IES/GATE

Electronics & Telecommunication Engineering

VOLUME-I

Basic Electrical Engineering
Basic Electronics Engineering

Contents

Basic Electrical Engineering →

(A.) Transformer
(B.) D.C. Machine → Generator / Motor
(C.) Induction machines → Motor / Generator
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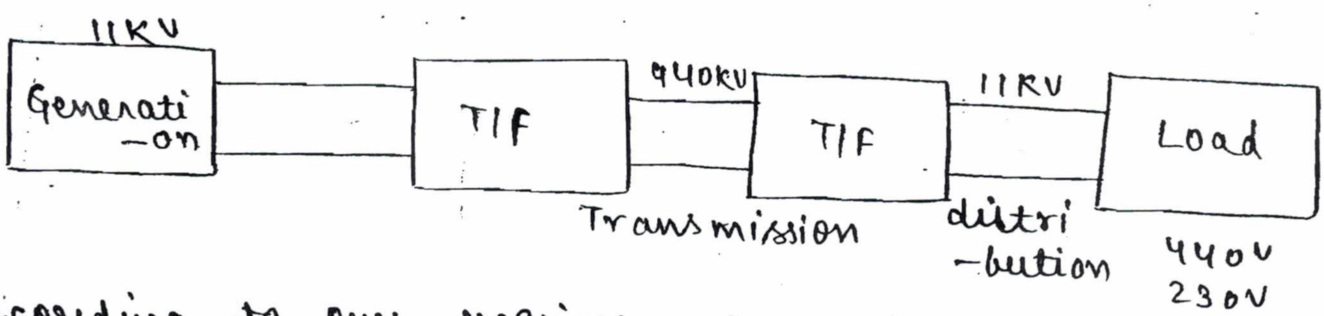
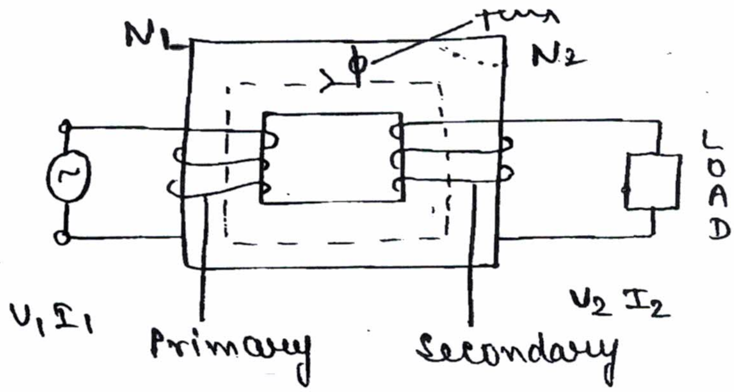
(E.) ① Thermal ② Nuclear ③ Hydro ④ Wind
⑤ Solar ⑥ Batteries.

{ Electrical Technology – Vol – II :– By B.L. Theraja.
Electric machines – By Ashfaq Hussain }

Transformer →



According to our requirement we can change the step up / down or voltages of transformer. This is advantage of it. To avoid the losses we use step up voltages. All the d.c. circuits are replaced by A.C. ckts. Transformer is a static device. It consist of two or more electrical circuits interlinked by common magnetic flux for the



These primary & secondary windings are electrically isolated from each other.

i) If $N_1 > N_2$ ⟶ step-down transformer
ii) If $N_1 < N_2$ ⟶ step-up "
iii) If $N_1 = N_2$ (Isolation transformer) (1:1) T/F.

i) Transformer is used for the purpose of transferring power from one circuit to another without changing any frequency.

ii) In the transformer w.r.t. external circuit no energy conversion is present but with respect to internal circuit electrical energy is converted to magnetic field and the magnetic field converted to electrical energy.

iii) In the transformer primary & secondary windings are electrically isolated and magnetically connected together.

v) In the T/F w.r.t. the number of turns in the primary & secondary is classified as above.

Applications → 1) To change the level of voltage.
2) To separate d.c. component in the A.C. system (Isolation transformer).
3) To obtain maximum power from source to load (Impedance matching transformer).

- Transformer works based on the principle of Faraday's law of electromagnetic induction.

To obtain the induced voltage in any system the minimum requirement is –

conductor magnetic field Relative velocity b/w conductor and magnetic field (w.r.t. space & time) (either w.r.t. space or time).

