepping down the transmission voltage** at various levels for **distribution and power utilization.**

Why T/F are used ??

In a modem power system, electric power is generated at voltages of 12 to 25 kV. Transformers step up the voltage to between 1 10 kV and nearly 1000 kV for transmission over long distances at very low losses. Transformers then step down the voltage to the 12- to 34.5-kV range for local distribution and finally permit the power to be used safely in homes, offices, and factories at voltages as low as 120 V.

$$P = VI$$

If V generated = low

& P demand = high

$\therefore$ $I \longrightarrow$ high

* losses = I^2R

    I high $\Longrightarrow$ losses high

* V drop = IR

    I high $\Rightarrow$ V drop high

Transformer Classifications

1. Number of windings

- → Conventional T/F : two windings
- → Auto-T/F : one winding
- → Others : more than two wndgs.

2. Number of phases :

- → Single-phase T/F
- → Three-phase T/F

T/F classifications contd...

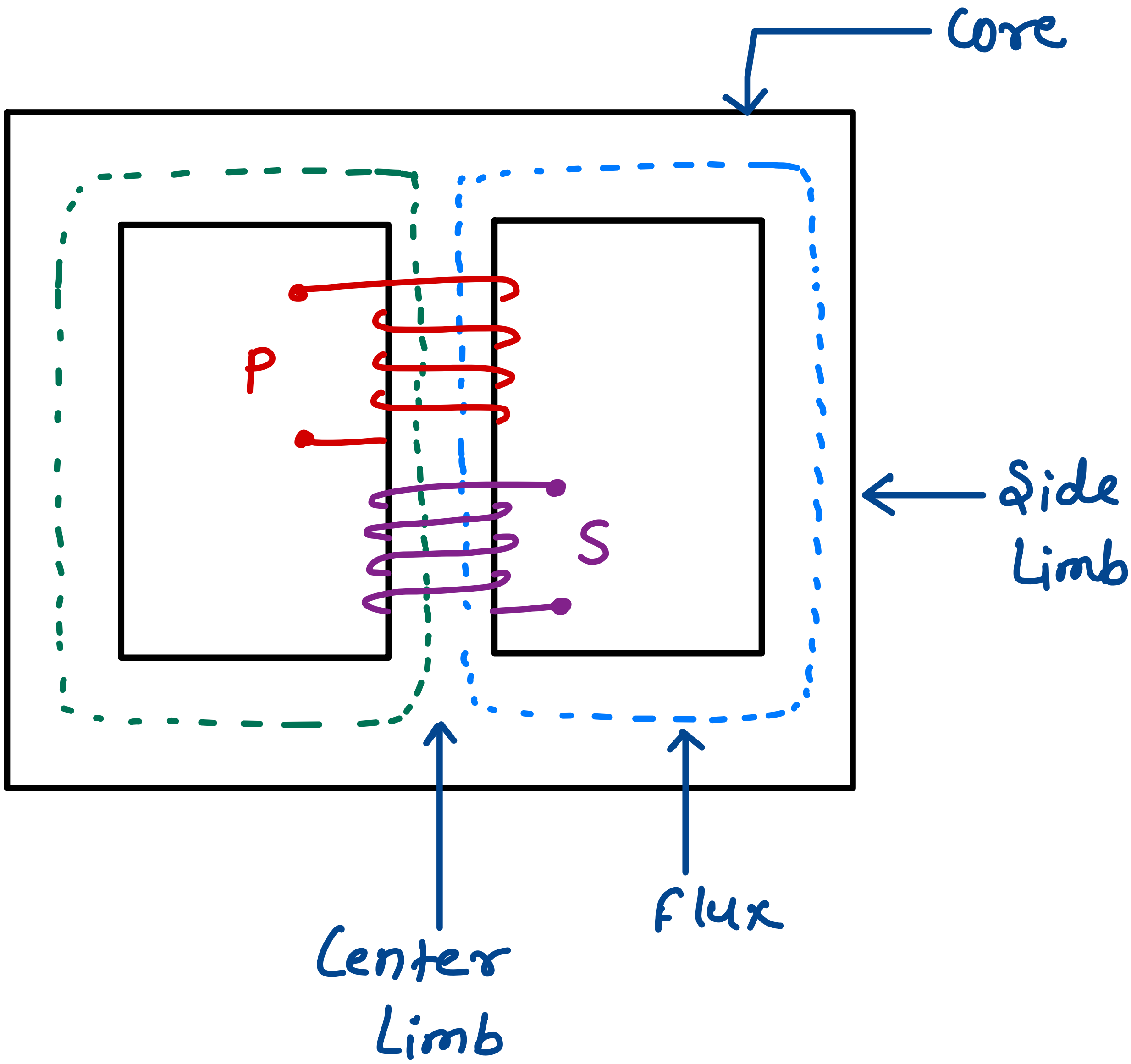
3. Voltage level at which wndg is operated :