Case 1. Dynamically Induced emf →

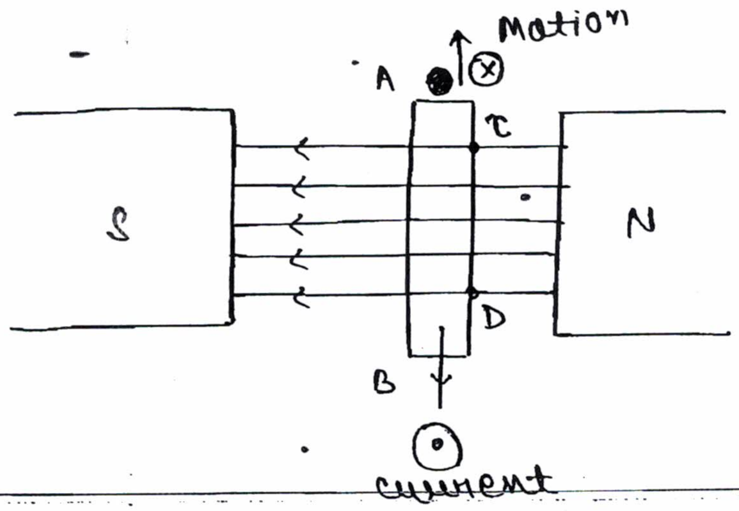
Emf induced in the conductor when it is being rotated in the steady magnetic field then it is called as dynamically induced emf.

When the conductor cuts a magnetic lines of force, an emf induced in the conductor.

Faraday's 2nd law →

Emf induced in conductor is directly proportional to rate of change of flux.

$$\boxed{e \propto \frac{d\phi}{dt}}$$



$e = Blv \sin\theta$

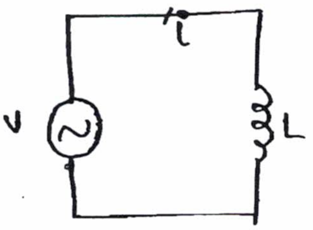
e =
l = Active length of conductor (CD).
v = linear velocity of conductor.
θ = Phase displacement between conductor & magnetic field.
B = flux density.

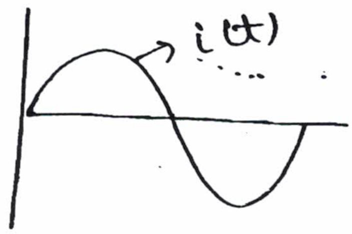
In the above figure direction of induced emf is obtained by using fleming's right hand rule.

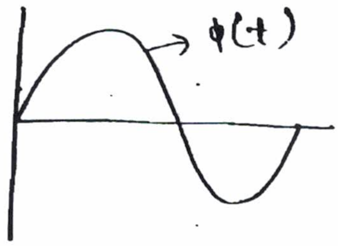
Thumb Indicates motion of the conductor.
Forefinger Indicates direction of flux (from N to S).
Middle finger Indicates dirn. of current / Induced v/g.

Case 2. Statically induced emf →

Emf induced in the conductor when it is subjected to time varying field is called as Staticelly induced emf.





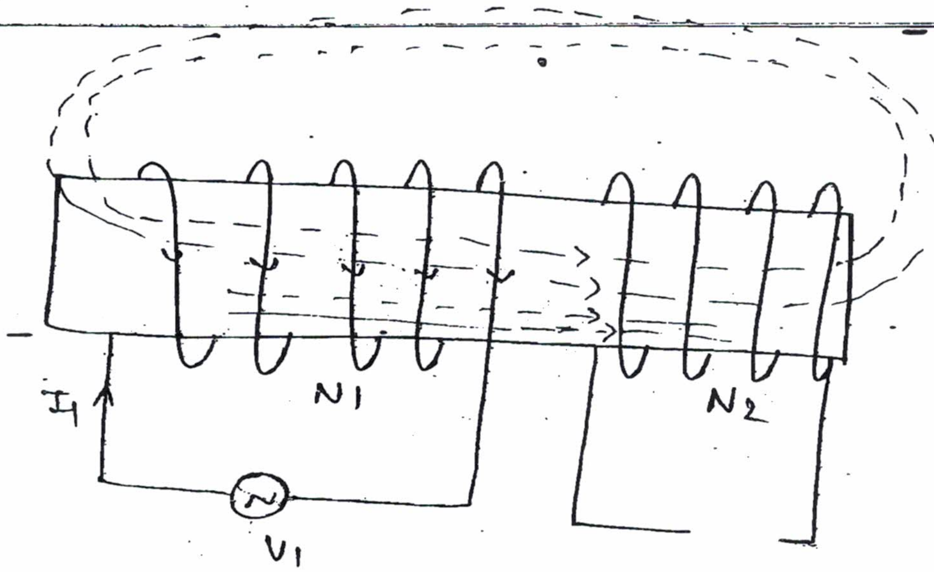


$e \propto \frac{d\phi}{dt}$

v, i, ϕ, e — Lenz's law

$$e = -N\frac{d\phi}{dt}$$

(−) → Lenz's law



$e_1 \propto \frac{d\phi_1}{dt}$

$e_1 = -N_1 \frac{d\phi_1}{dt}$

$e_1 = -N_1 \frac{d\phi_1}{di_1} \times \frac{di_1}{dt}$

$[\because L = \frac{N\phi}{i}]$

$$e_1 = -L_1 \frac{di_1}{dt}$$

↳ self induced emf (e_1)