- step-up T/F : primary wndg is a low voltage (LV) wndg.
- step-down T/F : primary wndg is a high voltage (HV) wndg.

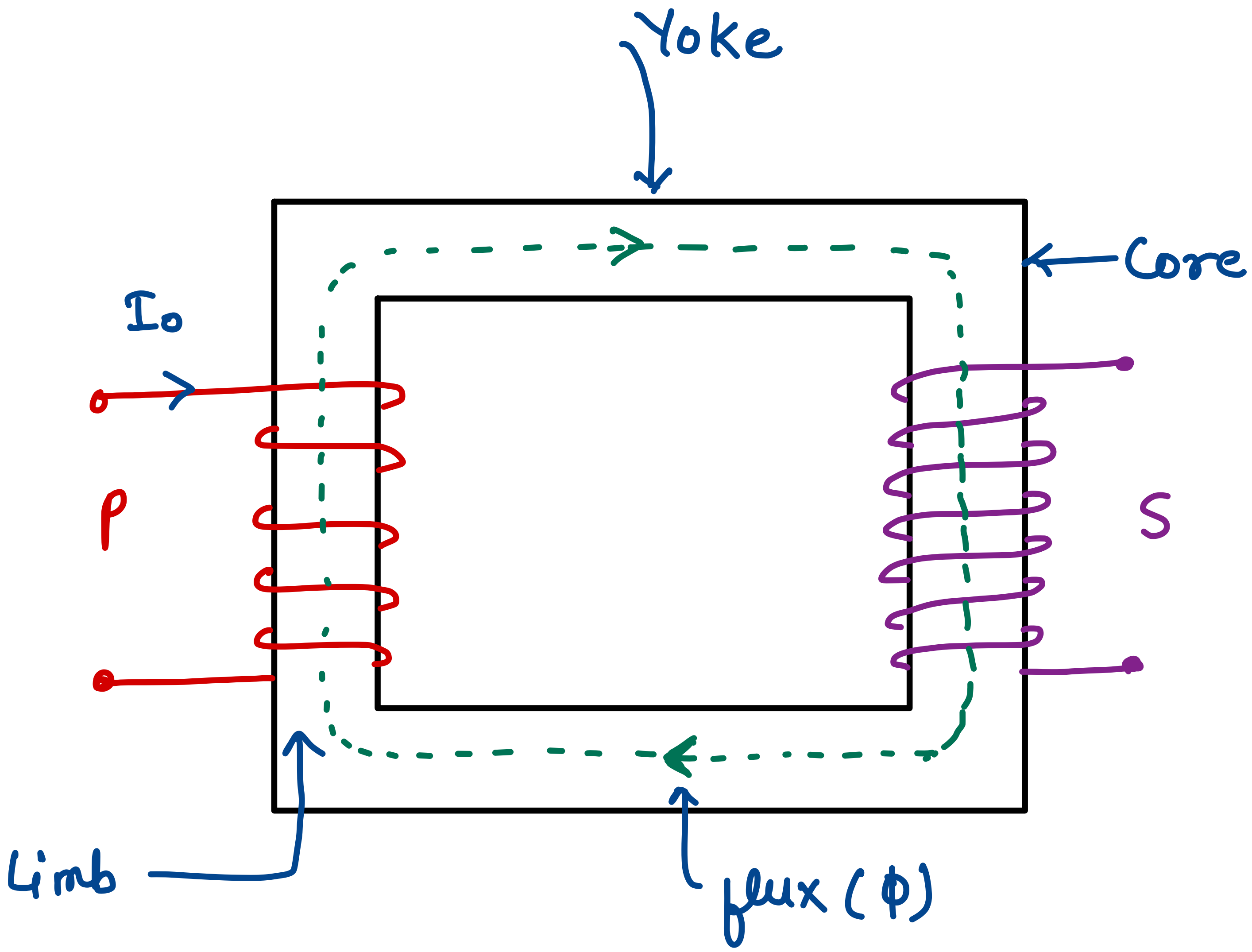
4. Construction :

- Core type T/F
- Shell type T/F

Constructional Details



Shell Type T/F : wndgs are wrapped around the center leg of a laminated core.

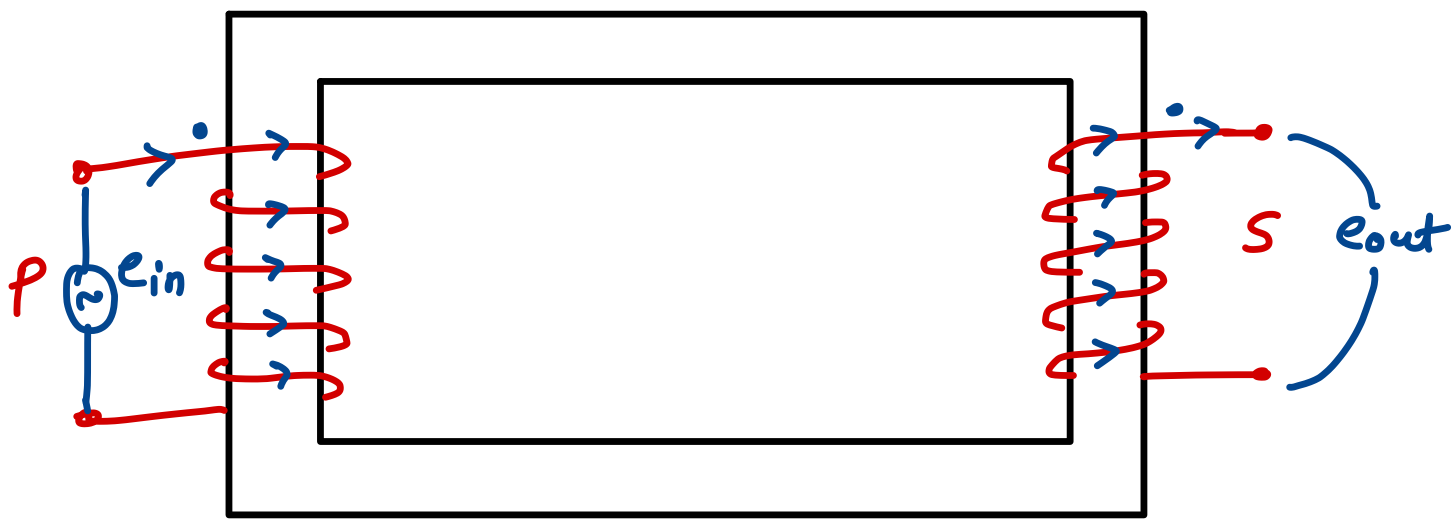


Core Type T/F :

wndgs are wrapped around two sides of a laminated square core.

Primary & Secondary Windings

A two-winding T/F consists of two wndgs interlinked by a mutual magnetic field.



Primary wndg: energized by connecting it to an input source.

Secondary wndg: wndg to which an electrical load is connected and from which output energy is drawn.