$e_2 \propto \frac{d\phi_1}{dt}$

$e_2 = -N_2 \frac{d\phi_1}{dt}$

$e_2 = -N_2 \frac{d\phi_1}{di_1} \times \frac{di_1}{dt}$

$$e_2 = -M \frac{di_1}{dt}$$

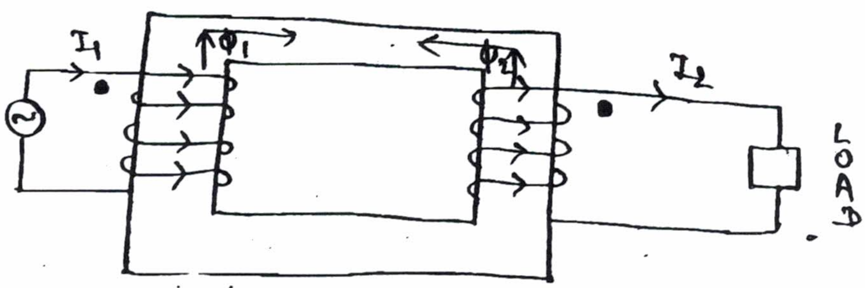
$\because [M = \frac{N\phi}{i}]$

↳ (Mutual induced emf)

e_1 & e_2 are statically induced emf.

Magnetic coupling →

Case 1.



- w.r.t. direction of flux magnetic coupling is classified as -

(i) +ve magnetic coupling. (ii) -ve magnetic coupling.

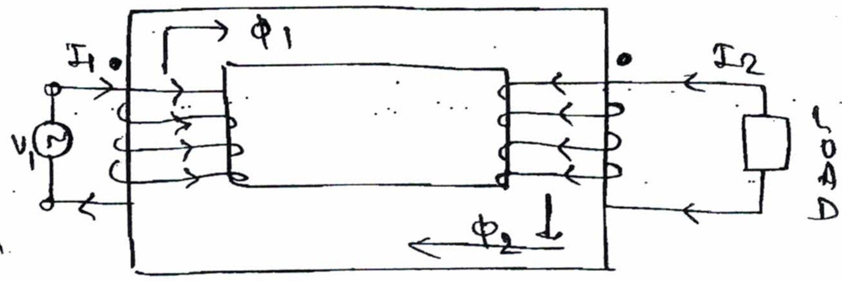
Case 1. -ve magnetic coupling →

i) when the flux in the two inductors are completing closed path in the opposite direction then it ~~is called as -ve magnetic coupling.~~

ii) when one current is entering and other current is leaving at ~~the~~ the dotted terminal then it is called -ve magnetic coupling.

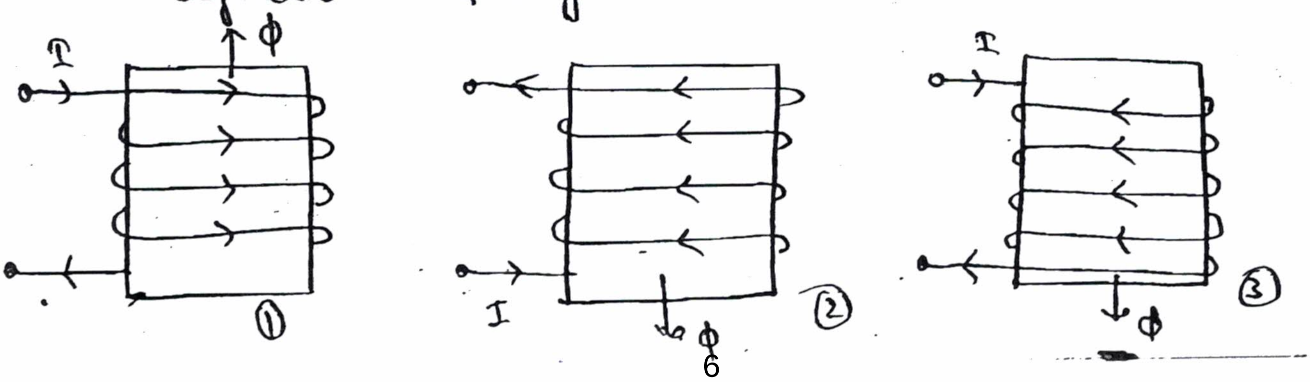
iii) In the T/F to maintain constant induced v/g -ve magnetic coupling is preferred.

Case 2.



i) when the flux of two inductors are completing closed path in the same direction then it is called as +ve magnetic coupling.

ii) when the current is either entering or leaving at both dotted terminals then it is called as +ve magnetic coupling.



from above figures it is concluded that direction of flux depends on-
(1) direction of current. (2) Sense (arrangement) of windings.

Classification of Transformers →

(1) Based on construction –
- core type T/F.
- Shell type T/F.

(2) Based on number of windings–
- Single winding t/f (Auto transformer).
- Two winding T/F
- Three winding T/F.

(3) Based on number of Phases –
- single phase transformer.
- 3-ϕ tranformer.

(4) Based on Power System application –
- Distribution T/F.
- Power T/F.

(5) Based on operating frequency –
- Power frequency transformer (25 Hz to 400 Hz).
- Audio frequency transformer (20 Hz to 20 KHz).

(6) Based on measurement applications –
- current Transformer.
- Potential transformer.

(7) Based on electronic applications –

- Isolation t/f.
- Impedance matching t/f.
- Pulse T/F.

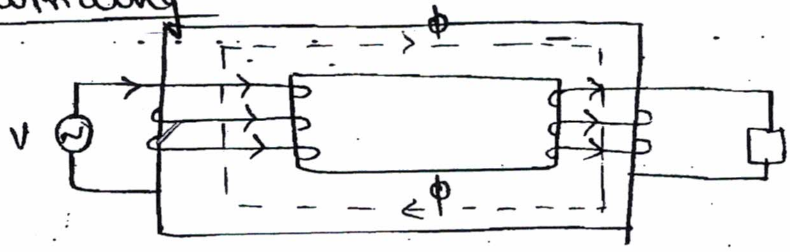
Essential points (parts) in transformer are -

1) Core → when the alternating flux links with the core due to conduction property emf is induced in the core and it causes to produce eddy current losses in the core.

→ Eddy current losses are resistive losses in core

→ To reduce the eddy current losses, core is laminated

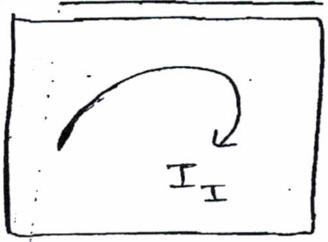
2) Winding



E_I, I_I, $I_I^2 R_I$ ↑ Temp.

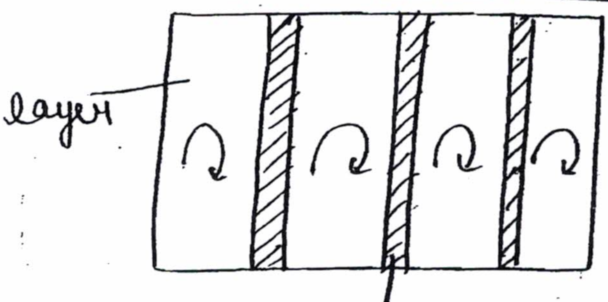
Eddy current losses

Solid core



↓ $R = \frac{\rho l}{A \uparrow}$

Laminated core



↑ $R = \frac{\rho l}{A \downarrow}$

→ The Process of bunching of all the layers is called as staggering.

Disadvantages due to improper staggering →

Due to improper staggering air gaps are present b/w the layers. Thereby reluctance of core ↑ses, to maintain rated (constant) flux, more magnetizing current is required [I_m = magnetizing current].

(1.) I ⟶ R

ϕ ⟶ S

$S_{air} > S_m$

$$S = \frac{l}{a \mu_0 \mu_r}$$

$$\phi = \frac{mmf}{S} = \frac{N I_m \uparrow}{S \uparrow}$$

$\mu_0 = 4\pi \times 10^{-7}$ H/m

$i = \frac{EMF}{R}$

μ_r = Relative permeab.

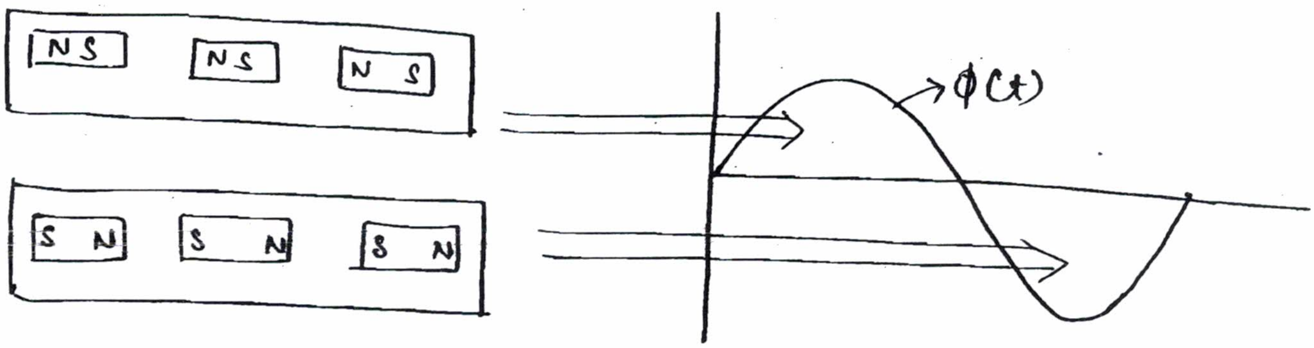
($\mu_r = 1$ = air).

S : Reluctance

(2.) Magnetostriction – due to magnetostriction t/f produce more noise (humming noise), It may causes interference in the communication lines.

→ Magnetostriction is a tendency of the magnetic material due to which slight changes are present in the physical dimension of the core.

→ In the solid core magnetostriction effect is less when compared to laminated core.



In the Practical system core is made up of Silicon steel [Silicon contribution is only 4–5%].