Fundamentals :

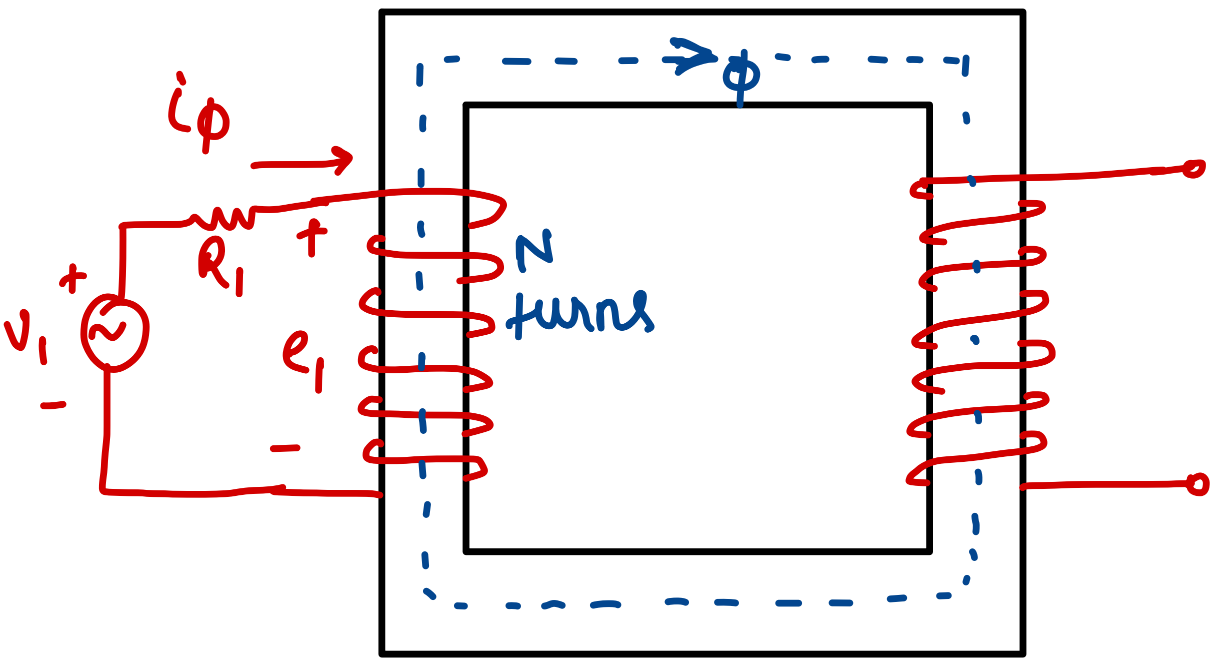
1. A voltage is induced in a coil when it links a variable flux.

2. A sinusoidal flux induces a sinusoidal voltage.

Ideal T/F :

↳ is a lossless device with an input winding and an output winding having following properties :

- No iron and copper losses.
- No leakage fluxes.
- A core of infinite magnetic permeability and of infinite electrical resistivity
- Flux is confined to the core and wndg resistances are negligible.



- AC current i_ϕ flows through primary winding.

  ⇒ establishes an alternating flux in mag. ckt.

  ⇒ flux induces an emf in primary

$$e_1 = \frac{d\lambda_1}{dt} = \frac{d(N_1\phi)}{dt} = N_1\frac{d\phi}{dt} \quad \text{——— (1)}$$

where,

λ_1 = flux linkage of primary wndg

ϕ = flux in the core linking both wndgs [wb]

N_1 = no. of turns in primary wndg.