Steel	Silicon
Good magnetic properties. (Ferromagnetic material)	• Good magnetic Properties.
High mechanical strength	• Resistivity is high.
• Good conducting Properties.	• Low hysterisis coefficient.
	✓ → desirable X → undesirable

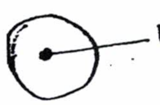
: For very high rating transformers, to decrease the size of T/F for the silicon steel CRGO (Cold Rolled grain Orientation) Process is done.

: By doing CRGO process flux density of material increases.

$$\uparrow B = \frac{\phi}{A\downarrow}$$

$\therefore$ A↓ size ↓

2.) **Winding** → disadvantages due to single strand wire



L, $X_L = 2\pi f L$

→ Due to high area of crosssection of the conductor more localized currents are present and it causes to produce stray load losses.

2A (D.C.) → $f = 0$

2A (A.C.) → f

→ Due to high area of cross-section of cond^r Skin effect is high. thereby effective Resistance of the conductor increases.

$$\uparrow R = \frac{\rho l}{a\downarrow}$$

$R_{D.C.} < R_{A.C.}$

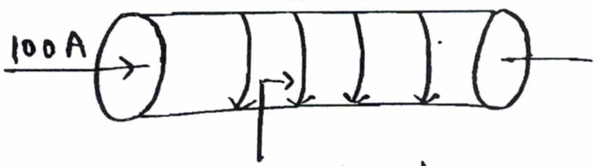
R – effective Resistance

Due to overcome above this disadvantages, multi-strand wire is present.

Flux linkage at centre of Conductor increases.

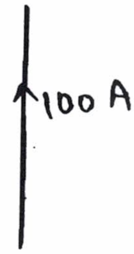
L → ↑ → X_L ↑

1.) $I \propto a$

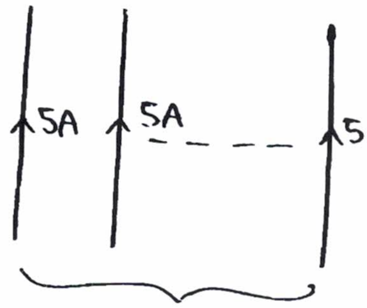


Localized current
[stray load losses]

single - Strand wire -



multi - Strand wire -



20 stands

$\downarrow I \propto a \downarrow$

I decreases due to $a \downarrow$.

2.) Skin effect $\propto d^2$

where d = diameter of conductor.

Ideal Transformer →

Assumptions →

(1.) Permeability is very high (approximately equal to ∞)

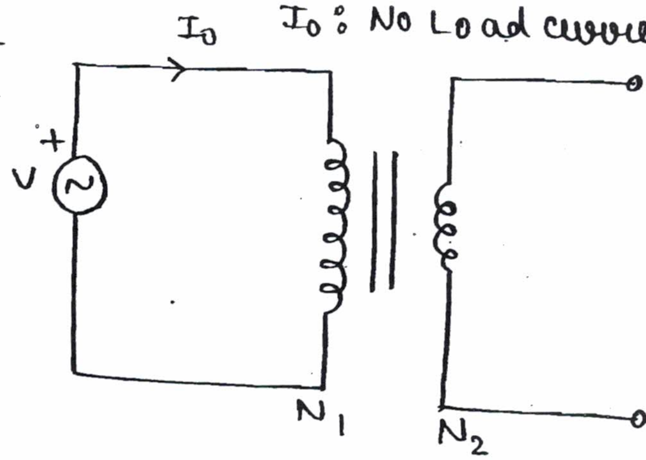
(2.) Iron losses are neglected.

(3.) Leakage flux equal to zero (coefficient of coupling $K = 1$)

(4.) Internal resistance of primary & secondary windi are neglected.

Case 1. No load:

I_o : No Load current



$i(t) = I_m \sin \omega t$

$$\phi = \frac{MMF}{S} = \frac{Ni}{S}$$

$$\phi(t) = \frac{N \cdot I_m}{S} \sin \omega t$$

$$\boxed{\phi(t) = \phi_m \sin \omega t}$$

$$e_1 \propto \frac{d\phi_1}{dt}$$

$$e_1 = -N_1 \frac{d\phi_1}{dt}$$

$$e_1 = -N_1 \frac{d}{dt}(\phi_m \sin \omega t)$$

$$e_1 = -N_1 \omega \phi_m \cos \omega t$$

$$e(t) = N \omega \phi_m \sin(\omega t - 90^\circ)$$

$$e_1(t) = E_{m_1} \sin(\omega t - 90^\circ)$$

we get – $\boxed{E_{m1} = N_1 \omega \phi_m}$

$$E_{1RMS} = \frac{E_{m1}}{\sqrt{2}} = \frac{N_1 \omega \phi_m}{\sqrt{2}} = \frac{N_1 2\pi f \phi_m}{\sqrt{2}} = N_1 f \phi_m \pi \sqrt{2}$$

$$\boxed{E_{1RMS} = 4.44 N_1 f \phi_m} \quad \text{—— (1)}$$

similarly for 2nd inductor –

~~$e_2 \propto \frac{d\phi_2}{dt}$~~

$$e_2 = -N_2 \frac{d\phi_1}{dt}$$

$$e_2 = -N_2 \frac{d}{dt}(\phi_m \sin \omega t)$$

$$e_2 = -N_2 \omega \phi_m \cos \omega t$$

$$e_2 = +\boxed{N_2 \phi_m \omega} \sin(\omega t - 90^\circ)$$

$$e_2 = \boxed{E_{m2}} \sin(\omega t - 90^\circ)$$

$$\boxed{E_{m2} = N_2 \phi_m \omega}$$

$$E_{RMS2} = \frac{E_{m2}}{\sqrt{2}} = \frac{N_2 \phi_m 2\pi f}{\sqrt{2}}$$

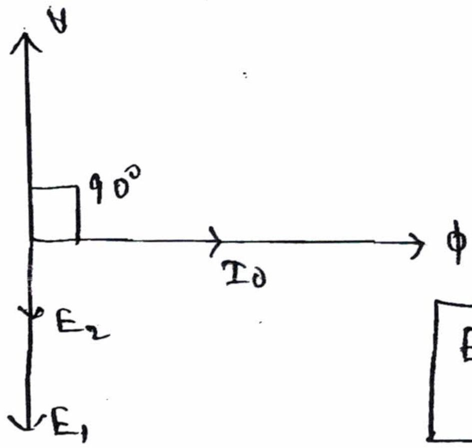
$$\boxed{E_{2RMS} = 4.44 N_2 f \phi_m} \text{ —— (2)}$$

$$\frac{\text{Eq}^n. (1)}{\text{Eq}^n. (2)} = \frac{E_1}{E_2} = \frac{4.44 N_1 \phi_m f}{4.44 N_2 \phi_m f} = \frac{N_1}{N_2} \Rightarrow * \boxed{\frac{E_1}{E_2} = \frac{N_1}{N_2}}$$

$$\boxed{\text{emf}|_{\text{Turn}} = \frac{E_1}{N_1} = \frac{E_2}{N_2}}$$

For Primary & secondary Emf | turn is equal.

Phasor diagram at No load condition →



$\because B_m = \frac{\phi_m}{A}$

$$\boxed{\begin{aligned} E_1 &= 4.44\, \phi_m f N_1 \\ E_1 &= 4.44\, B_m f N_1 A \end{aligned}}$$

$$E_1 = 4.44\, N_1 \phi_m f$$

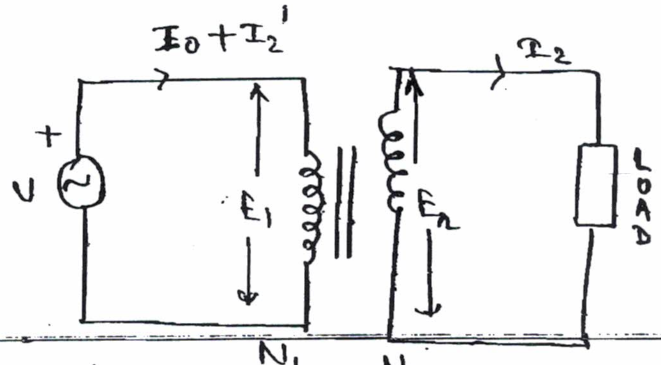
$$\phi_m = \frac{E_1}{4.44 N_1 f}$$

$$\phi_m \propto \frac{E_1}{f} \propto \frac{V}{f} \quad \text{i.e.} \quad \phi_m \propto \frac{V}{f}, \quad B_{max.} \propto \frac{V}{f}$$

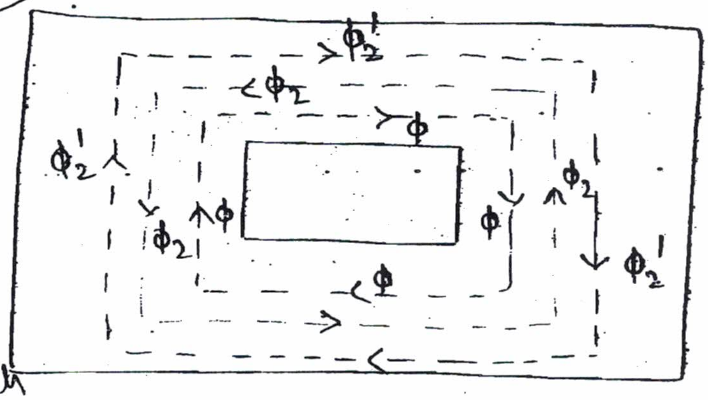
$E_1 = V$ = source v/g.