$e_1 \rightarrow$ induced emf [V]

$$v_1 = \underbrace{R_1 i_\phi}_{} + e_1 \quad \text{—— (2)}$$

↳ No load resistance drop → 0

$$\Rightarrow \boxed{v_1 \simeq e_1}$$

Let

$$\phi = \Phi_{max} \sin \omega t$$

then,

$$e_1 = N_1 \frac{d\phi}{dt}$$

$$e_1 = \omega N_1 \phi_{max} \cos \omega t$$

$\because \omega = 2\pi f$

$$\boxed{e_1 = 2\pi f N_1 \phi_{max} \cos \omega t}$$

NOTE:

$$\phi = \phi_{max} \sin \omega t$$

90°

$$e_1 = 2\pi f N_1 \phi_{max} \cos \omega t$$

⇒ induced emf leads the flux by 90°.

RMS (Effective) value of e_1:

$\because e_1 = \underbrace{2\pi f N_1 \phi_{max}}_{\rightarrow e_{max}} \cos \omega t$

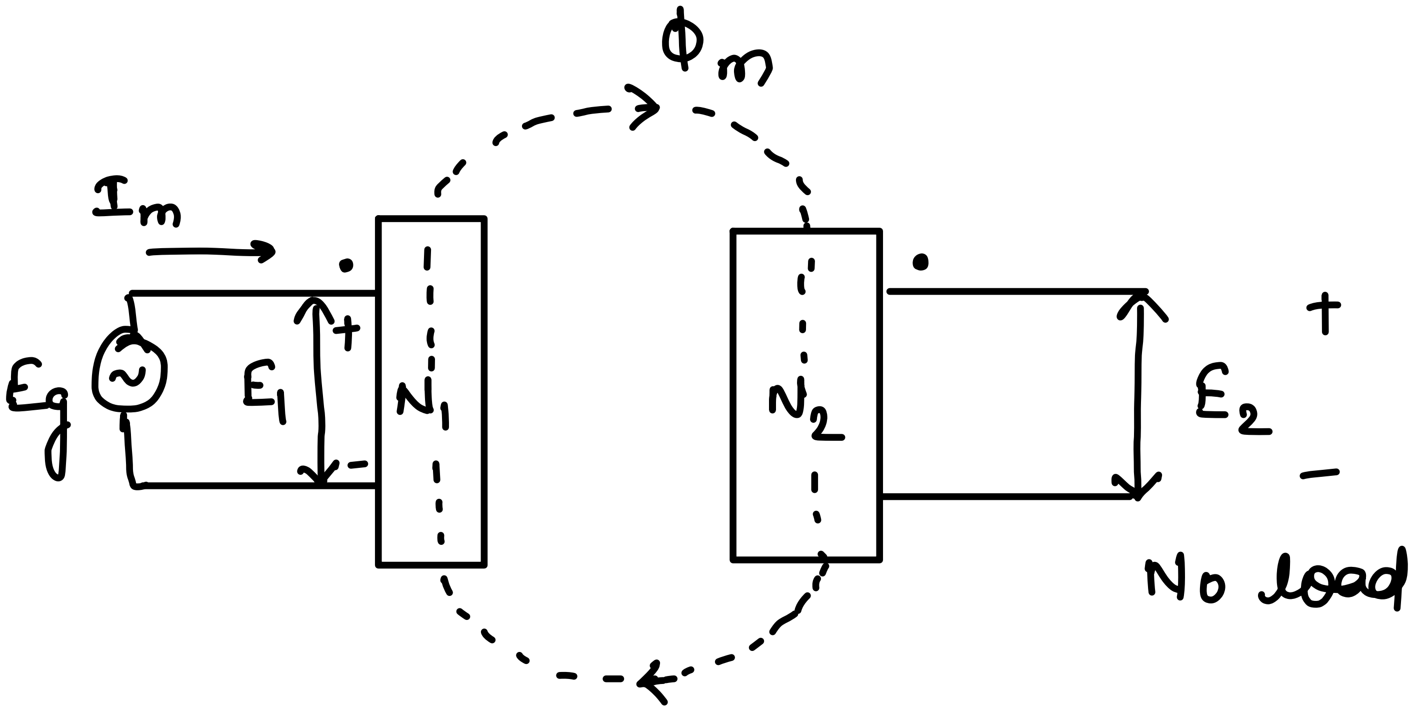