Case 2. Load:-

1.) ϕ, E_2, I_2, ϕ_2 — Lenz's Law



2.) ϕ_2, $\phi_{Net} = \phi - \phi_2 \downarrow$, $E_1 \downarrow$, I_2', ϕ_2' — Lenz's law



$$\phi_{Net} = \phi - \phi_2 + \phi_2'$$

I_2' (due to load)

(i) Transformer is designed such that mmf of the primary (N_1, I_2') and mmf of the secondary (N_2, I_2) are equal and in opposite dirn. thereby corresponding flux also equal

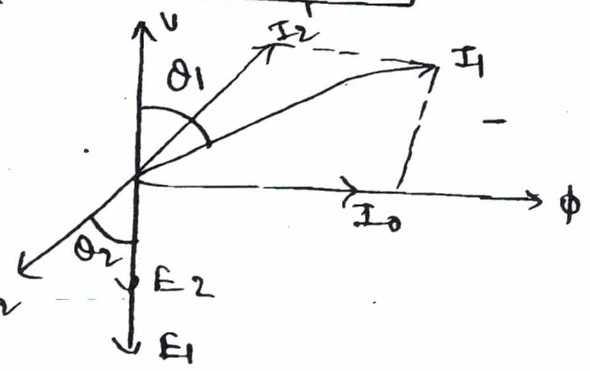
$$N_1 I_2' = N_1 I_2 \rightarrow \boxed{\phi_2' = \phi_2}$$

(ii) Transformer is also called as constant flux device. Since flux magnitude independent on the load curre

$$\phi_{Net} = -\phi_2 + \phi_2' + \phi = \phi$$

Phasor diagram →

R-L Load [lag by <90°]



Due to I_0

$$\theta_1 \neq \theta_2$$

$N_1 I_2' = N_2 I_2$ ∵ $I_1 = I_0 + I_2'$

I_0 is used only to establish flux. $I_2' > I_0$

$$\boxed{\frac{N_1}{N_2} = \frac{I_2}{I_2'}} \text{ (Accurate)}$$

∴ $\boxed{I_1 \simeq I_2'}$ I_0 = very less

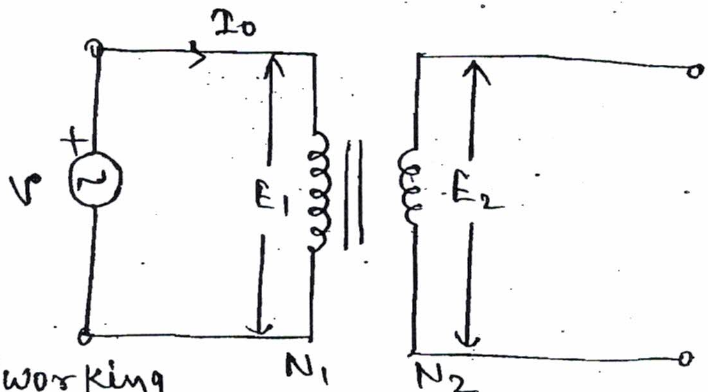
$$\boxed{\frac{N_1}{N_2} = \frac{I_2}{I_1}} \text{ (Approximate)}$$

$$* \boxed{\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}}$$

Practical Transformer →

Case 1. (No Load) –

In the practical TF at no load condition iron losses are present.



$I_w = AB = I_0 \cos\theta_0$ (Active/working compo. of I)

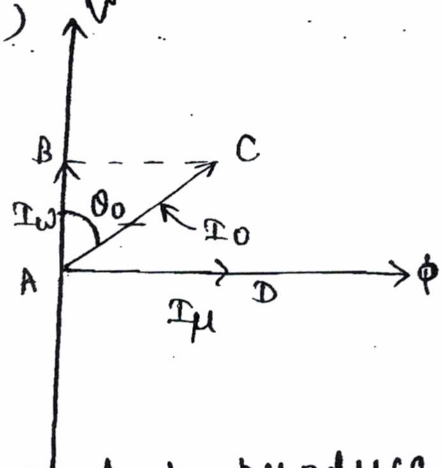
$I_w \rightarrow$ Iron losses

$I_w \rightarrow$ 1 to 2% of $I_{F.L.}$

(I_m) $I_\mu = AD = BC = I_0 \sin\theta_0$ (Reactive comp. of I)

$I_\mu \rightarrow$ Flux

$I_\mu \rightarrow$ 4 to 5% of $I_{F.L.}$



Active compon.
↓
along source V/g(U)

Reactive comp.
↓
Phase is 90° with V.

I_m = magnetizing current used to produce flux.

Function of magnetizing current is to establish flux in the core.

$$\boxed{I_\mu = (2 \text{ to } 3)\, I_w}$$

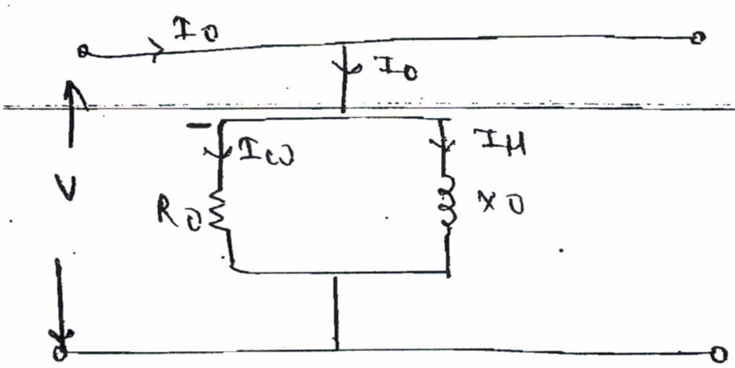
$\cos\theta_0 = \frac{P}{S} \rightarrow \downarrow \cos\theta_0 = \frac{P}{\sqrt{P^2 + Q^2}\uparrow}$ $\left\{ \begin{array}{l} P = VI\cos\theta \\ \uparrow Q = V(I\sin\theta)\uparrow \end{array} \right.$

* $\cos\theta_0 \simeq 0.2$ (lag) ; $\theta_0 \simeq 70$ to 75^0 (No Load condition)

Note 1) For the transformer at no load condition power factor is very less. Since magnetizing current is very high.

$I_0 \rightarrow I_w$ (along V)(R...

$I_0 \rightarrow I_\mu$ (along ϕ)(...



Equivalent ckt of T/F at no load cond^n.

$$R_0 = \frac{V}{I_w}$$

$$X_0 = \frac{V}{I_\mu}$$

Imp.

$I_w < I_\mu$

$R_0 > X_0$

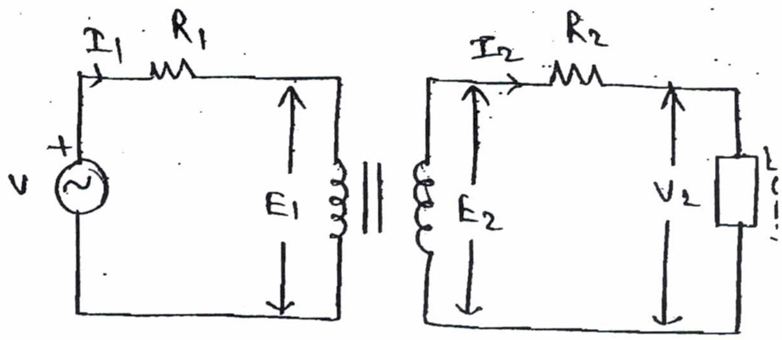
Shunt branch parameters obtained from no load cond^n.

Case 2. Load:

R_1 – Internal resistance of primary winding

R_2 – Internal resistance of secondary winding.

Primary & secondary windings are made of copper materials.



$V = E_1 + I_1R_1$; drop: I_1R_1

$E_2 = V_2 + I_2R_2$; drop: I_2R_2

Copper losses in Primary: $I_1^2R_1$

copper losses in sec.: $I_2^2R_2$

Total cu losses $= I_1^2R_1 + I_2^2R_2$

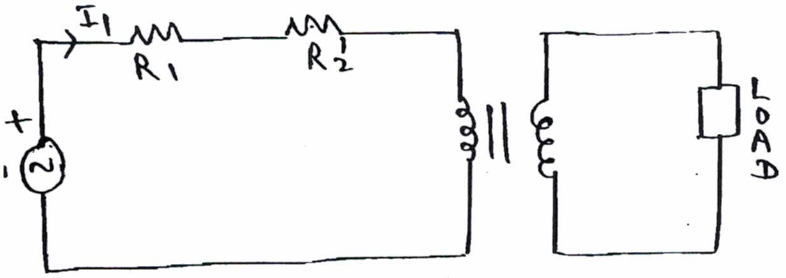
$$I_1^2R_2' = I_2^2R_2$$

$$R_2' = \left(\frac{I_2}{I_1}\right)^2 R_2$$

$$R_2' = \left(\frac{N_1}{N_2}\right)^2 R_2$$

R_2' = Primary equivalent of secondary resistance.

Equivalent ckt –



$R_{01} = R_1 + R_2'$

Total losses $= I_1^2 R_{01}$
$= I_1^2 R_1 + I_2^2 R_2$

R_{01} = total equivalent resistance w.r.t. primary.

Objective Quesn –

1.) [Per unit = $\frac{\text{Actual value}}{\text{Base value}}$]

Base value
↓
Rated V/g or
rated current.

Ex – 200V / 400V
↓ ↓
E_1 / E_2
(Induced v/g)
(rated v/g)

* Per unit Resistance w.r.t. primary $= \frac{R_{01}}{\frac{E_1}{I_1}}$

or

Per Unit resistance drop w.r.t. primary $= \frac{I_1 \cdot R_{01}}{E_1}$

} same

2.) % Resistance drop w.r.t. Primary $= \frac{I_1 \cdot R_{01}}{E_1} \times 100$

or

% copper losses w.r.t. Primary $= \frac{I_1^2 \cdot R_{01}}{E_1 I_1} \times 100$

} same

∴ % Resistance drop = % copper loss

on secondary side → $I_2^2 \cdot R_1' = I_1^2 R_1$

going from primary to secondary side.

$R_1' = \left(\frac{I_1}{I_2}\right)^2 R_1 \Rightarrow$ $R_1' = \left(\frac{N_2}{N_1}\right)^2 R_1$