$\downarrow$ RMS

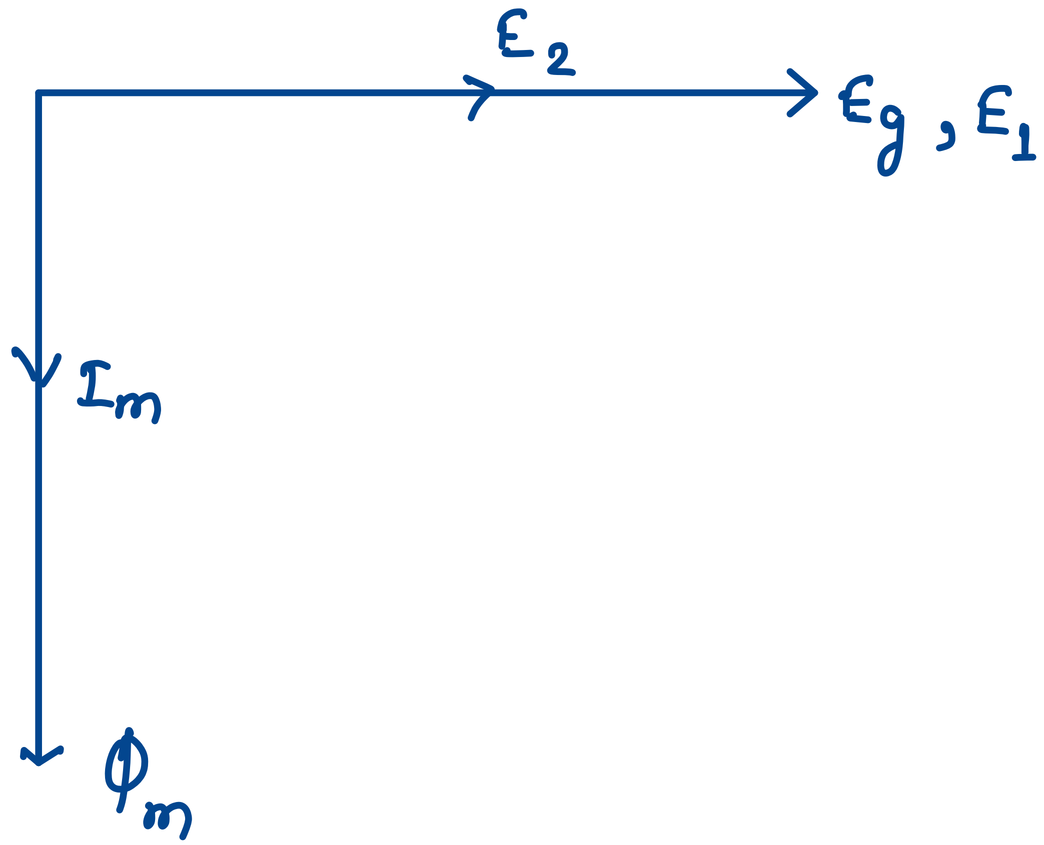
$$E_1 = \frac{e_{max}}{\sqrt{2}} \qquad \left[\because RMS = \frac{peak}{\sqrt{2}}\right]$$

$$\Rightarrow E_1 = \frac{2\pi f N_1 \phi_{max}}{\sqrt{2}}$$

$$\Rightarrow \boxed{E_1 = 4.44 f N_1 \phi_{max}}$$

Ideal T/F phasor diag. :





Formula:

$$E = 4.44 f N \phi_{max}$$

where,

E = effective voltage induced [V]

f = frequency of flux [Hz]

N = No. of turns on the coil

ϕ_{max} = peak value of the flux [wb]

Examples

1. The coil possesses 4000 turns and links an ac flux having a peak value of 2 mwb. If the frequency is 50 Hz, calculate the effective value and frequency of the induced voltage E.

RMS value

Soln.

$$E = 4.44 f N \Phi_{max}$$

$$= 4.44 \times 50 \times 4000 \times 0.002$$

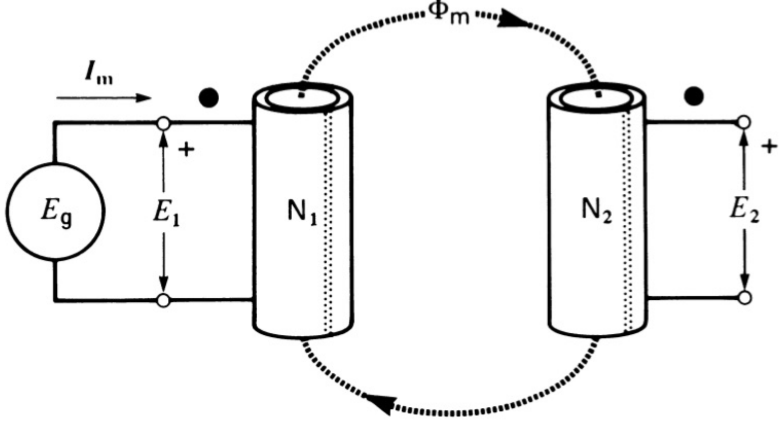
$$= 1776 V$$

$$f = 50 Hz$$

Voltage Ratio:

(Turns Ratio)

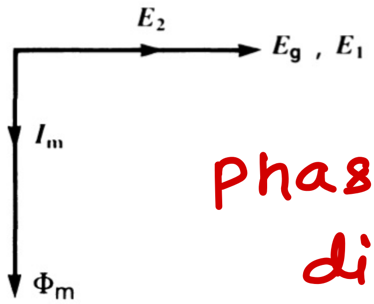
$N_1 \rightarrow$ primary wndg turns



(a)

$N_2 \rightarrow$ Secondary wndg turns

(b)



Phasor diag. at no-load

$E_g \rightarrow$ sinusoidal source

$I_m \rightarrow$ magnetizing current

ϕ_m
- $\rightarrow$ flux created by I_m
- $\rightarrow$ links both primary & secondary wndgs
- $\rightarrow$ mutual flux

$$E_1 = 4.44 f N_1 \phi_{max} \quad \text{--- (2)}$$

$$E_2 = 4.44 f N_2 \phi_{max} \quad \text{--- (3)}$$

∴ voltage ratio and turns ratio are given as:

$$\boxed{\frac{E_1}{E_2} = \frac{N_1}{N_2} = a}$$

where,

$E_1 \rightarrow$ Emf induced in primary [V]

$E_2 \rightarrow$ " " " secondary [V]

$a \rightarrow$ turns ratio

Q. An ideal T/F having 90 turns on the primary and 2250 turns on the secondary is connected to a 120V, 50Hz source. The coupling between primary and secondary is perfect, but the magnetizing current is 4A.

Calculate:

a) Effective voltage across the secondary terminals.

→ $E_1 = 120V$

$N_1 = 90$

$N_2 = 2250$

$\because \quad \frac{E_1}{E_2} = \frac{N_1}{N_2}$

$$\Rightarrow E_2 = \frac{N_2}{N_1} \times E_1$$

$$= \frac{2250}{90} \times 120$$

$$\boxed{E_2 = 3000V}$$

(b) peak voltage across secondary terminals

→ $\because$ Effective value $= \frac{\text{peak}}{\sqrt{2}}$

$$\Rightarrow \text{peak voltage} = \sqrt{2} \times E_2$$

$$= \sqrt{2} \times 3000$$

$$\boxed{E_{2\,peak} = 4242\ V}$$

(c) Instantaneous voltage across the secondary when the instantaneous voltage across the primary is 37V.

$$\because \quad \frac{E_2}{E_1} = 25$$

$$\therefore \quad e_1 = 25\, e_2$$

$$= 25 \times 37$$

$$\boxed{e_1 = 925\text{V}}$$